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Planning for Managed Retreat: Decision Making in the Face of Climate Uncertainty

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I. Project Description

Climate change impacts are already occurring and are likely to become more severe in the future without increased mitigation of greenhouse gas emissions (IPCC, 2018). There are now areas of the globe where climate change (especially in coastal and inland river areas) has made human habitation difficult or impossible. Accordingly, there is a recognition that a new strategy is needed to respond to climate change—managed retreat. The term "managed retreat" typically refers to the permanent relocation of people or infrastructure away from areas repeatedly threatened by climate-induced extreme weather events. Managed retreat as a response to impacts from climate change has only recently emerged as a subject of serious study, and continued research is needed.

Although managed retreat has been studied more extensively outside the United States (U.S.), especially in Europe, the past decade has seen a dramatic increase in attention to the topic among researchers and local planners in the U.S. American communities, and transportation planners in particular, are now more frequently facing the costs of repairing and maintaining expensive and long-lived transportation infrastructure in areas that are increasingly vulnerable to climate change. However, deciding to abandon such infrastructure, remove it, or re-invest (through upgraded, more resilient design or other measures) can be a challenging and complex process. Moreover, because the concept of "managed retreat" itself is relatively new, there is little precedent a community could follow in terms of approach or process to assure success. Diversity of cultures, communities, and resources similarly mean that there is not likely a "one-size-fits-all" approach to discussing or implementing managed retreat.

This project aimed to examine the need for, and approaches to, managed retreat in the transportation sector. Specifically, our objectives included undertaking a comprehensive national review of managed retreat from a community and transportation infrastructure perspective; developing case studies and analysis, examining the processes once the decision to retreat from higher risk areas has been made; and developing a framework for managed retreat decision making in the face of uncertainty.

The project successfully accomplished these goals, with the approach, methods, and results detailed and published in two academic journals, and a third paper which presents the framework and is currently under review (Dundon *et al,* 2023; Dundon & Abkowitz, 2021; Dundon & Abkowitz, n.d.)

II. Methodological Approach

To accomplish the project objectives, the project proceeded in three phases. First, we undertook a comprehensive literature review, spanning both U.S.-focused and global research on all aspects of managed retreat. This work included a review of the impacts of the terminology around managed retreat, a discussion of barriers to successful managed retreat, and a comparison between the approaches to managed retreat in the U.S. and globally. This

work also included a review of the emerging themes around managed retreat and a comprehensive analysis of the terminology surrounding managed retreat. This effort was published in the journal *Climate Risk Management* and is attached as Appendix A.

Second, we reviewed hundreds of examples of local and state policy responses to climate change to select, examine, and document case studies of managed retreat. From these examples, we selected several with characteristics of managed retreat–that is, transformative approaches to adapting to climate change. In particular, to broaden what we see as a currently limited understanding of managed retreat (that is, movement of people and infrastructure away from coastal regions), we explored case study examples of novel approaches to permanently change the way humans interact with their environment as a response to climate change. With these objectives in mind, we selected four illustrative case studies to examine in substantial depth emerging forms of managed retreat. We also selected case studies that would represent four discrete climate stressors: heat, flooding, wildfire, and sea level rise. These climate stressors also were selected to represent a wide geographic range of climate-induced extreme weather events occurring in the U.S. This effort, methodology, and results were published in the journal *Case Studies in the Environment*, and are attached as Appendix B.

Third, to meet our final project objective, we developed a comprehensive framework for approaching and implementing a managed retreat decision. To accomplish this task, we undertook a comprehensive review of the literature focused on available tools and methodologies for managed treat. We reviewed academic literature but also the work of policy-focused climate centers, especially those focused on transportation infrastructure. In particular, the work of the Georgetown Climate Center (GCC, n.d.) proved important as it developed, during the time period of this project, a Managed Retreat Toolkit aimed at policy makers and local planners. Our work revealed that there is a substantial need for more practice-ready, user-friendly managed retreat tools to inform decision making. The work developing the framework, and the framework itself, is documented in a recent paper submitted to the journal *Environmental Research Letters*, currently under review, and attached as Appendix C.

III. Results and Findings

The multiple project objectives resulted in the following findings and conclusions, set forth in more detail in Appendices A-C.

1. Most managed retreat projects still occur outside the U.S. Managed retreat within the U.S. is nearly exclusively implemented through home buy-out programs to remove homes and people in vulnerable (often coastal) communities. However, this is beginning to change as managed retreat considerations are now being increasingly explored (and often needed) in inland areas and through approaches beyond home buy-out programs in both coastal and inland areas.

2. Managed retreat and climate resilience work generally needs increased focus on inland areas. While sea-level rise and coastal impacts have tended to dominate the literature of managed retreat, inland areas in the U.S. are increasingly experiencing extreme weather events

such as flooding and extreme heat. Managed retreat considerations now apply beyond the coasts, and planners and communities across the country stand to benefit from managed retreat knowledge.

3. The terminology surrounding managed retreat itself may be a barrier to successful implementation of needed retreat strategies. Harmonizing the terminology and adopting terms that are sensitive to cultural and community needs is important to acceptance of retreat strategies. As managed retreat is in essence a form of adaptation strategy, we recommend the term "transformative adaptation measures" when discussing the permanent changes that may be necessary in some locations to adapt to a changing climate.

4. Managed retreat research in the U.S. can be categorized around five basic themes: (1) coastal retreat, 2) law, policy and planning, 3) climate and social justice, 4) infrastructure, and 5) frameworks and tools. These classifications can be useful to researchers and practitioners addressing specialized challenges or needs in a particular community.

5. There is no common definition of "managed retreat," which can lead to misunderstandings or lack of comparability between studies or examples. As set forth in Appendix A, an important result of this project is the comprehensive compilation of the variety of definitions assigned to the terms among a diverse group of researchers.

6. Because managed retreat is a relatively newly emerging area of study in the U.S., documenting case studies (both with successful and unsuccessful outcomes) is critical. These case studies can serve as helpful examples of both barriers and successful approaches to managed retreat decision making.

7. Communities across the country, as documented by our case study analysis, are embarking on novel and often successful examples of transformative adaptation (or managed retreat). As increased frequency and severity of extreme weather events become more of a reality for local planners charged with managed and maintaining expensive infrastructure, managed retreat can be considered a form of governance approach to climate change. *See* Appendix B.

8. Practice-ready frameworks and tools are needed to assist planners and communities as they begin to navigate the inevitable complexities surrounding managed retreat decision making. Much of the knowledge regarding managed retreat (i.e., factors that lead to successful or unsuccessful approaches to managed retreat) is housed in academic literature. While there are some notable examples of efforts to develop tools directed at stakeholders who most need them, more is needed. This project aimed to fill that gap. The project collected and assembled a range of knowledge (both existing and developed by the authors) into a practice ready framework (Appendix C). This framework is meant to contribute user-friendly knowledge to assist local planners in considerations regarding (1) whether managed retreat may need to be implemented and (2) successful implementation of a decision to retreat.

IV. Impacts/Benefits of Implementation

The project has substantially advanced the knowledge and study of managed retreat, an important contribution in this nascent and developing field, especially as it relates to the transportation sector. Transportation planners are faced with management decisions of long-lived and expensive infrastructure, and our work in this project provides knowledge, information, and useful frameworks to assist in informing those decisions.

In addition, the benefit of this work is being recognized through dissemination of the study results. The work for this project has resulted in three papers. Two were published in peer reviewed journals (Dundon & Abkowitz, 2021; Dundon *et al.,* 2023) and the third is currently under review with *Environmental Research Letters* (Dundon & Abkowitz, n.d.). Citations to these three papers appear below:

> Dundon, L. A., & Abkowitz, M. (2021). Climate-induced managed retreat in the US: A review of current research. *Climate Risk Management*, 33, 100337.
>
> Dundon, L. A., Abkowitz, M., & Camp, J. (2023). Governing transition: Case studies in transformative adaptation. *Case Studies in the Environment*, *7*(1).
>
> Dundon, L.A. and Abkowitz, M., n.d. Turning "managed retreat" research into practice ready tools: needed guidelines to reach stakeholders. Under Review with *Environmental Research Letters*.

In addition, the work was developed into conference proposals and accepted and presented (in whole or in part) at the following conferences:

> "When, where and how: Understanding infrastructure interdependencies when planning for long-term managed retreat", presented at Columbia University-Climate School June 23, 2021 Conference: "At What Point Managed Retreat: Resilience, Relocation, and Climate Justice"
>
> "Managed retreat," Transportation Research Board (TRB) - Second International Conference on Resilience to Natural Hazards and Extreme Weather Events – November 13-15, 2019, Washington D.C.
>
> "An interdisciplinary approach to climate change education: making infrastructure exciting." ICNET Global and University of New Hampshire Infrastructure Resilience Workshop on Teaching Climate Change and Civil Infrastructure. July 2020.

And presented at an invited guest lecture:

> "Climate change infrastructure resilience, law, and policy." Colorado State University – September 2021. (Invited Guest Lecture in Dr. Gillian Bowser's Course)

V. Conclusions

Major conclusions are set forth in Section III, above. The study of managed retreat, particularly in the transportation context, needs continued and additional study as the impacts of climate change are expected to continue to increase. The world is not currently on tract to meet its Paris Agreement goals. If that trajectory continues, we expect more frequent and more intense extreme weather that will continue to impact transportation infrastructure, coastal and riverine areas, and more. Further study of effective approaches to managed retreat, continued documentation of case studies, and development of practice-ready tools to assist transportation planners navigate the dynamic challenges inherent in adapting to a world with a changing climate are needed.

References

Dundon, L. A., & Abkowitz, M. (2021). Climate-induced managed retreat in the US: A review of current research. *Climate Risk Management*, 33, 100337.

Dundon, L. A., Abkowitz, M., & Camp, J. (2023). Governing transition: Case studies in transformative adaptation. *Case Studies in the Environment*, *7*(1).

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GCC, n.d. Georgetown Climate Center Managed Retreat Toolkit, available at https://www.georgetownclimate.org/adaptation/toolkits/managed-retreat-toolkit/introduction.html (accessed May 23, 2022).

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APPENDIX A

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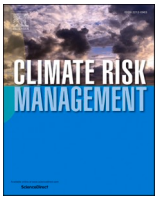

Climate-induced managed retreat in the U.S.: A review of current research

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ABSTRACT

Human responses to climate change are continuing to evolve. At one time, mitigation (reduction) of human emissions of greenhouse gases appeared to offer the best response to prevent the worst impacts of a changing climate. It soon became clear, however, that the world would not be able to reduce emissions quickly enough or to a level sufficient to prevent, in the words of the United Nations Framework Convention on Climate Change, "dangerous anthropogenic interference with the climate system". Climate change is already altering the frequency and severity of extreme weather events worldwide, and these trends are expected to increase in the foreseeable future. Accordingly, it is well recognized that adapting in place to the changing climate is necessary. Yet, that may not be enough. An additional step in responding to climate risks is emerging, one that requires fundamentally and permanently changing the human interactions with nature in parts of the world. This strategy is often referred to as "managed retreat," but that term has become controversial, and other terms are needed that express inclusion of the positive societal benefits that can emerge from proactive action. This paper provides a review of the emerging themes within the literature of managed retreat as a climate risk management approach, uses examples from the transportation and infrastructure sector, collects and identifies important nomenclature and definitions, key decision-making considerations, and research gaps that warrant immediate attention. The results of this review are intended to be useful to academic climate change adaptation researchers and infrastructure practitioners alike.

1. Introduction

Climate-induced managed retreat—the basic concept of permanently moving people or infrastructure out of harm's way—is a nascent field with a small, but growing, body of research, led by work conducted in Europe in terms of the number and breadth of peer-reviewed academic studies and professional literature as indicated by searches on Google Scholar (Blott and Pye, 2004; Hazelden et al., 2001; Klein and Bateman, 1998; Krolik-Root et al., 2015). Hino et al (2017) documented and evaluated the (then) most recent retreat projects globally and only three of twenty seven projects evaluated were occurring or had occurred in the United States. Work outside of the United States therefore serves as an important resource as managed retreat concepts more firmly take root in the U.S. As climate change impacts continue to increase and international mitigation goals are not yet being achieved, adaptation in place is now well

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recognized as an important component of the global response to climate change (IPCC, 2018; UNFCCC, 1992). However, managed retreat is slowly emerging as an additional strategy that will be a necessary part of the human response to climate change. Accordingly, further focus on managed retreat issues will be needed across a range of disciplines. For example, the U.S. Cybersecurity & Infrastructure Security Agency (CISA, n.d.) has identified sixteen critical infrastructure sectors deemed vital to the functioning of the country. One of those is the transportation sector, and transportation infrastructure is often the subject of managed retreat conversations, such as when re-flooding of roads or bridges demands examination of the wisdom of repeated repair and restoration. Indeed, research on transportation-related managed retreat concepts or practices, where it exists, tends to focus nearly exclusively on roads, with less research devoted to other modes. Although the examples used by the authors herein draw from the transportation and infrastructure sector, this review is applicable to a broad range of sectors because the emerging managed retreat research can, and should be, informed from an interdisciplinary perspective. Moreover, as discussed below, the term managed retreat itself is controversial and can be an impediment to successful retreat policies (Rott, 2018). The authors prefer the term transformative adaptation, but use the term "retreat" in this paper because it is the term used most often in the literature being examined herein.

In the U.S., managed retreat has occurred largely through post-disaster federal- or state-funded home buyout programs, with little pre-event planning (Siders, 2019a). Approaching managed retreat in this way, however, is not likely to adequately address the magnitude of the changes that climate change will bring. Current approaches also are not consistent and often lack a comprehensive plan that would maximize benefits to both the displaced and receiving communities (communities or areas where formerly displaced people move to settle permanently). Rather, managed retreat in the U.S. tends to be ad hoc, isolated to a few homes or small sections of infrastructure, and accomplished in a piecemeal way only after (an expensive) disaster strikes.

The study of managed retreat in the U.S. is also highly focused on coastal areas, primarily because of obvious flooding risks associated with sea level rise and storm surge in those locations. However, population pressures and changing extreme weather patterns (such as increased precipitation that expands river flood plains or increasing drought that limits water availability or river navigation) make some inland areas highly vulnerable. Accordingly, there is a significant need for literature to also address managed retreat in non-coastal areas.

In addition to removing or relocating expensive infrastructure (e.g., buildings, roads, ports), there are significant psychological and practical challenges preventing managed retreat from becoming a viable option (Siders, 2019a; Agyeman, et al., 2009). For example, the U.S. flood insurance program has operated at a deficit for years, depending entirely on continued bailouts from Congress. Many argue the program encourages building in flood prone, increasingly risky areas because the true risks and costs are not known to or experienced by the homeowners, developers, or even local community officials. In December 2019, Congress extended the program's authorization only through September 30, 2020, at which time Congress and the Federal Emergency Management Agency (FEMA) will need to decide whether to cease selling or renewing flood insurance policies for millions of properties (National Flood Insurance Program, 2019).

Using retreat or relocation as the country does now – as a post-hoc response to a disaster in one locality – may prevent achievement of substantial economic, social, and perhaps ecological benefits that could be realized with the adoption of a comprehensive, planned strategy. As Siders suggested in arguing for a comprehensive plan that includes large scale retreat, an appropriate national discussion "might require Americans to reconceptualize our relationship with risk and what it means to own property" (Siders, 2019a).

This paper provides a review of the emerging themes within the literature of managed retreat, as well as important nomenclature and corresponding definitions, key decision-making considerations, and research gaps that warrant immediate attention. It represents the first in a series of articles focused on managed retreat being prepared by the authors which, taken collectively, argues for a comprehensive approach to managed retreat in the U.S., examines specific case studies, and sets forth a framework for managed retreat decision-making. A concurrent goal of this paper is to assist academics focus on the needed research in the managed retreat literature, which ultimately will serve to improve legal and policy responses by public planners who are already being called on to address issues of retreat and relocation of people and infrastructure. Accordingly, the paper ends with a review of existing frameworks and tools, and suggestions for both academic and applied researchers to expand on tool development, especially so that communities can even begin to have these needed conversations.

