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REDUCING CLIMATE RISKS WITH NATURAL INFRASTRUCTURE

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"... recent assessments project alteration in the frequency, intensity, spatial extent or duration of weather and climate extremes, including climate and hydrometeorological events such as heat waves, heavy precipitation events, drought and tropical cyclones. ... New, improved or strengthened processes for anticipating and dealing with the adverse effects associated with weather and climate events will be needed in many areas."

—Intergovernmental Panel on Climate Change, 2012

Citation: IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Available at: http://ipcc-wg2.gov/SREX/

LEAD AUTHOR: Jim Downing
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FRONT COVER PHOTOS: TOP LEFT: Sacramento River, California © *Geoffrey Fricker* **TOP RIGHT:** Water from San Francisco Bay overflows the Embarcadero, San Francisco © *Mike Filippoff/California King Tides Initiative* **BOTTOM:** Surf crashes into seawall in Pacifica, California © *Jack Sutton/California King Tides Initiative*

BACK COVER PHOTOS: TOP LEFT: Canada geese in the Yolo Bypass © *CanadaGeeseYWAfeliz* **TOP RIGHT:** Road damage due to flooding © *USFWS/Flickr via a Creative Commons license* **MIDDLE RIGHT:** Eroded cliffs in Pacifica, California © *DeanWmTaylor/Flickr via a Creative Commons license* **BOTTOM LEFT:** Cyclist avoids flooding in Marin County, California © *Yanna.B/California King Tides Initiative* **BOTTOM RIGHT:** Wetlands serve as a natural solution to flood protection © *Tom Mikkelsen/California King Tides Initiative*

Reducing Climate Risks with Natural Infrastructure

Over the past two centuries, efforts to control flooding have transformed California's natural landscape. Rivers have been dammed and constrained by levees, wetlands have been drained and shorelines have been fortified against erosion. These projects opened land to urban and agricultural development but at a huge and ongoing cost to fish, migratory birds and other wildlife throughout the state. Roughly 10 percent[1] of California's historic wetlands remain, nearly all major streams have been altered dramatically and more than 100 miles of the state's coastline have been armored with rock and concrete.[2]

Despite these measures—implemented at great expense—significant risks to people and property remain. Coastal erosion threatens homes from San Clemente to Santa Barbara to Pacifica. Along the shores of San Francisco Bay, at least $29 billion in property, including major business centers, is currently at risk from a 100-year flood.[3]

Climate change is expected to drive a combination of extreme weather and sea level rise that will increase the risk of flooding in California. The Intergovernmental Panel on Climate Change, the leading international body for the assessment of climate change, anticipates a significant increase in heavy precipitation events, translating to increased flood risk in many watersheds. The state Ocean Protection Council projects that sea level will rise five to 25 inches by 2050, and 17 to 66 inches by 2100.[4]

Already, the state's communities are considering how to respond to the growing risks. Much is at stake, as substantial resources likely will be devoted to protecting communities. For example, Louisiana recently adopted a $50 billion plan to prepare for rising sea levels and future storms.[5]

As California considers how to adapt to a changing climate, planners often focus on defensive infrastructure with a negative habitat impact: bigger levees, rock walls to protect coastlines or even giant sea gates.[6]

But California can follow a different path. With natural or "green" infrastructure that leverages natural processes to reduce risk to human lives, property and businesses, the state can build resilience to the coming changes while restoring natural habitats instead of degrading them.

1. *California Natural Resources Agency, 2010 State of the State's Wetland report. www.resources.ca.gov/ocean/SOSW_report.pdf*
2. *Lesley Ewing, California Coastal Commission, pers. comm, 11 Sept 2013. Figure is 102 miles of 1,073 total miles of ocean coastline.102 miles is the total linear distance of armoring on coastland, and does not include offshore structures such as breakwaters.*
3. *Heberger et al, 2012. The Impacts of Sea Level Rise on the San Francisco Bay. California Energy Commission Report 500-2012-014. http://www.energy.ca.gov/2012publications/CEC-500-2012-014/CEC-500-2012-014.pdf. Page 20: estimated $29 billion in property currently at risk, replacement value of buildings and contents in 2000 dollars.*
4. *California Ocean Protection Council, 2013 State of California Sea-Level Risk Guidance Document. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf*
5. *State of Louisiana, 2012 Coastal Master Plan. http://www.coastalmasterplan.louisiana.gov/*
6. *http://www.scientificamerican.com/article.cfm?id=tidal-gate-across-san-francisco-bay-proposed-to-manage-sea-level-rise*

"Green" or "natural" infrastructure can include a range of strategies. Some projects focus on preserving existing natural systems, while others are highly engineered, combining green techniques with more traditional "gray" approaches.

This report evaluates nine green infrastructure case studies in California. Each improves flood or coastal protection, provides habitat and preserves or restores the natural dynamics between water and land. We review the available data on the costs and benefits of each case and, where possible, compare this information with the costs and benefits of a gray alternative at the same site.

What is a "100-year" flood?

Climate change and FEMA flood risk estimates

Estimates of flood risk in this report are based on standard Federal Emergency Management Agency (FEMA) analyses using historic precipitation, stream-flow and sea-level data. A 100-year flood has a 1 percent chance of occurring in any given year, based on past experience. Notably, these estimates have not been updated to reflect the effect of climate change on flood risk in California. Climate change is expected to increase flood risks in the future. A 2013 federal study,[7] for instance, estimates that the total land area subject to 100-year river floods nationwide will increase 45 percent by 2100, with climate change responsible for 70 percent of that increase.

