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THE COSTS OF CLIMATE DISRUPTION IN THE TRADE-OFFS OF COMMUNITY RESILIENCE

Keith H. Hirokawa[*] *& David Dickinson*[†]

Wetlands perform certain functions, including water filtration and the provision of wildlife habitats, from which humans benefit in the form of drinkable water and biodiversity. Trees produce oxygen, capture air and water pollutants, and provide shade, which help humans breathe, manage storm waters, and find a comfortable place to relax on a hot day. These are services that are provided by functioning ecosystems and are measured through the ecological economics of ecosystem services. The study of ecosystem services has provided an important insight: for the most part, those very services are ignored or undervalued. Although humans derive enormous benefits from ecosystem services, these services are neither bought or sold in the marketplace, and, therefore, have no market value.

This Article applies the idea of ecosystem services to the management of watersheds and, in particular, the manner in which decisions in floodplains often undermine ecosystem functionality in floodplains. For instance, road and home construction along water courses and riverbed dredging can disrupt (or trade-off) the ecosystem's ability to provide flood control and habitat services. The dangers in making such trade-off decisions are illustrated by the flood damage suffered during Tropical Storm Irene and contextualized within the framework of ecosystems services.

INTRODUCTION

Climate change presents challenges to communities in basic, day-to-day provision of necessities, such as drinking water, affordable housing, police and health services, and shared space. Significant disruptions—

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including changing sea levels, frequent and more intense storm events, migrating ecosystems, and coastline vulnerability—will impact communities' ability to maintain a functioning infrastructure in order to meet those needs at the local level.[1] The ecological economics of ecosystem services is an emerging and effective planning tool. Ecosystem services refers to the measurable—even if often invisible—benefits that humans receive from ecosystems.[2] Functioning ecosystems produce goods (e.g., lumber and apples), regulate climate, and provide cultural benefits.[3] Management decisions made in an ecosystem services framework help to identify both the benefits humans receive from the environment and the costs of losing a functioning ecosystem.

Although there is evidence that communities protecting ecosystems are better adapted to regional climatic circumstances,[4] the process of prioritizing ecosystem features is seldom a simple task. As communities engage in the dialogue on resiliency planning and integrate local ecosystem services to minimize climate disruption, they (knowingly or not) commit to a variety of ecosystem trade-offs. Ecosystem trade-offs concern the prioritization of particular ecosystem services and the management to maximize those services at the expense of others.[5] Of course, in many cases, the choice of one service over another may be intended. For example, filling coastal wetlands to build homes or plowing freshwater wetlands to expand agricultural operations may maximize certain cultural ecosystem services attendant to the location (here, cultural

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1. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 538 (Christopher B. Field et al. eds., 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf [https://perma.cc/5D89-KYWD].

> Climate change will have profound impacts on a broad spectrum of infrastructure systems (water and energy supply, sanitation and drainage, transport and telecommunication), services (including health care and emergency services), the built environment, and ecosystem services. These interact with other social, economic, and environmental stressors exacerbating and compounding risks to individual and household well-being (medium confidence, based on medium evidence, high agreement).

Id. (emphasis omitted).

2. Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital*, 387 NATURE 253, 253 (1997).

3. WALTER V. REID ET AL., MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: SYNTHESIS 1 (José Sarukhán et al., 2005), http://www.millenniumassessment.org/documents/document.356.aspx.pdf [https://perma.cc/JBH9-YCR3].

4. Caroline Howe et al., *Creating Win-Wins from Trade-Offs? Ecosystem Services for Human Well-Being: A Meta-Analysis of Ecosystem Service Trade-Offs and Synergies in the Real World*, 28 GLOBAL ENVTL. CHANGE 263, 269 (2014) (citation omitted).

5. J.B. Ruhl, *In Defense of Ecosystem Services*, 32 PACE ENVTL. L. REV. 306, 333 (2015).

ecosystem services derived from the view and location, and provisioning services, respectively), while simultaneously reducing and disrupting other services provided by the wetlands (such as storm surge and flood protection, biodiversity, water filtration, carbon capture, and habitat provision, among others). In other instances, development may proceed without even a basic understanding of how the decision will interrupt ecosystem functions or what services will be lost.

This Article considers the trade-offs that inevitably occur in identifying climate-change vulnerabilities and prioritizing community needs in resiliency strategies. By framing resiliency planning in ecosystem services terms, governance in preparation for climatic changes will involve more efficient and effective strategies for maintaining sustainable and livable communities. To contextualize the point, this Article first examines the concept of ecosystem services and introduces trade-offs as a critical factor in informing decisions that affect ecosystems. The Article then examines the circumstances of severe flooding damages during Tropical Storm Irene, an event that has forced a reconsideration of streambed and flood plain management. Finally, this Article identifies a few essential ingredients for resiliency planning to help minimize the cost and intensities of damages from storm events.

I. ECOSYSTEM SERVICES AND TRADE-OFFS IN ECOSYSTEM DECISION-MAKING

The study of ecosystem services has seen a groundswell of interest across disciplines. This is in part because of the wealth of information gathered and considered in the process, and in part because of the effectiveness of ecosystem services as a tool for making accurate decisions about ecosystem changes based on the costs of eliminating ecosystems.[6] Framing land use and landscape decisions as trade-offs illustrates that changes in ecosystems have both intended and unintended consequences. This Part introduces ecosystem services and explains the role of trade-off analysis, particularly in the context of flood plain and watercourse management.

