2013

Mapping, Modeling, and the Fragmentation of Environmental Law

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Abstract

In the past forty years, environmental researchers have achieved major advances in electronic mapping and spatially explicit, computer-based simulation modeling. Those advances have turned quantitative spatial analysis—that is, quantitative analysis of data coded to specific geographic locations—into one of the primary modes of environmental research. Researchers now routinely use spatial analysis to explore environmental trends, diagnose problems, discover causal relationships, predict possible futures, and test policy options. At a more fundamental level, these technologies and an associated field of theory are transforming how researchers conceptualize environmental systems.

Advances in spatial analysis have had modest impacts upon the practice of environmental law, little impact on environmental law's structure or theory, and minimal impact on environmental law research. However, the potential legal implications of these advances are profound. By focusing on several of environmental law's traditional core debates and by using urban development as a central example, this Article explores those implications. It shows that spatial analysis can change the problems environmental law addresses, the regulatory instruments environmental law uses, the entities law empowers to address those problems, and the methodologies of environmental law research.

INTRODUCTION

Imagine a proposed housing development—call it "Greenacres"—at the fringe of a metropolitan area. Greenacres will contain several dozen new homes,

 Professor, University of Maine School of Law. Research for this Article was supported by National Science Foundation award EPS-0904155 to Maine EPSCoR at the University of Maine and by the University of Maine School of Law. I thank Todd Aagaard, Colin Apse, Dmitry Bam, Eric Biber, William Boyd, Robin Craig, Lincoln Davies, Dan Farber, Eric Freyfogle, Kelley Hart, Rita Heimes, Blake Hudson, Michelle Johnson, Sanne Knudsen, Aga Pinette, Rebecca Purdom, J.B. Ruhl, Sarah Schindler, Sean Smith, Sarah Tran, Jennifer Wriggins, and participants in conferences and workshops at the University of Washington, Georgetown Law School, Vermont Law School, and the University of Maine for comments on earlier drafts, and Daniel D'Alessandro, Robin Campbell, John O'Hara, and Lauren Parker for research assistance.

all constructed on one-to five-acre lots.[1] The developer plans to clear forests, fill wetlands, and replace undeveloped wildlife habitat with buildings, pavement, and landscaped yards. Stormwater runoff from Greenacres will pollute local streams and increase flooding risk. The new roads, buildings, and driveways will limit groundwater recharge, reducing local water supplies even as the houses increase water demand.[2] The houses will also consume energy, most likely from fossil fuels, and the residents will burn gasoline while they drive, generating conventional air pollutant and greenhouse gas emissions.[3] Greenacres will also bring benefits: profits for the current landowner and the developer, construction jobs, new housing options, an increased tax base, and potential customers and employees for area businesses. But those benefits come with an environmental price.

If viewed in isolation, each of these impacts might seem like a drop in a bucket, not worthy of regulatory oversight or response.[4] When viewed in combination, however, and when combined with the impacts of other similar developments, Greenacres' consequences might seem problematic. A regulator taking a holistic view might conclude that development should occur elsewhere, or that it need not occur at all.[5] More plausibly, the regulator might negotiate changes that reduce or compensate for some of Greenacres' impacts.[6] That broader

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[1] This type of exurban development has rapidly expanded in recent decades. *See* Andrew J. Hansen et al., *Effects of Exurban Development on Biodiversity: Patterns, Mechanisms, and Research Needs*, 15 ECOLOGICAL APPLICATIONS 1893, 1893–94 (2005).

[2] *See* Dave Owen, *Urbanization, Water Quality, and the Regulated Landscape*, 82 U. COLO. L. REV. 431, 439–45 (2011); *see also* ROBERT GLENNON, WATER FOLLIES: GROUNDWATER PUMPING AND THE FATE OF AMERICA'S FRESH WATERS 108–11 (2002) (discussing how suburban sprawl has affected the Massachussett's Ipswich River Basin due to, among other reasons, a decrease in groundwater recharge).

[3] *See generally* TRANSP. RESEARCH BD., NAT'L RESEARCH COUNCIL, SPECIAL REPORT NO. 298, DRIVING AND THE BUILT ENVIRONMENT: THE EFFECTS OF COMPACT DEVELOPMENT ON MOTORIZED TRAVEL, ENERGY USE, AND CO_2 EMISSIONS (2009) (detailing studies on housing development patterns and their relationships to vehicle miles traveled and energy use, and predicting potential effects of more compact development patterns); OFFICE OF TRANSP. & AIR QUALITY, ENTL. PROT. AGENCY, EPA420-R-01-001, EPA GUIDANCE: IMPROVING AIR QUALITY THROUGH LAND USE ACTIVITIES (2001) (providing guidance on addressing land use in air quality planning).

[4] *See* William E. Odum, *Environmental Degradation and the Tyranny of Small Decisions*, 32 BIOSCIENCE 728, 728 (1982); Kevin M. Stack & Michael P. Vandenbergh, *The One Percent Problem*, 111 COLUM. L. REV. 1385, 1398–402 (2011); David M. Theobald et al., *Ecological Support for Rural Land-Use Planning*, 15 ECOLOGICAL APPLICATIONS 1906, 1908 (2005) ("The aggregate effect of land-use change is the result of many, relatively small individual decisions that are diffuse in space and time, made by a diverse array of planners and policymakers . . . .").

[5] For discussion of the non-environmental costs of development, see ALAN MALLACH, BRINGING BUILDINGS BACK: FROM ABANDONED PROPERTIES TO COMMUNITY ASSETS 3–9 (2006); David Streitfield, *Ruins of an American Dream*, N.Y. TIMES, Aug. 24, 2008.

[6] This sort of negotiation is more common than flat prohibitions. *See, e.g.*, Daniel A. Farber, *Taking Slippage Seriously: NonCompliance and Creative Compliance in*

perspective might also spur the adoption of legal measures—perhaps new administrative rules, or even legislation—to address the larger environmental impacts to which Greenacres is contributing.[7] Not surprisingly, environmental commentators have spent decades arguing for such holistic review.[8] Calls are legion for policymakers to consider their decisions' impacts upon a wider variety of environmental, social, and economic outcomes;[9] to consider broader spatial and temporal trends when making those decisions;[10] and to involve more entities, both public and private, in decisionmaking processes.[11]

Unfortunately, those aspirations have been difficult to fulfill. Environmental problems are notoriously complex,[12] and considering the impacts of a range of activities, all dispersed across space and time, upon a variety of environmental media can be exceedingly challenging.[13] The challenges become even greater

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Environmental Law, 23 HARV. ENVTL. L. REV. 297, 298–300 (1999); Dave Owen, *Critical Habitat and the Challenge of Regulating Small Harms*, 64 FLA. L. REV. 141, 182–84 (2012) (documenting the prevalence of negotiated outcomes in Endangered Species Act (ESA) consultations).

[7] For discussion of the ways that "[c]hanging [c]onceptions of [t]ime and [s]pace" influenced environmental law's formation, see RICHARD J. LAZARUS, THE MAKING OF ENVIRONMENTAL LAW 54–66 (2004).

[8] *See infra* Part I; *see also* Craig Anthony (Tony) Arnold, *Fourth-Generation Environmental Law: Integrationist and Multimodal*, 35 WM. & MARY ENVTL. L. & POL'Y REV. 771, 776, 831–36 (2011) (critiquing "[u]nimodal and fragmented responses to complex and multidimensional environmental problems"); Cass R. Sunstein, *Beyond the Precautionary Principle*, 151 U. PA. L. REV. 1003, 1011 (2003) ("[R]egulators should use a wide rather than narrow viewscreen . . . .").

[9] *See, e.g.*, Richard B. Stewart, *A New Generation of Environmental Regulation?*, 29 CAP. U. L. REV. 21, 21 (2001) (summarizing critiques of the current environmental regulatory system); *infra* Part I.

[10] *See, e.g.*, Grand Canyon Trust v. Fed. Aviation Admin., 290 F.3d 339, 346–47 (D.C. Cir. 2002) (setting aside an environmental assessment because it "treat[ed] the identified environmental concern in a vacuum, as an incremental approach attempts [to do]").

[11] *See, e.g.*, Jody Freeman & Daniel A. Farber, *Modular Environmental Regulation*, 54 DUKE L.J. 795, 797–98 (2005) ("There is rarely a single tool, or a lone agency at either the federal or state level, that is capable of producing the desired environmental benefit by itself . . . ."); Jody Freeman, *Collaborative Governance in the Administrative State*, 45 UCLA L. REV. 1, 28–29, 31–33 (1997).

[12] *See generally* LAZARUS, *supra* note 7, at 6–19.

[13] *See, e.g.*, JOSEPH L. SAX, DEFENDING THE ENVIRONMENT: A STRATEGY FOR CITIZEN ACTION 56 (1970) ("The greatest problems are often the outcome of the smallest-scale decisions precisely because the ultimate, aggregate impacts of those decisions are so difficult to see and the pressures so difficult to cope with . . . ."); William W. Buzbee, *Urban Sprawl, Federalism, and the Problem of Institutional Complexity*, 68 FORDHAM L. REV. 57, 58–60 (1999); Eric T. Freyfogle, *Better Ways to Work Together*, *in* THE EVOLUTION OF NATURAL RESOURCES LAW AND POLICY 98, 98 (Lawrence J. McDonnell & Sarah F. Bates eds., 2010) ("Other stresses stem from the difficulties of shifting resources to higher and better uses, and coordinating activities at landscape or watershed scales.").

when, as is often the case, many different entities have information about an activity's environmental impacts, opinions about the importance of those impacts, and partial capacity to respond.[14] A central conflict of environmental law therefore has pitted the desire for holistic decisionmaking against the obvious need to keep decisionmakers' tasks manageably discrete.[15] For decades, legal commentators have debated how this tension should be resolved.[16]

Meanwhile, other environmental disciplines have transformed, and their transformation has significant but unappreciated implications for these debates.[17] Over the past four decades, increased data availability, new software systems, and exponentially greater computing power have combined to turn spatial analysis—that is, quantitative analysis of data coded to specific geographic coordinates—into the coin of the environmental realm.[18] At federal, state, and local government offices, in the private sector, and throughout nonlegal academia, thousands of analysts in dozens of fields now spend their days gathering and crunching spatial data.[19] Their efforts serve a wide variety of purposes[20] and, more fundamentally,

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[14] *See* Freeman & Farber, *supra* note 11, at 797–98.

[15] For exploration of this debate, see James E. Krier & Mark Brownstein, *On Integrated Pollution Control*, 22 ENVTL. L. 119 (1991).

[16] *See, e.g.*, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law*, 37 STAN. L. REV. 1333, 1336–37 (1985) (arguing that incentive-based regulation ameliorates informational challenges created by alternative regulatory approaches); Wendy E. Wagner, *Commons Ignorance: The Failure of Environmental Law to Produce Needed Information on Health and the Environment*, 53 DUKE L.J. 1619, 1622–24, 1720–26 (2004) (arguing that "idyllic assumptions" about information availability distort debates about environmental law).

[17] *See infra* Part II. The transformation extends well beyond environmental management and research. *See, e.g.*, *About NGA*, NAT'L GEOSPATIAL-INTELLIGENCE AGENCY, https://www1.nga.mil/About/Pages/default.aspx (last visited Jan. 28, 2013) (describing activities of an agency that uses spatial data and analysis to promote national security); *see also* KEITH HARRIES, MAPPING CRIME: PRINCIPLE AND PRACTICE (1999) (describing the science of crime mapping); LAXMI RAMASUBRAMANIAN, GEOGRAPHIC INFORMATION SCIENCE AND PUBLIC PARTICIPATION 14–16 (2010) (describing the use of geographic data to prove racial redlining in insurance policy sales).

[18] *See* sources cited *supra* note 17; *see also* Jacek Malczewski, *GIS-Based Land-Use Suitability Analysis: A Critical Overview*, 62 PROGRESS PLANNING 3, 5 (2004) ("Over the last forty years or so GIS-based land-use suitability techniques have increasingly become integral components of urban, regional and environmental planning activities."). One author defines "spatial analysis" as representing "a collection of techniques and models that explicitly use the spatial referencing associated with each data value or object that is specified within the system under study." ROBERT HAINING, SPATIAL DATA ANALYSIS: THEORY AND PRACTICE 4 (2004).

[19] *See* Michael Keating, *GIS/Geospatial Sales Projected to Grow 8.3 Percent in 2011*, AM. CITY & COUNTY (Jan. 27, 2011), http://americancityandcounty.com/gis-gps/gisgeospatial-sales-projected-grow-83-percent-2011 (describing multibillion dollar sales and steady growth in the spatial data industry).

[20] *See, e.g.*, Tenley M. Conway & Richard G. Lathrop, *Alternative Land Use Regulations and Environmental Impacts: Assessing Future Land Use in an Urbanizing*

are leading to new ways of conceptualizing ecological systems and environmental change.[21]

The emergence of spatial analysis merits revisiting environmental law's traditional debates about integrative, holistic decisionmaking. Spatial analysis can facilitate better assessments of the cumulative environmental consequences of activities dispersed across space and time. By enabling analysts to simultaneously evaluate a variety of environmental impacts, spatial tools and models can allow concurrent pursuit of multiple environmental goals.[22] And by producing maps, which are a compelling and accessible means of conveying information, spatial analysis can improve communication among the many entities involved in environmental policymaking.[23] In short, spatial analysis can facilitate more integrative approaches to environmental law. Spatial analysis technologies are by no means perfect tools, and they cannot turn environmental regulators into omniscient seers.[24] But they still can change our approaches to environmental protection.

Despite that potential, legal thinkers have devoted little attention to spatial analysis. Legal-academic literature does contain abundant references to geographic information systems (GIS), and most practicing environmental lawyers are at least vaguely aware of the increasing pervasiveness of spatial analysis tools.[25] Environmental law researchers also increasingly draw on nonlegal literature, and many of the scientific and economic articles they cite draw on spatial analysis. But very few legal authors have considered whether emerging spatial analysis techniques hold transformative potential for either the practice or theory of

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Watershed, 71 LANDSCAPE & URB. PLAN. 1 (2005); Gerard Hoek et al., *A Review of Land-Regression Models to Assess Spatial Variation of Outdoor Air Pollution*, 42 ATMOSPHERIC ENV'T 7561 (2008); Alex Kuffner, *R.I.'s Offshore-Wind Mapping is Held Up as Model*, PROVIDENCE J., May 29, 2011; *Greenprinting*, TRUST FOR PUB. LAND, http://www.tpl.org/what-we-do/services/conservation-vision/greenprinting.html (last visited Aug. 24, 2011) (describing how data can be used to create maps to guide land conservation).

[21] *See, e.g.*, MARINA ALBERTI, ADVANCES IN URBAN ECOLOGY: INTEGRATING HUMANS AND ECOLOGICAL PROCESSES IN URBAN ECOSYSTEMS (2008); *see also* NAT'L RESEARCH COUNCIL, GRAND CHALLENGES IN ENVIRONMENTAL SCIENCES 4 (2001) (identifying spatial modeling of land use change as one of the greatest future challenges for environmental science).

[22] *See, e.g.*, Theodore C. Weber & William L. Allen, *Beyond On-Site Mitigation: An Integrated, Multi-Scale Approach to Environmental Mitigation and Stewardship for Transportation Projects*, 96 LANDSCAPE & URB. PLAN. 240 (2010). For more discussion, see *infra* Part III.

[23] *See infra* Part III.

[24] *See infra* notes 169–174 and accompanying text.

[25] As of June 27, 2013, a search of Westlaw's journals and law reviews database for the phrase "geographic information system" produced 692 hits. Most of these articles contained passing references to GIS systems, and the articles that discuss GIS in more depth generally focus on evidentiary issues and privacy questions.

environmental law.[26] Nor do legal researchers typically use spatial analysis tools.[27] Even as other research fields move toward quantitative analysis based on spatial data, environmental law research remains largely the domain of qualitative argument, often grounded in intuition and anecdote and delivered exclusively in prose.[28]

This Article argues for bridging the divide between spatial analysis and environmental law. Part I summarizes some of the classic fragmentation challenges of environmental law, and thus maps problems that spatial analysis might help law address. It first discusses fragmentation of different environmental regulatory programs, then fragmentation across space and time, and then federalism-based debates about decisionmaking authority. Part II turns from traditional legal debates to the technological and theoretical evolution of spatial analysis. Part III explores some of spatial analysis's implications for environmental law. Using land use as a central example, it explains how spatial analysis can change which environmental

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[26] For rare exceptions to this generalization, see William Boyd, *Ways of Seeing in Environmental Law: How Deforestation Became an Object of Climate Governance*, 37 ECOLOGY L.Q. 843 (2010) (arguing that spatial imaging and analysis led policymakers to a new understanding of deforestation problems); Daniel C. Esty, *Environmental Protection in the Information Age*, 79 N.Y.U. L. REV. 115 (2004) (considering the environmental law implications of a range of information technologies); Patricia E. Salkin & John R. Nolon, *Practically Grounded: Convergence of Land Use Law Pedagogy and Best Practices*, 60 J. LEGAL EDUC. 519, 532 (2011); Patricia E. Salkin & Michael Donahue, *Geographic Information Systems for Land Use Lawyers 101*, 5 N.Y. ZONING L. & PRAC. REP., Sept./Oct. 2004, at 1, 6, *reprinted in* LAND USE INSTITUTE: PLANNING, REGULATION, LITIGATION, EMINENT DOMAIN AND COMPENSATION 953, 958 (ALI-ABA Course of Study Materials, Course No. SL005, 2005).

[27] For rare exceptions to this generalization, see David E. Adelman, *The Collective Origins of Toxic Air Pollution: Implications for Greenhouse Gas Trading and Toxic Hotspots*, 88 IND. L.J. 273 (2013) (using geospatial data to analyze the potential for greenhouse gas cap-and-trade systems to create pollution hot spots); Nicklas A. Akers, *New Tools for Environmental Justice: Articulating a Net Health Effects Challenge to Emissions Trading Markets*, 7 HASTINGS W.-NW. J. ENVTL. L. & POL'Y 203, 219–21 (2001); Vicki Been & Francis Gupta, *Coming to the Nuisance or Going to the Barrios? A Longitudinal Analysis of Environmental Justice Claims*, 24 ECOLOGY L.Q. 1, 10–19 (1997) (using spatially coded data to investigate environmental injustice claims). While lawyers rarely use such analytical techniques, economists do sometimes use spatial data to investigate how regulated entities respond to legal incentives. *See, e.g.*, Elena G. Irwin et al., *Modeling and Managing Urban Growth at the Rural-Urban Fringe: A Parcel-Level Model of Residential Land Use Change*, 32 AGRIC. & RESOURCE ECON. REV. 83 (2003) (evaluating the effects of land use controls); Dean Lueck & Jeffrey A. Michael, *Preemptive Habitat Destruction Under the Endangered Species Act*, 46 J.L. & ECON. 27 (2003) (analyzing landowner responses to section 9 of the ESA).

[28] With the emergence of empirical legal studies, the primacy of qualitative arguments is fading. And some empirical legal research does draw upon data coded to geographically defined jurisdictions, like counties or congressional districts. *See, e.g.*, Lisa R. Pruitt & Beth A. Colgan, *Justice Deserts: Spatial Inequality and Local Funding of Indigent Defense*, 52 ARIZ. L. REV. 219 (2010).

problems we find cognitively tractable, what tools we use to address those problems, and to whom we allocate authority to respond. Finally, Part IV focuses on legal research, explaining how spatial analysis could generate more empirically grounded and practically useful academic inquiries about environmental law.

Throughout, the Article also discusses limitations of spatial analysis, which can suffer from the opacity, manipulability, and false certainty that plague any complex and quantitative mode of analysis.[29] It does not claim that spatial analysis will readily or easily solve environmental law's challenges, and in some circumstances spatial analysis tools will be too reductionist or too cumbersome to improve environmental regulation and research. Nor does this Article argue that better information will always lead to better decisions. As the politics of climate change have thoroughly demonstrated, such an expectation is unduly optimistic.[30] But despite these limitations, the emergence of spatial analysis is an important, and potentially quite positive, development for environmental law.

I. THE PERSISTENT FRAGMENTATION OF ENVIRONMENTAL LAW

The years 2008 and 2009 brought the Atlanta metropolitan region too much sun, too little rain, and a big legal scare. For decades, the metropolitan area had grown rapidly, piling one Greenacres-style development upon another and becoming a poster child for suburban sprawl.[31] Greater Atlanta's growth led to massive increases in water use, and when drought struck, the Atlanta region stretched the limits of its water supply.[32] Then the United States Court of Appeals for the D.C. Circuit and a federal district court held that greater Atlanta was using water to which it had no legal entitlement, raising the specter of legal limits atop

[29] *See generally* Kenneth A. Bamberger, *Technologies of Compliance: Risk and Regulation in a Digital Age*, 88 TEX. L REV. 669, 675–76 (2010) (describing the role of automated risk modeling software in the 2008 financial collapse); James D. Fine & Dave Owen, *Technocracy and Democracy: Conflicts Between Models and Participation in Environmental Law and Planning*, 56 HASTINGS L.J. 901 (2005) (recognizing "many sources of uncertainty" inherent in complex modeling systems); Wendy Wagner et al., *Misunderstanding Models in Environmental and Public Health Regulation*, 18 N.Y.U. ENVTL. L.J. 293 (2010) (highlighting a common misperception of complex models as "truth machines").

[30] *See generally* Irene Lorenzoni & Mike Hulme, *Believing Is Seeing: Laypeople's Views of Future Socio-Economic and Climate Change in England and Italy*, 18 PUB. UNDERSTANDING SCIENCE 383, 393–94 (2009) (finding that prior beliefs influence people's willingness to accept new information).

[31] *See The Sprawl Index: Atlanta, GA*, SMART GROWTH AM., http://www.smartgrowthamerica.org/documents/atlantasprawl.pdf (last visited Jan. 24, 2013).

[32] *See* Benjamin L. Snowden, *Bargaining in the Shadow of Uncertainty: Understanding the Failure of the ACF and ACT Compacts*, 13 N.Y.U. ENVTL. L.J. 134, 139 (2005) (describing Atlanta's water supply strains).

the natural drought.[33] Atlanta, it seemed, had grown far beyond its hydrologic means.

The drought has since ended, and an Eleventh Circuit decision placed Atlanta's water use on a less tenuous footing—providing a respite, at least, from the apparent water supply disaster.[34] But water conflict continues, and many other growth problems persist.[35] Atlanta has not attained federal air quality standards, and its nonattainment status is partly caused by a sprawling, automobile-dependent growth pattern.[36] At the region's urban fringe, development has clashed with the protective mandates of the Endangered Species Act (ESA).[37] Other social and environmental problems associated with sprawl—traffic congestion, for example, and isolation of people (particularly the socially and economically disadvantaged) from workplaces, services, and each other—continue to plague the region.[38] While Atlanta may present an extreme case, it is not unique. Similar tensions between development and environmental quality recur across the country.[39]

These tensions did not arise in a legal void. Many growth areas boomed after the early 1970s, when a series of federal and state statutes created legal standards that these areas now fail to attain.[40] Nor did these problems emerge because growing populations inevitably require our current pace of environmental degradation. By regulating the configuration, layout, and landscaping of

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[33] Se. Fed. Power Customers, Inc. v. Geren, 514 F.3d 1316 (D.C. Cir. 2008); *In re* Tri-State Water Rights Litig., 639 F. Supp. 2d 1308 (M.D. Fla. 2009), *rev'd sub nom. In re* MDL-1824 Tri-State Water Rights Litig., 644 F.3d 1160 (11th Cir. 2011).

