# Environmental Infrastructure

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*This essay explores how my recent work on infrastructure and commons applies to environmental resources. Part I briefly describes the core idea, which is developed extensively elsewhere. Part II suggests how it might apply to the natural environment, touching on a number of interesting implications in need of further exploration. Specifically, Part II (a) frames the difficult environmental valuation and management problems; (b) applies the infrastructure criteria and delineates environmental infrastructure; (c) offers a few insights regarding environmental management and regulation; and (d) considers how infrastructure theory relates to the literatures on ecosystem services and multiple use management.*





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## INTRODUCTION

The Environment can be viewed as a natural infrastructure that supports life on Earth. When we think of "traditional" infrastructure, we typically think of large scale, physical resources or facilities made by humans for public consumption—for example, roads systems and telephone networks. These resources play an incredibly important role in society and generate substantial social value by serving as *shared means to many ends*: infrastructure resources enable, frame, and support a wide range of human activities and generally are accessible to all members of a community[1] who wish to use the resources on nondiscriminatory terms, though such use is not necessarily free. The natural environment plays a similar functional role to traditional infrastructure. It functions instrumentally as an essential input into a wide range of human and natural goods and services, including "agricultural output, human health, recreation, and more amorphous goods such as quality of life,"[2] as well as "purification of air and water, detoxification and decomposition of wastes, regulation of climate, regeneration of soil fertility, and production and maintenance of biodiversity."[3]

In previous work (and a book in progress),[4] I develop a theoretical account of infrastructure resources. The account is grounded in economics but differs from conventional economic analyses in that it focuses extensively on demand-side considerations and explores, from a functional perspective, how

1. For many infrastructure resources, the relevant community is the public at large.

2. Richard L. Revesz & Robert N. Stavins, *Environmental Law and Policy* 9 (Harvard Law Sch. Pub. Law & Legal Theory Working Paper Series, Working Paper No. 102, 2004), *available at* http://ssrn.com/abstract=552043. Revesz and Stavins observe that "[t]his effect is analogous to the manner in which real physical capital assets [such as traditional infrastructure] provide service flows used in manufacturing. As with real physical capital, a deterioration in the natural environment (as a productive asset) reduces the flow of services the environment is capable of providing." *Id.*

3. Gretchen C. Daily et al., *Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems*, ISSUES ECOLOGY, Spring 1997, at 2, *available at* http://www.epa.gov/watertrain/pdf/issue2.pdf; *see also* A. Myrick Freeman III, *Economic Valuation: What and Why*, *in* A PRIMER ON NONMARKET VALUATION 1, 3 (Patricia A. Champ et al. eds., 2003) ("Examples include nutrient recycling, organic material decomposition, soil fertility generation and renewal, crop and natural vegetation pollination, and biological control of agricultural pests.").

4. Brett M. Frischmann, *An Economic Theory of Infrastructure and Commons Management*, 89 MINN. L. REV. 917 (2005).

infrastructure resources generate value for society. Three key insights from this analysis are (1) that infrastructure resources generate value as inputs into a wide range of productive processes; (2) that these processes often generate positive externalities to the benefit of society as a whole; and (3) that managing such resources as a commons is often socially desirable because doing so supports these downstream activities.[5] In my other work, I explain in detail the merits of this approach and how the analysis maps across different disciplines and resource environments, including, for example, communications, cultural, and natural environments.

In applying this framework to the natural environment, it is clear that the environment is comprised of many interdependent environmental infrastructures, which act as essential inputs into a wide range of human and natural processes. Consider, for example, a lake. Like a road system, a lake is socially valuable primarily because it facilitates a wide variety of different uses (user activities) that produce social benefits, often in the form of positive externalities (benefits not taken fully into account by the users and beneficiaries). Think about the wide variety of uses of many lakes. They can be used for fishing, boating, swimming, and for other recreational activities. Further, lakes can be used as subject matter for artwork, for commerce, for transportation of goods, for waste processing, as a sink for pollution, or as a drinking water source, to name a few. These uses are in addition to the socially valuable role lakes play in supporting a complex ecosystem. Sustaining a commons to support these varied, heterogeneous uses may be desirable despite difficult management and institutional design issues.

Elaborating on these insights, this Essay is intended to provoke discussion and exploration of how infrastructure theory might apply to environmental resources. Accordingly, it raises more questions than it answers. Part I briefly describes the core idea, which is developed extensively elsewhere.[6] Part II suggests how it might apply to the natural environment, touching on a number of interesting implications in need of further exploration.

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5. The arguments for and against commons management are complex and not easily summarized in short form, but the basic idea is that managing certain infrastructure as a commons may eliminate the need to rely on either market actors or the government to "pick winners" among downstream uses or users. *See id.* at 937, 978, 988–89 & n.271, 1016.

6. For a short summary, see Brett M. Frischmann, *Infrastructure Commons in Economic Perspective*, FIRST MONDAY, June 4, 2007, http://firstmonday.org/issues/issue12_6/frischmann/index.html. For a more detailed discussion of the theory, see Frischmann, *supra* note 4. For specific applications, see, for example, Brett M. Frischmann, *Peer-to-Peer Technology as Infrastructure: An Economic Argument For Retaining Sony's Safe Harbor For Technologies Capable of Substantial Noninfringing Uses*, 52 J. COPYRIGHT SOC'Y 329 (2005) (copyright); Brett M. Frischmann & Mark A. Lemley, *Spillovers*, 107 COLUM. L. REV. 257 (2007) (intellectual property); Brett M. Frischmann & Barbara van Schewick, *Network Neutrality and The Economics of an Information Superhighway*, 47 JURIMETRICS 383 (2007) (network neutrality/communications); Brett M. Frischmann & Spencer W. Waller, *Revitalizing Essential Facilities*, 75 ANTITRUST L.J. 1 (2008) (antitrust).

## I. INFRASTRUCTURE THEORY

Infrastructure constitutes an important class of resources for which society values common public access.[7] Of course, not all infrastructure resources are or should be managed as commons; the economic arguments for managing infrastructure as commons vary in strength and substance based on the resource in question and the various human and natural systems it supports. Though a simplification, one can appreciate the issue by understanding that managing infrastructure as commons potentially gives rise to both social harm via the "tragedy of the commons" and social benefit via the "comedy of the commons," and thus the case for commons often depends upon the context.[8] Moreover, since complex "semicommons" regimes may support management strategies that aim to avoid tragedy and sustain comedy, it may be more helpful to identify functional relationships between infrastructure resources and management regimes.

This Part offers a brief introduction to my prior work on infrastructure. It is divided into three sections. Subpart A describes three criteria that delineate infrastructural resources; essentially, the criteria define a set a resources that I refer to as "infrastructure" because of the functional role the resources play and the manner in which the resources generate value. Subpart B explains how markets may fail in managing infrastructure resources. Subpart C explains why commons management may be attractive. The points made in these subparts are abbreviated and developed further in Part II (and in considerably more detail elsewhere).

### *A. Defining Infrastructure*

Infrastructure resources often satisfy the following criteria, each of which I explain briefly below:

(1) The resource may be consumed nonrivalrously;

(2) Social demand for the resource is driven primarily by downstream productive activities that require the resource as an input; and

(3) The resource is used as an input into the production of a wide range of goods and services, including private, public and/or nonmarket goods.

7. Why? There are a number of approaches one could take to answering the question. There are certainly strong distributional considerations. My approach has been to work within an economic framework with a deliberate focus on the demand side because I believe there is important work to be done there. That said, I think that there are strong complementary arguments not rooted in economics that further support a societal commitment to managing infrastructure as commons; I hope to explore these arguments in the future and certainly encourage others to do so as well.

8. *See* Garrett Hardin, *The Tragedy of the Commons*, 162 SCIENCE 1243 (1968); Carol Rose, *The Comedy of the Commons: Custom, Commerce, and Inherently Public Property*, 53 U. CHI. L. REV. 711 (1986). A myopic focus on the tragedy of the commons and the potential for negative externalities may ignore the comedy of the commons and the potential for positive externalities. *See* Frischmann, *supra* note 4.

The first criterion captures the consumption attribute of nonrivalrous and partially (non)rivalrous goods. In short, this characteristic describes the sharable, nondepletable nature of infrastructure resources. Infrastructures are sharable in the sense that the resources can be accessed and used concurrently by multiple users for multiple uses. They are nondepletable where consumption by one user does not reduce the quantity available for other users. The quintessential example of a nonrivalrous resource is an idea, which can be possessed, shared, and used widely without additional cost for additional users.[9] Put in economic terms, rivalrousness of consumption is a function of the marginal cost of allowing an additional person to consume a good. When this marginal cost is zero, consumption is nonrivalrous.

Resources do not necessarily have a single degree of rivalrousness. Instead, many infrastructure resources, *including most environmental infrastructure*, are partially (non)rival, which means that the degree and rate of rivalry may vary.[10] As I explained in earlier work:

> Whether these resources are consumed nonrivalrously or rivalrously often depends on other conditions, such as how the resource is managed, the number of users, and the available capacity. I refer to these resources as partially (non)rival goods because they can be managed in a way that avoids rivalrous consumption. To be clear, this concept focuses on how one user's consumption directly affects another user's, not on how production costs are distributed among users. Consider a resource with finite, sharable capacity, such as a lake or computer network. Up to a point, the marginal costs of allowing an additional user to access and use the resource are zero; beyond that point, the marginal costs become positive and increase with each additional user.[11]

This also means that, depending on how partially (non)rival resources are managed, the resources may in fact be subject to depletion. Critically, as discussed below, environmental infrastructure are not necessarily doomed to rivalrous consumption and depletion.[12]

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9. On the public good nature of ideas, see Frischmann & Lemley, *supra* note 6, and the many sources cited therein.

