Sustainable Adaptive Gradients

Technical Report

Version 2

Sustainable
Adaptive
Gradients
in the Coastal
Environment

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ABSTRACT

Current and future climate-related impacts such as catastrophic and repetitive flooding, intense heat and drought, and sea level rise necessitate a new approach to developing and managing infrastructure. Traditional “hard” or “grey” engineering solutions are proving both expensive and inflexible in the face of a rapidly changing coastal environment. Hybrid solutions that incorporate natural, nature-based, structural, and non-structural features may better achieve a broad set of goals such as ecological enhancement, long-term adaptation, and social benefits. However, broad adoption of these approaches has been slow, in part due to a lack of a relatively quick but holistic evaluation framework which places environmental and societal goals on equal footing with hazard reduction. To respond to this need, the Adaptive Gradients Framework was developed as a qualitative, flexible, and collaborative process to evaluate and potentially select more diverse, typically greener and more equitable, kinds of infrastructural responses. The Framework enables rapid expert review of project designs based on eight metrics called “gradients”; gradients include exposure reduction, cost efficiency, institutional capacity, ecological enhancement, adaptation over time, greenhouse gas reduction, participatory process, and equitable outcomes. These are customizable to the goals of the project and the agency. This technical guide presents the framework and examples of its application, along with resources to enable wider application of the framework by practitioners and theorists.

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1. INTRODUCTION

Our climate is changing. Storms are increasing in strength and numbers; sea levels are rising, and in most parts of the world, days of extreme heat are increasing. It is time for communities to better manage their futures. While we cannot control the weather, municipalities and community groups can build infrastructure to be more resilient. A community or project that is resilient can adapt to environmental, social and economic change. Infrastructure and other resiliency measures can also support current and desirable goals, like improving ecology, equity and participation, and reducing greenhouse gases. The best projects achieve multiple goals, based on the input of community members to prioritize outcomes and processes.

To address the need for a flexible, shared framework for supporting resilient infrastructure decisions, a network of North American and Caribbean researchers, the Sustainable Adaptive Gradients in the coastal Environment (SAGE) network, developed the Adaptive Gradients Framework as a means of improving the visibility and facilitating the discussion of multiple goals for resiliency projects, including social, ecological, and technical aspects. While the original focus of the Gradients Framework was on coastal settings, it can also be applied to non-coastal climate adaptation projects.

This technical report is designed to help agencies and communities understand how proposed projects and infrastructure should be evaluated. One goal of this report is to encourage communities to consider greener infrastructure choices by illuminating the range of values that projects serve. Every location, group of people, and town has its own set of characteristics that will need to be taken into account as the evaluation process is followed. The process requires cooperation, creativity, time and work, but the end will result in the information needed to make the best decisions for a project, community and the environment.

2. BACKGROUND THEORY

The SAGE Gradients Framework was developed in response to recent coastal disasters which highlighted the importance of creating more resilient coastal areas. Climate change is exacerbating the impact of these events, along with the increased concentration of people and assets in coastal urban areas. While some impacted areas will be abandoned through retreat, others will be rebuilt, and new lands will continue to be urbanized, bringing opportunities to reenvision infrastructure designs.

The stakes are high—one study found that protecting seaports across the globe from climate change will require about 49 million metric tons of concrete alone [1], if traditional construction methods are used; globally, 271 million people are at risk from coastal flooding, and that number will rise to 345 million by 2050 [2]. The risks for small island developing states are particularly high [3,4], as 2017 hurricanes Irma and Maria in the Caribbean have shown.

All of these threats and concerns due to climate change are leading communities to reconsider approaches for environmental protection. More socially and ecologically beneficial resiliency actions are necessary given the continuing impacts of climate change and the interdependence of ecosystems and social-ecological resilience [5].

2.1 Gray green and hybrid infrastructure in coastal communities

Recent years have seen significant advances in developing a wider range of options for coastal restoration and protection [6], and projects now include approaches that go beyond traditional infrastructure. The range of choices includes natural, nature-based, and non-structural measures such as living shorelines [7], revised building codes, zoning, and community disaster preparedness [8].

Here, we define hybrid designs as those that include non-structural interventions such as zoning changes and local capacity building alongside green and grey approaches [8,19,20]. Current research suggests that hybrid projects may provide the greatest potential for improving resilience to climate impacts [9–12], with different components working together to create mutually supportive conditions.

When compared to traditional methods, this broader portfolio of coastal adaptation options can achieve social and environmental objectives alongside exposure reduction, and may achieve change across multiple criterion [13,14], as recommended in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report [15]. Despite the strong research into theory and design innovations in coastal adaptation, adoption of hybrid projects has been slow, albeit increasing [16].

One of the challenges of hybrid approaches is that they require holistic consideration of biophysical, engineering, economic, legal and sociocultural components. These projects bridge across discipline-specific practices and terminology, posing logistical and methodological challenges for policy-makers and designers [17]. An interdisciplinary approach that utilizes a diversity of expertise, experience, and perspectives across multiple stakeholders from the practitioner, academic, and public domains would assist in overcoming this barrier.

Figure 2.1 synthesizes language used across several disciplines around types of coastal resilience measures, particularly engineering, policy, and landscape architecture, to ensure interdisciplinary accuracy in conversation. [8,19,20].

NATURAL AND NATURE-BASED (or "Green")

Ecosystem-services based approaches which may be preserving long-standing natural processes or creating/recreating such systems through human intervention

EXAMPLES: Dunes and Beaches, Vegetated Features, Oyster and Coral Reefs, Barrier Islands, and Constructed wetlands and floodable parks

Sand Dune Replenish-ment, post-Sandy

New York City, USA
SAGE Field Trip, 2014 Workshop

STRUCTURAL (or "Grey")

Designed to decrease shoreline erosion or reduce coastal risks associated with wave damage and flooding

EXAMPLES: Levees, Storm Surge Barriers, Seawalls and Revetments, Groins, and Detached Breakwaters

Groins for wave reduction

New York City, USA
SAGE Field Trip, 2014 Workshop

NONSTRUCTURAL

Modifications in public policy, management practices, regulatory policy, and pricing policy to achieve resilience goals.

EXAMPLES: Floodplain Policy and Management, Increasing coastal building setbacks, Inter-agency recovery planning, Community organization for disaster safety, and Flood insurance rate management

Emergency Housing Planning shipping container prototype

New York City, USA

SAGE Field Trip, 2014 Workshop

INTEGRATED (or "Hybrid")

Draws from the full array of coastal risk reduction measures, considers the engineering attributes of the component features and the dependencies and interactions among these features over both the short and long term with a focus on effectiveness.

EXAMPLES: Combinations of Examples Listed Above

Replenishing Sand, Riprap, and Planting Mangroves

Palisadoes Tombolo, Jamaica

SAGE Field Trip, 2015 Workshop

TRANSFORMATIVE

Recognized through its aspirations for broader social and ecological change. Portfolio projects that integrate effectiveness goals along with local benefits, ecological improvement, and a just and transparent process.

EXAMPLES: Coastal defenses providing locally desired play space - Renters insurance subsidies along with integrated infrastructure - Hybrid design of dune nourishment, boardwalk development, removal of at-risk structures, local fisheries protection and shoreline access developed through participatory process.

Boardwalk, replenished sand & costal vegetation for tortoise habitat, and aesthetics for hotel redevelop-ment

Barbados

SAGE Site visit, 2016

Figure 2.1: Defining infrastructure intervention types

2.2 Current frameworks and challenges

The IPCC frameworks on risk provide a baseline language for resilience planning [22]. The IPCC finds that disaster risk is based on physical conditions amplified by anthropogenic contributions to climate change, using socially framed impact parameters. More precisely, risk from climate change is defined as a function of hazards, exposure and vulnerability.

Hazard is the climate-related physical event, including storms, droughts, landslides, increased disease vectors, etc., with climate change as an exacerbating factor. *Vulnerability* is defined as the level of susceptibility to harm, while *exposure* is the people, assets, and ecosystems that may be affected by a hazard event.

Applying these definitions to both coastal and non-coastal settings, the climate event, for example a hurricane or fire event, yields this basic form of analysis. The analysis then characterizes the seriousness of the hurricane or fire event (the hazard); how many people, which ecosystems, and what value or social importance of buildings and other assets will likely be affected (the exposure); and how well the systems and people will be likely to recover (the vulnerability). At the local level, projects may reduce hazard through such actions as reducing wave height and energy (coastal setting); or prescribed burning (fire event setting). They may also ameliorate exposure by moving or protecting the people, species, and ecological, social, and economic resources in at-risk areas. This reduces vulnerability [23]. Other definitions of risk take a more probabilistic approach, with risk being defined as the probability of an event (the hazard) times the consequences (the vulnerability [24, 25].

