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Enhancing the Connecticut River Watershed's Resilience to Climate-Driven Flood Disturbances through Ecologically-Centered Adaptation Strategies

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ABSTRACT

Climate adaptation planning relating to the freshwater biome is of critical importance because of the role these systems play in maintaining watershed-level social and ecological processes. Of the many climate-change effects altering the integrity of social and ecological systems, growingly severe flooding comprises one of the strongest. While flooding plays an important role in the development of some social and many ecological systems, novel climate-aggravated floods induce negative outcomes and necessitate river-adjacent urban system changes. Many temperate United States urban ecosystems face these flooding regime changes, and in this piece, I delve into the Connecticut River, one of the most vital watersheds in the Northeastern United States. This freshwater corridor connects natural, recreational, and cultural resources, and it serves millions of humans and non-humans. The concept of a socio-ecological systems also arises throughout this piece because of the linkages and relationships between these processes. Despite maintaining a large focus on how the creation of transformative climate adaptation strategies (e.g., adjusting suburban and urban settlement designs) might effectuate positive social change, I also tell ecological stories about river and shoreline-specific fish, wildlife, and plant communities. One of this work's most important themes includes the criticality of conserving and restoring watershed ecosystems consisting of interacting rivers, shorelines, and riparian forests as they respond to flooding regimes. In this opinion piece, I recognize the interconnections among social and ecological elements and therefore treat them as critical to one another's persistence.

KEYWORDS: Climate adaptation, Flooding, Urban ecosystems, Connecticut River watershed, Conservation and restoration

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Connecticut River Watershed Ecosystems (CRWEs) provide nearly 2.5 million individuals with invaluable social and ecological resources. Influencing urban, suburban, and rural social and ecological processes, the CRWE plays a role in the development of societies. Regional community-based, agency-supported, and research-centered stories spanning Vermont, New Hampshire, Massachusetts, and Connecticut segments provide information for possible climate adaptation planning avenues.[1] Watershed and climate adaptation planning overlap in significant ways, and across both practices, planners prescribe strategies to increase system resilience and reduce vulnerability. Moreover, planners must draw on social and ecological information to inform decision-making and

understand then intervention may promote system recovery.[2] Scholars and practitioners from environmental and river-facing fields diversely express this regional reliance. Moreover, CRWE services include offering irrigation potential, drinking water, nature-based outdoor recreation/tourism systems, environmental/ecological benefits, navigability for various industries, and cultural maintenance.[3,4] Together, these "services" continually offer the American Northeast region many opportunities, although wicked issues abound. One of the most vital components of CRWE planning includes the protection of river ecosystem health, which also includes smaller order waterways like creeks, brooks, and streams. Conserving riverine ecosystems also creates social system resilience because of available resource pools and other nature-based benefits, like the maintenance of parks and protected areas. Regardless of the sum of social and ecological successes, it is critical to process how transformative climate adaptation work can safeguard some of the most regionally important resources (Figure 1).

As amplified by many concerned scholars and practitioners, the human-nature connection is quickly and generally waning as people lose access to natural spaces. This fading connection may portend the decline in environmental and ecological literacy, which are crucial for the progression of regional initiatives like climate adaptation strategies with the potential to permanently transform the way people view watershed systems (Figure 2). These connectivity declines largely threaten the societal and public reception and understanding of good climate adaptation planning. Even more threatened include freshwater ecosystems, which receive far less attention when compared with forests, mountains, grasslands, and other terrestrial-centric systems. Throughout this piece, note the emphasis I place on the importance of connecting people to freshwater ecosystems. However, the generation of transformative climate adaptation strategies can directly and indirectly address many of the most pressing challenges. As witnessed at unprecedented and accelerated rates across terrestrial biomes, climate change effects induce severe land and riverscape changes.[5] These changes affect both terrestrial and aquatic matrices, or those large, interacting ecosystems and landscapes.