PHOTO: Flooded city street © *Don Becker, USGS/Flickr via a Creative Commons license*

7. *AECOM, The Impact of Climate Change and Population Growth on the National Flood Insurance Program through 2100. Report prepared for the Federal Insurance and Mitigation Administration and the Federal Emergency Management Agency. June 2013. Available at: http://www.aecom.com/deployedfiles/Internet/News/Sustainability/FEMA%20Climate%20Change%20Report/Climate_Change_Report_AECOM_2013-06-11.pdf*

Natural Infrastructure: Nine Cases, Multiple Approaches

Green infrastructure project approaches range from the preservation of natural systems to combinations of ecological restoration and engineered structures.

Preservation*
Protects existing ecology and river/coastal processes
Example: Conservation of floodplain maintains natural flood protection

Restoration*
Restores natural ecology and river/coastal processes
Example: Wetland restoration provides flood protection and habitat

Structure + Nature
Combines levees or other structures with restored natural systems
Example: Setback levee and floodplain restoration provide risk reduction as well as habitat

Structure Alone
Builds defenses with a neutral or negative impact on natural systems
Example: Armored seawall or levee reduces risk but does not provide habitat and may alter natural erosion and sedimentation processes

Case Studies	Preservation	Restoration	Structure + Nature	Structure Alone
1. Hamilton City Setback Levee Habitat Restoration			✔	
2. Napa River Restoration		✔	✔	✔
3. Yolo Bypass			✔	
4. Santa Clara River Floodplain Protection Program	✔			
5. Surfers Point Managed Retreat		✔		
6. Aramburu Island Coarse Beach Restoration		✔		
7. The SF Bay Living Shorelines: Nearshore Linkages Project		✔		
8. The Horizontal Levee Concept		✔	✔	
9. Monterey Bay Coastal Erosion Mitigation Alternatives Study[8] (concept only)	✔			

* "Preservation" is the protection of existing landscapes and land-water interactions, while "Restoration" typically involves actions such as earth moving, revegetation and ongoing monitoring and management designed to create healthy, diverse and sustainable ecosystems similar to what would exist in the absence of human disturbance.

8. *Managed retreat only.*

FIVE LESSONS

Done right and under the right conditions, green infrastructure can reduce risks to people and property as effectively as traditional "gray" infrastructure can, while potentially providing a number of additional benefits.

1. Green infrastructure can provide cost-effective flood and coastal protection.

In many cases, green infrastructure provides the same level of risk reduction at a lower cost than gray infrastructure because green projects take advantage of the protection provided inherently by natural systems. For instance, tidal wetlands reduce the size and erosive power of waves along the shoreline of an estuary, while floodplains can divert, hold and slow floodwaters, reducing risks to downstream communities. Preserving or restoring wetlands, floodplains and other natural systems can be less costly than building and maintaining structures of rock, steel and concrete. When other benefits—such as the provision of wildlife habitat or ecosystem services like improved water quality—are considered as well, the advantage of green projects can be even greater. Another factor influencing cost-effectiveness is implementation time; green projects, in particular those that primarily involve the protection of an existing natural system, can potentially be completed more quickly than alternatives requiring major construction.

2. Green infrastructure has been demonstrated successfully in a wide variety of settings.

Projects from the Central Valley to the Napa River to the mountains and coasts of southern California illustrate the breadth of designs that are being used to address risks in a range of geographies.

3. Green infrastructure can be designed to adapt to changing conditions.

Given adequate amounts of space and sediment, natural floodplains, beaches and shorelines can adapt to altered river flows and sea levels and continue to support healthy ecosystems. Well-designed green infrastructure projects can have the same flexibility.