Structural/grey infrastructure interventions, as the de facto baseline for many projects, are often well suited to addressing exposure. These traditional grey approaches may, however, also encourage maladaptation, in which projects intended to improve resilience also increase greenhouse gas emissions, burden the most vulnerable, or create other social issues while pursuing the stated mission (26). Particular organizational norms may strongly orient to structural interventions, such as the use of benefit-cost analysis for Environmental Impact Statement (EIS) by the U.S. Environmental Protection Agency (EPA) and/or structured decision-making practices used by the U.S. Geological Survey for environmental management [27,28] or the US Army Corps of Engineers. Even when agencies seek to expand beyond these traditional measures (see, e.g., [16]), they may be challenged by the complexity of social and environmental dimensions of resilience such as the technical challenge of an uncertain climate future [29], and difficulty in effectively addressing aspects of justice and public participation in decision-making under complexity [30]. As climate change impacts increase across the globe, well-established prescriptive approaches for identifying initial or preferred protection solutions [31] have been criticized for being too restrictive, often failing to encompass socioeconomic realities and plurality in stakeholder values and objectives [32]. This leaves prescriptive, unidimensional approaches inadequate for long-term resilience [33].

2.3. Barriers to innovative infrastructure

A range of barriers to the adoption of more innovative resilient infrastructure and adaptation strategies have been identified including longstanding organizational norms, path dependence, lack of information, and challenges in inter-disciplinary communication and information (36).

Path dependence

Among the barriers for uptake of infrastructure innovations is that most institutions experience path dependence, which Mathews et al. [34] define as "situations where institutions become used to responding to specific issues and are consequently reluctant to respond to new imperatives when they manifest". Minor incremental change is easier than major shifts in organizational culture. Deeply held social norms such as a preference for knowledge stability (comfort in knowing what we know, rather than the challenge of admitting what we do not know) and predictability may work against the kinds of innovative and novel practices required for climate change adaptation planning and policies [35].For green infrastructure, path dependence tends to lead to adding multiple goals as secondary considerations within existing planning frameworks, rather than undertaking more substantive change [34]. Path dependence exists at the project scale as well. Once design alternatives are identified and significant dollars are spent on modeling those alternatives, an organization is less likely to consider significant changes to a design. To overcome these issues, it may be helpful to influence processes early in the development of a project, before significant resources (financial, as well as institutional and reputational) are invested in a particular, and likely more traditional, approach.

Challenges in information and communication

Lack of information is a critical problem, as planners and decision-makers are often asked to implement adaptation measures without adequate information about local-scale impacts, vulnerabilities, or the long-term consequences of an intervention [37]. This is particularly challenging in situations which lack officially accepted projections or institutional mandates for using projections that do exist [38,39]. The breadth of disciplinary knowledge required for hybrid designs is another informational challenge; a decision framework that supports hybrid designs will need to supplement typical engineering expertise with ecological, social, land use, policy and participatory process knowledge.

2.4. Co-Benefits and holistic hazard mitigation planning

An important response to these challenges has been to complement traditional engineering effectiveness and benefit-cost analysis with a focus on the benefits of projects that go beyond their contributions to exposure reduction, central as that remains (see, e.g., [40]). The term co-benefits is defined in some contexts as complementarity between mitigation and adaptation [41]; here, we use a broader definition that describes how project outcomes achieve locally desired goals outside of primary hazard reduction, such as health benefits from particulate reduction through urban greening, provision of locally desired public space, or [42] support of local industry through improving ecological resilience.

A just distribution of benefits is an important theme in research and practice of climate adaptation because less-resourced communities tend to experience greater environmental risk [43,44]. Given the challenges and conflicting priorities facing local governments, it can be politically and practically helpful to publicly and clearly define these anticipated co-benefits [45].

Based on the current best practices, infrastructure planning and evaluation should incorporate concepts of resilience and vulnerability [46–48], address climate adaptation [36,49], establish indicator systems [50], and utilize monitoring and assessment as integral to the project [51]. A more inclusive process may help communities make better infrastructure decisions [52]. It is also good practice to include local knowledge of biophysical, socio-economic, and community components of resilient infrastructure, at both local and regional scales [53]. This local knowledge helps communities find solutions that work well for their particular needs.

2.5. Gradients – the intellectual construct

Many natural processes exist along a continuum that can be conceptualized as gradients. Gradients describe the range of conditions in a particular system, placed along some scale (e.g. temporal, spatial, bi-functional, etc.) that will allow comparison across cases [21]. For instance, climate tends to vary along a longitudinal gradient from hot, moist equatorial regions to cool, dry polar regions and historically, biological systems are fairly well adapted to the temperatures and weather patterns along this gradient. However, this adaptation is being challenged by climate-induced changes, such as droughts and extreme weather events. Many regional social-economic characteristics can be conceptualized along gradients as well, such as population density, income inequality or population health. Using the lens of gradient continuums for natural and socio-economic processes and characteristics may support a more nuanced and locally-sensitive analysis and solution-generation for climate impacts, as compared to more binary approaches.

2.6. Summary

Despite a portfolio of adaptation measures to choose from, practitioners may feel left without the resources necessary to confidently make decisions, particularly for innovative and complex projects. A structured, generalizable facilitation tool for project assessment and the development of resilient infrastructure could be used early in the decision process in order to clearly identify co-benefits, integrate a range of disciplines, facilitate a range of technical and social objectives, and promote a transparent process with the potential for high levels of stakeholder participation. The Adaptive Gradients framework uses the gradient construct as an intellectual foundation by suggesting that different aspects of resiliency can be evaluated along sliding scales. These observations underlie the Adaptive Gradients Framework that is proposed in this report.

3. GRADIENT ANALYSIS

Eight components capture the various goals and requirements of a good resiliency project. We call these ‘gradients’ to highlight that they are not binary items, but instead occur along ranges of values. Each of the eight gradients provides an important element for evaluation of a resiliency project or proposal. Different projects will have slightly different questions for each gradient, based on the project and the proposed interventions.

The gradients and their relationship to infrastructure projects is summarized in Figure 3.1. Resilient infrastructure protects communities from current and future hazards by reducing exposure while achieving multiple goals. Emerging practices focus on hybrid projects, which may include green (ecosystem based), grey (traditional built infrastructure), and non-structural (zoning, building codes, governance) components. The Adaptive Gradients, shown as the inner wheel, summarize the various dimensions of project success. Outcomes can be measured by

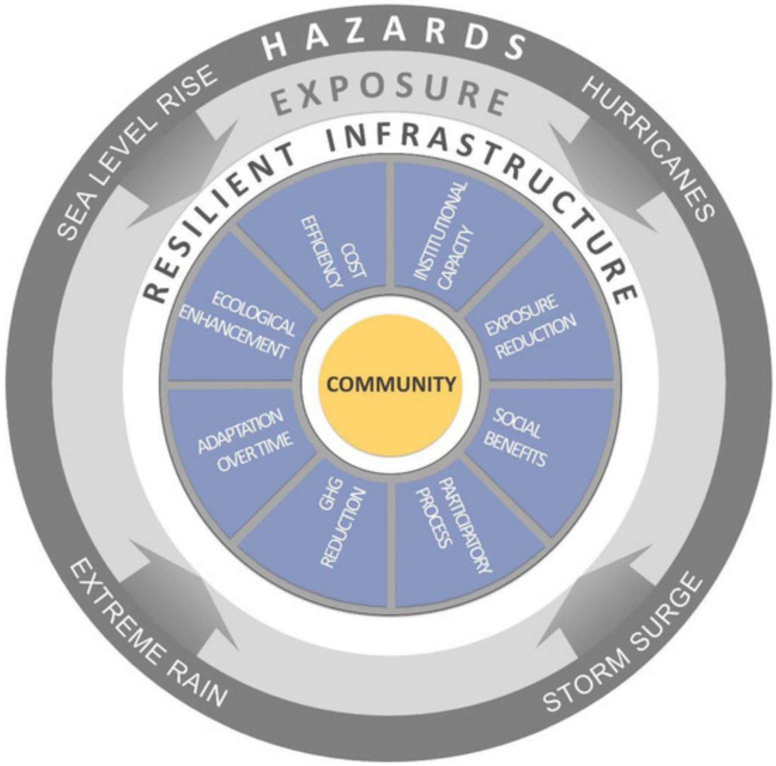


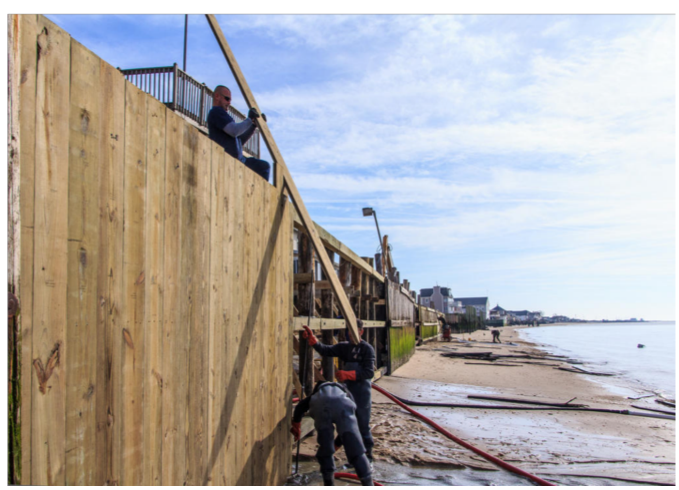
Figure 3.1: Adaptive gradients as dimensions of holistic project assessment

