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THE NEW LAW OF GEOLOGY: RIGHTS, RESPONSIBILITIES, AND GEOSYSTEM SERVICES

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SUMMARY

Humans are inescapably dependent upon geological processes and structures. Many of these interactions are direct, such as when we cultivate the soil or mine the earth. However, the terms of our interaction with geology are usually invisible and unacknowledged. Although the relationships are complex, a firm understanding of the environment and our dependence on it cannot ignore the interconnections between earth's systems, including subsurface geology, vegetation, oceans, and atmosphere. This Article suggests serious consideration of geosystem services, an effort to identify the value to humans of processes occurring throughout the geosystem for the services—not just the goods—that they provide. It proposes a legal regime of geosystem services, and illustrates the immense value of geosystem benefits that are at risk when they are not expressly included in decisionmaking processes.

> Civilization exists by geological consent, subject to change without notice.
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> — Will Durant[1]

We live on a dynamic planet—one that is constantly shifting and transforming, sometimes giving way, but other times struggling against the various pressures that come with physical existence. Mountains thrust at first to the earth's surface through a struggle with pressure and time, then slowly crack and crumble, leaving to living things the task of sifting through the remains in search of food and shelter and other life-supporting materials. Wind and water chisel away at the landscape, molding and supporting the terrain, removing and moving materials, and even trapping information about life and events to preserve an evolutionary history. Heat and pressure drive planetary transformations over time, in many cases at a pace and timescale that renders them imperceptible (to people), leaving only clues in the rocks and ice about how the planet sustained life (and how people have survived). The study of such phenomena in the geological sciences largely operates behind the scenes, and may be easily missed.

Humans are inescapably dependent upon geological processes and structures. Many of our interactions with geology are direct, such as when we cultivate the soil or excavate the earth to expose minerals that have value in the marketplace. However, the terms of our interaction with geology are usually invisible and unacknowledged. We walk on soil that lies over minerals in which organic matter is decomposing, water is moving, and plants are sprouting. We build over geological structures, typically with the hope that the earth will support the weight of the built environment. We recreate on, manipulate, and appreciate

Author's Note: The author would like to thank Max Lindsey for his exceptional work on earlier drafts of this Article. The author would also like to thank Dr. Krysia Kornecki and Profs. J.B. Ruhl, Cinnamon Carlarne, Karrigan Börk, and Jonathan Rosenbloom for their insightful comments, as well as Michelle Zaludek, Kathleen Anderson, Conor Lynch, Evan Levesque, and Adam Herron for their thorough research assistance.

1. Will Durant, *What Is Civilization?*, Ladies Home J., Jan. 1946, at 104.

materials from the earth, typically without a sophisticated regard for their physical and temporal contingencies.[2]

In the meantime, life happens, life ends; the cycle goes on. Although the relationships are often complex, it would be insincere (or worse, folly) to think that a firm understanding of the environment or our dependence on it could ignore the interconnections between earth's systems, including subsurface geology, vegetation, oceans, and atmosphere.[3] And yet, although the earth's geological integrity is constantly, critically, and undeniably important, it often goes unacknowledged.

Sometimes, we are forced to reckon with these interactions. Landslides, ground subsidence, volcanic eruptions, floods, and earthquakes are very noticeable when they result in the loss of human life. Beyond natural disasters, geological structures can fail—at least, these structures may "fail" to perform in the way we had hoped. In these situations, it may have been assumed that the geologic structure would perform in a certain way. Perhaps builders ignored the potential importance of observed water movement, or historic slope instability, or even past excavation at or around the site, when assessing the structural integrity of the earth. Of course, underground circumstances are out of view and, in many cases, have been deemed a mystery.[4] But more importantly, the law often fails to provide an incentive to assess ground reliability and other important contributions geosystems provide to human well-being.

Given that the relationship between human well-being and geological services is a largely unaddressed area of unfathomable economic, ecological, and social importance,[5] this Article suggests serious consideration of the value of geological structures and processes through the framework of ecosystem services. "Ecosystem services" constitutes the recent effort to better understand the risks of human disruption of natural systems by recognizing the value that ecosystems provide to human life and well-being.[6] The research methods of ecosystem services enlighten the observations from ecology with ecological economics, resulting in a better understanding of how and why natural processes are critically valuable.[7] The study of ecosystem services adds to past iterations of natural resource economics by identifying the value of the services—not just the goods—that nature provides.[8] Geosystem services, likewise, is an effort to identify the value to humans of natural processes occurring throughout the geosystem for the services—not just the goods—that they provide.

Although the Article is the first to propose a *legal* regime of geosystem services, the idea of evaluating ecosystem services has been applied to the services provided by geological processes, and continues to emerge in the scientific literature.[9] Indeed, because the point of ecosystem services is particularly persuasive in the case of geological services, the ecosystem services analysis provides valuable insights into the immense value of geosystem benefits that are at risk when they are not expressly included in decisionmaking processes.[10] Accordingly, the first section of the Article broadly identifies the benefits people receive from the geosystem, and provides a framework for understanding an array of geosystem services.[11]

Based on this review of the value of a functioning geosystem, the second section explores the principles of an effective law of geosystem services. Such a legal system

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2. Books celebrating the value of geologic resources often focus on the role that particular mineral discoveries have played in the civilization of humans and development of tools. *See, e.g.*, Eric Chaline, Fifty Minerals That Changed the Course of History 6 (2012):

   > Humanity's transformation of the environment began with the domestication of plants and animals, but as civilization moved from subsistence farming to urban living, the manufacture of goods, and trade, the emphasis shifted to minerals; stone for building; metals for tools and weapons, and later machinery; hydrocarbons for energy; earths, ores, and salts for industry; and precious and semi-precious stones and metals for currency and adornment.

3. Robert M. Hazen, The Story of Earth 256 (2012):

   > [T]he last half-billion years have seen the most astonishing interplay between life and rocks—a coevolution that continues with a vengeance in the age of technological man. Aeons ago rocks, water, and air made life. Life, in turn, made the atmosphere safe to breathe and made the land green and safe to roam. Life turned the rocks into soils that have, in turn, nurtured life and become home to an ever-widening array of flora and fauna.

4. *See, e.g.*, Marengo Cave Co. v. Ross, 10 N.E.2d 917 (Ind. 1937) (plaintiff landowner not responsible for knowing that neighbor occupied caves that extended under plaintiff's property for purposes of adverse possession).
5. *See, e.g.*, Unai Pascual & Caroline Howe, *Seeing the Wood for the Trees: Exploring the Evolution of Frameworks of Ecosystem Services for Human Wellbeing*, *in* Ecosystem Services and Poverty Alleviation: Trade-Offs and Governance 3, 9 (Kate Schreckenberg et al. eds., Routledge 2018) (recognizing that by focusing on the biotic, without regard for abiotic components of development pathways, research on ecosystem services "may perhaps have limited some of its potential policy uptake in relation to poverty alleviation"); Jessica Owley, *The Use of Property Law Tools for Soil Protection*, *in* International Yearbook of Soil Law and Policy 339 (Harald Ginzky et al. eds., Springer 2018) (noting that although all conservationists agree that soil protection is critical for health, prosperity, and adaptation, it does not get the same attention in the law as other resources).
6. Gretchen C. Daily et al., *Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems*, 2 Issues Ecology 1, 2 (1977); Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital*, 387 Nature 253, 253 (1997); Millennium Ecosystem Assessment, Ecosystems and Human Well-Being: Synthesis v (2005).
7. J.B. Ruhl et al., The Law and Policy of Ecosystem Services 24 (2006); James Salzman et al., *Protecting Ecosystem Services: Science, Economics, and Law*, 20 Stan. Env't L.J. 309, 311 (2001).
8. A perspective that focuses only on goods (or, the production services from an ecosystem) tends to ignore or even hide the other valuable benefits we receive from functioning ecosystems. *See, e.g.*, Steven Banwart et al., *Soil Processes and Functions Across an International Network of Critical Zone Observatories: Introduction to Experimental Methods and Initial Results*, 344 C.R. Geoscience 758, 758 (2012) ("Traditionally, soils have been largely managed with a single use in mind, primarily for food, feed or fibre production.").
9. C.C.D.F. (Derk) Van Ree et al., *Geosystem Services: A Hidden Link in Ecosystem Management*, 26 Ecosystem Servs. 58 (2017) (discussing the scarcity of research on geosystem benefits).
10. Gretchen C. Daily et al., *Ecosystem Services in Decision Making: Time to Deliver*, 7 Frontiers Ecology & Env't 21, 23 (2009) ("The main aim in understanding and valuing natural capital and ecosystem services is to make better decisions, resulting in better actions relating to the use of land, water, and other elements of natural capital.").
11. This Article often collapses the distinctions between ecosystem services, geosystem services, and natural services, because the literature on these subjects is so intimately related. Each of these terms refers broadly to the idea that natural systems provide services that are critical and valuable to human life and well-being. Where the more specific term "geosystem services" is used, it primarily refers to those services that are specifically traced to geological structure and processes. The terms "ecosystem services" and "natural services" typically refer more generally to the literature, which predominantly focuses on services from ecosystems.

would at minimum require an information-gathering exercise to assess the manner in which changes to geological structures and cycles (such as by mining, construction, water withdrawal, etc.) produce systemwide impacts and interfere with other benefits otherwise derived from geosystem services. In addition, an effective regime would consider valuation of geosystem services, provide a means to manage trade offs, and evaluate the distribution of valuable geosystem services in an equitable manner. Finally, the Article looks to the ways current law governs interactions with geosystem structure and function to assess how effective law has been in capturing geosystem service priorities, where law has failed, and where opportunities lie for integrating geosystem services into the current legal regime.

This Article is not intended to catalogue all of the benefits we derive from geosystem services or the laws that regulate geosystem integrity. Indeed, due to the pervasive character of our geological reliance, an exhaustive list of laws relevant to dirt, rock, water, support, and other geosystem processes would be fatally extensive.[12] Nevertheless, there is a clear benefit to laying out the foundations and framework for geosystem services regulation. Learning lessons from past regulation allows for a more productive dialogue on how to structure a decisionmaking framework that prioritizes and accounts for disruptions in geosystem services benefits.[13] Managing geosystem services in the law can facilitate a better understanding of the role of geosystem services and the risks of ignoring geosystem processes, while grounding regulations that produce better development decisions.[14]

I. Grounding the Concept of Geological Services

"Ecosystem services" refers to "the ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems."[15] Functioning ecosystems provide benefits to humans and human societies[16]; ecosystems provide "basic life support for human and animal populations and are the source of spiritual, aesthetic, and other human experiences that are valued in many ways by many people."[17] Acknowledging human reliance on these processes facilitates an understanding of the environment that accounts for both the traditional way of valuing nature—through the commodity values of the goods produced by ecosystems, such as timber, food, and water—and the value of the other services that ecosystem processes provide. Given that the services value of ecosystems is generally not reflected in the marketplace,[18] this emerging form of ecological economics is adding something new and insightful to the discussion of environmental valuation and protection.[19]

Ecosystem services focuses on the human benefits from ecosystem structure and processes: it is fundamentally about the way that humans benefit from functioning ecosystems. Hence, it should be noted how far the ecosystem services framework is from theories of nature that support nature's inherent value. Ecosystem services does indeed value the non-use of land and non-interference with ecosystem processes, although this is normally the case when non-use would serve a comparatively greater value than use. From the ecosystem services perspective, natural systems are seldom preserved "for their own sake," a phrase that has some philosophical import. As J.B. Ruhl states: "The bottom line: Ecosystem services are not about just birds and bees—they are about money, and lots of it."[20]

Two points should be made at the outset. First, it is important to recognize that the services approach to understanding natural systems succeeds in conveying how valuable functioning geosystem resources are for humans and in describing how the continuation of such services is dependent on functioning systems. In contrast, if we understand nature as only a collection of goods (and not services), we might find that soil, for instance, appears as "little more than ground up rock."[21] Yet, when we ask about

12. Given the breadth of geosystem structure and processes, as well as the pervasive impacts throughout the ecosystem from disruptions in geosystem processes, it is inevitable that a patchwork discussion of law affecting geosystem integrity will miss wide swaths of relevant law. Hence, this Article does not directly address laws affecting floodplains, wetlands, the regulation of different mining processes, road building, sand dunes and coastal environments, wild and scenic rivers, glaciers, or the Endangered Species Act (ESA) (particularly the critical habitat provisions of the ESA). Similarly, this Article does not directly discuss the role of many geologic processes, such as deformation, isostatic adjustment, weathering, tectonic movement, atmospheric circulation, crystallization, sedimentation, and so on.
13. National Research Council, Ecosystem Services: Towards Better Environmental Decision-Making 154 (2004) ("the value of ecosystem services becomes apparent only after such services are diminished or lost, which occurs once the natural processes supporting the production of these services have been sufficiently degraded"); Gretchen C. Daily, *Introduction: What Are Ecosystem Services?*, *in* Nature's Services: Societal Dependence on Natural Ecosystems 5 (Gretchen C. Daily ed., Island Press 1997) ("the nature and value of Earth's life-support systems have been illuminated primarily through their disruption and loss").
14. As economist Lisa Wainger points out, "[a]ny progress toward strengthening the functional or conceptual relations between human actions and meaningful ecological outcomes will improve our ability to make appropriate trade-offs between different types of benefits." Lisa Wainger & Marisa Mazzotta, *Realizing the Potential of Ecosystem Services: A Framework for Relating Ecological Changes to Economic Benefits*, 48 Env't Mgmt. 710 (2011).
15. Robert Costanza et al., *Twenty Years of Ecosystem Services: How Far Have We Come and How Far Do We Still Need to Go?*, 28 Ecosystem Servs. 1, 2 (2017). The term has also been defined as the "wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life." Daily et al., *supra* note 6, at 1, 2.
16. Daily et al., *supra* note 6, at 1, 2; Costanza et al., *supra* note 6, at 253; Millennium Ecosystem Assessment, *supra* note 6, at v.
17. U.S. Environmental Protection Agency Science Advisory Board, Valuing the Protection of Ecological Systems and Services 8 (2009).
18. Salzman et al., *supra* note 7, at 311.
19. Costanza et al., *supra* note 6, at 253.
20. J.B. Ruhl, *Toward a Common Law of Ecosystem Services*, 18 St. Thomas L. Rev. 1, 15 (2005).
21. Gretchen C. Daily et al., *Ecosystem Services Supplied by Soil*, *in* Nature's Services: Societal Dependence on Natural Ecosystems 113, 128 (Gretchen C. Daily ed., Island Press 1997). *See also* Banwart et al., *supra* note 8, at 759-60:

> Traditionally, soils have been largely managed with a single use in mind, primarily for food, feed or fibre production. However, soils provide other important functions including supporting and sustaining our terrestrial ecosystems, regulating the atmosphere through carbon storage, filtering water, recycling waste, preserving heritage, acting as an aesthetic and cultural resource, whilst main-

the benefits derived from soil, we must recognize that geological resources like soil support most, if not all, other ecosystem processes:

> Like a sponge, soil absorbs precipitation and gradually meters it out to plant roots and into subterranean aquifers and surface streams. Soil shelters seeds and provides physical support and nourishment to plants. It consumes wastes and the remains of dead plants and animals, rendering their potential toxins and human pathogens harmless, while recycling their constituent materials into forms usable by plants. In the process, soil organisms regulate the fluxes of important greenhouse gases. . . . Soil plays a critical role in fueling the entire terrestrial food chain and it is an important feature of many aquatic systems as well.[22]

It is a small stride from the services description of soils to the conclusion that "[s]oil provides an array of ecosystem services that are so fundamental to life that their total value could only be expressed as infinite."[23] When we take seriously the description of nature as a service provider—rather than as a pool of extractable, removable resources—the inquiry into the impacts from resources use or loss becomes much more robust.[24]

The second introductory point is that, in building from the advantages of describing nature as systems that provide benefits to humans, it becomes apparent that the geosystem services approach extends the reach of both a geosciences account of geological assets[25] and ecosystem services valuation.[26] In large part, ecosystem services focuses on the top layer of soils and structure. A geosystem approach, in contrast, expands the study area and captures more processes and, in turn, more essential services.

Geological researchers have identified research parameters for geosystem services as occurring throughout the critical zone,[27] which has been defined as the "terrestrial environment extending from the top of the vegetation canopy to the bottom of drinking water aquifers,"[28] and is further explained by the U.S. Geological Survey (USGS) as "a seamless collection of ecosystems that sustain life on the planet, and defines the area where humans interact with and often conflict with ecosystem functions."[29] Recognizing the interrelation of processes throughout the critical zone is an essential step in creating an "integrating framework to both understand, and better manage, the Critical Zone, including its vital soil layer."[30] Through an interdisciplinary approach, attention to geosystem services

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taining a vital gene pool and biological resource from which many of our antibiotics have been derived.

22. Daily et al., *supra* note 21, at 113. *See also* Ian Hannam & Ben Boer, Legal And Institutional Frameworks for Sustainable Soils: A Preliminary Report 10 (IUCN, Environmental Policy & Law Paper No. 45, 2002); Alexandra M. Wyatt, *The Dirt on International Environmental Law Regarding Soils: Is the Existing Regime Adequate?*, 19 Duke Env't L. & Pol'y F. 165, 169-78 (2008). *See also* Victor R. Baker, *Introduction: Regional Landforms Analysis*, *in* Geomorphology From Space (Nicholas M. Short Sr. & Robert W. Blair Jr. eds., National Aeronautics and Space Administration 1986):

    > Structural geomorphology derives from the fundamental observation that geologic structure dictates the resistance of Earth materials to degradational processes. The role of structure may be passive, in which case the composition of rocks or their discontinuities [joints, faults, and bedding] dictate the details of erosion. In this way, structure provides the boundary conditions for landscape denudation. Structure may also play an active role when tectonic processes create primary landforms and landscapes. Thus, volcanoes, fault-block mountains, grabens, and domes comprise fundamental elements of planetary surfaces.

23. Daily et al., *supra* note 21, at 129.
24. The project of shifting the scope of research and analysis from the environment as a collection of objects (e.g., water) to systems (e.g., watershed) has important implications for how such systems are valued and managed. This is not a new charge. More than a century ago, John Wesley Powell encouraged recognition that political boundaries were arbitrary in relation to natural processes. His lesson built an approach to governance upon an understanding of watersheds:

    > I want to present to you what I believe to be ultimately the political system which you have got to adopt in this country, and which the United States will be compelled sooner or later ultimately to recognize. I think each drainage basin in the arid land must ultimately become the practical unit of organization, and it would be wise if you could immediately adopt a county system which would be convenient with drainage basins.

    John Wesley Powell, *Testimony From the Montana Constitutional Convention* (1889), *in* Daniel Kemmis, This Sovereign Land: A New Vision for Governing the West 177 (2001).

25. To be clear, I am not suggesting that a geosystem services approach will expand the amount of geological information that we gather; rather, by placing geological information into the services construct, we extend the reach of how that information can be used. On the other hand, because the services approach focuses on services that create benefits to humans, there will inevitably be geological structures and processes that avoid the services analysis, if only because we have not yet identified with specificity the manner in which such capital provides measurable benefits to humans.
26. Jason P. Field et al., *Understanding Ecosystem Services From a Geosciences Perspective*, 97 Eos 10 (2016):

    > A traditional ecosystem services perspective focuses on relating active vegetation management [e.g., forest thinning] or vegetation change due to disturbance [e.g., fire, insect, or drought mortality] to water resources, often emphasizing precipitation, soil moisture, and surface water flows while not necessarily considering other influential processes. Explicitly expanding assessment of the service of water provision to include geosciences perspectives would in many cases lead to more robust understanding of relevant environmental processes and how to manage them for the benefit of society.

    (citing Younes Alila et al., *Forests and Floods: A New Paradigm Sheds Light on Age-Old Controversies*, 45 Water Res. Rsch. W08416 (2009), and Jason P. Field et al., *Critical Zone Services: Expanding Context, Constraints, and Currency Beyond Ecosystem Services*, 14 Vadose Zone J. 1 (2015)).

27. An important development in geosystems services analysis has been to focus in on the so-called critical zone, defined generally as the area extending vertically from the bottom of the groundwater to the top of the vegetative canopy. Framing ecosystem and geosystem processes as occurring throughout the critical zone brings into view the complex web of structural and process interactions that make life happen. By looking at ecosystem processes as occurring from the groundwater level to the top of the vegetation canopy, we can expand the timescale of ecosystem processes to include "nutrient release from rock to bioavailable form based on lithology, substrate age, atmospheric deposition, nutrient retention, and loss mediated by soil development, weathering-induced carbon sequestration, aspect-induced variation in subsurface water storage, and landscape-scale water dynamics affecting plant-available water." Researchers note that such a perspective "seeks to understand these larger-scale and longer-term processes associated with evolution of the weathering profile and their effects on regulating climate, nourishing ecosystems, and controlling water quality and quantity." Field et al., *supra* note 26.
28. Banwart et al., *supra* note 8, at 760.
29. R. Sky Bristol et al., USGS, U.S. Geological Survey Core Science Systems Strategy—Characterizing, Synthesizing, and Understanding the Critical Zone Through a Modular Science Framework (2013) (Circular 1383-B).
30. Banwart et al., *supra* note 8, at 760.

will result in a better understanding of ecological processes and services in space[31] and in time.[32]

It is well known, for instance, that vegetation removal such as logging has the potential to destabilize soils and contribute to erosion.[33] *Geosciences* help to explain why such destabilization occurs, how extensive this change can be, and how long it may take to reestablish functional geological support. *Geosystem services*, on the other hand, helps in identifying how such disruptions affect human well-being in a variety of ways, from the health and safety risks of landslide hazards and the costs of artificial slope stabilization, to the water quality impacts on downstream water users from fluvial and ecosystem effects of increased sediment loads and the long-term, interrelated impacts associated with degradation of tree canopy, biodiversity, and habitat. More importantly, a geosystem services perspective can account for the costs of lost services (geosystem and ecosystem), particularly as relevant to the time frame in which such services might be reestablished. That is, by taking a geosystem services perspective, we can investigate and account for a broader array of risks associated with changes to the land surface.[34]

Like ecosystems,[35] geosystems are workhorses. Geologic processes are an essential component to a wide range of ecosystem and natural systems, and are integral in the sustainability of many other valued ecological functions. As Murray Gray notes, "Since humans first started using stone tools hundreds of thousands of years ago, there has been a steady increase in the human use of geological materials. Today, it is no exaggeration to say that our modern society could not exist without the utilization of the Earth's geological resources."[36]

This Article borrows from the ecosystem services literature four basic categories[37] of geosystem services that can be used to prescribe values to each geologic function: support services, regulatory services, production services, and cultural services.[38] The geosystem shoulders the burden of human survival by supporting the built environment and ecosystem processes, regulating soil and atmospheric circumstances, producing materials that are valuable in society, and providing a sense of culture and history.

A. Support Services

The geosystem is responsible for maintaining circumstances in which all life is sustained and all geological, ecological, hydrological, and atmospheric processes occur. In some ways, natural and structural geological functions exist independently from human interactions and are often unsurprisingly at odds with human extraction of geologic resources. Geosystem support services involve those geological components that provide the background[39] in which other natural processes can occur.

1. Stable Land for Development

Structures are safer and more secure when constructed on stable land.[40] This function of geology provides a natural foundation for the built environment, and secures our expectations that shelters will be habitable. Land stabil-

31. Field et al., *supra* note 26 ("For example, ecologists who focus on the services provided by vegetation and reefs in reducing impacts of coastal hazards could benefit from geosciences input on how geomorphology, elevation, and coastline configuration interact with the living organisms to deliver those services.").