4. Green infrastructure provides multiple benefits.

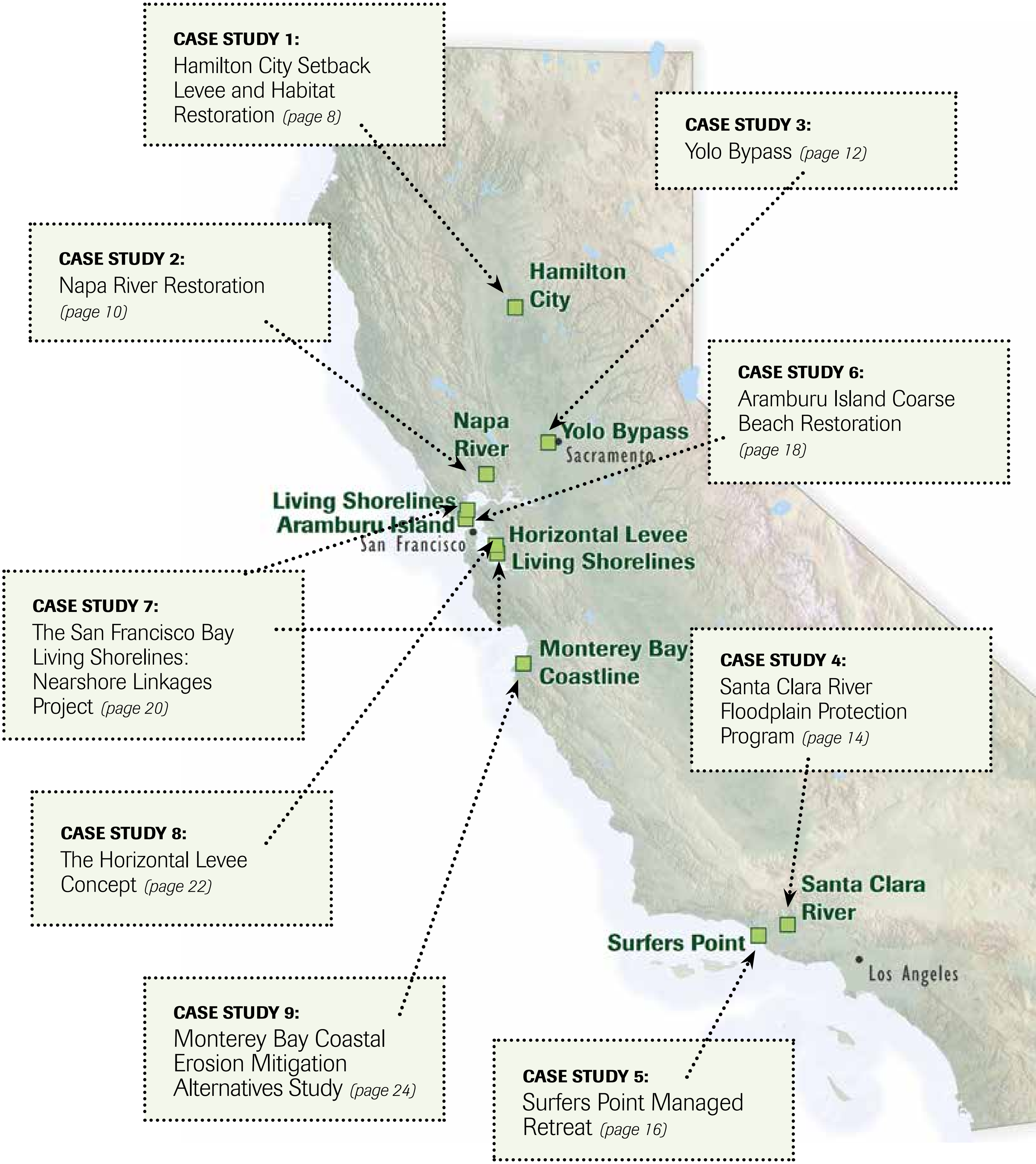
Each case examined for this report provides benefits beyond flood or coastal protection. These benefits include: habitat for fish, migratory birds and other wildlife; increased productivity from farms and fisheries; carbon sequestration; improved water quality; temporary water storage by wetlands and floodplains; recharge of aquifers; support for recreational activities including bird watching, surfing and fishing; increased property values; and jobs and economic activity supported by fisheries, recreation and conservation.

5. Green infrastructure can inspire strong local support.

Green projects tend to provide attractive and highly valued community amenities, such as restored river channels, river parkways, and beaches. This factor is critical for raising local funds, which is often a prerequisite for obtaining government and other outside project funding. As an example: In 1995 a $115 million[9] "gray" Napa River flood protection proposal from the Army Corps of Engineers was rejected amidst strong local opposition. Two years later, Napa County voters approved a local sales tax increase to fund a "Living River" design, despite its higher projected cost of $163 million.

PHOTO: Oxnard industrial drain wetlands © *Carey Batha/TNC*

9. Throughout the report, cost figures are presented in dollars in the year referenced.


CASE STUDY 1:
Hamilton City Setback Levee and Habitat Restoration (page 8)
CASE STUDY 3:
Yolo Bypass (page 12)
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Case Studies 1–9

The nine case studies, seven completed or under way and two conceptual projects, represent a range of geographic settings and illustrate the variety of ways that nature-based infrastructure can be used to mitigate the effects of extreme weather and rising sea levels.

MAP: © *The Nature Conservancy*

CASE STUDY 1:

Hamilton City Setback Levee and Habitat Restoration

Location: Six-mile stretch of the Sacramento River at Hamilton City

Summary: A 6.8-mile setback levee on the Sacramento River will provide flood protection while reconnecting the river to 1,500 acres of its historic floodplain and restoring 1,361 acres of riparian habitat.

Estimated Cost: $52 million (2013 estimate)

Vulnerability Addressed: The community of Hamilton City and surrounding farmlands are poorly protected from floods by a substandard private levee along the Sacramento River built in the early 20th century. Six times since 1983, floods have forced residents of Hamilton City to evacuate, imposing a major burden on a community where median household income in 2011 was less than $30,000.[10,11] The current levee protecting the community has only a 10 percent chance of withstanding a 75-year flood event. The portion of the new setback levee that will protect Hamilton City will have a 90 percent chance of passing such an event, reducing expected flood damage by $577,000 annually (2004 estimate).

THE PROJECT: As early as 1975, the Army Corps of Engineers drafted plans for a modern levee to protect Hamilton City. But because the value of the land and homes in need of protection was much lower than the cost of building the levee, the Corps could not justify the project on benefit-cost grounds.