6. Jon Paul Rodríguez et al., *Trade-Offs Across Space, Time, and Ecosystem Services*, 11 ECOLOGY & SOC'Y, no. 1, art. 28, 2006, https://www.ecologyandsociety.org/vol11/iss1/art28/ [https://perma.cc/4B7L-ASF2]. "Knowledge and awareness of the interactions between [ecosystem services] are necessary for making sound decisions about how to manage natural systems appropriately." *Id.* (citations omitted).

A. *Ecosystem Services*

"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."[7] The term "ecosystem services" has been defined as "a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life."[8] The study of ecosystem services provides significant insight into the ways that ecosystems provide essential services for humans; humans *need* functioning ecosystems because of the things that ecosystems do.[9] At the intersection of ecology and economics, ecosystem services focuses on how ecosystems secure benefits for human well-being and the value that accrues from such services.[10]

The *Millennium Ecosystem Assessment* (*Millennium Assessment*) provides four categories of services provided by ecosystems, including: "provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling."[11] In each category of services, ecosystems provide significant value by securing some human need, such that the service would need to be provided in some other way were it to disappear. Notably, a valuation of nature that focused only on commodities extracted from the environment would overlook the costs of an ecosystem unable to provide the other, non-commodity services.[12] As such, actions or

7. U.S. ENVTL. PROTECTION AGENCY, SCI. ADVISORY BD., VALUING THE PROTECTION OF ECOLOGICAL SYSTEMS AND SERVICES 8 (2009), https://yosemite.epa.gov/sab%5Csabproduct.nsf/F3DB1F5C6EF90EE1852575C500589157/%24File/EPA-SAB-09-012-unsigned.pdf [https://perma.cc/38DW-JUG4].

8. Gretchen C. Daily et al., *Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems*, ECOLOGICAL SOC'Y AM., Spring 1997, at 2.

9. *See* James Salzman et al., *Protecting Ecosystem Services: Science, Economics, and Law*, 20 STAN. ENVTL. L.J. 309, 310–11 (2001); *see also* J.P. Schmidt et al., *Integrating Ecosystem Services and Local Government Finances into Land Use Planning: A Case Study from Coastal Georgia*, 122 LANDSCAPE & URB. PLANNING 56, 57 (2014) ("Broadly, we may define ecosystem services as products of nature that directly benefit humans.").

10. Salzman et al., *supra* note 9, at 312.

11. REID ET AL., *supra* note 3, at v (emphasis omitted).

12. *See* DAVID BATKER ET AL., EARTH ECON., GAINING GROUND: WETLANDS, HURRICANES, AND THE ECONOMY: THE VALUE OF RESTORING THE MISSISSIPPI RIVER DELTA 7 (2010), https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?referer=https://search.yahoo.com/&httpsredir=1&article=1038&context=iss_pub [https://perma.cc/GG5G-VLHY]. "All 'built capital' is made of natural capital, including cars, buildings and food. An

decisions that interfere with functioning ecosystems can be understood to interfere with such services, constituting a cost in sustaining human well-being.[13]

Unfortunately, ecosystem services are typically ignored or undervalued. Unlike ecosystem goods, there is no shelf at the grocery store for the processes of nutrient cycling services provided by soils, for healthy pollination species populations or habitat to sustain them, or for climatic regulation provided by plants.[14] Most ecosystem services "have no market value for the simple reason that no markets exist in which they can be exchanged."[15] As J.B. Ruhl notes, "One does not have to purchase photosynthesis or the radiation screening effects of the ozone layer, and therefore no data on market price [is] available for them."[16] As such, the dilemma of ecosystem services may simply be that they are taken for granted.[17] Until the moment at which ecosystems cease providing essential services,[18] the market does not support incentives to insure that ecosystems continue to function. The thrust of the ecosystem services approach is in its suggestion that ecosystem disruptions and failures come at a significant, and potentially fatal, cost.[19]

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economy also requires hurricane protection, a stable climate, waste assimilation and other natural services. No economy can function without nature's provision of economic goods and services." *Id.*

13. *See* Keith H. Hirokawa & Jonathan Rosenbloom, *Thinking Ecosystems, Providing Water: The Water Infrastructure Imperative*, *in* CONTEMPORARY ISSUES IN CLIMATE CHANGE LAW & POLICY 45, 55–56 (2016) (discussing the cost of lost ecosystem functionality in the context of water infrastructure).

14. *See* Costanza et al., *supra* note 2, at 257 ("[The value of services] accrue[s] directly to humans without passing through the money economy at all. In many cases people are not even aware of them.").

15. Salzman et al., *supra* note 9, at 312.

16. J.B. RUHL ET AL., THE LAW AND POLICY OF ECOSYSTEM SERVICES 57 (2007).

17. *See* Ida Kubiszewski et al., *The Production and Allocation of Information as a Good that Is Enhanced with Increased Use*, 69 ECOLOGICAL ECON. 1344, 1347 (2010) ("[E]conomic markets . . . only reveal demand for marketed goods and services.").

18. *See* C. Max Finlayson et al., *Inland Water Systems*, *in* 1 ECOSYSTEMS AND HUMAN WELL-BEING: CURRENT STATE AND TRENDS ASSESSMENT 551, 573 (Rashid Hassan et al. eds., 2005). The Millennium Assessment concludes that management decisions made in ignorance of the relevant ecosystem trade-offs learn of the loss of ecosystem functionality the hard way. *See id.* ("These decisions have often resulted in the degradation of inland waters, and the loss or decline in the multiple services they provide, in favor of a smaller number of services, such as the supply of fresh water for drinking or irrigation or the supply of hydroelectricity or transport routes.").