In this piece, I utilize concepts facing socio-ecological systems (SES), or those dominated by abounding human-nature interactions. These SES assume that humans and non-humans behave somewhat alike because of the inextricable relationships, and each system affects the other in diverse ways. Considering these parts independently from one another largely detracts from the unified movement or progression of sustainable, ecologically friendly development (e.g., harmonious building practices or those that greatly minimize the burden on sensitive ecosystems). When inserting the climate adaptation piece into SES, it becomes evident that strategies, objectives, and transformations cover many overlapping dimensions. Otherwise noted, adapting to large-scale climate changes likely promotes multiple system health outcomes. I attempt to make explicit connections to the humans and non-humans involved in the adaptation planning processes because both systems require sufficient representation.

Figure 1. Public shoreline access points create nature-based opportunities for people to physically and emotionally connect with local natural resources. Also note that tidal river ecosystem dynamics in Maine, Massachusetts, and Connecticut have downstream effects on the Connecticut River Watershed. (Image courtesy of the author, 2024).

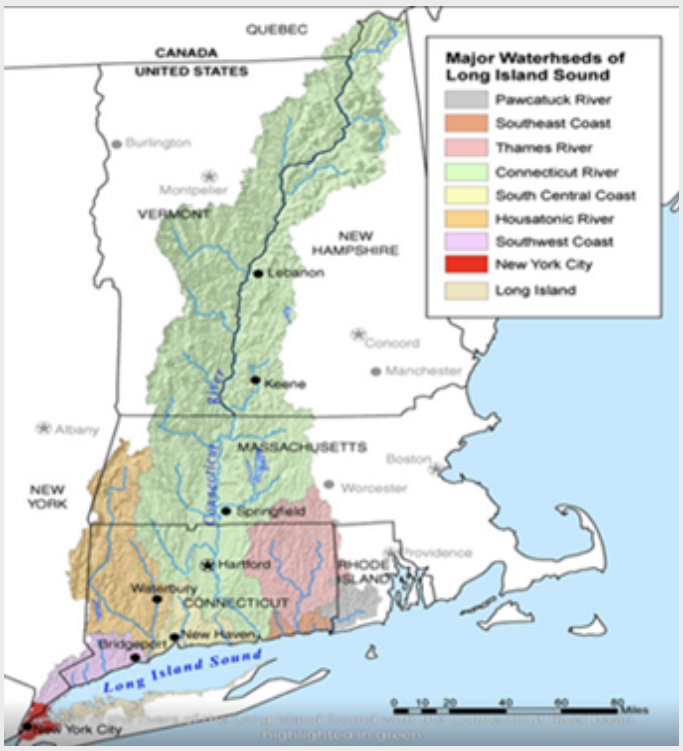

Figure 2. This visual shows the multiple interacting watershed ecosystems across the American Northeastern United States. Note that the Connecticut River watershed is the largest and most encompassing. Also consider how adaptation planning for or within one watershed system may exert influence on another. (Image courtesy of Connecticut River Conservancy, 2024).

This matter's urgency calls for immediate local, regional, national, and international collaboration and planning systems. Strong individuals, organizations, and agencies can create extensive, holistic, and transformative visions for the contemporary and future health of the freshwater biomes that spread across the United States.[6] Crafting such a transformative vision to adapt to changing ecosystems and

human connections undeniably involves a multiplicity of dynamic elements. In the case of this work, I center commentary and cases on the Connecticut River Watershed, the Northeastern United States' largest and most ecologically vital freshwater system.[7] Numerous stressors, threats, disturbances, and other challenges consistently grow in intensity and severity, each of which affects different social and ecological processes. Returning to governance, which is a major strand of this transformative story, I give concrete examples of the region's most prominent players.

Throughout this perspective, I consistently fold important local, state, and federal agencies into the conversation. Given this work's connection to watershed-level climate adaptation planning objectives, I discuss some of the most notable regional scholars, practitioners, and decision-makers who occupy various governmental levels. A transformative strategy poorly operates in the absence of strong minds across various natural, conservation, and water agency teams. Needless to say, freshwater ecosystems necessitate social and ecological champions. These linchpin community members can play crucial roles by advancing important scholarly and practitioner works.[8] However, the common denominator between scholars and practitioners is often whether the application to decision-making personnel is apparent.