2. Understanding managed retreat: terms and meaning

2.1. Terminology

A variety of terms are being used to describe the decision-making processes and actions taken in response to climate change that we commonly characterize as "managed retreat." These respective terms typically refer to activities that include moving or relocating people or assets from a vulnerable location, or deciding not to build in or move to areas that previously would have been considered for development or habitation.

The most popular term to describe this phenomena is "managed retreat;" however, use of this phrase can have problematic and controversial connotations, indicating failure and financial loss (Koslov, 2016; Campbell and Wilson, 2016; Carey, 2020). Koslov (2016) provides context for this negative association and the etymological history of the word "retreat". Accordingly, a number of other terms have evolved in the literature. Esteves (2014a, 2014b) and Bilkovic and Mitchell (2017) describe many of these terms, including "strategic retreat", "strategic or managed relocation", "planned relocation", "transformative adaptation," "managed realignment", "resilient relocation," or "habitat restoration."

We prefer use of the term "transformative adaptation" for several reasons. First, the term "managed retreat" has engendered such negative connotations that it may be politically infeasible to undertake any projects in some regions if the term "managed retreat" is

associated with it. Second, "transformative adaptation" includes the potential positive co-benefits—social, economic, and ecological—that can be realized through such fundamental changes undertaken in response to climate change. Finally, fundamental changes such as moving people and infrastructure permanently away from a particular area and allowing nature to reclaim that area, are a means of *adapting* to a changing climate. Indeed, Braamskamp and Penning-Rowsell (2018) and Freudenberg et al. (2016) discuss managed retreat as an adaptation option. Such a measure may be considered different in character or type than activities we often more typically consider as "adaptation"—e.g., installing a sea wall or changing crops in response to a new growing season—but these activities are inherently actions we take to adjust, or adapt, to the new climate within which humans now are finding ourselves. Notably, the UNFCCC, 1992, defines climate change "adaptation" as an "[a]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2020), this could certainly include activities associated with managed retreat strategies. Of particular note is that the UNFCCC glossary does not include "retreat" or other synonyms commonly used to identify managed retreat policies. Despite the authors' preferred term of "transformative adaptation," we continue to use the term "managed retreat" in this paper because the vast majority of the literature described herein uses this term.

2.2. Meaning

As in the case of managed retreat terminology, definitions also vary by author, location, and over time (Koslov, 2016; Neal et al., 2005). As shown in Table 1, definitions of retreat-related terms range from a narrow focus on coastal retreat due to sea level rise and storm surge (Esteves, 2014a; 2014b), to a strategy of retreat from any area in order to manage natural hazard risks (Hino et al., 2017), to a general meaning that encompasses a "suite of adaptation options" (Siders, 2019b).

As previously noted, we prefer use of the term "transformative adaptation," but recognize that other terms are acceptable and language used should take account of local preferences and values. However, it is important to note that terms such as "relocation" have considerable racist overtones, from the forced relocation of Native Americans to the internment of Japanese Americans during World War II. Accordingly, thought should be directed to effective outcomes, rather than adopting existing language that could be divisive. There will be regional differences in what terminology is likely to be effective; an approach is more likely to be successful if the terms and meanings are adopted early, and if the definitions used take into account the goals of the particular project and the culture of the area.

In this paper, we build on the existing definitions noted in Table 1 and define transformative adaptation as: permanent or long term change in where and how humans live that is a direct response to a permanently changing climate. This definition is deliberately intended to expand the definition of these types of permanent changes beyond mere retreat. Using the term 'managed retreat' to encompass *only* the movement or relocation of people or infrastructure is too limited and that limitation has proved problematic (Koslov, 2016; Campbell and Wilson, 2016; Carey, 2020). Accordingly, the term "transformative adaptation" would include moving/relocating people or infrastructure, but it is broad enough to include other measures that serve similar, permanent goals but that may not carry negative associations.

3. Classifications

Existing managed retreat studies can be organized into the following topical areas: 1) coastal retreat, 2) law, policy and planning, 3) climate and social justice, 4) infrastructure and 5) frameworks and tools. Although there is significant overlap in these concepts, and many researchers argue for a more holistic view of managed retreat programs, these classifications can be useful to practitioners. The ensuing discussion examines these categories, identifies gaps in research and knowledge, and suggests additional areas of focus needed in the study and practice of managed retreat.[1]

3.1. Coastal retreat

Perhaps not surprisingly, managed retreat in the context of coastal flooding from sea level rise and storm surge dominates the literature. Utilizing a Google Scholar search, over the last two decades, only 105 articles contained the term "managed retreat" in their titles. Most of these came from outside the U.S., and approximately 90% of these studies addressed primarily or exclusively retreat involving coastal issues (e.g., Townend and Pethick, 2002; Dachary-Bernard et al., 2019a,b; Olufson, 2019).

Siders (2019a); (2013;) argues for a comprehensive national plan for coastal retreat and adaptation that could include such approaches as dramatically expanding the National Seashore. National Seashores are akin to National Parks, they are coastal areas that are owned and managed by the federal government, set aside typically for public, recreational use (Repanshek, 2007). Accordingly, their expansion could prevent building in vulnerable coastal areas, or remove existing infrastructure. Braamskamp and Penning-Rowsell (2018) and Healy and Soomere (2008), taking a more pessimistic view, have noted that effective coastal managed retreat programs are not likely to occur proactively, and that successful examples typically occur only in response to a disaster. However, there are case studies of efforts underway in the U.S. and elsewhere to implement managed retreat as a response to beach loss (Abbott, 2014; Daniel, 2001; Dyckman, et al., 2014; Van Alstyne, 2015; Esteves, 2014a; 2014b;; Esteves and Williams, 2017; Rulleau and Rey-Valette,

[1] Because the literature primarily uses the term "managed retreat," the authors will continue to do so in this literature review.

Table 1
Managed retreat terms and definitions.

Source	Term used	Definition
Ajibade, et al., 2020	Managed retreat	"the deliberate and strategic 'move from climate-induced harm' – this encompasses moving people and the resources they value such as homes, businesses, infrastructure, ecosystems, and other assets from areas of risk and resettling them in safer locations"
Koslov, 2016p. 362	managed retreat	"the relocation of people to higher ground and associated efforts to plan and manage that movement. In practice, however, this often means restricting movement as much as facilitating it."
Siders et al., 2019	strategic and managed retreat	"a suite of adaptation options that are both strategic and managed. Strategy integrates retreat into long-term development goals and identifies why retreat should occur and, in doing so, influences where and when. Management addresses how retreat is executed."
Siders, 2019a	managed retreat	the purposeful, coordinated movement of people and assets out of harm's way
Doberstein, et al., 2020, p.1	managed retreat	"reduce the exposure of people and assets to flooding, storm surges and sea level rise by retreating from these threats in a planned fashion."
Braamskamp and Penning-Rowsell, 2018, p. 108.	managed retreat	"permanent resettlement of existing households and communities away from areas at risk."
Esteves, 2014a; 2014b, p. 19.	managed realignment	"a general term that can be used to describe collectively the many mechanisms implemented to allow coastlines to evolve more flexibly with the objective of promoting more sustainable flood and erosion risk management."
Bronen, 2011, p. 109	community relocation or managed adaptive retreat	A program in which "livelihoods, housing, and public infrastructure are reconstructed in a location, away from vulnerable risk-prone coastal and riverine areas …"
Dannenberg et al., 2019	planned relocation	"a proactive response prior to catastrophic necessity."
Hanna, et al., 2019	managed retreat	"a deliberate strategy to remedy unsustainable land use patterns that expose people, ecosystems, and assets to significant natural (and socio-natural) hazard and climate induced risks" or "the strategically planned withdrawal from development in risky spaces."
Hino, et al., 2017, p. 364	managed retreat or transformational adaptation	"the strategic relocation of structures or abandonment of land to manage natural hazard risk."
Cooper, 2003	managed retreat	"the deliberate breaching, removal or landward relocation of an existing tidal defence or coastal protection structure."
Townend and Pethick, 2002, p. 1477	managed retreat	In the U.K., an effort to "restore previously reclaimed areas in order to reduce flooding and other hazards of the estuarine system."
Alexander et al., 2012, p. 409.	managed retreat	"the relocation of homes and infrastructure under threat from coastal flooding"
Agyeman, et al., 2009, p. 509.	managed retreat	"the relocation of communities and ecosystems."
Lawrence, et al., 2020	managed retreat	"planned retreat that removes people and their assets away from hazards such as sea-level rise and flooding—pre-emptively and permanently."
Koraim, et al., 2011, p. 47.	managed retreat	"a strategy that safely removes settlement from threatened shorelines, allowing the water to advance unimpeded. It involves abandoning, demolishing or moving existing buildings and infrastructure to higher ground. It also includes banning new development in areas likely to be inundated." In addition, the "managed" aspect "involves establishing thresholds to trigger activities such as demolishing buildings or abandoning efforts to control shoreline erosion. These thresholds can be coupled with buy-back programs to compensate property owners for loss, plus strict building codes that allow only certain types of re-locatable or floodable structures.
Plastrik & Cleveland, 2019, p. 3.	managed retreat	An approach that "uses public policies, including regulations, investments, and incentives to remove existing development—buildings, infrastructure, entire neighborhoods—over time and prevent future development in parts of the city that cannot, should not, or will not be armored or accommodated for potentially devastating climate hazards."
Hamilton, et al, 2016, p. 1.	climigration	Migration caused by climate change."This term is often used to describe the permanent relocation, or movement, of a group of people away from their home to another area caused directly by climate-induced events. This could be large scale climate-induced drought making continued farming in an area impossible or difficult, or sea level rise that makes continued coastal habitation impossible or difficult.

2017). Dannenberg et al. (2019) has studied the health impacts of retreat in coastal communities and determined that additional work is needed to understand how to increase a community's resilience to retreat. There is also evidence that, properly implemented, managed retreat in coastal wetland areas may have carbon sequestration co-benefits (Rogers et al., 2014). Co-benefits of retreat programs are often overlooked and understudied in the literature.

The emphasis on coastal retreat overlooks the importance of studying retreat in non-coastal areas. For example, inland river flooding in the U.S. has had substantial economic and human livelihood consequences, and is on an upward trend in part due to climate change (Zhou et al., 2019). The City of Nashville (not unlike other U.S. cities) has a major navigable river that transects its metropolitan downtown business district. In 2010 the city experienced a 1 in 1000 year flood event due to excessive rain that caused the river to swell to record levelseur, causing more than $2 billion in damages, destroying thousands of businesses, and killing 11 people. Managed retreat literature's focuses on coastal areas overlooks thinking about whether, and how, to maintain expensive city infrastructure directly on riverbanks—even if the benefits of remaining in place ultimately are determined to outweigh the costs to retreat, it is a needed conversation so those stakeholders that bear the financial and physical risks are alerted. National Flood Services, a company that services private and government flood insurance products, such as insurance issued by the National Flood Insurance Program, has expressly recognized that inland flooding is increasing and is often overlooked (NFS, n.d.) by the focus on coastal

flooding. Moreover, extreme heat, precipitation and drought are increasing in frequency and severity in some inland areas of the U.S., and may have a major impact on the ability to maintain farming or to continue farming climate-sensitive crops. There may be similarities in response options between the extreme events in the context of urban heat or inland flooding and the traditional notions of retreat that we associate with coastal flooding. Broadening the narrative also may allow retreat options to be more actively considered in non-coastal settings, and may also serve to expand ideas for retreat—or transformative adaptation options—in the coastal context (Loeb, 2017).

3.2. Law, policy, and planning

Perhaps the most challenging subject in the study of managed retreat is how to design and implement effective policies and programs that have public support, will protect human life and livelihoods, and will preserve the public financial resources that are often the "last stop" for some citizens when a disaster occurs (Hanna et al., 2019). Determining what existing laws provide opportunities to be leveraged, and what new laws or policies are needed to move forward effectively are important considerations the research community is only beginning to address. The example of local government duties and obligations to maintain transportation infrastructure (noted below) is an important illustration of this problem. Substantially more work is needed to guide local, state, and federal policy makers who face the expectation that public and private services (e.g., roads, mail, utility delivery, access to work and entertainment venues, supplies and food, etc.,) will continue to operate as always despite a changed climatic environment.

A number of authors have collectively advanced the research in this area in recent years. Mach et al. (2019) completed detailed analyses of all FEMA-funded home buyouts across the United States, and Nguyen (2020), Mach et al. (2019) and others have recognized that home buyout programs tend to be the primary (and in most areas, only) program through which managed retreat is implemented (Byrne & Grannis, 2012; Mach et al., 2019). However, buyout programs are often accomplished without serious planning that relates more comprehensively to a community's goals, and may be utilized only after a disaster has occurred. *Id.*

As home buyout programs are typically subject to a patchwork of federal, local, and state laws, while they may be effective in a particular location and bring a myriad of benefits (reducing infrastructure and people in hazard areas, increasing green space and flood protection), they do little to contribute to a national strategy. Areas of Canada, however, have implemented buyout policies that encourage or require retreat. For example, Gatineau, Canada, requires abandonment of some homes if more than 50% of the value of the home is destroyed. For other homes, the program will compensate only $100,000 USD for damage repair, but will pay up to $250,000 for a buyout of the home no matter the actual market value. However, if the owner elects to take the compensation for repairs, the government will not provide any future support if the home is flooded again (Carey, 2020). However, there is less emphasis in Canada on individual property rights and more emphasis on the public good than in America, raising important cultural issues that may make retreat more difficult in the U.S. In addition, the legal frameworks in the two countries differ in important ways that both contribute to these cultural differences and make implementation of managed retreat in the U.S. potentially more difficult. For example, the Takings Clause of the Fifth Amendment to the U.S. Constitution, and counterparts in state constitutions, require a legal process (often lengthy and expensive) before the government can "take" private property (for managed retreat programs or otherwise). The law also requires that the taking be for a public purpose and the government must pay "just compensation" to the property owner (Ruppert, 2018). By contrast, in Canada, (based on the law of England), all land is owned by the Crown, so the expectation (and right) to private property is very different (Jeffery & Vaughati, 1993). Accordingly, successful implementation of retreat policies is also jurisdiction dependent (Hanna et al., 2021).

Study of impacts to receiving communities is also sorely needed (Hanna et al., 2019). The focus to date has predominately been on policies and practices to remove people or infrastructure from high risk areas, without consideration of advance planning regarding where those people will go, and the types of impact receiving communities will experience, such as effects on their infrastructure, social cohesion, and economic well-being. Both positive and negative impacts to receiving communities should be well understood as part of a comprehensive plan in order to increase positive outcomes and reduce negative impacts on both the receiving and relocated communities. The relocation of the inhabitants of the Isle de Jean Charles in Louisiana—the first federally funded project of its kind in the U.S.—is an early example of a concerted effort to entirely relocate a population that could no longer be sustained on its disappearing island (Louisiana Office of Community Development, 2020).

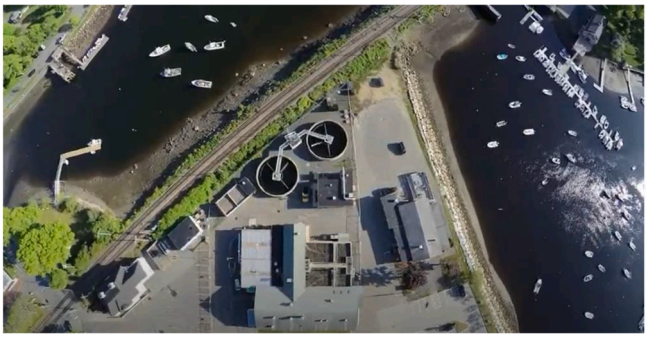

Fig. 1. Manchester by the Sea, MA; water treatment plant located directly on the ocean just 10 feet above sea level.