19. "[E]cosystem services have value insofar as they either change the benefits associated with human activities or change the costs of those activities." Costanza et al., *supra* note 2, at 255.

The moment one suffers from the loss of an ecosystem services is, in our view, the most opportune moment to value the service—the moment when reliance on the service and its importance are abundantly plain. However, it is not the most helpful time. Rather, potential ecosystem service losses can be foreseen, and in many cases avoided, by identifying the services that will be disrupted from any particular proposal.[20] This analysis is referred to as "trade-offs," and it entails a functional understanding, both of the benefits from changing the structure of a place and the lost services associated with changes to that ecosystem structure.[21]

> The principal challenges in managing [ecosystem services] are that they are not independent of each other, and that the relationships between them may be highly non-linear. Individual ES can be thought of as different elements of an interrelated whole or "bundle." Attempts to optimize a single service often lead to reductions or losses of other services—in other words, they are "traded-off." For example, forested areas provide a variety of extractive and non-extractive goods and services. If a region is managed for mining, this may decrease its value for carbon sequestration, flood control, or wilderness and biodiversity protection.[22]

Closely associated with trade-offs is the idea of ecosystem service synergy, defined as actions which simultaneously enhance multiple ecosystem services.[23] At base, both trade-offs and synergies analyses require investigations into the existing ecosystem functions, how those functions provide services locally and regionally (and in some cases, globally), and how the goals of proposed ecosystem changes might be met in ways that cause the least disruption (or alternatively, the most enhancement) to needed services.[24]

This is not to say that a trade-offs analysis is simple. Some trade-offs present complicated comparisons due to the difficulties in comparing costs and benefits across different landscapes,[25] or due to the time delay

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20. Rodríguez et al., *supra* note 6.

21. *Id.*

22. *Id.* (internal citations omitted).

23. *See* C. Raudsepp-Hearne et al., *Ecosystem Service Bundles for Analyzing Tradeoffs in Diverse Landscapes*, 107 PROC. NAT'L ACAD. SCI. 5242, 5242 (2010).

24. *Id.* at 5246 (analyzing ES trade-offs as they occur in bundles across different functions and scales). "Because these tradeoffs are not inescapable, as observed by a number of municipalities with weaker tradeoffs between categories of ecosystem services, knowing where these tradeoffs are occurring makes their management possible." *Id.*

25. *See* Simon Briner et al., *Trade-Offs Between Ecosystem Services in a Mountain Region*, 18 ECOLOGY & SOC'Y, no. 3, art. 35, 2013, https://www.ecologyandsociety.org/vol18/iss3/art35/ [https://perma.cc/C8VQ-C8LA] ("[C]limate change may differentially influence the

between the costs of protecting the ecosystem function and receipt of and gratification for the service.[26] Climate change illustrates this problem, given the immediacy of the costs but intergenerational benefits associated with climate resiliency investments. Trade-offs may be further complicated due to the manner in which we assess particular ecosystem services or groups of services, given the likelihood that ecosystem circumstances will change over time.[27] Yet, despite the difficulties, trade-offs are inevitable:

> Of course, there are tradeoffs when we manage natural capital for ecosystem services. There are tradeoffs in every decision we make about the environment. It's no different when engaging the ecosystem services framework. Indeed, if we were to not engage the ecosystem services framework in private markets and public policy, that would be a tradeoff, as we would have less information at hand to make informed decisions. So, if we don't want to manage for groundwater recharge or carbon sequestration because we are concerned about over-managing for a specific service, then fine. Or if we decide to manage for a specific service, fine. Those are the tough decisions we will need to make. But, we need to make the consequences of any decision about ecosystem services explicit. The tradeoffs need to be put on the negotiation table, and we need robust ecology and economics to back them up. Bottom line: Don't hide the tradeoffs, but don't hide from them.[28]

The trade-offs analysis makes visible our choices to prioritize particular ecosystem services over others, including (and especially) in those everyday choices in which ecosystem elimination and disruption are normalized.

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constituents of the ecosystem, e.g., the climatic response of grassland versus that of forest.") (citations omitted).

26. *See* Jeannine Cavender-Bares et al., *A Sustainability Framework for Assessing Trade-Offs in Ecosystem Services*, 20 ECOLOGY & SOC'Y, no. 1, art. 17, 2015, https://www.ecologyandsociety.org/vol20/iss1/art17/ [https://perma.cc/B4K5-MY9V] (discussing the temporal difficulties in valuing trade-offs). "For example, rebuilding fish stocks for long-term health of the fishing industry can require reducing or shutting down harvest for a period of time with an immediate burden on fishermen." *Id.*

27. *See* Robin Kundis Craig, *Perceiving Change and Knowing Nature: Shifting Baselines and Nature's Resiliency*, *in* ENVIRONMENTAL LAW AND CONTRASTING IDEAS OF NATURE 87, 87–88 (Keith H. Hirokawa ed., 2014).