[34] *See In re MDL-1824*, 644 F.3d at 1166 (holding that the Army Corps of Engineers had authority to deliver water to Atlanta).

[35] *See* Carole Rutland, *No Way to Run a River—After More than Two Decades of Water War, We Need a Truce—and a Fresh Approach*, LEDGER-ENQUIRER (Columbus, Ga.), Nov. 27, 2011 ("The case now lingers as Alabama and Florida think about their next move.").

[36] *See* Michael Lewyn, *How City Hall Causes Sprawl: A Case Study*, 30 ECOLOGY L.Q. 189, 191–92 (2003) (reviewing LARRY KEATING, ATLANTA: RACE, CLASS, AND URBAN EXPANSION (2001)); Larry Hartstein, *Atlanta's Air Quality: Better, but Still Bad*, ATLANTA J.-CONST., Apr. 29, 2010, *available at* http://www.ajc.com/news/news/local/atlantas-air-quality-better-but-still-bad/nQfcf/.

[37] *See* Seth J. Wenger et al., *Runoff Limits: An Ecologically-Based Stormwater Management Program*, 9 STORMWATER 1 (2008) (describing impacts on protected aquatic species in the Etowah watershed).

[38] *See* Robert D. Bullard et al., *The Costs and Consequences of Suburban Sprawl: The Case of Metro Atlanta*, 17 GA. ST. U. L. REV. 935 (2001).

[39] *See, e.g.*, Lincoln Davies, *Just a Big, "Hot Fuss"? Assessing the Value of Connecting Suburban Sprawl, Land Use, and Water Rights Through Assured Supply Laws*, 34 ECOLOGY L.Q. 1217, 1219–25 (2007) (discussing tensions between growth and water supplies); Ben Giles, *Chesapeake Bay Cleanup Could Cost Prince George's $800 Million*, WASH. EXAMINER, Nov. 27, 2011, at 4 (describing the costs of water pollution, partly derived from urbanization, in the Chesapeake Bay).

[40] *See* U.S. ENVTL. PROT. AGENCY, OUR BUILT AND NATURAL ENVIRONMENTS 4–8 (2001) (describing rapid growth in recent decades).

developments, communities can minimize or mitigate many environmental impacts, sometimes while imposing relatively small costs on developers and creating more livable communities.[41] Instead, one important reason why greater Atlanta and its sprawling brethren have grown problematically is that it is exceedingly difficult for any single entity to grasp, let alone respond to, the full range of impacts of sprawl.[42]

That challenge exemplifies an often-criticized feature of the United States' system of environmental law. Too often, critics argue, environmental law depends upon regulatory agencies addressing one environmental goal and one project at a time, and doing so with insufficient involvement from other agencies, levels of government, affected firms, or members of the public.[43] While alternative approaches exist, their informational demands can strain the cognitive capacities of the human mind. This section explores three prominent examples of that fragmentation—specifically, fragmentation across environmental media, space and time, and governmental jurisdictions—and the continuing debates about an optimal response.

A. *Fragmentation Across Environmental Media*

Environmentalists often cite the so-called First Law of Ecology: that everything is connected to everything else.[44] That law captures the widely shared view that human actions have far-reaching consequences, which are not confined to air, water, or any other single environmental medium.[45] Greenacres, for example, would likely impact air quality, water quality, wildlife habitats, energy

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[41] *See* Daniel A. Farber, *Sustainable Consumption, Energy Policy, and Individual Well-Being*, 65 VAND. L. REV. 1479, 1501–06 (2012) (describing how many measures to reduce the environmental impacts of development can improve quality of life); *The Economics of Watershed Protection*, *in* THE PRACTICE OF WATERSHED PROTECTION 171 (T. Schueler & H. Holland eds., 2000) (explaining the economic benefits of measures addressing the water quality impacts of development). Once development occurs, addressing those problems can be much more expensive. *See* Owen, *supra* note 2, at 488 (comparing costs).

[42] *See generally* Buzbee, *supra* note 13, at 63–74 (describing causes and effects of sprawl). This is not the only reason: consumer preferences, racial biases, poor urban schools, and the economic influence of development interests all also play substantial roles in sprawling development patterns. *See generally* ANDRES DUANY ET AL., SUBURBAN NATION: THE RISE OF SPRAWL AND THE DECLINE OF THE AMERICAN DREAM (2000).

[43] *See, e.g.*, Stewart, *supra* note 9, at 21.

[44] *See* Todd Aagaard, *Environmental Harms, Use Conflicts, and Neutral Baselines in Environmental Law*, 60 DUKE L.J. 1505, 1517 & n.40 (2011) (quoting ZYGMUNT J.B. PLATER ET AL., ENVIRONMENTAL LAW AND POLICY: NATURE, LAW, AND SOCIETY 5 (3d ed. 2004)) (documenting the frequent use of this phrase).

[45] Jonathan Cannon, *Environmentalism and the Supreme Court: A Cultural Analysis*, 33 ECOLOGY L.Q. 363, 369–70 (2006) ("Environmentalists share a belief that . . . human intervention affecting one part of a human-natural system can be expected to have deleterious effects elsewhere in the system.").

use, and aesthetics. Regulatory initiatives designed to control these impacts will create their own collateral effects.[46] The consequences will not merely be environmental, for environmental protection is inextricably intertwined with economics and health.[47] These interconnections inevitably inspire calls for holistic regulatory approaches that take into account the full range of consequences of any action.[48]

Despite these calls, much of our environmental regulatory system is divided into media-specific compartments. Many (though not all[49]) of the major federal environmental statutes focus on a single type of pollution or on protecting a single kind of environmental resource. The Clean Air Act, Clean Water Act, and ESA provide obvious examples.[50] Land use regulation is typically addressed not just by separate laws, but also by different levels of government.[51] Consequently, environmental regulation is often highly compartmentalized, with distinct agency offices applying separate statutes to address different environmental consequences of the same underlying action.[52]

This fragmentation is problematic in several ways. First, it can lead to counterproductive regulation. Constraints designed to protect one environmental medium can encourage alternative activities with even worse environmental effects.[53] Second, fragmentation could generate economically inadvisable

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[46] *See generally* RISK VERSUS RISK: TRADEOFFS IN PROTECTING HEALTH AND THE ENVIRONMENT (John D. Graham & Jonathan Baert Wiener eds., 1995).

[47] *See* PRESIDENT'S COUNCIL OF ADVISORS ON SCI. & TECH., EXECUTIVE OFFICE OF THE PRESIDENT, SUSTAINING ENVIRONMENTAL CAPITAL: PROTECTING SOCIETY AND THE ECONOMY 11–30 (2011) (describing links between environmental protection and human wellbeing); Robert N. Stavins, *Policy Instruments for Climate Change: How Can National Governments Address a Global Problem*, 1997 U. CHI. LEGAL F. 293, 295–96, 328 (1997) (summarizing the "multifaceted" costs of environmental regulation).

[48] *See, e.g.*, Lakshman Guruswamy, *Integrating Thoughtways: Re-Opening of the Environmental Mind?*, 1989 WIS. L. REV. 463.

[49] The National Environmental Policy Act (NEPA) provides a significant exception to this generalization, as do its state-law counterparts. 42 U.S.C. §§ 4331–4332 (2006); *see infra* notes 262–271 and accompanying text (discussing NEPA); *see also* 16 U.S.C. § 1455(d) (attempting to provide a framework for using planning to address multiple environmental issues in coastal zones).

[50] *See* 16 U.S.C. §§ 1536, 1538 (providing protection only to threatened or endangered species); John Charles Kunich, *Preserving the Womb of Unknown Species with Hotspots Legislation*, 52 HASTINGS L.J. 1149, 1150 (2001) ("The ESA focuses on species, and moves to protect only one species at a time.").

[51] *See* Solid Waste Agency v. U.S. Army Corps of Eng'rs, 531 U.S. 159, 174 (2001) (emphasizing "the States' traditional and primary power over land and water use").

[52] *See* Stewart, *supra* note 9, at 21.

[53] *See* STEPHEN BREYER, BREAKING THE VICIOUS CIRCLE 22 (1993) ("[T]he instances are sufficient in number to produce an overall impression of an interprogram, interagency coordination problem."); Peter J. Fontaine, *EPA's Multimedia Enforcement Strategy: The Struggle to Close the Environmental Compliance Circle*, 18 COLUM. J. ENVTL. L. 31, 33–34 (1993) ("[R]egulatory efforts to control pollutants in one environmental medium often merely transfer them to other environmental media.").

regulation, as agencies unwittingly impose controls that create economic costs outweighing environmental benefits.[54] Both of these potential problems have been exhaustively discussed in legal-academic literature, and avoiding them has been a recurrent justification for cross-media integration.[55] However, underregulation may be a greater problem. Many environmental statutes and regulations establish thresholds, and if an activity's impacts do not rise to those thresholds, more lenient regulatory controls apply.[56] There are obvious reasons for adopting such thresholds,[57] but sometimes an activity with media-specific effects that fall below those thresholds might seem inadvisable if all of its consequences are considered together.[58] Greenacres, for example, might not strike a water quality regulator, an air quality regulator, a wetlands regulator, or a land use planner as problematic if each impact is considered separately. The collective effects of the project, however, might justify major changes, and perhaps even an outright regulatory denial.

For years, environmental policymakers have been aware of these problems, and they have tried to respond in many ways. One category of responses seeks to expand the analytical scope of environmental decisionmaking. NEPA, for example, attempts to compel more integrative thinking by requiring a single study of a broad range of environmental impacts.[59] Mandates for cost-benefit and regulatory impact exemplify a similar impulse toward broadening analytical frames, albeit toward consideration of economic rather than environmental impacts.[60] Concepts like

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[54] *See* BREYER, *supra* note 53, at 11 (criticizing administrative "[t]unnel vision"); Sunstein, *supra* note 8, at 1010, 1027–28.

[55] *E.g.*, Fontaine, *supra* note 53, at 33–34; Cass R. Sunstein, *Cost-Benefit Default Principles*, 99 MICH. L. REV. 1651, 1653 (2001) (listing examples of unintended consequences of risk regulation).

[56] *See, e.g.*, DANIEL A. FARBER ET AL., CASES AND MATERIALS ON ENVIRONMENTAL LAW 547 (8th ed. 2010) (describing the Clean Air Act's distinctions between major and nonmajor sources); Robin Bravender, *EPA Issues Final "Tailoring" Rule for Greenhouse Gas Emissions*, N.Y. TIMES (May 13, 2010), http://www.nytimes.com/gwire/2010/05/13/13greenwire-epa-issues-final-tailoring-rule-for-greenhouse-32021.html (describing EPA's attempt to exempt smaller sources from greenhouse gas regulations).

[57] Regulating small sources of environmental degradation can be difficult for administrators, costly for regulated entities, and at odds with a widely shared ideological commitment to regulatory minimalism. *See* Exec. Order No. 13563, 76 Fed Reg. 3821, 3821 (2011) (asserting that our regulatory system "must identify and use the best, most innovative, and least burdensome tools"); Stack & Vandenbergh, *supra* note 4, at 1395–98.

[58] *See, e.g.*, Fontaine, *supra* note 53, at 38–46 (describing a facility that for too long escaped vigorous enforcement, largely because different regulators did not realize that violations were part of a larger trend).

[59] *See* 42 U.S.C. § 4332 (2006).

[60] *See* Sunstein, *supra* note 55, at 1656–63 (summarizing arguments in favor of cost-benefit analysis). For a summary of requirements for federal administrative rulemaking, see Mark Seidenfeld, *A Table of Requirements for Federal Administrative Rulemaking*, 27 FLA. ST. U. L. REV. 533, 536–37 (2000). A less-cited but still important motivation for these requirements is to place procedural hurdles before agencies likely to take undesired

"sustainable development" reflect the same underlying goal, for sustainable development's basic precept is that economic, social, and environmental systems should be viewed as integrated parts of a larger whole.[61] The concept of "ecosystem management," which now pervades the rhetoric of natural resource law, embodies similar ambitions.[62]

Putting these ambitions into practice has not been easy. The Environmental Protection Agency (EPA) has been the focus of several reform movements, each with the primary goal of addressing multiple pollutants and impacts through consolidated permitting processes.[63] Those efforts produced a few limited pilot programs and high-profile initiatives, but multimedia permitting processes remain rare.[64] Cost-benefit analysis is now entrenched in administrative decisionmaking processes.[65] But finding enough information to do a good cost-benefit analysis can be very difficult, and observers disagree vehemently about whether those analyses improve or worsen regulatory decisionmaking.[66] Sustainable development is now one of the most pervasive buzz-phrases in the environmental field, but giving the concept a meaningfully precise definition, let alone transforming it into legal mandates, has not been easy.[67] The ecosystem management concept has helped

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actions. *See, e.g.*, Matthew C. Stephenson, *Bureaucratic Decision Costs and Endogenous Agency Expertise*, 23 J.L. ECON. & ORG. 469, 473 (2007).

[61] *See* J.B. Ruhl, *Sustainable Development: A Five-Dimensional Algorithm for Environmental Law*, 18 STAN. ENVTL. L.J. 31, 35–36 (1999) ("[S]ustainable development defines all social problems in terms of three parameters—environment, economy, and equity—and projects them in the dimensions of geographic scale and time.").

[62] *See* Lee P. Breckenridge, *Reweaving the Landscape: The Institutional Challenges of Ecosystem Management for Lands in Private Ownership*, 19 VT. L. REV. 363, 370–77 (1995) (describing ecosystem management concepts, which call for considering multiple resources, geographic and temporal scales, and human and nonhuman impacts simultaneously); Harry N. Scheiber, *From Science to Law to Politics: An Historical View of the Ecosystem Idea and Its Effect on Resource Management*, 24 ECOLOGY L.Q. 631 (1997) (discussing the evolution of ecosystem management concepts).

[63] *See, e.g.*, Frances H. Irwin, *An Integrated Framework for Preventing Pollution and Protecting the Environment*, 22 ENVTL. L. 1, 23–42 (1992) (describing proposals for integrated, multimedia regulation); Krier & Brownstein, *supra* note 15, at 119–22.

[64] *See* Uwe M. Erling, *Approaches to Integrated Pollution Control in the United States and the European Union*, 15 TUL. ENVTL. L.J. 1, 4 (2001) ("[E]xamples of a truly holistic multimedia permit can rarely be found."); Irwin, *supra* note 63, at 3–4 (describing the limited achievements of EPA's early efforts).

[65] *See* John D. Graham, *Saving Lives Through Administrative Law and Economics*, 157 U. PA. L. REV. 395, 402 (2008) ("[T]here is universal consensus that [benefit-cost analysis] plays a more significant role today than it did a generation ago.").

[66] *See* Entergy Corp. v. Riverkeeper, Inc., 556 U.S. 208, 237–38 (2009) (Stevens, J. dissenting) (critiquing cost-benefit analysis); Wagner, *supra* note 16, at 1720–26 (arguing that proponents of cost-benefit analysis make unrealistic assumptions about information availability). For a contrasting view, see Sunstein, *supra* note 55 (discussing the rise of cost-benefit principles and their use to accomplish statutory goals).

[67] *See* Daniel C. Esty, *A Term's Limits*, FOREIGN POL'Y, Sept.–Oct. 2001, at 74, 74 ("[S]ustainable development has largely failed as an organizing principle.").

produce some concrete results,[68] but these, too, have a mixed track record of success, and critics have questioned the attainability of ecosystem management almost since the concept's emergence.[69] In the decades since multimedia integration became a widely shared aspiration, Congress has done little to reorient environmental law or to create major integrating institutions.[70] Instead, the fragmented statutory system commentators have been criticizing since the 1970s remains largely unchanged.[71]

The persistence of fragmentation should not be entirely surprising, for any integrative initiative raises significant informational challenges.[72] To understand the impacts of a project or regulatory action upon just a single environmental medium can be difficult. To understand the impacts of a single project or regulatory action across a range of media—and to understand all of the economic and social consequences of that action—may be much more than a single person or even agency office can accomplish.[73] That problem may be addressed by pulling more people and offices into the project, but then a coordination challenge partially replaces the initial informational challenge. Fragmentation, for all its dysfunctions, can be administratively efficient, and the continued compartmentalization of environmental law reflects a tacit recognition of this reality.[74]

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[68] The most notable examples are regional, multispecies habitat conservation plans developed under sections 9 and 10 of the ESA. *See* Matthew E. Rahn et al., *Species Coverage in Multispecies Habitat Conservation Plans: Where's the Science?*, 56 BIOSCIENCE 613, 613–14 (2006) (describing the increasing prevalence, and agency promotion, of this approach).

[69] *See* Alejandro E. Camacho, *Can Regulation Evolve? Lessons from a Study in Maladaptive Management*, 55 UCLA L. REV. 293, 335–42 (2007) (critiquing the HCP program); Oliver A. Houck, *On the Law of Biodiversity and Ecosystem Management*, 81 MINN. L. REV. 869, 974–78 (1997) (questioning whether ecosystem management can fulfill its ambitions); Rahn et al., *supra* note 68, at 616–19.

[70] The most prominent congressional attempt at integration involves air quality regulation and transportation planning. *See* Susan Hanson, *The Context of Urban Travel: Concepts and Recent Trends*, *in* THE GEOGRAPHY OF URBAN TRANSPORTATION 3, 24–25 (Susan Hanson & Genevieve Giuliano eds., 3d ed. 2004).

[71] *See* Peter A. Buchsbaum, *Permit Coordination Study by the Lincoln Institute of Land Policy*, 36 URB. LAW. 191, 193 (2004) (documenting "a general consensus that environmental land use regulation continues to suffer from lack of coordination").

[72] *See* Krier & Brownstein, *supra* note 15, at 125 (quoting Charles Lindblom, *The Science of "Muddling Through,"* 19 PUB. ADMIN. REV. 79, 80 (1959)) (arguing that integrated pollution control "assumes intellectual capacities and sources of information that men simply do not possess").

[73] Some environmental studies still address an impressive range of environmental consequences. *See, e.g.*, MINERALS MGMT. SERV., U.S. DEP'T OF INTERIOR, OCS PUBLICATION NO. 2008-040, CAPE WIND ENERGY PROJECT FINAL ENVIRONMENTAL IMPACT STATEMENT (2009) (providing detailed analysis of a broad range of impacts and alternatives). But that sort of comprehensive analysis is generally very expensive and time consuming to prepare.

[74] *See* Krier & Brownstein, *supra* note 15, at 126 ("[D]isjointed incrementalism is necessarily the actual method of policy making in the real world.").

That reality could change, however. In a complex world, some informational and coordination challenges will always accompany environmental decisionmaking. But if technology can effectively bolster the human mind's capacity to process information, then adjustment of current fragmentary approaches still would be appropriate. A key question for the future of environmental law is whether such tools are beginning to emerge.

B. Fragmentation Across Space and Time

Compartmentalization along media-specific lines may be a central challenge for environmental law, but it is by no means the only fragmentation problem. Environmental regulation also routinely confronts decisionmakers with the need to think across spatial and temporal scales.[75]

Few environmental problems arise solely from the consequences of a single event, project, or decision. Instead, environmental degradation is often the consequence of many different actions spread across space and time.[76] Greenacres, for example, might be just one of many developments in its watershed and air basin, and over time, the combined effects of those developments for water quality, water supply, and air quality might become significant.[77] With climate change, the relevant impact could even be global in scale.[78]

The incremental causes of environmental challenges create an obvious need for integrated responses. If policymakers focus only on one event or location, they may not recognize an important threat.[79] They also may respond inefficiently or inequitably. Some causes might be more cost-effectively redressed than others, but if regulators deal only with one activity at a time, they will miss those

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[75] *See* William W. Buzbee, *Recognizing the Regulatory Commons: A Theory of Regulatory Gaps*, 89 IOWA L. REV. 1, 56 (2003) ("Statutory schemes attempting to protect ambient environmental quality where large harms are created by diverse causes are often unsuccessful."); 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, 64–65 (2010) (identifying the complexity of these problems as one of environmental law's greatest challenges).

[76] *See* Buzbee, *supra* note 13, at 86 (discussing sprawl and the cumulative impact of individual decision); Theobald et al., *supra* note 4, at 1908–09.

[77] *See generally* Owen, *supra* note 2, at 439–45 (explaining how development incrementally degrades water quality). *See, e.g.*, Michael R. Yarne, Note, *Conformity as Catalyst:* Environmental Defense Fund v. Environmental Protection Agency, 27 ECOLOGY L.Q. 841, 869–71 (2000) (describing how Atlanta's growth affected air quality).

[78] See Stack & Vandenbergh, *supra* note 4, at 1402–12 (discussing the cumulative impact of greenhouse gas emissions).

[79] *See* U.S. ENVTL. PROT. AGENCY, OFFICE OF FED. ACTIVITIES, EPA 315-R-99-002, CONSIDERATION OF CUMULATIVE IMPACTS IN EPA REVIEW OF NEPA DOCUMENTS 1 (1999) ("The combined, incremental effects of human activity, referred to as cumulative impacts, pose a serious threat to the environment.").

efficiencies.[80] Conversely, if regulators deal with each contributing source in isolation, they may fail to establish consistent standards or equitable distinctions.

For all of these reasons, environmental policymakers for years have sought to broaden the geographic and temporal scope of environmental analysis. They have done so through several techniques. First, many statutes and regulations call for "cumulative impact analyses."[81] Such analyses strive to place the potential impacts of a proposed activity in a broader context by considering the effects of other related projects and trends.[82] Second, many environmental statutes, as well as most states' land use laws, call for planning processes,[83] which generally are designed to provide frameworks for decisions on individual projects or regulatory initiatives.[84] Often planning and cumulative impact analysis are tightly coupled, with planning initiatives providing opportunities for more programmatic environmental analyses.[85]

More recently, environmental policymakers have sought spatial and temporal integration through trading schemes. In their earliest and simplest form, these trading schemes expanded the geographic focus of regulation from individual smokestacks to facilities as a whole, and allowed regulated plants to compensate for emissions increases in one location through reductions elsewhere.[86] The appeal of this approach was straightforward: regulators would still obtain their desired emission limitations, and regulated entities could find the cheapest place to put

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[80] *See* Ackerman & Stewart, *supra* note 16, at 1335 (stressing these disparities in cost, though in an argument for market-based schemes).

[81] *See, e.g.*, COUNCIL ON ENVTL. QUALITY, CONSIDERING CUMULATIVE EFFECTS UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT (1997); U.S. FISH & WILDLIFE SERV. & NAT'L MARINE FISHERIES SERV., ENDANGERED SPECIES CONSULTATION HANDBOOK 4-31 to 4-33 (1998) (providing guidance for cumulative impact analyses); Zhao Ma et al., *Assessing Cumulative Impacts Within State Environmental Review Frameworks in the United States*, 29 ENVTL. IMPACT ASSESSMENT REV. 390 (2009) (documenting cumulative impact analysis requirements under state law).