10. I discuss this in more detail in Parts II and III *infra*. For a more general discussion, see Frischmann, *supra* note 4, at 951–52. Some economists would argue that only ideas are nonrivalrously consumed and all other resources are rivalrously consumed. *See* Charles I. Jones, *Growth and Ideas*, *in* 1B HANDBOOK OF ECONOMIC GROWTH 1063 (Philippe Aghion & Steven N. Durlauf eds., 2005). Moreover, "I recognize that this terminology is a bit unusual in the sense that most economists would not characterize precongestion consumption as nonrivalrous. Instead, they would view consumption as depletion of the fixed capacity available and thus as rivalrous. As I see it, temporary depletion of renewable capacity that does not cause any congestion externalities is not strictly rivalrous." Frischmann, *supra* note 4, at 952. If one insists on calling such consumption rivalrous, we might label it "irrelevant rivalrousness." *Cf.* James M. Buchanan & William Craig Stubblebine, *Externality*, 29 ECONOMICA 371 (1962) (discussing irrelevant externalities).

11. Frischmann, *supra* note 4, at 951.

12. *See infra* text accompanying note 52 (contrasting rival natural resources like oil with partially (non)rival resources like the atmosphere).

The second and third criteria focus on the manner in which infrastructure resources create social value. The second criterion emphasizes that infrastructure resources are inputs that create social value when utilized productively (rather than passively consumed). The third criterion emphasizes both the variance of productive uses or downstream outputs (the genericness of the input) and the nature of those outputs (particularly, public goods and nonmarket goods). The reason for emphasizing variance and the production of public goods and nonmarket goods is that when these criteria are satisfied, the social value created by allowing additional users to access and use the resource may be substantial but extremely difficult to measure or capture in market transactions because of the prevalence of spillovers (positive externalities).[13]

Since introducing these criteria, I have found that people often focus on one or two and forget that all three work together to delineate a set of infrastructural resources. So let me briefly explain how they relate to each other because, in my view, all three are necessary. The first criterion isolates those resources that are potentially sharable at low (or at least manageable) marginal cost and the latter criteria further narrow the set to those resources that are more likely to give rise to an assortment of demand-side market failures associated with externalities, high transaction and information costs, and path dependency.[14]

### B. *Markets May Fail to Meet Societal Demand for Infrastructure*

Infrastructure market failures can be two-sided and dynamic when spillovers are prevalent.[15] On the supply side, private property owners are not necessarily optimal suppliers of infrastructure because they have an incentive to investigate and support only those uses that generate observable and appropriable private returns, which may or may not be the uses with the greatest social value. On the demand side, users are not necessarily optimal purchasers of access and use rights, because if they are productive users they do not themselves capture the full social value of their use. Their private willingness to pay reflects only the benefits that they expect to realize, not the spillovers realized by others. Accordingly, users' private willingness to pay understates the social value of their use.[16] Dynamically, this "demand manifestation" problem works its way upstream and biases allocation, design,

13. On spillovers, see Frischmann & Lemley, *supra* note 6.

14. For details, see Frischmann, *supra* note 4; *supra* note 6 and references therein.

15. I simply mean that failures arise on both the supply and demand sides of the infrastructure market. I am not referring to "two-sided" markets.

16. I generally refer to willingness to pay as the basic economic measure of an individual's preference and do not differentiate other measures, such as willingness to accept, except where relevant to the discussion. Note, however, that the basic demand-side problem of individuals not taking into account spillovers associated with their own productive use of an infrastructure resource also calls into question the accuracy of other measures.

investment, management, and other supply-side decisions.[17] To society's detriment, this can lead to the undersupply of essential infrastructure to various producers of public and nonmarket goods, and it can lead to an optimization/prioritization of access and use of the infrastructure for a narrower range of uses than would be socially optimal.[18] I addressed these issues in an earlier article with the following example:

> [I]magine that you owned one of the Great Lakes. Further, imagine the difficulty in managing access to the lake, even assuming the costs of exclusion are low. In terms of appropriating maximum benefits (so as to maximize your own welfare, a key reason for granting [you ownership]), it should not be surprising that it would be much easier and more profitable to deal with a smaller number of large-scale commercial users rather than a much larger number of small-scale commercial and noncommercial users.
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> Difficulties in appropriation may be a function of transaction costs associated with dealing with a wide variety of different types of users. Such costs may relate to information acquisition and exchange, negotiation and enforcement of commitments, demand-side coordination and collective action problems, and other related costs.
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> More importantly [for purposes of our illustration], appropriation difficulties may result because the downstream users themselves generate positive externalities that they do not internalize. [For examples and further discussion, see Part II below.] Difficulties in appropriation also may arise in situations where there are simply no human agents engaged in production downstream. For example, socially valuable outputs may be products of natural rather than human processes. As noted [and discussed below], many environmental resources, including lakes, support a wide range of socially valuable ecosystem services . . . . [T]he social benefits of such services are diffuse, indirect, and difficult to observe, much less appropriate.
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> [Markets] exhibit[] a bias for outputs that generate observable and appropriable benefits at the expense of outputs that generate positive externalities. . . . The problem . . . is that potential positive externalities may remain unrealized if they cannot be easily valued and appropriated by

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17. *See* Frischmann, *supra* note 4, at 988–89. In my other work, I develop a typology of infrastructure that distinguishes between commercial, public, and social infrastructure. See *id.* at 959–69.

18. One way to appreciate this concern is to consider how infrastructure may evolve over time. Infrastructure resources are, by my definition at least, general purpose resources. They may evolve over time to become special purpose and, again by my definition, cease to be infrastructure. Of course, in some cases, this may be desirable and in other cases not. I should also note that special purpose resources may become general purpose over time. *See* Frischmann & Waller, *supra* note 6 (discussing evolution in both directions); Peter Lee, *The Evolution of Intellectual Infrastructure*, 83 WASH. L. REV. (forthcoming 2008) (discussing examples of intellectual resources becoming infrastructure and intellectual property doctrines that deal with such evolution). For a discussion of different stages in infrastructure evolution, see Gregory Mandel, *When to Open Infrastructure Access*, 35 ECOLOGY L.Q. 204 (2008).

those that produce them, even though society as a whole may be better off if those potential externalities were actually produced.[19]

Though this lake example focused on the problems faced by a hypothetical infrastructure owner seeking to maximize his or her own welfare, the underlying information problems are quite similar to those faced by a manager of a public resource.[20] As discussed in detail below in the context of environmental infrastructure, it is often quite difficult, if not impossible, to identify, understand, and assess the value of various downstream uses of infrastructure resources and thus to make decisions about how the resources should be managed. This difficulty is a common theme that connects infrastructure theory with the ecosystems literature. Both approach questions of valuation and management with an eye on systems, processes, goods, and services that are often taken for granted in market and other decisionmaking frameworks.

### C. *Managing Infrastructure Resources as Commons*

To overcome these problems, society often manages infrastructure resources as commons, though not always and, as I will discuss below, in some cases not completely.[21] The case for commons management depends upon a variety of contextual factors, including the resource in question, the types of productive activities it potentially supports, and the degree of rivalry among different activities. Let me briefly explain what I mean by "commons management" and explain why managing infrastructure as a commons may alleviate some of these problems.

"Commons" refers to a resource management regime,[22] rather than a resource.[23] Specifically, it refers to a regime in which access to and use of a

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19. Frischmann, *supra* note 4, at 987–89 (internal citations omitted). There are additional dynamic complications and market biases. *See id.*

20. *Cf.* Thomas C. Brown & George L. Peterson, *Multiple Good Valuation*, *in* A PRIMER ON NONMARKET VALUATION, *supra* note 3, at 221–22 (noting the need to measure and compare the value of multiple downstream goods).

21. *See infra* notes 83, 84 and accompanying text (discussing semicommons arrangements).

22. Yochai Benkler, *The Political Economy of Commons*, UPGRADE, June 2003, at 6–7. As Benkler explains:

> Commons are a particular type of institutional arrangement for governing the use and disposition of resources. Their salient characteristic, which defines them in contradistinction to property, is that no single person has exclusive control over the use and disposition of any particular resource. Instead, resources governed by commons may be used or disposed of by anyone among some (more or less well defined) number of persons, under rules that may range from "anything goes" to quite crisply articulated formal rules that are effectively enforced.

*Id.* at 6.

23. This is why I often refer to "commons management." People sometimes consider "commons" to be resources; that conceptual move leads to both confusion with resources such as public goods, common pool resources, club goods, toll goods, and so on, and conflation among property/management regimes. Hess and Ostrom explain that "scholars learned that they had to make some key distinctions

resource is open to members of a community (the public at large for most infrastructure) regardless of their identity or intended use. Essentially, commons implement a nondiscrimination rule, at least with respect to community members. For commons where the relevant community is not the public at large, nondiscrimination may be the rule for community members but discrimination (exclusion) is the rule for nonmembers.

There are many ways in which a resource can be managed as a commons.[24] Commons can be implemented through a variety of different institutions, including property rights, regulation, or some hybrid regime, depending on the context.[25] In evaluating the case for commons management, I abstract from the institutional *form* (property rights, regulations, norms, etc.) to

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between concepts that had previously and casually been treated as the same." Charlotte Hess & Elinor Ostrom, *Ideas, Artifacts, and Facilities: Information as a Common-Pool Resource*, 66 LAW & CONTEMP. PROBS. 111, 118–21 (2003). According to Hess and Ostrom:

> [F]our basic confusions . . . need to be untangled. The source of confusion relates to the differences between (1) the nature of the good (common-pool resources) and a property regime (common property regimes), (2) resource systems and the flow of resource units, (3) common property and open-access regimes, and (4) the set of property rights involved in "ownership." All four sources of confusion reduce clarity in assigning meaning to terms and retard theoretical and empirical progress.