28. Ruhl, *supra* note 5, at 333.

B. *Trade-Offs in Aquatic Ecosystems*

Watercourses and their associated flood plains provide a wide range of services, both to local communities and, more broadly, on a watershed, regional, or other subnational level. In some areas, communities derive benefits from the ways freshwater ecosystems *regulate* the environment, such as through influence of air temperature and other climate circumstances,[29] maintenance of water quality,[30] flood control, and management of disease, pests, pollination, and erosion.[31] Some communities benefit from *supporting* services, which are considered "necessary for the production of all other ecosystem services,"[32] such as those ecosystem functions that provide structure for successful photosynthesis, nutrient cycling, and the production of ecosystem goods.[33] Other communities value cultural services provided by freshwater ecosystems. These services include those "nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences,"[34] including water-based recreation, aesthetic values, social relations, sense of place, inspiration, and cultural heritage.[35] Finally, some communities rely heavily on the ability of an ecosystem to produce goods through *provisioning* services.[36] In freshwater ecosystems, provisioning services include the production of goods, such as food, water, building materials, fibers, and other consumables.[37]

Watercourses, riparian habitats, and flood plains have been targeted for the development of specific ecosystem services throughout history.[38]

29. Finlayson et al., *supra* note 18, at 557 ("Inland water systems play two critical but contrasting roles in mitigating the effects of climate change: the regulation of greenhouse gases (especially carbon dioxide) and the physical buffering of climate change impacts.").

30. *Id.* ("The capacity of many wetland plants to remove pollutants derived from chemical or industrial discharges and mining activities is *well established* and increasingly used as a passive treatment process.").

31. REID ET AL., *supra* note 3, at 40.

32. *Id.*

33. *Id.*

34. *Id.*

35. *Id.*

36. *See id.* at 7 tbl.1 (describing various provisioning services, as well as their global condition).

37. *See* Stephen Farber et al., *Linking Ecology and Economics for Ecosystem Management*, 56 BIOSCIENCE 117, 119 tbl.1, 124 tbl.3 (2006), made available at https://digitalcommons.fiu.edu/cgi/viewcontent.cgi?article=1097&context=fce_lter_journal_articles [https://perma.cc/QWG8-L2Q4].

38. Finlayson et al., *supra* note 18, at 568.

Navigable waterways have been regularly dredged to maintain navigability for transportation and commerce. Waterfront development is highly valued for the development of housing and infrastructure. Watercourses have been used to collect and transport human and animal waste, pesticides, herbicides, and fertilizers contained in agricultural runoff. The *Millennium Assessment* reports as follows:

> Water regimes of inland waters have been modified by humans for centuries, with the last 50 years in particular witnessing large-scale changes in many parts of the world, often associated with drainage and infilling activities . . . . Modifications include construction of river embankments to improve navigation, drainage of wetlands for agriculture, construction of dams and irrigation channels, and the establishment of inter-basin connections and water transfers. These changes have improved transportation, provided local flood control and hydropower, boosted fisheries, and increased agricultural output by making more land and irrigation water available.[39]

Many decisions to modify an ecosystem to secure or maximize a particular ecosystem service have resulted in the loss of some other ecosystem service due to interruption or displacement of ecosystem functions. Alterations to watercourses and flood plains can result in significant, sometimes unrecoverable, states; this is where trade-off analysis is important. Consider the costs that, as reported in the *Millennium Assessment*, "ha[ve] placed the ecosystem services derived from these systems and human well-being at increasing risk."[40] Development in and around waterbodies impacts water quality and displaces fish and wildlife. The *Millennium Assessment* adds that "physical changes in the hydrological cycle have resulted in the disconnection of rivers from their flood plains and wetlands, caused seasonal changes in water flows, increased the likelihood and severity of flooding, [and] disrupted links with groundwater systems . . . ."[41] The *Millennium Assessment* further attributes freshwater ecosystem degradation to overharvesting and extraction of ecosystem products,[42] and

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39. *Id.* (citations omitted).

40. *Id.* at 553.

41. *Id.* at 569 (internal citation omitted).

42. *See id.*

> Inland water systems are a major source of products that can be exploited for human use, including fruit, fish, shellfish, deer, crocodile and other meats, resins, timber for building, fuelwood, peat, reeds for thatching and weaving, and fodder for animals. Many of these products are exploited at subsistence, cottage industry, or the larger commercial scale in most parts of the world.

notes that stream modifications have exposed water systems to exotic species, resulted in an "overall loss of freshwater biodiversity," altered fish and bird migration patterns, and influenced the integrity of both upstream and downstream habitats.[43]

The pressures imposed by the built environment on flood plains vary by location, but in many cases ecosystem disruption is primarily caused or exacerbated by land development and exploitation.[44] As noted in the *Millennium Assessment*:

> The direct drivers of loss and degradation of inland waters are well known and documented and include changes in land use or cover due to vegetation clearance, drainage, and infilling, especially connected to expansion of agriculture; the spread of infrastructure, whether for urban, tourism and recreation, aquaculture, agriculture, or industrial purposes; the introduction and spread of invasive species; hydrologic modification; overharvesting, particularly through fishing and hunting; pollution, salinization, and eutrophication; and global climate change, which is expected (high certainty) to lead to even further degradation and to exacerbate existing pressures.[45]

For purposes of this Article, evidence of another important trade-off has become increasingly apparent: the impacts of streambed modifications for purposes of flood control include a host of long-term, negative impacts to the ability of the watershed to control flood surges. Floods have become more destructive in recent years, and it is predicted that this trend

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Id. at 558. "Wide-scale vegetation clearing has caused erosion to increase, filling many shallow water bodies with sediment and disrupting the transport of sediment to coastal areas." *Id.* at 556.

43. *Id.* at 569. Land use changes have taken a particularly significant toll on the ability of inland water systems to provide functioning habitats. *Id.* at 555.

44. ZACHARY CHRISTIN & MICHAEL KLINE, EARTH ECON., WHY WE CONTINUE TO DEVELOP FLOODPLAINS: EXAMINING THE DISINCENTIVES FOR CONSERVATION IN FEDERAL POLICY 7 (2017), https://www.aswm.org/pdf_lib/discincentives_for_conservation_in_federal_policy.pdf [https://perma.cc/597F-CKD5].