32. *See, e.g.*, *id.*:

> Time scales associated with plant community succession provide a more detailed example of how ecosystems services assessments can be improved through geosciences. The succession after a disturbance such as forest blowdown (high winds that topple trees) usually occurs in tens to hundreds of years, after initial colonization by short-lived species, followed by longer-lived species. However, geosciences perspectives also consider the conversion of rock to soil and the long-term evolution of the soil profile and are on the order of thousands to millions of years. For instance, the long-term evolution of Hawaiian tropical forest ecosystems occurs on lava flows that range in age from hundreds of years on the big island of Hawaii to about 4.1 million years on Kauai.

(citing Oliver A. Chadwick et al., *Changing Sources of Nutrients During Four Million Years of Ecosystem Development*, 397 Nature 491 (1999); Nathan Fox et al., *Incorporating Geodiversity in Ecosystem Service Decisions*, 16 Ecosystems & People 151 (2020):

> Services that are primarily driven by abiotic nature occur over longer time scales than those that are primarily driven by biotic nature. This is because the formation of geo-diversity components versus biological components that are then drawn on to form the service may take a long time due to difference in the geological and biological timescales.

33. Ellen Wohl, *Compromised Rivers: Understanding Historical Human Impacts on Rivers in the Context of Restoration*, 10 Ecology & Soc'y 2 (2005), *available at* http://www.ecologyandsociety.org/vol10/iss2/art2/.

34. The geosystem approach facilitates a broader perspective on the impacts from particular decisions. C.C.D.F. (Derk) Van Ree & Pieter J.H. van Beukering, *Geosystem Services: A Concept in Support of Sustainable Development of the Subsurface*, 20 Ecosystem Servs. 30 (2016) (arguing that geosystem services provides a platform that connects a wide variety of physical sciences).

35. Although this Article considers some geosystem services independently of ecosystem services, it is clear that there is overlap and interrelation between the two. Fox et al., *supra* note 32:

> The renewability of biotic features and processes providing services can be just at risk as abiotic features and processes. For instance, the renewability of agricultural products could be diminished if we do not sustainably manage the underlying supporting services, such as soil quality. Both the economic and environmental trade-offs of prioritizing short-scale services over relatively longer scale services should therefore be appropriately considered during ES [ecosystem services] decision-making.

36. Murray Gray, *Geodiversity, Geoheritage, and Geoconservation for Society*, 7 Int'l J. Geoheritage & Parks 226, 235 (2019).

37. Four classifications adapted from Murray Gray, *Other Nature: Geodiversity and Geosystem Services*, 38 Env't Conservation 271 (2011); Rudolf S. de Groot et al., *A Typology for the Classification, Description, and Valuation of Ecosystem Functions, Goods, and Services*, 41 Ecological Econ. 393 (2002); Michelle Webber, *The Social and Economic Value of the UK's Geodiversity*, 42 Eng. Nature Rsch. Reps. 12 (2006).

38. Murray Gray has suggested adding another category to capture the knowledge benefits from the geosystem. In this Article, those benefits are largely included within the cultural services category. *See* Gray, *supra* note 37.

39. I appreciate comments on this Article from Dr. Krysia Kornecki, who suggested that thinking about geosystem services as the "background" for other natural processes might unintentionally trivialize the roles played by the geosystem. Dr. Kornecki, who thinks of the geosystem not as the background, but as the "main event," suggests that the inanimation we attribute to the geosystem (due to our difficulties in observing geological change) allows humans to ignore the planetary processes that are more visible on a geologic timescale.

40. Amadi Akobundu Nwanosike et al., *Architect's and Geologist's View on the Causes of Building Failures in Nigeria*, 6 Mod. Applied Sci. 31 (2012) (identifying the importance of appropriate geotechnical information on ground stability before construction).

ity is challenged by human-made and natural factors. Construction projects, groundwater withdrawal, mining, drilling, and other such actions may remove a substantial portion of the existing surface land, create or exacerbate steep and unstable slopes, or compromise lateral or subsurface support.[41]

2. Water Storage in Aquifers

When water falls onto the surface of the earth, favorable geologic characteristics allow for that water to percolate and accumulate underground to be stored in aquifers. Common ground-types in the United States that create aquifers are alluvial deposits, glacial deposits, confined or artesian groundwater, and sedimentary basins or permeable and porous rock.[42] Groundwater is drawn from aquifers through wells for domestic, agricultural, and other purposes. Natural water storage capacity can be diminished by urbanization, groundwater overdraft, and agricultural and mining activities.[43] The ability of subsurface geological structures to provide the service is vulnerable to hydrogeological changes (e.g., construction of impermeable surfaces that change recharge rates), subsurface exploration and excavation (e.g., mining and blasting), and also contamination from releases of hazardous wastes (which has the potential to affect groundwater potability over a long term).

3. Protective Landscapes (Levees, Barrier Beaches, Sand Dunes)

The natural breakdown of rocks into particles of sand forms oceanic beaches and protects the built environment from coastal erosion. Ocean deposits of sand onto beaches, dunes, or barrier islands provide a buffer to protect shoreline areas from possible flooding, erosion, and storm surge. Such protective geological structures are necessarily under constant pressure, but human activities (such as construction and recreation) accelerate destabilization of these landforms.[44]

4. Physical Support for Agricultural and Habitat Provisions

Geologic formations combine with other living ecosystem functions to create habitats for a wide range of species.[45] In addition, many plants and animals require unique geologic habitats for survival such as cliffs, caves, alpine environments, wetlands and marshes, and intertidal zones.[46] Geological processes provide productive soils for agricultural and natural systems. However, geological structure and processes that support vegetative productivity are vulnerable to interference in a variety of ways, including westernized or industrialized agricultural practices themselves.[47]

B. Regulatory Services

"Regulatory services" have been defined as "the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes."[48] The geosystem plays many critical roles in the regulation of life support systems on the planet and in keeping the earth habitable.[49]

1. Soil Development and the Sedimentary Cycle

Soil is developed in a continuous cycle with minerals continuously (relative to geologic time) being pushed out of the earth in geologic formations, eroding away and depositing elsewhere, and eventually subsiding and subducting back into the earth to begin the process again.[50] Human activities alter or interfere with the rock cycle in many ways, including urbanization and the construction of impermeable surfaces (can increase erosion and affect surface and groundwater flows), fossil fuel extraction and mining (can alter geological stability, destabilize soils, and increase erosion), forest and agricultural activities (can increase erosion rates significantly), and constructing dams (can affect flu-

41. *See, e.g.*, Olson v. Mullen, 68 N.W.2d 640 (Minn. 1955); Xi Props. v. RaceTrac Petroleum, 151 S.W.3d 443 (Tenn. 2004).
42. Matthew R. Bennett & Peter Doyle, Environmental Geology—Geology and the Human Environment (1998).
43. Thomas C. Winter et al., USGS, Ground Water and Surface Water: A Single Resource (1998) (USGS Circular 1139) (identifying the impacts of human activities on the ability of surface and groundwater structures to provide water).
44. *See* Per Bruun, *Dunes—Their Function and Design*, 26 J. Coastal Rsch. 26 (1998); Fred J. Anders & Stephen P. Leatherman, *Effects of Off-Road Vehicles on Coastal Foredunes at Fire Island, New York, USA*, 11 Env't Mgmt. 45 (1987) (a variety of built environment and human activities can destabilize sand dunes and increase erosion).
45. Gray, *supra* note 37 ("[I]t is mainly the diversity of physical environments (such as geomaterials, topography, hydrology or physical processes) that has allowed biodiversity to evolve. Geodiversity provides the platforms and the range of physical habitats in which wildlife can flourish, whether in chalk grasslands, saltmarshes or mountain environments.").
46. Webber, *supra* note 37.
47. Carol Shennan, *Biotic Interactions, Ecological Knowledge, and Agriculture*, 363 Phil. Transactions Royal Soc'y B 717 (2008) (discussing farming practices that contribute to the decline in soil productivity); Vaclav Smil, *Phosphorus in the Environment: Natural Flows and Human Interferences*, 25 Ann. Rev. Energy & Env't 53 (2000) (phosphorus mobilization of this growth-limiting nutrient is naturally slow, but has increased due to use as fertilizer and runoff from fields and discharges of waste, resulting in eutrophication).
48. de Groot et al., *supra* note 37, at 395.
49. "The ecosystem or natural system functions that geodiversity provides are vital for the continued survival of our environment." Webber, *supra* note 37.
50. "On a shorter time scale, the sedimentary cycle includes the processes of physical or chemical erosion, nutrient transport, and sediment formation, for which water flows are mostly responsible. On the geologically longer timescale, the process of sedimentation, chemical transformation, uplift, seafloor spreads, and continental drift operate." Susan E. Alexander et al., *The Interaction of Climate and Life*, *in* Nature's Services: Societal Dependence on Natural Ecosystems 71, 73-74 (Gretchen A. Daily ed., Island Press 1997).

vial processes, hydrology, and geochemical and sedimentation processes).[51]

2. Flood and Erosion Control

Natural geologic processes break down landforms and transport the particles through waterways. Flowing rivers deposit the particles along the way, creating landforms (floodplains) that play critical roles as habitat and during storm events.[52] The natural floodplains that are created along rivers work to absorb excess river water in times of high discharge and work to protect against flooding in rivers and streams. These natural floodplains help to keep the water within the river channel, much as man-made levees do in urban rivers, but also provide a buffer for overflow water to be contained when rivers eventually breach their banks. Construction of infrastructure and residences in floodplain areas, as well as other activities that destabilize soils, such as removal of vegetative ground cover and alterations to stream form and function, tend to eliminate flood control capacity in natural systems.[53]

3. Geomorphology and Landscape Formation

Geomorphological processes such as erosion, weathering, fluvial transport, and surface runoff are responsible for topographical conditions in which people live, work, and play.[54] Such forces influence nutrient cycling, soil formation, sediment transport, and catchment capacity. Over both short- and long-term processes, geomorphological processes create distinctive landscapes (such as cliffs, caves, river and lake beds) and influence climate and ecological circumstances.

4. Water Filtration

Although there are many factors that determine water quality, geosystem processes carry much of the burden by providing water filtering processes (filtering, adsorption, biodegradation, and chemical precipitation) as water moves through the geosystem.[55] As precipitation seeps into the ground, it flows through soils and rock and into a variety of geologic structures. Porous aquifers naturally filter the water, alleviating the need for filtration facilities or water treatment. Overconsumption and pollution[56] have frequently interfered with this service, leaving water in natural aquifers unfit for human consumption or agricultural production.[57]

5. Atmosphere and Biochemical Processes

Carbon is the key ingredient for life on the planet. Although the majority of the earth's carbon is stored underground, carbon continuously cycles through "reservoirs" as dissolved carbon dioxide in the ocean and other water bodies, as carbon dioxide in the atmosphere, calcium carbonate and buried organic matter in the ground, and as organic compounds in organisms. Modifications to biochemical cycles (such as the increase in anthropogenic carbon emissions since industrialization, including deforestation and burning of fossil fuels) disrupt the transport and transformation of carbon and other macronutrients through critical biochemical cycles, undermining the range of ecosystem services associated with climate and atmosphere and resulting in atmospheric threats as seen in climate change, deterioration of air and water quality, and interference with ecosystem processes.[58]

C. Production Services

Also referred to as "provisioning" services, this classification of geosystem services focuses on geological processes that provide products that people use for sustenance or for the production of other goods. Production services, often valued as the price of geosystem goods in the marketplace, are the easiest geosystem services to quantify.

1. Water

Water on the earth is constantly moving through the hydrologic cycle.[59] The supply of groundwater in aquifers is one of the most important geological services to benefit human well-being. Vast irrigation systems used to supply the country with food as well as metropolitan areas rely heavily on

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51. S. Anders Brandt, *Classification of Geomorphological Effects Downstream of Dams*, 40 Catena 375 (2000); Wohl, *supra* note 33 (identifying the geomorphological impacts of particular land uses and activities).
52. Jon Erickson, Rock Formations and Unusual Geologic Structures: Exploring the Earth's Surface 36 (2001).
53. Sue L. Niezgoda & Peggy A. Johnson, *Improving the Urban Stream Restoration Effort: Identifying Critical Form and Processes Relationships*, 35 Env't Mgmt. 579 (2005) (arguing that a better tie between geomorphological form and function in urban stream restoration projects will result in better understanding the impacts of stream design decisions); Keith H. Hirokawa & David Dickinson, *The Costs of Climate Disruption in the Tradeoffs of Community Resilience*, 41 W. New Eng. L. Rev. 445 (2019) (discussing the trade offs occurring in reactionary stream-dredging projects intended to increase capacity for flood control).
54. Carmelo J. León, *Double Bounded Survival Values for Preserving the Landscape of Natural Parks*, 76 J. Env't Mgmt. 103 (1996); Ken G. Willis & Guy D. Garrod, *Valuing Open Access Recreation on Inland Waterways: On-Site Recreation Surveys and Selection Effects*, 25 Reg'l Stud. 511 (1991).
55. Nyle C. Brady & Raymond R. Weil, The Nature and Properties of Soils (Pearson Education eds., 1999).
56. Winter et al., *supra* note 43 (discussing the manner in which various human activities impact and impair groundwater recharge).
57. Fourteen percent of wells tested on the High Plains Aquifer, providing irrigation for 27% of the nation's irrigated agriculture, contain at least one pesticide. The most common of these is a known hormone disruptor and suspected of retarding fetal development. Julene Bair, *Running Dry on the Great Plains*, N.Y. Times (Nov. 30, 2011), http://www.nytimes.com/2011/12/01/opinion/polluting-the-ogallala-aquifer.html.
58. Wolfgang Cramer et al., *Tropical Forests and the Global Carbon Cycle: Impacts of Atmospheric Carbon Dioxide, Climate Change, and Rate of Deforestation*, 359 Phil. Transactions Royal Soc'y B 331 (2004) (considering the role of deforestation in carbon cycle disruption); Philip M. Fearnside, *Global Warming and Tropical Land-Use Change: Greenhouse Gas Emissions From Biomass Burning, Decomposition and Soils in Forest Conversion, Shifting Cultivation, and Secondary Vegetation*, 46 Climate Change 115 (2000).
59. "While the total amount of water found on earth may seem huge, the amount of precipitating freshwater available to people is a tiny fraction of this total. Earth's renewable supply of water is continually distilled and distributed through the hydrologic cycle." Alexander et al., *supra* note 50, at 73.

surface and groundwater impoundments. Historically, flowing water served multiple human domestic needs until human treatment resulted in degraded water that could no longer be used due to health risks. For instance, civilizations have long used rivers and oceans as available and free trash receptacles.[60] More recently, humans have paid closer attention to the negative impacts for such use, such as in discovering that the Cuyahoga River had become flammable.[61] Such developments have helped us to understand the ways in which the physical environment regulates the geological, hydrological, and ecological processes that we rely on.

2. Food

Productive soils are essential to support harvesting of timber and agricultural production of food. Other geological products are directly consumed. For instance, the mineral halite is mined for use as salt for food and industrial purposes. Food production depends on the availability of productive soils, which in turn depend on the many geosystem, ecosystem, and atmospheric cycles that help maintain conditions for growing.

3. Fuels

Geological resources are our main source for fuel and energy. Geologic processes create the fossil fuels that we rely on to power our society by compressing and heating buried organic material for thousands of years to create coal, oil, and gas. Geologic processes provide renewable geothermal power, which uses the heat from inside the earth. Hydroelectric power is a product of the geologic processes that carve out our lakes and rivers. Extraction (drilling, blasting, and erecting dams) and use of fuels (burning) can result in significant changes to geological structure, geosystem and atmospheric processes, water flows, and even landscape aesthetics. In addition, the production and use of many of these fuels has had the effect of creating potentially destructive dependencies on such resources, including for transportation and energy.[62]

4. Construction Materials (Sand, Gravel, Stone, Cement)

The construction industry relies heavily on minerals formed through geologic processes. The main minerals used in construction include sand, gravel, clay, limestone, aggregate rocks, and gypsum (the mineral used in the production of drywall). Different geologic deposits provide for the array of construction materials needed; sands and gravels are found in alluvial (river) deposits, clays are found in lacustrine (lake) deposits, and gypsum and limestone are found in buried marine environments.

5. Industrial Materials (Metals, Alloys, Fertilizers)

There are extensive mineral and geologic deposits in the United States that provide for industrial materials used in creating metals, alloys, and agricultural fertilizers. Sophistication in working with copper, bronze, iron, and rare elements has been credited with facilitating cultural and technological developments in human society. On the other hand, adaption of technologies to available resources has had the effect of creating dependencies on such resources, such as plastics and fertilizers.[63]

6. Ornamental and Decorative Products

Precious metals such as gold and silver have been used as currency or personal and religious ornamental purposes. Private collectors, museums, and the general public purchase millions of dollars' worth of geologic memorabilia every year ranging from fossils[64] and minerals to gemstones and precious metals. These products are taken as collectibles by themselves, used as materials to create decorative art and jewelry, or used as ornamental stone for carving, sculpting, and decorative architecture. The distinctly human valuation of ornamental geological products has led to fierce competition and, in many cases, oppression and aggressions, such as the tragedies associated with conflict diamonds in several African countries.[65]

D. Cultural Services

People interact directly or indirectly with the natural world in ways that illustrate a wide array of intangible benefits

60. The usable water supply is threatened by a plethora of human activities in quality (such as activities that alter the nitrogen, carbon, and sulfur cycles) and quantity (such as by water use for domestic, agricultural, and mining purposes). *Id*. at 73-74.
61. *See* Keith H. Hirokawa, *From Euclid to the Development of Federal Environmental Law: The District Court for the Northern District of Ohio and the Regulation of Physical Space*, *in* Justice and Legal Change on the Shores of Lake Erie: A History of the Northern District of Ohio for the Northern District of Ohio (Paul Finkelman & Roberta Alexander eds., Ohio Univ. Press 2012).
62. Brandt, *supra* note 51; Wohl, *supra* note 33 (identifying the geomorphological impacts of particular land uses and activities); Gordon E. Grant, *The Geomorphic Response of Gravel-Bed Rivers to Dams: Perspectives and Prospects*, *in* Gravel-Bed Rivers: Processes, Tools, Environments 165 (Michael Church et al. eds., Wiley-Blackwell 2012).
63. *See generally* Julia Rosen, *Humanity Is Flushing Away One of Life's Essential Elements*, Atlantic (Feb. 8, 2021), https://www.theatlantic.com/science/archive/2021/02/phosphorus-pollution-fertilizer/617937/ (describing the history of phosphorus and its role as a fertilizer, which was historically available in human and other animal waste, but as urban populations increased, human waste problems ensued, and civilized society intercepted the distribution of phosphorus from human waste by building sewage treatment plants).
64. In 1997, "Sue" the Tyrannosaurus rex sold in New York for $8.36 million. M. Forster, *Fossils Under the Hammer: Recent U.S. Natural History Auctions*, *in* A Future for Fossils 98 (M.G. Basset et al. eds., National Museum of Wales, Geological Series Number 19, 2001).
65. Norimitsu Onishi, *Sierra Leone Measures Terror in Severed Limbs*, N.Y. Times (Aug. 22, 1999), https://www.nytimes.com/1999/08/22/world/sierra-leone-measures-terror-in-severed-limbs.html.

that are generally classified as cultural services. Whether geologic processes are responsible for creating artifacts of spiritual value, preserving evidence of biological, atmospheric, or geological history, or even providing a steep incline for recreation, there is a geologic presence relevant to every experience and a geologic process that make the experiences possible.[66]

1. Spiritual and Historic Meaning[67]

Specific landscapes and landforms have shaped our nation's development and traditions, starting with the earliest Native Americans[68] and continuing into our modern society.[69] The easily recognized and enduring characteristics of many prominent geologic formations allow them to continue to show their importance over generations, such as Cliff Palace at Mesa Verde National Park,[70] Mount Rushmore, and Niagara Falls.[71] Even with legal protections, such special places are subject to human encroachment and natural deterioration, forcing decisions about whether and how to preserve cultural places and icons for the future.

2. Living Surroundings

The type of environment that surrounds human spaces has a direct influence on the character and quality of life in that region. The geologic landscape of an area affects house prices, landscape choices, agricultural opportunities, recreational values, and sense of place. Like many geosystem services, the human benefit of having living space has been subject to competition and conflict, often among individuals, and just as often between nations and tribes.

3. Recreational Resource

The United States boasts a vast supply of geologic features that provide a place for people to recreate. Anything from rock climbing and hiking, to mountain biking or sitting on a beach requires a specific type of geologic environment. In addition to on-land activities, geologic formations of lakes and rivers allow for the opportunity to recreate in fishing, boating, and swimming. Land development, privatization, and sprawl have made access to recreational lands more complicated for many people, particularly in urbanized areas.

4. Artistic Inspiration

Evidence of human use of ocher to color materials (perhaps as artistic expression) appears to emerge from 80,000 years ago.[72] Even in modern times, artistic media often draws inspiration from natural and geologic features, landforms, fossils, and stones. Many painters, sculptors, poets, and writers demonstrate the importance of natural landscapes as inspiration to their work. Artistic expressions are not only valued by how much the piece can fetch on the market,[73] but also by how much the artistic community contributes to the social development and education of society.

5. Employment (Education, Iindustry)

A wide array of employment opportunities flow from geologic structures and functions. Direct employment opportunities exist in the mining, education, museum, and tourism industries that value the earth processes as they exist naturally. Numerous other employment opportunities indirectly result from geologic functions or interactions with earth processes such as hotel and restaurant businesses throughout our nation's national parks that are sustained by geotourism.[74] Mining industries have suffered a negative public perception due to health risks of mining, such as coal workers' pneumoconiosis (commonly called black lung), to pollution from mining activities, and from the relationship between fossil fuels and climate change.[75]

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66. In the meantime, it is worth noting that each landscape feature, water body, glacier, and stone can proffer multiple meanings as mediated by cultural perspective: "Multiple identities associated with landscapes—both rural and urban—can exist simultaneously at local, regional, and national levels, with one or another being forced into dominance by historical and political circumstances." Millennium Ecosystem Assessment, *supra* note 6, at 405-06 (2005). Hence, Yi-Fu Tuan states, "[t]rees or boulders may be dense in a wilderness area, but nature lovers do not see it as cluttered. Stars may speckle the night sky; such a sky is not viewed as oppressive. To city sophisticates nature, whatever its character, signifies openness and freedom." Yi-Fu Tuan, Space and Place: The Perspective of Experience 61 (1977). *See also* Keith H. Hirokawa & Linnea Riegel, *An Ecosystem Services Approach to Cultural Resource Protection*, 50 Env't L. 665 (2020).
67. *See* William J. Cook, Preserving Native American Places: A Guide to Federal Laws and Policies That Help Protect Cultural Resources and Sacred Sites (2014).
68. Some of the earliest civilized developments on the continent have been found at Mesa Verde National Park.
69. Mount Rushmore is carved from a unique type of rock found only in the Black Hills of South Dakota; known as the "shrine of democracy," it represents the founding fathers of the United States. The Black Hills are also considered sacred by the Sioux Indians, combining ancient spirituality with more modern history in one geologic formation.
70. National Park Service, *Mesa Verde—Preserving Cliff Palace*, https://www.nps.gov/meve/learn/historyculture/cliff_palace_preservation.htm (last updated July 3, 2020).
71. Martin H. Krieger, *What's Wrong With Plastic Trees?*, 179 Science 446 (1973) (discussing the efforts of Canada and the United States to preserve Niagara Falls from continual erosion).
72. Nicholas St. Fleur, *Oldest Known Drawing by Human Hands Discovered in South African Cave*, N.Y. Times (Sept. 12, 2018), https://www.nytimes.com/2018/09/12/science/oldest-drawing-ever-found.html.
73. An original photograph from Ansel Adams, a well-known photographer who focused his art on national parks, most notably Yosemite, has an average value between $8,000 and $30,000. *See* Ansel Adams Gallery, *Home Page*, https://www.anseladams.com/ (last visited Mar. 12, 2022).
74. U.S. Government Accountability Office, National Park Service: Revenues From Fees and Donations Increased, but Some Enhancements Are Needed to Continue This Trend (2015) (identifying increased revenues from 2005 to 2014 in recreational fees from about $148 million to $186 million and commercial service fees from almost $29 million to $85 million).
75. Centers for Disease Control and Prevention National Institute for Occupational Safety and Health, *Mining Topic: Respiratory Diseases*, https://www.cdc.gov/niosh/mining/topics/RespiratoryDiseases.html (last updated Sept. 3, 2021); Sammy Fretwell, *Gold Mine Fined $100,000. Toxic Air Pollution Found at Big Mine Near Tiny Town*, State (Feb. 12, 2021), https://www.thestate.com/news/local/environment/article249177395.html; Bobby Magill, *Burning Coal Is Hot, the Global Warming Produced Is Even Hot-*

6. Distant Appreciation (Books, Television)

The people that do not directly live near, travel to, or recreate with specific geologic formations often appreciate them from afar through reproductions in television, movies, media, and books. Environmental documentaries such as "Planet Earth" and "North America" have recently created a large market for geologic appreciation without leaving one's living room.[76]

7. Sense of Place

Geological and ecological surroundings influence how people perceive themselves.[77] Sense of place tells a story about how a community creates itself in a specific place.[78] In particular, local geology and the challenges and advantages it poses make up the experiences of human life; it is where people suffered loss, as well as where they built and loved and laughed. It is the landscape that people recognize as home. Although it is easy to grasp how geology provides place, such a substantial portion of human life occurs in artificial environments, in urban, constructed areas, often resulting in less direct attachment between human experiences and geological place.