By 2003, however, changes in Corps planning policies[12] allowed the benefits of flood protection *and* habitat restoration to be considered in project cost-benefit analyses. These rules favor the most cost-effective combination of flood protection and habitat restoration. A new feasibility study[13] for the Hamilton City site determined that a setback levee (see map on facing page) would best meet these objectives and deliver benefits greater than the project cost, meaning the project could proceed. The Hamilton City project was the first in the nation to be approved by the Corps under the new multiple-benefit rules.[14]

During the project analysis, the option of upgrading the existing private levee was considered and discarded because it would involve extensive and costly rock armoring for erosion protection (and no habitat benefit). By contrast, the setback levee will be separated from the main river channel by floodplain and will require only limited rock armoring. Taking advantage of the natural function of the floodplain reduces the construction cost of the setback levee, in addition to providing a large habitat benefit.

The acreage to be restored by the project is mostly agricultural. Because the land is close to the river and not well protected by the current levee, it is subject to waterlogging, flooding and erosion. The setback levee will reconnect this land to the river's natural floodplain while providing flood protection to the higher-quality farmland further from the river. The Nature Conservancy has led the acquisition of the floodplain land, valued at roughly $12 million (actual dollars spent through 2013).

10. *U.S. Army Corps of Engineers, 2004. Hamilton City Flood Damage Reduction and Ecosystem Restoration, California. Final Feasibility Report and Environmental Impact Statement / Environmental Impact Report.*

11. *http://www.city-data.com/city/Hamilton-City-California.html*

12. *U.S. Army Corps of Engineers, 2003. Engineering Circular 1105-2-404. http://planning.usace.army.mil/toolbox/library/ECs/EC1105-2-404.pdf*

13. *U.S. Army Corps of Engineers and the Reclamation Board of the State of California, 2004. Hamilton City Flood Damage Reduction and Ecosystem Restoration, California, Final Feasibility Report and Environmental Impact Statement / Environmental Impact Report. Online at: bit.ly/1bhLy8p*

14. *Plain, Todd, 2011. "Corps' first multi-benefit project moves forward at Hamilton City." Army Corps of Engineers Web site, April 25, 2011. http://www.army.mil/article/55499/*

STATUS: The Corps and state regulators have approved the project. In 2012, 2013 and 2014, the president's federal budget recommended funding to start construction, but the project is on hold because of a Congressional block on new Corps projects.

FOR MORE INFORMATION:
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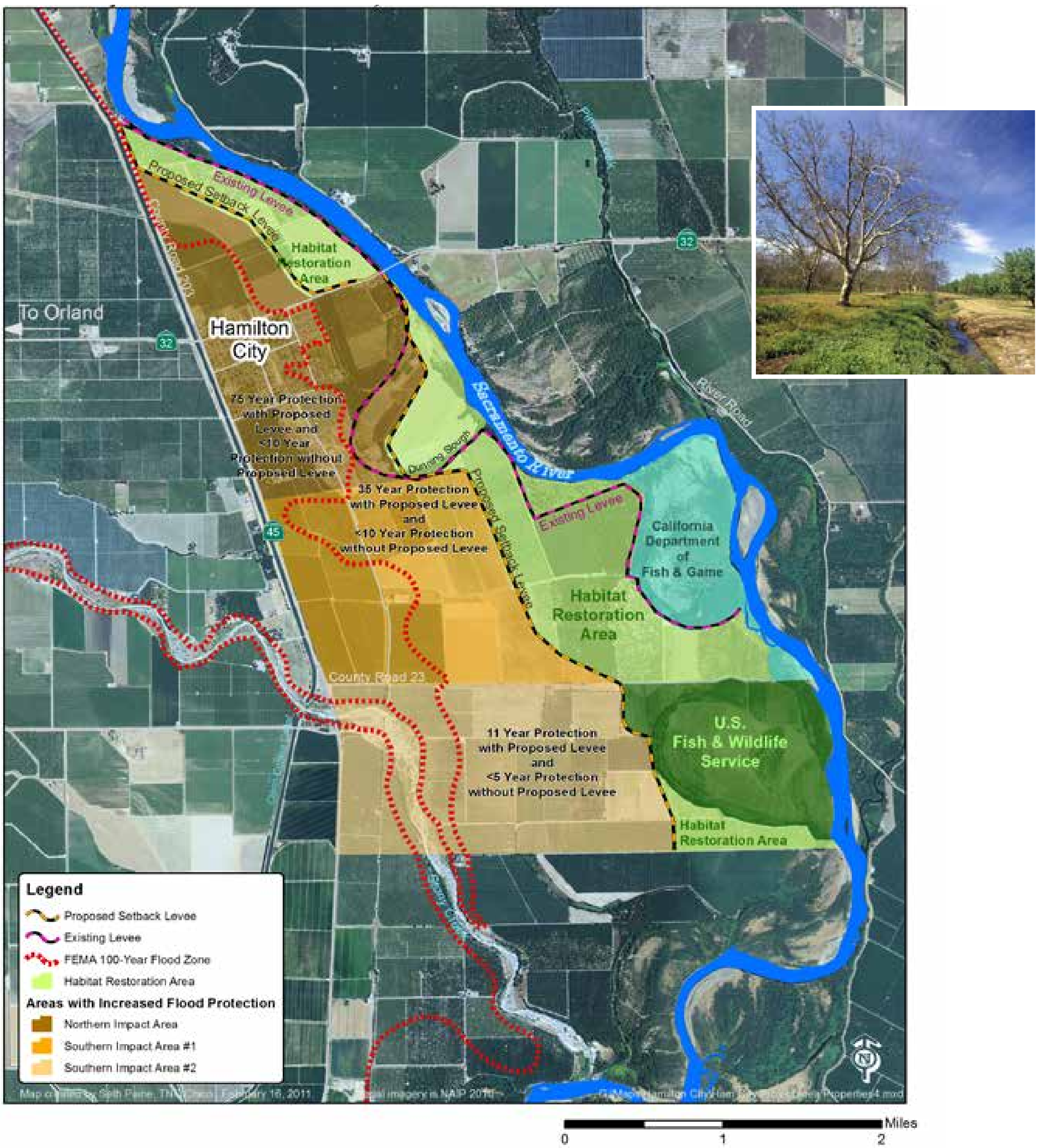
Hamilton City Flood Damage Reduction and Ecosystem Restoration Project