> Floodplain functions are lost or greatly diminished when floodwaters are disconnected or diverted from the floodplain by levees, dikes, railroads, or the fill associated with roads, homes, and buildings. Dysfunction also results from changes to the shape of river channels or changes in the inputs of water and sediment that have led to imbalance (disequilibrium) and vertical disconnection of the river from the floodplain . . . .

Id.

45. Finlayson et al., *supra* note 18, at 553.

will continue.[46] The direct health impacts from flooding events include death, physical injuries, infectious diseases, emotional distress, and impacts related to the loss of food and shelter. Flooding also causes indirect health impacts that include chronic disease and exposure to hazardous materials.[47] Both due to a disparity in flood control infrastructure investments across and within communities, and a disparity in community capacity to respond to flooding events, floods tend to disproportionally impact low-income populations.[48]

Two noticeable and avoidable trade-off dilemmas pervade flooding risk. First, much of the risk is self-imposed.[49] The state of knowledge regarding the relationship between major flood events and ecosystem conditions is lacking, in large part due to the inattention given to *natural* flood regulation conditions.[50] As stated by the *Millennium Assessment*, "[T]he importance of services derived from inland waters (such as fresh water, fish, and groundwater recharge) is often taken for granted or treated as a common good, with the real value only being recognized after the services have been degraded or lost."[51] We have paid insufficient attention to the economic value of surface water flow regulation by aquatic vegetation[52] to the flood control benefits of forested watersheds,[53] and, more generally, to the cumulative effects of piecemeal impacts to the

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46. Lelys Bravo de Guenni et al., *Regulation of Natural Hazards: Floods and Fires*, *in* 1 ECOSYSTEMS AND HUMAN WELL-BEING: CURRENT STATE AND TRENDS ASSESSMENT 441, 447 (Richard Norgaard ed., 2005).

47. *Id.* at 452.

48. *See id.*

49. *Id.* ("The number of deaths associated with flooding is closely related to the local characteristics of floods and to the behavior of victims.").

50. *Id.* at 443 ("Our knowledge of how ecosystems ameliorate or accentuate the impacts of extreme events on human well-being is limited for a variety of reasons.").

51. Finlayson et al., *supra* note 18, at 555.

52. *Id.*

> While it has been known for many years that aquatic vegetation attenuates surface flows, the considerable value of this service is not often widely and accurately assessed in economic terms. In contrast, figures on the cost of flood damage are readily available after this function has been lost or seriously eroded by unsustainable development; . . . .

Id. (internal citation omitted).

53. Bravo de Guenni et al., *supra* note 46, at 444 ("In the case of flooding, local or regional ecosystem conditions, such as increased deforestation, may contribute to the magnitude or scope of particular flooding events, setting the stage for increased vulnerability. Human vulnerability is conditioned by the characteristics of local ecosystems, social systems, and human modifications to them.").

watershed.[54] When viewed in isolation, individual contributors of the ecosystem may appear to provide an insignificant benefit during major flood events. However, wetlands and other flood plain features must be viewed as parts of a larger system of hydrological regulation to understand the effect of services provided.[55] Although we are aware that inland water systems contribute to aquifer recharge, including during flooding periods,[56] few jurisdictions appear to perceive lost recharge as a real threat.

Moreover, notwithstanding the efforts in federal regulations to discourage development in flood plains,[57] we continue to develop housing, commercial land uses, and infrastructure in areas that are vulnerable to frequent flooding. We continue to construct and maintain roads and other infrastructure in riparian areas, making such areas more accessible. Not insignificantly, we often see hedonic values (e.g., aesthetics) driving land values among waterfront properties to the exclusion of an accurate accounting of the critical natural protections benefitting such locations.[58] This is done without an accurate consideration of the risks both from hazards and from the loss of natural protections suffered to establish such locations as livable. Development trends suggest the unfortunate circumstance that people continue to settle in areas that are highly prone to flood hazards.[59]

The second trade-off dilemma arises during major flood events, when efforts to control the volume and rate of surface flow regularly focus on dredging streambeds to create wider and deeper channels for water collection and transportation—on getting the water out of town.[60] In the meantime, in addition to the direct costs of the damages suffered from flood events, there are significant, long-term costs of developing in the flood plain:

54. Finlayson et al., *supra* note 18, at 555. Although the loss of any particular flood plain or wetland feature may appear insignificant when considered in isolation, the loss "can be extremely high locally." *Id.*

55. *See* Bravo de Guenni et al., *supra* note 46, at 446.

56. Finlayson et al., *supra* note 18, at 557.

57. *See generally* 42 U.S.C. § 4001 (2018); 44 C.F.R. §§ 60.1–60.8 (2019).

58. Rodríguez et al., *supra* note 6 (discussing the creation of "lake communities" and the resulting impairment of other ecosystem functions).

59. Bravo de Guenni et al., *supra* note 46, at 451.

60. CHRISTIN & KLINE, *supra* note 44, at 7 ("Stream channel modifications have largely been pursued to protect adjacent land uses that may be threatened by flooding or fluvial erosion.").

> The downstream cost of channel works such as levees is reflected in the destruction of habitat and increased risk of downstream flooding. Channelization typically pinches the river and severs connections to the floodplain, funneling the water downstream faster, and causes flooding upstream as water backs up behind the pinch point. As a result, the river and floodplain processes no longer create critical habitats such as side-channels and off-channel areas that are essential shelter and forage areas for juvenile fish. Channels and levees are often lined with rocks (riprap), which creates an inhospitable habitat, often devoid of trees and vegetation that cool the water through shade.[61]

The short-term approach to flood control through channelization and structural stream modification tends to exacerbate, rather than control, the damage from major flooding events. In other words, the very normal efforts that are intended to control the risks from floods often contribute to, rather than solve, the problems caused by flooding.