contributions to exposure reduction, institutional capacity, cost efficiency, ecological enhancement, adaptation over time, greenhouse gas reduction, participatory process, and equitable outcomes.

Evaluation across all these measures will encourage adoption of more complete and community-appropriate resiliency interventions, both currently and as climate changes. Applying the Adaptive Gradient Framework is further explained following the discussion of the individual gradients.

3.1. The eight gradients

Exposure Reduction



- *How effective is the design likely to be in reducing risks to the humans in the area, to the local ecology, to local businesses?*
- *Does the project achieve its technical/engineering goals?*

Exposure reduction can be defined as the ability to successfully reduce impacts to at-risk populations or assets when a hazard occurs. Exposure reduction is often the primary goal of infrastructure projects evaluated with existing engineering methods. The amount of exposure reduction will also be relative to the assets (population, buildings, etc.) at risk. Project proposals that are highly rated on this gradient are judged to be technically likely to reduce the impact of hazards.

Some factors that are particularly important to consider for the Exposure Reduction category include how well the project design will function under different kinds of risk events. If the project is using built infrastructure such as jetties or seawalls, was consideration given to whether these hardened structures would increase vulnerabilities or other problems such as erosion to adjacent shorelines beyond the immediate project area?

Cost Efficiency

- *What are the costs involved?*
- *How do they compare to other options?*

Actions taken need to demonstrate efficient use of funds and resources, and return on investment, typically measured through standard or extended benefit-cost analysis. It is important to consider both construction and maintenance costs in this category. The incorporation of innovative funding practices like climate finance and green financial institutions may increase cost efficiency when compared to traditional loans and financing options. A highly rated project will represent a good/low-cost use of money from sources that suit the local situation.

If the information is available, a reasonable measure is whether the other approaches to the problem would cost more, or less, to achieve the same goals – in other words, does the green infrastructure solution cost less to build and maintain than the traditional grey option? Some green infrastructure, such as living shorelines, may have lower maintenance costs than grey infrastructure, as the reefs, dunes and marshes have the potential to improve and adapt with time. Green infrastructure is not without maintenance cost, however, as regular monitoring, waste removal and replanting are often required.

Institutional Capacity

- *Does the group who will plan, build and maintain the site have experience and the personnel to accomplish the project goals?*
- *How will the project be funded through the planning, implementing and upkeep stages?*

Projects that are highly rated on this gradient will be a good match to the responsible agency's ability to both fund and maintain the project. We define institutional capacity as the match of the proposed project to governmental or non-governmental strengths, attributes, and resources [59,60]. A strong match of institutional capacity to the particular challenges of the project being evaluated will bring a high rating on this gradient. For example, a long-standing and well-funded NGO with construction experience and community connections to do long-term maintenance would likely achieve a high rating.

During the design and construction phase, some factors to consider in this gradient include the experience of the design and construction team(s), their success rate with similar projects, and the diversity of the skills sets on the team(s). Also important to consider are how well the project team is going to work with local, regional and national level governments to facilitate the permitting process, to ensure that project designs will be well-received and are likely to receive regulatory approval. Partnerships with other local companies, NGOs, and academic institutions may be able to provide help with data collection and monitoring or input on design and implementation to facilitate a successful project. Post-construction institutional capacity matters as well.

In some situations, an important issue is the ability of the proposed group to fund the project; for instance, if an agency is near its bonding capacity and the project would excessively increase debts, the institutional capacity may be rated as low.

Ecological Enhancement

- *Does the project protect or regenerate a natural area?*
- *Does the project create a natural area that will enhance the local ecology?*
- *Does the design utilize native species and/or support other indigenous species?*

This gradient considers how much ecological "uplift" or improvement a project is going to achieve. Projects should be evaluated on how effectively they support or improve the health of local ecosystems. Analysis of this gradient is likely to vary depending on site and regional conditions—rural areas typically offer greater opportunity for ecological preservation due to low development density, while urban areas offer increased potential for innovative or resource-intensive solutions that support remaining coastal habitats. Additionally, it is important to balance the anticipated long-term ecological benefits with any negative construction impacts to score the overall ecological enhancement of the project. Destruction of coral reefs during construction, for instance, would be a significant reduction in scoring regardless of constructed features. If an area has lost beach or wetland habitat and the project aims to restore as much or more habitat than the amount lost, then this project will have an overall ecological benefit to the area.

Average rated projects are expected to contribute to sustaining the current ecology, while highly rated projects are expected to improve local and regional ecologies over the long term. Project design teams which include ecological expertise in order to ensure that ecological enhancements occur and to be able to accurately measure these enhancements in comparison to baseline (pre-project) conditions will likely be rated more highly.

Adaptation over Time

- *Do project specifications include projections of local climate change over the life of the project?*
- *Will the project, including the proposed planting species, respond well to the changing climate?*
- *Are there plans and funds available for testing how well the project is doing?*

Solutions should be effective over time, as social and particularly climatic conditions change. This can be conceptualized as adaptation pathways [62,63], creating windows of opportunity for matching infrastructural needs to emerging conditions [64]. A coastal dune system may become more effective at hazard reduction over time as plantings grow, for example, while a seawall may become less effective if sand is scoured from its base over the years. One identifier for adaptation over time is whether the design specifically considers future climate in its specifications. Examples include requiring wider setbacks from the shore now in expectation of future sea levels. Solutions may focus on flexibility over time as conditions change, such accommodating flooding now and planning for retreating from the shoreline as sea levels rise, or designing structures in which the mechanicals can be moved up a floor as needed.

Adaptation over time does not necessarily mean getting it right the first time, but instead having regular monitoring to identify successes and failings, and funding to implement adaptive management as needed to assure that the project functions well despite landscape and socio-economic changes. Plans for monitoring and assessment will support this gradient, particularly if those plans are binding and properly funded. Consideration of projected population and land use changes is equally important to consider in resilient designs. Thus, a project that explicitly considers climate and socio-economic projections, builds in flexibility or technical capacity to match expected future conditions, and/or enables flexible responses to future changes would receive a high score for adaptation over time.

Greenhouse Gas (GhG) Reductions

- *Do the construction materials require significant emissions to produce?*
- *Will the operations help minimize future greenhouse gas emissions?*
- *Does the plan involve vegetation that will help sequester carbon?*

Projects can be evaluated on whether they represent more or less embodied energy and/or carbon sequestration. Embodied energy is considered to be the sum total of energy used to extract or mine raw materials, manufacture the raw materials into a product, and transport that product to market, while carbon sequestration means the long-term storage of carbon in plants, soils and the like. Typically, concrete has a high embodied energy because it takes a great deal of energy to produce, while living shorelines have low embodied energy and also provide a carbon sink.

As another example, plantings in general and coastal wetlands in particular tend to sequester carbon, so project designs that include a substantial amount of living material will usually result in fewer GHG emissions. Projects can also be evaluated on whether they provide long-term energy efficiency, such as including wind turbines in a design. General principles of sustainability that are important to the specific locale and group, such as use of local or recycled material, can be considered here.

This gradient encourages intention in design, so that GHG-reducing strategies are more readily adopted into adaptation practices as they scale upwards over time. Currently, few projects include explicit GhG calculations. Including explicit discussion of GhG in the design or the request for proposals will contribute to higher ratings on this gradient, as will a lower overall accounting of greenhouse gases, associated with the project's construction and operation.