[82] *See* U.S. ENVTL. PROT. AGENCY, *supra* note 79, at 2.

[83] *See, e.g.*, 16 U.S.C. § 1533(f) (2006) (requiring recovery planning for threatened and endangered species); *id.* § 1604 (requiring forest planning); 33 U.S.C. § 1313(e) (requiring water quality planning); 42 U.S.C. § 7410 (requiring ambient air quality planning); 43 U.S.C. § 1712 (requiring "land use plans"); *see also* Patricia E. Salkin & Amy Lavine, *Regional Foodsheds: Are Our Local Zoning and Land Use Regulations Healthy?*, 22 FORDHAM ENVTL. L. REV. 599, 611 (2011) ("Most state statutes require that zoning regulations be developed and implemented in accordance with a comprehensive land use plan . . . .").

[84] *See* Ohio Forestry Ass'n v. Sierra Club, 523 U.S. 726, 729–30 (1998) (describing the relationship between a forest management plan and subsequent site-specific decisions).

[85] *See* V. Alaric Sample, *Assessing Cumulative Environmental Impacts: The Case of National Forest Planning*, 21 ENVTL. L. 839, 843 (1991).

[86] *See* Jody Freeman, *The Story of Chevron: Environmental Law and Administrative Discretion*, *in* ENVIRONMENTAL LAW STORIES 172, 178–84 (Richard J. Lazarus & Oliver A. Houck eds., 2005) (describing EPA's early efforts at pollution control).

those limitations into effect.[87] In other words, a spatially broader regulatory frame would serve as a means to greater economic efficiency. Subsequent initiatives, like the acid rain program under the 1990 Clean Air Act Amendments, expanded the geographic scope to allow trading between different plants, sometimes over large geographic areas.[88] They also allowed "banking," which means trading emission reductions in the present for emission increases in the future.[89] Such spatial and temporal trading programs are now central features of environmental and energy law.[90]

Like efforts at multimedia integration, these temporal and spatial integration efforts have faced challenges. For planning and cumulative impact analysis, the core problem is simple: doing either well requires gathering and processing a tremendous amount of information.[91] If many different governmental and private actors contribute to an environmental problem, even identifying all the activities that create that environmental problem can require a significant effort.[92] Predicting the collective consequences of those many activities can be even more difficult. Environmental systems are often complex and dynamic, with synergistic effects and feedback loops complicating efforts at prediction.[93] Consequently, cumulative impact analyses and comprehensive plans, while easy to call for, are often difficult to complete. The environmental law literature is filled with accounts of plans gone wrong,[94] and many critics have argued that environmental planning's unrealistic information demands doom it to failure.[95] Similarly, cumulative impact analyses often appear to be neglected afterthoughts within environmental impact statements,

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[87] *See id.* at 179–80.

[88] *See* Byron Swift, *How Environmental Laws Work: An Analysis of the Utility Sector's Response to Regulation of Nitrogen Oxides and Sulfur Dioxide Under the Clean Air Act*, 14 TUL. ENVTL. L.J. 309, 319–22 (2001).

[89] *See* Robert W. Hahn & Gordon L. Hester, *Marketable Permits: Lessons for Theory and Practice*, 16 ECOLOGY L.Q. 361, 368 (1989).

[90] *See* Lincoln L. Davies, *Power Forward: The Argument for a National RPS*, 42 CONN. L. REV. 1339, 1359–60 (2010) (discussing the role of trading schemes in renewable portfolio standards); James Salzman & J.B. Ruhl, *Currencies and the Commodification of Environmental Law*, 53 STAN. L. REV. 607, 609 (2000) (describing "growing interest in market-based instruments"); Tom Tietenberg, *Tradable Permits in Principle and Practice*, *in* MOVING TO MARKETS IN ENVIRONMENTAL REGULATION 63, 64–65 (Jody Freeman & Charles D. Kolstad eds., 2007) (describing applications).

[91] *See* OLIVER A. HOUCK, THE CLEAN WATER ACT TMDL PROGRAM: LAW, POLICY, AND IMPLEMENTATION 63 (2d ed. 2002).

[92] *See* Fine & Owen, *supra* note 29, at 953–55 (describing the information gathering necessary to support air quality modeling).

[93] *See* Ruhl & Salzman, *supra* note 75, at 88–92 (describing these dynamics).

[94] *See* Fine & Owen, *supra* note 29, at 962–64 (describing unsuccessful air quality planning); Arnold W. Reitze, Jr., *Air Quality Protection Using State Implementation Plans—Thirty-Seven Years of Increasing Complexity*, 15 VILL. ENVTL. L.J. 209, 357–65 (2004) (calling state implementation planning a "failure").

[95] *See, e.g.*, HOUCK, *supra* note 91, at 257 (describing planning-based approaches as "chronically difficult in their science and their political science").

as though the agency drafting the statement viewed the cumulative analysis requirement as an inconvenient and unrealistic demand, to be complied with as cursorily as possible.[96] As one EPA study succinctly observed, "Cumulative impacts . . . are not often fully addressed in NEPA documents."[97]

Trading schemes might seem to obviate some of these informational problems, for a market-based system theoretically can succeed without any single entity possessing synoptic knowledge of the activities at issue.[98] In practice, however, trading schemes raise their own informational challenges. The traded things rarely are fungible. For example, a natural wetland that will be destroyed to allow development may be far more ecologically valuable than a replacement wetland constructed elsewhere, and a ton of emissions at the upwind side of an air basin—or adjacent to a low-income, minority community—may be far more problematic than a ton of emissions at the basin's downwind edge.[99] A recurring concern about environmental trading schemes therefore is that the trades will be chronically uneven, with the environment and, perhaps, the disadvantaged on the losing end, unless regulators review each trade.[100] Providing that oversight, however, can be a substantial task, particularly if, as is often the case, the trading

[96] *See generally* Michael D. Smith, *Cumulative Impact Assessment Under the National Environmental Policy Act: An Analysis of Recent Case Law*, 8 ENVTL. PRAC. 228 (2006) (finding that cumulative impact analyses were often found inadequate by courts, and concluding that "inadequate cumulative impact analyses continue to be major shortcomings in many NEPA documents."). Smith's observations are entirely consistent with my own experiences litigating NEPA cases.

[97] U.S. ENVTL. PROT. AGENCY, *supra* note 79, at 1; *see also* Courtney Schultz, *Challenges in Connecting Cumulative Effects Analysis to Effective Wildlife Conservation Planning*, 60 BIOSCIENCE 545, 546 (2010) ("Past studies have found that [cumulative effects analysis] was absent or inadequate in many NEPA documents, and that the requirement has not been implemented to its full potential for numerous reasons, including a lack of monitoring data, funding, and adequate training."). Studies of cumulative impact analyses under state environmental laws have found similar problems. *See* Ma et al., *supra* note, 81, at 397.

[98] *See* Hahn & Hester, *supra* note 89, at 361–62 (identifying markets and marketable permits as an antidote to informational challenges).

[99] *See* Richard Toshiyuki Drury et al., *Pollution Trading and Environmental Injustice: Los Angeles' Failed Experiment in Air Quality Policy*, 9 DUKE ENVTL. L. & POL'Y F. 231, 252 (1999).

[100] *See* Eric Freyfogle, *Water Rights and the Common Wealth*, 26 ENVTL. L. 27, 31–33 (1996) (describing the importance of context for water use); Salzman & Ruhl, *supra* note 90, at 622–30 (describing the pervasiveness of trading in nonfungible things); Tietenberg, *supra* note 90, at 87 (describing traders' lack of incentive to ensure environmental fungibility). *But see* Holly Doremus & W. Michael Hanemann, *Of Babies and Bathwater: Why the Clean Air Act's Cooperative Federalism Framework Is Useful for Addressing Climate Change*, 50 ARIZ. L. REV. 799, 803 (2008) ("CO_2 emissions are extraordinarily fungible . . . .").

scheme involves many actors and actions.[101] Consequently, administering an environmentally protective trading scheme is often an information-intensive exercise, which raises transaction costs and limits efficiency.[102] Partly for these reasons, many commentators remain skeptical about the utility of environmental trading schemes.[103]

As with debates over multimedia integration, these debates over spatial and temporal integration remain unresolved.[104] In practice, environmental law retains a mix of all of these approaches, with technology-based systems, trading systems, and planning systems often overlapping in ways that defy easy categorization, and with the proper balance among those approaches still subject to vigorous discussion. That balance also could change. Our capacity for spatially and temporally integrative decisionmaking is limited largely by our capability for processing information. If technology is enhancing that capacity, then integrative regulatory approaches should be increasingly viable.

C. *Institutional Fragmentation*

These challenges of spatial, temporal, and media-based fragmentation are intertwined with challenges of institutional fragmentation. Most major environmental problems implicate federal, state, and local regulatory authority.[105] They also affect the interests of private businesses, advocacy groups, and individuals.[106] Often the knowledge necessary to understand environmental

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[101] *See* Doremus & Hanemann, *supra* note 100, at 814–16; Lesley K. McAllister, *The Enforcement Challenge of Cap-and-Trade Regulation*, 40 ENVTL. L. 1195, 1196–202 (2010).

[102] *See* James Salzman & J.B. Ruhl, *"No Net Loss": Instrument Choice in Wetlands Protection*, *in* MOVING TO MARKETS IN ENVIRONMENTAL REGULATION, *supra* note 90, at 323, 338–39 (discussing how this tension affects wetlands trading). For air pollution trading, some studies have concluded that informational burdens are more manageable. *See* Winston Harrington & Richard D. Morganstern, *International Experience with Competing Approaches to Environmental Policy: Results from Six Paired Cases*, *in* MOVING TO MARKETS IN ENVIRONMENTAL REGULATION, *supra* note 90, at 95, 117–18.

[103] *See, e.g.*, Salzman & Ruhl, *supra* note 90, at 648–63 (questioning the effectiveness of markets for habitat protection); Center on Race, Poverty, & Environment, *Climate Justice in California*, http://www.crpe-ej.org/crpe/index.php/campaigns/climate-justice/california (last visited June. 27, 2013) (calling cap-and-trade systems "ineffective").

[104] *See generally* MOVING TO MARKETS IN ENVIRONMENTAL REGULATION, *supra* note 90 (containing multiple views of markets, some complementary and others less so). For disparate views on environmental planning, compare HOUCK, *supra* note 91 (criticizing planning), with THE WHITE HOUSE COUNCIL ON ENVTL. QUALITY, FINAL RECOMMENDATIONS OF THE INTERAGENCY OCEAN POLICY TASK FORCE (2010) (calling for a massive new planning initiative).

[105] *See, e.g.*, LAZARUS, *supra* note 7, at 35; Robin Kundis Craig, *Climate Change, Regulatory Fragmentation, and Water Triage*, 79 U. COLO. L. REV. 825, 834–69 (2008).

[106] *See generally* Jody Freeman, *The Private Role in Public Governance*, 75 N.Y.U. L. REV. 543 (2000).

problems is dispersed throughout these complex institutional landscapes, and solving environmental problems is impossible without coordination across both jurisdictional and public-private boundaries.[107]

This dispersal of knowledge and authority frustrates environmental law at multiple levels. If multiple agencies hold responsibility over different aspects of the same activity, they may act at cross-purposes. Local land use regulators, for example, might pass large-lot zoning requirements designed to preserve aesthetic qualities (or, more insidiously, socioeconomic segregation),[108] yet those requirements can spread development across more of the landscape, creating perverse outcomes for water quality protection, habitat protection, air quality, and energy use.[109] Energy regulators might try to promote energy-efficient power plant cooling systems even as water quality and fishery regulators complain of impacts upon aquatic systems.[110] Regulators also may not act at all. An upstream or upwind state, for example, may have little incentive to control pollution emissions.[111] Even where multiple jurisdictions share the burden of an environmental problem, a "regulatory commons" dynamic, in which no agency has enough incentive to act, can preclude effective responses.[112] Combinations of inaction and conflicting action also may arise. When they do, as the bungled response to Hurricane Katrina illustrates, the result can be costly.[113] Addressing these problems of institutional complexity therefore remains another central challenge of environmental law.

These problems are centrally important to debates about environmental federalism. By design, our government is a system of divided authority, with federal, state, and local authorities and a robust private sector all theoretically playing important roles.[114] But when these different institutions come into conflict, questions arise about who holds decisionmaking authority and where jurisdictional boundaries lie.[115] For years, those questions have formed one of environmental law's key battlegrounds, with jurists and commentators asserting dramatically

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[107] Freeman & Farber, *supra* note 11, at 797–98.

[108] *See* Lawrence Gene Sager, *Tight Little Islands: Exclusionary Zoning, Equal Protection, and the Indigent*, 21 STAN. L. REV. 767, 781 (1969).

[109] *See* Peter Whoriskey, *Density Limits Only Add to Sprawl: Large Lots Eat Up Area Countryside*, WASH. POST, Mar. 9, 2003, at A1.

[110] *See* Entergy Corp. v. Riverkeeper, Inc., 556 U.S. 208, 216 (2009) (noting the energy costs of installing cooling systems with lower water-quality impacts).

[111] *See* Daniel C. Esty, *Toward Optimal Environmental Governance*, 74 N.Y.U. L. REV. 1495, 1543 (1999) ("[P]rogress on acid rain would likely never have been made as long as the issue were left to state level initiative . . . .").

[112] *See* Buzbee, *supra* note 75, at 6.

[113] *See* Erin Ryan, *Federalism and the Tug of War Within: Seeking Checks and Balance in the Interjurisdictional Gray Area*, 66 MD. L. REV. 503, 518–36 (2007).

[114] *See* Bond v. United States, 131 S. Ct. 2355, 2364–65 (2011) (arguing that federalism protects political liberty).

[115] *See generally* William W. Buzbee, *Interaction's Promise: Preemption Policy Shifts, Risk Regulation, and Experimentalism Lessons*, 57 EMORY L.J. 145 (2007).

different views about how our federalist system should face the challenges of jurisdictional fragmentation.[116]

These challenges also raise important questions about how to encourage effective coordination among multiple institutions.[117] In response to these questions, many legal scholars have explored what makes interjurisdictional coordination succeed.[118] They have focused primarily on bureaucratic structures, divisions of authority, and measures for public participation.[119] Such questions of power and procedure obviously are very important. But an equally consequential, and largely unexamined, set of questions involves the substance of interjurisdictional communication. Different agencies have different goals and cultures, rely on different data, and use different methods and terminology for communication.[120] Private firms and public participants often bring their own divergent perspectives and knowledge to the table. Finding common languages for these participants to pool information, develop shared understanding, and identify areas where their goals coincide or conflict therefore is crucially important. A key question for environmental law, then, is whether new mechanisms for communication should change approaches to environmental regulation.

D. Intertwining Systems of Fragmentation

These problems of fragmentation among media, within space and time, and across jurisdictions often occur in combination. With Greenacres, for example, impacts on different environmental media would be regulated not just by different statutes but also by different agencies—some local, some state, and some federal.[121] The impacts also would likely spill across municipal, state, and sometimes even national boundaries.[122] But jurisdictional boundaries and cultural

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[116] *See infra* notes 309–319 and accompanying text.

[117] *See* Ruhl & Salzman, *supra* note 75, at 64–65 (explaining the prevalence of these challenges).

[118] *See, e.g.*, Holly Doremus, *CALFED and the Quest for Optimal Institutional Fragmentation*, 12 ENVTL. SCI. & POL'Y 729 (2009); Freeman & Farber, *supra* note 11; Ruhl & Salzman, *supra* note 75, at 109–19.

[119] *See, e.g.*, Freeman & Farber, *supra* note 11, at 798 (offering "modular regulation" as a solution to coordination challenges); Ruhl & Salzman, *supra* note 75, at 109–19 (promoting solutions based on "weak ties networks").

[120] *See generally* Eric Biber, *Which Science? Whose Science? How Scientific Disciplines Can Shape Environmental Law*, 79 U. CHI. L. REV. 471 (2012) (exploring these differences).

[121] *See* Buzbee, *supra* note 13, at 91 (describing the dispersion of authority over sprawl's causes and effects).

[122] *See, e.g.*, U.S. ENVTL. PROT. AGENCY REGION 3 ET AL., CHESAPEAKE BAY TOTAL MAXIMUM DAILY LOAD FOR NITROGEN, PHOSPHORUS AND SEDIMENT ES-3 (2010) (describing sources of impairment of Chesapeake Bay); W.R. Stockwell et al., *Ozone Formation, Destruction and Exposure in Europe and the United States*, *in* FOREST DECLINE AND OZONE 1, 1 (Heinrich Sandermann et al. eds, Ecological Studies, vol. 127, 1997) (describing regional ozone transport); Hari M. Osofsky, *Is Climate Change*

differences will create barriers to coordination—a volunteer local planning board will likely frame issues quite differently from a federal agency dominated by wildlife biologists or air quality scientists and engineers.[123] The common result is what policy analysts refer to as a "wicked" problem, in which simply defining the scope of the regulatory challenge, let alone resolving it, is very difficult.[124]

In practice, those difficulties often seem insurmountable. Rather than coordinate effectively, state and federal regulators may initially leave oversight of Greenacres almost entirely under local control.[125] Local regulators, though perhaps generally aware that development affects habitat protection, water supply, water quality, air quality, and a variety of other environmental outcomes, may have little idea how to translate those broad concerns into site-specific regulatory controls.[126] Often, it is only when development patterns clearly become incompatible with state or federal environmental quality mandates that local, state, and federal entities attempt to coordinate—or resign themselves to do battle.[127] By that time, proactive solutions are unlikely to be available. The remedies instead will be expensive, if they are implemented at all, and both local autonomy and environmental quality will suffer. This dysfunctional dynamic creates an acute need to find a better way.

II. THE EMERGENT GEOCODED AGE

Forty years ago, when environmental law began developing its current responses to these challenges of fragmentation, the term "geographic information systems" was hardly ever used.[128] Computer-based modeling[129] was in its infancy,

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"International"? Litigation's Diagonal Regulatory Role, 49 VA. J. INT'L L. 585 (2009) (exploring the multiscalar dimensions of climate change).

[123] I base this claim on experience with local boards and with agency scientists and engineers. The differences in expertise and perspective are often profound.

[124] *See* Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future*, 94 CORNELL L. REV. 1153, 1159–60 (2009).

[125] *See* Buzbee, *supra* note 13, at 91 (noting presumptions favoring local control).

[126] Their inaction also may be motivated by the local political influence of prodevelopment entities and by collective action problems. *See id.* at 77–91 (exploring the political dynamics of sprawl). In working with local governments, however, I have often found genuine interest in protecting environmental quality but little understanding about how to connect those overall goals to specific land use decisions.

[127] *See, e.g.*, Owen, *supra* note 2, at 480–83, 502–03 (describing innovative but belated water quality protection efforts); Nat'l Ass'n of Home Builders v. San Joaquin Valley Unified Air Pollution Control Dist., 627 F.3d 730, 731–32 (9th Cir. 2010) (discussing a rule, adopted only after years in nonattainment status, designed to control ozone precursor emissions from development), *cert denied*, 132 S. Ct. 369 (2011); *supra* notes 31–39 and accompanying text (discussing the Atlanta region).

[128] Prototypes of modern GISs were emerging but not in widespread use. *See* KEITH C. CLARKE, GETTING STARTED WITH GEOGRAPHIC INFORMATION SYSTEMS 8–9 (1999) (describing the evolution of GIS).

and the processing capacity of computer systems was orders of magnitude lower than it is today.[130] Researchers in many fields used statistics, but regression analyses of large, multivariable data sets were enormously time-consuming.[131] Consequently, many environmental sciences were very different than they are now. Ecologists may have believed that "everything was connected to everything else," but they had limited tools to understand how.

In the past four decades, those tools have evolved dramatically, and this Part turns from the dysfunctions of fragmented regulation to the coevolution of spatial analysis and environmental research. The discussion is necessarily quite general, and it covers only a small subset of the ways in which spatial analysis is now used. Nevertheless, even that subset illustrates a critical point: spatial analysis has important implications for any field, like environmental law, that depends on information about the physical or human environment.[132]

A. *The Emergence of Quantitative Spatial Analysis*

In the mid-nineteenth century, London suffered a series of cholera outbreaks.[133] The cause of cholera then was unknown; a leading theory postulated that the primary disease vector was a "miasma" emanating from an infected person's body.[134] But John Snow, a young doctor, suspected that the disease instead was transferred through fecal-oral contact.[135] To test his hypothesis, Snow gathered and mapped data on cholera deaths during a particularly virulent outbreak

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[129] Environmental researchers understand the term "model" in a variety of ways, and one recent report defines a model as "a simplification of reality that is constructed to gain insights into select attributes of a particular physical, biological, economic, or social system." NAT'L RESEARCH COUNCIL, MODELS IN ENVIRONMENTAL REGULATORY DECISION MAKING 31 (2007). If the term is used in that broad sense, a map or even a single equation qualifies as a model. In this Article, the term "model" holds a narrower meaning. I use the term to refer to simulation models, which take a series of data inputs, run numeric calculations according to prespecified rules, and produce numeric outputs. This narrower usage distinguishes models from maps. As discussed in more detail below, however, maps can be both inputs for and outputs from models.

[130] *See* John O. McGinnis, *Laws for Learning in an Age of Acceleration*, 53 WM. & MARY L. REV. 305, 311–14 (2011) (describing exponential growth in computing power).

[131] *See* John O. McGinnis, *Age of the Empirical*, 137 POL'Y REV. 47, 49 (2006) ("One University of Chicago social scientist is said to have taken the entire summer to run a regression on a mainframe computer 40 years ago. Now researchers can run scores of regressions on their laptops in a few hours.").

[132] *See* Cary Coglianese et al., *Seeking Truth for Power: Informational Strategy and Regulatory Policymaking*, 89 MINN. L. REV. 277, 277 (2004) ("Information is the lifeblood of regulatory policy.").

[133] S.W.B. Newsom, *Pioneers in Infection Control: John Snow, Henry Whitehead, the Broad Street Pump, and the Beginnings of Geographical Epidemiology*, 64 J. HOSP. INFECTION 210, 211 (2006).

[134] *Id.*

[135] *Id.*

in London's Broad Street neighborhood.[136] His research showed, and subsequent studies confirmed, that the outbreak could be traced back to the contamination of a single well.[137] Snow persuaded the city to close the well, ending the epidemic, and he eventually earned recognition as one of the founding figures of epidemiology.[138] By coupling a database with a map—in other words, by using spatial analysis—Snow was able to solve a problem that previously had defied understanding, to save hundreds of lives, and to help redefine the methodologies of an emerging research field.

In the decades since, and particularly in the last forty years, researchers have turned Snow's methodology into one of the predominant research and planning practices in many fields.[139] That transition has been supported by several technological shifts, each of which has helped transform spatial analysis into a tool more powerful than John Snow ever could have imagined.