Environmental laws in particular should be examined to determine where there may be a relationship to managed retreat concepts. For example, although we typically think of private corporations as holding permits to discharge pollutants, public entities such as waste water treatment plants are subject to the same or similar permitting requirements before they can discharge pollutants to rivers and streams. Water quality criteria of the receiving water bodies is directly related to the permit conditions of the discharger. Changes in precipitation patterns (floods or droughts), aging water treatment infrastructure, and temperature increases in the receiving waterbody can all impact the financial bottom line of a treatment plant, which is funded entirely by the taxpayer. Indeed, EPA has provided funding in recent years to substantially upgrade wastewater treatment plants that are vulnerable to sea level rise (EPA, 2017).

Although the waste water treatment plant at Manchester by the Sea (Fig. 1) and many others in climate vulnerable locations across the country are nearing or have exceeded their design life, serious conversations are not being held about whether, how or where to rebuild them. The negative health impacts of combining old infrastructure with climate change events has also been well documented in the literature (Jagai et al., 2015). The authors (Jagai et al., 2015) studied the relationship between extreme precipitation events and old combined sewer systems (systems still in current use in the majority of the United States where storm water and sewage flow is combined and designed to overflow into creeks and rivers during high rain events) and found in some areas a significant increase in risk for gastrointestinal illness during extreme rain events. We are aware of no clear framework for incorporating these types of costs and burdens (e.g., health impacts, indirect tax burdens) to a community when weighing the costs and benefits of retreat versus remaining or fortifying.

Early identification of clear societal goals, and the integration of retreat polices and practice with these goals, effectively communicated between public and policy makers, are essential elements of success for managed retreat programs, especially in the U. S. (Siders et al., 2020; Greiving et al., 2018). Such a strategy is still lacking, perhaps because it has only recently become clear that traditional notions of adaptation are not likely to be sufficient in some areas, and managed retreat must be considered. Lawrence et al. (2020) discusses some of the governance and planning gaps in managed retreat implementation and suggests reforms that include minimizing long term costs, making public risk assessments available, offering better coordination between different levels of government, increasing incentives, and avoiding the characterization of retreat as the "last" option. Building on Lawrence et al.'s (2020) recommendation for better coordination between levels of government, Hanna et al. (2021) have developed a retreat governance framework that employs a "governance continuum," which can be useful to determine what level of government (if any) and what tools might be available to implement retreat practices. Hanna et al. (2021) also draws from the extensive literature on human mobility.

Plastrik & Cleveland (2019) define three kinds of retreat: 1) traumatic post-disaster retreat, 2) chaotic, market-driven retreat, and 3) forward-looking planned retreat. Siders (2013) has identified five legal mechanisms by which society can move towards planned retreat: 1) increased coastal management, 2) greater regulatory use of setbacks and easements, 3) regulations that prevent continued armoring of coastal areas, 4) restrictions on rebuilding after a disaster, and 5) buyout programs. However, law and policy should be used to not only prevent activities that increase risk or make communities more vulnerable, but should seek to incentivize activities that reduce risk or vulnerability.

Knowledge gaps include a better understanding of effective public communication strategies to increase local "buy-in." For example, the psychological theory known as "place attachment" is only beginning to be explored in the context of managed retreat, but has been recognized as a substantial barrier to successful managed retreat programs (Agyeman et al., 2009). This theory recognizes that people form deep and profound bonds with physical locations (Gurney et al., 2017). Plastrik and Cleveland (2019) have posited that place attachment runs so deep that the psychological phenome of the "five-stages of grief", identified in the 1950s describing how people react to personal loss, is entirely applicable to being asked to leave one's home or community because of climate change. More effective communication and messaging strategies in high risk areas where place attachment runs deep are critical to successful outcomes (Hanna et al., 2020).

There is also a lack of studies focusing on financial considerations. People being asked to support a local (or national) retreat program often lack access to the information needed to understand the true financial cost of failing to retreat. This may be because the true costs are complex and often hidden, involving a web of federal, state, or local disaster funding, private or subsidized insurance, and short-term incentives and tax-breaks (that are funded by the public) that may have drawn expensive infrastructure to risky locations in the first place. Untangling this web to understand and effectively communicate the true financial costs can be difficult.

Plastrik & Cleveland (2019) found that buyouts are the only retreat program through which cities can at least hope for some financial support from state or federal government, and often only after a disaster. Many buyout programs are, however, available pre-disaster, but are voluntary programs and are often not taken advantage of until after a disaster. This was the case in the City of Nashville, which has had a voluntary buyout program for many years, but it saw dramatic increase in utilization after the 2010 flood, with 305 homes purchased in just the first phase after the flood (Metropolitan Government of Nashville, 2011). Buyout programs also typically fail to consider the collective good and comprehensive retreat strategies, and instead focus on individual homes. Financial support that can be tapped pre-disaster and that will support a long-term perspective is critical, but currently unavailable. Other approaches to retreat, such as changes to zoning or setbacks, still implicate needed resources although less directly than the need for cash payments for homes. For example, changes to zoning that limits development in an area reduces the tax base and therefore revenue for the city if that revenue is not made up elsewhere. In general, managed retreat approaches are under resourced.

3.3. Climate and social justice

It is well documented that the most vulnerable members of society are the most vulnerable to climate change impacts (Siders, 2019b). They tend to live in areas with greater exposure to extreme weather events, lack the protective infrastructure to avoid harm,

and when disaster occurs, lack the resources and networks that enable more affluent people to recover more quickly. If people are unable to continue living in their home and have the means to do so, they relocate to a different location. This is true at every scale, from the individual to the national level. When entire communities or nations seek permanent relocation in response to climate change, this is often referred to as "climigration." Frameworks are emerging that recognize climate-induced migration as an inevitable part of the changing global socio-political landscape, and that human rights principles must be part of any interventions or solutions (Bronen, 2011; Rush, 2019; Ajibade, 2019).

Within the U.S., managed retreat has been accomplished primarily through home buyout programs, but these programs can exacerbate existing social inequalities. Siders (2019b) argues that increased transparency and awareness of bias and social inequalities in buyout programs is needed. Governments also may be more willing to implement buyout programs in areas with specific demographics, contributing to inequalities (Mach, et al., 2019). The social justice implications of buyout programs are critical to fully understand, because they continue to be the most available—and currently most important tool—to effect managed retreat policies (Freudenberg et al., 2016; Maldonado et al., 2014; Insurance Journal, 2020).

3.4. Infrastructure

The entrenchment of expensive and long-lived infrastructure in areas that are increasingly exposed to extreme weather events is one of the most challenging aspect of developing successful managed retreat plans. Infrastructure such as roads, office or residential buildings, sewer systems and water treatment plants typically have design lives of several or many decades, and it can seem impossible to "move" these major structures out of harm's way. In coastal cities, beach replenishment and home buyouts have been the primary options pursued, but Nash, et al. (2005) suggest another alterative, which is to develop phased plans in 10-year increments over a 100-year time frame, as needed. This novel approach provides the first 10 years to plan, and requires consideration of the costs of continuing to armor or defend existing infrastructure over a defined time horizon as compared to the cost of demolishing and rebuilding elsewhere. *Id.* As Nash has recognized, "virtually all coastal communities will need such programs of managed retreat over the next 100 years, or they will fulfill the prediction of retreating as the result of a series of coastline calamities" (Nash, et al., 2005, p. 605). There are also substantial political difficulties with retreat policies, as documented by Scott et al. (2020). Infrastructure vulnerability is not only caused by climate change, but by conscious choices to continue to build in (increasingly) risky areas, such as in fire-prone areas and coastal areas (Scott, et al., 2020; Larsen et al., 2008).

Research has begun to focus in earnest on the impacts of climate change to transportation infrastructure and the need for retreat (Ruppert et al., 2019). However, like coastal areas, roads dominate any discussion of how managed retreat programs may apply to transportation infrastructure (e.g., Fialkoff, 2017; Deady, et al., 2017; Jones et al., 2019; Ruppert and Grimm, November 2013). Ruppert et al. (2019) examined an important factor that may inhibit managed retreat programs from even being conceived in the transportation context; that is, the limits of local government authority and their corresponding duties under the law. In some areas, local governments may have a legal obligation to continue to maintain a road once it is there. These localities may face lawsuits from residents unable to access their property if a road is abandoned, as effecting an unconstitutional "taking" of their property without just compensation. The changing climate in areas where public roads or other infrastructure is at increased risk of damage has exacerbated tensions between the welfare of the larger community and the individual property right protections in the U.S. Constitution. Ruppert, *et al.*'s work highlights the need for state and federal government coordination and for state intervention in some cases, because local governments only have the authority granted to them by the State (Dundon and Abkowitz, 2018).

Managed retreat in the inland waterway context is nearly entirely missing from work being undertaken in the United States; however, European researchers provide an important resource in this area. Freight shipping by barge is one of the lowest cost and most environmental friendly shipping modes that exists (U.S. DOT, 1994). Yet, it is clear that inland waterway navigation is vulnerable to climate change (especially from increased droughts and floods that make navigation dangerous or impossible), and effective adaptation or retreat strategies may be overlooked.

The economic consequences of disruptions to the inland waterway systems have been studied. (Olsen, et al., 2005; Koetse & Rietveld, 2009; Jonkeren, et al., 2014; Fealy & Murphy, 2009a; 2009b). Managed retreat in the inland waterway context, however, is a nascent field with extremely limited work, with only one study in the U.S. that expressly addresses U.S. inland waterway transportation and managed retreat (Osman, 2017). That study discussed the major successes Illinois has had in expanding the floodplain, relocating communities and removing flood-prone infrastructure, but also noted that "accurate climate change data on major inland waterways and urban areas remains elusive." Zheng & Kim's work (2017) highlights the need to think of managed retreat more broadly in the inland waterway context. Using a river in Northern Canada as an example, the authors highlight that shipping schedules may need to permanently change, a type of "retreat" from business as usual under a previously stable climate.

Coastal ports in the U.S. are more likely than inland waterways to be considered regarding climate change risks. For example, the U.S. port of Norfolk, Virginia is experiencing major impacts from both sea level rise and land subsidence, making it one of the most vulnerable ports in the U.S., and it is also a major military installation. The city does not use the term retreat, but is working on policies that will have citizens "gradually decide to leave as the inconvenience of staying grows" (Morrison, 2020). However, Norfolk, like many cities, also continues to invest in resiliency efforts, which researchers have cautioned may create a "negative spiral" of encouraging more investment in infrastructure and obfuscating the real risks (*Id.*). More research is urgently needed to determine if the unintended consequences of resiliency efforts are likely to do more harm than good in the long term, because "resiliency" efforts have become the primary focus of many communities as a method to address climate change risks.

Substantial work is needed to examine how and whether climate data can be better utilized in the inland waterway context, and to determine what inland waterway transportation stakeholders are facing regarding shipping under changing climate conditions and

how they view potential responses. A framework for decision making that takes account of these variables will be important to future developments in this field.

Equally lacking in the field of managed retreat research is work on railway infrastructure. Roads and rail lines are both extremely expensive to rebuild or to relocate often requiring new land purchases or eminent domain proceedings to take new land (if relocation is the selected approach). One example presented by Rutledge (2018) involves the Burlington Northern Santa Fe Railway line at the western U.S. and Canada border. Two nearby cities in British Columbia are evaluating retreat options for a portion of the rail line that has become increasingly vulnerable to weather induced events, at a cost of $350-$450 USD million. For any managed retreat discussion to succeed with these types of costs, multiple stakeholders at all levels of government and private industry must be engaged (Rutledge, 2018). While rail lines traverse our nation, many are located directly on vulnerable coastal properties, cliffs or near riverbanks that will be increasingly vulnerable to extreme weather impacts (Fig. 2).

Airports and pipeline infrastructure are also just beginning to enter the managed retreat conversation. For example, Hawaii has long recognized the need to address climate change impacts, and recently issued a report on managed retreat in its coastal areas that addresses transportation infrastructure (State of Hawaii, 2019). The report notes that much of Hawaii's critical transportation infrastructure, including airports, is located on or near vulnerable coasts.

U.S. airports are at risk of permanent water inundation by the end of the century. Airports located in New Orleans, La Guardia (New York City), and Key West (Florida) all face critical threats from sea level rise and storm surge. Some U.S. airports have already installed flood barriers, such as Boston and San Francisco (Lavietes, 2020). Outside the U.S., small island nations often lack funding to undertake these types of infrastructure changes, and major development banks are often left to determine whether to continue repairing a literally drowning asset (World Bank, 2017). In the international development context, these decisions are often inextricably linked to issues of place attachment and social justice (poor island nations have not contributed meaningfully to the causes of climate change), but climate migration is likely to be inevitable.

In the northern hemisphere, a substantial amount of pipeline infrastructure is built on permafrost. If climate change causes that permafrost to melt, as expected, these pipelines are at risk, in addition to the major ecological damage from the attendant chemical spills if a pipeline fracture occurs (Hjort et al., 2018).

Although this section addresses primarily transportation infrastructure, other major infrastructure is largely missing from academic studies focused on the need for managed retreat. For example, water infrastructure such as wastewater treatment systems, are aging and nearly always located in low-lying areas on coasts or rivers. Most communities in the U.S. also use aging combined sewer systems, where stormwater and sewer waste are mixed and designed to overflow to rivers and streams. Waste water facilities, sewage systems and storm water systems are facing the dual threats of age and extreme precipitation in many locations. These issues are already being considered by water managers in many cities, but have not yet been adequately addressed by researchers. Kool et al. (2020), however, have modeled a dynamic adaptive pathway planning approach that could be used to identify thresholds for storm water and waste water that would trigger retreat policies that could be implemented over time and budgeted for. Kool et al's approach is an example of a *strategy* for treat that Siders et al.'s (2019) has argued is missing and particularly needed in the infrastructure sector in order to effectuate efficient retreat options that impose co-benefits on society and achieve short and long term societal goals.

3.5. Framework and tools

Practice-ready frameworks and tools are needed to support local, state, and federal decision making around managed retreat. A few are just beginning to emerge. Notably, the Georgetown Climate Center has developed a toolkit designed to help states assess risk and develop legally defensible managed retreat programs rooted in equity (GCC, 2020). As noted above, Kool et al. (2020) have developed a Dynamic Adaptive Pathway Planning (DAPP) approach for managed retreat of major water infrastructure.

Kousky (2014) sees effective retreat programs in the U.S. as unlikely, but proposes a framework for retreat to be implemented post-disaster. Storms, she notes, can be "windows of opportunity for change because they create a forced turnover in capital stock and a

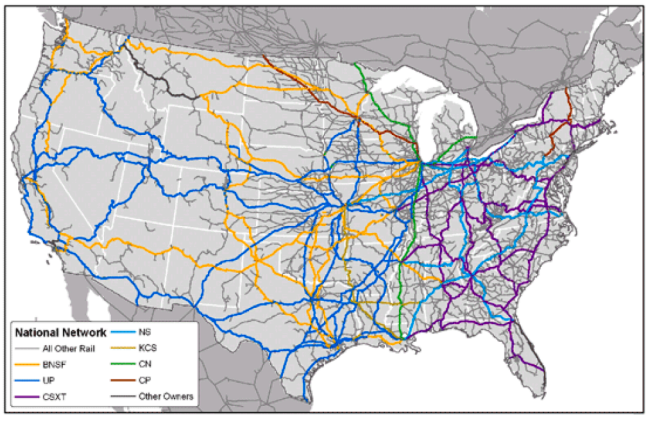

Fig. 2. Major U.S. freight rail lines.

chance to rebuild differently," but she argues that pre-disaster planning for post-disaster reform is critical. At the outset, local governments should carefully and creatively identify revenue sources for retreat programs, such as earmarking sales or hotel taxes, or increasing taxes on new construction in risky areas. Next, use funds to encourage (or require) retreat, utilizing creative mechanisms, such as bonuses for voluntarily moving as a neighborhood to encourage positive social pressure to move together, changing required setbacks, or changing disaster aid to encourage retreat (Kousky, 2014). Finally, limit public building and infrastructure in risky areas, even if private infrastructure remains.

