Appendix A: Adaptation Strategies

The fact sheets in this appendix provide general, introductory information about a variety of adaptation strategies that communities may consider. Many of these strategies could be used to protect either private property or public infrastructure. Some of the strategies are traditionally employed to protect private property but could also be viable options to protect public property as well. This appendix is not intended to be a comprehensive inventory, but rather to introduce a range of strategies that help illustrate varying approaches: managed retreat policies, tidal management, engineered barriers, infrastructure modification/design, land use policy, and green infrastructure.

The fact sheets provide an overview of costs, effectiveness, and barriers to implementation. When reviewing these strategies for use in your own community, keep in mind that:

- Costs can vary significantly depending on the unique characteristics of your community and the exact nature of a project or policy,
- Non-economic factors such as legal challenges or public outreach needs can increase the resources needed to implement a strategy,
- The lifespan and effectiveness of any project will depend on the severity of future events.

Some fact sheets include special considerations for certain adaptation strategies, but when investigating any potential strategy a community will need to consider a number of factors such as social feasibility, environmental impacts, and administrative and legal aspects.

The current state of knowledge pertaining to adaptation strategies is growing rapidly as more and more communities seek and test out solutions to current and future inundation hazards. Communities should seek out additional sources of information to learn more about the strategies contained in this appendix and to identify additional strategies. The resources listed in the "Key References" text box in Chapter 2 of this framework as well as those that follow are a few potential sources of additional information:

- The Federal Emergency Management Agency (FEMA) has a variety of publications related to flood hazard mitigation measures, including guidance documents as well as case studies. FEMA recently released Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards, which includes actions to mitigation risks from storm surge, flood, and sea level rise.
- The U.S. Army Corps of Engineers (USACE) has resources related to both structural and non-structural flood mitigation measures. Visit the Flood Risk Management for State and Local Partners section of the USACE Flood Risk Management Program website for more information.
- The Georgetown Climate Center has a searchable Adaptation Clearinghouse that provides more detailed information on a wide range of adaptation measures.
- NOAA's Adapting to Climate Change: A Planning Guide for State Coastal Managers includes a chapter on adaptation strategies, many of which are related to inundation hazards.

Fact Sheet A-9: Levees and Dikes

Levees, also known as dikes, are constructed embankments designed to reduce the risk of flooding to the areas behind them. Levees are typically built parallel to the course of a river or along coastlines in order to contain, control, or divert the flow of water. Levees are constructed from compacted soil or artificial materials such as concrete or steel. To protect against erosion and scouring, earthen levees can be covered with grass and gravel or a hard surface like stone, asphalt, or concrete.

Cost

When land acquisition costs are low, levees are often the cheapest form of hard defense relative to how much protection they can offer. In general, construction can cost between $100[11] and $1,500 per linear foot depending on the height and slope[12] Maintenance costs are also an ongoing requirement to ensure the structure continues to provide appropriate levels of protection.

Effectiveness

Levees can provide a high degree of protection against flooding in low-lying coastal areas. Effective levees are built with a high volume of material to resist water pressure, sloping sides to reduce wave energy, and crest heights sufficient to prevent overtopping by flood waters. Levees prevent flooding until they are overtopped with water or are breached (i.e., broken or eroded away), at which point flood waters will rise about as high as they would without a levee.

Barriers to Implementation

The high volume and sloping shape of levees necessitates a large building footprint. This factor will be especially important in areas with high property values.

[11] FEMA 2007. Selecting Appropriate Mitigation Measures for Floodprone Structures. Table 5.2
[12] Moore. 2009. The Impacts of Sea-Level Rise on the California Coast. Sacramento: California Climate Change Center.

Fact Sheet A-11: Elevated Development

Elevated development involves physically raising infrastructure (e.g., on stilts/pilings or raised land) so that water can temporarily flow underneath and/or around without harming the main structure.[15] Elevated development can be included in the original design or added as a retrofit. Traditionally, only buildings are elevated, while the surrounding infrastructure (e.g., roads, walkways) is not; thus, while a building may be protected from flood damage, access to it may be limited during a coastal flood. It is possible to raise surrounding infrastructure, including roads, bridges, walkways, and utility lines. One common example of elevated development is beach homes that are built on stilts, often with the first floor at a height of 10 feet or more above ground level. Elevating structures is a relatively easy feature to incorporate into the design of a facility or infrastructure during initial construction, but it is more challenging to incorporate as a retrofit. Physically raising a structure that is already elevated slightly (e.g. with a crawlspace) is more feasible than elevating "slab-on-grade" construction.

Cost

Incorporating elevated development into the design of a new house adds $2,000 to $30,000 to the cost of the house depending on its size and foundation type, while raising an existing building can easily be well over double this cost. The total costs for raising a building increase with building size and weight but are not directly related to building size.[16,17] Raising an area of land and/or raising surrounding infrastructure is much more expensive. The cost will vary depending on the amount and type of infrastructure being raised. Raising entire areas of land is very expensive because large amounts of dirt and fill must be transported to the raised site.

Effectiveness

Elevated development is effective in protecting buildings and infrastructure from floods at water levels lower than the base of the first floor of the raised facility and is generally effective for the expected life expectancy of the structure, which might range from 25 to 50 years.