One shift was an enormous expansion in societal capacity to gather spatially coded data. Remote sensing, which uses satellites to document landscape features like elevation or infrared radiation, now allows researchers to quickly gather information about the distribution of landscape features and to track changes in land cover.[140] Satellite photography serves similar purposes, and is particularly useful for mapping land use.[141] With the widespread availability of global positioning systems (GPS), data gathered through more traditional technologies also can be geographically coded.[142] Census data, for example, now are linked to specific geographic locations,[143] as are many of the datasets gathered through hundreds of ongoing environmental monitoring programs.[144] Funding has both spurred and followed these technological advances. The National Science

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[136] *Id.* at 213–14; *see* Paul Bingham et al., *John Snow, William Farr and the 1849 Outbreak of Cholera That Affected London: A Reworking of the Data Highlights the Importance of the Water Supply*, 118 PUB. HEALTH 387, 387–88 (2004) (using linear regression analysis to validate Snow's conclusions).

[137] Newsom, *supra* note 133, at 213–14.

[138] *Id.*

[139] *See infra* notes 164–168 and accompanying text.

[140] *See* HAINING, *supra* note 18, at 92 ("Satellites are an important source of environmental data.").

[141] *See* MICHAEL N. DEMERS, FUNDAMENTALS OF GEOGRAPHIC INFORMATION SYSTEMS 41–43 (2nd ed. 2000) (describing uses of satellite photography in land mapping).

[142] *See id.* at 37–39 (noting that "[m]any data are still observed through ground survey methods" and explaining how GPSs can help geocode those data).

[143] *See Data Access Tools*, U.S. CENSUS BUREAU, http://www.census.gov/main/www/access.html (last visited May 25, 2013) (providing access to data and to multiple mapping tools).

[144] *See, e.g.*, DEMERS, *supra* note 141, at 39 (describing the use of radiotelemetry to track animal movements); *Geospatial Data Downloads*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/waters/data/downloads.html (last visited May 25, 2013) (linking to sources of spatially coded water quality data).

Foundation and other major supporters of scientific research continue to call for, and support, major initiatives focused on gathering spatially coded data.[145]

Computing advances also improved the availability of those data.[146] Database programs now allow enormous datasets to be stored, searched, and transferred. In the 1980s, the emergence of personal computers allowed broader access to these databases; no longer did users need access to a large and expensive mainframe.[147] In the 1990s and 2000s, with the enormous growth in Internet use, many databases became available online.[148] These advances have not eliminated data shortages; despite improved technologies, data gaps remain persistent.[149] But the amount of spatial environmental data available for analysis has vastly increased.[150]

Improved technology also has offered new ways to convey the information stored in these growing databases. Using maps to convey data is nothing new; traditional maps convey information about where roads, landforms, and jurisdictional boundaries are located.[151] But traditional maps are unwieldy in some ways. Put too much data on the map and it becomes cluttered; put too little, and the map does not provide the information a user needs. Scale can be problematic; traditional paper maps do not allow a user to zoom in or out. The static nature of paper maps also presents difficulties. Landscapes evolve, but paper maps, once printed, do not.

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[145] *See, e.g.*, NEON, http://www.neoninc.org/ (last visited May 25, 2013) (detailing NEON's mission "to gather and provide 30 years of ecological data on the impacts of climate change, land use change and invasive species on natural resources and biodiversity").

[146] *See* Malczewski, *supra* note 18, at 9.

[147] *See* CLARKE, *supra* note 128, at 9; Malczewski, *supra* note 18, at 10 (emphasizing the importance of "low-cost mini and [personal computer] platforms"). This evolution continues to unfold. *See* John D. Landis, *A Brave and Better World? The iPad and the Future of Planning*, PLANETIZEN (Feb. 7, 2012, 2:00 PM), http://www.planetizen.com/node/54337.

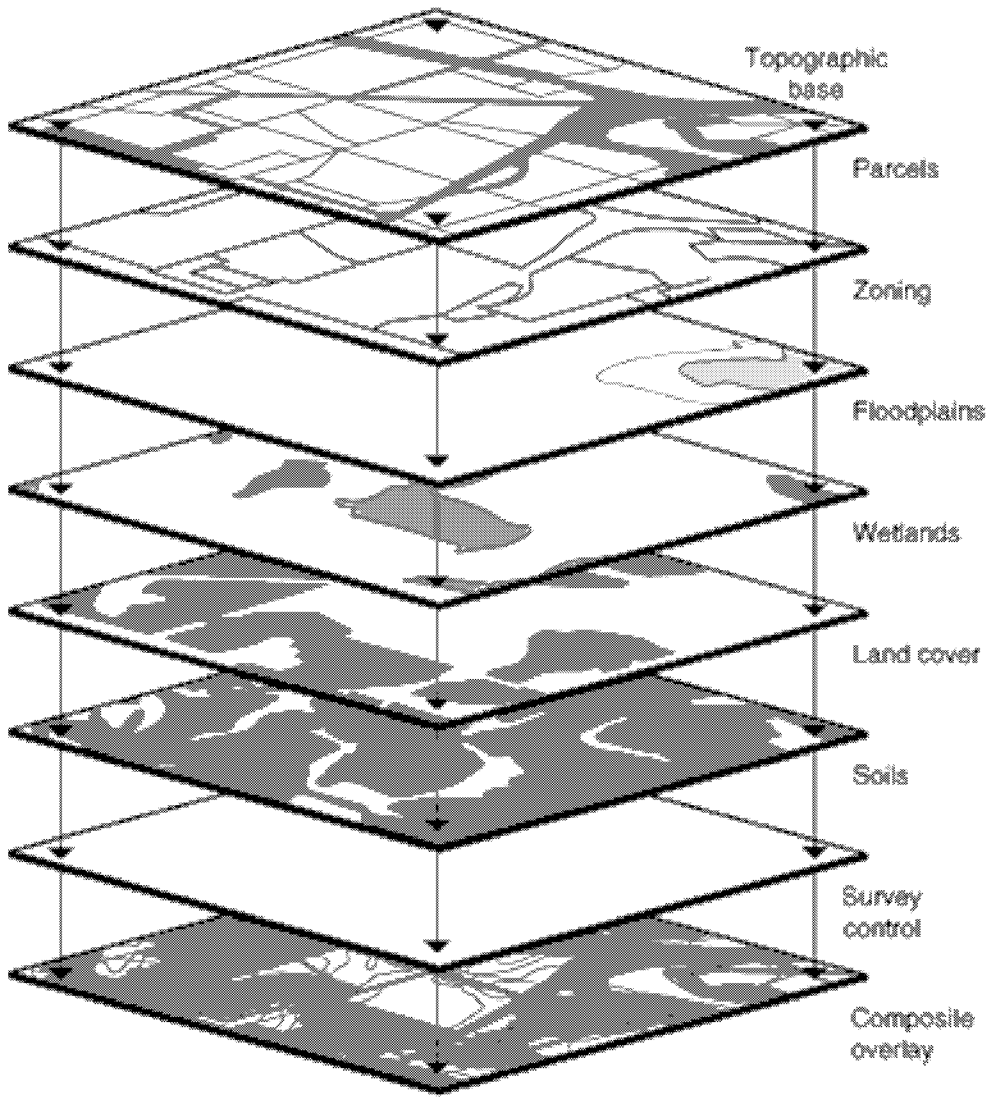
[148] *See* Malczewski, *supra* note 18, at 12 ("All major GIS vendors are developing procedures for WWW-based access to data and models developed with their software."). Government entities often play a major role in disseminating spatial data. *See* Peter M. Flannery, *How to Pry with Maps: The Fourth Amendment Privacy Implications of Governmental Wetland Geographic Information Systems (GIS)*, 29 RUTGERS COMPUTER & TECH. L.J. 447, 454–55 (2003) (listing governmental sources). Datasets have value, however, and both private and some governmental entities therefore have incentives to make data available only for a fee. *See* Amy Wilson Morris & Adena R. Rissman, *Public Access to Information on Private Land Conservation: Tracking Conservation Easements*, 2009 WIS. L. REV. 1237, 1242; Allyson Phillips, *A Portal to Reliable Real Estate Data or a Door to Nowhere?—A Look at How State and Local Dissemination Policies Have Impacted the Development of the National Spatial Data Infrastructure and Geospatial One-Stop Portal*, 34 REAL EST. L.J. 9, 9–10, 26 (2005).

[149] Eric Biber, *The Problem of Environmental Monitoring*, 83 U. COLO. L. REV. 1, 20–21 (2011).

[150] *See* Malczewski, *supra* note 18, at 12 (describing "an explosion of digital data").

[151] *See* CLARKE, *supra* note 128, at 7.

Figure 1: Adding Datalayers. *What is GIS?*, GIS TRAINING & APPLICATIONS FOR ETH., http://ethgis.colostate.edu/WebContent/WS/GISTraining/3_0_Whatisgis.html (last visited July 8, 2013).



Newer technologies address these problems in a variety of ways. Perhaps the most prevalent is to integrate graphical representations of many individual "datalayers," with each layer describing a particular set of geographic features. To build a map, a user can select whatever series of datalayers serves her present purpose while leaving out any extraneous information, and can do so at her preferred scale. Once the datalayers have been created, the process is fast and increasingly user-friendly; with just a few mouse clicks, the planner can create a customized map.[152] Indeed, many GIS platforms allow Internet users—even users with very little technological sophistication—to create and customize their own maps.[153] Datalayers also can be updated, so a map reflects the most recent version of the underlying databases, and maps themselves can be animated to show changes over time.[154] In short, in a variety of ways, computers can turn maps into more versatile, dynamic, and accessible tools for conveying information.

Technological advances also facilitate more sophisticated quantitative analyses of that information. For generations, economists, environmental scientists, and other researchers have used statistical analysis as an important research tool. Their statistical work, however, was once limited by the storage and processing capacity of the human brain. Advances in computer processing capacity have dramatically changed the game.[155] Computers now are capable of running millions of calculations in relatively short periods of time.[156] Concurrent with those advances, GIS programmers have developed multiple ways to mathematically represent the geography of features in their databases, thus allowing statistical analyses of the spatial relationships among data points.[157] With these advances, analysts now can analyze enormous spatially coded datasets to detect trends, correlations, and causal factors that even a few decades ago would have eluded discovery.[158]

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[152] *See* Malczewski, *supra* note 18, at 12 ("The common interface tools like on-screen 'buttons' and drop-down menus . . . can be understood quickly and easily with the result that GIS can tap into the growing market of untrained users."). I have watched planners do this, with results projected on a screen and participants suggesting changes. The ease with which maps can be customized is remarkable.

[153] *See, e.g.*, *MassGIS Online Mapping*, MASS.GOV, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/online-mapping/ (last visited May 25, 2013) (linking to mapping applications).

[154] *See, e.g.*, Cindy Bell et al., *Dynamic Mapping of Urban Regions: Growth of the San Francisco/Sacramento Region*, USGS LAND COVER INST., http://landcover.usgs.gov/urban/umap/pubs/urisa_cb.php (describing and linking to an animated map) (last modified Dec. 2012).

[155] *See* Malczewski, *supra* note 18, at 11 (explaining how computing power spurred GIS development); Robert A. Pietrowsky, *Foreword* to CONVERGING WATERS: INTEGRATING COLLABORATIVE MODELING WITH PARTICIPATORY PROCESSES TO MAKE WATER RESOURCES DECISIONS, at vi (Lisa Bourget ed., 2011) [hereinafter CONVERGING WATERS] ("[T]echnology has transformed what is possible").

[156] *See* McGinniss, *supra* note 131, at 49.

[157] *See* CLARKE, *supra* note 128, at 9 (describing the emergence of these techniques).

[158] *E.g.*, Kevin Costas et al., *A Case-Control Study of Childhood Leukemia in Woburn, Massachusetts: The Relationship Between Leukemia Incidence and Exposure to Public Drinking Water*, 300 SCI. TOTAL ENV'T 23, 24 (2002) (explaining how spatial analysis allowed researchers to conclusively link a leukemia outbreak—famously chronicled by the bestseller JONATHAN HARR, A CIVIL ACTION (1995)—to groundwater contamination); *see* Naomi Oreskes, *Why Believe a Computer? Models, Measures, and Meaning in the Natural World*, *in* THE EARTH AROUND US: MAINTAINING A LIVABLE PLANET 70, 73 (Jill S. Schneiderman ed., 2000) ("[F]ast, inexpensive computers . . . enable us to study problems that might otherwise remain intractable.").

Partly because of these increases in computing capacity, spatial analysis has become inextricably linked with environmental managers' large and growing dependence upon computer-based simulation modeling.[159] From climate change to wildlife management, models now pervade almost every sub-field of environmental decisionmaking.[160] Many of those models draw upon spatial data, and many produce spatially explicit outputs—which then can be used as input data by other models.[161] Consequently, spatially explicit modeling has become a pervasive, and often indispensable, part of environmental management and research. At their best, these models add a whole new power to spatial analysis.[162] Rather than just delineating the location of current landscape features, or, like John Snow's research, teasing out causal relationships based on data about past events, they allow environmental managers to offer spatially explicit representations of possible futures.[163]

These changes represent more than just the emergence of a new set of technological tools. Improvements in hardware, software, and remote sensing technology would have only modest utility if not accompanied by an associated body of theory. Researchers now refer to this field as "geographic information science," and it has its own professors, journals, conferences, blogs, and even subfields.[164] Many researchers who would not define themselves as geographic information scientists also consider spatial analysis techniques to be centrally important to their discipline.[165] Geography and planning, for example, are as reliant on spatial analysis as lawyers are upon web-based research systems like Lexis and Westlaw. In many other academic disciplines, spatial analysis also plays a growing role.[166] Most universities offer courses in spatial analysis, and many

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[159] For a brief discussion of computer-based modeling, and how modeling differs from mapping, see *supra* note 129.

[160] *See, e.g.*, Daniel A. Farber, *Modeling Climate Change and its Impacts: Law, Policy, and Science*, 86 TEX. L. REV. 1655, 1658 (2008); Fine & Owen, *supra* note 29, at 912–16 (describing the use of modeling in air quality regulation); 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 (2008); Wagner et al., *supra* note 29, at 294 (describing "extraordinary influence on environmental policy").

[161] *See* RALF SEPPELT, COMPUTER-BASED ENVIRONMENTAL MANAGEMENT 21–22 (2003); Fine & Owen, *supra* note 29, at 928 n.138 (describing air quality modelers' use of independently modeled population and economic growth projections as input data).

[162] *See* Fine & Owen, *supra* note 29, at 904, 913 (discussing benefits of modeling).

[163] *See infra* Part III (describing applications).

[164] *See* Malczewski, *supra* note 18, at 6 (describing GIS as an "emerging discipline"); Renee Sieber, *Public Participation Geographic Information Systems: A Literature Review and Framework*, 96 ANNALS ASSOC. AM. GEOGRAPHERS 491 (2006).

[165] J.T. Coppock & D.W. Rhind, *The History of GIS*, *in* 1 GEOGRAPHIC INFORMATION SYSTEMS 21–22 (David J. Maguire et al. eds., 1st ed. 1991).

[166] *See, e.g.*, Jim Baumann, *GIS Flourishes at Stanford University*, ARCUSER, Summer 2012, at 66, 66.

offer GIS certificates.[167] Their graduates use those skills for city planning departments, consulting firms, and state and federal agency offices throughout the country.[168] A new academic and professional discipline has emerged, with capabilities largely unheard of when our system of environmental law was formed, and with influence extending throughout—indeed, well beyond—the environmental field.

B. Spatial Analysis and Public Participation

While technological advances allow spatial analysts to do remarkable things, those advances are not an unqualified good. Any increase in the technological sophistication of decisionmaking creates the threat of overreliance on technology at the expense of common sense.[169] Quantitative modes of decisionmaking almost invariably involve oversimplifications, subjective judgments, and data of uneven quality, but the apparent precision of the numeric outputs can conceal these limitations behind veils of false certitude.[170] By combining visually compelling graphics with the deceptive precision of numbers, maps heighten these risks,[171] and spatial analysis tools can easily be misperceived as "truth machines," with their truths all dressed up in seductively pretty colors.[172] Similarly, increased reliance on quantitative decisionmaking methodologies threatens to exacerbate digital divides, with highly educated or well-funded elites enjoying preferential access to powerful technologies, and poorer or less savvy stakeholders further excluded.[173] Those fears have reverberated through the spatial analysis literature, with several articles warning, as one put it, that GIS "has effectively raised barriers to empowerment by creating exclusive, sophisticated user-communities beyond the reach of less powerful, resource poor citizens."[174]

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[167] *See* Mizuki Kawabata et al., *Multidisciplinary Cooperation in GIS Education: A Case Study of US Colleges and Universities*, 34 J. GEOGRAPHY HIGHER EDUC. 493, 496–97 (2010).

[168] *See Industries*, ESRI, http://www.esri.com/industries (last visited Jan. 23, 2013).

[169] *See generally* Wagner et al., *supra* note 29 (arguing that this threat is often realized).

[170] *See* Fine & Owen, *supra* note 29, at 922–34 (providing a detailed summary of the risks associated with reliance on modeling).

[171] *See* Farber, *supra* note 160, at 1674 (warning that "accessibility and clarity . . . may cause users to underestimate the amount of uncertainty associated with projections"). *See generally* DENIS WOOD, THE POWER OF MAPS (1992) (discussing the interests that maps serve).

[172] *See* Wagner et al., *supra* note 29, at 296 ("[M]odels are often misunderstood as 'truth machines' . . . .").

[173] *See, e.g.*, Rina Ghose, *Use of Information Technology for Community Empowerment: Transforming Geographic Information Systems into Community Information Systems*, 5 TRANSACTIONS GIS 141, 142 (2001) (warning of "differential access to data and technology").

[174] *Id.*

These threats of false confidence and digital divides are very real, but technological advances also can promote participation and inclusion. In part, that potential derives from increased access to computers and to data, and both general operating software and GIS-specific programs are far more intuitive than they were in decades past.[175] The communicative power of maps also increases information availability, for maps can convey large amounts of information in an easily searchable and visually accessible format.[176] Spatial analysts also can generate animations, computer-generated views of future land use patterns, and a variety of other visualizations, all capable of making future environmental change more cognitively "available."[177] Those advances, in combination with a massive effort by private nonprofit groups and by local, state, and particularly federal governmental entities to distribute maps and underlying data, have made extraordinary quantities of information not just accessible, but also potentially comprehensible, to millions of people.[178]

Spatial analysts also have developed multiple ways to actively facilitate participation. With increased computing speed, GIS technicians can sometimes project alternative scenarios within a single meeting, and thus can map several alternative futures as participants watch.[179] Environmental modelers also can involve lay people in building models. Land conservation modelers, for example, now often build models that allow community members to adjust the importance of different environmental goals—for example, habitat protection, groundwater protection, or aesthetics—and to produce multiple model runs showing how conservation strategies would be affected as preferences change.[180] Similarly,

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[175] *See* CLARKE, *supra* note 128, at 9–10 (noting the importance of low cost, efficient personal computers in GIS development); Malczewski, *supra* note 18, at 18 (describing increasingly user-friendly GIS systems).

[176] Sieber, *supra* note 164, at 491.

[177] *See, e.g.*, David W. Hulse et al., *Envisioning Alternatives: Using Citizen Guidance to Map Future Land and Water Use*, 14 ECOLOGICAL APPLICATIONS 325, 337 (2004) (showing computer-generated views of development scenarios for Oregon's Willamette River valley). For general discussion of the importance of cognitive availability to decisionmaking in contexts of uncertainty, see Amos Tversky & Daniel Kahneman, *Availability: A Heuristic for Judging Frequency and Probability*, 5 COGNITIVE PSYCHOL. 207 (1973).

[178] *See, e.g.*, *Data Catalog*, GEO.DATA.GOV, http://geo.data.gov/geoportal/catalog/main/home.page (last visited Jan. 27, 2013); *Geospatial Data Gateway*, USDA (Feb. 16, 2012, 12:29 PM), http://datagateway.nrcs.usda.gov/; Ghose, *supra* note 173, at 143 (describing Public Participation GIS providers and effective access to information).

[179] *See, e.g.*, Kurt Stephenson & Leonard Shabman, *Executing CADRe: Integration of Models with Negotiation Processes*, *in* CONVERGING WATERS, *supra* note 155, at 23, 33 (describing "[g]aming or what-if exercises"); *Greenprinting*, *supra* note 20 (explaining TPL's "greenprinting" process); *see also* Arnab Chakroborty, *Enhancing the role of participatory scenario planning processes: Lessons from Reality Check exercises*, 43 FUTURES 387, 391 (2011) (describing Reality Check Washington, a participatory GIS-based "one-day visioning exercise").

[180] *See, e.g.*, *Greenprinting*, *supra* note 20.

modelers can ask expert panels to help develop algorithms for selecting parcels for conservation or development, rather than simply relying on the modelers' intuitions or on historic data.[181] Lay participants also can run some models, perhaps playing roles different from those they occupy in real life, and can thereby better understand the consequences of their actions and the perspectives of competing resource users.[182] These methods for facilitating participation can be combined. Emerging processes known as "participatory modeling" or "computer-aided dispute resolution" involve stakeholders in iterative processes of building, running, critiquing, and rerunning models designed to resolve complex environmental management challenges.[183]

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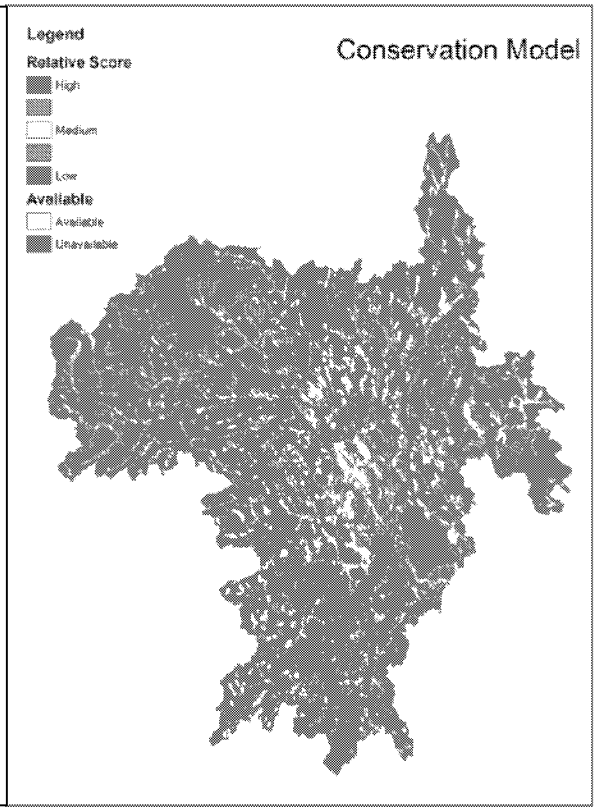
[181] *See, e.g.*, Jon T. McCloskey et al., *Using Bayesian Belief Networks to Identify Potential Compatibilities and Conflicts Between Development and Landscape Conservation*, 101 LANDSCAPE & URB. PLANNING 190, 194–95 (2011).