Participatory Process

- *Are all people in the community welcome and encouraged to take part in the planning and design of the project?*
- *Is the decision-making process transparent?*
- *Has community input changed the design of the project?*

A participatory process evaluation asks whether the process was transparent, who was included in the decision making, and whether participants had enough power in the process so that their perspectives made a difference in the final designs of the project [65,66]. Diverse groups should be engaged, including those who may not as readily come to community meetings such as minority or lower-income populations [68–70].

Factors to include in evaluation of this gradient are whether multiple mechanisms of engagement were used before, during, and after the project implementation, and, to the extent that it can be determined, the level of enthusiasm of the participants and their assessment of the inclusivity of diverse perspectives and consideration of stakeholder goals. Typically, if a project is about the same before the participatory process as after, the process may not have been genuine and substantial.

A high ranking on this criterion will come from having processes that included the diverse communities affected by the project, a strong institutional history of engaging diverse publics and directing projects toward achieving expressed stakeholder goals, and a demonstration that the public participation and expressed stakeholder goals changed the design of the project.

Social Benefits

- *Do project benefits go to less-advantaged populations?*
- *Does the project create jobs, health benefits, safety, or other locally desired outcomes?*

This category addresses both distributive equity and co-benefits. Regardless of participatory process, the actual or anticipated outcomes of a project can contribute to a more equitable and fair distribution of benefits and costs and may redress old harms. Conversely, projects can have unintended negative distribution of consequences, thereby continuing patterns of injustice [39,71]. Highly rated projects should appropriately distribute benefits and costs and build a more equitable society through improving the position of those most affected by economic and environmental injustice [72,73].

A particular concern is that climate risk is unevenly distributed, as is the ability to pay for protection and recovery from hazard. Thus, projects that are scored highly in this gradient should benefit community members in historically disadvantaged groups. They may provide indirect social community benefits, such as jobs, recreation opportunities, and healthy accessible environments for a broad population. Specific evaluation of the co-benefits of a project will help to operationalize this issue—are there clear advantages, such as recreational access or improved air quality, for disadvantaged populations? If the investment is likely to increase property values and thus has the potential to bring in new development pressure, has consideration been given to gentrification possibilities?

3.2. Gradient summary

The criteria below (Table 3.1) provide a starting point; however, SAGE Gradients can be adapted and weighted for the relative importance of that gradient to the specific programs' goals. Rubrics can be collaboratively developed for each gradient to allow for consistency in scoring. For an example of SAGE gradient rubrics, see Appendix 7.2.

Table 3.1: Summary of the 8 gradients

GRADIENT	GRADIENT DEFINITION
Exposure Reduction	The technical or engineering components of the project that reduce the consequences of hazardous event on human, ecological, social and economic resources.
Cost Efficiency	Positive benefit-cost outcomes. Least-cost or low-cost solutions.
Institutional Capacity	Project development and long-term management/maintenance requirements suit the organizational capacity of the responsible parties. Funding methods appear suitable for the host agency.
Ecological Enhancement	Project preserves and supports the long-standing ecology of the area or creates/mimics/replaces native ecological systems.
Adaptation over Time	Expected ability to respond to a changing climate as well as other social, economic and ecological variation over time, either as a function of design or through anticipated monitoring and assessment.
Greenhouse Gas Reduction	Project will minimize current or future greenhouse gases, including low embodied energy, long-term efficiencies, or carbon sequestration. General sustainability of materials used.
Participatory Process	Community involvement and public transparency in planning, design, and implementation of the project; whether participation changed project plans.
Social Benefits	Project achieves justice goals, often measured by benefit to disadvantaged communities. Project provides co-benefits to local communities such as jobs, public health, or other locally desired outcomes.

4. METHOD

The philosophy behind the scoring process is that knowledge is built collaboratively and through shared development of understanding. Scoring is done by the whole team on all gradient categories to enable discussion about differences in evaluation. The application of the gradients will vary based on the professional background and values of individual panel member responding to the individual site, which is why a team approach is necessary. It may be helpful to have individuals do their own scoring first, and then to discuss those ratings collaboratively to come to a consensus evaluation. Confidence in analyses is increased with multiple iterations of scoring and discussion, helping to create a consistent scale interpretation across disciplines and individuals. Evaluations are descriptive, qualitative, and highly contextual, which is why we believe that non-numeric ranking is best (e.g., ‘low’ to ‘high’). A low score in some categories may be acceptable in certain cases, depending on project goals and stakeholder mission. *Please refer to the underlying research article by Hamin et al (2018) for more on the methodology.*

4.1. Implementation of the Adaptive Gradients Framework

Based on our pilot tests of the framework, we envision that an agency or city using the Adaptive Gradients process for a proposed site will proceed as follows:

1. ***Form an Evaluation Team*** to begin evaluating a proposed or built project. Evaluation teams will include experts from a range of disciplines, such as a coastal ecologist or a landscape architect, but they should also include representatives of the affected communities. If the project involves a Native American historical site, for instance, be sure to include a tribal representative. If they impact a neighborhood, be sure to include a representative or two from the neighborhood association.

2. ***Team collects relevant information*** such as a project proposal and basic background information on the site and community. If an Environmental Impact Statement or similar reports have been done, these will be useful. The basic information is organized along the gradients and is made accessible to all team members. Once all of the information is collected, the group should meet and look through the files. The information will always be imperfect, and the team should decide together what is good enough for the project goal. Optional: ***Develop a scoring rubric:*** Teams can use the definitions provided above, or can customize the decision criteria to suit their specific situation. Either way, the team should define how they will define success for the eight gradients. Examples of Gradient rubrics can be seen in Appendix 7.2.

3. ***Pre-scoring*** is conducted by each member of the panel based on case study materials (see Table 4.1: Sample scoring sheet). The rating system is intentionally kept simple and qualitative: 1= low; 2= medium; 3= high;.5 = if something in between.

Table 4.1: Sample scoring sheet

8 Gradients	Team Member 1	Team Member 2	Team Member…	Average Score	Comments
Exposure Reduction					
Cost Efficiency					
Institutional Capacity					
Ecological Enhancement					
Adaptation over Time					
GhG Reduction					
Participatory Process					
Social Benefits					

It may seem surprising to have the first round of scoring done before the site visit, but our experience suggests that this allows the team members to be fully cognizant of the overall proposal and to identify their own questions that need to be answered at the time of the site visit

Note that sometimes it can be helpful to reverse the order above for rubrics and pre-scoring and have individuals do their own scoring first, and then discuss what each person weighed in evaluating each gradient. The group might then decide to specify a shared rubric, or they could decide to each keep their own individual definitions while doing combined scoring. In this way a more grounded scoring process that reflects the particular situation may result.

4. ***Site visit*** will include a discussion of site conditions, meetings with stakeholders, a review of the proposal with knowledgeable sponsors, and discussion amongst team members to share perspectives.

5. ***Meetings with stakeholders*** may be possible to do remotely, or to identify the interests of stakeholders through records of public hearing if there is a good existing record and time is tight.

6. ***Panelists discuss their preliminary scoring*** of the project to highlight differing perspectives; individuals may choose to change their own scoring based on the discussion. While team members can change their individual scores as the result of team discussion, consensus is not the goal – it is appropriate that different people score items differently. Any needed further information is gathered

7. ***Re-ranking*** of the case study by individual panel members based on new information and collaborative discussion of results. A final score or score range for each gradient is agreed upon by the group. Where consensus on a score is not reached, the range of scores that individual panel members endorse is included in the final report. The group can score different scenarios of a proposed project to see how the project's resiliency changes depending on planning and design.

8. Finally*, **results are placed into the 'spider diagram'*** (Figure 4.1), a simple visual summary which helps inform policymakers regarding different policy goals achieved by different proposals. The wider the web, the higher the resiliency of the project. Using the spider diagram, people can see the strengths and weaknesses of the project.