MAP: The new setback levee will reconnect the Sacramento River to its historic floodplain, protecting Hamilton City and making room for the restoration of 1,361 acres of river-connected habitat. © *The Nature Conservancy* **INSET:** Flood-prone land near Hamilton City will be restored to floodplain habitat. © *Grant Johnson*

CASE STUDY 2:

Napa River Restoration

Location: Napa River from Trancas Road, Napa, to where Highway 29 crosses the river, as well as Napa Creek from the confluence to one mile upstream

Summary: A "Living River" plan of restoration and flood protection provides 100-year flood protection for the city of Napa, valued at $26 million annually; restores more than 900 acres of tidal wetlands and 135 acres of floodplain and associated habitat; and improves the aesthetics and visibility of the river for the community.[15]

Estimated Cost: $500 million[16]

Vulnerability Addressed: The Napa River and Napa Creek presented a severe flood risk to the City of Napa: From 1970 to 1998, flood damage totaled $542 million (actual damage valued in the year of each event). The 1986 flood alone, estimated to be a 50-year event, caused $100 million in damage (1986 dollars). The new project will provide protection from 100-year floods.

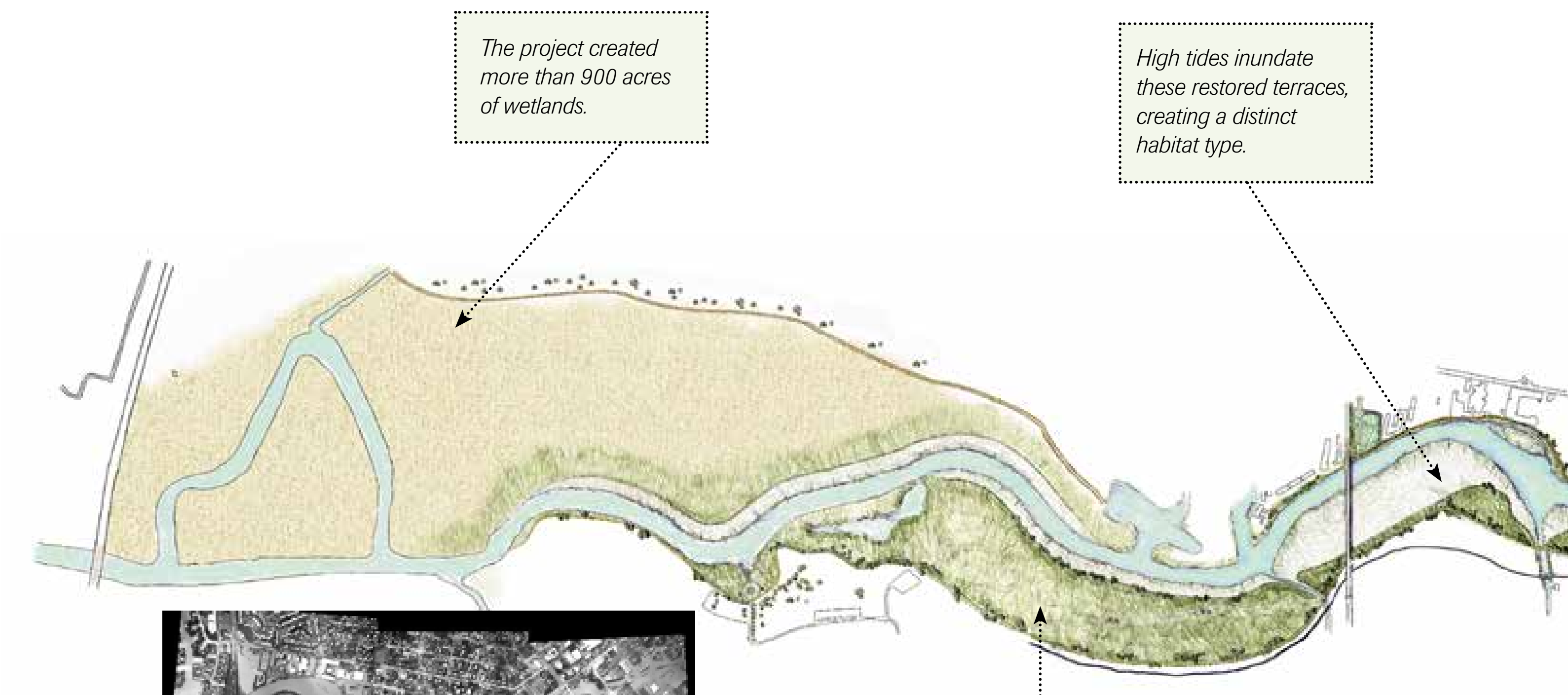


PHOTO: Flooding along the Napa River in February, 1986
© Napa County Flood Control and Water Conservation District