*Id.* at 118–19. Hess and Ostrom then untangle these issues. *See id.* As explained below, however, I abstract somewhat from the property-focused analysis reflected in (1), (3), and (4).

24. Related, there are many ways in which a resource can come to be managed as a commons. A resource may be open for common use naturally. The resource may be available to all naturally because its characteristics prevent it from being owned or controlled by anyone. *See* Carol Rose, *Romans, Roads, and Romantic Creators: Traditions of Public Property in the Information Age*, 66 LAW & CONTEMP. PROBS. 89, 93 (2003) (discussing the traditional Roman categories of nonexclusive property, one of which, *res communes*, was incapable of exclusive appropriation due to its inherent character). For example, for most of the earth's history, the oceans and the atmosphere were natural commons because exercising dominion over such resources was beyond the ability of human beings or simply unnecessary because there was no indication of scarcity. *Id.* ("The usual Roman law examples of *res communes* resources were the oceans and the air mantle, since they were impossible for anyone to own."). A resource also may be open for common use as the result of social construction. That is, laws or rules may prohibit ownership or ensure open access for community members, or a commons regime may arise through norms and customs among owners and users. For example, Paul David and Dominique Foray note that the "activity of diffusing economically relevant knowledge is not itself a natural one." Paul A. David & Dominique Foray, *Information Distribution and the Growth of Economically Valuable Knowledge: A Rationale for Technological Infrastructure Policies*, *in* TECHNOLOGICAL INFRASTRUCTURE POLICY: AN INTERNATIONAL PERSPECTIVE 91 (Morris Teubal et al. eds., 1996). "Rather, it is socially constructed through the creation of appropriate institutions and conventions, such as open science and intellectual property . . . ." *Id.*; *see also id.* at 93–99 (discussing the distribution of scientific and technological knowledge through institutions). The open source and creative commons movements are two prominent examples. *See* LAWRENCE LESSIG, THE FUTURE OF IDEAS: THE FATE OF THE COMMONS IN A CONNECTED WORLD 164–65, 255–56 (2001); *see also* Frischmann & Lemley, *supra* note 6; J.H. Reichman & Paul F. Uhlir, *A Contractually Reconstructed Research Commons for Scientific Data in a Highly Protectionist Intellectual Property Environment*, 66 LAW & CONTEMP. PROBS. 315, 430–32 (2003).

25. *See* Frischmann, *supra* note 4, at 934–35. For examples of different institutional approaches, see Frischmann & Lemley, *supra* note 6 (intellectual property regimes that mix private property rights with commons); Frischmann & van Schewick, *supra* note 6; Frischmann & Waller, *supra* note 6 (ex post remedy in antitrust suit).

focus on a particular institutional *function* (nondiscriminatory access for the relevant community). Tying form and function together obscures the fact that access can be provided for or restricted by a variety of institutional forms, which are often mixed (property and regulation, private and communal property, etc.), and not necessarily through one particular form. In other work, I demonstrate that environmental, information, and Internet commons are sustained through very different sets of institutional arrangements. In Part II.C below, I briefly touch on this point and tentatively explore the concept of regulatory semicommons.

The general values of commons management are that it maintains openness, does not discriminate among users or uses of the resource, and eliminates the need to obtain approval or a license to use the resource. Generally, managing infrastructure resources as a commons alleviates the need to rely on infrastructure managers (whether private owners or public officials) to make decisions about the types of users or uses (or downstream markets) that are worthy of priority. As noted in the previous section, demand manifestation problems may distort market allocation, as well as government management, of infrastructure access and use to society's detriment.

As mentioned above, the demand manifestation and valuation problem may be at its worst when infrastructures are used to produce public and nonmarket goods that yield social benefits not easily accounted for in economic decisionmaking. Still, pointing out the existence of spillovers from the production of public and nonmarket goods is not in itself sufficient to explain the role of commons management. To the extent that such goods are undersupplied to society, there is a much simpler solution: the government may direct subsidies to public and nonmarket goods producers. Why manage the infrastructure upon which those producers depend as a commons? The short answer is that managing infrastructure as a commons kills two birds with one stone:

> Economists recognize that there is a case for subsidizing public and nonmarket goods producers because such goods are undersupplied by the market. The effectiveness of directly subsidizing such producers will vary, however, based on the capacity for subsidy mechanisms to identify and direct funds to worthy recipients. In some cases, open access to the infrastructure may be a more effective—albeit blunt—means for supporting such activities than targeted subsidies. Open access is not necessarily a subsidy, but it eliminates the need to rely on either the market or the government to "pick winners" or uses worthy of access. On one hand, the market picks winners according to the amount of appropriable value generated by outputs and consequently output producers' willingness to pay for access to the infrastructure. On the other hand, to subsidize production of public goods or nonmarket goods downstream, the government needs to pick winners by assessing social demand for such goods based on the social value they create. . . . [T]he inefficiencies, information problems, and transaction costs associated with picking

> winners under either system may justify managing . . . infrastructure resources [as a commons].[26]

II. ENVIRONMENTAL INFRASTRUCTURE

Infrastructure theory provides a framework for understanding how to value, and for evaluating how to manage, certain resources.[27] Focusing attention on those foundational environmental resources that serve as essential infrastructure highlights the complexity and fragility of our relationship to the environment and at the same time aims to take a crucial step forward in understanding the dynamic nature of that relationship.[28] Like many infrastructure resources, environmental infrastructure resources generate value for society by supporting many different types of value-creating activities. The resources play a fundamental role in both complex natural systems (ecosystems) and complex human systems (cultural, economic, and social systems).[29] This characteristic makes valuation and management incredibly difficult.[30] Accurate valuation and management thus requires appreciation of

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26. Frischmann, *supra* note 4, at 978.

27. The theory may be useful for articulating and evaluating management strategies and engaging in comparative institutional analysis. In particular, the theory suggests the need to evaluate the case for constructing sustainable semicommons–complex institutional arrangements that sustain commons for certain groups of uses/users while regulating access and use of the infrastructural resource for other groups of uses/users. I briefly touch on these ideas below but cannot fully explore them in this Essay.

28. On an economic dynamic approach to understanding this relationship, see DAVID M. DRIESEN, THE ECONOMIC DYNAMICS OF ENVIRONMENTAL LAW (2003); David M. Driesen, *An Economic Dynamic Approach to the Infrastructure Commons*, 35 ECOLOGY L.Q. 215 (2008).

29. *See generally* Frischmann, *supra* note 4. Environmental infrastructures, such as lakes, are foundational resources for many different overlapping human systems—cultural, economic, social. This is true for many infrastructure resources. The overlapping, complex interdependencies among different types of infrastructure resources and different types of social and natural systems is an issue I touch on in *An Economic Theory of Infrastructure* and hope to pursue further in future research. This is a topic of significant importance and is only beginning to receive the attention it deserves. *See* Steven Shermer, *The Drinking Water Security and Safety Amendments of 2002: Is America's Drinking Water Infrastructure Safer Four Years Later?*, 24 UCLA J. ENVTL. L. & POL'Y 335, 379 (2006). The topic is beyond the scope of this Essay, however.

30. These resources, and the ecosystems that they support, are capital assets, which economists often refer to as natural capital. *See, e.g.*, Robert Costanza et al., *The Value of the World's Ecosystem Services*, 387 NATURE 253 (1997); Geoffrey Heal et al., *Protecting Natural Capital through Ecosystem Service Districts*, 20 STAN. ENVTL. L.J. 333 (2001); Revesz & Stavins, *supra* note 2, at 9; R. Kerry Turner et al., *Valuing Nature: Lessons Learned and Future Research Directions*, 46 ECOLOGICAL ECON. 493, 495 (2003). Costanza et al. estimate the value of the globe's ecosystem services to be in the range of US$16–54 trillion per year, an average of US$33 trillion per year; this significantly exceeds the global GNP of about US$18 trillion. *See* Constanza et al., *supra*. These estimates have been critiqued. *See* David Pearce, *Auditing the Earth*, ENVIRONMENT, March 1998, at 23.

Valuing ecosystems has garnered significant attention over the past decade. *See, e.g.*, sources cited *supra*; NAT'L RESEARCH COUNCIL, COMM. ON ASSESSING & VALUING THE SERVICES OF AQUATIC & RELATED TERRESTRIAL ECOSYSTEMS, VALUING ECOSYSTEM SERVICES: TOWARD BETTER ENVIRONMENTAL DECISION-MAKING (2005); Thomas C. Brown et al., *Defining, Valuing and Providing Ecosystem Goods and Services*, 47 NAT. RESOURCES J. 329 (2007); Geoffrey M. Heal & Edward B. Barbier, *Valuing Ecosystem Services*, ECONOMISTS' VOICE, Feb. 2006, *available at* http://www.bepress.com/cgi/viewcontent.cgi?article=1118&context=ev; *see also* James Boyd & Spencer the full range of different activities, uses, and processes that generate value.[31] It also requires consideration of a host of other complexities, including long-term implications, such as effects on future generations and risks of path dependency—for example, where marginal changes increase the likelihood of similar incremental changes that have cumulative, sometimes nonlinear, effects.