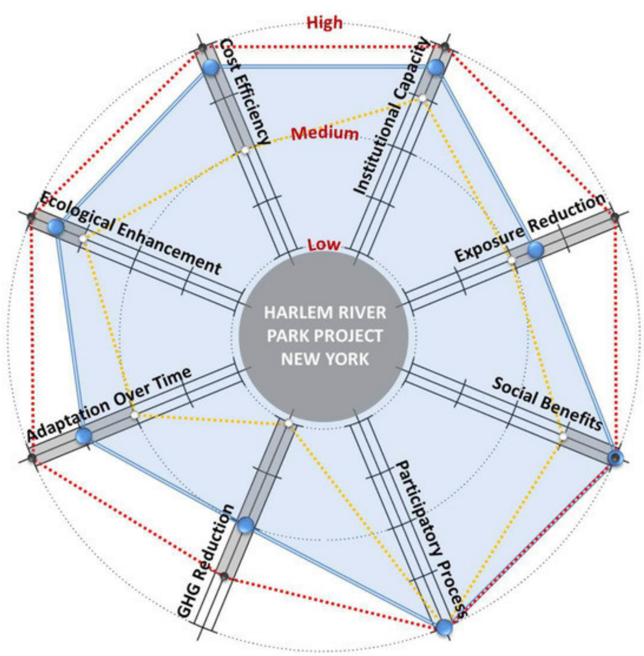


Figure 4.1 Spider Diagram by Yaser Abunnasr

9. ***Use the spider diagram and a brief write-up*** of the research and conversation that went into scoring to educate the decision makers and the community involved. It can be helpful to write up a one-page summary to share with decision-makers, including your spider diagram summary of various proposals.

An optional step is for the evaluating team to ***make recommendations*** *f*or improving the project based on the analysis done in the steps above.

4.2. Portfolio approach

Smaller projects may have difficulty maximizing all the SAGE Gradients. Instead, it may be helpful for an agency to review their overall portfolio of projects compared to the Gradient goals. With a portfolio approach the goal is to maximize the portfolio of projects instead of attempting to have perfect scores on each project (Figure 4.2).

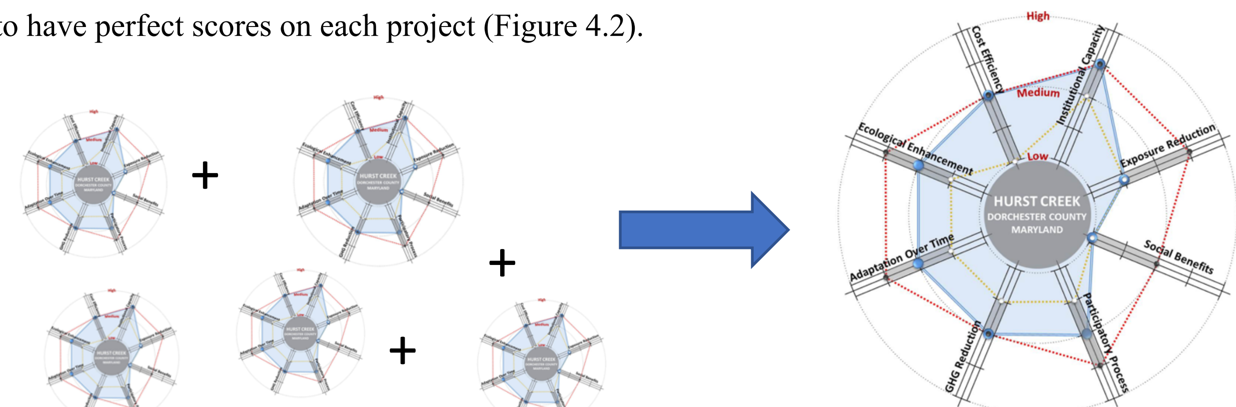


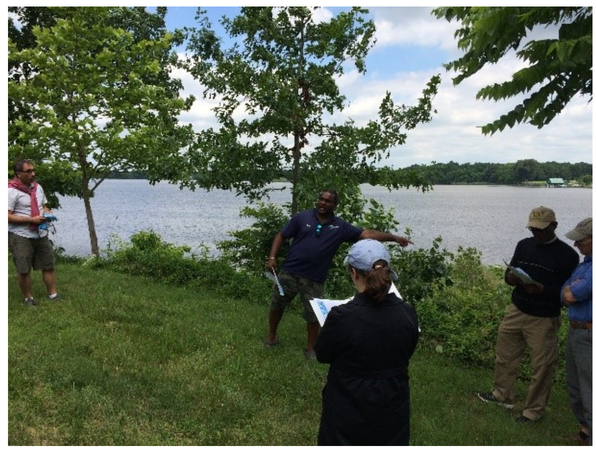
Figure 4.2: Portfolio Approach

An example of a portfolio approach might include:

- Develop rubrics for each SAGE Gradient to allow for consistency in scoring.
- Weigh each of the SAGE Gradients for the relative importance of that gradient to the specific programs' goals.
- Develop a case study for each project under consideration or implemented.
- Score each case study using rubrics and apply weights to develop aggregate score.
- Aggregate different combinations of case studies to determine which combination maximizes SAGE gradients or
- Assess for each case study and the portfolio opportunities to increase the SAGE gradient score.
- There may be projects with inherent characteristics that will not allow a particular gradient to be increased.

5. DISCUSSION

The Adaptive Gradients Framework outlines the process an expert review panel can use for a fairly rapid and holistic assessment of general project designs. Because it is content specific, it is designed for use on one site at a time, with a host who provides information and can use the results, rather than as a cross-case comparison tool. It will be especially useful in comparing proposed design packages early in the determination of a project. Using a portfolio approach with associated projects provides opportunities to maximize scores of the portfolio of projects collectively.



Analysis using the Adaptive Gradients Framework could also occur in different phases of a project's life, for assessment at intervals along the planning and post-construction timeline for a particular project. Time up front is required for working with the host together information and discuss evaluation goals and then for the panel leader to develop a case study following the protocol identified above. At the site, two or three days would likely suffice.

A typical timetable for using the Adaptive Gradients Framework could include a 2-3-day workshop. Prior to the workshop, the expert team scores the gradients using the documentation they received before the workshop. Each of the workshop days have a combination of open and closed sessions. Open sessions refer to the times when the team meets with stakeholders who provide information about the site, either through field trips, presentations, or opportunities for questions and answer. During closed sessions, the team conducts an iterative process of scoring. The Hurst Creek, Maryland and the Buena Vista Santurce, Puerto Rico case studies in the Appendix demonstrate the application of the Adaptive Gradients Framework; see also the SAGE website at www.resilient-infrastructure.org.

5.1. Limitations

The Adaptive Gradients Framework is designed as a discussion tool, providing a holistic approach to project and proposal evaluation. It does not take the place of a full Environmental Impact Statement, and engineering reviews will still be necessary; in fact, these studies will often form the basis of the information used to do the Gradients analysis.

The qualitative rankings are intended to encourage a more interdisciplinary and holistic approach to the decision-making process. The inclusion of qualitative data and more elusive concepts like participation and process is necessary but is challenging for scoring. The more technical member of each team (e.g. engineers) may find qualitative scoring particularly difficult. Similarly, scoring the effectiveness of exposure reduction, for instance, may be challenging for social scientists on the team. For both of these cases, collaborative discussion of results led by experts from the appropriate topic area will be beneficial.

This points to the necessity of cross-disciplinary teams and discussion among members to create a valid outcome. The visual of the gradients can be construed as an argument that each gradient should be equally weighted: rather, each situation will have goals that are most important, and thus gradients will be differentially important in different contexts. Therefore, a local implementation should consciously discuss weighting as part of their analysis. Furthermore, project scale matters: smaller projects may be constrained in ways that prevent high achievement across all the gradients, while more complex and larger projects or a portfolio of smaller projects may be expected to perform better across all gradients.

5.2. Conclusions

Current and anticipated acute and chronic climate change impacts such as catastrophic and repetitive flooding, severe heat, and sea level rise are compelling communities to consider new approaches to make their communities more resilient to these threats. However, to help broaden the suite of solutions being considered by communities, and in particular to make those solution options more holistic and inclusive, it is very important that communities consider a wider range of objectives when discussing alternative solutions This includes considering factors such as social equity or ecological benefits of projects which have typically not been considered when only traditional built approaches are considered to deal with environmental protection.

The Adaptive Gradients Framework uses the explicit qualitative evaluation of eight adaptive gradients covering the most relevant socio-economic and biophysical variables in a multi-day, interdisciplinary process.

There are opportunities for application of the Adaptive Gradients Framework by public and private sector entities with responsibility for choosing resilient interventions. While our original focus was coastal projects, there is no reason that the framework needs to be limited to coastal application—holistic solutions are needed in a range of ecological and social settings. We invite others to use the case study template and contribute case study data, and to utilize the framework for collaborative inquiry and decision-making; together, this will build a stronger evidence basis for understanding the goals and mechanisms that lead to more resilient infrastructure.