With governance and agency support in mind, I focus on the role of state agencies like the Connecticut Department of Energy and Environmental Protection (DEEP), New Hampshire Fish and Game (NHFG), Vermont Department of Environmental Conservation (VDEC), the Massachusetts Department of Environmental Protection (MDEP), and the Massachusetts Department of Conservation and Recreation. Although the American Northeast contains smaller federal parks, protected areas, and other land/water parcels, and influence, I note how the United States Army Corps of Engineers (USACE), Environmental Protection Agency (EPA), National Park Service (NPS), and the United States Fish and Wildlife Service (USFWS) currently contribute and could continue to effectuate meaningful transformative adaptation change across the Connecticut River Watershed. Finally, I draw on the executive offices associated with various governors with open positions on climate adaptation. These perspectives offer glimpses into the past, present, and future. Moreover, gubernatorial platforms and viewpoints largely shape how state general assemblies and houses operate within the climate space. I pay special attention to policy positions held by the sitting Connecticut governor, Ned Lamont.[9]

CONNECTICUT RIVER WATERSHED FIELD INVESTIGATIONS: BROAD APPLICATIONS

To uphold concise writing and display my knowledge of the most optimal flooding-related climate adaptation strategies, I incorporate a handful of images where I think transformation can appropriately occur. I took each of the images during independent field site visits over the semester. Images and commentary either directly align with the Connecticut River or smaller still waterbodies and streams, creeks, and other tributaries. I will offer one or more reasons why decision-makers and the governmental players with a stake in the unique system should promote robust adaptation.

AMERICAN NORTHEASTERN FLOODING SYSTEMS

Flooding is the largest and arguably the most dangerous climate change effect facing the Connecticut River Watershed. The cities confronting the greatest challenges in Connecticut are Hartford and Middletown. Springfield, Massachusetts, also experiences increasingly large floods. Heavy rainfall begets river, coastal, and flash flooding, each of which alters public and private properties. Intense precipitation costs local, state, and federal officials, in addition to private citizens, millions of direct and indirect dollars. For instance, the flooding of property and the mass removal of debris comprise direct social effects. Debris accumulation and property flooding are much more likely to occur within areas near urban and suburban areas.[10] These effects also pose issues for communities on the rural peripheries of the Connecticut River Watershed. However, city and rural-edge accounts are far more limited, exposing large gaps in these areas. Onto indirect effects, these elements often involve the severing of social opportunities, like traveling for work. Flooding can impede the flow of people from place to place, which induces a suite of less easily detected but economically felt challenges.[11] Some scholars have begun considering which transformative adaptation strategies can restructure the distance of transportation systems from areas of extreme flood risk.[12] I am a proponent of redrawing current public and private transit channels across both Hartford and Springfield and distancing them from the consistently flooded Connecticut River embankments (Figure 3). The annual flooding events are increasing and causing even greater costs.[13] Throughout my exploration of this topic, it has become apparent that this disturbance negatively affects social and ecological systems (although sometimes improves ecosystem productivity).

Figure 3. Image shows a prominently known local recreational and cultural resource along the Hartford, Connecticut, river shoreline. This flooding event lasted several days, and the public park remained closed because of erosion and a high probability of soft ground caving (Image courtesy of the author, 2025).

BROAD APPLICATION TO LOCAL SOCIO-ECOLOGICAL SYSTEMS

As part of the local system connectivity associated with this transformative adaptation strategy, I photographed a public park that floods each spring and summer, and during unusually wet (i.e., high precipitation) days in both the fall and winter. Please refer to the preceding image that I took in Hartford over this semester. In this case, I suggest that adaptation activities focus on expanding the shoreline park to permanently absorb or receive the floodwaters. Floodwater expansion areas could even become novel parks, which will undoubtedly increase some forms of human connection through recreational uses. Agencies like the USFWS and USNPS have indirectly proposed the need for suburban and urban areas to allow floodwaters to "take on" their natural progression. This progression does not have to hinder and harm human communities.[14]

Both of these agencies manage small freshwater protected area units throughout Vermont, Massachusetts, and Connecticut, and their involvement aligns with the conservation of freshwater fish and wildlife. However, over the 2020s, the NPS has written policy directions that involve redesigning how urban and suburban areas respond to floodwaters as they become normal climate-driven manifestations.[15] The NPS also stewards several cultural and historical resources along the main stem of the Connecticut River, and this stake directly involves the regional identity. It would be wise to consider how to adapt to growing floodwaters when old buildings and culturally significant places are threatened. Finally, the state of Connecticut could work with local and county partners to design new shoreline park floodwater expansion zones, instead of attempting to quickly pump water and redirect it into other waterbodies.