This Part begins to explore how infrastructure theory can be applied to environmental resources. It is organized into four sections. Subpart A frames the difficult valuation and management problems. Subpart B applies the infrastructure criteria and delineates environmental infrastructure. Subpart C offers a few insights regarding environmental management and regulation. Subpart D considers how infrastructure theory relates to the literatures on ecosystem services and multiple-use management.[32]

### *A. Valuing and Managing the Environmental Resources*

Valuing and managing environmental resources is extremely difficult. We tend to take for granted the environment within which we live; our own preferences and values fail to appreciate the complex interdependencies between ourselves, our environment, and others. Consequently, our decisions about how to manage our own interactions with the environment are not likely to be social welfare maximizing.[33] It persistently contributes to our well-being, but most often it does so only indirectly.[34] We rarely pay directly for its benefits, and so when it comes down to individual preferences or valuation—

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Banzhaf, *What are Ecosystem Services? The Need for Standardized Environmental Accounting Units*, 63 ECOLOGICAL ECON. 2 (2007) (arguing for "consistently defined units of account to measure the contributions of nature to human welfare" with the goal of "comparability with the definition of conventional goods and services found in GDP and the other national accounts"); Brown et al., *supra*, at 350 ("Based on a review of the literature, de Groot et al. tabulated the methods that have been used to value different ecosystem goods and services. The overall impression from their survey is that the production function approach has typically been used to value ecosystem goods and the replacement cost method has typically been used to value ecosystem services. The nonmarket approaches, about which so much has been written, have typically found application for just a few of the ecosystem goods and services.").

31. A recent survey of ecosystem valuation studies concluded that most studies valued a single ecosystem function and failed to adopt a multifunction (or multiple-use) perspective. Valuing multiple uses is at the forefront within the ecosystem literature and multiple-use common pool resource literature. *See* Turner et al., *supra* note 30, at 493–510.

32. To forecast a bit for readers familiar with those literatures, I tentatively conclude that infrastructure theory fits neatly within those literatures, i.e., does not represent a significant departure, and also connects those literatures with valuation and management questions faced by other infrastructure resources. These may be issues worth exploring in more detail in the future.

33. *See, e.g.*, Gretchen C. Daily et al., *Value of Nature and the Nature of Value*, 289 SCIENCE 395, 395 (2000) (discussing the difficulties of valuing ecosystem assets and noting that "[o]ften, the importance of ecosystem services is widely appreciated only upon their loss.").

34. For an interesting framework that links ecosystem services and human well-being along many important dimensions, see MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: SYNTHESIS vi, fig.A (2005), *available at* http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

for example, preferences measured in terms of willingness to pay or revealed through our actions—it should not be surprising that we persistently undervalue the environment, in terms of its contributions to our own well-being (and putting aside notions of intrinsic value).[35]

One reason we undervalue the environment is that it is hard to understand; it is complex and involves many different sets of interdependent resource systems. Until recently (i.e., the past half-century), we haven't had to pay much attention or seek to better understand our interactions and interdependencies with the environment. But that has changed; we no longer have the luxury of abundance or ignorance. Environmental problems that have arisen with industrialization and population expansion, and increased use of the environment for recreational purposes, have drawn public attention to the environment.

Environmental science has vastly improved in the past century (as it must continue to do), and to some degree, this has improved our appreciation of environmental systems. However, environmental science is not enough to solve environmental valuation and management problems. While improvements in science improve our capability to understand and value the environment, science can only get us so far given the complexities involved.

Ordinary individuals frequently fail to appreciate environmental resources. One reason is that many individuals do not understand environmental science, as demonstrated by pervasive misunderstanding of various environmental risks, such as climate change.[36] This poses a significant problem for economic valuation based on individual preferences. It is hard to value what one fails to understand.[37] Another reason individuals fail to appreciate the environment is its relative obscurity and our dependence on it. Like many infrastructure resources, it remains in the background, taken for granted, and thus

35. Intrinsic or existence values only exacerbate undervaluation of the environment. Incorporating them into the analysis might be an interesting avenue to pursue in the future.

36. *See, e.g.*, Cornelia Dean, *Where Science and Public Policy Intersect, Researchers Offer a Short Lesson on Basics*, N.Y. TIMES, Jan. 31, 2006, at F3 (reporting that few members of Congress have a background in science and many congressional members lack even a basic understanding of scientific principals); Adil Najam, *Climate Change Conversation*, BOSTON GLOBE, June 8, 2007, at A15 (discussing U.S. resistance to recognition of climate change and stating that "[m]ost people were already convinced that something was happening to the global climate, but they assumed that any change was in the very distant future."); Sam Dillon, *Test Shows Drop in Science Achievement for 12th Graders*, N.Y. TIMES, May 25, 2006, at A20 (reporting a decline in basic science knowledge and a general lack of interest in science).

37. *See, e.g.*, Heal et al., *Protecting Natural Capital through Ecosystem Service Districts*, *supra* note 30 (ecosystems are under threat because they are unrecognized and even when recognized, easily ignored or forgotten); James Salzman, *A Field of Green? The Past and Future of Ecosystem Services*, 21 J. LAND USE & ENVTL. L. 133, 134 (2006) (discussing ignorance of ecosystem services); James Salzman, Barton H. Thompson, Jr., & Gretchen C. Daily, *Protecting Ecosystem Services: Science, Economics, and Law*, 20 STAN. ENVTL. L.J. 309, 311 (2001) (discussing "[o]ur unthinking reliance on ecosystem services").

insufficiently reflected in existing preferences.[38] It seems reasonable to argue that we, as individuals and as a society, haven't really learned to appreciate the environment yet. Most people lack both the information and *experience* necessary to make accurate assessments or judgments concerning the value of the environment (again, in terms of its contributions to our welfare). I emphasize experience to suggest that context and cultural factors affect our capacity to judge value, especially but not only where complexity and uncertainty make such judgments difficult.[39] Information may reduce uncertainty and bring complex phenomena within reach of human understanding, but knowledge and the related capacity to judge require experience. As I discuss below, participation in recreational activities may provide the information, context, and experience needed to shape preferences and enable improved valuation of the environment.[40] That is, learning to appreciate what one takes for granted is an exercise that shapes preferences, and it may very well be the case that collectively, society would make better decisions and be better off over the long run if such shaping took place.

Despite such problems, most economic approaches to valuing environmental resources and weighing different management options rely on aggregated individual preferences.[41] Economists use a range of sophisticated methods, such as stated preference methods and revealed preference methods, which have advanced significantly in the past few decades, to approximate preferences.[42] Although used in many policy and resource management settings,[43] however, it is important to make clear that these methods are, *at best*, useful but incomplete proxies for measuring the social value of environmental resources.[44] Even if economists could accurately measure

38. J.B. Ruhl & James Salzman make this point quite succinctly in a recent article. *See* J.B. Ruhl & James Salzman, *The Law and Policy Beginnings of Ecosystem Services*, 22 J. LAND USE & ENVTL. L. 157, 157 (2007).

39. *See, e.g.*, Daily et al., *supra* note 33, at 396 (noting "serious pitfalls" in relying on "individual preferences to construct social values" and "[p]references depend upon institutional context").

40. *Cf.* Pete Morton, *The Economic Benefits of Wilderness: Theory and Practice*, 76 DENV. U. L. REV. 465, 473–78, 481–82, 483 (1999) (noting comparable dynamics with respect to wilderness recreation).

41. The two principal types of valuation methods that do not rely on individual preferences are production function methods and replacement cost methods. On the various methods, see NAT'L RESEARCH COUNCIL, *supra* note 30, at 95–152 (2005); J.B. RUHL ET AL., THE LAW AND POLICY OF ECOSYSTEM SERVICES 70–71 (2007).

42. *See, e.g.*, A PRIMER ON NONMARKET VALUATION, *supra* note 3. Stated preference methods, such as contingent valuation, rely on statements made by individuals in response to questions about various hypothetical scenarios. *Id.* at 21, chs. 4–7. Revealed preference methods rely on observations of how people act in actual scenarios. *Id.* at 21, chs. 8–11. *See also* Revesz & Stavins, *supra* note 2, at 12–20 (providing an accessible account of these and other methods).

43. *See* Daniel W. McCollum, *Nonmarket Valuation in Action*, *in* A PRIMER ON NONMARKET VALUATION, *supra* note 3, at 483.

44. *See* Richard C. Bishop, *Where to from Here?*, *in* A PRIMER ON NONMARKET VALUATION, *supra* note 3, at 537, 539 ("true economic values are unobservable"); Revesz & Stavins, *supra* note 2, at 12 (These and other related methods attempt to "infer [individuals'] willingness to trade off other goods (or monetary amounts) for environmental services."); *see also id.* at 9 ("[T]he benefits of environmental

everyone's current preferences, the resulting valuation would nonetheless be skewed in a manner that undervalued the environment's "true" contribution to human well-being.[45]

Economists value environmental resources "at the margin," meaning that they aim to estimate marginal values based on incremental changes in the amount or quality of the resource. Such valuation may be based on the expected incremental effects from proposed public policy options.[46] Economists generally do not attempt to identify the absolute value of environmental resources, although some have tried to do so with macroeconomic approaches.[47] The marginal or incremental approach to valuation makes (some) sense because valuation is used to evaluate discrete tradeoffs that are inevitable in resource management or policy making.[48] As James Salzman notes, "[t]he tough decisions revolve not around whether protecting ecosystems is a good thing but, rather, how much we should protect and at what cost."[49] Despite the

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policy are defined as the collection of individuals' willingness to pay (WTP) for the reduction or prevention of environmental damages or individuals' willingness to accept (WTA) compensation to tolerate such environmental damages."); James Salzman & J.B. Ruhl, *Currencies and the Commodification of Environmental Law*, 53 STAN. L. REV. 607, 623 (2000) ("environmental law relies almost entirely on proxy measures").

45. *See* Frischmann, *supra* note 4, at 967–69, 973–74, 975–78, 983–84, 987–88 (explaining that much of the value is due to public and nonmarket goods and services that are underappreciated and insufficiently reflected in existing preferences). *See generally* Morton, *supra* note 40.