8. Educational Development

Earth's history is imprinted in the soils and rock beneath our feet.[79] Gradual and sudden shifts in climate, biological and geological evolution, and volcanic eruptions can be read in the earth. Knowledge of past, present, and anticipated future geologic events is an indispensable resource ranging from scientific and historic discovery to policy formation in determining how to adapt to current or future changes in earth processes. Information and knowledge derived from geologic functions provides a wide array of valuable services to society, including employment opportunities, education, scientific discovery, and environmental forecasting and monitoring.[80]

II. Starting From Bedrock: Thinking About Needs for a System of Geosystem Services Law

Not long ago, the most significant obstacle to constructing an effective regime of ecosystem services law was in pushing for acknowledgment of the idea that functioning ecosystems are valuable for the *services* they provide to humans.[81] At this point in time, it appears we have crested the hill on the idea of natural services; we have long since abandoned the idea that the only consequence of cutting a tree is more board-feet of lumber, or that dredging a wetland only results in more farmable land. Ecosystem services research has helped us to acknowledge the risks inherent in disrupting natural processes, by giving a basis for estimating the benefits of leaving nature in place and the costs of losing the ecosystem services we depend on. At this point, the importance of ecosystem service valuation has become more understood, and the vocabulary of ecosystem services has reached a more common parlance. Hence, we now turn to understanding how to make decisions about our interactions with the geosystem and, of course, what sorts of laws might result in informed decisions and decisionmakers.[82]

Not surprisingly, given that the evolution of our legal system was largely uninfluenced by the ecological economics of ecosystem services, we find little in the law that expressly identifies geosystem values or services or implements protections for the beneficiaries of such services. Nevertheless, given the extensive dependencies that humans have on geosystem structures and processes, human needs for services from nature, we also should not be surprised to find a patchwork of legal tools that could accommodate geosystem services. That inquiry is taken up in the next section. This section lays the groundwork for that inquiry by linking geosystem services principles to policy to construct a framework for thinking about what a law of geosystem services should accomplish.

As in all areas of law, there are many ways that we might construct the law of geosystem services.[83] Given the complicated processes through which people derive critical benefits from geological structure and function, a legal framework for geosystem services should centralize the complexity of the geosystem in the decisionmaking process and recognize the localness of geosystem benefits, while providing objective valuation standards to promote equitable enjoyments of those benefits.[84] Given the vast

ter, Sci. Am. (June 3, 2015), https://www.scientificamerican.com/article/burning-coal-is-hot-the-global-warming-produced-is-even-hotter/.

76. The episode "Caves" from the *Planet Earth* series had an estimated 13.1 million viewers worldwide. Note that this was for all seven episodes, which are focused both on geologic features as well as the natural life that exist in these environments. *See* BBC Earth, *Home Page*, https://www.bbcearth.com/ (last visited Mar. 12, 2022).
77. Keith H. Basso, *Wisdom Sits in Places: Notes on a Western Apache Landscape*, *in* Senses of Place 54, 54 (Steven Feld & Keith Basso eds., School of American Research Press 1996).
78. Jonathan Rosenbloom & Keith H. Hirokawa, *Foundations of Insider Environmental Law*, 49 Env't L. 631 (2019); Keith H. Hirokawa, *Environmental Law From the Inside: Local Perspective, Local Potential*, 47 ELR 11048 (Dec. 2017); Carlos Marques da Silva, *Geodiversity and Sense of Place: Local Identity Geological Elements in Portuguese Municipal Heraldry*, 11 Geoheritage 949 (2019) (noting that sense of place is a question of "who we are," which in turn is dependent on "where we are," which makes geodiversity relevant).
79. Baker, *supra* note 22 ("Because many planetary surfaces have been relatively stable for billions of years, they preserve the effects of extremely rare, exceedingly violent processes. Such processes include impact cratering, sturzstroms (large avalanches of rock and debris), and cataclysmic flooding.").
80. Steven Semken, *Sense of Place and Place-Based Introductory Geoscience Teaching for American Indian and Alaska Native Undergraduates*, 53 J. Geoscience Educ. 149 (2005) ("If sense of place influences the ways that people observe and interpret natural phenomena, it must influence geoscience learning, and it merits study by geoscience educators.").
81. J.B. Ruhl & James Salzman, *The Law and Policy Beginnings of Ecosystem Services*, 22 J. Land Use & Env't L. 157 (2007).
82. J.B. Ruhl, *In Defense of Ecosystem Services*, 32 Pace Env't L. Rev. 306, 319 (2015).
83. We often discuss legal regimes in the environmental policy arena through the helpful tools of the "Five P's": prescription, property, penalty, payment, and persuasion. James Salzman, *Teaching Policy Instrument Choice in Environmental Law: The Five P's*, 23 Duke Env't L. & Pol'y F. 363 (2013). In this Article, we are focusing on how the law of geosystem services would operate, given the characteristics and value of geosystem services.
84. From this analysis, a geosystem services law should incorporate three basic criteria: (1) the law should identify the flow of services (and disruptions in

array of human needs for geosystem benefits, the legal framework should recognize the complicated competition between existing expectations and the circumstances in which development and other changes to geosystem processes will disrupt those expectations.

In addition, in light of the historical divide between geoscience and treatment of geological resources in the law, the general ignorance of the role of geosystem services, and the importance of services derived from the geosystem, the principal needs of a legal system of geosystem services will include at least five considerations: (1) the legal process should require sufficient information to assess the impacts of an action on the flow of geosystem services; (2) the legal process should include valuation to beneficiaries of particular geosystem services; (3) the law should establish baseline standards that account for the differing values of geosystem services performance in particular cases; (4) the law should require consideration of the distribution of geosystem services and account for inequities among beneficiaries; and, finally, (5) geosystem services planning (ideally, planning throughout the critical zone) should precede decisions that will impair geosystem processes.

A. Require Sufficient Information to Assess the Impacts of an Action on the Flow of Geosystem Services

As Gretchen Daily notes, "the safeguarding of critical ecosystem services requires that they first be identified."[85] Securing information on geosystem services sooner, rather than later, avoids decisions that result in unrecoverable expenditures of natural capital or, at least, results in identifying vulnerable natural capital in a way that elevates the need for good geosystem decisionmaking. Moreover, in 2019, the Global Assessment report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services reiterated the critical importance of knowledge about the risks inherent in the disruption of ecosystem processes: an inventory of natural capital helps to understand where investments are needed, which investments are unnecessary, and which investments are too costly.[86]

services) from the moment an activity affects the geosystem to the impacts of such changes on human well-being; (2) the law should broadly consider all relevant geosystem services, including ecosystem services that influence geological processes and ones impacted by geosystem changes; and (3) the law should recognize that different people will benefit from geosystem services differently. Although these criteria were used by Joke van Wensem et al. to identify when an ecosystem services framework is being employed, they provide some insights into how we might construct a legal framework to govern geosystem services. Joke van Wensem et al., *Identifying and Assessing the Application of Ecosystem Services Approaches in Environmental Policies and Decision-Making*, 13 Integrated Env't Assessment & Mgmt. 41, 42-43 (2016).

85. Nature's Services: Societal Dependence on Natural Ecosystems 369 (Gretchen C. Daily ed., 1997).

86. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, The Global Assessment Report on Biodiversity and Ecosystem Services—Summary for Policy Makers (2019).

Yet, governance of geological services suffers an informational deficit.[87] It is often recognized that many environmental decisions are done without understanding of, or in disregard for, the systemic impacts to ecosystems and geosystems, including whether ecosystems will be capable of continuing to provide services over the long term.[88] Knowledge regarding the relationship between major geosystem disruption and human needs is lacking, in large part due to the inattention given to natural conditions.[89] In 2005, the Millennium Ecosystem Assessment pointed out that such a decisionmaking process may be the norm, rather than the exception.[90]

Research into the flows of benefits from ecosystem and geosystem processes can provide *better* baseline data on geosystem processes, and illustrate our dependencies on particular geosystem outcomes.[91] For instance, surveys on soils[92] and groundwater will aid in identifying the most significant threats to soil productivity, developing groundwater budgets, predicting hydrological connectivity, and

87. *See, e.g.*, Francis Turlkelboom et al., *Ecosystem Service Trade-Offs and Synergies*, *in* OpenNESS Ecosystem Services Reference Book (M. Potschin & K. Jax eds., 2016), http://www.openness-project.eu/library/reference-book/sp-ecosystem-service-trade-offs-and-synergies (noting that the current lack of understanding about trade offs and synergies or how to manage them is largely due to the rarity with which local knowledge is sought).

88. *See, e.g.*, *id.*

89. Joachim Maes et al., *Mapping Ecosystem Services for Policy Support and Decision Making in the European Union*, 1 Ecosystem Servs. 31 (2012) (discussing the importance of research into ecosystem services in order to make the concept suitable for policy decisions).

90. Millennium Ecosystem Assessment, Ecosystems and Human Well-Being: Current State and Trends 573 (2005) ("Management of inland waters worldwide has been regularly based on decision-making mechanisms that have not included sufficient consideration of the wider implications or outcomes of specific actions or responses.").

91. Economics Prof. Elizabeth Porter and I have elsewhere described this difference as follows:

> In neoclassical economic theory, the value of natural resources is limited to that of an input in the production function. The more natural capital is extracted and converted through the production process, the greater our capacity to produce the goods and services that increase society's wellbeing. In traditional market-based valuations of natural resources, only the benefit of converting resources through the production process is compared to the cost of converting those resources (including present and future costs and benefits inherent in the conversion of the resources into goods and services). The ecosystem services perspective not only recognizes that natural resources are producers of goods and services, but also that the goods and services produced by ecosystems might represent a greater economic, social, and environmental value than the goods and services acquired from the conversion of those natural resources over time.

Keith H. Hirokawa & Elizabeth J. Porter, *Aligning Regulation With the Informational Need: Ecosystem Services and the Next Generation of Environmental Law*, 46 Akron L. Rev. 963, 987 (2013).

92. For instance, in the European Union, the eight major threats to soils were identified as erosion, organic matter decline, compaction, salinization, landslides, contamination, sealing, and biodiversity decline, costing billions annually. *See* Commission of the European Communities, Impact Assessment of the Thematic Strategy on Soil Protection, Document to Accompany Communication From the Commission to the Council, the European Parliament, the European Economic and Social Committee, and the Committee of the Regions—Thematic Strategy for Soil Protection (2006); *see also* Commission of the European Communities, Impact Assessment of the Thematic Strategy on Soil Protection, Communication From the Commission to the Council, the European Parliament, the European Economic and Social Committee, and the Committee of the Regions—Thematic Strategy for Soil Protection (2006).

identifying the beneficiaries from particular aquifers, especially when that analysis accounts for interrelated geosystem and ecosystem processes throughout the critical zone.[93] Research into bedrock circumstances and topography,[94] wetlands, and floodplain capacity[95] can help in understanding which communities will suffer flooding from development of the floodplain, or better understand the historical and cultural foundations in a community.[96]

Informational laws can aid in developing a geological services inventory and facilitating an investigation of existing geosystem dependencies. The informational processes will inform us when it becomes "far better economics to avoid wrecking productive natural systems, or to restore them when damaged, than attempt to displace or do without them."[97] Given the role that geosystem stability plays in everyday lives, the legal framework should be used to facilitate a better understanding of risks and benefits of the geosystem.

Laws incorporating geosystem services need not result in protection of geological resources, although they may have that effect. But the services approach *should* result in more informed decisions about the extent of geosystem services loss from particular transformative actions. Many current laws in the United States envision an information-gathering exercise that could provide information on geosystem processes and values. However, as detailed below, such laws are seldom used to gather geosystem services information. The information that is typically acquired under these laws is deficient for the needs of geosystem services law as it seldom identifies the services provided by the system and less often connects geosystem services with beneficiaries.

B. The Legal Process Should Include Valuation to Beneficiaries of Particular Geosystem Services

Under a geosystem services analysis, geological assets have value "insofar as they either change the benefits associated with human activities or change the costs of those activities."[98] That is, the geosystem is valuable when it serves human needs, and the study of geosystem services, like ecosystem services, is distinctive for its attention to beneficiaries of natural systems.[99] Therefore, a legal framework addressing geological services can make better use of services and their relevance to governance where they are found. Characterization of the services that are received from the geosystem can facilitate a location-specific valuation and help discern the conditions of geosystems as they relate to the needs of communities. Specifically, such characterization will assist governments at all levels in prioritizing trade offs from the menu of geosystem services that are subject to economic pressures.

Like many ecosystem services, valuation is difficult for geosystem attributes, in part because of how fundamental and pervasive the services are. In the ecosystem services context, much of the literature on valuation concerns particular crises or disasters, such as hazardous waste releases and oil spills where restoration and compensation have arisen in the litigation context. Some communities have partnered with governmental and nongovernmental entities to consider the ecosystem service values of particular resources in particular locations. Examples include the work done to value urban forest services,[100] the long-standing and continuing work of wetlands value in the context of artificial wetlands and wetland enhancements,[101] and the varieties of open space values and stormwater control benefits through green infrastructure.[102] However, at present, there are no explicit drivers in law that require the valuation of geological services, and as such little is understood about the ways and methods that geosystem service values might be identified and incorporated into decisionmaking.

Common among these successful efforts for ecosystem services has been the identification of the beneficiaries of particular natural services.[103] Without knowing the ben-

93. Bristol et al., *supra* note 29.
94. *See, e.g.*, Southwest Region Planning Commission, Town of Hinsdale, New Hampshire, Natural Resources Inventory (2006):

> Bedrock geology also has a profound influence on the movement and quality of water above and below the surface. The mineralogy of bedrock directly influences water chemistry and in turn, aquatic ecology and human health. The shape of the land has an obvious influence on the direction and rate of water runoff, ponding and infiltration.

95. Although not addressed in this Article, regulation of critical natural services such as wetlands under the Clean Water Act do account for some geosystem services. For analysis of wetlands services and relevant regulations, see J.B. Ruhl & R. Juge Gregg, *Integrating Ecosystem Services Into Environmental Law: A Case Study of Wetlands Mitigation Banking*, 20 Stan. Env't L.J. 365 (2001); *see also* Keith H. Hirokawa, *Local Planning to Preserve Wetlands Assets: Community, Baselines, and Ecosystem Services*, 39 Zoning & Plan. L. Rep. 1 (2016).
96. *See, e.g.*, Scott O'Mack, Rock Art, Ranch, and Residence: Cultural Resources in the Town of Oro Valley and Its Planning Area (William Self Associates, Technical Report No. 2009-51, 2010):

> Ancient rock art and Hohokam villages, historic trails and roads, nineteenth-century homesteads and ranches, and post-World War II residential subdivisions have all helped to shape the modern community of Oro Valley. All of these resources can contribute to an understanding and appreciation of Oro Valley and its history, but all present notable challenges to town planning.

97. Harold Mooney & Paul Ehrlich, *Ecosystem Services: A Fragmentary History*, *in* Nature's Services: Societal Dependence on Natural Ecosystems 11, 11 (Gretchen C. Daily ed., Island Press 1997).
98. Costanza et al., *supra* note 6, at 255.
99. *See* Kai M. Adam Chan et al., *Conservation Planning for Ecosystem Services*, 4 PLoS Biology 2138, 2138-39 (2006) ("The key feature that distinguishes these services from ecosystem functions or processes is the explicit involvement of beneficiaries. As such, a proper characterization of ecosystem-service targets involves consideration of the demand for services—its magnitude and spatial distribution—in addition to the underlying ecosystem processes.").
100. John Dwyer et al., Connecting People With Ecosystems in the 21st Century: An Assessment of Our Nation's Urban Forests 3 (2000).
101. William J. Mitsch et al., *Ecosystem Services of Wetlands*, 11 Int'l J. Biodiversity Sci. Ecosystem Servs. & Mgmt. 1-4 (2015); Alexandros I. Stefanakis, *The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management*, 11 Sustainability 6981 (2019).
102. Liana Prudencio & Sarah E. Null, *Stormwater Management and Ecosystem Services: A Review*, 13 Env't Rsch. Letters 1 (2018).
103. Lydia Olander et al., *Benefit Relevant Indicators: Ecosystem Services Measures That Link Ecological and Social Outcomes*, 85 Ecological Indicators 1262 (2018) (discussing benefit-relevant indicators (BRIs) and importance of following the flow of services to beneficiaries). "Benefit-relevant indicators" are defined as:

eficiaries of particular services, any estimation of the risks from loss of services is directionless, arbitrary, and ultimately unhelpful.[104] Environmental information on benefit flows is important in identifying which activities disrupt ecosystem processes (and how that disruption occurs).[105] By taking a beneficiary approach, we get more information (and more important information) about how environmental changes affect people.[106]

Acknowledging specific changes to geosystem processes is critical where loss or gain of geosystem services is the most noticeable impact of such changes. The legal system should make efforts to capture the *actual* costs to a community from geological changes and avoid relying too heavily on estimations calculated in the aggregate,[107] particularly for purposes of understanding the disparate impacts that environmental impacts can have across communities.[108] Legal standards should anticipate that cultural and technological shifts may impact the effectiveness of particular policies and programs, where the intended outcomes may differ from the actual ones.[109] In addition, a thoughtful regulatory process will also be better able to grasp the divergent ways that changes to geosystem services will affect different regions and communities,[110] and account for noneconomic values (a particularly complicated idea that historically has been easy to dismiss).[111]

C. Establish Baseline Standards That Account for Differing Values of Geosystem Services Performance in Particular Cases

Geosystems are subject to contingencies such as location, ecosystem needs in the relevant critical zone, and the needs of identifiable human beneficiaries. Of course, geological processes do not occur in a vacuum, or in separate silos: they occur in nonlinear ways within a geosystem that provides support and regulatory services for ecosystems and to different beneficiaries in different ways.[112] A legal framework for geosystem services should include a process for assessing the relevance of particular services based on objective performance standards.

This is not to say that the exercise of formulating such standards will be easy. Governance of ecosystem services must account for the dynamic nature of service provision, including market, systemic, climatic, and cultural changes both in how ecosystems are functioning and how we perceive the benefits in trade off decisions. The interconnectivity of geosystem processes suggests that an evaluation of geosystem functions cannot be limited to a narrow and local context; typically, geologic functionality operates at a variety of different scales and in relation to different ecosys-

> measurable descriptors of ecosystem services of all types, whether market goods or non-market, including those that support existence values for species and ecosystems. BRIs use well-defined measurement scales; these can be categorical, ordinal, or continuous, permitting measurement of qualitative as well as quantitative characteristics that are compatible with valuation and decision analysis methods. BRIs make explicit the connections between ecological conditions and human use and enjoyment using causal chains, which can be implemented as mental models or as formal predictive models, along with servicesheds that clarify the areas and beneficiaries affected.

Id. at 1271.

104. Geographer Edward Relph notes that intentional changes in landscapes have the effect of disconnection, displacement, and placelessness:

> A rational landscape, created from the perspectives of intentional rationality, can nevertheless be experienced as absurd, as alien and impenetrable, and yet it can also be taken for granted as the setting for everyday life. . . . We find increasingly that we are confronted and confused by landscapes that lack clear centres and boundaries and which are constantly changing identity.

Edward Relph, Place and Placelessness 133 (1976).

105. "Incorporating ecosystem services into decision-making can change the way a problem is perceived and the way solutions are formulated because decision makers consider not only changes to ecological conditions but also how these changes can affect people." Kenneth J. Bagstad et al., *From Theoretical to Actual Ecosystem Services: Mapping Beneficiaries and Spatial Flows in Ecosystem Service Assessments*, 19 Ecology & Soc'y 64 (2014) (attributing decline in geological, biological, and hydrogeological processes in the Puget Sound to human population growth and economic development).

106. Olander et al., *supra* note 103, at 1271.

107. Christopher A. Armatas et al., *An Integrated Approach to Valuation and Tradeoff Analysis of Ecosystem Services for National Forest Decision-Making*, 33 Ecosystem Servs. 1 (2018) (discussing the importance of impact assessments and land use planning to project the consequences of changes to ecosystem service flows).

108. Lisa Mandle et al., *Who Loses? Tracking Ecosystem Service Redistribution From Road Development and Mitigation in the Peruvian Amazon*, 13 Frontiers Ecology & Env't 309 (2015) (discussing the importance of identifying actual ecosystem services benefits and losses, instead of in the aggregate, for determining equitable distribution of benefits).

109. Lawrence A. Kapustka et al., *Coordinating Ecological Restoration Options Analysis and Risk Assessment to Improve Environmental Outcomes*, 12 Integrated Env't Assessment Mgmt. 253 (2016) (observing the possibility that ecosystem service investments may fail to reach the intended beneficiaries due to changes in social, cultural, and economic circumstances).

110. Mandle et al., *supra* note 108 (discussing the importance of considering trade offs between differently situated communities from the same action).

111. *See* Olivia Serdeczny et al., German Development Institute, Non-Economic Loss and Damage: Addressing the Forgotten Side of Climate Change Impacts (2016); Olivia Serdeczny et al., German Development Institute, Non-Economic Loss and Damage in the Context of Climate Change: Understanding the Challenges (2016).

112. *See* Lynn Scarlett & James Boyd, *Ecosystem Services and Resource Management: Institutional Issues, Challenges, and Opportunities in the Public Sector*, 115 Ecological Econ. 3, 5 (2015). In a sense, even mentioning these important but complicated geosystem characteristics begs the question of whether an effective legal approach to geosystem services is feasible. Law is plagued by jurisdictional constraints, sector-based regulations (e.g., mining law, water allocation law, and water pollution control are distinct legal frameworks), and, in many cases, the need for certainty in both what is being regulated and the consequences of particular actions to the environment. Nevertheless, focusing on the complicated characteristics in laws that govern our interactions with geosystems does elevate the importance of informed regulation and may result in a better allocation of risk. And the risk allocation is complicated.