THE PROJECT: Congress authorized a flood control project for the Napa River in 1965. In 1975, the Army Corps of Engineers prepared a plan to deepen, straighten and armor the river channel, but local residents twice voted not to approve a sales tax increase to fund it. In 1995, the Corps presented a similar plan; it too was abandoned due to opposition from local groups as well as state water quality regulators.

From 1995 through 1997, local leaders, environmental and business groups, and state agencies worked with the Corps to draft a "Living River" plan that would yield 100-year flood protection through a combination of gray and green measures: restored floodplain areas as well as restored downstream wetlands to give the river room to spread out and provide wildlife habitat, combined with levees and rock and concrete structures where needed. The plan also added trails and a downtown riverfront promenade, turning the river into a community amenity.

The projected cost of the new plan was 42 percent higher than the Corps' 1995 proposed plan,[17] but the community was mobilized in favor of it. In November 1997, a two-thirds majority of Napa County voters approved a sales tax increase to provide the local share of the funds for the project.

STATUS: As of June 2013, the project is roughly 70 percent complete.

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15. *http://www.countyofnapa.org/FloodDistrict/*
16. *2013 Napa County Flood Control and Water Conservation District estimate for total actual expenditures to date and projected future expenditures to complete the project.*
17. *U.S. Army Corps of Engineers, 1995. Napa River, California: Draft Supplemental General Design Memorandum/Environmental Impact Statement/Environmental Impact Report. Vol. 1. (the 1995 plan estimated cost was $115 million, compared with $168 million for the 1998 plan)*