46. *See, e.g.*, Freeman, *supra* note 3, at 3; James Salzman, *Valuing Ecosystem Services*, 24 ECOLOGY L.Q. 887 (1997); Turner et al., *supra* note 30, at 493–510; *see also* DRIESEN, *supra* note 28, at 17 (discussing cost-benefit analysis of environmental regulation and how it is framed by allocative efficiency concerns).

47. *See* Costanza et al., *supra* note 30; Pearce, *supra* note 30. In his reply to Pearce, Costanza et al. explained that their estimate of the value of earth's ecosystems at a global scale employed macroeconomics and necessarily differed from more traditional microeconomic approaches. Costanza et al., *supra* note 30; *see also* Paul C. Sutton & Robert Costanza, *Global Estimates of Market and Nonmarket Values Derived from Nighttime Satellite Imagery, Land Cover, and Ecosystem Services Valuation*, 41 ECOLOGICAL ECON. 509 (2002) (looking at special patterns of conventional GDP and also at the value of nonmarketed ecosystem services that are not currently included in the GDP). There is a substantial literature debating the merits of environmental valuation methods. *See, e.g.*, Jason Scott Johnson, *Desperately Seeking Numbers: Global Warming, Species Loss, and the Use and Abuse of Quantification in Climate Change Policy Analysis*, 155 U. PA. L. REV. 1901 (2007); Richard S. J. Tol, *Why Worry About Climate Change? A Research Agenda* (FEEM Working Paper No. 136.06, Nov. 2006), *available at* http://ssrn.com/abstract=945044. Some scholars have advanced alternative approaches. *See, e.g.*, DRIESEN, *supra* note 28; Katherine Farrell, *Living with Living Systems: The Co-Evolution of Values and Valuation*, 14 INT'L J. SUSTAINABLE DEV. & WORLD ECOLOGY 14, 14 (discussing a new "co-evolutionary" approach to economic valuation of ecosystems and arguing that "monetary unit-based environmental valuation methods are counter-productive").

48. *See, e.g.*, Freeman, *supra* note 3, at 3; Turner et al., *supra* note 30. *But see* Josh Eagle, *Regional Ocean Governance: The Perils of Multiple-Use Management and the Promise of Agency Diversity*, 16 DUKE ENVTL. L. & POL'Y F. 143 (2006) (arguing that "the poor condition of the marine environment is in part a product of the multiple-use mandate under which agencies currently operate").

49. Salzman, *supra* note 46. Similarly, Revesz and Stavins note:

> Protecting the environment usually involves active employment of capital, labor, and other scarce resources. Using these resources to protect the environment means they are not available to be used for other purposes. Hence, the economic concept of the value or benefit of environmental goods and services is couched in terms of society's willingness to make

inevitable tradeoffs and consequent need for marginal valuation, we should not pretend that such proxies accurately capture the full social value humans derive from environmental resources.

### *B. Delineating Environmental Infrastructure*

Applying infrastructure theory to environmental resources delineates a class of environmental resources that create benefits for society primarily through the facilitation of a wide range of uses (user activities and natural processes), many of which generate positive externalities. Oceans and lakes, forests, and the atmosphere are a few examples of environmental infrastructure.[50] These resources play a foundational role in cumulative, dynamic, and complex systems—both natural and human systems—that remains underappreciated and understudied.[51]

Each of the above resources satisfies the first infrastructure criterion, in that each is at least partially (non)rivalrously consumed when used. Recall that the first infrastructure criterion focuses attention on the "sharability" of the resource and degree of rivalry among users and uses. Environmental infrastructures, in contrast with intellectual resources like ideas, are not purely nonrivalrous. That is, for most environmental infrastructures, at some point(s), consumption of the resource by one user will impose costs on other users and potentially diminish the resource's capacity to support other users.[52] At the same time, in contrast with some nonrenewable natural resources such as oil, environmental infrastructures generally are not purely rivalrous in consumption, such that consumption by one user necessarily diminishes the capacity of the resource to support other users. Environmental infrastructures are partially (non)rival, meaning that the resources have finite, *potentially*

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> trade-offs between competing uses of limited resources, and in terms of aggregating over individuals' willingness to make these trade-offs.

Revesz & Stavins, *supra* note 2, at 9.

50. Pete Morton described "wildland ecosystems" in infrastructural terms:

> Wildland ecosystems represent natural capital capable of producing a wide range of goods and services for society. Some of these outputs, such as timber, are freely exchanged in formal markets. Value is determined in these markets through exchange and quantified in terms of price. However, many other outputs, watershed protection, carbon storage, scenic beauty, trophy caliber wildlife, and native fish for example, contribute to our quality of life, but are without formal markets and therefore without prices. Although highly valued by society, the benefits of nonmarket goods and services are typically underestimated in production and consumption decisions—i.e., underproduced by private markets.

Morton, *supra* note 40 (internal citations omitted).

51. As J.B. Ruhl describes, various disciplines study these systems and are developing improved interdisciplinary approaches to understanding the complex, dynamic relationships among these systems. *See* RUHL ET AL., *supra* note 41.

52. *Id.* at 64–65 (describing risk of congestion); *id.* at 52 (describing a "threshold of irreversibility" and noting that "once thresholds are crossed, it can take enormous spans of time to rebuild natural capital through ecological processes").

renewable, and *potentially* sharable capacity.[53] Critically, for many environmental infrastructures, the degree and rate of rivalry varies across uses and across time. The possibility of avoiding (or minimizing) congestion and resource depletion "while still allowing multiple users (uses) is what makes the resource partially (non)rivalrous."[54] The degree of rivalry can be thought of in terms of the degree of scarcity or even joint costs. Where an environmental resource is consumed nonrivalrously—for example, when someone appreciates a scenic view—there is no scarcity or cost involved; however, where it is consumed rivalrously—for example, when pollution precludes swimming (or vice versa)—scarcity arises and opportunity costs must be weighed. Resource management generally entails managing tradeoffs among potentially competing rival uses. To manage rivalry and begin to evaluate such tradeoffs, managers need information about what parameters drive rivalry among specific uses—for example, which water quality characteristics, such as heat, salinity, and concentration of various chemicals, give rise to costs for joint use—and whether impacts on the resource (or resource characteristics) are reversible.[55]

Concerns about renewal rates, reversibility, and sustainability, which are prevalent in environmental scholarship but largely absent from the other literatures upon which I draw, highlight another important dimension along which the degree and rate of rivalry may vary: time. That is, we can frame the

53. Realizing these *potentials* requires management. Unfortunately, there is substantial evidence of unsustainable degradation of many environmental resources that amounts to a "persistent decrease in the capacity" of ecosystems to deliver services. *See* MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 34, at 1–2, 39–48. "Human use of all ecosystem services is growing rapidly. Approximately 60% (15 out of 24) of the ecosystem services evaluated in this assessment (including 70% of regulating and cultural services) are being degraded or used unsustainably." *Id.* at 39.

54. Frischmann, *supra* note 4, at 952.

55. Erik Bluemel raises an interesting issue concerning congestion and nonlinearity of externalities: "Take, for example, driving and CO2 emissions. Existing scientific literature suggests that once a certain threshold level of CO2 is emitted into the atmosphere, warming will be non-linear, self-perpetuating, and unstoppable, even if day-to-day traffic congestion is eliminated. The use of the infrastructure resource itself might not be rivalrous, but the externalities can create potentially rivalrous outcomes." E-mail from Erik Bluemel, Assistant Professor of Law, Univ. of Denver Sturm Coll. of Law (Dec. 29, 2007) (on file with author); *see also* MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 34, at 1 ("[T]here is *established but incomplete* evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes in ecosystems (including accelerating, abrupt, and potentially irreversible changes) that have important consequences for human well-being. Examples of such changes include disease emergence, abrupt alterations in water quality, the creation of "dead zones" in coastal waters, the collapse of fisheries, and shifts in regional climate."). On "accounting for cumulative impacts across nonlinear scale domains" in spatial and temporal models, see RUHL ET AL., *supra* note 41, at 53–56. For a discussion of how the nonlinearity of externalities may depend upon different forms of spatial and temporal differentiation among environmental degradations, see Jonathan Remy Nash, *Trading Species: A New Direction for Habitat Trading Programs*, 32 COLUM. J. ENVTL. L. 1, 13–19 (2007). For a discussion of how nonlinearities may call for spreading a pollutant around or trying to isolate it in relatively few locations, 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, 577–80 (2001).

valuation and management problems in a manner that takes into account the degree and rate of rivalry among users and uses across time (generations).[56]

The partially (non)rival nature of environmental infrastructure is only part of the puzzle, in a sense, highlighting the relative costs of supplying infrastructure to different profiles of users. The second and third infrastructure criteria focus attention on the manner in which environmental infrastructure generate value for society, and, in particular, on the diversity and nature of outputs (private, public, and nonmarket goods).[57] The social value of environmental infrastructure ultimately derives from infrastructure-dependent human and natural systems that directly and indirectly contribute to human well-being in a wide variety of different ways.[58] In the remainder of this section, I briefly explore categories of uses to show how the second and third infrastructure criteria apply. I then explore the concept of a "nonhuman" user.

An advantage of the infrastructure lens is that it differentiates the infrastructural asset from the users that depend upon the asset as well as the outputs those users produce. In his book, *The Measurement of Environmental and Resource Values: Theory and Methods*,[59] A. Myrick Freeman III explains that environmental and resource "service flows" may be classified according to the "economic channel through which human well-being is affected" (market system or nonmarket system) and whether the flow affects humans directly, indirectly through impacts on other living organisms, or indirectly through impacts on inanimate systems. This is a helpful way to differentiate among infrastructure uses and resulting service flows (outputs):[60] we can adapt the classification to differentiate between market, direct nonmarket, and indirect nonmarket uses. This classification system remains incomplete, however, because it focuses mainly on the means of supplying services without paying

56. Though important and quite interesting, exploring intergenerational issues is beyond the scope of this Essay. *See infra* note 79.