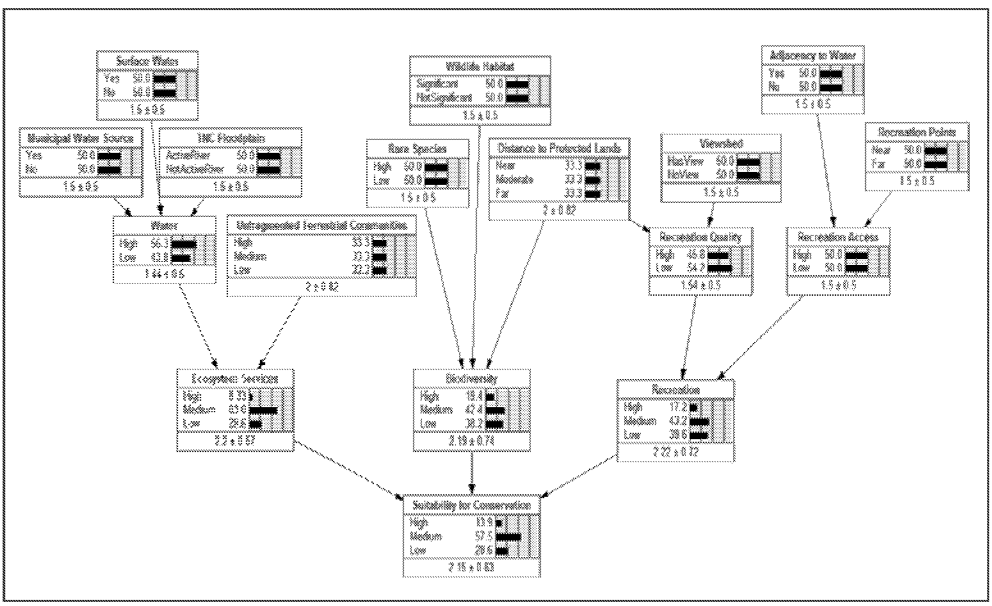
[182] *See, e.g.*, Erik Hagen, *New Approaches in the Potomac River Basin and Beyond—Pioneering Work in the Development of Shared Vision Planning*, *in* CONVERGING WATERS, *supra* note 155, at 35, 48 ("The managers gained a new understanding of the system, and a new sympathy for the challenges and positions of the other utilities."); Claudia Pahl-Wostl & Matt Hare, *Process of Social Learning in Integrated Resources Management*, 14 J. COMMUNITY APPLIED SOC. PSYCHOL. 193, 198 (2004) (describing benefits of this approach).

[183] Leonard Shabman & Kurt Stephenson, *The Purpose and Goal for CADRe*, *in* CONVERGING WATERS, *supra* note 155, at 9; *see also* Hulse et al., *supra* note 177, at 325 (describing citizen input for land and water use models).

Figure 2: Example of a participatory modeling process

This figure shows steps in the process of creating a Bayesian model of the suitability of land in Maine's lower Penobscot River watershed for conservation. The modelers brought together a group of conservation planners and advocates, who identified and assigned relative values to various features they believe make land desirable for conservation. The modelers then combined the resulting algorithm with land use and land cover data to produce a map (shown here in draft form) identifying high-value conservation areas. They will later combine that map with maps of lands suitable for development, forestry, and agriculture to identify areas of potential conflict and compatibility. *See infra* Figure 4. Images courtesy of Robert Lilieholm, University of Maine Alternative Futures research project.





These efforts generally require substantial time investment, but they also can produce significant benefits.[184] Perhaps most importantly, they can bring multiple perspectives into the model-development process, helping balance policy preferences and unexamined assumptions held by the modelers.[185] Actively involving nonmodelers can be a more effective way of conveying information, allowing participants to be active rather than passive learners.[186] Involvement also can promote both realism and trust. A participant who has helped develop a model—or, perhaps, helped run it—is likely to have a more realistic understanding of the limitations and uncertainties of the model, yet also may have more confidence that the modeling outputs represent a good faith effort toward objectivity.[187] In an era when environmental debates are routinely undermined by both overconfidence in and distrust of scientific information, building that sort of realism can be crucially important.[188]

Despite its promise, spatial analysis will never offer perfectly transparent, objective decisionmaking tools. Uncertainties, concealed subjective choices, and false precision are likely to remain ubiquitous.[189] Modelers also face difficult tradeoffs between simple models, which are often faster and more transparent, and more complex models, which often, though not always, provide outputs that better correspond to the complexity of the real world.[190] Even where models perform well, spatial information, like most information, can serve as an instrument of

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[184] *See, e.g.*, Erica J. Brown Gaddis et al., *Effectiveness of a Participatory Modeling Effort to Identify and Advance Community Water Resource Goals in St. Albans, Vermont*, 25 ENVTL. MONITORING & SOFTWARE 1428, 1434–36 (2010) (describing benefits); Hagen, *supra* note 182, at 35, 39 ("[A]n imaginative and groundbreaking water supply solution was conceived and its implementation solved the long-term water supply problem . . . ."). Despite positive case studies, the empirical literature on the benefits of scenario evaluation and participatory modeling remains thin. Christian Albert, *On the Influence of Scenario-Based Landscape Planning—A Comparison of Two Alternative Futures Projects*, 28 PROBS. LANDSCAPE ECOLOGY 33, 33 (2010) ("[L]ittle light has so far been shed on [scenario planning's] effectiveness to change local governance.").

[185] *See* Fine & Owen, *supra* note 29, at 926–30 (explaining the prevalence of judgment in modeling, and the associated importance of public input).

[186] *See* Joan P. Baker et al., *Alternative Futures for the Willamette River Basin, Oregon*, 14 ECOLOGICAL APPLICATIONS 313, 321 (2004) (describing "greater stakeholder understanding, a feeling of ownership in the final product, and increased likelihood that the results will be used").

[187] *See* Stephenson & Shabman, *supra* note 179, at 28 (explaining the value of "model architecture that is transparent").

[188] *See* Laura K. Schmitt Olabisi et al., *Using Scenario Visioning and Participatory System Dynamics Modeling to Investigate the Future: Lessons from Minnesota 2050*, 2 SUSTAINABILITY 2686, 2700 (2010) (discussing this potential to "mediate the extremes of distrust or blind acceptance").

[189] *See* Fine & Owen, *supra* note 29, at 921–38 (discussing limitations of environmental modeling).

[190] *See id.* at 924–26 (discussing advantages and disadvantages of model complexity).

power or exploitation, and increasing the availability of such information does not guarantee that it will be used in just or fair ways.[191]

Nevertheless, if carefully used, these tools have much to offer. If they are to act at all, environmental managers cannot avoid the necessity of trying to understand and, often, predict the behavior of complicated systems. Any set of tools that even incrementally improves those abilities therefore holds value. With spatial analysis, that value can be substantial.

III. SPATIAL ANALYSIS, ENVIRONMENTAL LAW, AND CHANGING LAND USE

Despite all the promise of spatial analysis, its emergence has done little to change environmental law. Law generates many lines on maps; between critical habitat designations, flood insurance mapping, and traditional zoning, to name just a few examples, environmental law and mapping are in some ways closely integrated.[192] But while environmental lawyers often confront the products of spatial analysis, that does not mean they understand the tools their colleagues in other environmental fields now routinely use.[193] Instead, lawyers, whether practicing or academic, rarely analyze spatial data.[194] And while past changes in environmental science have raised basic questions about environmental law, the evolution of spatial analysis technology has generated only a limited academic reaction and minimal legislative or regulatory change.[195] Among environmental fields, law stands alone in its diffident reaction to the emergent geocoded world.

If environmental law already dealt effectively with all the problems it faced, that diffident reaction would not be problematic. But clearly that is not the case. Environmental scholars routinely identify information management as a central

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[191] *See* Dorothy L. Hodgson & Richard A. Schroeder, *Dilemmas of Counter-Mapping Community Resources in Tanzania*, 33 DEV. & CHANGE 79 (2002) (describing well-intentioned exercises with mixed outcomes); Michelle Wilde Anderson, *Mapped Out of Local Democracy*, 62 STAN. L. REV. 931, 935–49 (2010) (describing political boundaries drawn to exclude relatively poor minority communities).

[192] *See FWS Critical Habitat for Threatened & Endangered Species*, U.S. FISH & WILDLIFE SERV., http://criticalhabitat.fws.gov/crithab/ (last visited May 25, 2013) (linking to an interactive map); *Flood Insurance Rate Map (FIRM)*, FEMA, http://www.fema.gov/hazard/map/firm.shtm (last visited May 25, 2013).

[193] *See* Salkin & Nolon, *supra* note 26, at 526 ("While planning schools offer hands-on courses in the use of these new technologies, they are not typically part of the curriculum in law school.").

[194] *See supra* note 26 and accompanying text.

[195] *See* Mary Jane Angelo, *Harnessing the Power of Science in Environmental Law: Why We Should, Why We Don't, and How We Can*, 86 TEX. L. REV. 1527, 1527 (2008) ("Environmental law was born out of the new scientific understandings of ecology . . . ."); Donald T. Hornstein, *Reclaiming Environmental Law: A Normative Critique of Comparative Risk Analysis*, 92 COLUM. L. REV. 562 (1992); A. Dan Tarlock, *The Nonequilibrium Paradigm in Ecology and the Partial Unraveling of Environmental Law*, 27 LOY. L.A. L. REV. 1121, 1121 (1994) ("Environmental law derives its political power and legitimacy from science.").

challenge, and that challenge severely constrains environmental law's ability to turn the theoretical appeal of integrated regulation into a practical reality.[196] For environmental law, then, the emergence of quantitative spatial analysis could represent a crucially important development. This section discusses that potential. The discussion is by no means exhaustive. Nevertheless, even a few examples from one subfield of environmental law should illustrate the potential breadth of spatial analysis's implications and the ways it can facilitate more integrative regulatory approaches.

A. *What We Understand*

Perhaps the most important way spatial analysis can change environmental law is by improving our understanding of environmental problems. Almost any regulatory response to an environmental problem requires a demonstration that the problem exists, some explanation of its causes, and a reasonably robust grasp of how individual activities create problems manifested at broader temporal and spatial scales and across jurisdictional boundaries.[197] If the regulatory response is to be effective, it requires some understanding of the negative tradeoffs and positive synergies likely to arise from regulatory intervention, including tradeoffs and synergies that span the compartmental boundaries of individual regulatory programs.[198] Because of the complex, multiscalar, and intertwined nature of environmental problems, achieving that understanding can be difficult, and those difficulties can limit the problems we respond to—or even recognize.[199] As the following examples illustrate, however, advances in spatial analysis can expand that realm of understanding.

1. *Diagnosing Environmental Problems*

Sometimes an environmental problem and its source are obvious. Pollution belching from a factory or untreated sewage discharging from a pipe can demand attention, and the impacts can be difficult to miss. But many present-day environmental challenges—including many challenges associated with land use change—involve multiple stressors, some acting through geographically or temporally attenuated chains of causation.[200] Understanding those causal

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[196] *See, e.g.*, Holly Doremus, *Data Gaps in Natural Resource Management: Sniffing for Leaks Along the Information Pipeline*, 83 IND. L.J. 407, 408 (2008); Wagner, *supra* note 16.

[197] *See supra* notes 75–78 and accompanying text (discussing the tendency for large environmental problems to arise from an accumulation of smaller impacts).

[198] *See supra* notes 44–58 and accompanying text.

[199] *See generally* Boyd, *supra* note 26, at 847 (developing this argument).

[200] *See* Carol M. Rose, *The Story of* Lucas*: Environmental Land Use Regulation Between Developers and the Deep Blue Sea*, *in* ENVIRONMENTAL LAW STORIES 239 (Richard J. Lazarus & Oliver A. Houck eds., 2005) (exploring how incremental change

relationships can be nearly impossible without a large, spatially coded data set and a computational model.[201] Consequently, spatial analysis now plays a central role in monitoring environmental changes and in diagnosing environmental problems, particularly when those problems manifest themselves at broad spatial or temporal scales.[202] The applications are far too numerous to list, but of many possible examples, the relationship between urbanization and water quality illustrates particularly well how spatial analysis can transform our capacity to understand environmental problems.

For decades, environmental scientists have understood, at least at a general level, that urbanization degrades water quality.[203] As development progresses, both dry spells and floods become more extreme, aquatic and riparian habitats are degraded or disappear, water temperatures become warmer and more variable, and pollutant loads increase.[204] Usually no single lot or even development project is the cause, and the degradation instead arises from the cumulative effect of dozens—perhaps hundreds—of land use decisions.[205] At even sparse suburban densities, the result is usually an impaired waterway, particularly if the watershed is small.[206]

Environmental scientists have understood these general dynamics for years. But building a regulatory regime has been difficult, largely because of the informational difficulties associated with translating a general understanding of watershed degradation into site-specific regulatory controls, and because of jurisdictional divides between federal environmental regulation and local land use control.[207] The primary focus of water quality regulation instead has largely been the sort of large, discrete sources amenable to regulatory coverage under a temporally and geographically focused, media-specific regulatory regime.[208] Consequently, many metropolitan areas developed with minimal regard to water

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complicates land use regulation); Ruhl & Salzman, *supra* note 75, at 88–92 (explaining the complexity of cumulative effects problems).

[201] *See* Oreskes, *supra* note 158, at 70–71 ("One of the driving forces behind the increased use of computer models in the earth sciences is their applicability to systems that are too large, too complex, or too far away to study by other means.").

[202] *See, e.g.*, NAT'L RESEARCH COUNCIL, *supra* note 129, at ix (stating that modeling is necessitated by "[t]he spatial and temporal scales on which environmental controls and environmental quality are linked"); Oreskes, *supra* note 158, at 71 (describing several applications).

[203] LUNA B. LEOPOLD, U.S. DEPT. OF THE INTERIOR, HYDROLOGY FOR URBAN PLANNING—A GUIDEBOOK ON THE HYDROLOGIC EFFECTS OF URBAN LAND USE 15–17 (1968).

[204] *See* Christopher J. Walsh et al., *The Urban Stream Syndrome: Current Knowledge and the Search for a Cure*, 24 J. N. AM. BENTHOLOGICAL SOC'Y 706 (2005).

[205] Owen, *supra* note 2, at 460.

[206] *See* CTR. FOR WATERSHED PROT., IMPACTS OF IMPERVIOUS COVER ON AQUATIC SYSTEMS 2 (2003); NAT'L RESEARCH COUNCIL, URBAN STORMWATER MANAGEMENT IN THE UNITED STATES 20–26 (2009); Walsh et al., *supra* note 204, at 710.

[207] *See* Owen, *supra* note 2, at 445–50 (explaining these challenges).

[208] *See id.* at 446.

quality, and impaired waterways are now pervasive features of American suburban and urban landscapes.[209]

In recent years, spatial analysis has helped researchers build a more robust conceptual foundation for addressing these problems. By comparing spatially coded water quality data with land use and land cover data, environmental scientists have refined their understanding of the dynamics of urban water quality impairment. A series of studies has identified a close relationship between impervious cover—primarily roads, roofs, and pavement—and water quality impairment, and has identified rough impervious cover thresholds above which water quality impairment almost invariably occurs.[210] Those findings have transformative implications for water quality regulation. They connect individual increments of land development—an activity already subject to regulation, but through local land use regulations and building codes rather than federal water quality law—with a broader-scale environmental problem that previously seemed intractable.[211] Some recent research initiatives have gone a step further and can bring spatial data on water supply withdrawals into the analysis.[212] The result of this work is an improved understanding of the relationships between urban development and aquatic ecosystems.

In addition to helping researchers understand the dynamics of present problems, spatial analysis also can help identify areas where future water quality problems are likely to arise. Some studies have used "build-out" analyses, which assume future development to the full extent allowed by current zoning, to predict the extent and geographic location of future water quality problems.[213] Those build-out analyses also can be adapted to predict impairment under alternative zoning regimes, providing a community with some sense of the implications of

[209] *See id.* at 443–44 (describing the pervasiveness of the problem).

[210] *See* CTR. FOR WATERSHED PROT., *supra* note 206, at 1–2; NAT'L RESEARCH COUNCIL, *supra* note 206, at 226–30. Some recent studies have found that degradation begins at even lower levels of development, while others have raised questions about whether widely used thresholds are adequately supported. *See, e.g.*, Thomas F. Cuffney et al., *Responses of Benthic Macroinvertebrates to Environmental Changes Associated with Urbanization in Nine Metropolitan Areas*, 20 ECOLOGICAL APPLICATIONS 1384, 1398 (2010) (finding an onset of degradation at lower levels); Glenn E. Moglen & Sunghee Kim, *Limiting Imperviousness: Are Threshold-Based Policies a Good Idea?*, 73 J. AM. PLANNING ASS'N. 161, 168–69 (2007) (arguing that the existing studies are based on very different methods of calculating impervious area, which limits their ability to support consistent thresholds). Nevertheless, the literature documents widespread agreement that increasing impervious area correlates with decreasing water quality.

[211] *See* Owen, *supra* note 2, at 462–63 (describing how a focus on impervious cover can facilitate local responses).

[212] *See, e.g.*, DAVID S. ARMSTRONG ET AL., PRELIMINARY ASSESSMENT OF FACTORS INFLUENCING RIVERINE FISH COMMUNITIES IN MASSACHUSETTS (2010), *available at* http://pubs.usgs.gov/of/2010/1139/pdf/ofr2010-1139.pdf.

[213] *See, e.g.*, Conway & Lathrop, *supra* note 20 (assessing build-out scenarios for coastal New Jersey).

alternative growth strategies.[214] They also can expand the analytical focus from the community to the regional scale, examining, for example, the aggregate water quality impacts if individual communities use large-lot zoning or other growth-spreading regulatory regimes.[215] By integrating economic growth models into future land use projections, modelers now can go beyond these build-out analyses and create more nuanced projections of the extent and location of future development.[216] That could help water quality regulators and land use planners not just understand, but also improve, the relationship between developments like Greenacres and regional water quality trends.[217]

By providing visually accessible outputs, spatial analysis also can help modelers and scientists explain water quality problems to lay audiences, and thus can expand the realm of understanding beyond technically sophisticated regulatory agency staff. Even a relatively simple concept, like the relationship between large-lot zoning and aggregate impervious cover levels, is far easier to explain with a conceptual map than with a series of sentences.[218] Sophisticated models can add even more explanatory power. One intriguing example is the UVa Bay Game, a model that allows users to act as farmers, municipalities, environmental regulators, and other players in the complex dynamics of protecting Chesapeake Bay.[219] Researchers report that the game already has proven a valuable educational tool, helping both students and actual stakeholders understand the interconnections and complexities involved in Chesapeake Bay management.[220]

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[214] *See, e.g.*, *id.* at 9.

[215] *See* U.S. ENVTL. PROT. AGENCY, EPA 231-R-06-001, PROTECTING WATER RESOURCES WITH HIGHER-DENSITY DEVELOPMENT 11–25 (2006).

[216] Several collaborators and I are currently developing a water quality model that uses this approach, which is particularly appropriate where zoning classifications are either aspirational, negotiable, or both, and a buildout scenario therefore is implausible. But buildout analyses have the advantage of using relatively simple, transparent rules. *See* Robert Gilmore Pontius Jr. & Neeti Neeti, *Uncertainty in the Difference Between Maps of Future Land Change Scenarios*, 5 SUSTAINABILITY SCI. 39, 46–48 (2010) (stressing these advantages).

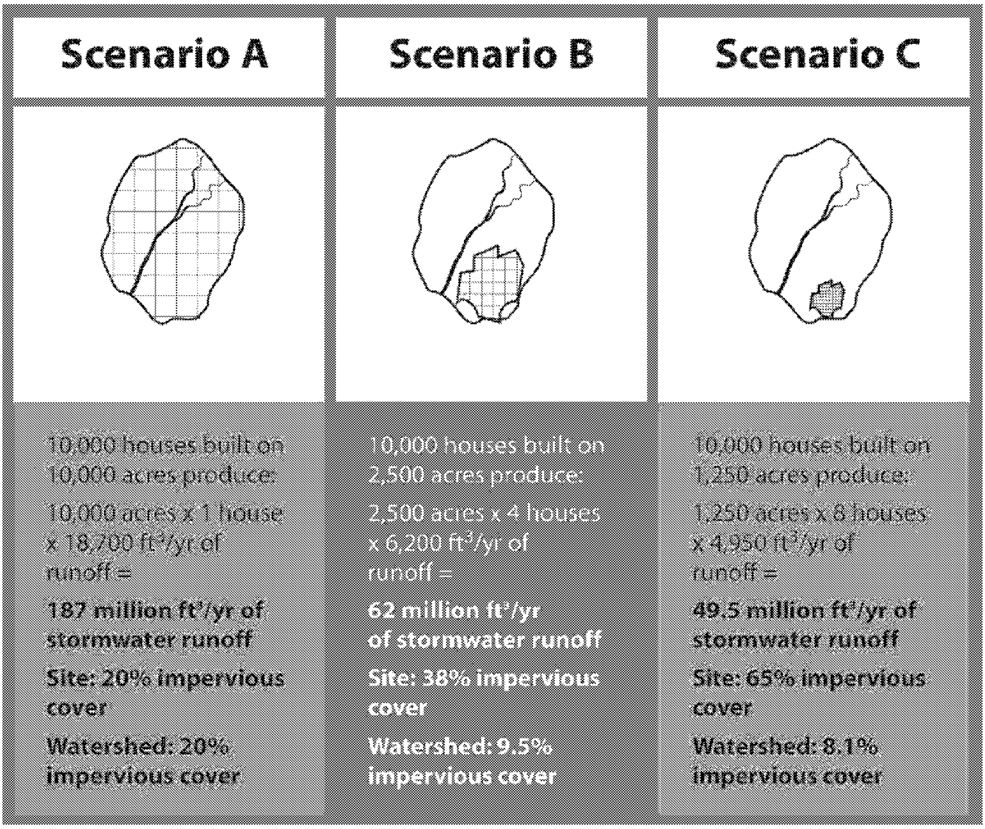
[217] *See, e.g.*, Baker et al., *supra* note 186, at 316 (describing a modeling process that contrasted river and stream conditions under alternative future regulatory regimes).

[218] *See, e.g.*, U.S. ENVTL. PROT. AGENCY, *supra* note 215, at 17.

[219] *See* THE UVA BAY GAME, http://www.virginia.edu/baygame/ (last visited May 25, 2013).

[220] Gerard P. Learmonth Sr. et al., *A Practical Approach to the Complex Problem of Environmental Sustainability: The Uva Bay Game*, INNOVATION J., http://www.innovation.cc/scholarly-style/learmonth_sustain_inviroment_v16i1a4.pdf (last visited May 23, 2013) (describing positive results).

Figure 3: Large lot zoning and impervious area. From U.S. ENVTL. PROT. AGENCY, *supra* note 215, at 17.



In sum, these advances are helping watershed scientists and regulators overcome the temporal, spatial, and jurisdictional fragmentation that often hamstrings efforts to address the environmental consequences of urbanization. And watershed scientists are by no means the only ones using spatial analysis to understand the environmental impacts of urbanization. For years, ecologists have used spatial models to track the impacts of regional development on habitat and to identify areas particularly under threat, and their analytical tools continue to evolve.[221] While connections between air quality regulation and land use planning

[221] *See, e.g.*, Jeffrey A. Hepinstall et al., *Predicting Land Cover Change and Avian Community Responses in Rapidly Urbanizing Environments*, 23 LANDSCAPE ECOLOGY 1257 (2008) (using an "integrated modeling approach to simulate future land cover and predict the effects of future urban development and land cover on avian diversity in the Central Puget Sound region"); David M. Theobald, *Targeting Conservation Action Through Assessment of Protection and Exurban Threats*, 17 CONSERVATION BIOLOGY 1624 (2003) (using "socioeconomic indicators of risk" to measure "the proportion of conservation lands affected by developed areas").

traditionally have been attenuated,[222] numerous studies now model the air quality implications of alternative development patterns, making quantification of the aggregate air quality impacts of developments like Greenacres increasingly feasible.[223] Consequently, some new regulatory initiatives now integrate development permits and air quality control.[224] Similar analytical tools could help link developments like Greenacres with specific increments of greenhouse gas emissions.[225] All of these efforts increase our capacity to understand the relationships between developments like Greenacres and the goals reflected in a wide variety of environmental laws.