A common thread through this body of work, without being stated explicitly, is that communities should start talking about retreat (through whatever language is appropriate locally) early and often. Retreat should not be seen as a radical, last resort solution to avoid, but as a strategy to consider among others as communities think long-term about their viability and the livelihoods of their citizens in 10, 50, or 100 years (Plastrik & Cleveland, 2019; Linnenluecke et al., 2011; Pinter and Dalbom, 2017).

4. Conclusion

None of the aforementioned considerations exist in silos. Infrastructure is difficult to move in part because it is large and expensive, but also because it is intimately intertwined with human connectedness to place and purpose. Similarly, law directly bears on the feasibility or even authority of any government to undertake regulatory measures implementing retreat options, and the defensibility of those measures when they are challenged. Perhaps even more so than climate change, managed retreat (by any name), to be successful, demands perspectives and information from a broad range of disciplines. Researchers from a diverse group of backgrounds are beginning to come together to discuss these issues, and frameworks are emerging that may be more useful from this multi-disciplinary perspective.

Managed retreat (or transformative adaptation) is also not static, and any definition should evolve to include a range of the permanent changes humans make in light of a changing climate (Zheng & Kim, 2017). This could include shifting away from specific crops in certain areas, changes to the types of vessels or scheduling used in inland waterway freight shipping, changes to the flood insurance program to stop rewarding building in high risk areas, or shifts in regulations governing water management practices in areas of increasing drought. Including a broad scope within the term's meaning may make such "transformative adaptation" polices more acceptable and typical, and they may even come to be accepted as the more responsible and reasoned approach to addressing the continued viability of high-risk areas and the well-being of our citizenry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Disclaimer

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APPENDIX B

Governing Transition: *Case Studies in Transformative Adaptation*

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ABSTRACT Global climate change presents both acute and long-term risks to humanity. Managed retreat has emerged in the literature as one method by which to manage some acute and slow-onset events caused by climate change, but it requires substantial additional research and examination. It is now clear that humanity must scrutinize how and where we live and the wisdom of policies that support continued rebuilding and reinvestment after climate-related disasters. Despite its emergence as a potential policy response to risk, the phrase "managed retreat" is documented as a barrier in itself to successful adaptation actions, largely because the term is currently almost exclusively considered to mean physical movement of infrastructure or people out of harm's way—that is, retreat. There is a need to document and consider case studies where managed retreat is being utilized more broadly and to consider these case studies as a climate governance approach to managing risk. The case studies presented of local policy responses to climate-induced disaster events demonstrate examples of the permanent changes that are already occurring to the existing and historical governance of climate-related risks. These case studies can serve to broaden the climate adaptation discussion and framework beyond "managed retreat" and may lead to more successful implementation of adaptation measures that reduce climate risks. We adopt the term "transformative adaptation measures," rather than "managed retreat," and provide case study illustrations of climate governance strategies that communities faced with a changing climate risk profile may consider, rather than focusing on "retreat." KEYWORDS managed retreat, adaptation, climate law and policy, transformative adaptation, climate policy implementation, case studies

1. INTRODUCTION

Managed retreat, also known as managed relocation or transformative adaptation, is an emerging field requiring substantial additional research and examination. This article is the second in a series addressing managed retreat strategies and outcomes, with the first paper focused on the emerging literature on managed retreat (Dundon & Abkowitz, 2021). The term "managed retreat" is often limited in the literature to descriptions of movement of people or infrastructure. However, this article argues that managed retreat should be considered much more broadly and is a critical adaptation strategy that can take many forms, beyond simply moving houses and roads away from the coast as it is now nearly exclusively examined. Furthermore, managed retreat should not be viewed as an isolated action in discrete locations but as an emerging governance approach that will be necessary at different scales and across the globe in a variety of locations as the world moves toward life in a changing climate. "Governance" as used in this article describes the structures, systems, rules, and procedures that direct and control society with respect to addressing and managing the shared problem of climate change. In short, climate governance is aimed at *effectively* addressing climate change. The "governance" approaches can occur at the local, city, state, or national level. While the term governance applies to any organization's ability to effectively manage itself (such as a company or even a family), here, the term is used primarily to refer to *public government institutions* such as a city councils, boards of health, state legislatures, national governments, and other similar institutions with the authority to establish or influence rules or policies to address climate change.

Through four illustrative case studies, this article identifies adaptation strategies that are forms of managed

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retreat yet go far beyond the typical movement of coastal infrastructure and instead exemplify the novel and important policy solutions that governments can implement to address the unique environmental problem of climate change.

New and more inclusive terminology is needed in this nascent field (and such terminology changes are actively being pursued; Climigration, 2020) because the term itself is documented as a barrier to implementation of needed retreat policies in certain areas. Notions of "retreat" can convey defeat and have been met with opposition in some communities (Campbell & Wilson, 2016; Carey, 2020; Koslov, 2016). This is especially true where "managed retreat" is additionally associated with the loss of private property or private financial resources—such as where homes are purchased by city or other governmental entities and the property is converted to open space or flood buffer zones. In addition, as noted above, the phrase "managed retreat" has nearly exclusively been used to convey notions of "retreating" from the coasts—that is, moving people and infrastructure away from coastal areas where sea-level rise, storm surge, or hurricane risks have increased. The term is rarely used to discuss the permanent responses occurring in inland areas that are the direct result of other, noncoastal forms of climate-induced weather events (such as riverine flooding, extreme heat, drought, or declining freshwater resources). Dundon and Abkowitz (2021) have documented the numerous differing and at times inconsistent definitions of the term used throughout the literature. Because climate change is having impacts to human life and livelihoods far beyond the coasts and because "managed retreat" is a term that has had negative connotations that make successful "retreat" actions difficult to implement, we suggest new terminology be used.

We adopt the phrase "transformative adaptation measures" (TAMs) and define these as adaptation strategies or governance responses that include a permanent change, due to climate change, in the way humans interact with their environment in some form. This definition is intentionally broad to include the range of permanent actions and policy responses that are needed to adapt to a world with a changing climate. For example, TAMs would include physical relocation of a coastal community as a response to sea-level rise but also permanent changes in scheduling or routing that a transportation company may undertake in response to a recognized (and likely permanent) shift in weather events, such as chronic seasonal flooding or changing ice conditions (Zheng & Kim, 2017). However, we recognize that "managed retreat" remains the dominant term in the literature and is therefore used in the context of this article interchangeably with the term TAMs, unless otherwise noted.

Adapting to the reality of a changing climate is increasingly being seen by citizens and policy makers around the globe as a new and necessary approach. It is also clear that some areas of the world, including certain (especially coastal) areas within the United States, may no longer support permanent structures and human habitation now or in the foreseeable future, particularly if greenhouse gas emissions continue unabated (Carey, 2020). Adapting to that reality in the United States has begun, and this article uses case studies from the United States to demonstrate and document several adaptation strategies that are occurring in climatically diverse areas of the country. The example approaches set forth may effectuate "managed retreat," but, in some cases, novel approaches are used that are more than mere "retreat" and represent examples that suggest a new governance framework.

The United States was selected because it is a large and geographically diverse nation with a variety of different climate regions, each experiencing unique climate stressors. For example, the U.S. Department of Agriculture (USDA, n.d.) divides the nation into 11 different climate zones based on agricultural plant hardiness. Until 2012, the USDA had not updated its plant hardiness zones since 1990. The 2012 update relied on climate data from 1976 to 2005 and resulted in a recognizable shift of zones northward, acknowledging the observed warming trend. Two new zones were also established, although it can be argued that additional modifications to zonal definitions are warranted based on what has been experienced more recently. These types of permanent (or potentially permanent) changes are precisely the types of emerging transformative strategies that will facilitate and increase community resilience as warming continues and that should be carefully documented and examined in the literature.

The Department of Energy (DOE), through its Building America Program, also defines various climate zones, primarily for the purpose of building for energy efficiency. As shown in figure 1, DOE recognizes eight different

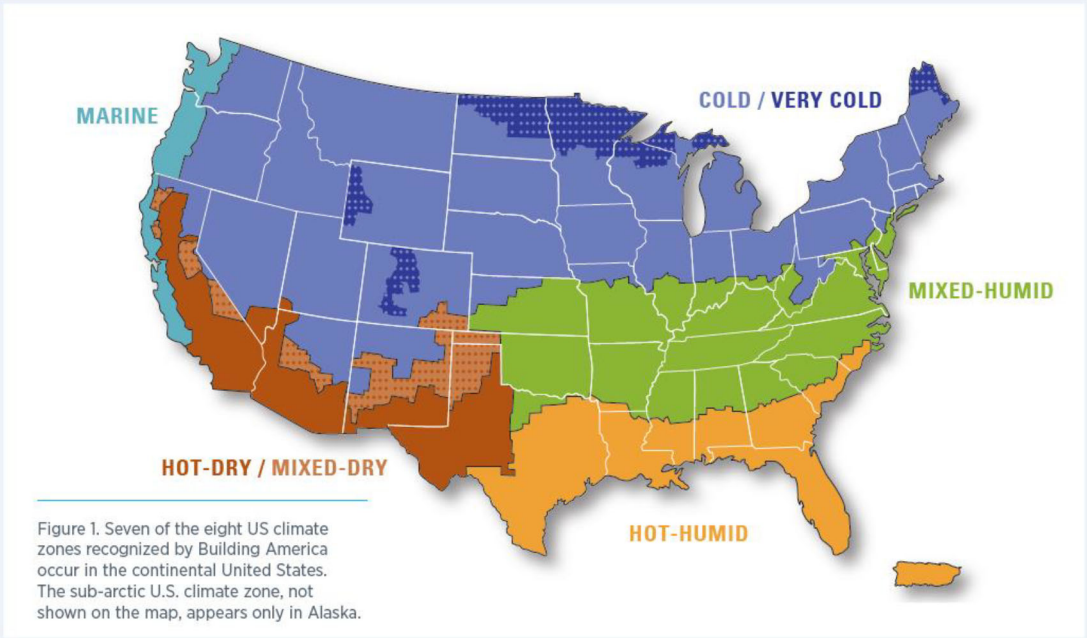

Figure 1. U.S. Department of Energy climate zones. Source: DOE Building America Program.

zones (seven in the continental United States), which are defined by factors such as the number of heating days needed, temperature, humidity, and precipitation (USDOE, 2015).

Each climate zone can be expected to experience differing extreme weather and other climate-induced events. Figure 2 shows generally the types of natural hazard events occurring in different portions of the United States, with wildfires occurring more frequently in the middle and western part of the country, floods occurring in coastal but also riverine inland areas, and droughts occurring more frequently (but not only) in the western half of the country.

Through four case studies representing transformational governance responses to extreme weather events, categorized by the authors as TAMs, this article examines the factors and processes that relate to successful TAMs and that can be utilized to inform the development and implementation of TAMs more widely. We also focus on impacts to frequently overlooked stakeholders when TAMs are implemented, such as receiving communities when people are permanently displaced. The TAMs documented in this article can serve as important models of innovative approaches to the types of environmental policies and institutional governance structures that will continue to be needed to address the myriad of impacts climate change will bring.

2. CASE EXAMINATIONS

Four case studies are presented in the following that represent a variety of climatic conditions, extreme weather events, geographic locations, and response strategies. Case studies were selected that were representative of both acute, sudden climate-induced events (wildfire in Section 2.1 and flooding in Section 2.3) and slow-onset events (sea-level rise in Section 2.4). The authors also selected case studies that provided geographic diversity (within the United States) of the types of climate events often experienced in different regions. Extreme heat events in already hot and dry climates such as Arizona (Section 2.3) present a challenging risk to populations. The case studies also were chosen based on the availability of data and the likelihood that readers, and students, have some familiarity with the type of climate event discussed, given disaster event coverage in recent years in both academic and popular new sources. Finally, we selected case studies that present interesting examples of the TAMs we identify in this article, are likely to be relatable to many readers, and prompt thoughtful discussion.

The first case study addresses *wildfire* risk, using the 2018 event in California known as the "Camp Fire." It represented the worst and deadliest fire in the State's history, as well as the costliest disaster worldwide in 2018, yet permanent changes to law and policy that affect

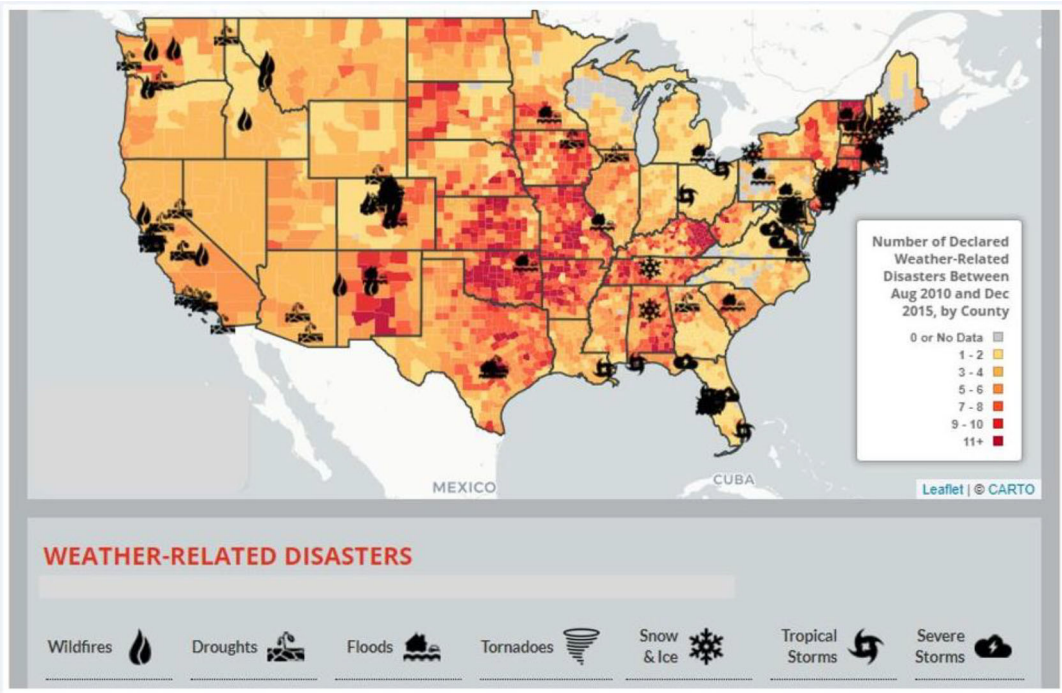

Figure 2. Weather-related events resulting in a disaster declaration, 2010–2015. Source: Environment America (n.d.).

resiliency to fire events are often overlooked. Second, *extreme heat* events, already increasing in both severity and duration, are expected to become more prevalent and are a leading cause of weather-related deaths in the United States every year. The second case study, therefore, examines an extreme heat event in Maricopa County, AZ, in 2020 that killed more than 300 people, the highest number of heat-related deaths on record for a single year. Strategies such as heat warnings and cooling shelters, among others, are being augmented and further considered at the local level and are likely to become permanent policy approaches as extreme heat events increase. The third case study focuses on the home buyout program that was utilized as a response to a major and unprecedented *riverine flood* event in Nashville, TN, in 2010. Finally, the fourth case study represents a more traditional case of managed retreat, the displacement of the Isle de Jean Charles residents from their ancestral homeland in Louisiana that has nearly entirely disappeared due to *sea-level rise*, among other contributing factors.