The challenges of planning in the face of changing climates is extremely critical in both coastal and non-coastal settings. The Adaptive Gradients Framework provides a unique and innovative approach to address these hazards while at the same time strengthening social, economic, and ecological resilience to those challenges. As described by Kelman et al (74) “those most vulnerable to one challenge tend to be most vulnerable to other challenges, creating a condition of multiple exposure to hazards.” The framework allows planners to help vulnerable community address a range of challenges that are exacerbated by coastal flooding and other disaster events. Building climate change resilience requires addressing the range of issues facing a community beyond engineering and technical solutions, and will assist communities in creating projects with benefits now and into the future.

6. WORKS CITED

The research paper underlying the SAGE framework is Hamin, E.M., Y. Abunnasr, M.R. Dilthey, P.K. Judge, M.A. Kenney, P. Kirshen, T.C. Sheahan, D.J. Degroot, R.L. Ryan, B.G. McAdoo, L. Nurse, J.A. Buxton, A. Sutton-Grier, E.A. Albright, M.A. Marin, R. Fricke (2018). "Pathways to coastal resiliency: The Adaptive Gradients Framework." *Sustainability,* 10(8), 2629:https://doi.org/10.3390/su10082629.

1. Becker, A.; Chase, N.T.L.; Fischer, M.; Schwegler, B.; Mosher, K. A method to estimate climate-critical construction materials applied to seaport protection. Glob. Environ. Chang. **2016**, 40, 125–136.
2. Jongman, B.; Ward, P.J.; Aerts, J.C.J.H. Global exposure to river and coastal flooding: Long term trends and changes. Glob. Environ. Chang. **2012**, 22, 823–835.
3. Mycoo, M. Sustainable tourism, climate change and sea level rise adaptation policies in Barbados. Nat. Resour. Forum **2013**, 38, 47–57. [
4. Pelling, M.; Uitto, J.I. Small island developing states: Natural disaster vulnerability and global change. Glob. Environ. Chang. Part B Environ. Hazards **2001**, 3, 49–62.
5. Adger, W.N.; Hughes, T.P.; Folke, C.; Carpenter, S.R.; Rockström, J. Social-ecological resilience to coastal disasters. Science **2005**, 309, 1036–1039.
6. Sandifer, P.A.; Sutton-Grier, A.E.; Ward, B.P. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. Ecosyst. Serv. **2015**, 12, 1–15.
7. National Oceanic and Atmospheric Administration (NOAA). Guidance for Considering the Use of Living Shorelines; NOAA: Silver Spring, MD, USA, 2015.
8. Sutton-Grier, A.E.; Wowk, K.; Bamford, H. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environ. Sci. Policy **2015**, 51, 137–148.
9. Chen, L.C.; Liu, Y.C.; Chan, K.C. Integrated Community-Based Disaster Management Program in Taiwan: A Case Study of Shang—An Village. Nat. Hazards **2006**, 37, 209–223.
10. Allen, K.M. Community-based disaster preparedness and climate adaptation: Local capacity-building in the Philippines. Disasters **2006**, 30, 81–101.
11. Muttarak, R.; Pothisiri, W. The role of education on disaster preparedness: Case study of 2012 Indian Ocean earthquakes on Thailand's Andaman Coast. Ecol. Soc. **2013**, 18, 1–16.
12. Lutz, W.; Muttarak, R. Forecasting societies' adaptive capacities through a demographic metabolism model. Nat. Clim. Chang. **2017**, 7, 177–184.
13. Neuman, M. Infiltrating infrastructures: On the nature of networked infrastructure. J. Urban Technol. **2006**, 13, 3–31.

14. Brown, H. Next Generation Infrastructure: Principles for Post-Industrial Public Works; Island Press: Washington, DC, USA, 2014.

15. Klein, R.J.T.; Midgley, G.F.; Preston, B.L.; Alam, M.; Berkhout, F.G.H.; Dow, K.; Shaw, M.R. Adaptation opportunities, constraints, and limits. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK, 2014; pp. 899–943. [Google Scholar]

16. Zaidi, A.; Timothy, D.T.M. Incorporating Natural Infrastructure and Ecosystem Services in Federal Decision-Making. Available online: https://www.whitehouse.gov/blog/2015/10/07/incorporating-natural-infrastructure-and-ecosystem-services-federal-decision-making (accessed on 20 November 2016).

17. Kenney, M.A.; Hamin, E.M.; Sheahan, T.C. Reconceptualizing the Role of Infrastructure in Resilience. Eos Trans. Am. Geophys. Union **2014**, 95, 298.

18. Nordenson, G.; Seavitt, C. Structures of coastal resilience: Designs for climate change. Soc. Res. **2015**, 82, 655–671.

19. Bridges, T.S.; Burks-Copes, K.A.; Bates, M.E.; Collier, Z.A.; Fischenich, J.C.; Piercy, C.D.; Russo, E.J.; Shafer, D.J.; Suedel, B.C.; Gailani, J.Z.; et al. Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience; U.S. Army Engineer Research and Development Center, Environmental Laboratory, Coastal and Hydraulics Laboratory: Vicksburg, MS, USA, 2015.

20. National Research Council; Division on Earth and Life Studies; Board on Atmospheric Sciences and Climate. America's Climate Choices: Panel on Adapting to the Impacts of Climate Change. In Adapting to the Impacts of Climate Change; National Academies Press: Washington, DC, USA, 2011; ISBN 9780309145916.

21. Brown, C.; Ghile, Y.; Laverty, M.; Li, K. Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. Water Resour. Res. **2012**, 48.

22. IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.

23. IPCC. Climate Change 2014: Impacts, Adaptation, and Vulnerability Summaries, Frequently Asked Questions, and Cross-Chapter Boxes, a Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; World Meteorological Organization: Geneva, Switzerland, 2014.

24. Di Risio, M.; Bruschi, A.; Lisi, I.; Pesarino, V.; Pasquali, D. Comparative Analysis of Coastal Flooding Vulnerability and Hazard Assessment at National Scale. J. Mar. Sci. Eng. **2017**, 5, 51.

25. Silva, S.F.; Martinho, M.; Capitão, R.; Reis, T.; Fortes, C.J.; Ferreira, J.C. An index-based method for coastal-flood risk assessment in low-lying areas (Costa de Caparica, Portugal). Ocean Coast. Manag. **2017**, 144, 90–104.

26. Barnett, J.; O'Neill, S. Maladaptation. Glob. Environ. Chang. **2010**, 20, 211–213.

27. EPA. Guidelines for Preparing Economic Analyses. Available online: https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses#download (accessed on 3 October 2017).

28. USGS. Structured Decision Making for Management of Warm-Water Habitat of Manatees. Available online: https://www.usgs.gov/centers/wetland-and-aquatic-research-center-warc/science/structured-decision-making-management-warm?qt-science_center_objects=1#qt-science_center_objects (accessed on 3 October 2017).

29. Hallegatte, S. Strategies to adapt to an uncertain climate change. Glob. Environ. Chang. **2009**, 19, 240–247.

30. Ellen, I.G.; Yager, J.; Hanson, M.; Bosher, L. Planning for an Uncertain Future Can Multicriteria Analysis Support Better Decision Making in Climate Planning? J. Plan. Educ. Res. **2016**, 36, 349–362.

31. CEQ. Revised Draft Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews; Council on Environmental Quality: Washington, DC, USA, 2014; Volume 79.

32. Serban Scrieciu, S.; Belton, V.; Chalabi, Z.; Mechler, R.; Puig, D. Advancing methodological thinking and practice for development-compatible climate policy planning. Mitig. Adapt. Strateg. Glob. Chang. **2014**, 19, 261–288.

33. Jones, L.; Champalle, C.; Chesterman, S.; Cramer, L.; Crane, T.A. Constraining and enabling factors to using long-term climate information in decision-making. Clim. Policy **2017**, 17, 551–572.

34. Matthews, T.; Lo, A.Y.; Byrne, J.A. Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. Landsc. Urban Plan. **2015**, 138, 155–163.

35. Moser, S.C.; Dilling, L. Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change; Cambridge University Press: Cambridge, UK, 2007; ISBN 9781139461085.

36. Moser, S.C.; Ekstrom, J.A. A framework to diagnose barriers to climate change adaptation. Proc. Natl. Acad. Sci. USA **2010**, 107, 22026–22031.

37. Mimura, N.; Pulwarty, R.S.; Duc, D.M.; Elshinnawy, I.; Redsteer, M.H.; Huang, H.Q.; Nkem, J.N.; Sanchez Rodriguez, R.A. Adaptation Planning and Implementation. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK, 2014; pp. 869–898.