RECOGNIZING THE MULTIFACETED DYNAMICS OF FLOODING DISTURBANCE

While most of this transformative climate adaptation vision emphasizes the role flooding plays throughout human communities, it is myopic to sideline the original non-human inhabitants. Moreover, both climate adaptation scholars and practitioners must recognize the multidimensional nature of flooding before crafting visions and prescribing management objectives across entire watersheds. Flooding opens and closes ecological opportunities; however, more often than not, this disturbance effectuates positive change.[16] In this vision, the most important (i.e., graded with ecological functionality, performance, and contributions to humans as the cardinal components) inhabitants include three major ecological divisions. First, the stream or riverine biota that inhabit various habitats across and within the flowing ecosystems play important ecological roles. These inhabitants often drive forward vital ecological processes with direct human connections. For instance, intact and minimally disturbed stream fish create small-scale nature-based recreational opportunities.[17] Within the Connecticut River watershed, recreational angling often comprises the most popular activity. Outside of the recreational context, complex stream fish communities offer subsistence and light fishery harvesters consumption opportunities. One of the largest and most socially positive outcomes of adapting to flooding in the Northeast includes the potential to grow resource pools. For instance, by encouraging the natural movement of floodwater into shorelines and nearby riparian zones, conservation agencies can help both people and nature adapt to these new normal conditions.[18]

When positioned within an ecological system context, climate-change exacerbated flooding often creates winners and losers. This simple economic concept parallels much of the ecological complexity that applied ecologists view across disturbance-dependent and prone ecosystems.[19] When flooding occurs, some species (e.g., river otter) quickly flee from their suitable habitats, while other, more thermally, sediment-load heavy, and turbulent-ready biotas strap into the system. Some fish species, often those with larger and heavier bodies, embrace the ecological disturbance.[20] Otherwise said, these flooding events do not hinder the behavior and health of all river fish and wildlife. Flooding events may arrest the development of some species reliant on quieter and less energetic environmental characteristics, while dramatically helping others. For instance, one of the most important Connecticut River Watershed Ecosystem (CRWE) components includes a medium-sized river with headwaters in Southern Massachusetts. The Lower Farmington River transports important fish and wildlife resources into the Connecticut River, while also creating numerous high-quality nature-based outdoor recreation and tourism opportunities. During wetter spring and summer months, urban and suburban segments of this river flood, resulting in frequent bank-jumping events (Figure 4). Flooding into riparian forests and shoreline depressions promote rich habitat for threatened and endangered amphibian species, ultimately driving forward social and ecological processes.

BROAD APPLICATION TO LOCAL SOCIO-ECOLOGICAL SYSTEMS

As part of the local system connectivity associated with this Connecticut River Watershed Ecosystem (CRWE) climate adaptation evaluation, I imaged a segment of the Sawmill River, a tributary

Figure 4. Shoreline and riparian forest habitats associated with urban sections of the Lower Farmington River rely on seasonal flooding. Severe and unpredictable floods hinder the development of shoreline and riparian forest habitats (Image courtesy of the author, 2026).

transporting ecologically unique and culturally significant fish and wildlife resources.[21,22] Native Sea lamprey populations, threatened and endangered mussels, and water birds form complex communities within relatively small Sawmill River riverine and floodplain habitats. These fish and wildlife resources also play roles in the maintenance of cultural connections, and their persistence directly relates to the integrity of Indigenous (i.e., Pequot tribal communities and sacred shoreline spaces) river connections and outdoor recreation systems. During seasons when climate change effects induce large floods, aquatic fish and wildlife resources often face habitat and population displacement. This negative change also involves the reduction in the Sawmill River's effectiveness to pass fish and wildlife resources, causing downstream issues in other social and ecological communities.