Together, the elements of these case studies represent a need to build a framework around managed retreat measures to more broadly include, and facilitate consideration of, the types of permanent changes that will ultimately increase infrastructure and community resilience.

2.1. Wildfire: Paradise, CA—The "Camp Fire"

The Camp Fire in 2018 in Paradise, CA, perhaps best exemplifies how managed retreat policies should not be limited to considerations of physically moving or relocating people or infrastructure permanently out of harm's way but should also consider adjustments to law and policy. Indeed, such changes might enable people or homes to *remain in place* while at the same time anticipating and providing increased protection from future climate-induced events.

Originating in Paradise, CA, the Camp Fire (named after the Camp Creek Road where the fire began) burned over 153,000 acres, destroyed 18,804 structures (over 14,000 homes), and caused 85 human deaths, in addition to firefighter fatalities (California Department of Forestry and Fire Protection, 2019). Insured losses exceeded US$12 billion (California Department of Insurance, 2019).

Research conducted after the fire revealed how building codes and the use of modern climate data to inform hazard and risk zones can have a substantial impact on the number of homes destroyed when a fire of this magnitude occurs again. Most of the homes in the Camp Fire area were built prior to the enactment in 2008 of a more stringent fire and building code, which mandated fire-resistant roofs in certain high-fire hazard zones. As shown

Table 1. Percentage of Homes Damaged or Destroyed in the 2018 Camp Fire Based on Building to Pre- or Post-2008 Building Code Standards (Kesley, 2019).

Level of Damage	Homes Built in 2008 or Later (%)	Homes Built Before 2008 (%)
No damage	50	17.7
Minor damage	8.8	3.3
Entirely destroyed or major damage	40.6	79.0

in table 1, the destruction rates between the homes built to the 2008 standards and those built to pre-2008 standards demonstrate a dramatic difference in the ability to withstand the fire based on nothing more than compliance with the code.

While table 1 demonstrates that the 2008 building code likely contributed to saving a significant percentage of homes, nearly half of the homes built to the "better" 2008 standard were still destroyed. This could be attributed, at least in part, to the fact that identification of "very high-fire hazard severity zones," California's designation for areas highly vulnerable to devastating wildfires, was established more than 10 years ago, so the fire-risk maps are outdated in light of climatic and zoning changes that have occurred during that time period (Sabalow et al., 2019). Fire zone mapping is based on a variety of factors, including available fuel, slope, and fire weather (e.g., winds; California Geoportal, 2020). These fire hazard zone maps are used to determine whether and where certain building codes apply but also are used by local governments in fire response and other planning (California Geoportal, 2020). California is developing new fire hazard zone maps based on updated climate and weather information, as well as updated development data (Pickoff-White, 2019).[1] This effort is expected to be completed by the end of 2022 (Dundon, 2021).

The experience in California is instructive because, as shown in figure 3, many homes in the United States are increasingly built within what is known as the wildland–urban interface (WUI), an "area where houses and wildland vegetation coincide" (Stewart, n.d.). The WUI area corresponds with locations where wildfires are more likely, and structures built there are at increased risk.

Climate change is further exacerbating and expanding the wildfire potential in these areas (Abatzoglou & Williams, 2016). Figure 4, an excerpt from California Governor Newsom's Strike Force report, shows the dramatic impact climate change has already had on wildfire occurrence and the number of acres burned. Although increased building within the WUI is known to increase risk, the Camp Fire case study shows the potential for risk to be reduced through modern planning, innovative building codes, and improved awareness of climate-related impacts on wildfire potential. Moreover, the Camp Fire revealed that evacuation routes were inadequate, and the State has responded with new laws mandating that cities and counties identify areas with inadequate routes in hazard zones and update their respective emergency response systems (Luna, 2019).

Forbidding any building or rebuilding in known severe fire risk areas or removing infrastructure already there—the traditional form of managed retreat policy—is only one approach. Data emerging from the Camp Fire demonstrates that updated risk maps which account for the current and future impact of climate change, together with modern building codes regarding fire-resistant structures and updated emergency response systems, can substantially lessen the destruction of homes by fire in these areas and presumably human casualties as well. Updated mapping and codes (and polices that require updating of mapping and codes at certain frequencies that better reflect a changing climate) can also be used to more appropriately allocate resources to mitigate wildfire risk.

Properly pricing insurance and risk is another approach. If developers, insurance companies, and lenders utilize updated information and require building to codes and standards that reflect current risk, the private market may function better, making it uneconomical to build (or rebuild) in some areas. Where building does occur, constructing to updated codes can protect homes from expected fires, insurance premiums and mortgage rates can be adequately priced, and the risk of loss may be more appropriately allocated away from taxpayers and to individuals and the private marketplace that voluntarily and knowingly assume certain risks. Municipalities could even consider establishing a high-risk fee that builders or owners pay annually to offset the inevitable costs that will impact public funds when a fire does occur

1. Importantly, a fire hazard zone is not a risk zone; hazard zones indicate how a fire will behave and where it can spread, not the damage it can cause.

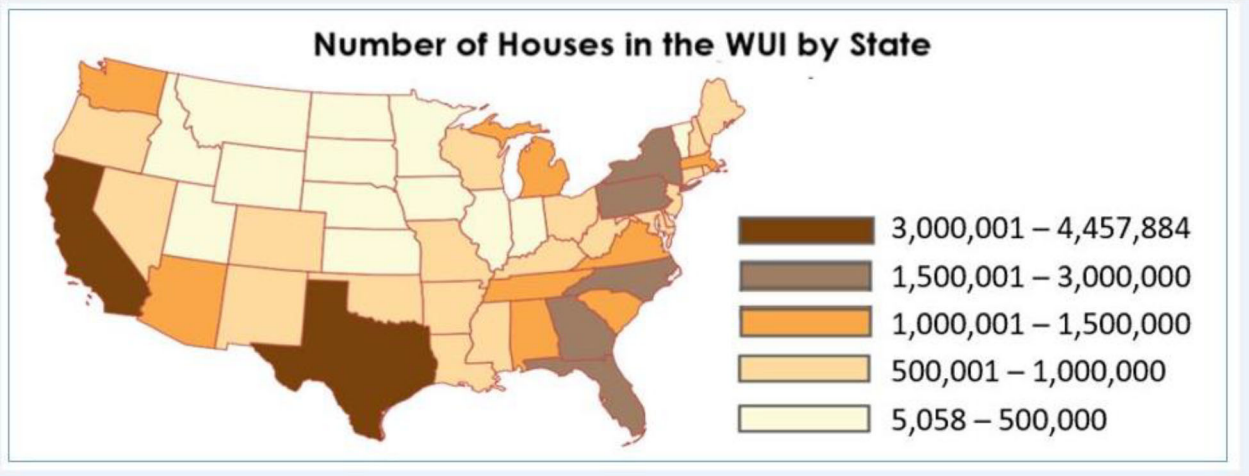

FIGURE 3. Number of houses in the wild–urban interface by state (Governor Newsom Strike Force, 2019).

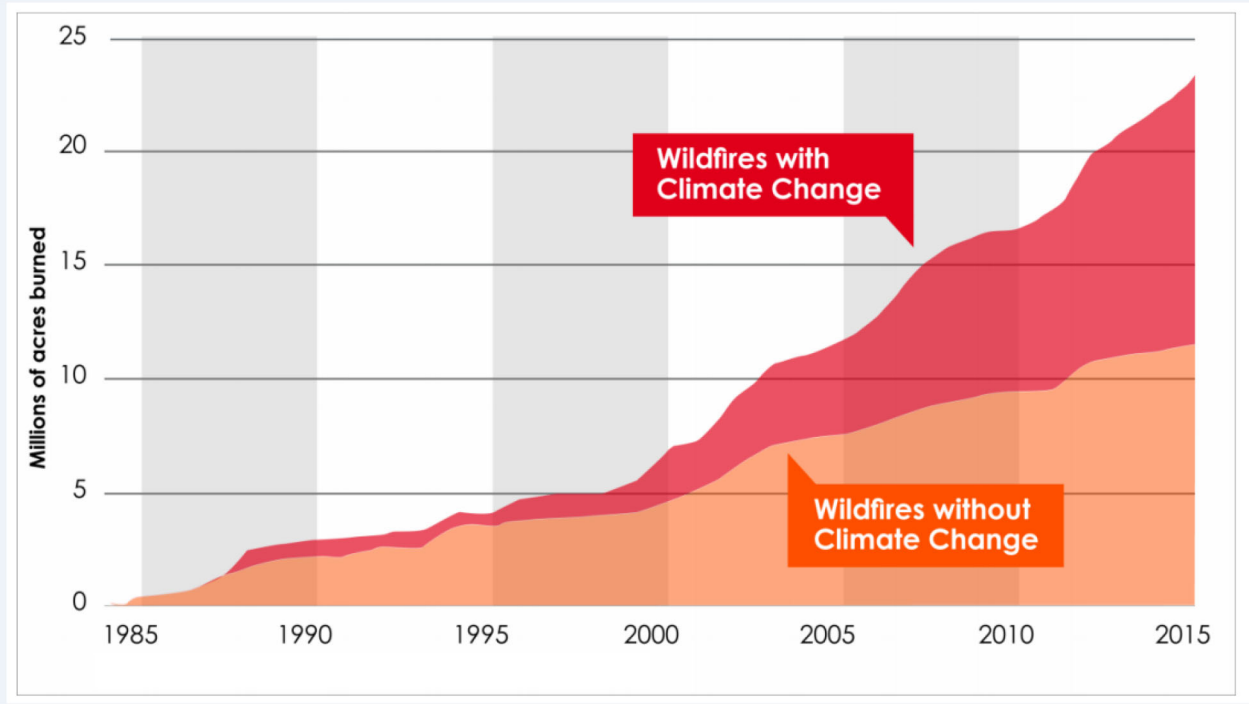

FIGURE 4. Impact of climate change on California wildfires over time (Governor Newsom Strike Force, 2019). Source: Abatzoglou and Williams (2016), PNAS 113.

(e.g., firefighter response costs, state relief payments, natural area restoration).

These response examples demonstrate that managed retreat is better thought of as "transformative adaptation," a strategy that can be accomplished through a range of approaches, not only through physical "retreat." This perspective may be particularly important with respect to overcoming documented barriers to effective "retreat" policies, such as the defeatist character many stakeholders associate with the phrase, or the psychological phenomenon known as place attachment (Agyeman et al., 2009).

Once the fire hazard maps in California are updated to reflect current climate risk data, as they are expected to be completed imminently, the use of such updated maps to change policy may be considered a TAM. For example, revised laws and policies that rely on updated mapping to mandate where and how building may occur would affect

a permanent change in response to evolving climate conditions. Such a shift may make humans and their infrastructure more resilient to wildfire risk and potentially facilitate public awareness of the changing risks.

2.2. Extreme Heat: Maricopa County, Phoenix, AZ

Of all the extreme weather events for which science has established a connection between human-caused greenhouse gas emissions and climate change, that link is strongest with respect to extreme heat events (Baldwin et al., 2019; Intergovernmental Panel on Climate Change [IPCC], 2014). Extreme heat events are the leading cause of weather-related deaths in the United States (Center for Disease Control and Prevention, 2019, 2020; Luber & McGeehin, 2008; Russell et al., 2020). Although considered a largely preventable cause of death (Ito et al., 2018), on average over 700 people have died annually in the United States from heat-related exposure between 2004 and 2018 (Vaidyanathan et al., 2019, 2020).

Warmer and poorer regions of the world are expected to experience substantial increase in heat-related mortality events as climate impacts continue to worsen (Gasparrini et al., 2017). Even within the United States, areas that already experience extreme heat are likely to experience more intense, prolonged, and more frequent extreme heat events (Baldwin et al., 2019). Studies have also shown a high correlation between the average monthly high temperatures and hospitalizations for heat-related illnesses (Union of Concerned Scientists, 2018).

The summer of 2020 was the hottest on record for Arizona, with extreme heat causing or contributing to the deaths of 520 people and in-patient hospitalizations of 893 others (Arizona Department of Health Services, 2021b). The highest number of heat-related deaths on record in Arizona previously was 283 during the summer of 2019, and state officials see increasing urgency to address this hazard, given such a disturbing trend (James, 2021). Figure 5 shows the average summer temperatures in Arizona since recordkeeping began, demonstrating a substantial upward trend in average temperatures, which only causes any "extreme" heat event to be even more extreme. As figure 5 demonstrates, temperatures that are now summer averages in 2020 would have been considered "extreme" heat in past decades.

During the summer of 2020, Phoenix experienced 145 days, in which the temperature reached 100°F or higher, and for 53 of those days the temperature was 110°F or higher (see figure 6). The actual impact of heat on the human body is best measured using the WetBulb Globe Temperature (WBGT), which accounts for not only temperature but also humidity, cloud cover (amount of solar radiation), wind, and sun angle, and is used by the military, the U.S. Occupational Safety and Health Administration, and others to guide decisions regarding outdoor work or play (e.g., sports; National Weather Service, n.d.). In short, the WBGT provides information regarding the conditions, in which human sweat will not evaporate sufficiently to cool the human body. A WBGT of 95° is generally considered fatal to humans, but severe impacts can occur within a matter of hours when the WBGT is 79° (NOAA Research News, 2020). In Phoenix, AZ (Maricopa County) on August 1, 2020, the WBGT was 76.8° and the standard (dry bulb) temperature was 111.7°F (Tiggr Weather, 2021). The extreme heat in summer 2020 in Maricopa County was a result of climate change, urban heat island effect, and short-term weather fluctuations (Arizona Department of Health Services, 2021a).

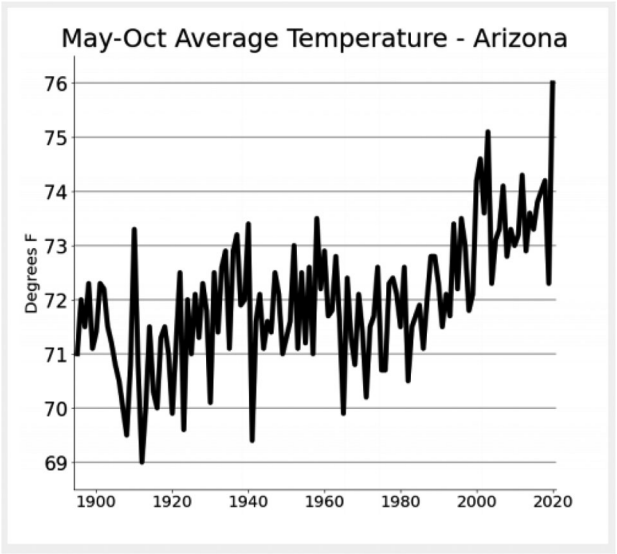

Figure 5. Average summer temperatures over time in Arizona. Temperatures are based on 24-h daily temperatures so would include nighttime lows. Source: Arizona Department of Health Services (2020).