57. Although infrastructure theory focuses on "productive activities" engaged in by "users" to generate "outputs"—terminology not ordinarily found in environmental scholarship—the functional structure of the theory maps quite well to environmental scholarship.

58. Some partially nonrival environmental assets are special purpose or only support a narrow range of uses, and thus would not constitute infrastructure within the meaning of this theory. For example, a fishery would not in itself constitute infrastructure. Even though it is sharable (partially nonrival), it is primarily used commercially for harvesting fish, naturally as part of an ecosystem, and perhaps noncommercially for recreational fishing. While important and worthy of attention, the fishery does not support a wide range of different activities and thus would not be infrastructural. The same probably could be said for (many) individual species. Both fisheries and individual species, however, may be important components of a networked infrastructure (biodiversity; ecosystem). It should be clear that, on one hand, environmental infrastructures are a subset of environmental resources, and yet on the other, environmental resources outside of the infrastructure subset may combine with others to constitute infrastructure.

59. A. MYRICK FREEMAN III, THE MEASUREMENT OF ENVIRONMENTAL AND RESOURCE VALUES: THEORY AND METHODS 12–13 (2d ed. 2003).

60. I acknowledge that I am conflating distinctions between products and processes, goods and services, things and flows, and so on.

sufficient attention to the nature of the service (output) that ultimately provides value to humans.[61]

We can bring Freeman's classification together with infrastructure theory by differentiating among uses based on (1) whether they are consumptive or productive, and (2) whether the outputs (goods or services) produced can be expected to yield positive or negative externalities (due to the character of the output or its joint products).[62] Just as the degree and rate of rivalry varies across uses, so does the degree and rate of positive and negative externalities. It is worth noting that some externalities are due to interdependencies among infrastructure users (intra-use) or different user groups (inter-use) and other externalities are due to interdependencies between an infrastructure user and nonuser, such that the external benefit (cost) is unrelated to use of the infrastructure by the beneficiary.[63] Finally, and related to the last point, it is also necessary to consider the degree to which streams of external benefits and costs associated with user activities are (un)known, (un)observable, or (un)foreseeable and whether the activities have any feedback effects on the system.

*a) Market Uses: Source and Sink for Commercial Users; Transport*

Environmental infrastructures support a variety of commercial activities. For example, users extract food, fuel-wood, fiber, biochemicals, genetic resources, fresh water, and other resources; release waste products for dilution and assimilation; and use environmental infrastructure as transportation infrastructure. The goods and services derived from these activities are bought and sold in markets and the benefits derived from them are largely captured in market transactions. In other words, the degree and rate of positive externalities may be insignificant. Many joint products (or byproducts) of these activities can produce negative externalities due to rivalry with other uses of the environmental infrastructure (e.g., resource extraction may displace or lessen the attractiveness of various recreational opportunities), collateral effects on

61. I do not mean to critique this approach because it is influenced by the economists' focus on valuation methods that rely one way or another on individual preferences (whether directly or indirectly impacted). *See* FREEMAN, *supra* note 59, at 12–13. Freeman explains that there are many different ways to classify environmental and resource flows. *See id.*

62. I have also differentiated outputs as private, public, and nonmarket goods, and also at times, as network goods.

63. Negative externalities are often congestion-related. That is, a polluter may fail to account for the costs imposed on swimmers or fishers; this is an inter-use negative externality derived from competing or incompatible uses of the lake. An intra-use externality would occur, for example, where a fisherman harvested too many fish from a lake without regard for the impact on other local fishermen. In other scenarios, however, the negative externality may not be due to such effects but may instead be a cost not associated with infrastructure use (say, a health cost). Positive externalities may be due to network or community effects where interdependencies among infrastructure users (or different user groups) provide a mechanism for beneficial flows; positive externalities may also be due to outputs unrelated to infrastructure use (say, a health benefit).

neighboring communities (e.g., pollution associated with resource extraction may have negative health effects on communities), and depletion of the resource in an unsustainable manner (e.g., resource extraction at a rate that exceeds renewal rate).

*b) Direct Nonmarket Uses: Source and Sink for Noncommercial Users; Recreation*

Environmental infrastructures also support a variety of noncommercial activities. Of course, the use of the environment as source of raw materials and sink for waste products is often noncommercial and not accounted for in market systems. For example, emission of carbon dioxide by a wide variety of household and individual activities uses the atmosphere freely and without restriction. In fact, many day-to-day human activities use environmental infrastructure without mediation by the market system. Some of these activities have the potential to generate (small scale) externalities, both positive and negative, but perhaps mostly negative.[64] Driving is an obvious example.

It is worth discussing a category of noncommercial uses that have grown tremendously in popularity and developed cultural significance over the past century: recreational activities. Environmental infrastructures support a variety of recreational uses, including swimming, fishing, boating, camping, hiking, running, biking, sightseeing, and so on. The value derived by recreational users generally depends upon various characteristics of the environmental resource, such as the air or water quality, that in turn depend upon other uses. Thus, recreational uses tend to be potentially rival with other uses, particularly commercial uses that introduce waste (pollution) or extract resources (e.g., timber, minerals, wildlife).[65] Access to the infrastructure for recreational use is generally nondiscriminatory such that "access is typically open to all comers at a zero price or a nominal entrance fee that bears no relationship to the cost of providing access."[66] Economists tend to see recreational uses as consumptive such that willingness to pay is an accurate assessment of value derived from

64. See Richard J. Lazarus, *Human Nature, the Laws of Nature, and the Nature of Environmental Law*, 24 VA. ENVTL. L.J. 231, 234–35 (2005). Most everyday activities are consumptive, such that the bulk of the value from using the environmental infrastructure is captured by the particular user and does not generate benefits for others. Yet, as global warming demonstrates, many of these activities may generate small-scale negative externalities that aggregate into a significant cumulative effect. *See id.* at 236.

65. Recreational uses tend to be weakly rivalrous with other recreational uses but strongly rivalrous with commercial uses. In some cases, recreational uses can also be strongly rivalrous with other noncommercial uses, such as spiritual uses. *See* Erik B. Bluemel, *Accommodating Native American Cultural Activities on Federal Public Lands*, 41 IDAHO L. REV. 475 (2005); Erik B. Bluemel, *Prioritizing Multiple Uses on Public Lands After* Bear Lodge, 32 B.C. ENVTL. AFF. L. REV. 365 (2005).

66. FREEMAN, *supra* note 59, at 417.

use.[67] Thus, although access generally is not allocated via the market system, some economists have argued that it should be.[68]

For purposes of this argument, recreational activities should be distinguished from many day-to-day activities that use the environment for a few reasons. First, demand for recreational activities is comparatively elastic. Second, recreational activities are often tied directly to a particular environmental infrastructure resource (e.g., lake or woodland). Third, recreational users are often engaged directly with their setting and are aware of the connection with the environment. Finally, recreational activities are more easily privatized and allocated through the market mechanism (and regulated) than many of the day-to-day activities. Thus, when it comes to resource management, recreational uses are more easily seen as "available" to tradeoff with other uses.

It might be worth exploring whether recreational uses of environmental infrastructure generate (small-scale) spillovers. It seems reasonable to view recreational uses as primarily consumptive but partially productive of the following: health, community, and environmental appreciation. Recreational activities, such as swimming and hiking, promote good health, and that has some positive spillovers (as do other forms of exercise). Recreational activities also promote community values and support social networks, and that also may have some beneficial spillovers (as do other activities).[69] Perhaps most importantly, participating in recreational activities that depend upon environmental infrastructure—that derive value from the specific connection to the environmental setting—may provide the experience, context, and connection necessary to appreciate and value the environment; such learning may have significant external effects if it impacts individuals' behavior and (gradually) influences culture and public policy.

*c) Indirect Nonmarket Uses: Supporting Ecosystems and Ecosystem Services; Sustaining Natural Infrastructure for Future Generations*

Environmental infrastructures support an incredible diversity of life (users) and a wide variety of natural processes (uses) that provide incalculable value to human beings. An especially important set of uses, which may be classified as indirect nonmarket uses, includes a wide variety of ecosystem services, such as flood prevention, pest control, water purification, and climate

67. *Id.* at 418.

68. MILTON FRIEDMAN, CAPITALISM AND FREEDOM (1962) (arguing that there were no externalities associated with using national parks and thus owners should be able to capture the full economic value of uses through admissions fees) (cited in FREEMAN, *supra* note 59, at 249).

69. *See* Marc R. Poirier, *Modified Private Property: New Jersey's Public Trust Doctrine, Private Development and Exclusion, and Shared Public Uses of Natural Resources*, 15 SE. ENVTL. L.J. 71, 101–03 (2006) (drawing a connection between infrastructure, recreation, and these types of benefits in light of Carol Rose's work); Rose, *supra* note 8, at 713–14, 779–81.

control, to name just a few.[70] These services provide tremendous value to humans yet often indirectly and not through the agency of human users.