Hence, Katie Leach et al. have suggested adoption of a hierarchical system for classifying and accounting for natural capital to ease the comparison of different services. Katie Leach et al., *A Common Framework of Natural Capital Assets for Use in Public and Private Sector Decision Making*, 36 Ecosystem Servs. 100899 (2019). This approach to a natural services regime constructs an objective and transferrable classification system for various geosystem services. Of course, standardization remains complicated in ecosystem science, given that "the way in which natural capital assets combine to support services and benefits is complex, and the data available for reporting on such assets is often incomplete, and may only provide a partial picture of overall status and trends." Nevertheless, such a system (and the understanding that accompanies it) will facilitate a non-expert understanding of how natural capital provides benefits to humans, which in turn could help to prioritize among the risks of service loss and understand how particular services may be valued in combination with other services.

tem and geological processes.[113] Moreover, administration of a geosystem services framework requires an accounting for the vast uncertainties suggested by geological interactions over time and at different scales.[114]

Yet, because each geographic location has unique and complex geologic structures, the effort to standardize the study of geologic functions and values is not to implement a uniform system of geosystem values, applicable to all places. Rather, the effort is to craft a rubric for regulations that places local decisionmaking in a broader context to address distributional and other problems at other scales.[115] By focusing on lessons from the aggregate, we do not want to misunderstand the direction of critical benefit flows, or even the identity of beneficiaries of particular ecosystem services.[116]

A systemic analysis of geosystem benefits on a broad scale will help decisionmakers to identify potential planning partners and facilitate identification of geosystem beneficiaries outside of the proposed action, as well as provide for deep consideration of both the impacts of a particular action on outside beneficiaries and how the actions of those parties affect benefits from the proposed action.[117] Other frameworks for assessing the impacts of development decisions or other environmental transformations may capture biophysical impacts to ecosystems, but they fail to trace those changes to disruptions of the system's ability to deliver services. Moreover, thinking about natural processes for the services they provide (and the people that benefit) lays to rest any confusion about the reasons people have interests in property they do not own (a nice little trick that helps understand how environmental interests fit into the standing inquiry), while facilitating a more meaningful inquiry into the trade offs in geosystem choices from particular decisions.

That is, while we may objectively grasp how a decision may alter geological processes, we may not grasp the gravity of those changes until we understand the impacts to specific beneficiaries of the lost geosystem services. For instance, hard-rock mining near a rural residence may yield economic returns from extracted geological products, but the impacts from those gains (the trade offs) become a bit more realistic when the neighbors' wells are contaminated or run dry (a loss of groundwater quality, quantity, and reliability due to changes in groundwater levels or aquifer characteristics) or the foundations of their homes begin to crack and fail (loss of surface stability from fracturing from explosives or removal of lateral support). In contrast to approaches that aggregate data into standardized valuations, by identifying levels of service among differently situated beneficiaries, this approach will be better focused on distinguishing among disparate levels of benefits among different groups or in different locations (e.g., upstream or downstream).[118] By looking for such differences in particular cases, decisionmakers will be able to identify inequitable distribution of geosystem benefits and have the opportunity to adjust accordingly.

D. The Law Should Require Consideration of the Distribution of Geosystem Services and Account for Inequities Among Beneficiaries

An essential element of a geological services model concerns problems of distributional equity, principles of environmental justice, and the demands of social justice.[119] Geosystem services planning (like all ecosystem planning) implicates a variety of equitable issues. Who bears the cost of securing geosystem services? Which needs will be primarily served, or, who derives the greatest benefits? When and where will trade offs have the most significant negative implications for particular populations? Of course, these decisions are complicated because valuation of competing needs for services can be very complex, particularly given competing perspectives, economic needs, and cultural biases.[120] Moreover, much of the developing research recognizes the difficulties that ecosystem complexity imposes on understanding ecosystem services trade offs, where research may be mired in the "reductionist approach focusing on single services, resources or measures of wellbeing."[121]

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113. *See* Scarlett & Boyd, *supra* note 112, at 5 (any system of governance addressing the services provided by ecosystems would have to include four related but discrete conceptual elements that are relevant to natural systems: complexity, dynamism, interconnectivity, and uncertainty).

114. *Id*.

115. *See* Nikolas C. Heynen, *The Scalar Production of Injustice Within the Urban Forest*, 35 Antipode 980 (2003) (pointing out that resolutions for environmental equity problems at the local scale may cause inequities across boundaries or at a larger scale).

116. Jesse Caputo et al., *Integrating Beneficiaries Into Assessment of Ecosystem Services From Managed Forests at the Hubbard Brook Experimental Forest, USA*, 3 Forest Ecosystems 13 (2016):

> These processes become services when and only when they begin to contribute (directly or indirectly) to human well-being, in other words, when they are "used" by beneficiaries. Without knowing the relative importance of those services to beneficiaries, however, we can have only very limited understanding of the cumulative impact of those services on well-being, or of tradeoffs or synergies among services in terms of total utility.

117. National Ecosystem Services Partnership, Federal Resource Management and Ecosystem Services Guidebook 1:18-1:19 (2014), https://nespguidebook.com [hereinafter NESP Guidebook]. The NESP Guidebook adds, "Incorporating ecosystem services into assessments can complement efforts to evaluate the impact of largescale threats, such as drought, nutrient enrichment of waters, habitat fragmentation, air pollution, and invasive species, and develop strategies to deal with them."

118. Peleg Kremer et al., *The Value of Urban Ecosystem Services in New York City: A Spatially Explicit Multicriteria Analysis of Landscape Scale Valuation Scenarios*, 62 Env't Sci. & Pol'y 57 (2016).

119. The Justices and Injustices of Ecosystem Services (Thomas Sikor ed., 2013); Joan Flocks et al., *Environmental Justice Implications of Urban Tree Cover in Miami-Dade County, Florida*, 4 Env't Just. 125 (2011); G. Darrel Jenrette et al., *Ecosystem Services and Urban Heat Riskscape Moderation: Water, Green Spaces, and Social Inequality in Phoenix, USA*, 21 Ecological Applications 2637 (2011); Henrik Ernston, *The Social Production of Ecosystem Services: A Framework for Studying Environmental Justice and Ecological Complexity in Urbanized Landscapes*, 109 Landscape & Urb. Plan. 7 (2013); Bill M. Jesdale et al., *The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation*, 121 Env't Health Persps. 811 (2013).

120. *See* Michalis Skourtos et al., *Reviewing the Dynamics of Economic Values and Preferences for Ecosystem Goods and Services*, 19 Biodiversity & Conservation 2855 (2010) (examining a dynamic approach to ecosystem services valuation).

121. Belinda Reyers & Odirilwe Selomane, *Social-Ecological Systems Approaches: Revealing and Navigating the Complex Trade-Offs of Sustainable Development*,

We have general knowledge about the manner in which ecosystem challenges tend to disproportionally impact low-income and vulnerable populations, due to disparities in infrastructure investments and differences in community capacity to respond to catastrophic events. In the meantime, we are only beginning to think seriously about cultural and intergenerational inequities resulting from the services and opportunities we trade in the present. Due to geographic situatedness, some communities will shoulder a disproportionate cost of maintaining geological services compared to other communities.

Likewise, some communities will derive disproportionate benefits from geosystem services. A geosystem services regulatory scheme should conceptualize how the valuation component of geosystem services can facilitate a different distribution of ecosystem benefits and responsibilities, even though there is little direct research into the interrelationship between environmental justice and ecosystem services.[122] In addition, such a scheme should address the question of where geosystem investments can minimize disparities in light of the place-based needs for services.[123]

As noted above, law must extend beyond mere confirmation that there will be trade offs (which we can guess even without any underlying understanding of a project or decision), and should acknowledge what services are being traded and which beneficiaries are winning and losing, how the benefits are distributed across individuals and communities, and ultimately how to decide whether particular distributions exhibit equitable outcomes.[124] More importantly, the distribution of geosystem services is more than a question of economics or a rational choice of where to live.[125] The services we receive from a functioning geosystem are not all economic, and the losses we suffer from interruption of those services can defy estimation. And this is the problem that is addressed by geosystem services and the critique from social equity: the way we have allocated ecosystem benefits in the past has ignored or omitted the voices and the values that are expressed from those who are disfavored in trade offs, who bear an inequitable burden of maintaining natural services, but have no claim of ownership over the benefits.

Equity concerns should be addressed without waiting for a crisis, and allocation inequities are present when public lands or benefits are allocated to particular uses or interests. Natural resource investments will tend to favor particular interests or burden others. Lands in closer proximity to swimmable and potable water, with uncontaminated or more productive soils, more stable ground, or simply not yet populated over the carrying capacity of the land, have been reserved for the fortunate few by market forces. The others, suffering fewer available natural services, and therefore with greater environmental risks, need to be participants in geoservices planning, and planning across the serviceshed is a good start. In particular, "[a] landscape analysis of services and beneficiaries can increase the transparency of distributional effects," which in turn can help "clarify which ecosystem services can be provided over time and across the landscape with minimal tradeoffs. Even when it reveals distributional conflicts, more transparent measures of ecosystem service benefits can reveal options that reduce perceived inequities."[126]

E. Geosystem Services Planning Should Precede Decisions Regarding Particular Geological Changes

We often prioritize actions that promise immediate gratification, or short-term benefits, against actions that present a better return over the long term.[127] The vast expanses of mining operations, the value of which is easy to calculate, support this tendency, much like development in floodplains or in wetlands. Yet, integrating geosystem services through the planning framework helps sharpen our cost-benefit analysis to include an accounting of different ways to secure the services that humans need for survival. As noted by the National Ecosystem Services Partnership, adding ecosystem services to existing planning activities provides access to more information:

> Expanding the scope of outcomes to include additional ecosystem services during a planning exercise may not change a manager's assessment of which management alternative is best. Incorporating ecosystem services into decision making does not replace an agency's existing priorities—but it does provide additional information about how best to meet existing priorities while also addressing other objectives.[128]

in Ecosystem Services and Poverty Alleviation: Trade-Offs and Governance 39 (Kate Schreckenberg et al. eds., Routledge 2018):

> While useful in calculating the values of some ecosystem services, and raising awareness of the importance, distribution, trends and links between ecosystems and wellbeing, these studies have largely failed to demonstrate the contribution of biodiversity and ecosystem services to poverty alleviation, particularly the mechanisms or causal pathways by which this takes place.

122. Ian R. Cook & Erik Swyngedouw, *Cities, Social Cohesion, and the Environment: Towards a Future Research Agenda*, 49 Urb. Stud. 1959 (2012) (research into the distribution of ecosystem services is a much-needed component of an environmental justice agenda).
123. *See, e.g.*, Thomas Elmqvist et al., *Benefits of Restoring Ecosystem Services in Urban Areas*, 14 Current Op. Env't Sustainability 101 (2015) (arguing that investing in urban ecological infrastructure in urban areas is ecologically, socially, and economically beneficial).
124. *See, e.g.*, Aritta Suwarno, *Who Benefits From Ecosystem Services? A Case Study for Central Kalimantan, Indonesia*, 57 Env't Mgmt. 331 (2016) (noting that the conversion of forests to the production of palm oil effects an increase in income to private entities but a decrease in monetary and recreational benefits to the public).
125. Henrik Ernstson, *The Social Production of Ecosystem Services: A Framework for Studying Environmental Justice and Ecological Complexity in Urbanized Landscapes*, 109 Landscape & Urb. Plan. 7, 14 (2013) (discussing the fallacy "that the process of 'finding the right trade off' between different ecosystem services is often simplified into a consensual process, or a rational choice game between actors with fixed interests (so called stakeholders) that can be steered/guided by economic incentives").
126. NESP Guidebook, *supra* note 117.
127. Jon Paul Rodriguez et al., *Trade-Offs Across Space, Time, and Ecosystem Services*, 11 Ecology & Soc'y 28 (2006) ("Decisions about ES typically defaults to the short-term needs of humans, even when such decisions might interfere with ES that are necessary for the long-term sustainability of human well-being."); Hirokawa & Dickinson, *supra* note 53.
128. NESP Guidebook, *supra* note 117, at 1:17.

That is, an ecosystem services approach to planning will not necessarily upend our planning priorities, but it might foster better decisionmaking[129] by enriching what we are planning for and our understanding of the ways to achieve it.[130]

In its best form, land use planning engages an interested community of stakeholders (who typically present themselves with a diversity of interests and needs) to participate in creating a vision. A planning process that is inclusive and participatory has a better chance of incorporating the values of those affected, both for the purpose of securing acceptance of management priorities[131] and in terms of positive and negative geosystem services.[132] Access to the planning process, the relevant information, and to one another is critical. And because changes to the geosystem can have far-reaching and lasting impacts—through a watershed or aquifer, affecting downstream beneficiaries, neighboring properties, public water supplies, increasing flood risks, and so on—planning priorities should be coordinated across an area that may exceed jurisdictional boundaries. Hence, geosystem services planning should engage stakeholders throughout the serviceshed.

The focus on beneficiaries in geosystems analysis is what drives the more social features of environmental assessment,[133] as it recognizes the human need for and benefit from functional geosystem processes. More specifically, by using the natural services approach, we spend more energy thinking about what is important to people. Geosystem services involves a conversation that is important to community identity and sense of place.[134] Many trade offs involve services that are central to our norms and values, and some are controversial, such as where property rights are involved. Yet the engineering and construction decisions that dominate infrastructure investments are often made behind closed doors, or in vocabularies that do not easily translate into community priorities.

Communities and their local governments should be involved in understanding and prioritizing the anticipated losses of place-based resources. Without benefitting from the type of knowledge that only comes from experiencing local treasures, suffering local tragedies, navigating local costs, and enjoying local opportunities, environmental program managers are more likely to misunderstand cultural circumstances and approve geosystem trade offs that do not address social and cultural values.[135] Moreover, when communities are isolated from the decisionmaking process, there may be a tendency to act in defense of the local, as if in competition with other communities. Upstream and downstream communities may pursue competitive, rather than complementary, goals, and meaningful consideration of ecosystem trade offs is subject to local needs.[136] Being inclusive about resource planning gives the public an effective vocabulary, informs the public of trade off risks, and deepens into a sense of accountability.

This section offered objectives for a law governing geosystem services based on informational needs regarding geosciences and the geosystem, the overarching importance of geosystem functionality to human well-being, the manner in which the geosystem provides benefits, and the equity problems inherent in allocating rights to such critical natural systems. Additional research is needed to better connect piecemeal landscape changes to geosystem functionality. We need a better understanding of how the geosystem reacts to immediate and cumulative anthropocentric pressures, of where the limits of geosystem resiliency may lie, and in particular how shifts in geosystem processes may cause disruptions in geosystem services in the future.

In the meantime, conceptualizing the basic policy priorities for a regulatory scheme that governs geosystem services reveals the importance of information, planning, perspective, and equity. Like any law concerning natural systems, a system of geosystem services law should hold

129. *See* Daily et al., *supra* note 10, at 23 ("The main aim in understanding and valuing natural capital and ecosystem services is to make better decisions, resulting in better actions relating to the use of land, water, and other elements of natural capital.").

130. NESP Guidebook, *supra* note 117. The NESP Guidebook identifies the benefits of planning broadly:

> Incorporating ecosystem services into planning can improve efficiency, reveal tradeoffs, demonstrate win-win conservation solutions, and avoid mistakes that arise from management of a resource or specific ecosystem service in isolation. Without systematic identification and consideration of the connections between management and ecosystem services, some impacts (positive or negative) will be left out of the decision-making process. Unaccounted for, or externalized, costs and benefits can lead to poor decisions. This situation is most common when resources managed by an agency affect services not directly managed by that agency. By clarifying how all benefits—and any potential tradeoffs—effected by management choices have been considered by the agency, an ecosystem services approach may help generate support for agency actions and reduce conflict and litigation.

131. Deborah L. Myerson, Urban Land Institute, ULI Community Catalyst Report Number 1: Involving the Community in Neighborhood Planning (2004) ("With little or no planning occurring at the neighborhood level, local residents and stakeholders often become active only when proposed changes or persistent problems arise.").

132. Kremer et al., *supra* note 118 (suggesting that broad, serviceshed-scale planning can consider differential distributions of ecosystem benefits among groups and based on different scenarios).

133. G. Tracy Mehan III, *A Symphonic Approach to Water Management: The Quest for New Models of Watershed Governance*, 26 J. Land Use & Env't L. 1, 16 (2010) (In the watershed services context, Tracy Mehan notes, "If watershed management is going to be effective, it must address the human dimension as well as hydrology, soil science, biology, and water chemistry. For this reason, watershed governance requires reinventing the watershed as a social as well as a scientific reality.").

134. For explanation of the role of sense of place, see Hirokawa, *supra* note 78; Rosenbloom & Hirokawa, *supra* note 78.

135. Turlkelboom et al., *supra* note 87:

> The explanatory variables for observed ES relationships can be attributed to social, economic, institutional and ecological factors, which are also highly context-specific. Thus place-based studies are required which focus on the local specificities of trade off mechanisms, while taking into account both supply and demand. The involvement of local knowledge of experts and stakeholders is often the most efficient and reliable way to identify and explain ES trade-offs.

136. Millennium Ecosystem Assessment, *supra* note 90, at 451 ("Local authorities and their interactions with public, private, and civil society may play an important role in urban risk reduction to bridge the gap between national and international risk management players and local communities. But this implies a high level of municipal governance.").

accountable those actions that alter or disrupt natural processes, including those processes on which humans rely for life and well-being. A system of geosystem services law that acknowledges complexity and uncertainty, but addresses interconnectedness of natural processes over time, will be suited to identify poorly conceived projects.

III. Surveying the Landscape: Laws Governing the Use and Loss of Geosystem Services

As this Article turns to assessment of current geosystem governance, the challenge is obvious and apparent: there are presently no laws that provide prescriptive regulation of the values and interconnectivity reflected in critical zone science, that require a geosystems valuation to assist in determining the negative impacts from development activities affecting the geosystem, or that require an identification of geosystem beneficiaries or analysis of geosystem trade offs. There are no laws expressly allocating liability for disrupting geosystem processes that do or could provide services to people—at least, not because of the services themselves. Yet, the loss of geological services can be anticipated, regulated, and mitigated. This begs the question: how do we examine law to uncover those legal gems that have the capacity to govern geosystem services?

Although the literature on geosystem services tells a story of a still-emerging dialogue on valuing natural resources, the law illustrates some instances of heartfelt appreciation for the geosystem, even if such appreciation is limited to particular values. In some cases, law respects the value of geological products as found in the marketplace. Marketable minerals, such as hard rock, gems, and gold, valued as the price that willing (but not obligated) buyers would pay and willing (but not obligated) sellers would sell, are examples of geosystem provision services.

Evidence of other geosystem services, which are difficult (but not impossible) to value because they are not traded on the market,[137] nonetheless pervade the law. For instance, liquefaction, landslides, and sinkholes threaten a built environment that relies on slope stability. Imposing liability for rebuilding or reinforcing geologic support through artificial structures, as well as replacing the damage that is done by slope failure, can provide some estimate of value for the geologic features at issue. In like manner, the water-filtering services provided by soils, wetlands, and plants can be valued as the cost of capturing and filtering water through artificial means, or loss of soil productivity due to erosion can be estimated by the cost of importing topsoil to farmland.

Other geosystem services are incredibly difficult to value and difficult to regulate because of (among other things) the temporal aspects of geological processes. The expansion of temporal relevance demanded by this framework complicates the regulatory opportunities immensely. The consequences of an action might not surface for a long time, obscuring causation and regulatory proportionality.

For instance, the process of petroleum formation through deposits of organic matter, pressure, and heat is not immediate, but can take millions of years. Discharge of pollutants onto land may be transported through percolation and groundwater movement, but can remain subsurface for years before reaching a well or spring. The problem inherent with the temporal aspects of geological processes is the false sense that the negative consequences can be avoided or, worse, that such impacts are too speculative. As humans continue to extract and burn fossil fuels at an alarming rate, the question must be asked: how will humans manage when they reach the next ice age but do not have sufficient supplies of fossil fuels to mitigate the climatic circumstances?

Without the benefit of a coordinated or coherent legal approach to address the value of geosystem services or the trade offs that occur from land uses that interfere with geosystem benefits, this section examines a few illustrative examples in which geosystem values are or can be accommodated in the legal process, but where a choice of priorities or procedures prevents the law from presenting an effective tool for regulating geosystem services. We might imagine laws falling into the following categories: laws that focus on geological products to the exclusion of services; laws that engage in trade offs by protecting some geosystem benefits, but to the exclusion of other geosystem services; informational laws that fail to gather information on services and beneficiaries; land use laws as the piecemeal appreciation for use of the geosystem; and, finally, laws that subject geosystem services to the choices of individuals to the exclusion of common needs through the allocation of a property right.

A. Laws That Focus on Geological Products to the Exclusion of Services

In many instances, law narrows its view of the geosystem by focusing on geosystem products without accounting for services. Such a view precludes meaningful consideration of information on the risks of losing services, of the identity of geosystem beneficiaries, of trade offs among geosystem services, and of disruptions in geosystem services at different scales and over time. It is critical to see how laws governing the protection of geological resources result in objectification of the geosystem to the point of transforming the geosystem into a collection of products—even the geosystem itself as a product—thereby obviating any consideration or role of geosystem process, function, beneficiaries, or performance. In these laws, any appreciation of the geosystem is offset by the little regard it may have for the ongoing nature of geological processes that produce the desired product.

137. For instance, the value of slope stability and the support services that are provided by a functioning geologic structure could be measured by the cost of avoiding slope failure or the damages of such a failure, although the divide between the two values could be substantial.

1. Mining—Making Use of Production Services

One of the most commonly recognized geosystem services is production of goods—a service that provides wealth to those able to extract resources from the ground. Geologic resources once fueled the expansion and growth of the United States,[138] and mining contributes more than $232 billion to the gross domestic product.[139] Mining laws illustrate the importance of geosystems by valuing the extractive value of minerals over their value-in-place. Understandably, mining laws almost exclusively prioritize the consumption of geological production services to the exclusion of non-use geological benefits (or losses) or information relevant to that inquiry.

The Mining Law of 1872[140] declared federal lands holding "valuable mineral deposits" to be "free and open to exploration and purchase . . . by citizens of the United States" or those who intend to become citizens.[141] Since that time, the Mining Law has incentivized mineral exploration by offering rights to extract and profit from the discovered minerals and land ownership to the discoverer. The Act promotes diligence in exploration and extraction and disfavors letting mineral exploration sit idle.[142] Furthering this value process, the Mining Law allows for possession of a mining right to be gained by "possession and working of the claims for such a period" that is sufficient to establish a right to a claim.[143] To ensure easy access to the minerals, additional non-mineral land may be included in the mineral purchase if it is needed for "mining or milling purposes."[144] The Mining Law reaches many geologic products found in the earth, defining "valuable minerals" as "all minerals and mineral fuels including oil, gas, coal, oil shale and uranium,"[145] and encourages the private development of mineral resources by opening federal lands to mineral exploration.[146]

The challenge with mineral extraction is that the mere act of taking products from the natural geologic structure of the land may compromise the land's ability to support overlying structures or landforms. The Economics of Ecosystems and Biodiversity (TEEB) identifies the disruptions of natural services from mining operations as follows:

> The direct use of ecosystem services for mining and quarrying includes the need for freshwater supplies for mineral processing, which can be very significant. More often, the sector is associated with adverse impacts on biodiversity, due to habitat disturbance and conversion. The largest direct impacts result from surface mining, in which entire habitats and the geological features underlying them are removed during the period of extraction. In addition, the quarrying process can disturb plant and animal (and human) communities through noise, dust, pollution and the removal and storage of waste (tailings). Less direct but nonetheless significant impacts can come from the wider footprint of mining exploration, such as access roads that bring people into ecosystems where there has previously been little or no human presence, or the "honey pot" effect of increased economic activity attracting large numbers of workers, who may engage in other environmentally damaging activities (e.g. farming to supplement mining wages). Finally, the use and disposal of some heavy metals can have significant negative impacts on soils, water resources, animal and human health.[147]

Understanding these geologic tendencies informs geosystem priorities for law during and after extraction, a host of considerations that influence mining approval, permissible mining methods, and standards for post-mining reclamation plans.