38. Hamin, E.M.; Gurran, N.; Emlinger, A.M. Barriers to municipal climate adaptation: Examples from coastal Massachusetts' smaller cities and towns. J. Am. Plan. Assoc. **2014**, 80, 110–122.

39. Shi, L.; Chu, E.; Anguelovski, I.; Aylett, A.; Debats, J.; Goh, K.; Schenk, T.; Seto, K.C.; Dodman, D.; Roberts, D.; et al. Roadmap towards justice in urban climate adaptation research. Nat. Clim. Chang. **2016**, 6, 131–137.

40. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breil, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ. Sci. Policy **2017**, 77, 15–24.

41. Duguma, L.A.; Minang, P.A.; van Noordwijk, M. Climate Change Mitigation and Adaptation in the Land Use Sector: From Complementarity to Synergy. Environ. Manag. **2014**, 54, 420–432.

42. Younger, M.; Morrow-Almeida, H.R.; Vindigni, S.M.; Dannenberg, A.L. The built environment, climate change, and health: Opportunities for co-benefits. Am. J. Prev. Med. **2008**, 35, 517–526.

43. Hallegatte, S.; Corfee-Morlot, J. Understanding climate change impacts, vulnerability and adaptation at city scale: An introduction. Clim. Chang. **2011**, 104, 1–12.

44. Cutter, S.L.; Finch, C. Temporal and spatial changes in social vulnerability to natural hazards. Proc. Natl. Acad. Sci. USA **2008**, 105, 2301–2306.

45. Heltberg, R.; Siegel, P.B.; Jorgensen, S.L. Addressing human vulnerability to climate change: Toward a "no-regrets" approach. Glob. Environ. Chang. **2009**, 19, 89–99.

46. Smit, B.; Wandel, J. Adaptation, adaptive capacity and vulnerability. Glob. Environ. Chang. **2006**, 16, 282–292.

47. Cutter, S.L.; Boruff, B.J.; Shirley, W.L. Social vulnerability to environmental hazards. Soc. Sci. Q. **2003**, 84, 242–261.

48. Cutter, S.L.; Barnes, L.; Berry, M.; Burton, C.; Evans, E.; Tate, E.; Webb, J. A place-based model for understanding community resilience to natural disasters. Glob. Environ. Chang. **2008**, 18, 598–606.

49. Moser, S.C.; Boykoff, M.T. Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World; Routledge: Abingdon-on-Thames, UK, 2013; ISBN 9781135071301.

50. Kenney, M.A.; Janetos, A.C.; Lough, G.C. Building an integrated U.S. National Climate Indicators System. Clim. Chang. **2016**, 135, 85–96.

51. Ahern, J. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Landsc. Urban Plan. **2011**, 100, 341–343.

52. Mendoza, G.A.; Martins, H. Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. For. Ecol. Manag. **2006**, 230, 1–22.

53. Bierbaum, R.; Smith, J.B.; Lee, A.; Blair, M.; Carter, L.; Chapin, F.S.; Fleming, P.; Ruffo, S.; Stults, M.; McNeeley, S.; et al. A comprehensive review of climate adaptation in the United States: More than before, but less than needed. Mitig. Adapt. Strateg. Glob. Chang. **2013**, 18, 361–406.

54. McDaniels, T.; Chang, S.; Cole, D.; Mikawoz, J.; Longstaff, H. Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation. Glob. Environ. Chang. **2008**, 18, 310–318.

55. Scannell, L.; Gifford, R. Personally relevant climate change: The role of place attachment and local versus global message framing in engagement. Environ. Behav. **2013**, 45, 60–85.

56. Boulton, E. Climate change as a "hyperobject": A critical review of Timothy Morton's reframing narrative. Wiley Interdiscip. Rev. Clim. Chang. **2016**, 7, 772–785.

57. Gifford, R. The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. Am. Psychol. **2011**, 66, 290–302.

58. Keeley, M.; Koburger, A.; Dolowitz, D.P.; Medearis, D.; Nickel, D.; Shuster, W. Perspectives on the Use of Green Infrastructure for Stormwater Management in Cleveland and Milwaukee. Environ. Manag. **2013**, 51, 1093–1108.

59. Aldrich, D.P.; Meyer, M.A. Social Capital and Community Resilience. Am. Behav. Sci. **2015**, 59, 254–269.

60. Smith, J.B.; Klein, R.J.T.; Huq, S. Climate Change, Adaptive Capacity and Development; Imperial College Press: London, UK, 2003.

61. IPCC. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., et al., Eds.; IPCC: Cambridge, UK; New York, NY, USA, 2012.

62. Haasnoot, M.; Kwakkel, J.H.; Walker, W.E.; ter Maat, J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Glob. Environ. Chang. **2013**, 23, 485–498.

63. Rosenzweig, C.; Solecki, W. Hurricane Sandy and adaptation pathways in New York: Lessons from a first-responder city. Glob. Environ. Chang. **2014**, 28, 395–408.

64. Abunnasr, Y.; Hamin, E.M.; Brabec, E. Windows of opportunity: Addressing climate uncertainty through adaptation plan implementation. J. Environ. Plan. Manag. **2015**, 58, 135–155.

65. Arnstein, S.R. A Ladder of Citizen Participation. J. Am. Inst. Plan. **1969**, 35, 216–224.

66. Collins, K.; Ison, R. Jumping off Arnstein's ladder: Social learning as a new policy paradigm for climate change adaptation. Environ. Policy Gov. **2009**, 19, 358–373.

67. Innes, J.E.; Booher, D.E. Planning with Complexity: An Introduction to Collaborative Rationality for Public Policy; Routledge: Abingdon-on-Thames, UK, 2010; ISBN 9781135194277.

68. Meadow, A.M.; Ferguson, D.B.; Guido, Z.; Horangic, A.; Owen, G.; Wall, T. Moving toward the Deliberate Coproduction of Climate Science Knowledge. Weather Clim. Soc. **2015**, 7, 179–191.

69. Head, B.W. Community Engagement: Participation on Whose Terms? Aust. J. Political Sci. **2007**, 42, 441–454.

70. Cornwall, A. Unpacking "Participation": Models, meanings and practices. Community Dev. J. **2008**, 43, 269–283.

71. Adger, W.N. Place, well-being, and fairness shape priorities for adaptation to climate change. Glob. Environ. Chang. **2016**, 38, A1–A3.

72. Goodin, R.E. Utilitarianism as a Public Philosophy; Cambridge University Press: Cambridge, UK, 1995.

73. Rawls, J. A Theory of Justice; Harvard University Press: Cambridge, MA, USA, 2009.

74. Kelman, I.; Gaillard, J.C.; Lewis, J.; Mercer, J. Learning from the history of disaster vulnerability and resilience research and practice for climate change. Nat. Hazards **2016**, 82 (Suppl. 1), S129–S143.

7. APPENDICES

7.1. Sample SAGE assessment workshop schedule: the Hurst Creek Project

The Hurst Creek Resiliency Project in Dorchester County, Maryland was proposed to reestablish a stable, functioning aquatic ecosystem and increase boating access to a river. (From Kenny, M.A., D. M. Weeks, et al. (2018) Hurst Creek, Maryland, Adaptation Gradients Framework Expert Scoring Workshop Report of Sustainable Adaptive Gradients in the Coastal Environment (SAGE). http://www.resilient-infrastructure.org/).

Table 7.1: Hurst Creek: Method for Assessment

Pre-Workshop	**Phase 1**: Pre-scoring the gradients
Workshop Day 1	Open session with Maryland DNR Chesapeake & Coastal Service and contractor design **Phase 2:** closed session here expert team discussed initial scores and individually re-scored the gradients given the group discussion
Workshop Day 2	Site visit of Hurst Creek with MD DNR and Delmarva RC&D Council board members. **Phase 3** closed session scoring done in small teams based on self identified interest and expertise, discussion of gradient assessment, and rubric development. Open session preliminary scoring presentation to MD DNR
Workshop Day 3	Open session field trip to implemented living shoreline resilience project sites. Phase 4 closed session consisting of individual reflections, finalization of rubric, individual scoring, consensus scoring discussion, and final reflection for each gradient: - Justification for the score - What works well - Recommendations Open session presentation to MD DNR

7.2. Maryland Department of Natural Resources Draft Gradients Score Sheet

In 2019, the Maryland Department of Natural Resources Chesapeake and Coastal Service (DNR) will use the gradients approach for selecting restoration projects through the Department's Community Resilience Program. The DNR team, facilitated by Nicole Carlozo, Kevin Smith, and Bhaskaran Subramanian, adapted the generic gradients presented in the body of this report to reflect DNR's community resilience goals. Melissa Kenney, of the SAGE team, worked closely with Nicole, Kevin, and Bhaskar as they revised the components. Shown below is the draft set of gradients that DNR will distribute to project reviewers in a guidance document. These gradients are meant to assist reviewers with project evaluation (see Table 7.1). Reviewers will score each gradient from 1 (low) to 5 (high) and provide an overall score out of 40 possible points for all assigned projects. This process will not only provide standardized scores for all projects, but also help determine if the selected projects are achieving the goals outlined for DNR's overall project portfolio. Following the initial launch of this gradient-focused review process, DNR plans to poll reviewers and partners to better streamline the review process, increase usability of the gradients, and ensure that community resilience goals are adequately represented. End-user feedback will be incorporated into future decision making.