The ecosystem services literature has developed a number of quite refined typologies to differentiate among ecosystem services.[71] For example, J.B. Ruhl has emphasized the importance of distinguishing between provisioning and regulating services:[72] *Provisioning services*, such as pollination, that support the human production of food and fiber commodities are used indirectly by humans and thus the value of such services is embedded in the commodities' value.[73] *Regulating services*, such as storm surge mitigation, gas regulation, groundwater recharge, and thermal regulation, are used directly by human beings, meaning that there is no intermediate step or conversion to another form of good or service and thus the value of such services is not embodied in marketable commodities.[74] Both categories of ecosystem services give rise to complex valuation problems. Ruhl observes that "[f]rom the perspective of formulating economic and regulatory policies for managing ecosystem services, this distinction between direct and indirect use will be of utmost importance, because it reflects the human perception of the service use values."[75]

This last category of uses is perhaps the most difficult to conceptualize. In earlier work, I suggested that one way to think about ecosystem services was to imagine a nonhuman user of the environmental infrastructure that produced ecosystem services. Such a user would not have "preferences" measured in terms of willingness to pay (or some other measure), would not be able to participate in market or political systems, and would be difficult to account for in policymaking discussions.[76]

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70. For more comprehensive lists, see RUHL ET AL., *supra* note 41, at 23–30; PATRICIA BALVANERA & RAVI PRABHU, UN MILLENNIUM PROJECT TASK FORCE ON ENVIRONMENTAL SUSTAINABILITY, ECOSYSTEM SERVICES: THE BASIS FOR GLOBAL SURVIVAL AND DEVELOPMENT 3 (2004), *available at* http://www.unmillenniumproject.org/documents/TF6_IP2_Ecosystem.pdf; MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 34; Costanza et al., *supra* note 30, at 254 tbl.1 (providing a list of "renewable ecosystem" services organized into seventeen groups); Daily et al., *supra* note 3, at 2; Geoffrey Heal et al., *Protecting Natural Capital through Ecosystem Service Districts*, *supra* note 30, at 342; Cecilia M. Holmlund & Monica Hammer, *Ecosystem Services Generated by Fish Population*, 29 ECOLOGICAL ECON. 253 (1999). Economists attempt to approximate the value of such services indirectly. *See, e.g.*, A PRIMER ON NONMARKET VALUATION, *supra* note 3; U.S. EPA, ECOLOGICAL RESEARCH PROGRAM MULTI-YEAR PLAN FY 2008–2014 app. A (Feb. 2008) (Draft Review); Brown & Peterson, *supra* note 20.

71. *See, e.g.*, RUHL ET AL., *supra* note 41, at 26–27.

72. *See id.*; *see also* MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 34, at 1–2.

73. Ruhl describes this category in terms of "structure-based benefits of indirectly used ecosystem services." RUHL ET AL., *supra* note 41, at 29.

74. Ruhl describes this category in terms of "dynamics-based benefits of directly used ecosystem services." *Id.* at 29.

75. *Id.* Ruhl and his coauthors go on to show how directly used service benefits present the "most difficult problems for envisioning ecosystem service law and policy." *Id.*

76. *Cf.* Heal et al., *Protecting Natural Capital through Ecosystem Service Districts*, *supra* note 30, at 342 (2001) (noting that "[i]n most instances, the political process fails to recognize the value of natural capital").

In a sense, my imagined user was already incorporated into the notion of an "ecosystem," which is defined as the complex system of *living communities* (plant, animal, and microorganisms) and *nonliving environmental resources* that interact as a unit.[77] In essence, "ecosystem" brings together environmental infrastructure and users within a system but expands the notion of users beyond humans to encompass all organisms. For purposes of valuation and examining management strategies, it may be helpful to maintain our focus on the infrastructure resource and continue to differentiate among different types of users and uses. I do not mean to suggest that the preferences of nonhuman users should be incorporated into valuation studies; that would be impossible. My point is that acknowledging both the demands and contributions of nonhuman users complicates the analysis and perhaps dooms the valuation enterprise to the extent that it rests on aggregating approximations of existing preferences. It highlights the demand manifestation problem with stark clarity (at least, for me).

Thinking of the nonhuman user that produces ecosystem services as an entity that fails to manifest demand in either market or political systems is important. It might be worth identifying this "user" as akin to the other class of user not represented in either system, the unborn members of future generations.[78] Granted, future generations are not users that generate value for current users, and instead are recipients of whatever we leave for them.[79] But, of course, the same could have been said in the past. Working out the details of an intergenerational theory is beyond the scope of this Essay, but the point is that valuing and managing environmental infrastructure need not and should not ignore the demands of these classes of users.[80]

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77. *See, e.g.*, MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 34, at v. On a more holistic theory of environmental ethics that is not centered on humans, see PAUL W. TAYLOR, RESPECT FOR NATURE: A THEORY OF ENVIRONMENTAL ETHICS (1986).

78. Manifesting the demand of these users within existing decisionmaking frameworks requires clever institutions, such as the public trustee. In his provocative book, *Capitalism 3.0*, David Barnes argues that we could create common property trusts to be managed by trustees with obligations to these sets of users. DAVID BARNES, CAPITALISM 3.0: A GUIDE TO RECLAIMING THE COMMONS (2006).

79. I am intrigued by Marc Poirier's suggested connection between infrastructure theory and intergenerational stewardship obligations. *See* Marc R. Poirier, *Natural Resources, Congestion, and the Feminist Future: Aspects of Frischmann's Theory of Infrastructure Resources*, 35 ECOLOGY L.Q. 179 (2008). I briefly explored this issue in an essay and would like to explore it further in the future. *See* Brett M. Frischmann, *Some Thoughts on Shortsightedness and Intergenerational Equity*, 36 LOY. U. CHI. L.J. 457 (2005). *See generally* EDITH BROWN WEISS, IN FAIRNESS TO FUTURE GENERATIONS: INTERNATIONAL LAW, COMMON PATRIMONY, AND INTERGENERATIONAL EQUITY (1989); Richard L. Revesz, *Environmental Regulation, Cost-Benefit Analysis, and the Discounting of Human Lives*, 99 COLUM. L. REV. 941, 987–1016 (1999).

80. Infrastructure theory relies on functional economic concepts that are useful in understanding relationships among people, resources, and institutions. But ultimately, economics does not provide definitive answers to the difficult social questions of infrastructure policy. What type of environment we live in and how we structure relationships within that environment involves complex tradeoffs among values that often transcend economics. Nonetheless, economics does help frame the tradeoffs and thus the questions we need to ask ourselves. Sustaining environmental infrastructure for current and future generations of human and nonhuman users can be understood in terms of social welfare economics,

### C. Managing Environmental Infrastructure

Managing environmental infrastructure is extremely difficult. The resources play a critical foundational role in supporting complex human and natural systems. Most importantly, these resources support life and the basic needs of present and future generations. Managing environmental infrastructure in a sustainable manner to support these overarching needs is essential. Still, this priority leaves a series of unavoidable tradeoffs to manage. As the last section showed, resource management requires, among other things, consideration of the following functional economic variables that describe the relationship between infrastructure resource and the systems it supports:[81]

- Degrees and Rates of Rivalry Among Uses
    - Relevant resource characteristics
    - Interdependence among uses
    - Path dependence and reversibility
- Nature of Outputs from Uses
    - Private, public, and nonmarket goods
    - Rate and degree of externalities
    - Degree to which observable, known, and foreseeable
- Nature of infrastructure user / output producer
    - Market actor
    - Nonmarket, human
    - Nonmarket, nonhuman

Of course, this is only the first step toward framing the resource management problem. Sustaining environmental infrastructure poses challenges for policymakers in terms of (1) reconciling competing values; (2) dealing with uncertainty, cognitive biases, and a variety of other decision making dilemmas; and (3) institutional design.[82]

Infrastructure theory also provides a useful analytical tool for articulating and evaluating the case for managing certain infrastructure as commons. Despite the powerful lessons taught by the tragedy of the commons story, the fact that environmental infrastructures are congestible does not mean that the resources are doomed to either tragic depletion or to centralized micromanagement of each and every use. Yet the partially (non)rival nature of environmental infrastructures suggest that pure commons is not sustainable because it risks congestion and depletion.

In practice, the dominant approach in the environmental area is a mixed strategy that regulates some uses and sustains a commons for others. In essence, environmental infrastructure resources are often sustained through

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although incorporation of the contributions of nonhumans and the welfare of future generations may be theoretically difficult and empirically impossible.

81. Essentially, these variables are inputs to evaluating scenarios and formulating welfare analysis.

82. These complexities are beyond the scope of this Essay.

complex institutional arrangements that form something akin to semicommons property regimes,[83] although often through regulatory regimes rather than pure property regimes. This approach to constructing semicommons (1) assigns and regulates private rights (access, use, exclusion, and/or exchange) for certain fields of use, such as diversion for industrial purposes; (2) defines commons in terms of community rights (access and use) for certain fields of use, such as recreational use;[84] and (3) sustains the integrity of the resource for nonhuman users and future generations. It is beyond the scope of this Essay to explore fully the complex management regimes that construct regulatory semicommons. But it is worth noting that often we regulate fields of use that are strongly rivalrous with each other and many other activities—and thus are likely to give rise to congestion, surpass renewal rates, or risk depletion—and which also may be less spillover intensive (i.e., the users observe and capture much of the value associated with their use). By managing these uses, we sustain commons for a wide variety of other uses that often are nonrivalrous (or only weakly rivalrous) and may be more spillover intensive (as well as for those users not well represented in current market or political systems).

### D. *Multiple-use Management and Ecosystems*

The concept of environmental infrastructure seems to fit well within existing environmental scholarship. Specifically, it appears to complement bodies of work on (1) multiple-use management (MUM) strategies for public lands and forests, and (2) ecosystem valuation and management.[85] MUM primarily focuses on valuing and managing natural resources that have multiple competing *human* uses.[86] Different sets of uses are characterized and valued under different scenarios; where uses are rival, the different scenarios consider

83. See Henry E. Smith, *Semicommon Property Rights and Scattering in the Open Fields*, 29 J. LEGAL STUD. 131 (2000).

84. I recognize that some recreational uses are regulated. In some cases, regulations focus on safety issues associated with the recreational activity itself. *See, e.g.*, Illinois Boat Registration and Safety Act, 625 ILL. COMP. STAT. 45 (2008) ("It is the policy of this State to promote safety for persons and property in and connected with the use, operation and equipment of vessels and to promote uniformity of laws relating thereto."). In some cases, regulations focus on how participation in the activity affects the environmental resource or other resource users. In national parks, for example, recreational uses are often limited to protect environmental resources through park general management plans. *See* Bluemel, *Accommodating Native American Cultural Activities on Federal Public Lands*, *supra* note 65; Bluemel, *Prioritizing Multiple Uses on Public Lands After* Bear Lodge, *supra* note 65.