The problem is that, for all of the property rewards funneled toward extraction of natural resources in the Mining Law, there is remarkably little consideration for impacts of mining to the geosystem structure and processes.[148] Indeed, the Mining Law of 1872 evidences no consideration of the adverse impacts of mining practices,[149] authorizes the collection of very little (such as royalties or patent fees) from the mining claimant (compared to the externalities of extraction), and otherwise encourages mining activities without requiring reclamation of the land. Instead, environmental concerns about mining have largely been borne by states.[150]

138. Andrea McDowell, *From Commons to Claims: Property Rights in the California Gold Rush*, 14 Yale J. L. & Human. 1, 2 (2002). *See also* U.S. Environmental Protection Agency, EPA's National Hardrock Mining Framework 1 (1997) (identifying hard-rock mining as a "basic building block[ ] of a modern society").

139. National Mining Association, The Economic Contributions of U.S. Mining (2012), at E-2 (2014), http://www.nma.org/pdf/economic_contributions.pdf.

140. 30 U.S.C. §§22 et seq.

141. *Id.* §22.

142. *Id.* §27 ("[F]ailure to prosecute the work on the tunnel for six months shall be considered as an abandonment of the right to all undiscovered veins on the line of such tunnel."). *See also id.* §28:

> [N]ot less than one hundred dollars' worth of labor shall be performed or improvements made during each year . . . for each one hundred feet in length along the vein. . . . [U]pon a failure to comply with these conditions, the claim or mine upon which such failure occurred shall be open to relocation in the same manner as if no location of the same had ever been made . . . .

143. *Id.* §38.

144. *Id.* §42(a).

145. *Id.* §21a.

146. *Id. See* Ronald Warren Tank, Legal Aspects of Geology 295 (1983). The main principles of the 1872 Act combined with more than a century of judicial interpretations are the basis for the general federal mining laws. *See* 30 U.S.C. §§21-50 (2012). Subsequent laws are more narrowly tailored to specific mining practices or areas.

147. TEEB, Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions, and Recommendations of TEEB 22 (2010).

148. Braden Murphy, *Note: Financial Assurance for Hardrock Mining: EPA and CERCLA*, 94 Notre Dame L. Rev. 1855 (2019).

149. 30 U.S.C. §21a (much later, in the Mining and Minerals Policy Act of 1970, the U.S. Congress established a national minerals policy that included a call for the development of disposal and reclamation processes "so as to lessen any adverse impact . . . upon the physical environment that may result from mining or mineral activities").

150. People v. Rinehart, 1 Cal. 5th 652, 46 ELR 20142 (Cal. 2016) (Mining Law does not preempt state environmental laws); Bohmker v. Oregon, 903 F.3d 1029, 48 ELR 20160 (9th Cir. 2018) (same). In contrast, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), 30 U.S.C. §1201, which was the first comprehensive statute governing coal mining, was intended to regulate the surface impacts from surface and subsurface coal mining. SMCRA is intended to "assure that surface mining operations

2. Archeological Finds—Benefitting From Access to History

Many of our geological resources have more value in place than when extracted: geosystem services also produce archeological resources by preserving history, identity, and knowledge in the ground, often hidden from view for centuries.[151] This geosystem service provides an intact history of human life and culture through capture and compression. The excavation of these resources threatens knowledge of the past and, as such, the value of geosystem services can be in competition with the very discoveries that give value to this service.[152]

The Archaeological Resources Protection Act (ARPA)[153] was adopted in 1979 to emphasize the role and importance of particular geological services to local and national identity.[154] The U.S. Congress identified "archeological resources" as "an accessible and irreplaceable part of the Nation's heritage."[155] "[F]or the present and future benefit of the American people," ARPA authorizes the protection of "cultural resources," "heritage resources," and "archaeological resources" against threats due to "uncontrolled excavations and pillage." Excavated materials are "of archaeological interest" if they are "capable of providing scientific or humanistic understandings of past human behavior . . . through the application of scientific or scholarly techniques."[156]

Accordingly, ARPA applies to "physical evidence of human habitation, occupation, use, or activity, including the site, location, or context in which such evidence is situated."[157] ARPA authorizes issuance of a "permit to excavate or remove any archaeological resource located on public lands or Indian lands and to carry out activities associated with such excavation or removal."[158] Permits may be issued "for the purpose of furthering archaeological knowledge in the public interest,"[159] and ownership of artifacts removed under ARPA is retained by the federal government.

Evidence of life and evolution is as important as culture, and it is subject to the same threats. The term "paleontological resource" is defined as "any evidence of fossilized remains of multicellular invertebrate and vertebrate animals and multicellular plants, including imprints thereof."[160] Such resources, often referred to more generally as "fossils," are an essential component of an education in natural history:

> Fossils provide the only direct means by which to measure the history of life on the Earth, which dates back as far as 3.5 billion years. This knowledge of the history of life on this planet has had a profound impact not only upon our understanding of the evolution of life and the ability to measure changes in the Earth's environments, but also upon human inquiry into our own existence in a perspective of time and evolution.[161]

In addition to the permitting requirement, the statute establishes civil and criminal liability for unlawful removal of this fragile geosystem service.[162] Notably, fines assessed under ARPA may be based on "archeological value," defined as a backward-looking estimate of "'what it *would have cost* the United States to engage in a full-blown archaeological dig at the site, notwithstanding the fact that the United States had no plans to engage in any such effort.'"[163]

Despite its far-reaching purposes, ARPA has found limited success in furthering the protection of history and culture served by the geosystem. First, ARPA only governs the intentional discovery and removal of archeological

are so conducted as to protect the environment," *id.* §1202(d), and identifies "[e]nvironmental protection performance standards," "applicable to all surface mining and reclamation operations," *id.* §1265(b). This statute was "enacted to strike a balance between the nation's interests in protecting the environment from the adverse effects of surface coal mining and in assuring the coal supply essential to the nation's energy requirements." Bragg v. West Va. Coal Ass'n, 248 F.3d 275, 288, 31 ELR 20582 (4th Cir. 2001) (citing 30 U.S.C. §1202(a), (d), (f)); *see also* Hodel v. Virginia Surface Mining & Reclamation Ass'n, 452 U.S. 264, 269, 11 ELR 20569 (1981). Whether SMCRA accomplishes that task is beyond the scope of this Article, but, like other natural resources statutes, it is limited enough that courts look to other statutes for consideration of environmental impacts from coal mining. *See, e.g.*, Sierra Club v. Powellton Coal Co., LLC, 662 F. Supp. 2d 514, 39 ELR 20199 (S.D. W. Va. 2009) (Clean Water Act enforcement in conjunction with enforcement under SMCRA).

151. Julie A. Hoggarth et al., *Integrating Human Activities, Archeology, and the Paleo-Critical Zone Paradigm*, 6 Frontiers Earth Sci. art. 84 (2018) (explaining that archaeology provides the best insights into the conditions in context in which human cultural practices have had an impact on surface and subsurface ecological conditions).
152. The focus on extraction activities could appear as overly broad, given that unextracted (in place) archeological treasures are less valuable, as they are less apt to be studied when left in the ground. Undoubtedly, Prof. Karrigan Börk is correct. However, the point here is that extraction of archeological resources results in a trade off: extraction of archeological finds, and their associated ground disruption, can result in interruption of other services, including undermining other cultural geosystem services. Where we statutorily authorize geological displacement to benefit from geosystem goods, we typically do so without regard for the impacts of harvesting on other services (which are deemed less valuable or simply ignored).
153. 16 U.S.C. §470aa.
154. *See* Francis P. McManamon, *Cultural Resources and Protection Under United States Law*, 16 Conn. J. Int'l L. 247, 265 (2001) ("The primary impetus behind ARPA was the need to provide more effective law enforcement to protect archaeological sites."); *see also* Roberto Iraola, *The Archaeological Resources Protection Act—Twenty Five Years Later*, 42 Duq. L. Rev. 221, 222-24 (2004).
155. 16 U.S.C. §470aa.
156. 43 C.F.R. §7.3(a)(1) (2021).
157. *Id.* §7.3(a)(2).
158. 16 U.S.C. §470cc(a).
159. *Id.* §470cc(b)(2).
160. 36 C.F.R. §261.2 (2013).
161. David J. Lazerwitz, *Bones of Contention: The Regulation of Paleontological Resources on the Federal Public Lands*, 69 Ind. L.J. 601, 604 (1994) (Congress recently authorized the protection of paleontological finds in the Paleontological Resources Preservation Act); *see also* 16 U.S.C. §§470aaa to 470aaa-11 (2012).
162. *See* Keith Cronin, *A Bone to Pick: The Paleontological Resources Preservation Act and Its Effect on Commercial Paleontology*, 7 Alb. Gov't L. Rev. 267 (2014) ("Although public interest in dinosaurs has waned since the 1990s, results from a recent private fossil auction suggest that the market for dinosaur fossils remains very strong."). Keith Cronin notes that "the development of the Internet as a global marketplace has increased the volume of fossils on the black market, and fossil poaching is now a very lucrative career path."
163. United States v. Wells, 873 F.3d 1241, 1269-70 (10th Cir. 2017) (quoting United States v. Hunter, 48 F. Supp. 2d 1283, 1288 (D. Utah 1998)) (particularly where market value is an inadequate measure of harm that may be caused).

resources from certain lands.[164] Moreover, laws governing archeological finds appear to be based on the idea that the present population *owns* history and the vessel of its documentation; ARPA is triggered by discovery of an archeological resource, and does not have regulatory impact on projects where geological circumstances might be optimal for preserving historical data (but as of yet there has been no discovery).[165] ARPA saves no space for how the geosystem might preserve the present as a historical resource, and it does not operate to protect the geosystem service of documenting human history.[166] It leaves as *damnum absque injuria* any allegations of harm caused by digging and removing the geological structures that have not yet provided this service. Hence, such a construct ignores geosystem services and the beneficiaries of such services, begging the conclusion that ARPA treats archeological finds as goods, rather than as the result of an ongoing process.[167]

B. Laws So Intended to Preserve Geosystem Services That Trade Offs Are Ignored

Similar to laws that prioritize ecosystem goods, some laws almost exclusively prioritize in-place geosystem services to the exclusion of other values. These preservation laws give little attention to trade offs and instead focus on the importance of protecting geosystem services from consumptive uses, including surface and subsurface land development. Of course, it is not surprising that law often excludes non-use values of the geosystem: seldom do prospective purchasers think of non-use as an added value, and less often do property owners apply to regulatory agencies for permission to leave geological assets in place and unused. Hence, without a process to explicitly consider the value of geosystem services, they are relegated to consideration during review of potential disruptions to such services, such as in excavation, construction, mining, and water withdrawal projects.

The 1906 Act for the Preservation of American Antiquities (Antiquities Act)[168] has acted as a counterbalance to the development and loss of cultural resources. Under the Antiquities Act, geosystem assets that provide cultural benefits are effectively removed from lands available for development, extraction, or other activities that might interfere with the receipt of geosystem benefits. The Antiquities Act authorizes the president to set aside "historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest" situated on federal land to be designated as national monuments.[169] Although Congress originally enacted the Antiquities Act to protect historic ruins and spiritually important sites from looting and excavation,[170] it has increasingly been used to protect unique, and often large, geologic features as well.[171] The Act confines designations "to the smallest area compatible with the proper care and management of the objects to be protected," yet the final bill did not include any restriction on the size of an area that can be designated as a national monument.[172]

Designation as a national monument results in protection from "any person who appropriates, excavates, injures,

164. In *San Carlos Apache Tribe v. United States*, 272 F. Supp. 2d 860 (D. Ariz. 2003), the district court of Arizona ruled that the planned drawdown of a reservoir for irrigation purposes that would expose Native American cultural items, including graves, was not in violation of nor would require a permit under ARPA. The court found that "[n]o ARPA permit is required to conduct activities on public lands when those activities are entirely for purposes other than the excavation or removal of archaeological resources." *Id.* at 888. Rather, ARPA "is clearly intended to apply specifically to purposeful excavation and removal of archeological resources, not excavations which may, or in fact inadvertently do, uncover such resources." *Id.* (citing Attakai v. United States, 746 F. Supp. 1395, 1410, 21 ELR 20433 (D. Ariz. 1990)).

165. ARPA has little impact on extractive activities, such as mining or similar actions, that might interfere with archeological resources if those activities are authorized by federal agencies as permits, leases, or licenses. In such cases, the activities may be subject to review under informational laws such as the National Environmental Policy Act (NEPA). Karuk Tribe of Cal. v. U.S. Forest Serv., 681 F.3d 1006, 42 ELR 20116 (9th Cir. 2012), *cert. denied*, 133 S. Ct. 1579 (2013) (recognizing that although the Mining Law authorizes a right to engage in mining activities, private activities are subject to multiple sources of authority, including environmental regulations such as the ESA).

166. Although ARPA and similar statutes do identify certain small artifacts for purposes of protection, we should also remember that ARPA also helps identify historical presence and occupancy of Native Americans on the land, identifies the manners in which such peoples interacted with the land and geosystem, and the values exhibited in those land use practices. There is so much more information to glean from the discovery of archeological resources, but ARPA does not speak to such values. On the other hand, an interesting counterexample might be found in contemporary rules governing recent artifacts such as old beer cans. *See* Blake DePastino, *At 50, Ring-Tab Beer Cans Are Now Officially Historic Artifacts*, W. Digs (Jan. 15, 2017), http://westerndigs.org/ring-tab-beer-cans-are-now-officially-historic-artifacts/; David Maxwell, *Beer Cans: A Guide for the Archaeologist*, 27 Hist. Archaeology 95 (1993).

167. Other examples of the objectification of cultural geosystem services only as geosystem goods include the Native American Graves Protection and Repatriation Act, 25 U.S.C. §§3001-3013 (governing the possession of Native American artifacts, including burial remains and sacred objects that are held by the federal government and that were discovered on federal lands); the National Museum of the American Indian Act, 20 U.S.C. §80q (governing Native American burial remains held by the Smithsonian Institution); the National Historic Preservation Act, 16 U.S.C. §§470 to 470x-6 (protecting certain historic resources by placing informational and stewardship responsibilities on federal agencies for sites listed on or eligible for listing on the National Historic Register); §4(f) of the Department of Transportation Act, 49 U.S.C. §303, 23 U.S.C. §138, 23 C.F.R. pt. 774 (2021) (offering some protection for cultural resources affected by projects within the jurisdiction of the U.S. Department of Transportation, such as highway construction and airport design and construction, including requiring an analysis of feasible alternatives to projects that would disrupt such resources).

168. 16 U.S.C. §§431-433.

169. *Id.* §431. While national monuments are often pictured as vast, beautiful, natural landscapes, the initial focus of the Antiquities Act was to preserve important "historic and prehistoric ruins" on small tracts of land. Christine A. Klein, *Preserving Monumental Landscapes Under the Antiquities Act*, 87 Cornell L. Rev. 1333, 1340 (2002). Although this initial purpose has been vastly expanded, spiritual and inspirational functions of geosystem services continue to be recognized as a main aspect of the Act. Declaring a national monument is about more than preserving pretty scenery, "it's about a whole, interwoven landscape[.] It's about communities that were . . . drawing their living and their inspiration and their spirituality from a landscape." Bruce Babbitt, *From Grand Staircase to Grand Canyon Parashant: Is There a Monumental Future for the BLU? Transcript Remarks: University of Denver College of Law Carver Lecture* (Feb. 17, 2000), *in* 3 U. Denv. Water L. Rev. 223, 227 (2000). This recognition of spiritual and historic values coupled with the ability to protect culturally important geologic landscapes opens the imagination on how geosystem services can interact with law.

170. Klein, *supra* note 169, at 1334.

171. *Id.*

172. 40 Cong. Rec. H7888 (1906) (comments of Rep. John Lacey).

or destroys" any important feature of the monument.[173] Specific excavation projects may be permissible, so long as they are designed to protect these places of spiritual and historic value from "commercial plundering."[174] Permits authorized at particular monuments are granted to museums, universities, or other scientific or educational institutions with a purpose of increasing the public knowledge of such objects to be excavated.[175] Valuing geology in place, instead of for the goods taken out of the land, is the unique aspect of the Antiquities Act.

The Antiquities Act has often been used as a first step to provide quick protection to unique landscapes without waiting for the approval of Congress or the National Park Service.[176] This allows for the protection of important landscapes in the face of imminent danger, because while "the President can act in a matter of weeks or months, congressional debate over landscape protection might continue for years or even decades."[177] Designation of an area as a national monument can be a first step toward Congress declaring such area as a national park.[178]

Although preservation under the Antiquities Act can be used to protect geosystem services, the Act is not ideal. On its face, the Antiquities Act authority is subject to the whim and discretion of the president.[179] A president who values the importance of geologic landscapes can wield the powers granted in the Antiquities Act to preserve many unique geosystem services.[180] On the other hand, when the president places little importance on protecting historic landscapes, the Act is either an unused tool that provides little opportunity to protect geological functions and processes[181] or, worse, the president might act under the auspices of Antiquities Act authority to remove such protections.[182]

The designation of Grand Staircase-Escalante National Monument illustrates the potential fragility of the Antiquities Act authority. Several areas of the monument bear the ruins and rock art of past societies, and were recognized as "provid[ing] a significant opportunity for archeological study."[183] President William Clinton set aside 1.7 million acres in southern Utah as the Grand Staircase-Escalante National Monument in 1996,[184] declaring that the "monument is a geologic treasure" that must be preserved for study and enjoyment by "geologists, paleontologists, archeologists, historians, and biologists."[185] This massive monument encompasses three distinct sections, each with its own geologic and historical features: the Grand Staircase, the Kaiparowits Plateau, and the Escalante Canyons.[186]

The Grand Staircase section, which has been home to humans since the Anasazi inhabited the land around 500 A.D., combines 200 million years of exposed geologic landforms in terrace-like steps that showcase multicolored cliffs, arches, and petrified dunes.[187] Encased in these landforms is a collection of historic remnants ranging from marine deposits to dinosaur fossils.[188] Geology on the Kaiparowits Plateau contains perhaps "the best and most continuous record of Late Cretaceous terrestrial life in the world."[189] The Canyons of the Escalante provide a maze of canyons in the arid desert with an unanticipated collection of lush riparian habitats.[190] And then, with a stroke of the pen, on December 8, 2017, President Donald Trump decreased the size of Grand Staircase by approximately 46% (800,000 acres)[191] and simultaneously reduced the size of Bears Ears

173. Barbara J. Van Arsdale, *Validity, Construction, and Application of Antiquities Act of 1906, et seq.*, 11 A.L.R. Fed. 2d 623 (2006).
174. *Id*. The punishment for anyone who "shall appropriate, excavate, injure, or destroy" any ruin from a national monument is up to a $500 fine and/or up to 90 days in prison. 16 U.S.C. §433.
175. 16 U.S.C. §432.
176. In 1916, Congress created the National Park Service, which is now responsible for designating national parks. New parks must have national significance, unique natural landscapes or resources, and possess some interpretive or educational potential. Robert B. Keiter, *The National Park System: Visions for Tomorrow*, 50 Nat. Res. J. 71, 74, 75 (2010).
177. Klein, *supra* note 169, at 1395.
178. Carol Hardy Vincent & Pamela Baldwin, Congressional Research Service, RL30528, National Monuments and the Antiquities Act: Recent Designations and Issues 4 (2000) (noting that more than one-half of the national parks were first designated as national monuments). In the few years after the Antiquities Act's enactment, President Theodore Roosevelt quickly took advantage of his new discretionary power by designating 17 national monuments, including the 808,120-acre Grand Canyon National Monument in 1908. Klein, *supra* note 169, at 1334-35.
179. *See* 16 U.S.C. §431 ("The President of the United States is hereby authorized, in his discretion, to declare by public proclamation historic landmarks . . . to be national monuments."). The use of the presidential power under the Antiquities Act has been well established in the position of the executive. Klein, *supra* note 169, at 1343 (noting that 14 of the 17 presidents during the 20th century utilized their power under the Act). Only twice in the history of the Act has Congress enacted any measures to curb the president's power. 16 U.S.C. §§431a, 3213. *See generally* Sanjay Ranchod, *The Clinton National Monuments: Protecting Ecosystems With the Antiquities Act*, 25 Harv. Env't L. Rev. 535 (2001); Mark Squillace, *The Monumental Legacy of the Antiquities Act of 1906*, 37 Ga. L. Rev. 473 (2003) (arguing President William Clinton's expansive designation of monuments may have overstepped the legislative purpose of the Antiquities Act).
180. President Franklin Roosevelt used his power under the Antiquities Act more than any other president, preserving 28 national monuments. *See* National Park Service, *National Monument Facts and Figures*, https://www.nps.gov/subjects/archeology/national-monument-facts-and-figures.htm (last updated Mar. 15, 2022).
181. *See* Carol Hardy Vincent, Congressional Research Service, National Monuments and the Antiquities Act 1 (2021), http://www.fas.org/sgp/crs/misc/R41330.pdf ("Presidents who have not used this authority are Richard M. Nixon, Ronald Reagan, [and] George H.W. Bush.").
182. John E. Echohawk, *President Trump's Bears Ears Order Is an Illegal Attack on Tribal Sovereignty*, HuffPost (Dec. 4, 2017), https://www.huffpost.com/entry/trump-bears-ears-tribal-sovereignty_b_5a25b663e4b03c44072fcc02.
183. Proclamation No. 6920, 16 U.S.C. §431 (Jan. 1, 1997), *available at* http://www.presidency.ucsb.edu/ws/index.php?pid=51948 ("As witnesses to the past, these relict areas establish a baseline against which to measure changes in community dynamics and biogeochemical cycles in areas impacted by human activity."). In addition to the unique geologic and historical components of the Grand Staircase-Escalante, the monument also provides "some of the most outstanding hiking opportunities to be found on earth." Utah.com, *Escalante Canyon*, http://www.utah.com/playgrounds/canyons_of_escalante.htm (last visited Mar. 12, 2022).
184. James R. Rasband, *Utah's Grand Staircase: The Right Path to Wilderness Preservation?*, 70 U. Colo. L. Rev. 483, 483 (1999). Since its creation, the monument has been expanded to nearly 1.9 million acres. Utah.com, *Grand Staircase-Escalante National Monument*, http://www.utah.com/nationalsites/grand_staircase.htm (last visited Mar. 12, 2022).
185. Proclamation No. 6920, *supra* note 183.
186. Utah.com, *supra* note 184.
187. *Id*.
188. *Id*.
189. *Id*.
190. *Id*.
191. 82 Fed. Reg. 58089 (Dec. 8, 2017). *See also* John D. Leshy, *Public Land Policy After the Trump Administration: Is This a Turning Point?*, 31 Colo. Nat. Res. Energy & Env't L. Rev. 471, 488 (2020); Colin Dwyer, *Trump Administration Finalizes Plans to Allow Development on Downsized Monuments*, Nat'l Pub. Radio (Feb. 6, 2020) https://www.npr.

by 85% (1.1 million acres).[192] It remains unclear whether the president is authorized to remove national monuments from designation.