II. Flood Vulnerability and the Engineering Approach to Emergency Management: The Case of Tropical Storm Irene

Hurricane Irene made landfall in North Carolina in late August 2011 and continued up the coast to New England as a tropical storm, dumping heavy and historic amounts of rainfall along the way.[62] Although Vermont had seen increasingly frequent flood events over the preceding forty years, the state had not suffered a flood event on the level of Irene since 1927.[63]

The wrath of Irene in Vermont is a story of flood vulnerabilities. Vermont land development has historically directed resident populations toward flood-prone areas, including valleys and their associated watercourses.[64] Channelization, construction of stream-side berms, and commercial gravel extraction (at least until the practice was banned in

61. *Id.* at 9 (footnote omitted).

62. LIXION A. AVILA & JOHN CANGIALOSI, NAT'L HURRICANE CTR, TROPICAL CYCLONE REPORT: HURRICANE IRENE, 1 (2011), https://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf [https://perma.cc/565H-Y4NQ].

63. *Entrenched Ideas Targeted at Conference to Consider Lessons of Irene*, BURLINGTON FREE PRESS (Apr. 29, 2012), https://www.patrout.org/docs/stream-cleaning-and-channelization/post-irene-conference-in-vermont.pdf?sfvrsn=0 [https://perma.cc/9FVC-DXCW] [hereinafter *Entrenched Ideas*].

64. David K. Mears & Sarah McKearnan, *Rivers and Resilience: Lessons Learned from Tropical Storm Irene*, 14 VT. J. ENVTL. L. 177, 195 (2012).

1986),[65] as well as infrastructure construction, such as roads, water, and sewer, facilitated the development of population centers in such areas. The practices were so widespread that one study of more than 8,000 miles of Vermont's rivers and streams revealed that seventy-five percent were "unstable due to centuries of actions taken to control their flows and reshape their channels."[66] A report published in 2006 by the Bennington County Conservation District and Hoosic River Watershed Association noted that a series of braided streams (Barney Brook, Walloomsac River, Furnace Brook, and Roaring Branch) had "at times of flood transported huge and devastating volumes of water and sediment to the urbanized village center."[67] As elsewhere in Vermont, the community historically addressed stream malfunction through additional channelization, the introduction of riprap to watercourse banks, construction of berms and walls, and, in the case of Roaring Branch, dredging.[68] Large-scale dredging in affected rivers and streams followed previous major flood events (in 1973 and 1976), resulting in the channelization of those rivers and streams along much of their length.[69] The Roaring Branch offers evidence of this history: "As recently as the late 1980s, the Roaring Branch throughout much of its length in Bennington was dredged, and a series of historic berms on both banks of the Branch are evidence that this activity was a common one in earlier years."[70] The Roaring Branch has been straightened along an average of ninety-four percent of its reaches.[71] In the meantime, flood plain function is estimated to "ha[ve] been lost along seventy-five percent of Vermont stream miles."[72]

Irene followed. Reaching Vermont on August 28, Tropical Storm Irene brought three to five inches of rain across much of the state, with

65. *See* JORDAN WHITE ET AL., RIVERBED GRAVEL REMOVAL 1 (2012) (citations omitted), https://www.uvm.edu/~vlrs/Environment/gravel%20removal%20from%20rivers.pdf [https://perma.cc/GA96-FXWQ].

66. Mears & McKearnan, *supra* note 64, at 200 (citation omitted).

67. BENNINGTON CTY. CONSERVATION DIST. & HOOSIC RIVER WATERSHED ASS'N, PHASE I GEOMORPHIC ASSESSMENT OF THE WALLOOMSAC RIVER WATERSHED IN SOUTHWESTERN VERMONT 2 (2006), https://anrweb.vt.gov/DEC/SGA/finalReports.aspx [https://perma.cc/M6K7-5WTQ] [hereinafter GEOMORPHIC ASSESSMENT].

68. *Id.*

69. MIKE KLINE, RIVER CORRIDOR MANAGEMENT IN A FLOOD RESILIENT VERMONT: AN APPROACH TO REDUCING VULNERABILITY IN A FLOOD-PRONE STATE 3 (2011), http://vnrc.org/vnrc_river_conference/River%20Corridor%20Management%20in%20a%20Flood%20Resilient%20Vermont.pdf [https://perma.cc/4EVX-BGTM].

70. GEOMORPHIC ASSESSMENT, *supra* note 67, at 9.

71. *Id.* at 8.