These advances have their limits, and water quality modeling exemplifies the continuing challenges as much as the positive potential. No water quality model can precisely and accurately quantify the impacts of each individual development, or even the aggregate consequences of a growth program or regulatory regime. Instead, data gaps and errors are ubiquitous, and some relationships remain poorly understood.[226] Even where understanding is robust, models still must reduce the complexity of real-world ecological interactions to a relatively simple set of algorithms and equations.[227] But if modeling produces a general understanding of the dynamics of environmental impairment and provides some basis for comparing alternative regulatory approaches, and if candid disclosures accompany the model results, even an imperfect effort can provide analytical traction for problems that regulators previously grasped only at the most conceptual of levels.[228]

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[222] *See* Patrick Del Duca & Daniel Mansueto, *Indirect Source Controls: An Intersection of Air Quality Management and Land Use Regulation*, 24 LOY. L.A. L. REV. 1131, 1149–55 (1991) (describing failed integration efforts).

[223] *See* TRANSP. RESEARCH BD., *supra* note 3, at 3 (summarizing studies, and concluding that "[d]eveloping more compactly . . . is likely to reduce VMT").

[224] *See* Nat'l Ass'n of Home Builders v. San Joaquin Valley Unified Air Pollution Control Dist., 627 F.3d 730, 731–32 (9th Cir. 2010) (describing a rule imposing air quality impact mitigation fees on development projects), *cert denied*, 132 S. Ct. 369 (2011).

[225] *See* TRANSP. RESEARCH BD., *supra* note 3, at 2 (noting that greenhouse gas emissions associated with land use change are largely due to fossil fuel consumption, which also generates conventional air pollutants).

[226] *See* Christer Nilsson et al., *Ecological Forecasting and the Urbanization of Stream Ecosystems: Challenges for Economists, Hydrologists, Geomorphologists, and Ecologists*, 6 ECOSYSTEMS 659, 660 (2003) ("[O]ur ecological forecasts were crude, largely qualitative in nature, and essentially based on expert knowledge . . . and correlative evidence . . . .").

[227] *See* Fine & Owen, *supra* note 29, at 922–30.

[228] *See* ALBERTI, *supra* note 21, at 225–26 (noting that planners must evaluate the future implications of policies); Sierra Club v. Costle, 657 F.2d 298, 334–35 (D.C. Cir. 1981) ("The safety valves in the use of such sophisticated methodology are the requirement of public exposure of the assumptions and data incorporated into the analysis and the acceptance and consideration of public comment, the admission of uncertainties where they exist, and the insistence that ultimate responsibility for the policy decision remains with the agency rather than the computer." (citations omitted)).

2. Recognizing Tradeoffs and Synergies

Helping researchers understand and explain a particular environmental problem, like the relationship between urbanization and water quality, is a significant achievement. But Greenacres' water resource impacts will likely overlap with impacts on a variety of other environmental media and nonenvironmental outcomes. Similarly, some regulatory responses to Greenacres' water impacts may create counterproductive results for other environmental goals, or for economic outcomes, while others may produce synergistic benefits.[229] Understanding those tradeoffs and opportunities also has been a central challenge, often unmet, for environmental law.[230] But in several ways, spatial analysis already is improving responses to multifaceted environmental problems.

One of the best illustrations of this potential involves mapping environmental constraints when siting development projects.[231] Most development projects are subject to multiple regulatory constraints that can be depicted spatially. For example, wetlands, floodplains, zoning controls, conservation lands, and protected habitat areas all can be mapped, and all provide important signals about where a project might face a difficult regulatory process.[232] Similarly, many landscape features desired by developers, like favorable soils and slopes, low taxes, quality school districts, proximity to complementary businesses, and access to roads and other preexisting infrastructure, also can be mapped.[233] If the map layers are publicly available—and in many communities, they are—GIS technology allows developers to find areas that maximize positive features and minimize negative ones and also allows local officials to steer development projects toward particularly promising sites.[234]

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[229] *See supra* notes 53–58 and accompanying text.

[230] *See supra* Part I.A.

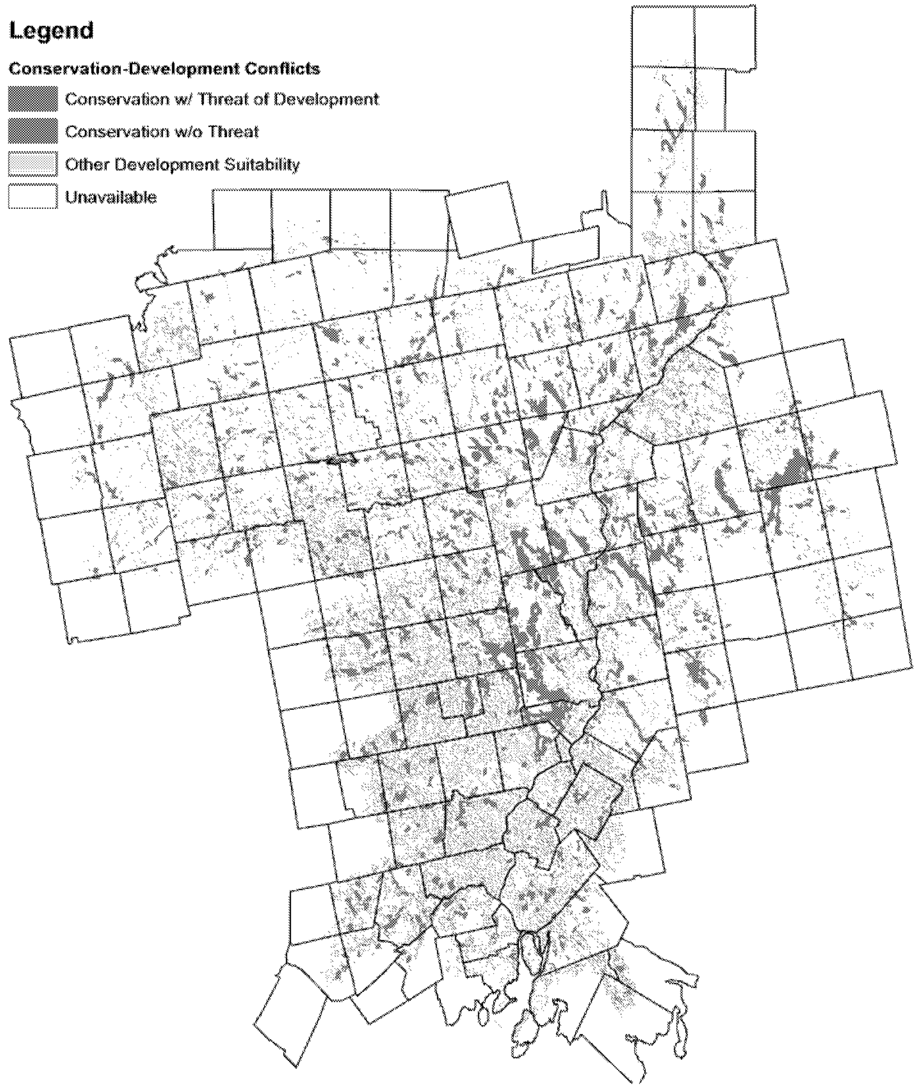
[231] *See generally* Malczewski, *supra* note 18, at 4 (describing applications).

[232] *See, e.g.*, *FWS Critical Habitat for Threatened & Endangered Species*, *supra* note 192; *Office of Geographic Information (MassGIS)*, MASS.GOV, http://www.mass.gov/mgis/ (last visited May 25, 2013) (linking to a mapping tool).

[233] *See, e.g.*, McCloskey et al., *supra* note 181, at 192–94.

[234] *See, e.g.*, *Office of Geographic Information (MassGIS)*, *supra* note 232. Recently, ocean spatial planners have begun using similar techniques. *See, e.g.*, 1 OFFICE OF ENERGY & ENVTL. AFFAIRS, MASSACHUSETTS OCEAN MANAGEMENT PLAN (2009), *available at* http://www.env.state.ma.us/eea/mop/final-v1/v1-complete.pdf.

Figure 4: Land use suitability map, Lower Penobscot River watershed, Maine. Image courtesy of Rob Lilieholm, University of Maine. The image is a prepublication draft and is included solely for illustrative purposes.



The same approach can target conservation efforts. A land trust might overlay data layers showing wetland resources, aquifer recharge zones, rare plant and wildlife habitats, and potential habitat corridors to determine where to purchase conservation easements.[235] At broader scales, conservation organizations often use

235 *See, e.g.*, TRUST FOR PUBLIC LAND, THE PENOBSCOT VALLEY COMMUNITY GREENPRINT 20 (2009).

a process called "gap analysis," which involves using GIS to identify regionally underprotected habitat types.[236] They also can use economic development models to identify parcels where development potential is high, and therefore the threat to resources is larger, or, conversely, where development potential is lower, reducing purchase prices and potential conflict with community economic development goals.[237] Likewise, economic models can explore whether purchase- or zoning-based strategies would more effectively accomplish conservation and economic goals.[238]

Like other applications of spatial analysis, these uses have significant limitations. Turning land use and land cover databases, which usually contain gaps and inaccuracies, into suitability maps inevitably involves some distortion and oversimplification.[239] Features like a community's receptivity to development, the efficiency of a town's regulatory approval processes, and the willingness of state or local governments to grant variances or leave laws unenforced all have important implications for development patterns but are not easily mapped. Consequently, spatial analysis is not a perfect tool for identifying all the implications of development proposals or regulatory initiatives. But it can facilitate simultaneous consideration of a variety of different environmental and nonenvironmental opportunities and constraints and exploration of some of the implications of planned activities. In these capacities, it now sees widespread use, with new innovations continuing to emerge.[240]

3. Modeling Complicated Systems

The emergence of tools for conceptualizing individual environmental problems or siting individual projects is quite important in its own right, but these capabilities also form building blocks toward a larger goal. The complex relationships among multiple environmental challenges, human activities, and

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[236] *See* Theobald, *supra* note 221, at 1625 (describing U.S. Geologicial Survey's Gap Analysis Program, which uses GIS technology to detect conservation "gaps").

[237] *See, e.g.*, Kathleen A. Lohse et al., *Forecasting Relative Impacts of Land Use on Anadromous Fish Habitat to Guide Conservation Planning*, 18 ECOLOGICAL APPLICATIONS 467, 479 (2008) (describing this tradeoff).

[238] *See, e.g.*, D.T. Robinson & D.G. Brown, *Evaluating the Effects of Land-Use Development Policies on Ex-Urban Forest Cover: An Integrated Agent-Based GIS Approach*, 23 INT'L J. GEOGRAPHICAL INFO. SCI. 1211, 1221–30 (2009); John M. Quigley & Aaron M. Swoboda, *The Urban Impacts of the Endangered Species Act: A General Equilibrium Analysis*, 61 J. URB. ECON. 299 (2007).

[239] *See generally* WOOD, *supra* note 171, at 25 (noting that maps often draw sharp lines where natural conditions form more of a continuum).

[240] *See* Malczewski, *supra* note 18, at 4 ("GIS-based land-use suitability analysis has been applied in a wide variety of situations . . . ."). The Obama Administration has called for a major increase in spatial mapping in ocean and coastal areas. *See* THE WHITE HOUSE COUNCIL ON ENVTL. QUALITY, *supra* note 104, at 51–59.

regulatory policies create a need for ways to understand larger human-ecological systems.[241] Again, innovations in spatial analysis hold promise.

In recent years, spatial analysts have begun creating comprehensive urban simulation models.[242] Rather than modeling a single component of the urban system, these models would integrate multiple systems, including transportation, land uses, employment and economic outcomes, municipal finances, and a range of environmental outcomes, into systemic models.[243] These models would have the capacity to simulate possible futures, testing, for example, the potential effects of different regulatory regimes upon a range of environmental and economic outcomes.[244] More conceptually, the models should be able to explore and predict ways in which environmental outcomes both derive from and drive other urban dynamics.[245] Ambitious though it may sound, the modelers' goal is a quantitative, spatially explicit representation of the coupled human and natural ecology of urban systems.[246]

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[241] *See* Marina Alberti & Paul Waddell, *An Integrated Urban Development and Ecological Simulation Model*, 1 INTEGRATED ASSESSMENT 215, 215 (2000).

[242] *See, e.g.*, John D. Landis, *Imagining Land Use Futures: Applying the California Urban Futures Model*, 61 J. AM. PLAN. ASS'N. 438 (1995); Paul Waddell, *UrbanSim: Modeling Urban Development for Land Use, Transportation, and Environmental Planning*, 68 J. AM. PLAN. ASS'N 297, 297 (2002).

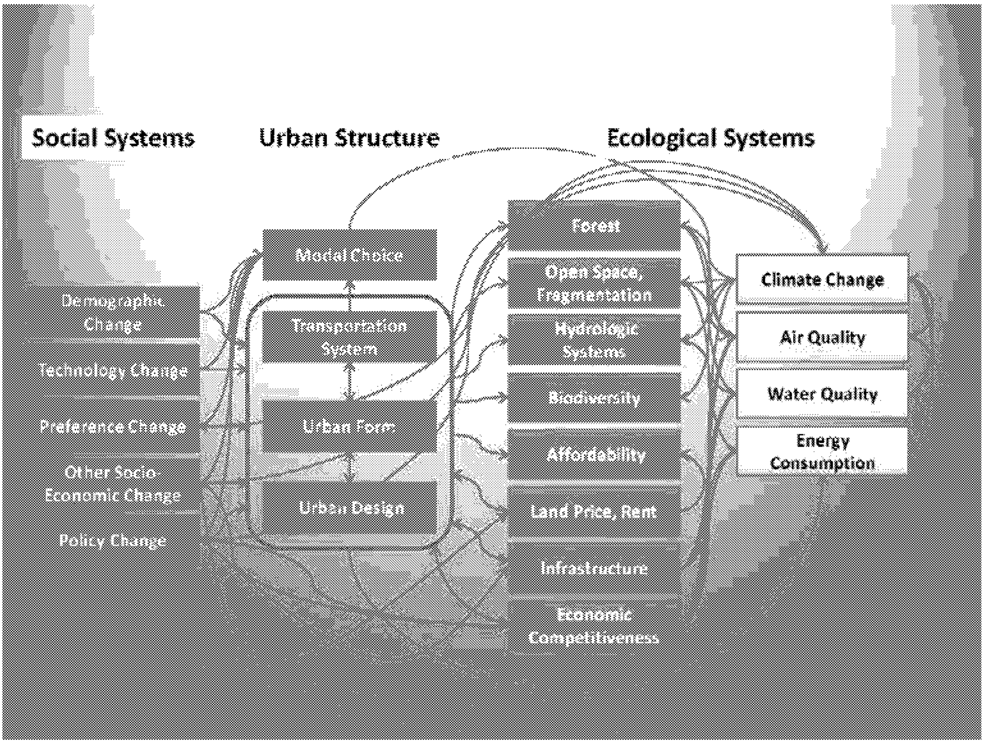
[243] *See, e.g.*, *Welcome to the UrbanSim Project*, URBANSIM, http://www.urbansim.org (last visited May 25, 2013).

[244] *See, e.g.*, Baker et al., *supra* note 186 (describing a multifaceted modeling effort for Oregon's Willamette Basin).

[245] *See* S.T.A. Pickett et al., *Urban Ecological Systems: Scientific Foundations and a Decade of Progress*, 92 J. ENVTL. MGMT. 331, 351–52 (2011) (discussing the challenges of modeling integrated social and ecological processes).

[246] *See generally* ALBERTI, *supra* note 21.

Figure 5: Conceptual diagram of an urban growth model. Image courtesy of Charles Colgan, University of Southern Maine, and adapted from urbanism.org.



Modelers are pursuing this goal in a variety of ways. Some use "cellular automata" models, which divide the study area into grid cells, each assigned a particular set of values, and then project landscape change through an iterative process of updating each cell's values based on the values of neighboring cells.[247] "Agent-based models" simulate land use change by modeling the behavior of multiple actors, each trying to achieve some set of economic, social, or environmental goals, and each reacting to other actors and to the changing landscape.[248] "Bayesian belief network" models use expert opinions to develop a set of model preferences and then combine those preferences with land use and land cover data to simulate future changes.[249] Multiple other techniques exist, and

[247] *See* Diana Mitsova et al., *A Cellular Automata Model of Land Cover Change to Integrate Urban Growth with Open Space Conservation*, 99 LANDSCAPE & URB. PLAN. 141, 143 (2011).

[248] *See* Elena G. Irwin & Jacqueline Geoghegan, *Theory, Data, Methods: Developing Spatially Explicit Economic Models of Land Use Change*, 85 AGRIC., ECOSYSTEMS & ENV'T 7, 8 (2001) (praising agent-based modeling); Pickett et al., *supra* note 245, at 352.

[249] *See, e.g.*, McCloskey et al., *supra* note 181, at 191.

many of these approaches can be combined.[250] Indeed, some of the most complex modeling systems are really aggregations of multiple models.[251]

Despite this explosion of methodologies, building an urban model that provides reliable predictions remains an aspiration. The data needs of highly complex urban models are extraordinary.[252] While some spatial data sets are now widely available, mismatches between the modelers' needs and available data are almost certain to occur.[253] Other modeling techniques, like Bayesian belief network modeling, create lesser (though still significant) data demands, but their reliance on expert opinion heightens the risk that the model will incorporate rather than challenge flaws in conventional wisdom.[254] Additionally, any model's internal logic is effectively a set of simplified assumptions about the behavior of human and environmental systems, and there are many aspects of that behavior that we poorly understand or that cannot be predicted with any real confidence.[255] As the complexity of the model grows, the combined effect of uncertainties and judgments can grow as well, leading to poor simulations and inhibiting error detection.[256]

For all of these reasons, the day is a long way off when urban modelers can take a municipality's proposed general plan, plug it into a model, and quickly produce reliable predictions about air quality, water quality, ESA compliance, economic growth, governance costs, transportation efficiency, and the social equity implications of both regulation and development.[257] Even further away, if it ever comes, is the day when modelers can provide those predictions for a single

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[250] *See* Peter Gomben et al., *Impact of Demographic Trends on Future Development Patterns and the Loss of Open Space in the California Mojave Desert*, 49 ENVTL. MGMT. 305, 311–16 (2012) (explaining multiple techniques).

[251] *See, e.g.*, Hulse et al., *supra* note 177, at 331 (diagramming a set of interlocking models); Waddell, *supra* note 242, at 303 (describing UrbanSim as "a software architecture for implementing models and a family of models implemented and interacting within this environment").

[252] *See* Hulse et al., *supra* note 177, at 327 (describing a two-year data gathering effort).

[253] *See* Pontius & Neeti, *supra* note 216, at 41, 46–48 (describing sources of uncertainty).

[254] *See* McCloskey et al., *supra* note 181, at 191 ("[Bayesian belief network's (BBN)] models are particularly useful when empirical data are limited and decisions are based largely on expert knowledge . . . ."). BBN modeling relies on people's opinions, which may be informed and accurate, but people are often ignorant of biases driving their own decisionmaking. *See generally* DANIEL KAHNEMAN, THINKING, FAST AND SLOW (2011).

[255] *See* Pickett et al., *supra* note 245, at 352 (acknowledging that "identifying causal effects of land use change is extremely challenging"); Pontius & Neeti, *supra* note 216, at 41 (noting the potential for modeled algorithms to poorly reflect actual processes).

[256] *See* NAT'L RESEARCH COUNCIL, *supra* note 129, at 10 (advocating "model parsimony").

[257] In comments on an earlier draft, Kelley Hart of the Trust for Public Land pointed out that the lack of specificity in many general plans also would limit such analyses.

development project.[258] The current generation of highly integrative urban models is better viewed as a preliminary set of exploratory tools, usually best applied at broad geographic scales, rather than as comprehensively accurate and detailed representations of urban systems.[259]

Nevertheless, even in their present state, urban growth models can help policymakers understand some of the likely environmental consequences of development trends and explore the sensitivity of those trends to different economic scenarios and regulatory interventions.[260] Because of these capabilities, complex urban models already are important to environmental planners, and the push to develop more sophisticated tools shows no sign of abating.[261] The time may yet arrive when many environmental and nonenvironmental regulatory processes can be linked through computer-based simulations, allowing policymakers to think about multiple environmental goals, at multiple scales, and across jurisdictional boundaries all at once.

B. How We Regulate: Changing Legal Instrument Selection

The evolution of spatial analysis has important implications not just for our conceptualization of the dynamics of environmental change, but also for the legal tools we use to address these dynamics. This section discusses two ways in which spatial analysis can support instruments that attempt to integrate regulation across spatial and temporal scales and media-specific boundaries, and thus can shift environmental law's core debates about regulatory instrument choice.

1. Muddling Toward Synoptic Regulation

One of environmental law's most venerable debates concerns regulatory approaches that demand information-intensive studies or plans. Environmental assessment laws like NEPA, which requires far-ranging environmental impact statements in advance of governmental actions, exemplify one version of this approach.[262] Comprehensive planning statutes are another common example.[263] In

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[258] *See, e.g.*, R.D. Swetnam et al., *Mapping Socio-Economic Scenarios of Land Cover Change: A GIS Method to Enable Ecosystem Service Modeling*, 92 J. ENVTL. MGMT. 563, 573 (2011) (noting that modeled scenarios can have greater value at larger geographic scales).

[259] *See id.* at 564 ("[E]ach scenario should be thought of as a description of a possible future, albeit one which is plausible . . . .").

[260] *See, e.g.*, Baker et al., *supra* note 186, at 313, 317–20 (considering the implications of the Willamette Basin's development trends).

[261] *See* Gomben et al., *supra* note 250, at 311–16 (noting many existing uses); *User List Sorted by Location*, URBANSIM, http://www.urbansim.org/Main/UserListByLocation (last visited May 25, 2013) (listing dozens of countries where versions of UrbanSim have been used).