A second, more systemic challenge of the Antiquities Act concerns the role of interests (and risks) relevant to a designation. The exercise of executive power under the Antiquities Act has seen persistent conflict between local prerogative and the nationalization of scientific interest and cultural symbols.[193] In these disputes, local values and perspectives are typically undermined in the designation and protection process—which may ignore how geosystem services provide benefits (and where those benefits are received). On the one hand, given the remoteness of many Antiquities Act designations, there is less concern that establishing a monument will unduly burden local economies.[194]

On the other hand, critiques of Antiquities Act designations typically tout local needs, particularly where those needs are based on natural resources extraction.[195] Consider, for instance, the battle brought by timber interests against the expansion of Cascade-Siskiyou National Monument,[196] or the "land grab"[197] rhetoric in opposition to the Bears Ears designation.[198] Yet, although negative reactions to vast tracts of land in the Jackson Hole National Monument in Wyoming and the Wrangell-St. Elias National Monument in Alaska have resulted in amendments to the Antiquities Act,[199] courts have avoided limiting executive authority,[200] perhaps suggesting that the value of geosystem appreciation will be shielded from political review.

The appropriate response to this dilemma is that the Antiquities Act could facilitate a reasoned collaboration about trade offs between local development priorities and the cultural geosystem benefits that are identified at a national level.[201] Local perspectives and values do not need a super-priority in the antiquities designation process—but they do need a voice and a process for that voice to be meaningfully considered.

C. Informational Laws That Could Require Information on Services and Beneficiaries

A system of geosystem services law would require an understanding of the geosystem processes and beneficiaries at stake before the shovel hits the ground. The National Environmental Policy Act (NEPA)[202] of 1969 appears to be an excellent vehicle for gathering and disseminating information about ecosystem services and beneficiaries.[203] Through NEPA, Congress mandated consideration of "the interrelations of all components of the natural environment," "in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[204] To implement this duty, Congress directed federal agencies to

> (A) utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decisionmaking which may have an impact on man's environment; and
>
> (B) identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by title II of this Act, which will *insure that presently unquantified environmental amenities and values may be given appropriate consideration in decisionmaking along with economic and technical considerations*.[205]

In *Idaho Conservation League v. U.S. Forest Service*, the court faced a challenge to a U.S. Forest Service decision that alleged the Forest Service failed to take a "hard look"

org/2020/02/06/803467297/trump-administration-finalizes-plans-to-allow-development-on-downsized-monuments.

192. 82 Fed. Reg. 58081 (Dec. 8, 2017); Richard H. Seamon, *Dismantling Monuments*, 70 Fla. L. Rev. 553 (2018).

193. *See, e.g.*, Utah Ass'n of Counties v. Clinton, 255 F.3d 1246, 1248, 31 ELR 20796 (10th Cir. 2001) (plaintiffs alleged that the creation of the Grand Staircase monument was intended to interfere with a coal mine); *dismissed in* Utah Ass'n of Counties v. Bush, 316 F. Supp. 2d 1172 (D. Utah 2004).

194. *See* Paul M. Jakus & Sherzod B. Akhundjanov, *The Antiquities Act, National Monuments, and the Regional Economy*, 95 J. Env't Econ. Mgmt. 102 (2017) (arguing that because most monument areas do not otherwise contribute too much to local economies, converting them to monuments under the Antiquities Act does not have more than a marginal economic impact).

195. For instance, one Salt Lake City publication declared, "We need to recognize these monuments for what they are: a special-interest boondoggle that sacrificed local populations and the American taxpayers to appease the demands of quasi-religious special-interest groups that the land be cleansed of humanity." Klein, *supra* note 169, at 1335 (quoting Rainer Huck, *Clinton's Monument Designations Must Not Be Allowed to Stand*, Salt Lake Trib., Mar. 23, 2001, at A15).

196. Proclamation No. 9564, 82 Fed. Reg. 6145 (Jan. 12, 2017); *see* Leila Javanshir, *Even President Obama Makes Mistakes: Why Expansion of the Cascade-Siskiyou National Monument Was Improper*, 42 Seattle U. L. Rev. 1509 (2019).

197. Andrew Diaz, *The Transformation of the Antiquities Act: A Call for Amending the President's Power Regarding National Monument Designations*, 49 Golden Gate U. L. Rev. 117 (2018).

198. Proclamation No. 9558, 82 Fed. Reg. 1139 (Dec. 28, 2016).

199. Congressional approval is now required for any designation of a national monument in Wyoming, or any area exceeding 5,000 acres in Alaska. 16 U.S.C. §§431a, 3213.

200. The five judicial decisions in the Act's first 100 years refused to limit the executive's power, leaving the determination to do so up to Congress. *See* Klein, *supra* note 169, at 1346. Arguably, one of the few ways a president's power is limited is that after an area is established as a national monument, "the president is thereafter without authority to abolish such reservation." 39 Op. Att'y Gen. 185, 186-87 (1938) (Opinion of Hon. Homer Cummings).

201. A similar observation might be made regarding designations under the Wild and Scenic Rivers Act, the Wilderness Act, and the National Park Service programs.

202. 42 U.S.C. §§4321-4370h, ELR Stat. NEPA §§2-209.

203. *See id.* §4332; 30 U.S.C. §1232. NEPA encourages agencies to identify and require measures designed to mitigate the environmental impacts that development projects may have. NEPA requires an environmental impact statement (EIS) for any "major Federal actions significantly affecting the quality of the human environment." 42 U.S.C. §4332(c). NEPA has largely been deemed a procedural statute.

204. 42 U.S.C. §4331(a).

205. *Id.* §4332(A), (B) (emphasis added). NEPA also expressly recognizes the "worldwide and long-range character of environmental problems," the need for "international cooperation in anticipating and preventing a decline in the quality of mankind's world environment," and the need to acknowledge "the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity." *Id.* §4332.

under NEPA when it determined that a gold mining project would not contaminate groundwater in and around Dog Bone Ridge.[206] The mining company's environmental assessment noted that the region of the proposed site was *generally* composed of highly porous rock. It was believed that water from Dog Bone Ridge was to likely drain into the nearby Corral Creek, but neither the Forest Service nor the mining company knew how much water drained into the creek. The Forest Service declined to require further hydrogeological monitoring of Dog Bone Ridge, despite the uncertainty regarding groundwater contamination.

As the court noted, NEPA at least requires agencies to wield sufficient information to understand the likely adverse impacts from a particular project: "baseline data is crucial to the monitoring program to provide a basis for comparison—without a baseline the agency will not know when conditions are deteriorating."[207] The Forest Service should have used its "expertise to determine whether this general hydrogeology was actually present in the Dog Bone Ridge drainage or to estimate its presence by comparison to" hydrogeologic conditions on the opposite side of the project.[208] The Forest Service therefore did not satisfy NEPA's "hard look" standard when it examined general impacts on groundwater quality in the Dog Bone Ridge drainage.[209]

NEPA, which requires agencies to analyze all direct, indirect, and cumulative impacts from proposed actions, also mandates that all policies, regulations, and public laws of the United States "shall be interpreted and administered in accordance with the policies set forth in this Act."[210] Moreover, NEPA requires analysis of adverse impacts *and also beneficial impacts* (of which ecosystem services provides an ideal platform).[211] As Robert Fischman has observed, "[v]aluation of ecosystem services is exactly the kind of assessment NEPA envisions, providing a means to inform the public and decision-makers about what we stand to gain or lose in several alternative scenarios."[212] Moreover, NEPA could, in theory, give attention to geological features that are not otherwise afforded value or protection under a specific statutory or regulatory program, such as biodiversity, glaciers, small and isolated wetlands, or many sand dunes.

Notwithstanding the foregoing, NEPA has not yet lived up to its potential as an ecosystem or geosystem services mechanism.[213] Of course, many courts have required searching environmental inquiries where impacts (including geological impacts) were ignored by federal[214] and state[215] agencies. Some local and federal agencies have committed to engaging in ecosystem services analyses, both at the programmatic level and in particular cases.[216]

206. *See* 429 F. Supp. 3d 719 (D. Idaho 2019).
207. *Id.* at 730-31.
208. *Id.*
209. *Id.* (quoting Idaho Conservation League v. U.S. Forest Serv., No. 1:11-CV-00341-EJL, 2012 WL 3758161 (D. Idaho Aug. 29, 2012)) (failure to establish a baseline hydrogeologic study to "examine the existing density and extent of bedrock fracture, [to examine] the hydraulic conductivity of the local geologic formations, and [to] measure [ ] the local groundwater levels to estimate groundwater flow directions before making a determination of no impact") (internal quotation marks omitted). In contrast, the court found that the Forest Service did not violate NEPA when it determined that proposed roads for the mining project "would not pose a significant risk of landslides, slope failures, or erosion." Here, the Forest Service based its determination on a report prepared by a slope specialist that considered all of the soils in the project area and prepared guidance and standards for slope stability in different areas. The Forest Service's decision to examine the different soils across the project area as opposed to making a general determination made its conclusion adequate under NEPA.
210. 42 U.S.C. §4332.
211. Dinah Bear explains:

> CEQ's [Council on Environmental Quality's] regulations explain that the effects to be analyzed under NEPA "include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial." [citing 40 C.F.R. §1508.8(b)] This stipulation is important for three reasons: (1) the characterization of an effect may vary with an individual's perspective; (2) even an action intended to improve the environment may benefit from an analysis of alternative ways of achieving that goal; and (3) ultimately, decision makers must make a judgment about the benefits versus the negative impacts of a proposal. The commonplace but faulty belief that NEPA applies only to adverse impacts undermines analysis of the value of ecosystem services and the impacts that a proposed action and alternative actions would have on them in the context of an EIS or environmental assessment.

Dinah Bear, *Integration of Ecosystem Services Valuation Analysis Into National Environmental Policy Act Compliance: Legal and Policy Perspectives*, *in* NESP Guidebook, *supra* note 117, at 12.
212. Robert L. Fischman, *The EPA's NEPA Duties and Ecosystem Services*, 20 Stan. Env't L.J. 497, 501 (2001).
213. This might be in contrast to the informational projects undertaken by the USGS, such as mapping fossil fuel reserves, soil types, and groundwater resources.
214. *See, e.g.*, New York v. Nuclear Regul. Comm'n, 681 F.3d 471, 42 ELR 20124 (D.C. Cir. 2012) (taking issue with finding that reasonable assurances existed that geologic capacity to dispose of nuclear waste would be available when necessary); Center for Biological Diversity v. Bureau of Land Mgmt., 937 F. Supp. 2d 1140, 43 ELR 20076 (N.D. Cal. 2013) (reversing issuance of an oil and gas lease for intentional omission of the potential impacts from hydrofracking and horizontal drilling technologies); Oak Ridge Env't Peace All. v. Perry, 412 F. Supp. 3d 786 (E.D. Tenn. 2019) (requiring agency to supplement environmental review when the USGS published a map showing increased risk of earthquake activity after the U.S. Department of Energy prepared NEPA documents on the Department's plan to modernize a national security complex at which it manufactured and processed enriched uranium); Cowpasture River Pres. Ass'n v. Forest Serv., 911 F.3d 150, 49 ELR 20204 (4th Cir. 2018) (court rejected agency's analysis of impacts of pipeline construction impacts for failure to give a hard look at landslide risks, erosion, and water quality), *rev'd on other grounds*, 140 S. Ct. 1837 (2020); Holy Cross v. U.S. Army Corps of Eng'rs, 455 F. Supp. 2d 532, 36 ELR 20208 (E.D. La. 2006) (ordering supplemental environmental review and finding that Corps failed to take a "hard look" at the environmental consequences of dredging and sediment disposal following the catastrophic events of Hurricane Katrina); Natural Res. Def. Council, Inc. v. U.S. Army Corps of Eng'rs, 399 F. Supp. 2d 386 (S.D.N.Y. 2005) (ordering supplemental review of impacts from a dredging project); Burkey v. Ellis, 483 F. Supp. 897, 10 ELR 20305 (N.D. Ala. 1979) (invalidating agency environmental review of a river channelization project for lack of transparency and consideration of costs and benefits, including downstream flooding and erosion); Akers v. Resor, 443 F. Supp. 1355, 8 ELR 20388 (W.D. Tenn. 1978) (finding failure to take a hard look in stream realignment project for failure to consider cumulative impacts, particularly flooding risks).
215. *See, e.g.*, Kutzke v. San Diego, 218 Cal. Rptr. 3d 206 (Cal. Ct. App. 2017) (upholding city's denial of subdivision application in light of expert evidence showing deficiencies in the project's geotechnical report regarding safety of project on a steep sandstone hillside); California Oak Found. v. Regents of Univ. of Cal., 115 Cal. Rptr. 3d 631 (Cal. Ct. App. 2010) (finding draft environmental impact report adequate that provided in-depth look at baseline geologic conditions, including the likelihood of archeological findings, in construction of university athletic facility close to fault line).
216. Keith H. Hirokawa & Charles Gottlieb, *Sustainable Habitat Restoration: Fish, Farms, and Ecosystem Services*, 23 Fordham Env't L. Rev. 1 (2012) (detailing the use of ecosystem services analysis during the local environmental review process for the proposed breach of a water control feature for salmon reintroduction).

However, on the whole, courts have demonstrated some reluctance to require an ecosystem services analysis under existing informational mandates.[217] Although environmental impact assessments often delve deeply into biophysical and hydrological impacts to ecosystems, "[s]uch assessments typically do not frame impacts in terms of the delivery of goods and services or the value of these services."[218] NEPA has not yet made a significant impact on geosystem services information-gathering practices, perhaps due to a misunderstanding of NEPA,[219] lack of familiarity with ecosystem service concepts, lack of demand for ecosystem services analysis, and lack of agency capacity to undertake the analysis.[220] NEPA's potential remains untapped.

D. Land Use Laws as the Piecemeal Appreciation for Use of the Geosystem

Another promising category of laws surveyed in this Article involves local governments and a host of different opportunities to address geosystem services at the local level.[221] Local law is particularly relevant because of the convergence of natural services and the manner in which local regulations relate to the values of those services: because many of the benefits of geosystem services are enjoyed by those in close proximity to the geological structure or process that provides the benefits, the appropriate regulation and allocation of geosystem services are always a matter of local concern.[222] Second, because managing environmental risks and benefits is the majority of what local governments do, geosystem services is a matter of local governance.[223] Finally, geosystem management may require the tools that local governments already wield.[224]

Pursuant to their police powers, local governments adopt land use regulations to protect the public health, safety, and welfare.[225] Many states and municipalities have adopted grading and excavation regulations to reduce and manage the negative impacts of human development on existing geologic and hydrologic structures.[226] Local ordinances may restrict encroachment of buildings on steep slopes, control erosion risks through construction techniques and vegetation replacement,[227] or enhance aquifer recharge by limiting impermeable surfaces.[228] Some such regulations serve the specific purpose of protecting altered land from catastrophic slope failures,[229] while others focus on water quality or flooding.[230] In some areas, local governments have implemented zoning and land use planning schemes to prevent development of lands that have productive soils[231] or offered tradable development rights to preserve prime soils.[232]

Of course, local governance of geosystem services is subject to the common list of criticisms of parochial local governance.[233] Local governments often appear uncoordinated across jurisdictional boundaries, underfunded, unsophisticated, and disinterested in geological resources, all of which severely undermine the ability of a local government to effectively regulate geosystem changes.[234] More importantly, local governments, as creatures of the state,[235] typically separate the relevant considerations in an application into the variety of regulatory programs they are required to (or opt to) implement: a road project might be reviewed for compliance with excavation standards (how much soil will be moved), stormwater standards (how much extra surface flow will result), and wetland standards (how much of the wetlands will be dredged or filled) to determine whether the application meets the individual permit requirements—

217. *See, e.g.*, Fischman, *supra* note 212, at 507; Hirokawa & Porter, *supra* note 91.
218. Stephen Polasky et al., *Setting the Bar: Standards for Ecosystem Services*, 112 PNAS 7356, 7360 (2015).
219. This is in addition to the Trump Administration's effort to amend NEPA regulations to omit consideration of cumulative impacts, collapse the distinction between direct and indirect impacts, and (importantly) omit the agencies' obligation to take a hard look at probable impacts if those impacts fall into the jurisdiction of another agency.
220. Bear, *supra* note 211.
221. This Article does not address the potential of wetlands regulations under the Clean Water Act to account for geosystem services. For analysis of wetlands regulations, see Ruhl & Gregg, *supra* note 95; *see also* Hirokawa, *supra* note 95.
222. For an explanation of the roles of place and proximity for identifying ecosystem service beneficiaries, see Keith H. Hirokawa, *Sustaining Ecosystem Services Through Local Environmental Law*, 28 Pace Env't L. Rev. 760 (2011).
223. *Id.*
224. *Id.*
225. Euclid v. Ambler Realty Co., 272 U.S. 365 (1926).
226. *See, e.g.*, New York Department of Environmental Conservation, New York State Standards and Specifications for Erosion and Sediment Control (Blue Book) (2016), http://www.dec.ny.gov/chemical/29066.html. Many local governments have adopted an ordinance to reduce the impacts of soil compaction. Soil compaction is regulated to reduce adverse conditions for vegetation and groundwater flow. Compaction results in soils that are difficult for trees to penetrate to an appropriate depth, construct healthy root systems, or absorb water and nutrients from the ground, thereby making trees and other vegetation vulnerable to a host of threats. *Soil Requirements of Healthy Urban Trees*, GreenBlue Urb. (Feb. 1, 2015), https://perma.cc/WYU6-NJF4. Compacted soil can obstruct percolation and groundwater flow. Conversely, soils left in place (not compacted) can help manage stormwater flows, recharge aquifers, cycle nutrients, and provide support and regulatory functions that help vegetation establish and grow. Local governments have adopted ordinances regulating land disturbance through site plan review, stormwater regulations, and grading and excavation regulations. *See, e.g.*, Bass River Township, N.J., Code of Ordinances §13.08.260 (2007) (site review); Albert Lea, Minn., Code of Ordinances §74-2027(2)(h) (2015) (banning equipment from driving over areas designated as a future site for runoff flows in order to prevent soil compaction).
227. City of Portland, Oregon, Natural Resource Inventory Update: Riparian Corridors and Wildlife Habitat (2012), https://www.portland.gov/sites/default/files/2020-02/oct2012_adopted_nriu_projectreport.pdf.
228. Center for Watershed Protection, Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds 2.3 (reprt. 2001) (1998).
229. New York Department of Environmental Conservation, *supra* note 226.
230. Vei Zhang et al., *Ecosystem Services and Dis-Services to Agriculture*, 64 Ecological Econ. 253, 255 (2007).
231. Dennis J. McEleny, *Using Transferable Development Rights to Preserve Vanishing Landscapes and Landmarks*, 83 Ill. B.J. 634 (1995).
232. Montgomery County, Md., Code §4.9.18 (2018) (protects farmland in the county through the Transfer of Development Rights Program).
233. *See, e.g.*, Richard L. Revesz, *The Race to the Bottom and Federal Environmental Regulation: A Response to Critics*, 82 Minn. L. Rev. 535 (1997); Daniel C. Esty, *Revitalizing Environmental Federalism*, 95 Mich. L. Rev. 570 (1996).
234. Blake Hudson, *Land Development: A Super-Wicked Environmental Problem*, 51 Ariz. St. L.J. 1123, 1141 (2019).
235. For an explanation of Dillon's Rule and its impact on governance, see Charles R. Adrian & Ernest S. Griffith, A History of American City Government: The Formation of Traditions, 1775-1870, at 29 (1976).

but without consideration of how the resulting stormwater flows would not be mitigated because of the lost wetlands, and without consideration of how those impacts would affect topography and slope stability.

This, of course, is the lesson that the geosciences offer in framing the geosystem as the multitude of interacting forces and processes with the critical zone. However, from the perspective of geosystem services, the many relevant laws create relatively distinct and independent legal systems to govern the same services. Across the spectrum of local entities, it appears that, at best, law has capacity to consider geosystem services only in a patchwork, fragmented manner.[236] On the other hand, there are examples of ordinances that suggest local governments are extremely well-placed to intervene in matters involving our dependence on geosystem services and regulate to protect geosystem expectations.

1. Protecting the Productive Capacity of Soils

One of the primary causes of loss of productive soils is land development, amounting to more than 30 million acres of development converted from farmland since 1982.[237] Other disruptions in soil productivity include contamination, compaction, and unsustainable farming practices.[238] In addition, billions of tons of topsoil are washed off of the land every year from surface runoff and erosion, a challenge that is exacerbated by the frequency and intensity of storms due to climate change.[239] Protecting the ability of the geosystem to support agricultural productivity is a significant service to human needs and is vital to local and national economies alike.