72. CHRISTIN & KLINE, *supra* note 44, at 9.

amounts over seven inches falling on some of the state's higher elevations.[73] The river level gage on the Otter Creek in Center Rutland showed a level of 9.21 feet above the flood stage, while the Mad River in Moretown and the White River in West Hartford showed levels of 12.1 feet and 10.4 feet above their flood stages, respectively.[74] In all, "[i]ntense flooding occurred in at least 10 of Vermont's 17 major river basins."[75] River berms and streambank structures were ripped away by raging water, and bridges across the state were washed out.[76]

The damage wrought by the heavy rainfall and subsequent flooding was historic: 225 of Vermont's 251 towns had seen some form of water damage, and thirteen of those towns were unreachable due to washed out roads.[77] Perhaps that only thirteen towns had impassable roads is surprising considering "[m]ore than 500 miles of state road and 2,260 sections of town highway suffered washouts and damaged bridges."[78] The damage stacked up quickly: 229 businesses, 629 historic buildings, more than 3,500 homes, and 20,000 acres of farmland were affected by the deluge,[79] with at least five deaths reported.[80] In the aftermath, "more than 450 farms filed Farm Loss claims" with the United States Department of Agriculture (USDA).[81] Some of the consequences lingered: hazardous spill reports increased "by a factor of fourteen" in just the first week after Irene, the Vermont Agency of Natural Resources reported, as a result of rising floodwaters lifting home fuel tanks and severing their connections.[82] Making matters worse, the main Waterbury offices of both the Vermont Agency of Natural Resources (ANR) and Vermont Emergency Management were flooded, requiring the disaster response headquarters to relocate in the midst of a crisis.[83]

Although work to restore safe conditions and repair infrastructure commenced immediately, flood response construction was generally

73. SACHA PEALER, VT. AGENCY NAT. RES., LESSONS FROM IRENE: BUILDING RESILIENCY AS WE REBUILD 1 (2012).

74. *Id.* at 5.

75. *Id.*

76. Mears & McKearnan, *supra* note 64, at 178.

77. PEALER, *supra* note 73, at 1–2; *Entrenched Ideas*, *supra* note 63.

78. *Entrenched Ideas*, *supra* note 63.

79. *Id.*

80. Joel Banner Baird, *Vermont's Roads: Ready for the Next Irene?*, BURLINGTON FREE PRESS (Aug. 29, 2016), https://www.burlingtonfreepress.com/story/news/local/vermont/2016/08/29/vermonts-roads-ready-next-irene/89271976/ [https://perma.cc/P63X-DYGD].

81. PEALER, *supra* note 73, at 5.

82. *Id.* at 3.

83. *Id.* at 2.

consistent with historical, conventional practices. "Vermonters responded as they always have in the past: They used heavy equipment to put the river back in its old channel, to straighten it, to dig the channel deeper, to rip-rap its banks higher and more heavily."[84] To speed the recovery efforts, then-Governor Peter Shumlin stayed a twenty-five-year-old ban on gravel removal from the beds of rivers and streams.[85] Additionally, the United States Army Corps of Engineers likewise eased the burden of regulatory compliance for activities aimed at responding to storm damage, including exempting such activities from regulation under the Clean Water Act.[86] Vermont Agency of Natural Resources' guidance on river work and channel modification were largely ignored in reliance on contrary statutory provisions that allowed municipalities to work in river channels during emergencies under the auspices of "the urgency to rebuild at any cost."[87] This prompted concern among river scientists and engineers "that the roads and bridges would be constructed in a manner that would increase the risk of flooding downstream or make them vulnerable to being washed away in the next high-water event."[88] A subsequent Vermont Fish and Wildlife Department report confirmed the fear, noting that "a significant amount of instream activity was . . . conducted without proper consultation and oversight or for reasons beyond necessary flood recovery."[89]

Given the hasty, largely-unchecked, array of flood responses,[90] it might not be surprising that recovery efforts included many decisions that

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84. *Entrenched Ideas*, *supra* note 63.

85. WHITE ET AL., *supra* note 65, at 1.

86. *In Aftermath of Tropical Storm Irene: Corps Provides Details on Exemptions, Permit Emergency Procedures for Storm Damage Repairs in New England*, U.S. ARMY CORPS OF ENGINEERS (Aug. 31, 2011), https://www.nae.usace.army.mil/Media/News-Releases/Article/490105/in-aftermath-of-tropical-storm-irene-corps-provides-details-on-exemptions-permi/ [https://perma.cc/MN8A-DTNZ].

87. KLINE, *supra* note 69, at 3.

88. Mears & McKearnan, *supra* note 64, at 190.

89. RICH KIRN, VT. FISH AND WILDLIFE DEP'T, IMPACTS TO STREAM HABITAT AND WILD TROUT POPULATIONS IN VERMONT FOLLOWING TROPICAL STORM IRENE 5 (2012).

90. Vermont now prohibits the changing, alteration, or modification of "the course, current, or cross section of any watercourse or of designated outstanding resource waters . . . by movement, fill, or excavation of ten cubic yards or more of instream material in any year, unless authorized by the Secretary." VT. STAT. ANN. tit. 10, § 1021(a) (2018). Subsection (c) contains the commercial ban: "No person shall remove gravel from any watercourse primarily for construction or for sale." *Id.* § 1021(c). However, subsection (b) carves out an exception for "emergency protective measures necessary to preserve life or to prevent severe imminent damage to public or private property, or both," so long as the protective measures are "limited to the minimum amount necessary to remove imminent threats to life or property." *Id.* § 1021(b)(1).

seemed to offer short-term benefits, but likely insured long term damage. Flood response activities included "large scale removal of streambed material and natural wood, berming of streambed materials to raise streambank elevations and the straightening of stream channels."[91] Despite the common assumption that increasing flow capacity would provide immediate flood relief, the known consequences from such stream modifications actually include flood vulnerability.[92] As David Mears and Sarah McKearnan noted, "[t]hese actions caused floodwaters to move downstream faster, which increased erosion and fomented the catastrophic movement of rivers that can occur during major flood events."[93] Moreover, these activities were reported to have resulted in widespread reductions in the habitat diversity needed to support aquatic species' populations.[94]

The story of Tropical Storm Irene is largely one about how Vermont's government calculated long and short-term goals about flood risk management, both in advance of and in response to a major storm event. Development in flood plains—resulting in the loss of flood plain functionality—has historically been the rule rather than the exception in Vermont.[95] Much of Vermont's public infrastructure has been located along waterways.[96] Not surprisingly, much of the damage wrought by Irene occurred in areas historically served by straightened watercourses, and "most of the post-Irene river work has been done to reclaim lands by dredging and redirecting streams that had been impacted by channelization before."[97] Millions of dollars were spent to respond to the

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91. KIRN, *supra* note 89, at 5.