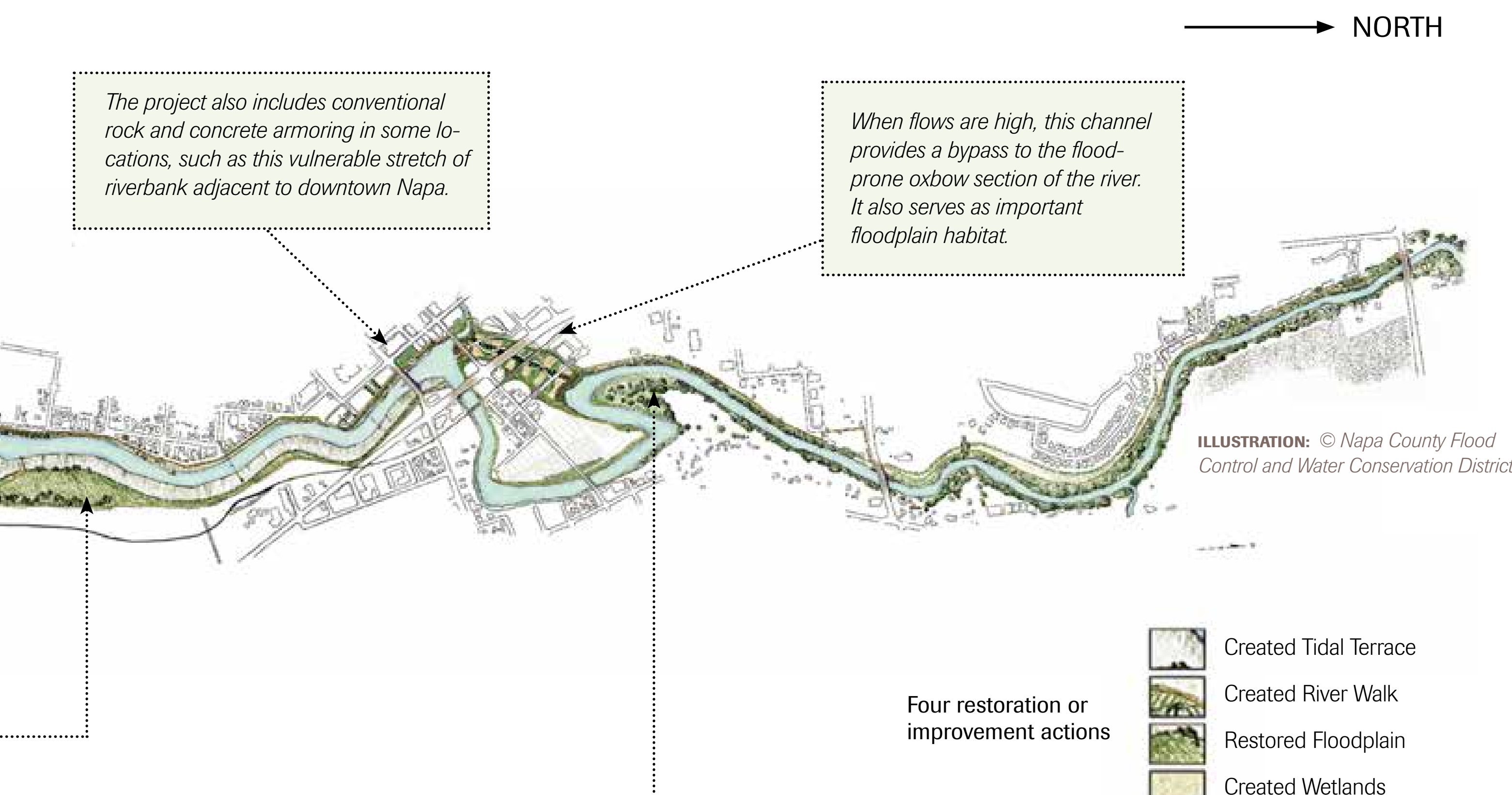

ILLUSTRATION: *© Napa County Flood Control and Water Conservation District*

CASE STUDY 3:

Yolo Bypass

Location: A 37-mile-long river bypass running north to south between the cities of Sacramento and Davis.

Summary: This 59,000-acre river bypass serves as a floodplain for the Sacramento River. It can convey 490,000 cubic feet of water per second, more than three times the capacity of the main Sacramento River channel as it passes downtown Sacramento.

Estimated Cost: Not available. The Yolo Bypass was part of the Sacramento River Flood Control Project, which had a reported cost in 1925 of $51 million.[18]

Vulnerability Addressed: In the 19th century, floods frequently inundated the city of Sacramento, much of which occupies the natural floodplain of the Sacramento and American rivers.

THE PROJECT: The Yolo Bypass is one of several elements of the Sacramento River Flood Control Project, which was federally authorized in 1917.[19]

When the river rises above a certain level, water flows over the Fremont Weir into the bypass. Adjustable flood gates at the Sacramento Bypass allow for additional diversions into the bypass if needed. At the downstream end of the bypass, water flows into the Sacramento–San Joaquin Delta.

The land in the bypass, which is under a mix of public and private ownership, is the largest contiguous area of river floodplain remaining in the Central Valley. The state Department of Water Resources holds flood easements that allow for the land to be inundated. The river rises high enough to crest the Fremont Weir and send water into the bypass in roughly 60 percent of all years.

The Yolo Bypass is an excellent example of the multiple benefits that a green infrastructure project can provide. Roughly two-thirds of the bypass land is farmed—crops include rice, tomatoes, corn, millet, wheat and safflower—or used for grazing livestock, generating as much as $50 million in agricultural revenue annually. An area of more than 16,000 acres makes up the Yolo Bypass Wildlife Area, which includes restored wetlands as well as uplands. The bypass provides thousands of acres of migratory bird habitat, which has substantial economic value: Elsewhere in the Central Valley, programs to incentivize bird-friendly management of agricultural land cost roughly $30 per acre annually.[20]

Inundation of the bypass also creates prime habitat for many native fish, including Sacramento splittail, Chinook salmon, sturgeon and lamprey. The nutrient-rich seasonal wetlands provide abundant food for juvenile fish as well as protection from predators. Non-native fish, which can be predators as well as competitors for food, are generally less prevalent in the bypass than in the main channel of the Sacramento River. Sacramento splittail spawn in the bypass, and multiple migratory species benefit by using it as an alternate route to and from the Delta.[21]

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18. *The project was part of the Sacramento River Flood Control Project, which had a 1925 cost of $51 million but included many levee projects in addition to the bypass. Source: I19 U.S. Congress, Senate Document 23, 69th Congress, 1st Session (The Grant Report of the California Debris Commission January 5, 1925). The total flood control project cost included building 180 miles of bypass levees and 500 miles of river levees, and acquiring and clearing bypass areas.*

19. *California Department of Water Resources, 2012 Central Valley Flood Protection Plan. Pages 1–4.*

20. *From 2011 to 2013, Natural Resources Conservation Service contracts through the Waterbird Habitat Enhancement Program and the Migratory Bird Habitat Initiative totaled $8.7 million. These contracts covered 98,289 acres, typically for a duration of three years—or roughly $30 per acre per year. Data are from the NRCS ProTracts database, accessed August 2013.*

21. *Bay Delta Conservation Plan Draft Conservation Measure 2: Yolo Bypass Fisheries Enhancement, pages 3.4-29 to 3.4-56 in:http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/BDCP_Chapter_3_%E2%80%93_Conservation_Strategy_3-14-13.sflb.ashx.*

A "gray" alternative to the bypass would have been increased upstream reservoir storage for floodwaters. An analysis of the February 1986 flood found that during the 3-day peak, the bypass conveyed a total of 2.7 million acre-feet of water. During this period, upstream reservoirs were nearly full, meaning that roughly 2.7 million acre-feet of additional reservoir capacity would be needed to provide the same flood protection afforded by the bypass.

Controlling a flood of that size without the Yolo Bypass would require roughly doubling the amount of flood storage currently provided by upstream reservoirs[22] — something that is likely not feasible for several reasons, including a scarcity of dam sites, the high monetary and environmental costs of dam construction and popular opposition to new dams.

Replicating a project today on the scale of the Yolo Bypass would likely be very costly as well. However, major flood channel restoration projects planned for the Mississippi River in Louisiana indicate that such efforts are still feasible under the right conditions.