Local governments have tried several different approaches to discourage or prevent activities that interfere with soils. For instance, some local governments protect prime soils on a more piecemeal basis. Some ordinances identify areas suitable for open space designations based on soil capacity classification.[240] Some ordinances limit the area of a lot that can be disturbed[241] or require setbacks from agricultural lands. Others create a preference for development on non-prime soils.[242]

Oregon's land use planning scheme requires local governments to adopt and update comprehensive plans that address a detailed list of statewide planning goals. Goal 3,[243] which addresses agriculture, is an essential component of the state's economy and identity:

> The preservation of a maximum amount of the limited supply of agricultural land is necessary to the conservation of the state's economic resources and the preservation of such land in large blocks is necessary in maintaining the agricultural economy of the state and for the assurance of adequate, healthful and nutritious food for the people of this state and nation.[244]

Oregon regulations define "agricultural lands" as lands with designated classifications under the Soil Capability Classification System of the U.S. Soil Conservation Service, "and other lands which are suitable for farm use taking into consideration soil fertility, suitability for grazing, climatic conditions, existing and future availability of water for farm irrigation purposes, existing land-use patterns, technological and energy inputs required, or accepted farming practices."[245] Under Goal 3, counties are required to identify and designate farmland through the comprehensive planning process, then adopt an "exclusive farm use" (EFU) to protect such lands from conversion to other uses. Lands in an EFU zone "shall be used exclusively for farm use except as otherwise provided."[246] Removing development restrictions on farmland requires a high burden of showing that land is not farmable.[247]

2. Geosystem as a Critical Area

Under Washington's Growth Management Act (GMA), local governments are required to engage in critical areas planning, defined in the Act to include wetlands, aquifer recharge areas, fish and wildlife conservation areas, frequently flooded areas, and geologically hazardous areas.[248] Local governments are required to use best available sci-

236. A. Dan Tarlock, *Land Use Regulation: The Weak Link in Environmental Protection*, 82 Wash. L. Rev. 651, 654-57 (2007).
237. Lori Sallet, *American Farmland Trust: 2018 Farm Bill a Victory for Farmland Protection, Environmentally Sound Farming Practices, and Keeping Farmers on the Land*, Am. Farmland Tr. (Dec. 11, 2018), https://perma.cc/G4PW-9NWW.
238. Food and Agriculture Organization of the United Nations, *Healthy Soils Are the Basis for Healthy Food Production*, https://perma.cc/29AQ-AVMX (last updated Feb. 19, 2015) ("When the soil is exploited for crop production without restoring the organic matter and nutrient contents, the nutrient cycles are broken, soil fertility declines and the balance in the agro-ecosystem is destroyed.").
239. American Farmland Trust, *Amazing Grass*, https://perma.cc/63U2-BH4N (last visited May 29, 2020).
240. Tewksbury Township, N.J., Development Code §723.3 (2004) (promoting agricultural preservation while creating subdivisions, and protecting prime soil from exploitation, with at least 75% of each tract designated as open land, and providing within those open lands "[at] least 65% . . . shall be non-critical areas and prime agricultural soils, soils of Statewide importance, or tillable soils").
241. Many local governments require cluster zoning, which requires denser development on a smaller portion of a property to conserve open space. *See, e.g.*, Whitman County, Wash., Code of Ordinances §19.10.110 (2015).
242. Elk Township, Pa., Zoning Ordinance §702(b)(4)(a)-(c) (2012) (to protect prime, farmable soil, subdivision proposals on prime soil in agricultural zones must overcome presumption that development on non-prime soils is not feasible).
243. Or. Admin. R. 660-015-0000(3) (2008).
244. Or. Rev. Stat. §215.243 (1973).
245. Or. Admin. R. 660-015-0000(3) (2008). For background on soil classifications and the relevance of soil erodibility, see Douglas Helms, Readings in the History of the Soil Conservation Service 60-73 (1992).
246. Or. Rev. Stat. §215.203 (1979). For a history of the protection of farmland in Oregon, see Myrl L. Duncan, *Agriculture as a Resource: Statewide Land Use Programs for the Preservation of Farmland*, 14 Ecology L.Q. 401 (1987); Edward Sullivan & Ronald Eber, *The Long and Winding Road: Farmland Protection in Oregon 1961-2009*, 18 San Joaquin Agric. L. Rev. 1 (2008/2009).
247. *See, e.g.*, Rhinhart v. Umatilla Cnty., 53 Or LUBA 402 (2007) (the mere existence of challenges to farm property are not sufficient to except from Goal 3 (agricultural lands)). *But see* Peterson v. Crook Cnty., 52 Or LUBA 160 (2006) (land of water rights and persistent irrigation problems were sufficient to support finding that land was not suitable for farm use).
248. Wash. Rev. Code §36.70C (2010); *id.* §36.70A.030.

ence in designation and protection of critical areas.[249] One such critical area, referred to as "geologically hazardous areas," is defined in the GMA as those areas that, "because of their susceptibility to erosion, sliding, earthquake, or other geological events, are not suited to the siting of commercial, residential, or industrial development consistent with public health or safety concerns."[250] Echoing the notion that "earthquakes don't kill people, buildings do," many Washington local governments have addressed geological hazards by adopting steep slope regulations and detailed structural building requirements in seismic and earthquake codes.[251]

Clark County, Washington, distinguishes several types of critical areas in its geological hazards ordinance: steep slope hazard areas, landslide hazard areas, seismic hazard areas, and volcanic hazard areas.[252] Clark County's ordinance regulates "all construction, development, earth movement, clearing, or other site disturbance which requires a permit, approval or authorization from the county in or within one hundred (100) feet of a geologic hazard area," subject to a few exceptions.[253] The ordinance recognizes that, despite past and ongoing attempts to inventory and map a variety of hazards throughout the county, geological hazards may have been created through human activities (such as clearing and grading) over time, and, as such, a site-specific analysis may be required.[254]

In general, land developments in geological hazard areas are required to manage erosion potential, and are not permitted to treat stormwater by infiltration due to the increased risks of slope destabilization.[255] The characteristics of steep slopes are reviewed by county engineers to make sure that improvements do not create or exacerbate landslide risks, and applicants for development are required to leave slope vegetation in place and build outside of setbacks from vegetated buffers.[256] In areas presenting landslide hazards, the county may require permanent protection by identification on site plans and execution and recordation of a conservation covenant that prohibits further development or clearing in the designated area.[257] However, compliance is incentivized by possible tax incentives or density transfers.[258]

A second of Clark County's relevant critical areas programs, known as the Critical Aquifer Recharge Protection program, concerns threats to groundwater quality.[259] The county's ordinance aims to "prevent[ ] degradation, and where possible, enhance the quality and quantity of groundwater which will be, or might likely be, used in the future for drinking water or business purposes."[260] The ordinance regulates a wide array of industrial activities and their associated discharges and hazardous wastes, but also includes less obvious activities such as golf courses. Other uses that commonly impact groundwater quality, such as landfills, cesspools, and surface mining, are prohibited in certain recharge areas.

Permit applicants under the Critical Aquifer Recharge Protection program "must demonstrate . . . how they will integrate necessary and appropriate best management practices (BMPs) to prevent degradation of groundwater."[261] Although BMPs are encouraged, applicants can avoid implementing BMPs with an engineering certification that their projects will not degrade groundwater quality. The engineer's report must include an evaluation of groundwater impacts from the proposed development based on the profile of the property's geologic and hydrologic characteristics.[262] Hence, the ordinance does contemplate that the applicant's performance may alleviate the need for an understanding of the physical characteristics of the property.[263] In addition, the ordinance offers tax credits for leaving land pervious and voluntary land exchanges in areas that are critical for groundwater recharge.[264]

249. *Id.* §36.70A.172.
250. *Id.* §36.70A.030.
251. *See* Federal Emergency Management Agency, *Seismic Building Codes*, https://www.fema.gov/emergency-managers/risk-management/earthquake/seismic-building-codes (last updated July 1, 2021).
252. Clark County, Wash., Unified Development Code §40.430.010.B.1, .C (2021).
253. *Id.* §40.430.010B.1.
254. *Id.* §40.430.010.D.2.
255. *Id.* §40.430.020.B, .C.
256. *Id.* §40.430.020.A.1.
257. *Id.* §40.430.030.B.
258. *Id.* §40.430.010.G, .H.
259. Although Clark County's ordinance focuses on contamination, in the state of Washington, water supply planning results from coordination among several statutory schemes. The Watershed Planning Act (Wash. Rev. Code ch. 90.82 (1997)) establishes the geographical basis for planning by local governments and water utilities, and divides the states into water resources inventory areas. The state or local governments can establish groundwater management areas. *See* Wash. Rev. Code §90.44.400 (1985). In addition, under the GMA, local governments plan for all critical areas, including critical aquifer recharge areas, with the understanding that groundwater is "inextricably linked with all of the critical areas." Laurie Morgan, Washington State Department of Ecology, Critical Aquifer Recharge Areas: Guidance Document (2005).
260. Clark County, Wash., Unified Development Code §40.410.010 (2021). This program implements several legal requirements, including the GMA, Wash. Rev. Code ch. 36.70A; the Public Water Systems Penalties and Compliance, Wash. Rev. Code ch. 70.119A (2020); the Washington State Wellhead Protection Program and the Public Water Supplies, Wash. Admin. Code ch. 246-290 (2021); the Dangerous Waste Regulations, Wash. Admin. Code ch. 173-303 (2020); the Water Quality Standards for Groundwater of the State of Washington, Wash. Admin. Code ch. 173-200 (1990); the Underground Injection Control Program, Wash. Admin. Code ch. 173-218 (2008); and the Regulation of Public Ground Waters, Wash. Rev. Code ch. 90.48 (2020). Clark County, Wash., Unified Development Code §40.410.010.A (2021).
261. Clark County, Wash., Unified Development Code §40.410.030 (2021).
262. The ordinance requires baseline information on groundwater characteristics that will influence the transportation of any pollutants entering the system:

> (1) Lithologic characteristics and stratigraphic relationships;
> (2) Aquifer characteristics including recharge and discharge areas, depth to and static water-flow patterns, and an estimate of groundwater-flow velocity;
> (3) Contaminant fate and transport including probable migration pathways and travel time of a potential contaminant release from the site through the unsaturated zone to the aquifer(s) and through the aquifer(s), and how the contaminant(s) may be attenuated within the unsaturated zone and the aquifer(s);
> (4) Appropriate hydrogeologic cross-sections which depict lithology, stratigraphy, aquifer, units, potential or probable contaminant pathways from a chemical release, and rate of groundwater flow; and
> (5) Existing groundwater quality.

Id. §40.410.030.B.2.c.
263. *Id.* §40.410.040.A.
264. *Id.*

Clark County's critical areas ordinances illustrate several positive features relative to the goals of geosystem services regulation. The regulations are built on the premise that county residents benefit from geological processes that provide for surface stability and clean, drinkable groundwater. The regulatory process is intended to produce information sufficient to facilitate a thorough review of threats to geosystem services, such as the safety implications of destabilization at a particular site or groundwater contamination in the groundwater system.

In the geological hazard regulations, most applications will produce detailed information on slope stability at the subject property and adjacent properties, planned improvements with estimated compaction and load changes, soil compaction, site geology and soil properties, lateral pressures, topography, surface and subsurface drainage (streams, seeps, springs, and seasonal water volumes), and vegetation management. The ordinances also assume that geological resources involve dynamic processes that provide specific benefits and specific risks from the interrelation of ecosystem and hydrological processes and recognize that human actions alter and impact geosystem processes. Local governments address these concerns because they affect the local environment and community well-being.

In sum, local regulations are often criticized for creating a patchwork of uncoordinated regulations that do not reach the core risks to a productive environment. Indeed, at present, human activities that impact the geosystem are regulated in a patchwork, inconsistent manner across various federal, state, and local agencies, as well as being fragmented in many instances by division into resource-specific regulations. Laws governing placer mining are not applicable to hard-rock mining, and regulations governing dredge and fill of wetlands may apply to both activities. Local forestry and tree protection regulations may have some overlap with state forestry laws, but share little jurisdiction over federal timber sales and logging regulations. Endangered species regulations governing consultation of prohibiting "take" of a species apply with little regard over property ownership.

In contrast, federal, state, and local governments may exercise authority over different aspects of a specific land use activity on private lands, such as gravel mining. Yet local governance of the geosystem offers some examples of specific services and risk of interruption of those services, and it is emboldened by the relationship between local governance, local knowledge, and risks that geosystem services present to the local welfare.

E. Laws That Identify Geosystem Services Within a System of Property Rights

Among the laws examined in this Article, property is the most curious because, in contrast to mining, archeological, informational, and land use, property laws seem to begin at a place that is disconnected from the objects over which rights are exercised. When it comes to most regulatory schemes concerning the environment, the process is simple: we investigate the laws of natural science to understand the context in which we act, formulate policy about the outcomes we want those actions to produce, and make decisions about how to allocate rights within the laws of natural science.

In contrast, property is first about claiming exclusive rights against the world (and is only resource-specific as an afterthought). As a result, imposing a system of property rights onto specific resources can be messy, a process we often make more complicated than it needs to be. Most of the mess appears when we learn enough about a resource to understand the sloppiness of property rights in a particular context.

As we transition into the framework of geosystem services, it is understandable that we would find property rights at odds with a vast array of geosystem services.[265] Because the owner of land is entitled to possess, use, exclude, transfer, and bequeath the land within the physical boundaries of what is owned, the owner's land use choices may interfere with geosystem processes.[266] An owner may desire a belowground pool in the yard, or may want to build a skyscraper, or pump water to support a bottled water business, grow crops, drain marshes, store hazardous wastes, cut trees, grow trees, or even pave the entire thing to build a parking lot. The property owner is concerned (perhaps) about whether the ground is stable enough for the use, but is less concerned that the use will obstruct groundwater flows that serve as a neighbor's water source, or make the ground vulnerable to erosion, or compact the soils, or any of the consequences that prevent others from receiving geosystem benefits.

In such cases, the exercise of property rights inevitably competes with geosystem services.[267] The competition is not always obvious, but it may become so when we realize that most geosystem processes do not respect boundary lines or the right to exclude. Indeed, it is often said that the rights of property, together with the demarcation of boundaries and the attendant right to exclude, create a people entitled to make their own choices, but isolated from one another and from the community.[268] Likewise, property lines draw artificial boundaries in the geosystem.[269] For purposes of

265. The goals of regulating human impacts to land structure and function often compete with the economic value of land, such as seen in the battles of *Pennsylvania Coal Co. v. Mahon*, 260 U.S. 393 (1922) (addressing mining to prevent subsidence, finding that "[t]he general rule at least is, that while property may be regulated to a certain extent, if regulation goes too far it will be recognized as a taking"), and *Lucas v. South Carolina Coastal Council*, 505 U.S. 1003, 22 ELR 21104 (1992) (addressing regulations to protect coastal sand dunes from development and associated impacts, finding a taking for "total deprivation of beneficial use").

266. For additional discussion on this point, see Keith H. Hirokawa, *Three Stories About Nature: Property, the Environment, and Ecosystem Services*, 62 Mercer L. Rev. 541 (2011).

267. *But see* Owley, *supra* note 5, at 339 (identifying property tools that appear well-designed to integrate the services provided by soils into the protection scheme of property-based conservation tools).

268. For instance, Kunstler noted, "Our laws gave the individual clear title to make his own decisions, but they also deprived him of the support of community and custom and of the presence of sacred spaces." James Howard Kunstler, The Geography of Nowhere 26 (1993).

269. Although not addressed at length herein, it is worth noting that an analysis of the idea of severing the surface from mineral estate seems at severe odds

geosystem services, the boundaries are meaningless, if not severely counterproductive to understanding how geosystems work and how they benefit people.[270]

Notwithstanding the foregoing, evolution in property rights and our growing knowledge about how ecosystems provide benefits (until they are degraded or disappear) has, in some instances, made property more amenable to a services perspective of land.[271] The very complicated law of nuisance, addressed in detail by J.B. Ruhl in a series of forward-thinking articles, might be the best opportunity to integrate ecosystem services into the property regime.[272]

Nuisance law protects against a substantial and unreasonable interference with use and enjoyment of land. Where enjoyment of land is dependent upon geosystem processes occurring on another's land—such as the flow of wind above ground, water on or below ground, travel of light across land, lateral support, and so on—interference with that process will have an adverse effect on the use and enjoyment of land. It may take some minor adjustments in how we view property rights and property duties (e.g., would we characterize the burden borne by the owner on which geosystem processes occur as servitudes or other duties that may accompany property ownership?), but some tools already exist to support this characterization. Here, we consider the property constructs of lateral support, groundwater allocation rights, and the doctrine of *ad coelum*.

1. Lateral Support and Surface Stability

The surface of the earth results from geologic processes laying down the materials that create, for the most part, stable land for construction and development. Surface geology provides a basic and obvious connection to the development of society by providing a foundation upon which homes, streets, sidewalks, and schools are built. Surface topography and subsurface geological structure facilitate water flows in underground aquifers that are critical to human water needs.[273] One aim of the legal system is to value such structural functions in ways that accommodate different environmental and societal needs, and here we deal specifically with the manner in which human needs for geological stability are represented in property rights.

Consider a common story in Florida:

> A second sinkhole has formed in the Tampa area, just two miles from the one which likely killed a 37-year-old man last week.
>
> This new sinkhole is so far about 13-feet across, five-feet deep and located between two homes, the occupants of which have both been evacuated. The formation of this new hole isn't so much a surprise as probably just the beginning of what's been referred to as "sinkhole season" in an area dubbed "Sinkhole Alley."[274]

There are many reasonable reactions to this story—fear, awe, amazement, pity, and so on. Each begs the conclusion that the built environment rests upon geological structures that we do not fully understand.

The Florida sinkhole story raised awareness of the geological services problem and compelled a particular response, one that is relevant to this Article:

> The geographic phenomena is so common in Florida that new rules to limit soaring sinkhole insurance claims went into effect in 2011. "Sinkhole lawyers" are actually a thing there. And nowhere are sinkholes as prevalent as the west coast county cluster of Hernando, Pasco, Hillsborough, and Pinellas. The town of Spring Hill has 3,145 verified sinkholes alone.[275]

Florida's Department of Environmental Protection now maintains a website[276] for information on sinkholes that is complete with, among other things, access to the subsidence incident report forms.[277] The Florida Legislature has adopted laws that require property insurance policies to provide coverage for catastrophic ground cover collapse, and additionally require insurers to offer coverage for sinkhole damages to structures and personal property.[278]

Although surface stability can be undermined by natural processes, such as percolating water, human-caused topographical changes are more or less avoidable interferences with geosystem services. Construction alters land. Con-

with the geosciences notion that most geological processes occur with the critical zone—between the bottom of the aquifer to the top of the vegetative canopy. Hence, severed estates leases make property look quite a bit like the way courts used to view rights to groundwater—an allocation scheme that grants rights without regard to science and without an interest in exploring the character and constitution of the ground. And, like groundwater, a legal framework in which severed estates depict different, potentially competing ownership regimes within the same horizontal bounds of space guarantees that advancements in the understanding of the critical zone will be unlikely to improve allocation of rights to the land.

270. Hirokawa, *supra* note 266. *See also* Jesse C. Ribot & Nancy Lee Peluso, *A Theory of Access*, 62 Rural Socio. 153 (2003) (discussing a "theory of access" viewed as "the ability to derive benefits from things," which diverges from the idea of benefits flowing from ownership interests).

271. Ruhl, *supra* note 20, at 12-13 ("It may very well be that nuisance law was overwhelmed by industrial society, that the Public Trust Doctrine was eclipsed by federal legislation, and that property law was heavily influenced by our nation's boundless frontier mentality; but all those conditions have changed.").

272. *See* J.B. Ruhl, *Making Nuisance Ecological*, 58 Case W. Rsrv. L. Rev. 753 (2008).

273. *See* 3 Joseph W. Dellapenna, Waters and Water Rights §18.02 (1991 ed. repl. vol. 2003).

274. Ben Brumfeild, *Massive Florida Sinkhole That Swallowed a Man Reopens*, CNN (Aug. 20, 2015), https://www.cnn.com/2015/08/20/us/florida-sinkhole-seffner/index.html.

275. Jeff Harrington, *Florida's "Sinkhole Alley" Homeowners Stuggle With Insurance Overhaul*, Tampa Bay Times (Oct. 13, 2014), https://www.tampabay.com/news/business/banking/floridas-sinkhole-alley-homeowners-struggle-with-insurance-overhaul/2201564/; Emily Holbrook, *Disappearing Florida: The Risk of Sinkholes in the Sunshine State,* Risk Management Moniter (Mar. 14, 2013), https://www.riskmanagementmonitor.com/disappearing-florida-the-risks-of-sinkholes-in-the-sunshine-state/.

276. Florida Department of Environmental Protection, *Sinkholes*, https://floridadep.gov/fgs/sinkholes (last visited Mar. 12, 2022).

277. Florida Department of Environmental Protection, *Subsidence Incident Reports*, https://floridadep.gov/fgs/sinkholes/content/subsidence-incident-reports (last modified Nov. 9, 2021).

278. Fla. Stat. §§627.706, 627.707-.7077 (2011).

struction depends on geological stability while challenging geological stability by changing the surface structure and adding to the surface. The common law has long supported an expectation about natural geological conditions. Many courts have allocated absolute rights in the form of lateral support rights for the protection of natural topographical support, thereby vindicating an owner's expectations in maintenance of topographical conditions of the land. As one court has noted:

> [E]very owner of land has the right to naturally necessary lateral support from the adjoining soil, and if a landowner removes the soil from his own land so near the land of his neighbor that his neighbor's soil will crumble away under its own weight, he is liable for damages naturally resulting therefrom, including damage to structures on the subsiding land, without the necessity of showing negligence or want of skill on the part of the adjoining owner in making the excavation.[279]

Excavation that removes otherwise essential support for natural topographic conditions and causes property to collapse or subside is governed by strict liability rules. Proof of negligence is not required, suggesting that the protection for lateral support legitimizes expectations that the land is valuable in its natural state.[280] Hence, lateral support rights typically amount to property duties in which each property owner owes all others the duty to avoid interfering with geosystem support services.

From the geosystem services perspective, the shortcoming of absolute lateral support rights concerns the gap between geosystems knowledge and law. In the articulation of absolute rights to natural topography, the law internalizes the forces of gravity and pressure. The only evidence needed—and relevant—to define the injury is topographic change: a person who removed dirt and rock that provided lateral support for neighboring topography is liable for topographic changes that result.

Yet, the geosciences detail so many impacts from removal of geologic support that might be, under the circumstances of a particular case, more meaningful and beneficial to the neighboring property owner, including changes in capacity of the land to support vegetation, to absorb storm surges and flood water, to percolate surface flows and reduce stormwater, to recharge the aquifer, to support ecological needs of vegetation and wildlife, and a host of others. Although lateral support rights appear to favor geologic support in place, they actually represent a trade off decision in which law presumes the benefits of low-hanging fruit to the exclusion of other geosystem needs and values.

Arguably, the law can be more interesting and inclusive from a geosystem perspective when the standard of liability departs from the narrow confines of strict liability and shifts to negligence. Under artificial circumstances—such as when the injured party's use of the land contributes to the slope failure—disruption of slope stability is judged on the basis of negligence or nondisclosure liability.[281]

2. Groundwater Rights

Some geologic structures provide subsurface containment for water, in a sense holding underground reserves of usable water[282] while providing physical support for surface geology. Of course, underground water in many aquifers does not simply sit stagnant, waiting to be extracted for human consumption. Percolating water from the surface seeps into cracks and fissures and through loosely packed soils and in unconfined aquifers along the path of least resistance, known as the hydraulic gradient.[283] Water can remain underground for years or decades before being recaptured or finding its way to the surface. Especially in areas that suffer limited surface water supplies, groundwater provides usable water for agriculture, domestic, and industrial uses for a vast population. On the other hand, subsurface geology continually moves earth and water across large geographical areas, which can cause problems such as erosion, sinkholes, and landslides.

In large part, the law relating to subsurface water storage is relegated to allocation doctrines. Historically, courts have suffered through the difference between surface water and groundwater by throwing in the towel. To some courts at least, the "secret, changeable, and uncontrollable character of underground water in its operation is so diverse and uncertain that we cannot well subject it to the regulations of law, nor build upon it a system of rules, as is done in the case of surface streams."[284]

In other words, the courts were reluctant to transition between a system of allocation based on absolute rights or *ad coelum*,[285] to a correlative distribution of groundwater rights precisely due to a lack of knowledge regarding the reasons water flows underground at a particular pace, in a particular direction, or at a particular elevation. Courts had little understanding of groundwater hydrology, and

279. Williams v. Southern Ry. Co., 396 S.W.2d 98, 99-100 (Tenn. Ct. App. 1965) (citing Puckett v. Sullivan, 12 Cal. Rptr. 55 (Cal. Ct. App. 1961); Levi v. Schwartz, 95 A.2d 322 (Md. 1953)).

280. Lateral support rights favor land uses that leave nature to perform its services: overtaxing the land's natural support operates as a waiver of the absolute right. Sime v. Jensen, 7 N.W.2d 325, 327 (Minn. 1942); *see also* Restatement (Second) of Torts §817 cmt. c (Am. L. Inst. 1979) (stating that naturally necessary support "does not include the support needed because of the presence of artificial additions to . . . the surrounding land").

281. *See, e.g.*, Massei v. Lettunich, 56 Cal. Rptr. 232 (Cal. Ct. App. 1967) (finding a developer liable for damage caused by a landslide when he developed property in an area known to be susceptible to landslides without conducting adequate testing of soil stability at his development site).

282. *See* Dellapenna, *supra* note 273, §18.02.

283. *See* James H. Davenport, *Less Is More: A Limited Approach to Multistate Management of Interstate Groundwater Basins*, 12 U. Denv. Water L. Rev. 139, 155 (2008).

284. Chatfield v. Wilson, 28 Vt. 49, 54 (1855); Frazier v. Brown, 12 Ohio St. 294, 311 (Ohio 1861):

> the existence, origin, movement and course of such waters, and the causes which govern and direct their movements, are so secret, occult and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be, therefore, practically impossible.