92. *See* CHRISTIN & KLINE, *supra* note 44, at 9 ("Levee walls and channelization alter flood heights, increase floodwater velocities, and result in more powerful flood surges downstream, all of which increase channel erosion and downstream deposition, risking homes and commercial property.").

93. Mears & McKearnan, *supra* note 64, at 180.

94. KIRN, *supra* note 89, at 4. Wild trout populations responded poorly to Irene, in some streams suffering population reductions down to thirty-three to fifty-eight percent of their pre-flood levels. *Id.*

95. *See* Mears & McKearnan, *supra* note 64, at 195.

> In many areas, towns and villages developed in narrow valleys, near river crossing locations and waterfalls. In these settlements, land with low slopes was limited, and floodplains provided large, flat areas, free of the natural features that made building difficult. As a result, many floodplains in Vermont have already been developed and development pressures in these areas may continue.

Id.

96. *Id.* at 196.

97. KLINE, *supra* note 69, at 4.

damage in these areas of self-created vulnerability, and, given the foregoing, much of that cost could have been avoided.[98]

CONCLUSION: MAKING BETTER RESILIENCY DECISIONS BY MANAGING TRADE-OFFS IN RESILIENCY PLANNING

History is replete with examples of drastic, perhaps unanticipated, experiences in communities that owe some consequence to significant ecosystem service trade-offs. In Houston, the decision to forego land use regulation, combined with intentionally narrowed natural waterways, illustrated a community prioritization of self-determined development over natural flood readiness that left the city vulnerable to the historic rainfall dropped by Hurricane Harvey.[99] The rapid disappearance of coastal wetlands in Louisiana, due to coastal development in and around the city of New Orleans, hobbled the existing natural protection against destructive storm surges, a pivotal circumstance that explains the damage done when Hurricane Katrina hit the city in 2005.[100] This Article considered the extensive damage caused by Tropical Storm Irene and the role that land development and flood management choices played in producing a maladapted built environment. The Vermont story, like the choices made in other regions, illustrates the dilemma in which a decision to prioritize one ecosystem service may curb the ecosystem's ability to provide other essential services to the community.

In this vein, it is worth noting that Tropical Storm Irene also reveals some, albeit isolated, examples of effective trade-off decision making. In 2006, Bennington County began taking steps to recapture flood plain services for the benefit of its over 800 structures that lie in the Special Flood Hazard Areas, including 312 single family homes, 209 commercial buildings, 149 mobile homes, 108 multi-family apartment buildings, and over a dozen critical facilities.[101] The Bennington community enhanced flood plains and adopted zoning regulations that restricted development along waterways, allowing for the restoration and creation of flood plain

98. Baird, *supra* note 80.

99. *See* Dylan Baddour, *The Trouble with Living in a Swamp: Houston Floods Explained*, HOUS. CHRON. (May 31, 2016), https://www.houstonchronicle.com/local/explainer/article/The-trouble-with-living-in-a-swamp-Houston-7954514.php [https://perma.cc/HK6Y-YU3C].

100. *See generally* David Uberti, *Is New Orleans in Danger of Turning Into a Modern-Day Atlantis?*, GUARDIAN (Aug. 24, 2015, 6:59 AM), https://www.theguardian.com/cities/2015/aug/24/new-orleans-hurricane-katrina-louisiana-wetlands-modern-atlantis [https://perma.cc/RNQ7-QD9R] (discussing the history and effects of development in New Orleans and their contributions to flood damage during Hurricane Katrina).

101. *See* Mears & McKearnan, *supra* note 64, at 195–96.

area.[102] The project is estimated to have cost around $750,000, but it likely prevented millions of dollars in flood damage to public infrastructure and private property.[103]

Land use decision-making would benefit from a sincere and genuine dialogue on the integration of ecosystem service trade-offs. The thrust of the argument is that development should be subjected to trade-offs analysis so that development decisions are made in light of the vulnerabilities we create. Hence, the argument here is not intended to undercut the role and importance of authorizing land uses that benefit the public, but rather to emphasize the critical role of implementing well-reasoned decisions and, in most cases, making sure that we are planning for the next emergency or the next public need.[104] Through this shift, trade-offs analysis is likely to reveal previously unidentified climate risks, help us understand the ways our choices influence the identity of climate winners and losers, and provide reliable resilience strategies.

102. *See* Jim Therrien, *Pre-Irene Streambed Work Helped Limit Damage*, VTDIGGER (Aug. 9, 2018), https://vtdigger.org/2018/08/09/pre-irene-streambed-work-helped-limit-damage/ [https://perma.cc/JW7A-6JPR].

103. *Id.*

104. *See* 2 U.S. GLOB. CHANGE RESEARCH PROGRAM, FOURTH NATIONAL CLIMATE ASSESSMENT 165 (2018) ("Proactive adaptation initiatives—including changes to policies, business operations, capital investments, and other steps—yield benefits in excess of their costs in the near term, as well as over the long term. Evaluating adaptation strategies involves consideration of equity, justice, cultural heritage, the environment, health, and national security.").