Not surprisingly, as shown in figure 7, there is a direct correlation between the hottest temperature days and the number of heat-related visits to emergency rooms (James, 2021). Of the overall emergency room admissions, the percentage related to heat may appear small, but in Maricopa County, 1,237 people were admitted to the

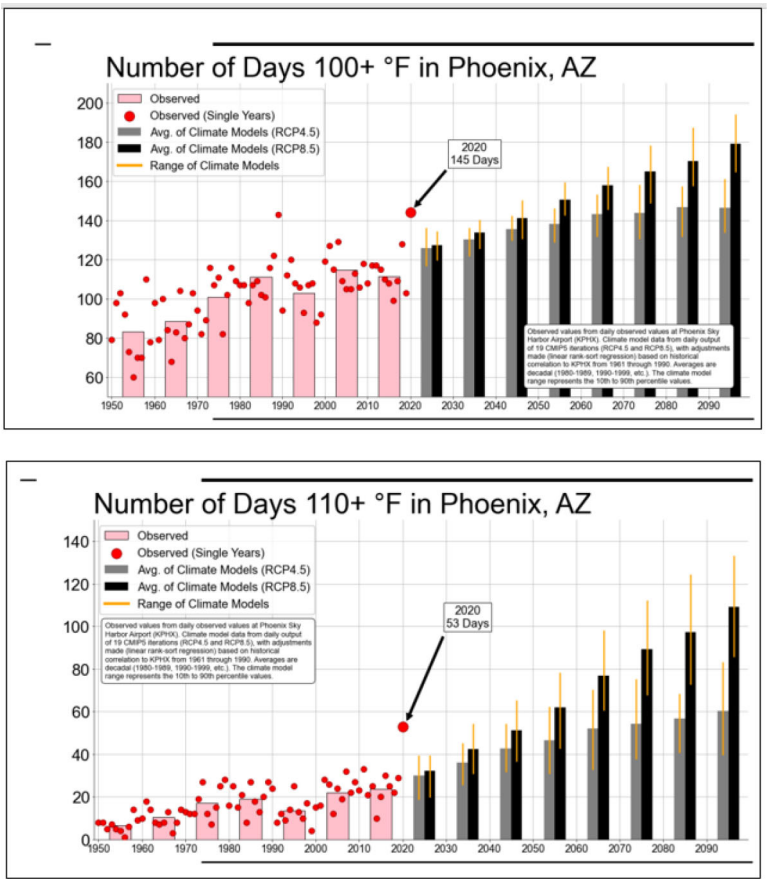

Figure 6. Number of days above 100°F and 110°F in Phoenix in 2020 as compared to observed and expected trends under different warming scenarios (Arizona Department of Health Services, 2020).

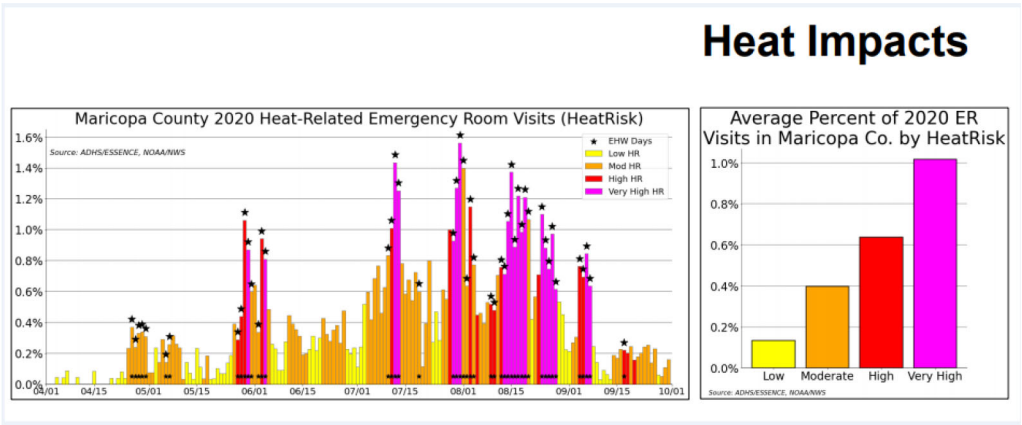

Figure 7. Percentage of all emergency room visits that were heat-related (left chart) and percentage of visits as correlated to level of heat risk days (right chart) (Arizona Department of Health Services, 2020). Left chart admissions in pink indicate very high heat-risk days.

emergency department in 2020 alone, and on average, 3,000 people annually visit Arizona emergency departments for heat-related issues (Arizona Department of Health, 2021b). If a hospital is short staffed or nearing capacity, additional high heat days can cause a substantial additional burden on the health system. Moreover, it is well known that certain groups are more vulnerable to extreme heat, including older populations, people who

live or work outdoors, or those who reside in mobile homes or in any home without air conditioning (Sampson et al., 2013; Voelkel et al., 2018). Indeed, in Maricopa County, over half of the heat-related deaths from the extreme heat of 2020 were those of homeless people (James, 2021), raising profound questions of justice and equity with regard to the negative impacts of extreme weather events. Experts recognize that planners must do more to mitigate the anticipated worsening impacts to human life and health that climate change presents.

Because of the already increasing number of heat-related illnesses and deaths in Arizona, coupled with the impact of COVID-19 on the capacity of hospitals and medical staff, the Arizona Heat Resilience Workgroup was created to bring together stakeholders to coordinate on approaches to addressing the increasingly deadly problem (Arizona State University, n.d.). A subworking group was also formed to focus exclusively on cooling centers as a risk reduction strategy (Arizona State University, n.d.).

A significant number of projects are underway in Arizona to address extreme heat, many of which are transformative in nature, designed to increase resiliency in the face of expected increases in extreme heat events, enabling citizens to remain in place. The City of Phoenix, together with Arizona State University, has initiated a "cool pavement" pilot program, which uses an asphalt seal that is designed to be lighter and more reflective than traditional asphalt seals, reflecting heat and reducing the urban heat island effect (City of Phoenix, n.d.). Known as Cool Seal, it has been installed in eight neighborhoods (36 miles of roads) to pilot test and measure its impacts on temperature (City of Phoenix, n.d.; see figure 8). Preliminary results indicate that this seal is producing significantly cooler surface temperatures and small but meaningful reductions in surface air temperatures (City of Phoenix, n.d.). Investments in long-lived infrastructure, such as roads, and permanent changes to the types of sealants routinely used on these roads are TAM that may reduce risks from extreme heat to existing communities without displacing these communities.

The City of Phoenix has also proposed in its budget, for the first time, substantial funding for the creation of a new Office of Heat Response and Mitigation. This would be the only office of its kind in the United States and would represent the first creation of a new government institution, whose sole purpose is to address the impacts of extreme heat events due to climate change (Arizona Department of Health Services, 2021a).

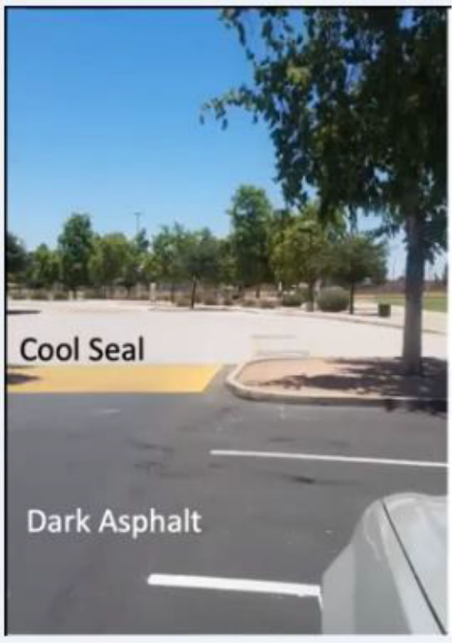

Figure 8. Cool Seal versus dark asphalt. Source: Arizona Department of Health Services (2021a).

Finally, the Arizona Corporation Commission, the regulatory body that oversees utility providers in the State, is working on permanent changes to law in response to the increasing number of utility customers who are at risk on high-heat days. This work is largely emerging in response to the death of a 72-year-old woman from extreme heat after her electricity was disconnected for failure to pay a US$51 bill (Richburg, 2021). An emergency rule was adopted after her death prohibiting disconnections during the summer, while new disconnection rules have been under debate. The Commission recently voted on a set of rules, that if adopted, will make the disconnection rules uniform among most utility providers in the State. These rules require the utility to select between two approaches, either no disconnections in the summer or no disconnections on days where the temperature exceeds 95°F. Additionally, utilities would be prohibited from shutting off service, where a customer is less than US$300 delinquent on their electric bill (Arizona Department of Public Health, 2021). The extent of the benefit of the regulations as applied is currently unknown because they are new, and it is not clear whether a utility that legally disconnects when the temperature is below 95°F is required to reconnect if the temperature subsequently increases above 95°. Nevertheless, a review of regulations governing utility disconnections in areas that

experience high heat—particularly in those areas with populations especially vulnerable to heat, such as the elderly—can be an important strategy for planners to address the changing climate conditions in which we now live.

The types of responses described in this case are permanent changes that may serve to avoid the need for (or delay) *additional* permanent changes, such as human displacement and migration. However, there is real concern that certain counties in Arizona may become uninhabitable for humans by midcentury because of extreme heat (Shaw et al., 2020), with those counties expected to experience above 95°F days for nearly half the year. These extreme temperatures are incompatible with daily living, food production, and more, and scientists expect climate migrations to occur (of rich and poor alike) away from these areas if climate change continues unabated. In addition to this type of long-term human displacement, extreme heat can cause temporary displacement during extreme heat waves if a person's housing is not adequate (such as lack of air conditioning or lack of proper insulation as can occur in mobile homes). If people are increasingly required to relocate to shelters or other housing as extreme heat waves become more common and more severe, a permanent change in where or the types of housing utilized may be needed. This raises issues of equity because affluent people are more likely to have adequate access to air conditioning or the ability to move permanently to cooler climates; lower income people may be required to move to shelters more frequently and are more at risk remaining in place during extreme heat events.

While slow increases in average temperatures over time are more difficult to discern and react to (these are referred to as "slow-onset events"), extreme heat waves resemble acute disaster events, such as wildfires or flooding, in terms of their local impacts. Heat waves cannot be predicted more than a few days ahead and typically occur over a short time frame (usually a few days) often with disastrous health consequences. The increasing frequency and intensity of extreme heat waves in Maricopa County followed by immediate consequences—increased hospital admissions, impacts to the function of transportation infrastructure and more—has served to drive the approaches discussed in this case study.

The types of changes exemplified by this case study—innovative pavement construction, establishment of new government offices, and changes to law and policy—all effect transformative governance strategies to the way humans interact with their environment in the face of climate-induced extreme weather. They offer the potential to reduce illness and death and reduce negative economic impacts of extreme heat, while allowing citizens to remain in place, even while extreme heat in their locations is expected to increase dramatically.

2.3. Flooding: May 2010 Flood in Nashville, TN

Like extreme heat events, observed precipitation changes also are strongly linked to climate change (IPCC, 2014). Risk from flooding, including in inland river areas, is expected to increase (Ward et al., 2017). On May 1–2, 2010, Nashville, TN, experienced the most rain on record dating as far back as 1870. On May 1, 2020, the area received 9.09 inches of rain (far surpassing the prior 24-h record of 6.68 inches in 1979; National Weather Service, 2020). Additional rain on May 2 broke the 2-day rainfall record, with 2-day total precipitation in Nashville of 13.57 inches (National Weather Service, 2020). The May 2010 flood was considered a "1,000 year flood event" in the most severely flooded areas, meaning that based on historical understanding of climate in that area, that amount of rainfall in that short time frame statistically has a 0.1% chance of occurring in any particular year (National Weather Service, 2020).

The Cumberland River runs directly through the City of Nashville near the center of the downtown business district and is controlled by a series of dams operated by the U.S. Army Corps of Engineers (USACE). As shown in figure 9, the river is typically below 20 feet (as measured by flood gauges) during the spring months but reached 51.8 feet on May 3 because of the unprecedented rain volume on May 1–2. Figure 10 shows some of the flooded areas of downtown Nashville during the 2020 flood.

Property damage exceeded US$2 billion, President Obama issued a Presidential Disaster Declaration, and 11 people were killed in Nashville, with additional deaths elsewhere in Tennessee and Kentucky from the rainfall event (National Weather Service, 2020).

One of the most common responses in the United States to reduce risk to individuals and property in areas that experience repetitive flooding is to remove structures from flood plains or flood-prone areas, primarily through the implementation of home buyout programs. These programs allow local or state governments to purchase at-risk homes or properties, permanently remove the

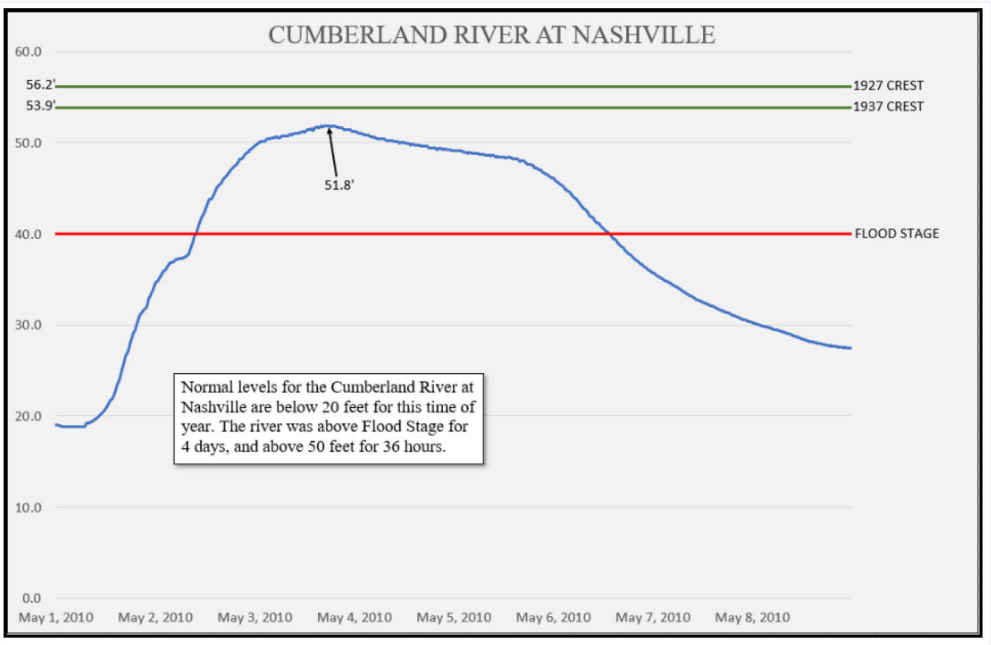

Figure 9. Flood stages for Cumberland River from May 2020 flood. Source: National Weather Service (2020).

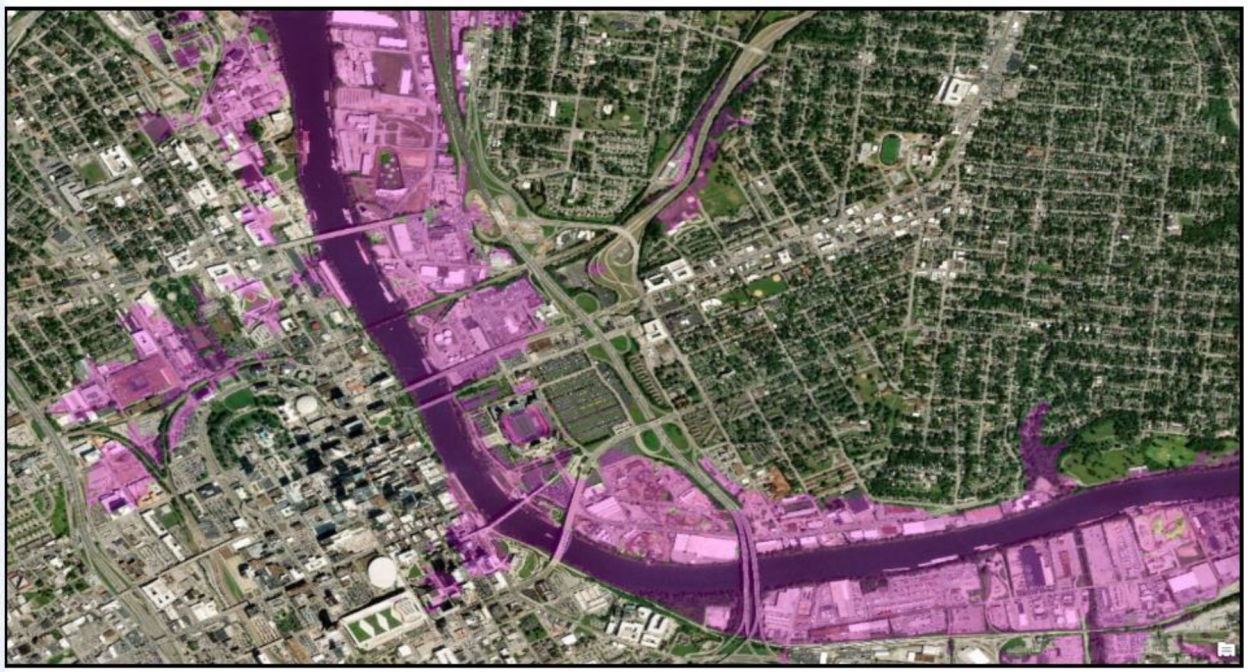

Figure 10. U.S. Army Corps of Engineering mapping of flooded areas near downtown Nashville during the 2010 flood. Source: National Weather Service (2020).

home, and restore the area for other uses such as green space (e.g., natural flood protection, waterway buffers, parks). The Federal Emergency Management Agency (FEMA) or the U.S. Department of Housing and Urban Development, and sometimes, the USACE, typically fund the majority of the cost of the buyouts (Nelson & Camp, 2020). This approach is often considered the traditional form of "managed retreat" in the United States.