Barriers to Implementation

There are rarely major barriers to implementing elevated development into new construction. Cost to implement, particularly for larger and older buildings, as well as the potential for structural damage, are major barriers to raising an existing building. Creating sufficient access for the handicapped and elderly is also a potential concern. Potential legal liability can hinder being able to raise roads in existing developed areas, because the government entity raising the road is then responsible if drainage patterns are altered and increased flooding results.

[15] http://www.usace.army.mil/Missions/CivilWorks/ProjectPlanning/nfpc.aspx
[16] http://www.nytimes.com/2005/12/12/national/nationalspecial/12flood.html
[17] Deschapelles, Natalie (2012). Dissertation: *An Evaluation of, and Suggestions for, Charlotte County Coastal Management, with Regards to Sea Level Rise Vulnerability*.

Special Considerations

Unless the surrounding infrastructure is also raised, flooding will still impact the accessibility of the raised structures and disrupt the economic activities they support.

Fact Sheet A-20: Wetlands

Wetlands are ecosystems that may be saturated with water during all or part of the year and are often found at the boundary between land and water. By absorbing flood waters, wetlands protect inland areas from flooding. Coastal wetlands in the United States have been estimated to provide up to $23.2 billion annually in storm protection services.[26]

Communities can take steps to conserve, enhance, restore, or create wetlands in their area. Restoration—returning a degraded or former wetland to its original condition—is typically easier and cheaper to implement than wetland creation, which involves converting either dry land or open water to a wetland.

Cost

Communities can engage in a variety of activities to conserve, create, enhance, or restore wetlands, and specific costs will vary depending on the scope of the project and local conditions. Land acquisition can be a significant upfront cost. Wetland restoration can cost between $3,500 and $80,000 per acre, excluding land costs, and wetland construction typically costs between $35,000 and $150,000 per acre, excluding land costs.[27] Communities usually face additional costs for planning, long-term management, and monitoring, but maintenance costs are typically very low.

Effectiveness

Wetlands reduce the risk of property damage and loss of life from flooding through a number of mechanisms. Wetlands act as natural reservoirs, storing flood waters and then slowly releasing them, delaying and attenuating peak flood flows. Wetlands also dissipate wave, wind, and storm surge energy through resistance provided by the wetland vegetation. Studies have found that a loss of one hectare (about 2.5 acres) of wetland corresponds to an average increase of $33,000 in storm damage from hurricanes.[26] However, wetlands are less likely to be effective in mitigating the effects of very large flood events, particularly regional floods of long duration.

Barriers to Implementation

Construction of new wetlands may not be well-suited for highly developed areas, where there is often no land available or the land can be costly.

Special Considerations

Wetlands provide a number of other valuable services, including improving water quality, providing fish and wildlife habitats, and maintaining water supplies during drought periods.

[26] Anderson, Sharolyn J. and Kenneth Mulder (2008). "The value of coastal wetlands for hurricane protection." *Ambio* 37(4): 241.
[27] http://www.bnl.gov/erd/peconic/factsheet/wetlands.pdf

Fact Sheet A-24: Barrier Island Restoration

Barrier islands are naturally occurring, narrow strips of land that run parallel to the coast. Barrier islands protect inland areas during severe weather events by reducing wind and wave energy and by mitigating storm surges. In many areas, however, barrier islands are eroding at extreme rates. In some places, barrier island shorelines are shrinking by up to 100 feet per year.[38]

Barrier island restoration projects are designed to protect and restore barrier island chains. Restoration projects may incorporate a variety of techniques, including using dredged material to increase island height and width, building hard structures to protect the island from erosion, and using sand-trapping fences to build and stabilize sand dunes.

Cost

Barrier island restoration is a large-scale undertaking and can cost tens or hundreds of millions of dollars. For example, restoring East Grand Terre Island in Louisiana, which included restoring 2.8 miles and 620 acres of barrier shoreline and 450 acres of marsh by dredging 3.3 million cubic yards of offshore material, cost $31 million.[39] In addition, barrier island restoration projects require periodic maintenance to ensure resiliency.

Effectiveness

Barrier islands protect coastal communities from damage caused by waves and storm surge. Studies have indicated that the loss of barrier islands can increase wave height by as much as 700 percent during fair-weather forecasts.[40] Recent observations following hurricanes have shown that areas behind restored barrier islands weather storms much better than nearby areas.[41]

Barriers to Implementation

Cost is typically the largest barrier to restoring barrier islands.

Special Considerations

In many cases, barrier islands help shelter wetlands, so restoring barrier islands can indirectly preserve many of the benefits of coastal wetlands.

[38] http://pubs.usgs.gov/fs/barrier-islands/
[39] http://www.nola.com/environment/index.ssf/2012/01/louisiana_releases_50-year_blu.html
[40] Stone, Gregory W. and Randolph A. McBride (1998). "Louisiana barrier islands and their importance in wetland protection: forecasting shoreline change and subsequent response of wave climate." *Journal of Coastal Research* 14(3): 900–915.
[41] http://www.habitat.noaa.gov/abouthabitat/barrierislands.html