85. For excellent explorations to these complex, interdisciplinary literatures, see JOHN COPELAND NAGLE & J.B. RUHL, THE LAW OF BIODIVERSITY AND ECOSYSTEM MANAGEMENT (2nd ed. 2006); RUHL ET AL., *supra* note 41.

86. *See, e.g.*, MICHAEL D. BOWES & JOHN V. KRUTILLA, MULTIPLE-USE MANAGEMENT: THE ECONOMICS OF PUBLIC FORESTLANDS (1989). A related body of environmental scholarship focuses on managing multiple-use common pool resources. It addresses the complexity attributable to multiplicity of use when devising management strategies, for example, the added institutional difficulties where multiple, heterogeneous user communities share a common pool resource. *See* Nathalie A. Steins & Victoria M. Edwards, *Platforms for Collective Action in Multiple-Use Common-Pool Resources*, 16 AGRIC. & HUMAN VALUES 241–55 (1999).

shared but coordinated use versus dedicated use (e.g., to one or the other of two rival uses). In managing a forest unit, for example, one would compare the net benefits of joint production of timber and recreational amenities with the net benefits of dedicating the unit to a "dominant use" (timber production or recreation).[87] MUM does not directly incorporate ecosystems services as a set of "uses" within the multiple-use framework.[88]

The ecosystems literature, on the other hand, brings together resource management perspectives in economics, ecology, and other related fields and takes a more holistic view of systems of nonliving environmental resources and the living resources that support and are supported by the environment.[89] Working from the premise that tradeoffs are inevitable, the literature reflects a concerted effort to improve economic valuation methods in order to improve decisionmaking processes and regulatory frameworks. Yet due to complex interactions between ecosystems, between ecosystems and services, and between services themselves, economic valuation of ecosystems and the wide variety of services they provide are bound to be incomplete and inaccurate.[90] This has led some scholars to argue forcefully that reliance on necessarily incomplete valuations may make matters worse.[91]

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87. *See* BOWES & KRUTILLA, *supra* note 86, ch. 3.

88. MUM and ecosystems management might be seen as two competing approaches to environmental management. But the approaches may be converging. *See* NAGLE & RUHL, *supra* note 85, at 489–90; Janet Neuman, *Thinking Inside the Box: Looking for Ecosystem Services Within a Forested Watershed*, 22 J. LAND USE & ENVTL. L. 173, 194 (2007) ("This 'simple' list demonstrates that the Tillamook State Forest ecosystem is much greater than the sum of its parts. Until a true ecosystem approach is adopted, the forest managers, the interest groups, and the public will all fail to see the forest for the trees . . . or the fish . . . or the off-road-vehicle trails . . . or any other single interest."); Ruhl & Salzman, *supra* note 38, at168 (2007) ("Attention to ecosystem services and the conservation of the natural capital principal of the forest, [scholar Jan Neuman] posits, is not only consistent with multiple use management, but would alter the calculus to promote sustainable conservation of the principal and ensure a stream of ecosystem service revenues for future generations."). MUM has evolved to incorporate some ecosystem planning and management principles. *See, e.g.*, Federal Interagency Ecosystem Management Task Force, Memorandum of Understanding to foster the Ecosystem Approach between the Council on Envtl. Quality et al. (Dec. 15, 1995), *available at* http://www.fhwa.dot.gov/legsregs/directives/policy/memoofun.htm; *see also* Multiple Use Sustained Yield Act of 1960, 16 U.S.C. § 528 (2006) (creating a multiple-use framework for the federal regulation of national forests); Sheila Lynch, *The Federal Advisory Committee Act: An Obstacle to Ecosystem Management by Federal Agencies?*, 71 WASH. L. REV. 431, 433 (1996) (stating that "most agree that ecosystem management requires some form of coordinated management of public and private lands within ecosystems").

89. *See, e.g.*, NAT'L RESEARCH COUNCIL, *supra* note 30, at 153 ("Valuing ecosystem services requires the integration of ecology and economics."). The National Research Council stresses the importance of differentiating between valuing a single ecosystem service and valuing an entire ecosystem, stating that "single service valuation exercises may provide a false signal of the total economic value of the natural processes in an ecosystem." *Id.* at 156.

90. *Id.* at 71.

91. LISA HEINZERLING & FRANK ACKERMAN, PRICELESS: ON KNOWING THE PRICE OF EVERYTHING AND THE VALUE OF NOTHING (2005); *see also* Mary Jane Angelo, *Embracing Uncertainty, Complexity, and Change: An Eco-Pragmatic Reinvention of a First-Generation Environmental* Law, 33 ECOLOGY L.Q. 105, 160 (2006) ("the bulk of scholarly literature in environmental law has failed to adequately grapple with ecological concerns" (citing Ruhl and Heinzerling)).

Difficulties of scale, jurisdiction, and fractured regulatory regimes present significant challenges for existing ecosystem management and governance regimes. One federal commission recently called for a more holistic form of governance; one that is "effective, participatory, and well coordinated among government agencies, the private sector, and the public."[92] Emerging management perspectives recognize the limitations of traditional rule-based regulation, leading a push towards a more integrated (holistic) regime:

> This new style of "post-sovereign" governance is discernible in both domestic and transboundary contexts in places like the Chesapeake Bay, Florida's Everglades, the Baltic Sea, and to some degree, the Great Lakes. In general, these governance arrangements are characterized by a "place-based" focus on a particular ecosystem or hydrologically defined basin, and they are attentive to the specific features of the local environmental and ecological context. They emphasize integrated management of multiple resources and stressors comprising the local ecological context. In turn, this demands high levels of interagency, intergovernmental, and public-private collaboration; and a pooling of the information, expertise, and capacities of a variety of national, subnational, and non-state actors. This blending of competencies then leads to a subtle blurring of the usual distinctions between state and non-state, sovereign and subject, as non-state parties—including environmental nongovernmental organizations (NGOs), independent scientists, industry groups, sub-national governments, and sometimes ordinary citizens—join together with state agencies as collaborators, co-authors, and co-implementers of environmental and natural resources management policy.[93]

There are a number of potential affinities between MUM and ecosystems approaches on one hand and infrastructure theory on the other. All three approaches explore from a functional perspective how social value is generated in complex social-ecological systems, and how across many different systems we fail to appreciate or simply massively discount values that are difficult to

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92. *See* Eagle, *supra* note 48, at 153 (quoting U.S. COMMISSION ON OCEAN POLICY, AN OCEAN BLUEPRINT FOR THE 21ST CENTURY: FINAL REPORT (2004)).

93. Bradley C. Karkkainen, *Managing Transboundary Aquatic Ecosystems: Lessons from the Great Lakes*, 19 PAC. MCGEORGE GLOBAL BUS. & DEV. L.J. 209, 226 (2006). Bradley Karkkainen lays out ten characteristics that would embody such an approach:

> (1) a high level of interagency, intergovernmental, and public-private information-pooling, collaboration, and coordination;
> (2) integrated databases, common monitoring protocols, and joint ecosystem modeling;
> (3) a peak coordinating body;
> (4) a set of functionally defined committees, subcommittees, or working groups;
> (5) central staff support;
> (6) a coordinated program of communications, public education, and outreach;
> (7) nested scales of governance;
> (8) specific goals, targets, and timetables at all levels;
> (9) an iterative and adaptive management approach; and
> (10) genuine integration across issue areas and mission-specific agency responsibilities.

*Id.* at 227–28.

observe, measure, and capture in markets. It is not that the existence of these values is doubted. It is the magnitude, persistence, comparative weight, and distribution that is underappreciated. All three approaches aim to develop an improved appreciation of these values by seeking to identify, understand, and better account for the complex interactions and dependencies in social-ecological systems.

But let me be perfectly clear that my claim is not that infrastructure theory challenges or supplants these literatures. At this stage of research, I would offer a more modest claim: the MUM and ecosystem literatures highlight an important context in which the infrastructure theory seems to apply rather well. This suggests another modest claim: these environmental literatures may have some important lessons for other resource contexts where the infrastructure theory applies, such as communications and information policy. This is a topic I take up elsewhere.[94] Finally, I should note that I do suspect that there are some important lessons from infrastructure theory for the environmental literatures. Whether those lessons concern the limits of valuation techniques based on willingness to pay (or another measure of existing preferences) or the construction of regulatory semicommons remains to be seen. As this Essay is meant to provoke further exploration of how infrastructure theory might or might not apply, I leave such issues for future work.

## CONCLUSION

My goal has been to introduce some ideas and stimulate a discussion. The excellent essays collected in this volume begin to explore some of the ways in which infrastructure theory might apply in the environmental context as well as some of the obstacles.

94. *See* Brett Frischmann, *Cultural Environmentalism and* The Wealth of Networks, 74 U. CHI. L. REV. 1083 (2007) (reviewing YOCHAI BENKLER, THE WEALTH OF NETWORKS: HOW SOCIAL PRODUCTION TRANSFORMS MARKETS AND FREEDOM (2006)); *see also* Frank Pasquale, *Toward an Ecology of Intellectual Property*, 8 YALE J. L. & TECH. 78 (2006).