[262] 42 U.S.C. § 4332(2)(C)(i) (2006).

theory, these laws should facilitate the sort of broad, integrative thinking that almost everyone agrees is desirable.[264] The practical utility of those laws has been hotly debated for decades, however, with one representative critique asserting that "NEPA ambitiously, and naively, demands the impossible: comprehensive, synoptic rationality, in the form of an exhaustive, one-shot set of *ex ante predictions* of expected environmental impacts. In the ordinary course of events, that task proves insuperable."[265] Planning's skeptics often say much the same thing, and argue that alternative regulatory approaches should receive more emphasis.[266]

These debates have important practical implications. Both environmental assessment laws and planning statutes occupy influential roles in federal and state environmental law.[267] But they are not ubiquitous. Most states lack laws like NEPA, and many states and localities have a rather uneven commitment to planning.[268] Consequently, many sources of environmental impact, including the kind of urban development exemplified by Greenacres, are only partially covered.[269] Even where such laws do exist, their application is often controversial. NEPA continues to generate legislative and administrative complaints, with federal agencies often seeking opportunities to "streamline" its processes.[270] Initiatives to limit the applicability of state environmental assessment requirements are also

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[263] *See, e.g.*, 33 U.S.C. § 1313(e) (requiring water quality planning); 42 U.S.C. § 7410 (requiring air quality planning). For further examples of comprehensive planning statutes, see *supra* note 83.

[264] *See* Calvert Cliffs' Coordinating Comm., Inc. v. U.S. Atomic Energy Comm'n, 449 F.2d 1109, 1114 (D.C. Cir. 1971) (arguing that only through such broad analyses is it "likely that the most intelligent, optimally beneficial decision will ultimately be made").

[265] Bradley C. Karkkainen, *Toward a Smarter NEPA: Monitoring and Managing the Government's Environmental Performance*, 102 COLUM. L. REV. 903, 906 (2002).

[266] *See, e.g.*, Oliver A. Houck, *Of Bats, Birds and B-A-T: The Convergent Evolution of Environmental Law*, 63 MISS. L.J. 403, 410–28 (1994) (critiquing environmental planning).

[267] *See* FARBER ET AL., *supra* note 56, at 522 ("NEPA has remained an important pillar of environmental law."); Dave Owen, *Probabilities, Planning Failures, and Environmental Law*, 84 TUL. L. REV. 265, 266–67 (2009) (describing environmental law's extensive planning requirements).

[268] *See* DANIEL MANDELKER, NEPA LAW AND LITIGATION § 1:7, at 1-14 to -15 (2011) (noting that "state environmental policy acts . . . have been enacted in 15 states, Puerto Rico and the District of Columbia"). Some states without full-blown environmental policy acts still require some environmental review of development projects. *See, e.g.*, ME. REV. STAT. ANN. tit. 38, §§ 481–490 (2001).

[269] NEPA still applies to some development projects, but only to the extent the projects trigger discretionary federal review. *See* 42 U.S.C. § 4332(2)(C) (2006) (establishing requirements for "major Federal actions").

[270] *See* Bradley C. Karkkainen, *Whither NEPA?*, 12 N.Y.U. ENVTL. L.J. 333, 336–38 (2004) (describing initiatives, in response to "[l]ong-simmering dissatisfaction among agency officials and resource extraction industries" to limit NEPA).

quite common.[271] Federal, state, and local governments therefore often debate how much, if at all, to pursue comprehensive planning and environmental review requirements.[272]

Advances in spatial analysis have important implications for these debates. While spatial analysis cannot make the challenges of synoptic analysis disappear, it can expand the realm of the possible, making spatially and temporally broad analyses viable where they previously were unrealistically ambitious. The ability of models to simulate the combined effect of many different emission sources on regional air pollution, or of a variety of land use changes upon water quality, both exemplify that capacity.[273] Similarly, spatial analysis can facilitate the multimedia inquiries that environmental laws like NEPA are supposed to promote. Environmental impact assessment laws provide a rare obligation to address, in a single process leading to a unified document, the impacts of a project on a variety of environmental media, and to consider alternatives to that project.[274] That obligation would mean little if environmental scientists lacked the tools to produce the required predictions, and instead were providing encyclopedic compilations of semi-informed guesswork.[275] But as modeling capabilities increase, retaining a procedural obligation for crossmedia, multi-scalar analysis should become increasingly important.

Those advances do not imply that we should abandon the hedge strategies we have adopted to compensate for pervasive informational shortfalls. Spatial analysis will never make those shortfalls completely disappear, and technology-based standards, adaptive management programs, and all the other ways we now address the informational challenges of environmental regulation will continue to play important roles.[276] But increases in our analytical capacity clearly do mean that the debate over these competing approaches needs to evolve. Comprehensive planning and analysis have produced uneven results, but as we choose among regulatory instruments, past limitations should not prevent us from asking whether technological advances are closing the gaps between our synoptic ambitions and

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[271] *See, e.g.*, Timm Herdt, *Lawmakers Approve Measures to Speed Up Large Developments*, VENTURA COUNTY STAR (Sep. 9, 2011, 9:48 PM), http://www.vcstar.com/news/2011/sep/09/lawmakers-approve-measures-to-speed-up-large/.

[272] *See, e.g.*, THE WHITE HOUSE COUNCIL ON ENVTL. QUALITY, *supra* note 104 (proposing ambitious new planning initiatives for marine resource management).

[273] *See supra* notes 210–221 and accompanying text.

[274] *See supra* notes 49–74 and accompanying text.

[275] *See* Paul J. Culhane, *The Precision and Accuracy of U.S. Environmental Impact Statements*, 8 ENVTL. MONITORING & ASSESSMENT 217, 235–36 (1987) (questioning the value of predictions in NEPA documents).

[276] *See generally* Karkkainen, *supra* note 265, at 907–08 (promoting adaptive management in contexts of uncertainty); Wendy E. Wagner, *The Triumph of Technology-Based Standards*, 2000 U. ILL. L. REV. 83 (arguing that technology standards are an important hedge against information deficits).

our practical realities.[277] The role of planning and assessment in environmental law should at least remain stable, and there are many opportunities—particularly at state and local levels—for their greater use.[278]

2. Making Environmental Trading Systems Work

A second recurring challenge of environmental law involves turning the theoretical appeal of environmental trading systems into practical results. Here, as well, spatial analysis offers the potential for supporting more economically efficient and environmentally protective regulatory approaches.

In theory, the appeal of trading systems is elegantly simple: by allowing exchanges across large geographic areas and through time, trading systems should allow regulated actors to efficiently allocate the burdens of compliance while still attaining the desired environmental result.[279] But that theory works best when relatively large actors trade fungible things, and in practice, such simplicity and fungibility are rare.[280] They are particularly rare for the kinds of impacts typically generated by development. Development often involves large numbers of relatively small actors and actions, and for most of the impacts that a project like Greenacres generates—filling wetlands, increasing water withdrawals, or generating air pollution, to provide just a few examples—context matters.[281] Consequently, each trade creates a risk that the balance of benefits and burdens will somehow be skewed, with the imbalance operating to the detriment of environmental protection, and perhaps also creating objectionable distributional impacts.[282]

Market designers can respond to those complications in several ways, but each traditional option is problematic. One option, which provides little assurance of environmental benefit, is to simply live with skewed outcomes.[283] Alternatively, regulators can impose offset ratios, which will compensate for nonfungibility by

[277] *See, e.g.*, Owen, *supra* note 267, at 282 n.93 (quoting EPA employees describing successful air quality planning processes).

[278] *See* MANDELKER, *supra* note 268, § 1:7, at 1-14 (noting that fifteen states have statutes like NEPA).

[279] *See* E. Donald Elliott & Gail Charnley, *Toward Bigger Bubbles*, 13 F. APPLIED RES. & PUB. POL'Y 4, 48 (1998); Robert Stavins, *Market-Based Environmental Policies: What Can We Learn from U.S. Experience (and Related Research)?*, *in* MOVING TO MARKETS IN ENVIRONMENTAL REGULATION, *supra* note 90, at 19, 20.

[280] *See* Salzman & Ruhl, *supra* note 90, at 622–30 (describing examples of nonfungibility).

[281] *See* Freyfogle, *supra* note 100, at 31–33 (describing the importance of real world context to water rights trading); Salzman & Ruhl, *supra* note 102, at 342 (discussing the challenges of using trading systems to address habitat).

[282] *See* Tietenberg, *supra* note 90, at 87 (describing the risk of environmental imbalances). *See generally* Drury et al., *supra* note 99 (describing the potential for environmental justice problems arising from environmental trading systems).

[283] *See* Salzman & Ruhl, *supra* note 90, at 612 (arguing that wetlands trading historically involved an excessive tolerance for nonequivalent trades).

imposing a sort of tax on transactions.[284] Thus, for example, the developer who destroys one acre of wetlands might be required to construct four new acres. That approach may provide better environmental protection, but the tax undermines the economic appeal of the market and may deter participation.[285] A third alternative is for regulators to review each trade, making sure it provides sufficient environmental value. That approach may ensure equivalence, but regulators will have much more work to do, and the concomitant unpredictability and higher transaction costs may deter market participation.[286] Incremental review also may squander the efficiency that might come from integrating individual trades into a broader plan.[287] Despite these potential problems, regulators use all of these approaches, and many trading systems still function.[288] But because of the resulting complications, some commentators question whether environmental trading systems offer desirable options outside of a few exceptional circumstances.[289]

Advances in spatial analysis can support a promising alternative approach. Rather than relying on regulated entities to identify their preferred mitigation option, regulators can preapprove a set of mitigation options. Thus, for example, wetlands regulators can identify areas with high restoration potential, or where high-value wetlands are under threat, and can specify those areas as preapproved mitigation zones. Developers then would receive expedited approval for trades involving mitigation in those areas. In theory, all participants benefit. Regulators and the public receive better assurance that individual trades will protect environmental values and will fit into a coherent larger plan, and developers avoid the uncertainty and delay associated with protracted review of each individual transaction.

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[284] *See, e.g.*, 42 U.S.C. § 7511a(e)(1) (2006) (establishing ratios for ozone emission offsets). This approach also is commonly used where destruction of habitat is being allowed in return for preservation of existing habitat elsewhere. The ratio then compensates—hopefully—for the possibility that the preserved area might have remained intact even without legal protection and that the trade may therefore involve real destruction and superfluous preservation.

[285] *See* Stavins, *supra* note 279, at 26 (noting this disincentive).

[286] *Id.* at 25 ("[R]equiring prior government approval of individual trades may increase uncertainty and transaction costs, thereby discouraging trading . . . ."). Commentators often cite water rights trading as an area where such transaction costs have resulted in suboptimal trading levels. *See, e.g.*, Stephen N. Bretsen & Peter J. Hill, *Transaction Costs and Water Markets: An Anticommons Perspective*, *in* AQUANOMICS: WATER MARKETS AND THE ENVIRONMENT 143, 143–81 (B. Delworth Gardner & Randy T. Simmons eds., 2012).

[287] *See* James H. Thorne et al., *Evaluating Aggregate Terrestrial Impacts of Road Construction Projects for Advanced Regional Mitigation*, 43 ENVTL. MGMT. 936, 937 (2009); Jessica B. Wilkinson & Robert Bendick, *The Next Generation of Mitigation: Advancing Conservation Through Landscape-Level Mitigation Planning*, 40 ENVTL. L. REP. 10023, 10025 (2010).

[288] *See generally* Tietenberg, *supra* note 90, at 63–64 (describing many uses of environmental trading systems).

[289] *See* Salzman & Ruhl, *supra* note 102, at 342.

This basic concept is not new,[290] and it does not necessarily require spatial analysis.[291] But in several ways, spatial analysis can make this alternative approach much more effective. Initially, spatial analysis can inform decisions about the scale and construction of the trading system. By using spatial models, analysts can approximately predict how much development is likely, where it may occur, and what kinds of impacts that development might create.[292] That information can help the analysts assess what sort of mitigation is needed, and also how much.[293] Similarly, spatial models can predict the economic value generated by a trading program, which can help regulators set fee or offset schedules and determine how much mitigation work they will be able to do.[294] All of this information can help

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[290] *See, e.g.*, EMMONS & OLIVIER RES., INC., LINO LAKES SPECIAL AREA MANAGEMENT PLAN (SAMP) 3–4 (2010), *available at* http://www.ricecreekwatershed.govoffice2.com/vertical/Sites/%7BF68A5205-A996-4208-96B5-2C7263C03AA9%7D/uploads/Lino_SAMP_Edited_Oct_10.pdf (describing several "Special Area Management Plans," which the Army Corps of Engineers sometimes uses to implement a similar regulatory approach); Buchsbaum, *supra* note 71, at 194–95 (describing habitat conservation planning under sections 9 and 10 of the ESA); Royal C. Gardner, *Banking on Entrepreneurs: Wetlands, Mitigation Banking, and Takings*, 81 IOWA L. REV. 527, 550–76 (1996) (describing wetlands mitigation banking and its benefits to private landowners and the environment); Julian Conrad Juergensmeyer et al., *Transferable Development Rights and Alternatives After* Suitum, 30 URB. LAW. 441, 443–54 (1998) (describing transferable development rights, which local governments use to direct development to growth areas and compensate landowners in areas where growth is to be limited); Gregory M. Parkhurst & Jason F. Shogren, *Incentive Mechanisms*, *in* 1 THE ENDANGERED SPECIES ACT AT THIRTY: RENEWING THE CONSERVATION PROMISE 247, 249 (Dale D. Goble et al. eds., 2006) (describing habitat conservation banking); K. Shawn Smallwood et al., *Environmental Auditing: Indicators Assessment for Habitat Conservation Plan of Yolo County, California, USA*, 22 ENVTL. MGMT. 947 (1998) (using a similar approach to identify target areas for a multispecies habitat conservation plan).

[291] In working on one such program, I observed that experienced planners and scientists were comfortable working off paper maps to develop this sort of approach, at least at a single-municipality scale. Interestingly, a generational difference also seemed to be present, with older participants preferring the paper maps and younger participants leaning toward computer-based systems.

[292] *See, e.g.*, Thorne et al., *supra* note 287, at 939–40 (describing the use of a GIS for this initial step); *see also* Patrick R. Huber et al., *Regional Advance Mitigation Planning: A Pilot Study Integrating Multi-Agency Mitigation Needs and Actions Within a Comprehensive Ecological Framework*, 2009 INT'L CONF. ON ECOLOGY & TRANSP. PROC. 221, http://www.icoet.net/ICOET_2009/downloads/proceedings/ICOET09-Proceedings-Session143.pdf (describing a similar process).

[293] *See, e.g.*, Thorne et al., *supra* note 287, at 941–45 (summarizing regional mitigation needs).

[294] I am currently a minor participant in an effort to use this approach to allow locally led vernal pools regulation. *See generally* ME. VERNAL POOLS, http://www.umaine.edu/vernalpools/ (last visited May 25, 2013) (describing the community-based conservation project, though focusing primarily on earlier phases).

regulators decide on the scale and mechanics of the trading program. It also can help them determine whether a trading program will be viable at all.

Additionally, spatial analysis can help maximize the return on mitigation purchases. Analysts routinely use spatial analysis to identify areas with multiple features desirable for some use, whether that use is a housing development or a conservation purchase, and that same approach can be adapted to target mitigation efforts.[295] Regulators also can use development models to identify areas where, absent mitigation purchases, development would be likely to occur.[296] That identification could reduce the "additionality" problems that result when public money is expended to protect resources not under any realistic threat.[297] Spatial analysis also can link individual purchases into a coherent larger plan. By analyzing not just the individual value of each protection or restoration project, but also the potential interconnections between different mitigation areas, analysts can create synergy among separate transactions.[298] Similarly, if a central goal of the trading scheme is to keep mitigation in relatively close geographic proximity to the impacted site, modelers can add a geographic-preference criterion to the site selection algorithm.[299]

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[295] *See supra* notes 231–240 and accompanying text (discussing land use suitability analyses).

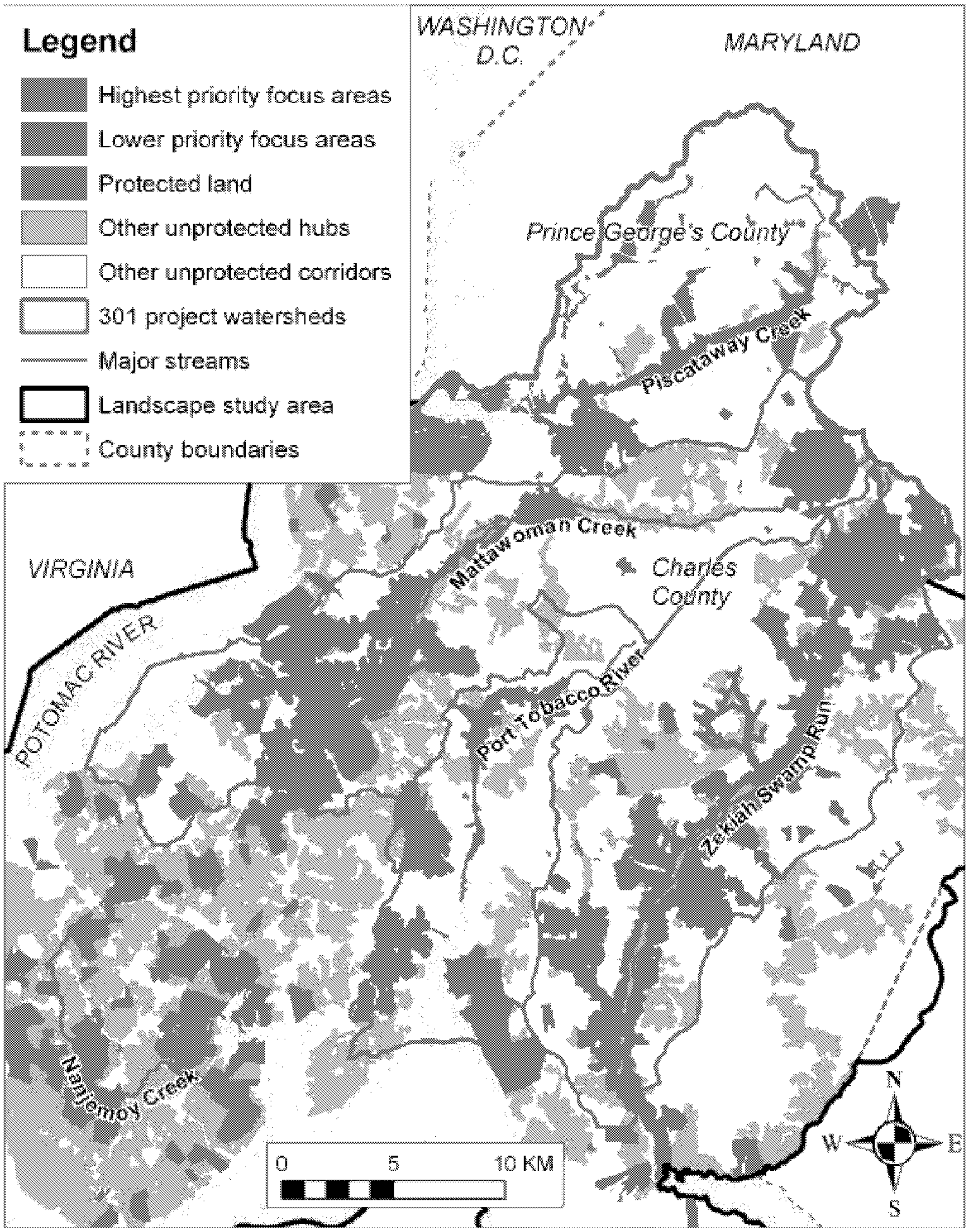
[296] *See, e.g.*, Lohse et al., *supra* note 237, at 469 (describing the combined use of ecological, land use, and hedonic models to identify priority sites); Theobald, *supra* note 221 (using biological and socioeconomic data to identify ecologically valuable areas likely to be developed).

[297] *See* Bruce A. McKenney & Joseph M. Kiesecker, *Policy Development for Biodiversity Offsets: A Review of Offset Frameworks*, 45 ENVTL. MGMT. 165, 170–71 (2010) (identifying additionality as a key challenge).

[298] *See* Thorne et al., *supra* note 287, at 937. *See generally* Mikel Gurrutxaga et al., *GIS-Based Approach for Incorporating the Connectivity of Ecological Networks into Regional Planning*, 18 J. NATURE CONS. 318 (2010) (explaining how GIS can be used to maintain productive connections between conservation areas that otherwise might be isolated).

[299] *See* Joseph M. Kiesecker et al., *A Framework for Implementing Biodiversity Offsets: Selecting Sites and Determining Scale*, 59 BIOSCIENCE 77, 80–81 (2009) (factoring geographic proximity into the site prioritization process).

Figure 6: Targeted mitigation zones generated by combining multiple spatial databases. From Weber & Allen, *supra* note 22, at 251.



All of these advances have value within a single-purpose trading system, where the goal is simply to protect wetlands, farmland, or habitat for one particular endangered species. But spatial modeling also raises the possibility of coordinating multiple trading systems.[300] The core concept is similar: instead of selecting sites based on one environmental value, the model could select sites based on their value for multiple species, wetlands protection, water supply protection, and recreation.[301] By prioritizing multiple targets, the program also could facilitate an integrated response to mitigation requirements set by several different laws.[302] Indeed, as integrated urban modeling becomes increasingly advanced, it may become possible to integrate vehicle miles traveled, air quality, greenhouse gas emissions, and infrastructure costs into the trading exercise.[303] The end result could be a trading system based on preapproved receiving zones, all selected to maximize a broad set of environmental and nonenvironmental goals.

These kinds of integrative trading systems are still quite new, and schemes integrating a full suite of environmental goals do not yet exist.[304] If and when they do, they will suffer from all the standard problems with any approach dependent upon quantitative environmental modeling.[305] Assigning relative weights to the various goals sought by the model also will likely be a challenge.[306] But the potential benefits are significant. Despite their flaws, trading systems already pervade environmental regulation, and improvements that ameliorate some of the externalities and inefficiencies of those existing systems therefore could have immense value, even if the reforms are only partial. These advances also could make trading feasible in many areas where it is not currently used, and that also is a potentially significant gain. Often the practical alternative to the existence of a trading scheme is widespread tolerance of small environmental impacts, as regulators decline to impose prohibitory regulatory approaches they perceive as overly stringent.[307] In these circumstances, the flexibility afforded by a trading

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[300] *See, e.g.*, Huber et al., *supra* note 292 (describing a multi-agency mitigation strategy); Weber & Allen, *supra* note 22, at 252 (describing the use of multiple criteria).

[301] *See, e.g.*, Weber & Allen, *supra* note 22, at 240.

[302] *See, e.g.*, Huber et al., *supra* note 292.

[303] For a proposal for air quality trading using a spatially explicit model, see Jonathan Remy Nash & Richard L. Revesz, *Markets and Geography: Designing Marketable Permit Schemes to Control Local and Regional Pollutants*, 28 ECOLOGY L.Q. 569 (2001).

[304] Systems that attempt to protect multiple species are not so new, and there is evidence that they provide significant benefits over single-species approaches. *See, e.g.*, Jared G. Underwood, *Combining Landscape-Level Conservation Planning and Biodiversity Offset Programs: A Case Study*, 47 ENVTL. MGMT. 121, 126 (2010) ("Our results show that significantly more conservation has occurred for almost all species of concern in the area with a combined conservation-offset plan.").

[305] *See supra* notes 169–174 and accompanying text (discussing modeling's limits).

[306] *See generally* Salzman & Ruhl, *supra* note 102, at 334 (discussing how the necessity of making apples-to-oranges comparisons creates difficulties for environmental trading systems). One intriguing way of resolving those problems is to allow community participants to vote on weights. *See, e.g.*, TRUST FOR PUBLIC LAND, *supra* note 235, at 8 (describing the use of public outreach to identify features that would make land relatively important to protect).