285. *See* John G. Sprankling, *Owning the Center of the Earth*, 55 UCLA L. Rev. 979, 981 (2008) (*cuius est solum, eius est usque ad coelum et ad inferos* ("for whoever owns the soil, it is theirs up to Heaven and down to Hell")).

less respect for how geosystem processes provided water for human use.[286] Law that has no regard for the rules of natural processes is bound to make mistakes and result in the assertion of unfortunate rights.

Today, most jurisdictions have abandoned the idea that groundwater is a mystery. However, current groundwater allocation schemes have arguably replaced one shortsighted approach for another. For instance, prior appropriation systems (both with respect to surface and groundwater allocation) are premised on the idea that unused water is wasted[287]; prior appropriation incentivizes more capture, more pumping, and more use. Rights to use water are less based on the geological processes that provided the water, and more based on demand.

Not surprisingly, under pressure from dwindling water supplies in populated areas, law has undergone some updating to address hydrological connectivity (the connectivity between surface and groundwater supplies). Intense groundwater pumping can result in lower surface water flows and, vice versa, impermeable surfaces and surface water diversions can deplete groundwater availability. In addition, mining, ground excavation, or compaction can change groundwater flow.

The challenge of hydrological connectivity has been to overcome history: groundwater and surface water have been regulated independently and treated as if these waters were not connected, and therefore some water users have vested surface or groundwater rights that have not been subject to rights to take from the counterpart source.[288] Yet particularly in areas that accommodate an increasing population, diminishing water supplies have forced the scientific and legal communities to diverge from traditional water allocation approaches to explore the subsurface structure that creates an infrastructure of water transfer and storage[289] and treat groundwater and surface water collectively as a single source of water.[290]

Wyoming has adapted its water law to include the concept of hydrologic connectivity, stating "where underground waters and the waters of surface streams are so interconnected as to constitute in fact one source of supply, priorities of rights to the use of all such interconnected waters shall be correlated and such single schedule of priorities shall relate to the whole common water supply."[291] The legislature recognized the need to include this concept in its water planning, noting that "the use of underground water is approaching a use equal to the current recharge rate[, and] groundwater levels are declining or have declined excessively."[292] The codification of this service—the manner in which the geological system supports an interconnected hydrological system—recognizes an integral part to water supplies and helps in understanding the value of geology of hydrological connectivity.[293]

3. *Ad Coelum*

William Blackstone once opined: "Land in its legal signification has an indefinite extent, upwards as well as downwards; whoever owns the land possesses all the space upwards to an indefinite extent; such is the maxim of the law."[294] This ancient characterization of property—*cuius est solum, eius est usque ad coelum et ad inferos* ("for whoever owns the soil, it is theirs up to Heaven and down to Hell")[295]—was well established before humans dreamed of taking flight.[296] The rule worked reasonably well in disputes involving tree limbs and scaffolding, but was less equipped to manage property disputes once humans conquered the sky.[297]

The U.S. Supreme Court eventually settled the matter of airspace rights by limiting the right to eject to that

286. Perhaps some courts were interested in hearing evidence regarding subsurface movement of water, including where it involved the allocation of rights among competing users. Tampa Waterworks Co. v. Cline, 20 So. 780 (Fla. 1896); Huber v. Merkel, 94 N.W. 354 (Wis. 1903); McClellan v. Hurdle, 33 Pac. 280, 282 (Colo. App. 1893); Rancho Santo Margarita v. Vail, 81 P.2d 533 (Cal. 1938). However, it was common for courts to avoid wading into the debate over the most effective groundwater allocation schemes. Roath v. Driscoll, 20 Conn. 533 (Conn. 1850) (groundwater operates "by influences beyond our apprehension. These influences are so secret, changeable and uncontrollable, we cannot subject them to the regulation of law nor build upon them a system of rules, as has been done with streams upon the surface."). That refusal also extended to situations in which wells and streams were contaminated and degraded due to pollution of groundwater. Rose v. Socony-Vacuum Corp., 173 A. 627, 631 (R.I. 1934):

> If, in the process of refining petroleum, injury is occasioned to those in the vicinity, not through negligence or lack of skill or the invasion of a recognized legal right, but by the contamination of percolating waters whose courses are not known, we think that public policy justifies a determination that such harm is damnum absque injuria.

Uses of land that incidentally interfered with the water needs or dependencies of other properties was relegated to *damnum absque injuria*. *See, e.g.*, City of Atlanta v. Hudgins, 19 S.E.2d 508 (Ga. 1942) (city excavated a trench for a sewer line 50 feet deep, after which several wells and a surface stream ran dry or were depleted, but plaintiff was unable to prove causation).

287. Janet C. Neuman, *Beneficial Use, Waste, and Forfeiture: The Inefficient Search for Efficiency in Western Water Use*, 28 Env't L. 919 (1998).

288. *See, e.g.*, Metropolitan Utils. Dist. of Omaha v. Merritt Beach Co., 140 N.W.2d 626 (Neb. 1966).

289. *See* Dellapenna, *supra* note 273, §18.02 ("The intertwined relationship between law and hydrogeology, which has had a long-established history, will become even more intimate in the future.").

290. Davenport, *supra* note 283, at 155.

291. Wyo. Stat. Ann. §41-3-916 (2007).

292. *Id.* §41-3-912(a).

293. It should be noted that a majority of jurisdictions have been unable to recognize the concept of hydrologic connectivity, essentially ignoring a valuable geosystem service. *See, e.g.*, Baumler v. Town of Newstead, 247 A.D.2d 861, 861 (N.Y. App. Div. 1998) (failing to credit expert in hydrogeology's affidavit that a connection existed between stream and aquifer). However, one interesting development outside of water allocation was recently seen in the U.S. Supreme Court, where surface and groundwater connectivity may have influenced regulatory programs focused on water quality. *See* County of Maui v. Hawaii Wildlife Fund, 140 S. Ct. 1462, 50 ELR 20102 (2020) (recognizing groundwater movement as a functional equivalent to a direct discharge into a navigable water).

294. Herrin v. Sutherland, 241 P. 328, 332 (Mont. 1925) (citing Cooley's Blackstone, Book II, 18; vol. 1, 445; Kent's Com. 401).

295. Sprankling, *supra* note 285, at 981. Sprankling traces the origins of this doctrine to Cinus of Pistoia, an Italian scholar from the 14th century. *See* Jean Brissaud, History of French Private Law 283 (Rapelje Howell trans., Little, Brown & Co. 1912). *See id.* n.5.

296. *See, e.g.*, Hannabalson v. Sessions, 90 N.W. 93 (Iowa 1902); Whittaker v. Stangvick, 111 N.W. 295 (Minn. 1907); Grandona v. Lovdal, 70 Cal. 161 (Cal. 1886); Harrington v. McCarthy, 48 N.E. 278 (Mass. 1897); Puerto v. Chieppa, 62 A. 664 (Conn. 1905).

297. *See generally Trespass by Airplane*, 32 Harv. L. Rev. 569 (1919).

elevation where a property owner had a reasonable expectation to occupy the space. In *United States v. Causby*, the Court freed the skies of individual control, made way for human flight, and ruled that *ad coelum* "has no place in the modern world. The air is a public highway, as Congress has declared. Were that not true, every transcontinental flight would subject the operator to countless trespass suits. Common sense revolts at the idea."[298] Although the Court rejected trespass actions against those travelling in the skies, property owners were not left staring into *damnum absque injuria*: any such activities that had the effect of interfering with the owner's quiet enjoyment could still be challenged as a nuisance.[299]

In a sense, it might be a stretch to think that the *Causby* Court modified *ad coelum* to protect or accommodate the ecosystem services that facilitate (or obstruct) flight—circulation, wind, temperature, atmospheric pressure, fog, storm events, and so on. Nonetheless, it is a productive exercise to grasp the change in law relative to atmospheric ecosystem services. The times changed, and human understanding of the planet changed. As humans improved our understanding of the processes and structure of the atmosphere and gained a greater appreciation of the benefits that could be enjoyed, *ad coelum* became more obviously inconsistent with that understanding. *Ad coelum* divided the skies by lot lines and boundaries (think patchwork array of walls and fences that extend into the heavens). The shift away from *ad coelum* was an effective response to developments in science and technology, but, more importantly, was an effective response to a law that would prevent people from capturing the benefits of atmospheric services.

The persuasiveness of the *Causby* decision begs the question: is the shift away from *ad coelum* reproducible beneath the surface? Certainly, there are some characteristics that align between the heavens and the center of the earth, as those terms are relevant to *ad coelum*. In many ways, groundwater moves like air, pushed by a variety of pressures along the path of least resistance around obstructions. Like the elevations that often serve as the reasonable heights at which people might expect to control the air space, but beyond which physical occupation is either uncommon or unlikely, most subsurface uses do not extend very far into the earth's crust and toward its core. However, assuming geosystem services and atmospheric services differ in at least one regard—due to gravity, we necessarily benefit from the two in different ways (e.g., it would be difficult to envision navigation of the subsurface as we do the air)—we have to wonder whether freeing the subsurface from property boundaries and trespass actions would achieve the same public need as the Court accommodated in *Causby*.

Allowing boundaries to become subservient to geosystem services need not serve the *exact* same purposes as in the air. Instead, we might think about the consequences of removing boundaries from the air. First, removing boundaries from airspace allows the benefits from atmospheric services to be shared across great distances without fear of exclusion or privatization; this consequence articulates the "common pool" construction of natural resources.[300] So, for instance, pilots chart courses for thousands of miles across the sky, treating airspace as open, accessible, and usable. Likewise, whether we think about the scale of geothermal resources, or subsurface occupation by oil and water resources, groundwater flow, watershed drainage patterns, or even soil formation or geological structures at the scale of tectonic plates, the geosystem services approach articulates the manner in which small changes to the planet can affect many people across a large terrain.

Second, as in *Causby*, modification of the subsurface legal scheme need not leave the surface owner with *damnum absque injuria*: the removal of boundaries in the air did not result in a meaningful loss of protectable property interests. Instead, the owner was still protected against unreasonable interferences as nuisances, while allowing more common benefits from atmospheric services. In like manner, if appropriately conceived, releasing the geological structure from the confines of property boundaries is unlikely to prevent property owners from using and enjoying their land, but it will allow the geosystem to provide benefits on a greater scale than when geosystem service flows are subjected to property within boundaries.

Third, courts have already begun the process of withdrawing *ad coelum* from the subsurface. We are beyond the time when, as in *Marengo Cave*, the Court rejected a claim of adverse possession of an underground cave system, opining that the surface owner could not be held to know what was going on beneath his very feet.[301] We no longer marvel at the magic of the subsurface water flow, previously thought to be so "secret, changeable, and uncontrollable" that some refused to subject groundwater to liability and allocation rules.[302] And indeed, from the geosystem ser-

298. United States v. Causby, 328 U.S. 256 (1946). *See also* Willoughby Hills v. Corrigan, 278 N.E.2d 658, 665 (Ohio 1972) (quoting Hinman v. Pacific Air Transp., 84 F.2d 755, 758 (9th Cir. 1936):

> We own so much of the space above the ground as we can occupy or make use of, in connection with the enjoyment of our land. This right is not fixed. It varies with our varying needs and is coextensive with them. The owner of land owns as much of the space above him as he uses, but only so long as he uses it.

299. This is not to suggest that nuisance remedies were not already available; to this extent, the *Causby* Court did not make a meaningful difference to the protections afforded by property rights.

300. Jonathan Rosenbloom, *New Day at the Pool: State Preemption, Common Pool Resources, and Non-Place Based Municipal Collaborations*, 36 Harv. Env't L. Rev. 446 (2012).

301. Marengo Cave Co. v. Ross, 10 N.E.2d 917 (Ind. 1937).

302. Chatfield v. Wilson, 28 Vt. 49, 54 (1855). In the 1855 case of *Ellis v. Duncan*, 11 How. Pr. 515 (N.Y. Ct. App. 1855), the New York Court of Appeals offered a particularly instructive perspective in a suit against a property owner who, to make his land more livable, dug drainage ditches that had the unfortunate and unforeseeable (or at least unforeseen) consequence of interrupting the flow of groundwater to his neighbor's property. The court noted that if the defendant had interrupted a surface water body that had otherwise benefitted others, the defendant could have been liable. In such a case, "the owners have knowingly permitted the waters to flow in their natural course, for the benefit of all those whose lands they pass, from time immemorial. They have acquired their title with a full knowledge of what is visible, and (peremptorily) of the rights which result from it." *Id.* at 517. Groundwater, however, is different:

> The owners of the superior soil are not generally aware of their existence, and cannot be supposed to have voluntarily acquiesced in any appropriation of them. When they purchase, they are ignorant

vices perspective, it might be noteworthy that the *Causby* Court's analysis reveres knowledge as the basis for expectation. With the many advancements in imaging and understanding geosystem processes, including a sophisticated understanding of the manner in which humans benefit from the geosystem, courts have adopted the reasoning in *Causby* to modify subsurface rights.

Much like the need for public access to airspace in *Causby*, courts are moving toward a new understanding of the ways the public's welfare depends on the conditions of the subsurface.[303] In *Boehringer v. Montalto*,[304] the court considered whether a sewer commission's sewer easement underneath property could constitute an encumbrance sufficient to violate the deed warranty. The court noted that *ad coelum* was formulated "at a time when nobody foresaw the use to which the air above the land might be put," and noted the absence of any actual injury from the subsurface interest. The court concluded:

> It therefore appears that the old theory that the title of an owner of real property extends indefinitely upward and downward is no longer an accepted principle of law in its entirety. Title above the surface of the ground is now limited to the extent to which the owner of the soil may reasonably make use thereof. By analogy, the title of an owner of the soil will not be extended to a depth below ground beyond which the owner may not reasonably make use thereof.[305]

Likewise, in *Chance v. BP Chemicals*,[306] the court considered competing claims over the property implications of the potential migration of waste following deep well injection of industrial waste byproducts from a chemical production facility. Plaintiff's case sounded in trespass and relied on the doctrine of *ad coelum*. The court rejected the idea of "absolute ownership of everything below the surface" of property: "Just as a property owner must accept some limitations on the ownership of property rights extending above the surface of the property, we find that there are limitations on property owners' subsurface rights."[307] The court concluded that, just as in *Causby*, *ad coelum* "has no place in the modern world," and that "appellants' subsurface rights in their properties include the right to exclude invasions of the subsurface property that actually interfere with appellants' reasonable and foreseeable use of the subsurface."[308]

Any benefit enjoyed from allowing property rights to determine control over such critical services is outweighed by our complete dependency on the services that the geosystem provides, suggesting that the understanding we get from geosystem services demands preventing people from interfering with geosystem processes. As Justice Oliver Wendell Holmes noted, it might be time to diverge from vestigial laws that have outlived their purposes: "just as the clavicle in the cat only tells of the existence of some earlier creature to which a collar-bone was useful, precedents survive in the law long after the use they once served is at an end and the reason for them has been forgotten."[309]

IV. Conclusion: Moving Toward Informed Regulation of Rocks and Their Services

Although geological failures can be catastrophic, and geological discoveries can reap rewards, geology in place can be valuable far beyond surface stability or mining.[310] Of course, many geosystem goods (such as sand and rock, oil and water) have been adapted to serve everyday human needs and are readily valued in the marketplace.[311] How-

> of any obstacle to the free use of their property ab centro ad coelum; and to arrest some valuable improvement, such as digging a well, or a cellar, draining the land, taking valuable stone from a quarry, or leveling the ground for building or agricultural purposes, because it would cause some consequential suspension, and, possibly, inconsiderable damage to another, would seem to be unreasonable and unjust.

It would be so unreasonable and unjust, stated the court, that property purchasers would always be plagued by the uncertainty of the ways their property would be burdened by the duty to serve others. *Id*.:

> If the principle, that the man who interrupts a subsurface stream to the prejudice of his neighbor, commits a wrong for which the law will give redress, is sound, no one will be safe in purchasing land adjoining or near a private stream of water, as he may be restrained forever from making some valuable, and frequently, from the progressiveness of the age, necessary improvement.

With such a perspective, a *Causby*-like transformation of the role of property boundaries may have seemed unlikely.

303. *See also* John Sprankling's proposal that

> the surface owner's title should extend downward for only 1000 feet, subject to special exceptions for mineral rights. The subsurface beneath this point would be owned by the federal government. By rejecting center of the earth rhetoric, this model would eliminate over 99 percent of the theoretical real property ownership in the United States, as measured by volume.

Sprankling, *supra* note 285, at 982.

304. 142 Misc. 560 (N.Y. Sup. Ct. 1931).

305. *Id*. at 562.

306. 77 Ohio St. 3d 17 (Ohio 1996).

307. *Id*. at 26.

308. *Id*. This decision has clear impacts on the viability of using subsurface pore space for carbon sequestration. *See* Joseph A. Schremmer, *Getting Past Possession: Subsurface Property Disputes as Nuisances*, 95 Wash. L. Rev. 315, 323-24 (2020); Robert Zadick, *The Public Pore Space: Enabling Carbon Capture and Sequestration by Reconceptualizing Subsurface Property Rights*, 36 Wm. & Mary Env't L. & Pol'y Rev. 257 (2011); Bryan Endres, *Geologic Carbon Sequestration: Balancing Efficiency Concerns and Public Interest in Property Rights Allocations*, 2011 U. Ill. L. Rev. 623.

309. Oliver Wendell Holmes Jr., The Common Law 35 (1881) (1963 ed.).

310. It may be worth noting that the services perspective on nature may be very persuasive in instances where environmental changes result in loss of services, but we seem to ignore the relevance of a functioning natural system when natural services are providing uninterrupted benefits. When nature is working to our advantage, we are less likely to dig deeply into the manner in which we are disrupting nature's processes. *See* Wohl, *supra* note 33 ("If a river appears relatively attractive and healthy, the history of land use and the river responses that have directly influenced its current condition are unlikely to be explored. The net effect of most land use is to reduce the complexity and diversity of river form and function.") (emphasis added).

311. USGS, Mineral Commodity Summaries 2021, at 5 (2021), https://doi.org/10.3133/mcs2021:

> In 2020, the estimated total value of nonfuel mineral production in the United States was $82.3 billion, a decrease of 2% from the revised total of $83.7 billion in 2019. The estimated value of metals production increased by 3% to $27.7 billion. Increased prices for precious metals, such as gold, which reached a record-high price of $2,060 per troy ounce in August, contributed to the increased value of metal production. The total value of industrial minerals production was $54.6 billion, a 4% decrease from that of 2019. Of this total, $27.0 billion was construction aggregates production (construction sand and gravel and crushed stone). Crushed stone was

ever, the production of these goods, like other significant geosystem services, operates at a longer timescale and otherwise outside of our immediate vision.[312] This Article proposes a framework for acknowledging our reliance on geological structure and function and accounting for that reliance in laws regarding property, environmental, land use, and natural resource use.

Studying the laws regulating our interactions with the geosystem helps in understanding what we have valued about geological services and, perhaps more importantly, what we have not valued or otherwise not protected. This analysis concerns the regulation of mineral extraction, which is based on laws that help to identify the minerals that we value, but largely ignores the unmarketable geological processes and unmarketable minerals. The analysis looks to local land use laws that determine when and where we can build on the earth and when we must create artificial geological structure for support. It also considers the ways that property and tort law allocate duties to maintain support for the benefit of others.

Of course, the project of developing a comprehensive regulatory scheme for geological services is complicated. Like other areas of ecosystem services research, geological services serve many people and values in many different ways; acknowledging the benefits of geological services is to recognize that there are competing needs to such services. As such, the system will be effectively regulated by paying close attention to the inevitable trade offs that accompany individual and public choices and accounting for both the distribution of burdens and allocation of benefits.

Yet, the conversations—often difficult ones—required to implement a geosystem services legal regime are important.[313] We have arrived at a moment in history best characterized as focusing attention on the market values of goods that can be taken from ecosystems, without also accounting for the methods of sustaining the production of those goods or the loss of production in the future. In the process, we have expedited the decline of functionality throughout the natural systems:

> From time immemorial we have too lightly valued some of the most basic resources on which we depend, including the air we breathe, the water we drink, and the ability of the earth to support a wide variety of life. The cumulative impact of human activity on the natural systems that produce these resources, particularly over the past one hundred years, and our rather recent understanding of the dramatic scope of that impact, make it impossible for us to take them for granted any longer.[314]

While we have enjoyed the fruits of the earth, we have discovered that nature cannot always fix itself, which in turn means that we are permanently depleting the resources we have come to rely upon. As the United Nations Environment Programme recently noted: "Human activities are changing the Earth's ecosystems and climate and leaving a geological signature so significant that the current geological epoch may be named the Anthropocene."[315] We should take this stuff more seriously.

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the leading nonfuel mineral commodity in 2020 with a production value of $17.8 billion and accounted for 22% of the total value of U.S. nonfuel mineral production.

312. For instance, geosystem services that are at risk in an era of climatic change, such as sequestration of water and carbon in glaciers and the permafrost, typically fall outside of our conventional perspective on the reach of regulation. The impacts of climate change lay at the center of social, economic, and environmental projections into the near and distant future. Yet we are beginning to grasp many of the connections between geosystems and hydrology, climate, and human well-being. Geosystems analysis adds (among other things) the factors of scale of change across time, an inquiry that fits centrally into the geological framework, but perhaps less so in other disciplines.

For instance, as recently noted by climate-focused geologists, "most [sea-level] projections do not account for a key natural process—ice-cliff instability—which is not observed in the short instrumental record. This is why geological observations are vital." Fiona Hibbert et al., *Scientists Looked at Sea Levels 125,000 Years in the Past. The Results Are Terrifying*, Conversation (Nov. 6, 2019, 2:05 PM), https://theconversation.com/scientists-looked-at-sea-levels-125-000-years-in-the-past-the-results-are-terrifying-126017. Recent attention to geosystem services has catalogued the releases of greenhouse gases from melting glaciers and the permafrost. *See, e.g.*, Eelco J. Rohling et al., *Asynchronous Antarctic and Greenland Ice-Volume Contributions to the Last Interglacial Sea-Level Highstand*, 10 Nature Commc'ns 5040 (2019) (identifying correlations between climate, sea level, and melting ice in a historical context); Edward A.G. Schuur et al., *Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle*, 58 BioScience 701 (2008). *See also* Fox et al., *supra* note 32 ("Some abiotic aspects of soils, such as the physical processes governing the weathering of bedrock, are not practically manageable.").

313. Mark G. Anderson & Charles E. Ferree, *Conserving the Stage: Climate Change in the Geophysical Underpinnings of Species Diversity*, 5 PLoS 11554 (2010) (suggesting a shift in focus from ecosystems to "conserving nature's stage").

314. Joshua S. Reichert, *Perspectives on Nature's Services*, *in* Nature's Services: Societal Dependence on Natural Ecosystems xviii-xix (Gretchen C. Daily ed., Island Press 1997).

315. United Nations Environment Programme, Making Peace With Nature: A Scientific Blueprint to Tackle the Climate, Biodiversity, and Pollution Emergencies (2021), https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/34948/MPN.pdf. *See also* Jan Zalasiewicz et al., *The Anthropocene: A New Epoch of Geological Time?*, Phil. Transactions Royal Soc'y A 369, 835-41 (2011) ("[T]he sum of human activity through deforestation, agriculture, mining, transport, waterway 're-plumbing,' coastal trawling and climate change has produced an effect equivalent to the level of a geological climate event, such as seen in the transition between the Pleistocene and the Holocene.").