Table 7.2: DRAFT Gradients Scoring Rubric: Maryland Department of Natural Resources

PROPOSAL COM			
	Low	**Medium**	**High**
Context	Incomplete/Unclear context with no connection to flooding hazards or other climate change impacts.	Complete/Clear context but indirectly addresses flooding or other climate change impacts.	Complete/Clear context with a direct connection to flooding and other climate change impacts.
Timeline	Timeline is absent or unrealistic.	Timeline requires adjustments or does not take permitting into account.	Timeline is reasonable & realistic with state & local permitting considered.
Project Partners	Partners not identified.	Partners identified but are minimal or without concrete roles.	Partners and roles are clearly identified.
Goals	Goals not consistent with Outcome 3. Utilize natural and nature-based infrastructure to enhance climate change resilience.	Goals consistent with Outcome 3, but not feasible under current budget and time constraints. Changes to project scope may be needed.	Goals are feasible and consistent with Outcome 3 as described.
Budget	Budget is incomplete, proposes ineligible funds, or requests high overhead given project size.	Budget is complete with majority of funds directly supporting design, permitting, and/or construction.	Budget directly supports design, permitting, and/or construction with leveraged funds identified for other line items.
Supporting Documents	Required supporting documentation is absent (e.g. Photographs of existing conditions; Letters of Support for non-profit applicants; Landowner/Access agreements for projects on private property; Full designs for construction-ready projects).	Provides required supporting documentation and at least 1 letter of support from project partners or a local government representative.	Provides required supporting documentation and letters of support from all project partners, including a local government representative.

COST EFFICIENCY			
	Low	**Medium**	**High**
Innovative Cost Savings	Cost-savings innovations are not planned (e.g. use of on-site materials or local dredged material).	Cost-savings innovations are planned (e.g. use of on-site materials or local dredged material).	Cost-savings innovations have been coordinated (e.g. use of on-site materials or local dredged material).
Maintenance	High maintenance costs given project size.	Reasonable maintenance costs given project size. Maintenance is supported by the applicant. Frequency is reduced because of some self-maintaining elements.	Low maintenance costs, or a fully self-sustaining system that will bounce-back following disturbance.
Ecosystem Services	Provides no new benefits or loss of eco-systems services (e.g. access, habitat, etc.).	Provides some co-benefits or ecosystem services beyond the project goals (e.g. ecological, economic).	Provides significant co-benefits or ecosystem benefits beyond the project goals.
Local Match or Leveraged Funds	No local match or leveraged funds. Project costs are paid mainly by those who will not experience the benefit.	Partial local match or leveraged funds. Project costs are paid partially by those who will benefit. Beneficiaries partially contribute through time or resources.	Significant local match or leveraged funds. Project costs are paid solely or significantly by those who will benefit. Innovative funding streams are used with leveraged funds from diverse sources. Beneficiaries contribute time and resources.
Project Transferability	High project cost precludes the project from being transferable to other communities (not realistically replicated).	Project costs may preclude project replication or transferability to other communities.	Project costs support project transferability to other communities (realistically replicated).

ECOLOGICAL ENHANCEMENT			
	Low	**Medium**	**High**
Green Infrastructure	Project includes all or a majority of gray infrastructure solutions (e.g. bulkheads, conventional stormwater system upgrades, sea walls).	Project includes hybrid solutions incorporating gray and green infrastructure.	Project includes a majority of green infrastructure solutions (e.g. wetlands, dunes, nearshore habitat, bioswales, rain gardens, etc.)
Habitat and Native Species	Destroys habitat for project installation and maintenance with minimal mitigation. Uses or preserves non-native or invasive species.	No habitat changes during installation, or small-scale habitat created or enhanced to promote flora and fauna.	Restores ecosystems, including natural processes of native species.
System Dynamics	Does not consider system dynamics. Likely to negatively impact ecological systems over time.	Considers system dynamics and accounts for anticipated change (e.g. stream meanders).	Considers system dynamics and accounts for anticipated change due to climate (e.g. wetland migration).
Environmental Benefits	Limited or zero environmental benefits.	Some environmental benefits (e.g. water quality, habitat).	Significant environmental benefits beyond those for which the project is designed (e.g. water quality, habitat, carbon sequestration, etc.).

ADAPTATION POTENTIAL			
	Low	**Medium**	**High**
Time Horizon	Project addresses immediate needs only.	Project addresses needs over the expected project lifespan (e.g. 15-25 years).	Project addresses immediate needs and considers long-term changes due to climate change within the project's useful lifespan.
Local Planning	Project is not connected to a state or local adaptation planning effort.	Project complements ongoing efforts already addressing flood and climate hazards, but is not connected to a state or local adaptation planning effort.	The project implements a recommendation outlined in a state or local adaptation planning effort (e.g. County Hazard Mitigation Plan).
Ease of Adaptation	Project has an inflexible design that does not allow for modifications given future changes. Requires continual maintenance without a responsible party identified.	Project design has some flexibility given future changes, but other features are inflexible or costly to change. Project is partially self-sustaining with limited maintenance required.	Project design has significant flexibility to adapt to changing conditions. The system will self-maintain, becoming more robust and effective over time and able to bounce-back following disturbance.
Monitoring	Monitoring is not planned. No processes are in place to facilitate adaptive management.	Minimal monitoring is planned (e.g. 1-year timeframe; qualitative data). Adaptive management is applied in a limited capacity and primarily when there is a major failure.	Long-term site monitoring is planned (e.g. 3-5 years; rigorous quantitative data). Adaptive management is applied. Monitoring data provides justification for design modifications.

LOCAL CAPACITY FOR IMPLEMENTATION			
	Low	**Medium**	**High**
Stakeholders	Stakeholders are not defined. Stakeholder participation opportunities are limited. Stakeholders do not represent all community perspectives.	Stakeholders are defined. Stakeholder participation opportunities exist before, during, and after project implementation, but limited to broader public meetings.	A broad group of stakeholders is defined. Multiple processes are in place to encourage diverse participation before, during and after implementation.
Community Support	Community support of the project is not apparent. Project is not community-driven.	Project has local community support and addresses community needs. Project is driven by stakeholder goals.	Project has broader community support (beyond those most impacted) and provides community benefits beyond the most immediate needs. Top-down and bottom-up participatory processes address stakeholder goals and broader co-benefits.
Project Team	Project team is not established, or has limited experience working with identified stakeholders. Local government representative(s) do not participate on the project team.	Project team is established and has a history of project implementation and working with similar stakeholder groups. Local government representative(s) participate as needed on the project team.	Project team has successfully implemented similar projects and worked with the defined stakeholder group. Local government representative(s) participate on the project team.
Transparency and Communication	Small closed group of team leaders with limited transparency and communication plans. Knowledge transfer is limited.	Transparency and communication are planned for some project aspects, allowing for some knowledge transfer.	Transparency and communication are planned for all project aspects, allowing for knowledge transfer through multiple pathways (e.g. written media, visual media, etc.)
Local Planning	Project does not support any type of local planning effort (e.g. Green Infrastructure Plan).	Project supports a formal or informal community planning effort (e.g. Community Resilience or Sustainability Plan).	Project supports a formal and official local planning effort (e.g. County Hazard Mitigation Plan, Comprehensive Plan, etc.).

Sustainable
Adaptive
Gradients in the
Coastal Environment

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Project title: Sustainable Adaptive Gradients in the Coastal Environment (SAGE): Reconceptualizing the Role of Infrastructure in Resilience NSF Research Collaboration Network (RCN): Science, Engineering and Education for Sustainability (SEES)
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Website: www.resilient-infrastructure.org

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