[307] *See, e.g.*, Owen, *supra* note 6, at 192–94 (describing potential benefits of trading schemes for critical habitat protection).

program can provide a practicable way of securing some compensation for impacts that otherwise would go unregulated.[308]

These changes therefore should transform how environmental lawyers evaluate trading systems. Any time such systems are proposed, a key question is whether informational challenges will be manageable or, alternatively, will create a Hobson's choice between an efficient system that provides no environmental benefit and a protective system that is dysfunctionally cumbersome. In the future, answers to that question will often depend in part on the ability of spatial analysis to support the trading scheme. Where spatial tools allow better planning and oversight, environmental trading schemes should present viable options, sometimes, even, in circumstances where a trading scheme would have been infeasible or unwise twenty years ago.

C. Who Regulates: Toward a More Functional Federalism

Just as advances in spatial analysis will affect which environmental problems we attempt to address and how we address them, they also have implications for some of environmental law's traditional *who* questions: which entities, within or outside government, should address environmental problems, and how, if at all, should those entities coordinate their efforts? Those questions will likely emerge in a variety of contexts, but one in particular implicates foundational questions about our systems of environmental law. Spatial analysis can help complex systems of overlapping federalism work.

For decades, environmental policymakers and scholars have been obsessed with federalism. The subject looms large in the Supreme Court's environmental jurisprudence,[309] pervades political rhetoric,[310] and generates reams of academic articles. Broadly speaking, the debaters can be divided into two camps. On one side are the "dual federalists,"[311] whose thinking is most clearly exemplified by several recent decisions of the Supreme Court.[312] In their view, federalism functions best as a system of boundary rules protecting state and local governments from federal interference and insulating federal prerogatives from state and local

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[308] *See, e.g.*, *id.* at 193–94.

[309] *See, e.g.*, Rapanos v. United States, 547 U.S. 715, 738 (2006) (rejecting a regulatory interpretation that would establish the U.S. Army Corps of Engineers as "a de facto regulator of immense stretches of intrastate land"); Solid Waste Agency v. U.S. Army Corps of Eng'rs, 531 U.S. 159, 174 (2001) (rejecting a regulatory interpretation that "would result in a significant impingement of the States' traditional and primary power over land and water use").

[310] *See* Erin Ryan, *Negotiating Federalism*, 52 B.C. L. REV. 1, 1, 6–7, 28 (2011) (describing recent debates in which federalism assumed prominence).

[311] This term comes from Robert A. Schapiro, *From Dualist Federalism to Interactive Federalism*, 56 EMORY L.J. 1, 4 (2006).

[312] *See, e.g.*, Bond v. United States, 131 S. Ct. 2355, 2364–65 (2011); Alden v. Maine, 527 U.S. 706, 714–15, 748–52 (1999).

intermeddling.[313] Importantly for Greenacres, land use planning implicates a particularly important divide. The Supreme Court has often asserted that even as the federal government takes the lead in environmental regulation, land use should remain "a quintessential state and local power."[314] On the other side are the "interactive" or "dynamic" federalists.[315] Like the dual federalists, they see value in a system with federal, state, and local authority. But they argue that jurisdictional overlap can promote collaboration and communication, leading to more effective use of the "laboratories of democracy" that federalism is supposed to promote.[316]

Many differences of opinion divide these camps, but one potentially important—albeit largely implicit and unexamined—divide involves assessments of the capacity for effective communication among different levels of government. If that capacity is limited, then a system of rigid spheres of authority may make sense.[317] Different levels of government otherwise would stumble across each other's efforts, with that interference often culminating in federal displacement of state or local discretion, and the isolating boundaries envisioned by the dual federalists could be necessary to preserve meaningful state and local governance.[318] Conversely, if the potential for effective intergovernmental dialogue is high, different levels of governments should be able to communicate their needs and priorities, isolate areas of disagreement, and find common ground.[319] Lawmakers and judges then would not need to worry quite so much

[313] *See Bond*, 131 S. Ct. at 2364 ("The federal balance is, in part, an end in itself, to ensure that States function as political entities in their own right."); United States v. Morrison, 529 U.S. 598, 599 (2000) ("The Constitution requires a distinction between what is truly national and what is truly local . . . ."); *Alden*, 527 U.S. at 751 (rejecting authority that "would blur . . . the distinct responsibilities of the State and National Governments").

[314] *Rapanos*, 547 U.S. at 738; *see Solid Waste Agency*, 531 U.S. at 174 (rejecting wetlands regulations partly because of impacts on state and local land use authority); Cal. Coastal Comm'n v. Granite Rock Co., 480 U.S. 572, 587 (1987) (emphasizing a distinction between land use planning and environmental protection).

[315] *See, e.g.*, Kirsten H. Engel, *Harnessing the Benefits of Dynamic Federalism in Environmental Law*, 56 EMORY L.J. 159 (2006); Heather K. Gerken, *The Supreme Court 2009 Term, Foreword: Federalism all the Way Down*, 124 HARV. L. REV. 4 (2009); Hari M. Osofsky, *Diagonal Federalism and Climate Change: Implications for the Obama Administration*, 62 ALA. L. REV. 237, 268 (2011); Schapiro, *supra* note 311. These authors also use several other terms to describe variations on this general theory.

[316] Schapiro, *supra* note 311, at 8–9.

[317] Alternatively, consolidating authority within a single, unitary government might make sense, but that possibility is so politically unthinkable that this Article does not consider it.

[318] *See generally Bond*, 131 S. Ct. at 2364–65 (arguing that federalism protects liberty by protecting spheres of state and local primacy).

[319] To put the point slightly differently, if we are choosing between a federalism of voice and a federalism of exit, we need to know about the effectiveness of the means of communication. *Compare* Gerken, *supra* note 315 (promoting a federalism of voice), *with*

about allowing federal or state environmental programs to affect land use authority and other state and local prerogatives.

In several ways, spatial analysis can help answer that question,[320] and a particularly illustrative set of examples involves processes sometimes called "alternative futures modeling" or "scenario planning."[321] These processes use spatial analysis to model future land use scenarios.[322] Modelers can develop the scenarios in a variety of ways, including working with people in the affected area to define scenarios they think are plausible or desirable.[323] The modelers then explore the implications of those scenarios for a variety of potential outputs, including development patterns, water quality, biodiversity, and, potentially, economic impacts like costs to state and local government and private property values.[324] Based on the initial results, they also can develop new scenarios or work backward from desired future outcomes to recommended present policy approaches.[325] The end result is generally a series of detailed maps that depict plausible alternative futures for the modeled area, as well as charts and graphs explaining differences between the alternatives.[326]

In several ways, these processes can facilitate the kind of interjurisdictional coordination upon which dynamic federalism theories implicitly rely. Initially, they allow evaluation of the combined implications of a variety of current trends

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Richard A. Epstein, *Exit Rights Under Federalism*, 55 LAW & CONTEMP. PROBS. 147, 147–49 (1992).

[320] Land use suitability analysis, which Part III.B describes at length, also has important implications for federalism, for it provides an effective mechanism for communicating local, state, and federal regulatory constraints.

[321] *See, e.g.*, CARL STEINITZ ET AL., ALTERNATIVE FUTURES FOR CHANGING LANDSCAPES: THE UPPER SAN PEDRO RIVER BASIN IN ARIZONA AND SONORA (2003); Baker et al., *supra* note 186; Tony Prato et al., *Evaluating Alternative Economic Growth Rates and Land Use Policies for Flathead County, Montana*, 83 LANDSCAPE & URB. PLAN 327 (2007). Researchers also sometimes use terms like "scenario planning" to describe these types of analyses. For warnings about limitations of alternative futures analysis, see Pontius & Neeti, *supra* note 216, at 39.

[322] *See* Pontius & Neeti, *supra* note 216, at 39.

[323] *See, e.g.*, Baker et al., *supra* note 186, at 315 ("The future landscapes are designed with stakeholder input to illustrate major strategic choices.").

[324] *See, e.g.*, *id.* at 316 (evaluating implications for water availability, riparian habitats, and terrestrial wildlife); Chakroborty, *supra* note 179, at 396–97 (describing a scenario-modeling exercise for Maryland).

[325] *See* Baker et al., *supra* note 186, at 315 ("As stakeholders see results for the initial set of alternative futures, it may lead to new ideas or compromise positions that warrant design of additional future scenarios or analysis of additional endpoints.").

[326] *See, e.g.*, U.S. ENVT'L PROT. AGENCY, EPA 600/R-02/045(a), WILLAMETTE BASIN ALTERNATIVE FUTURES ANALYSIS: ENVIRONMENTAL ASSESSMENT APPROACH THAT FACILITATES CONSENSUS BUILDING (2002), http://www.epa.gov/wed/pages/projects/alternativefutures/ninepager.pdf.

and policies.[327] That review may reveal future conflicts or opportunities that might never have become apparent through individual plan-by-plan or project-by-project studies.[328] Futures modeling also allows participants to explore the potential implications of—and perhaps, to reconsider—their assumptions. By visually depicting tradeoffs between competing goals, modeling creates an opportunity to consider whether rigid adherence to their prior preferences will produce a landscape participants want to live in.[329] For similar reasons, the process of developing a model and a set of maps provides an opportunity to move discussions out of the realm of ideological abstraction.[330] Scenario maps grab attention and convey information in a language readily understood by many people, making a possible future seem much more real.[331] Sometimes, of course, the maps can make the future seem too real, and participants may forget that the maps are explorations of possible futures, not reliable predictions.[332] But if the modelers are attentive to that possibility, the possibility of new insight can significantly outweigh the risk of new misconceptions.[333]

Facilitating a more inclusive and constructive discussion may be valuable, but if that discussion only reveals intractable conflict, the exercise ultimately will have modest value. Often, however, modeling reveals otherwise unseen options that can

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[327] *See, e.g.*, Baker et al., *supra* note 186, at 319 (describing a scenario that "provided a unique opportunity to examine [the] joint implications" of a variety of land use plans).

[328] *See, e.g.*, *id.* (describing surprising results).

[329] *See, e.g.*, Schmitt Olabisi et al., *supra* note 188, at 2693–94 (discussing an exercise that confronted participants with unexpected implications of a commitment to local energy production).

[330] *See* Hulse et al., *supra* note 177, at 339 (explaining how mapping exercises can facilitate constructive dialogue).

[331] Yaakov Garb et al., *Scenarios in Society, Society in Scenarios: Toward a Social Scientific Analysis of Storyline-Driven Environmental Modeling*, ENVTL. RES. LETTERS, Oct.–Dec. 2008, letter 045015, at 1, 3, http://iopscience.iop.org/1748-9326/3/4/045015/pdf/1748-9326_3_4_045015.pdf (emphasizing the importance of dialogue about models and maps). Of course, participants may also discount scenarios that do not conform to their prior beliefs. *See* Lorenzoni & Hulme, *supra* note 30, at 393–94.

[332] *See generally* Wagner et al., *supra* note 29 (warning of this risk).

[333] *See* Jonathan R. Thompson et al., *Scenario Studies as a Synthetic and Integrative Research Activity for Long-Term Ecological Research*, 62 BIOSCIENCE 367, 374 (2012) (explaining that a review of multiple scenario planning studies demonstrates "how more interactive engagement can enhance the interest and ownership for the challenges as well as potential solutions across different stakeholder groups"). Indeed, a similar risk exists even without computerized simulation models. Most people likely have prior assumptions about the future, and those future assumptions may be even more erroneous, and significantly less examined, than the predictions produced by a model. Discussions about a model can provide a valuable opportunity to expose and examine those assumptions. *See generally* ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT 95–106 (C.S. Holling ed., 1978) (explaining the benefits of ongoing discussions about iterative processes of building and running models).

ameliorate interjurisdictional tensions.[334] Even environmentally sensitive regions often have many areas where development can occur while causing relatively modest environmental impacts.[335] Similarly, if policymakers act proactively, many mechanisms, including protecting habitat corridors, preserving riparian buffers, and promoting cluster development and other compact patterns of growth, can help integrate development into a landscape while retaining important ecological functions.[336] Prioritizing development in some areas and limiting it in others obviously has potential implications for property values, but advance planning gives communities opportunities to set up financial mechanisms, like environmental trading systems or transferable development rights, to ameliorate those impacts.[337] Alternatively, confronting the future implications of unrestrained development may lead people to conclude that some uncompensated limitation on property use is an appropriate contribution toward maintaining a community's identity and quality of life.[338] In short, in a variety of ways, modeling alternative futures can help people achieve the goals of environmental law while still preserving ample local discretion and community autonomy.

To be clear, this Article's claim is not that the emergence of spatial analysis will generate universal acceptance of dynamic federalism. There are many other reasons—including generalized hostility to regulatory governance and ideological opposition to federal authority—for continued interest in federalism's more boundary-based forms, and the prospect of effective intergovernmental collaboration will not make that interest disappear.[339] Similarly, spatial analysis will not always reveal options that meet everyone's needs. Some conflicts really are intractable.[340] But spatial analysis can communicate federal, state, and local goals, explore compatibilities between those goals, and cabin conflict to more manageable and discrete zones. That capacity should give at least a moment's pause to lawmakers and judges who assume that rigid limits on federal or state

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[334] *See, e.g.*, Prato et al., *supra* note 321, at 336–37 (concluding that a "moderately restrictive" land use policy could accommodate future growth).

[335] *See, e.g.*, McCloskey et al., *supra* note 181, at 198 (finding abundant opportunities for conflict-free development); John Van Sickle et al., *Projecting the Biological Condition of Streams Under Alternative Scenarios of Human Land Use*, 14 ECOLOGICAL APPLICATIONS 368, 378 (2004) (concluding that a "Conservation scenario" would allow environmental improvements even as the Willamette Valley's population doubles).

[336] *See* U.S. ENVTL. PROT. AGENCY, *supra* note 40, at 35–79 (describing smart growth mechanisms).

[337] *See supra* Part III.B.2. (discussing trading systems); *supra* note 290 and accompanying text (discussing transferable development rights).

[338] *See generally* ERIC FREYFOGLE, ON PRIVATE PROPERTY: FINDING COMMON GROUND ON THE OWNERSHIP OF LAND (2007) (arguing that because property derives its value from human communities, those communities should be able to use democratic processes to adjust property rights).

[339] It is very difficult to imagine, for example, that the venom currently directed at federal greenhouse gas regulation would disappear if those controls derived from the states.

[340] *See, e.g.*, Albert, *supra* note 184, at 36–39, 41–42 (describing the minimal influence of one alternative futures modeling project).

environmental regulation are necessary to protect spheres of state or local autonomy.

IV. SPATIAL ANALYSIS AND ENVIRONMENTAL LAW RESEARCH METHODOLOGIES

So far, this Article has focused on implications of spatial analysis for our understanding of environmental problems and for the design and implementation of legal solutions. Obviously that discussion should inform environmental law research, for the structure and application of environmental law are central research subjects for many academic inquiries. But the implications of spatial analysis extend beyond the subjects of environmental law research and also implicate its methodologies. This Part explores how. The discussion here is illustrative and preliminary, but even a few examples demonstrate how quantitative spatial analysis can change environmental law research. In turn, those research advances could facilitate improvements in the structure and application of environmental law.

For decades, assessing how environmental law changes real-world outcomes has often been difficult. Many environmental laws generate only partial implementation, and determining the extent of the gaps between the law on the books and the law in practice is not always easy.[341] Even if something approaching full compliance exists, the consequences of that compliance can be difficult to discern. Determining the environmental benefits of NEPA, for example, is complicated by the attenuated causal chain between required actions and actual environmental outcomes.[342] Environmental laws also often generate unintended consequences, and the nature and extent of those consequences is similarly difficult to predict.[343] For all of these reasons, debate is still robust about whether and how some of our most familiar environmental laws provide environmental protection.[344]

Spatial analysis gives environmental law researchers new tools to address these questions. For example, by comparing development patterns in areas subject to a particular law to development patterns in exempted areas, researchers can assess how that law actually affects outcomes.[345] Similarly, longitudinal studies,

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[341] *See* Farber, *supra* note 6, at 298–99 (describing the pervasiveness of such "slippage").

[342] *See* Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 350–51 (1989) (holding that NEPA is only procedural and establishes no substantive constraint). The lack of substantive standards complicates efforts to identify actions taken because of NEPA.

[343] *See, e.g.*, Lueck & Michael, *supra* note 27, 28–29 (concluding that ESA section 9 has generated counterproductive incentives).

[344] *See, e.g.*, Karkkainen, *supra* note 270, at 338 ("Observers hold divergent views on NEPA's effectiveness and its value as an environmental policy tool."); Owen, *supra* note 6, at 145–46 (summarizing debates about what one key ESA provision actually accomplishes).

[345] *See, e.g.*, Irwin et al., *supra* note 27, at 88–102 (evaluating regulatory controls in the Chesapeake Bay watershed).

which examine development patterns before and after the imposition of some environmental constraint, could help assess what on-the-ground impact laws actually have. Each type of study involves complications; most importantly, the complexity of human and environmental systems assures a potential overabundance of confounding variables. But with the increased availability of spatial data sets and the possibility of using linear regressions to minimize statistical noise, opportunities for new insight exist.

This sort of research is not exactly new. For decades, economists have been using both theoretical models and actual datasets to test the implications of environmental laws.[346] But such work rarely appears in legal journals, and even when it does, the authors usually are not lawyers.[347] That is a significant absence. While an economist's perspective has obvious value, there are ways in which lawyers could contribute to this sort of work. Environmental lawyers may not be trained in quantitative analysis or GIS, but they are taught to understand, at least at a qualitative level, how particular regulatory provisions fit within broader environmental law systems, how environmental law evolves and changes, what roles environmental law assigns to different actors, and how different institutions tend to respond to their roles. That legal perspective could help interdisciplinary research teams identify important research questions, develop hypotheses, flag potentially confounding variables, and interpret results.

The rise of environmental modeling creates similar opportunities for engagement. One primary goal of many environmental modelers is to understand and simulate the feedback loops between human and natural systems.[348] Those feedback loops are partly mediated by economics, for economic incentives play a significant role in determining human actions. Consequently, and not surprisingly, economists have engaged the process of modeling land use change.[349] But the relationships between human and environmental systems are also heavily mediated by law. Though they have rarely played this role, lawyers could offer important insights about how legal rules might generate environmental consequences and about how environmental change generates legal responses.[350] In some circumstances, that legal perspective should help modelers build better and more useful models. In others, environmental lawyers' insight may be that the dynamics are too complicated and unpredictable to model. But that also can be an important contribution, for it can send the modelers on to more useful endeavors.

These possibilities support a broader point about legal research. In recent years, legal research in many fields has moved toward greater reliance on quantitative analysis of empirical data and broader integration with other academic

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[346] *See supra* note 26 (citing studies).

[347] *See id.* (citing some exceptions).

[348] *See, e.g.*, ALBERTI, *supra* note 21, at 4.

[349] *See, e.g.*, Irwin & Geoghegan, *supra* note 248, at 8 (explaining economic land use change models).

[350] *See generally* LAZARUS, *supra* note 7 (exploring the dynamics that spurred the creation of American environmental law).

fields.[351] In some sense, a move toward quantitative spatial analysis would simply represent a continuation of that trend. But the shift has been gradual and sometimes controversial, with critics arguing, among other complaints, that both changes threaten to sidetrack legal research into a realm of impractical abstraction.[352] Clearly a movement toward quantitative spatial analysis could create that same threat, because sometimes models are so data intensive and complex that they are unworkable or so abstract that they are meaningless. But the present uses of spatial analysis suggest that here, at least, the critiques of quantitative and interdisciplinary legal research will often miss the mark. Helping federal, state, and local governments balance economics, environmental protection, and autonomy is a highly practical goal. If, in working toward that goal, legal researchers can help achieve a better understanding of some of the core challenges of environmental law, the effort will be well worthwhile.

CONCLUSION

Since the 1960s, when ecology emerged as a scientific discipline, law has never been the same.[353] The core concepts of ecology—its focus on interconnectedness, interdependence, and environmental fragility—energized an environmental movement and led to a generation of environmental laws.[354] Similarly, the emergences of law and economics, quantitative risk analysis, and complexity theory all have had profound implications for the practice and theory of environmental law.[355] Environmental law is inextricably, if sometimes

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[351] *See* Richard L. Revesz, *A Defense of Empirical Legal Scholarship*, 69 U. CHI. L. REV. 169, 188 (2002) (describing "what may be the most important intellectual development in legal scholarship in the last couple of decades: its gradual integration with other parts of the academy"); Gregory C. Sisk, *The Quantitative Moment and the Qualitative Opportunity: Legal Studies of Judicial Decision Making*, 93 CORNELL L. REV. 873, 874–75 (2008) (describing the recent increase in quantitative empirical scholarship).

[352] *See, e.g.*, Justice John G. Roberts, *Remarks at the Annual Fourth Circuit Court of Appeals Conference*, C-SPAN (June 25, 2011, 3:31 PM), http://www.c-span.org/Events/Annual-Fourth-Circuit-Court-of-Appeals-Conference/10737422476-1/ (arguing that legal scholarship is excessively interdisciplinary and esoteric); Karen Sloan, *Empiricism Divides the Academy: Upstart Number-Crunchers Attract Praise and Derision*, NAT'L L.J. & LEGAL TIMES, Feb. 28, 2011, at 1. Others argue that legal researchers are less rigorous in their methodologies than empiricists in other fields. *See, e.g.*, Lee Epstein & Gary King, *The Rules of Inference*, 69 U. CHI. L. REV. 1 (2002).

[353] *See* Angelo, *supra* note 195, at 1527 ("Environmental law was born out of the new scientific understandings of ecology in the mid-twentieth century.").

[354] *See* Tarlock, *supra* note 195, at 1121–22, 1125–28 (describing ecology's role in environmental law's formation).

[355] *See* Lynne E. Blais, *Beyond Cost/Benefit: The Maturation of Economic Analysis of the Law and Its Consequences for Environmental Policy*, 2000 U. ILL. L. REV. 237, 241 (2000); Hornstein, *supra* note 195, at 565–69 (describing the rise of risk analysis); J.B. Ruhl, *Complexity Theory as a Paradigm for the Dynamical Law-and-Society System:*

uncomfortably, intertwined with environmental science, and when environmental science evolves, legal thinkers usually ask whether law should evolve too.[356]

The emergence of quantitative spatial analysis has just begun to spur a similar reaction.[357] The products of spatial analysis often form the evidentiary basis for decisions required by environmental laws, and spatial analysts often work to fulfill environmental law's informational demands. But while environmental law has influenced spatial analysis, the feedback loop has not closed. Advances in spatial analysis have not led to any significant revisions to the structure, practice, or theory of environmental law. The time for greater engagement has come.

Wake-Up Call for Legal Reductionism and the Modern Administrative State, 45 DUKE L.J. 849 (1996).

[356] *See, e.g.*, Ruhl, *supra* note 355; Tarlock, *supra* note 195, at 1134–44 (considering potential reactions to the decline of ecology's equilibrium paradigm).

[357] *See, e.g.*, Boyd, *supra* note 26 (considering the implications of spatial data for global climate change policy and forest management).