Enlarging shoreline access, associated public park viewing space, and other climate adaptation strategies that distance people from sensitive riverine systems serve as candidate planning ideas (Figure 5). Severe flooding can also overly stress some species, inducing unwanted stressors, and when combined with consistent human presence, may substantially overwhelm the biota. Otherwise said, one of the strongest adaptation strategies might comprise limiting human presence around shoreline resources. This strategy somewhat distances humans from natural-inspection "up-close", but it promotes the health of ecological communities during times of environmental hardship. Society must undeniably craft transformative adaptation plans for non-human communities including fish, amphibians, birds, mammals, reptiles, insects, and a myriad of plant life. This adaptation strategy is a long-term investment for society because, as floods increase, our ecosystems can better adapt to new conditions.[23] As a closing remark illustrating the nature and society connection in relation to climate adaptation planning strategies, Connecticut's sitting Governor Ned Lamont, the state DEEP, and the USFWS indirectly support the plan of investing in aquatic ecosystems like streams and rivers. A series of climate-forward directives from the Lamont administration stress the criticality of long-term solutions and a transformative adaptation idea involving public access and the expansion of these zones to accommodate both CRWE social and ecological changes.

CONCLUDING IDEAS AND ADAPTING TO FLOODING DISTURBANCES AND NATURE-BASED SOLUTIONS

A final suite of ideas revolves around the utilization of nature to improve the social and ecological well-being of flood-impacted communities.[24] Nature-based solutions involve the management, protection, or restoration of freshwater ecosystems to maintain or improve community livability. In urban ecosystems, like within the Connecticut River Watershed, the nature-based solution concept becomes much more important, given the steep decline in species, habitat, and ecosystem integrity. Reforesting embankments, incorporating dense shrubs, and planting thick herbaceous species serve as some strategies to limit floodwater movement. These strategies are long-term in nature, and they not only reduce the probability of private and public property damage but also enhance ecosystem performance and stability.[25] While relocation events,

Figure 5. The Sawmill River is a small tributary flowing into the Connecticut River in Montague, a small town located in Northern Massachusetts. Through a strong local, state, and federal conservation partnership, research ecologists, sociologists, restoration practitioners, policy makers, aquatic conservation planners, and citizen scientists pooled resources and designed climate adaptation (e.g., increasing floods or droughts and associated ecological community effects) strategies. These strategies consisted of ways to proactively restore important aquatic habitats (e.g., woody debris, consistent flow, richly varied substrate) to encourage the passage of Sea Lamprey and the presence of threatened and endangered mussel species and native water birds (Visual courtesy of the author, 2025).

Figure 6. The following image demonstrates a very commonly flooded area of the Connecticut River Watershed in Central Connecticut. The bridge in the background floods during almost every "regular" precipitation event, and larger/more intense precipitation results in an impassible transportation system (Image courtesy of the author, 2025).

roadway elevation increase, flood diversion structures, and other strategies may work for some community members, these plans are often costly and result in more surface-level natural connections. Many state conservation agencies recommend taking this route as the most ecologically and socially sustainable way to adapt to flooding disturbances.

The people, firms, organizations, and agencies involved in the governance of the Connecticut River Watershed Ecosystems have expressed interest in designing and implementing forward-looking climate adaptation strategies. Now, these local, state, and federal partners must request financial allocations and seek local scholars and practitioners to help with wide-scale implementation activities.[26] I am confident that nature-based solutions like shoreline park expansion zones and the synthesis of living freshwater littoral/nearshore zones serve as critically meaningful investments in this watershed's future (Figure 6). In closing, I acknowledge the robust work of current Connecticut River Watershed climate adaptation planning teams, and I hope these additional ideas inform subsequent landscape and watershed-scale activities.[27]

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The authors declare no conflicts of interest and have no declarations.

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No sensitive human or non-human subjects were used in the completion of this manuscript

DATA AVAILABILITY

All data supporting this manuscript are publicly accessible

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