The City of Nashville has had a home buyout program since 1977, but generally cities and property owners often do not take advantage of such programs until after a major or catastrophic event. In Nashville, the City had only

purchased 90 properties from the program's inception through the May 2010 flood (Metro Nashville Office of Internal Audit, 2014). Since the 2010 flood event, the program has purchased over 400 properties (NewsChannel 5, 2021), in part because after the 2010 flood, the City more actively sought to purchase homes in areas with repetitive flooding risk (such as by proactively notifying residents of the program and their home's location in a risk area), and residents may have been more likely to sell postdisaster. The Nashville program has historically leveraged combined funding from FEMA, the Tennessee Emergency Management Agency, the USACE, and local resources. Typically, the federal money supports approximately 75% of the costs, with State and local funds supporting the remaining 25%. Nashville has also used entirely local resources for some buyouts.

A recent study quantified the benefit of Nashville's buyout program, including benefits that are often overlooked, such as avoided storm water management costs, avoided damage, and improved quality of life from increased greenspace resulting from the removed infrastructure (Nelson & Camp, 2020). The study concluded that if the homes known to be at risk before the 2010 flood had been purchased and removed, US$33 million in flood damage costs would have been avoided, 1,000 people would have avoided a flooded home, and 17 new acres of green space would have effectively prevented the need to manage 875,000 gallons of storm water flow (Nelson & Camp, 2020).

In addition to increased efforts to implement the home buyout program, other strategies were implemented in Nashville after the 2010 flood to protect against future flood events. First, new river gauges have been installed, dramatically improving the existing data network in areas where the Cumberland River is prone to flooding, which will improve flood warning information (National Weather Service, 2020). Second, advances in computer modeling since 2010 allow for more refined spatial and temporal resolution that has vastly improved extreme weather forecasting at a more local level (National Weather Service, 2020). Additionally, through a partnership with the USACE's Nashville District Office, the city can leverage a real-time flood forecasting model that utilizes some of the information from the more refined gauge network (Thames, 2018). The success of the home buyout program, made possible in part by Nashville's proactive approach, coupled with permanent investments in river gauges and advanced modeling, both reduces risk by removing people and infrastructure, but also better protects the people and property that remain.

2.4. Sea-Level Rise: Displacement of Isle de Jean Charles Residents

Perhaps the most classically cited managed retreat program, and the first program to address the plight of what are now often referred to as climate migrants in the United States (or "persons displaced in the context of disasters and climate change" by the United Nations Refugee Agency) has been the voluntary relocation of the residents of Isle de Jean Charles, members of the Biloxi-Chitimacha-Choctaw Tribe of Louisiana. The island once covered over 22,000 acres, but as of 2020, only 320 acres (about one-half square mile) remained, a result of both sea-level rise, erosion, unsustainable water management practices, and oil and gas production (Carter et al., 2018; figure 11). The land loss had already driven all but about 85 of the island's 400 inhabitants to other places within Louisiana, resulting in family separation and loss of tribal livelihood and culture (Carter et al., 2018). Although Isle residents and the State of Louisiana recognized the need for relocation for more than 20 years, it took until 2016 to begin the relocation process (Government Accountability Office [GAO], 2020).

In 2016, the U.S. Department of Housing and Urban Development issued a grant of US$48.3 million to the State of Louisiana to implement a voluntary and permanent relocation of the island's residents (Louisiana Office of Community Development, 2020). In 2018, a new site was selected, located approximately 40 miles north of the Isle, encompassing roughly 515 acres that the State has purchased (Louisiana Office of Community Development, 2020), upon which 120 new homes will be constructed (Louisiana Office of Community Development, 2020). In short, the State of Louisiana, with the financial support of the federal government and working with input from the affected residents, is undertaking the first known instance of community-scale managed retreat in the United States.

As this project unfolds, there will be a continued need to learn from and improve upon future managed retreat actions. Research is needed on a range of topics, from environmental and climate justice concerns given the Native-American status of these residents, to infrastructure and engineering approaches that can improve well-being and community connectedness. Studies have already noted that the relocation process has

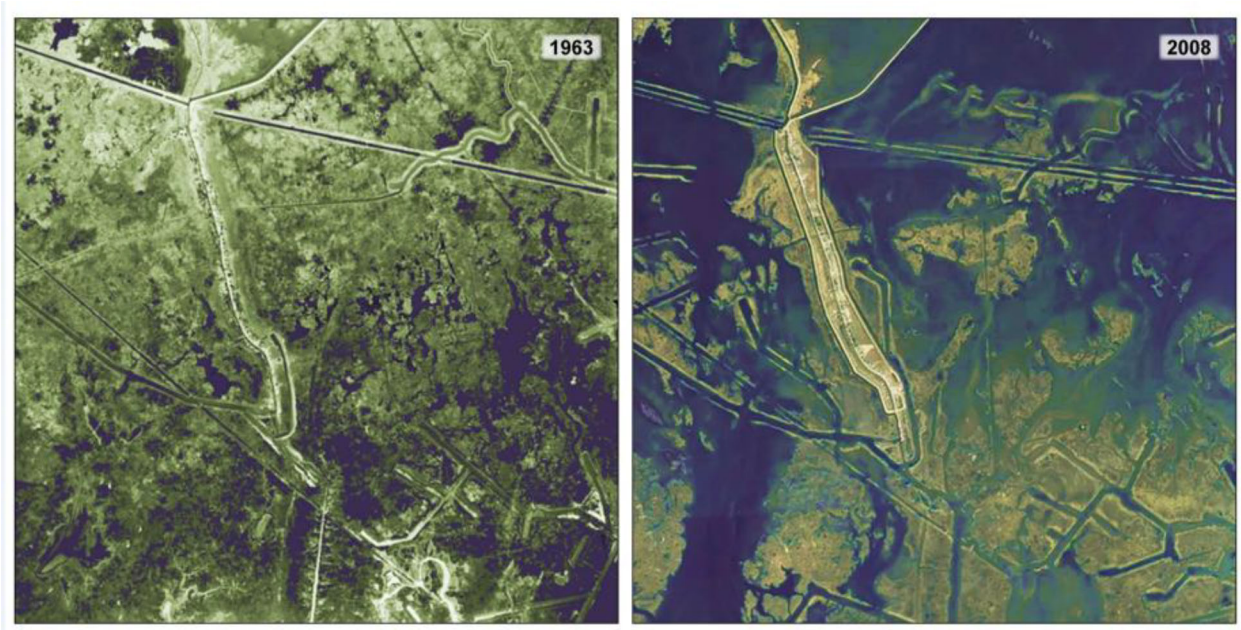

Figure 11. Land loss in the Isle de Jean Charles, Louisiana between 1963 and 2008 (Government Accountability Office, 2020). The sole road connecting the island to the mainland is frequently flooded and impassable. Source: U.S. Geological Survey, GAO-20-488.

encountered challenges and in particular that the process was not well-suited to meeting unique tribal needs (GAO, 2020). One cited example is the complex and confusing mortgage requirements associated with the relocation programs, where tribal residents often have passed a home down through multiple generations without documentation (GAO, 2020).

Indeed, the successes and challenges from the ongoing relocation of Isle de Jean Charles are critical to understand because an increasing number of communities will need to move in the coming years. The GAO has recognized that while Isle de Jean Charles is one of only two U.S. communities (the other is Newtok, AK) that have actively moved forward with permanent relocation in response to climate change, "many more communities will need to consider relocating in the coming decades" (GAO, 2020). The GAO recognized that relocation assistance and approaches have been slow and inadequate, largely because there is no central federal agency with the authority to lead relocation efforts as a resilience strategy (GAO, 2020). As a result, the GAO recommended that Congress establish a pilot program focused on identifying and providing assistance to communities that are interested in moving as a response to climate change.

Federal leadership or authority with respect to managed retreat strategy or relocation can be pivotal to ensuring successful outcomes as climate change impacts worsen; however, that leadership is also critical to reducing the need for substantial postdisaster assistance that is currently the focus of most federal programs. The GAO and others have recommended that federally coordinated, predisaster risk mitigation is necessary to a more effective U.S. response to climate change and to reduce the financial impacts of climate disasters (GAO, 2020). The GAO expressly recommended the development of a climate migration pilot program as a "key part" of a national strategic approach to "target federal resources to the nation's most significant climate risks" (GAO, 2020).

The Isle de Jean Charles case study represents a unique place in managed retreat literature. There are few examples of physical relocation of entire communities in the United States or elsewhere and fewer still where the residents would be relocated to undeveloped land built for the community from the ground up and with their input. Despite available federal and state funding and coordinated federal and state efforts, this relocation effort is still meeting substantial challenges, including how "success" can be measured in a case where an entire indigenous community is permanently displaced from its ancestral

Table 2. Examples of Transformative Adaptation Measure (TAMs; Policy Responses) From Selected Case Studies.

Extreme Weather Event and Case Study	TAM
Wildfire: Camp Fire, California	• Update fire hazard area maps using modern climate data • Update building codes to incorporate modern fire prevention technology into buildings constructed in fire hazard areas • Use updated fire hazard maps to inform emergency response and planning • Consider needed frequency of fire-hazard mapping updates as climate changes
Extreme heat: Maricopa County, Phoenix, AZ	• Cool pavement pilot program to reduce dark surfaces and increase reflective surfaces • Creation of new permanent government agency, the Office of Heat Response and Mitigation, to focus exclusively on addressing extreme heat impacts • Changes to law to govern when utility disconnection is allowed given life-saving potential of air conditioning in high heat conditions
Flooding: May 2010 Flood in Nashville, TN	• Increased, proactive implementation of an existing home buyout program, including notifying residents that their home is in a flood risk area and of their option to sell • Expansion of an existing network of river gauges and improved modeling to enhance flood risk warnings and response
Sea-level rise: Displacement of Isle de Jean Charles residents	• Community-scale managed relocation of human population, including purchase of undeveloped land for relocation of the people and development of infrastructure

homeland. Clearly, this will need to be the subject of substantial research over the coming years, given that relocation of entire communities as a response to climate change is likely to radically increase in the decades to come, but relocation also cannot be the first-line policy response where other strategies may be effective.

3. CONCLUSION

Managed retreat measures, in the nascent literature, have been nearly entirely focused on adaptation strategies that permanently remove, either infrastructure or people, from an existing location (Alexander et al., 2012; Fruedenberg et al., 2016; Hino et al., 2017; Siders et al., 2019). However, rather than focus on the "retreat" aspects of this approach, we emphasize the permanence and transformative nature of such responses. Accordingly, although permanent relocation is certainly a TAM, targeted changes in infrastructure, law, or governance also may be considered TAMs. Changing the vocabulary and thinking around TAMs is critical to inform decision-making that may be more likely to lead to successful adaptation outcomes. This is because the term "managed retreat" and concepts of retreat and relocation are controversial and have themselves prevented effective polices from being implemented due to deeply held negative associations with these terms (Ajibade et al., 2020; Bragg et al., 2021). True retreat or relocation measures may be required in some places, but broadening the literature and vocabulary to discuss retreat and relocation as merely one form of TAM, which include numerous approaches to ultimately protecting human life and livelihood in the face of a permanently shifting climate, may be key to more positive associations with these polices and increased adoption. The case studies presented herein provide examples of transformative change across four climate stressors that are already being adopted.

In addition, managed retreat research and literature has been more robust outside of the United States, and the international work provides an important source of information, data, and perspectives to inform the fast-emerging, but still early discussions, in the United States. For example, Bertana (2020) has examined faith-based narratives of climate change within the context of managed retreat on the island of Fiji. Researchers in the United Kingdom and France have done extensive reviews of adaptation science and discuss managed retreat as a form of "transformational adaptation" (Magnan et al., 2020, p. 167). Robinson (2017) and Narayan et al. (2020) have focused on climate and adaptation efforts, including managed retreat, in Small Island Developing States; others have looked at impacts to small island

communities that are part of developed nations (Barnett et al., 2015). An important area of focus for managed retreat research in the United States has been the small coastal and riverine indigenous communities in Alaska, where erosion, sea-ice decline, and other climatic encroachments have made some villages unlivable. The ongoing and established Alaskan research also serves as an important reference point, especially for U.S. policy makers and researchers (Albert et al., 2018; Bronen, 2015).

Table 2 represents TAMs that have emerged from the case studies discussed herein that could be useful references for other local, state, or federal planners. They are by no means the only TAMs that a jurisdiction should consider when addressing the impacts of climate change but rather are representative of the spectrum of options and creative thinking that warrant consideration based on the unique characteristics of the location in question. Ultimately, a common theme among the TAMs is to change the status quo of approaches toward being proactive, looking to the future as opposed to relying on past experiences related to weather and natural hazards.

The case studies presented herein represent both classical "retreat" programs in response to flooding and sea-level rise (buyouts and relocation) but also more broadly considered TAMs that adopt law, policy, and institutional shifts in government and its approach to governing. These types of TAMs, taken together, can be extremely beneficial from a community livelihood perspective. Despite shortcomings and the need for improvement highlighted by these case studies, TAMs present a new outlook on the human response to climate change and how types of managed retreat can be incorporated into innovative policy solutions. Shifting the vocabulary and study away from notions of "retreat" and toward the types of TAMs, including new governance approaches, that will increasingly be needed in a world with a changing climate may lead to more successful and creative outcomes.

CASE STUDY QUESTIONS

1. What do you think "governance" means as discussed in this article? Describe how each of the four example case studies does or does not provide an example of governance of climate change issues.

2. What role did climate or weather data, if any, play in the decisions made by policy makers in each of the four case studies?

3. Can law or regulations be considered a transformative adaptation strategy? Why or why not?

4. Which of the four cases provides the *best* example of traditional understandings of managed retreat as a response to climate change? Why?

5. Why do you think the phrase "managed retreat" has not been successful when it comes to adapting to climate change? Describe why the strategies represented by the four case studies might be more effective.

6. The second case study examines the increasing instances of extreme heat in Arizona and the resulting impacts on human health and local infrastructure (such as roads). The case study details a number of responses the government instituted to respond to this threat, such as new government offices, new laws, and new pavement construction. Do you think these responses should be considered forms of managed retreat? Do you think the types of responses detailed in this case study would meet the authors' definition of "TAM" (which appears in Section 1)?

AUTHOR CONTRIBUTIONS

Leah A. Dundon served as the primary researcher and writer of this article. Mark Abkowitz contributed research and numerous revisions and editorial direction. Janey Camp contributed research and data, in particular to the flooding case study, and also contributed to numerous revisions and editorial direction.

COMPETING INTERESTS

The authors have no actual or potential competing interest in this work.

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APPENDIX C

Journal: Environmental Research Letters
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Turning "Managed Retreat" Research into Practice Ready Tools: Needed Guidelines to Reach Stakeholders

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I. Introduction

The study of "managed retreat" as a response to climate change impacts has emerged in recent years as an important field of inquiry that is in need of substantial further research and improved understanding—particularly in the United States (Dundon and Abkowitz, 2021; Plastrik and Cleveland, 2019; Hino, *et al.*, 2017; Dachary-Bernard, *et al*., 2019). However, the critical participant stakeholders in managed retreat discussions—often city/county planning officials and community members in vulnerable areas—often do not have adequate access to meaningful planning information or other tools to support decision making. With some notable exceptions, important research in this field that could assist communities is often relegated to academic journals that are not often visited by city or county planners faced with the very decisions this research could inform. Although the realities of research careers often require a focus on publication in prestigious academic journals, more attention is now needed to get actionable research knowledge in the hands of the practitioner.

The need to develop user-friendly tools that direct research information into the hands of stakeholders most likely to benefit from such work is even more urgent than ever: climate change presents current, continuing, and substantial challenges for humanity in nearly every sector of the economy. Many extreme weather events have already increased (in frequency and/or severity) because of our changing climate, including flooding, heavy precipitation, extreme heat, and other climate-induced events (U.S. EPA, n.d.). Among critical infrastructure sectors, transportation is a notable example of the impacts of these events. Transportation planners, local governments, and others responsible for building, maintaining, and even insuring and financing expensive and long-lived infrastructure are keenly aware of the need to adapt. Indeed, there is substantial literature documenting climate change resilience adaptation efforts ongoing around the globe involving transportation and other sectors (Tonn, et al., 2021). Planners now recognize that the risk profile of assets exposed to such extreme weather events has permanently changed. In some localities, adapting in place will not be affordable or even possible, and the only viable option may be to "retreat" or remove the infrastructure asset, and potentially the communities that rely on that asset, to a new, less climate-sensitive location. This adaptation strategy is most often referred to as "managed retreat," but also "transformative

adaptation," "managed relocation," or "strategic retreat" (Dundon and Abkowitz, 2021). Under any name, it is a bourgeoning topic of emerging inquiry, and an area that will need substantial additional study in the years and decades to come.

Several researchers, including the current authors, have documented approaches and case studies to managed retreat that are intended to be useful for considering, planning, and implementing a managed retreat strategy. This work identifies critical issues of social and environmental justice, human behavior, and implementation challenges that represent critical and insightful knowledge (Siders, 2019a; Hanna *et al.*, 2019; Siders, 2019b, Mach & Siders, 2021; Kool *et al.*, 2020; Lawrence, *et al.*, 2020). Research has also demonstrated the importance of a thoughtful and considered approach to communication, which can be the pivotal factor to determining whether a managed retreat policy response succeeds or fails (Bragg, *et al.*, 2021). However, many of these studies are often published for an academic audience and are not often in a form that is most useful for transportation planners and community practitioners.

The approach described herein aims to fill that gap. Drawing on our own research and perspectives of an emerging consensus among managed retreat researchers regarding the most salient issues in managed retreat decision-making, we present a comprehensive Managed Retreat Framework (MRF) intended to convey in a flow chart form key considerations and processes. The framework consists of two sequential components: (1) the decision of *whether* to retreat, and then if a decision to retreat has been made, (2) *how to plan for implementation*.

While the intended audience for the MRF, as described and illustrated, is primarily local transportation planners at the city, town, or county government level, the structure and logic flow is expected to be applicable in many different contexts and could be helpful to a broad and diverse range of stakeholders. While it is not meant to be the *only* decision-support tool applied in any given circumstance, we believe it provides an important and user-friendly means for planners to navigate through this often complex process. Importantly, it is designed to assist planners to identify and potentially strategize around barriers to implementation *before they arise*.

II. Example Frameworks

Figures 1 and 2 depict the aforementioned framework involving the respective decisions of whether to retreat and how to plan for implementation While not every item on these flowcharts will be relevant to every interested party, the approaches represent an adaptable format that can aid communities in considering—and planning for—the benefits and challenges likely to arise when considering managed retreat actions. The steps documented in Figures 1 and 2 were collected and adapted from a wide variety of relevant literature cited herein (*see e.g.,* GCC, n.d.), including case studies (Kool, 2020), but also emerge from the authors' own views and experiences, in particular in working with local and state transportation agencies and municipalities in addressing climate change impacts to infrastructure, and retreat planning and decision making.

Figure 1 represents a framework for early stages of determining the potential for managed retreat as a policy response option to a particular climate impact or stressor. This specific example is

aimed at a decision of whether to move or remove an individual piece of public infrastructure, such as a road or a bridge, but could be easily utilized in a wide range of managed retreat planning scenarios. The framework starts with an assessment of whether the asset has experienced prior loss and damage from extreme weather. *See* Figure 1. This initial understanding is important in determining the potential financial cost to a community of continuing to rebuild in place (Tonn, *et al.*, 2021). If continued or future climate impacts are expected, the user is directed through a series of considerations, including whether adapting in place may be feasible. If retreat needs to be considered, the framework then identifies specific factors (such as equity or cost impacts of a managed retreat decision) that can further inform whether retreat may be appropriate depending on individual circumstances.

If, based on the considerations identified in Figure 1, a decision to consider retreat is reached, Figure 2 can then be utilized to provide guidance to planners, communities, and other stakeholders on the types of retreat mechanisms that may be considered and the planning processes and elements necessary to facilitate a successful retreat strategy. Evaluation of some of these factors may lead a community to reverse its decision to pursue retreat; for example, in the case of publicly owned assets such as roads or bridges, the government may have a legal obligation to upkeep and maintain the asset, including constant rebuilding after storm events despite costs. Figure 2 assists planners to understand possible barriers early in the process, and provides greater potential to develop strategies in advance that may be needed to overcome such barriers.

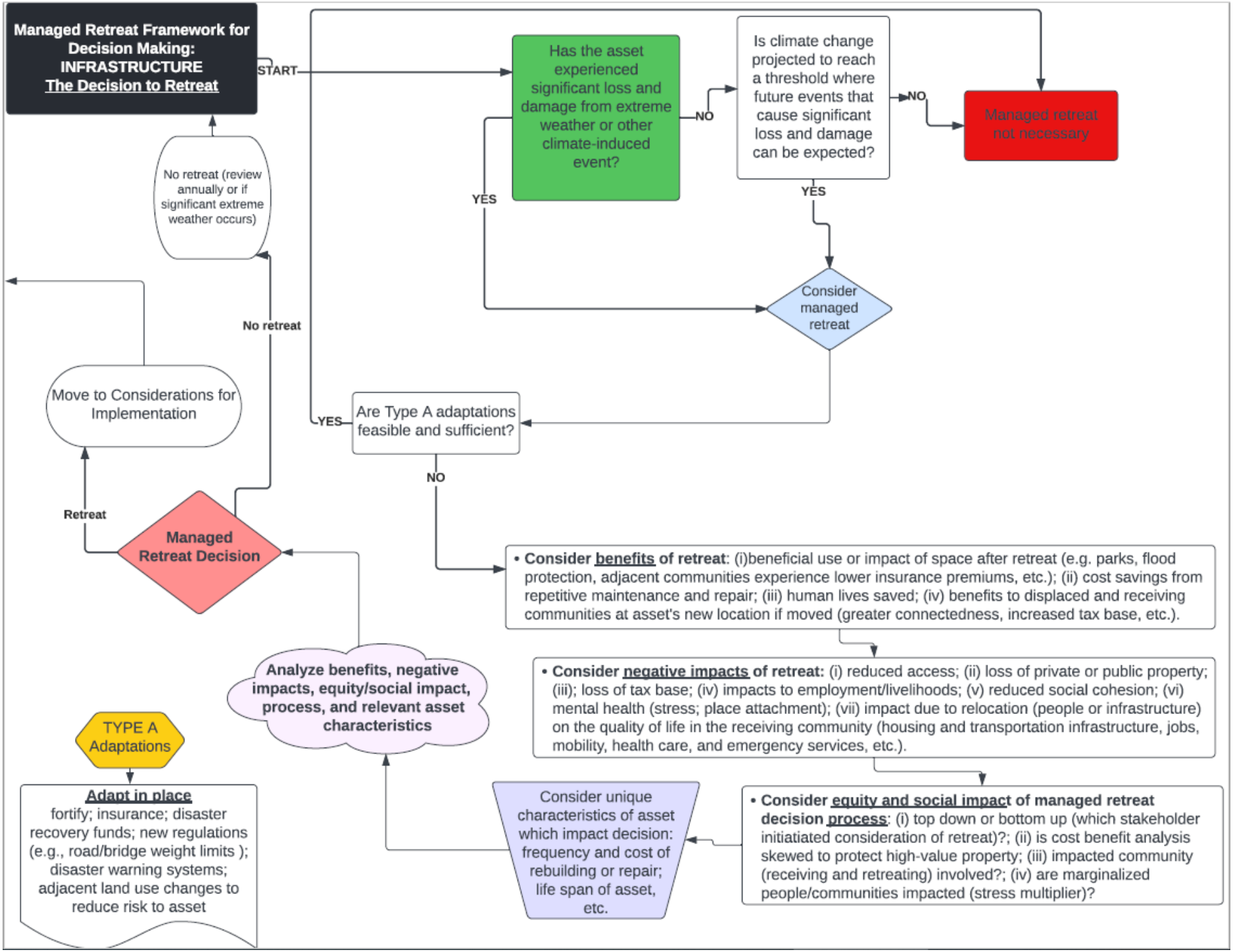

Figure 1 – Managed Retreat Framework – The Decision to Retreat

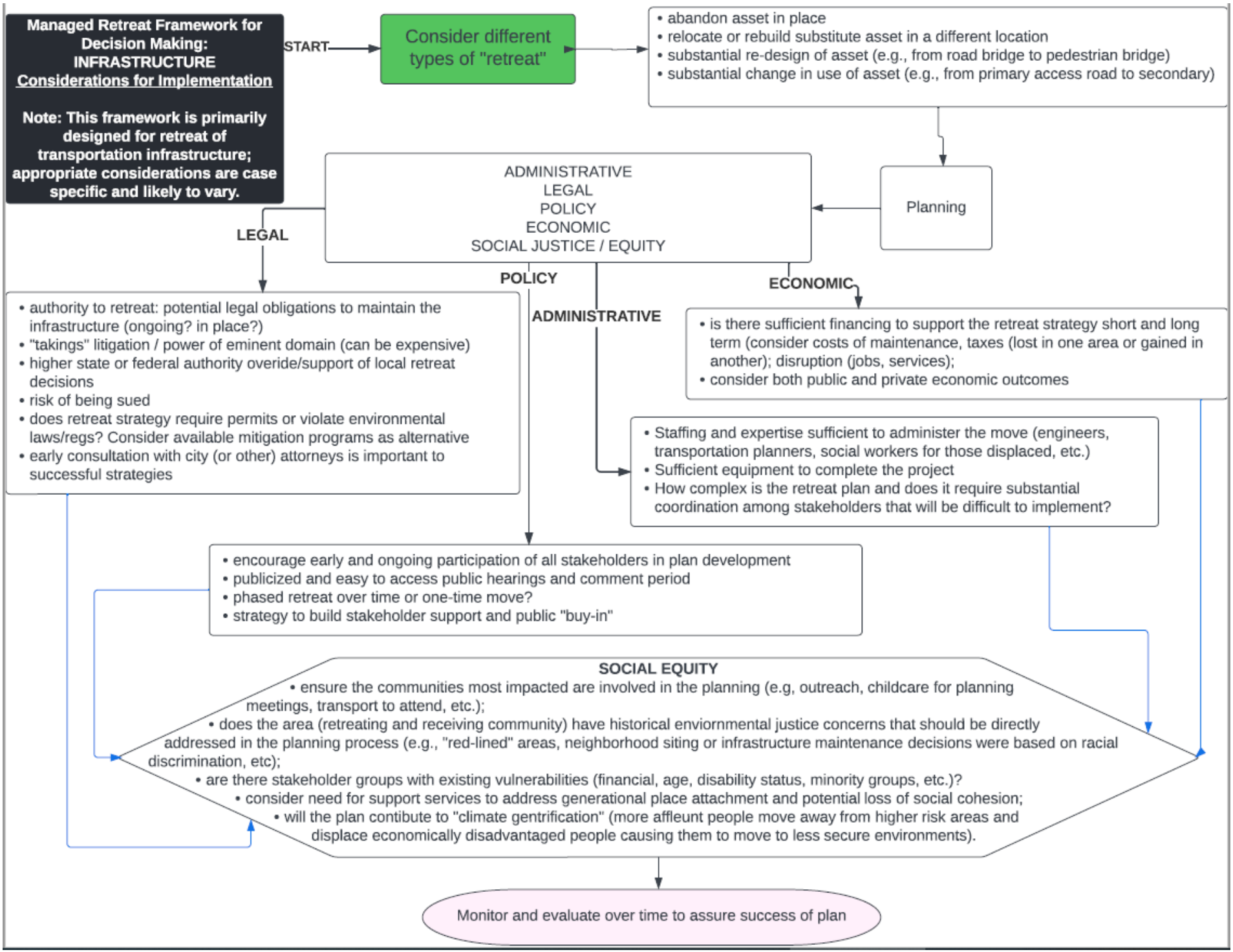

Figure 2. Managed Retreat Framework - Considerations for Implementation

III. Conclusion

While the framework we have introduced is not intended to account for every factual element that a community or planner may address when considering managed retreat, it represents an important effort at synthesizing and disseminating available knowledge in a systematic and structured fashion. The characteristics of different communities, asset types, and exposure levels to different climate stressors will of course dictate the needs and approaches of any particular decision on managed retreat.

Despite critical knowledge emerging in the last 5-10 years, substantial future work regarding managed retreat is still needed. This is true with respect to all facets of managed retreat, including communication methods, likely human responses, and the phenomenon of "place attachment" that can be a barrier to retreat solutions (Agyeman, *et al.*, 2009). Taxpayers bear a huge financial burden of the impact of extreme weather events on both public and private infrastructure—whether directly through increased private insurance premiums or the increased cost of public maintenance or costs of responding to extreme weather events. Managed retreat research is sorely needed to better inform when communities should continue to invest in restoration and when relocation may be the best response.

In 2022 alone, the U.S. experienced over $165 billion in damage from extreme weather events (this is a low estimate because it only includes the total from events that individually caused $1 billion in damage or more) (Smith, 2023). This is a trend that is steadily increasing, in part because disasters are becoming more frequent or more intense due to climate change. Improved methods for identifying costs—both economic and non-economic—and translating them into meaningful and relevant information for community stakeholders can better inform the decision of whether to retreat.

Research is also needed at all scales to inform managed retreat decision making regarding individual assets, to the community and even nation-state level. Relocation of entire communities within the U.S. from Louisiana's Isle de Jean Charles to native Alaska villages has already occurred. Entire island nations in the Pacific Ocean see the livability of their homeland under threat, and some human migration can now be attributed to climate-induced impacts (Zeya, 2022). Society will benefit from increased understanding of how managed retreat can be successfully implemented to improve human livelihoods, and from a continued increase in the development of tools and frameworks that widely disseminate that knowledge in a practical manner.

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Because the focus of this framework is on practice-ready solutions, we would like to especially acknowledge the work of the Georgetown Climate Center (GCC) in developing GCC's Managed Retreat Toolkit (GCC, n.d.), and which informed the development of our Framework. Like the attached Framework, GCC's Toolkit was developed with practice-ready application in mind. After determining which aspects of the attached Framework may be most applicable to a particular circumstance, the GCC Toolkit can serve as an important reference to provide more

detail on key decision points, as well case studies that planners may wish to consult. The work presented in this paper was supported by the U.S. Department of Transportation under Grant Award Number 69A3551747130. The work was conducted through the Maritime Transportation Research and Education Center at the University of Arkansas.

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