STATUS: A variety of modifications are being considered to optimize habitat conditions for fish species of concern. Changes may include altering the Fremont Weir to provide more control over the timing and duration of bypass inundation, and improving passage for migrating fish between the bypass and the Sacramento River.

FOR MORE INFORMATION:
California Department of Water Resources
Aquatic Ecology Section
water.ca.gov/aes/yolo/

Yolo Basin Foundation
yolobasin.org

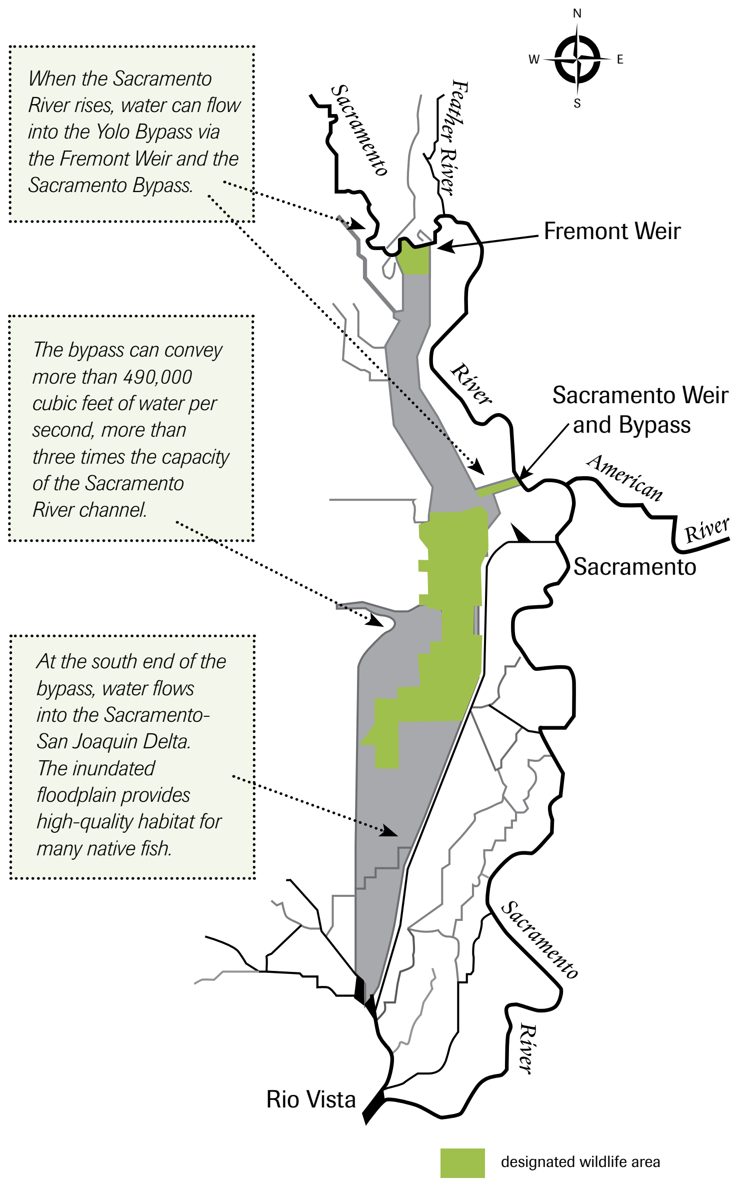

ILLUSTRATION: *© Redrawn from maps provided by the California Department of Water Resources and the California Department of Fish and Wildlife.*

22. *Opperman et al., 2011. Integrated floodplain-reservoir management as an ecosystem-based adaptation strategy to climate change. Paper for the AWRA 2011 Spring Specialty Conference. http://www.ecosystemcommons.org/sites/default/files/andrewwarner_floodplains_climate_change.pdf.*

CASE STUDY 4:

Santa Clara River Floodplain Protection Program

Location: Santa Clara River from the Ventura County line to the river mouth between the cities of Ventura and Oxnard

Summary: The project aims to preserve agricultural land in the 500-year floodplain of the Santa Clara River in Ventura County through the purchase of flood easements by The Nature Conservancy.

Estimated Cost: Easement costs and priorities are currently being evaluated.

Vulnerability Addressed: Protecting the river's floodplain from development allows flood waters to spread out over open space and farmland, reducing flood risk for downstream communities (see map on the facing page). According to a 2011 Ventura County study, if the river is leveed to allow for development in the floodplain, the risk to downstream communities would increase sharply. The estimated damage to these downstream communities from a 100-year flood would roughly double, from $182 million to $385 million. In a 500-year flood, the loss of the upstream floodplain would result in a tripling of damages, from $512 million to $1.56 billion.[23] New downstream levees could mitigate the increased risk, but at great cost—at least $300 million, according to a 2013 estimate.[24]

THE PROJECT: Though it flows through a region with significant urban and agricultural development, the Santa Clara River is one of the least altered rivers in southern California. Much of the river's natural floodplain is currently used for farming and has not been separated from the river by structural levees. However, residential development could eventually encroach on much of the floodplain and would likely be accompanied by new flood-protection levees along the river.

The Floodplain Protection Program aims to conserve the river's natural processes by purchasing easements on agricultural lands in the floodplain that will permanently protect the land from development, promote agriculture in a historic farming community and allow natural flooding to continue.

STATUS: Acquisition of flood easements for agricultural land is under way.

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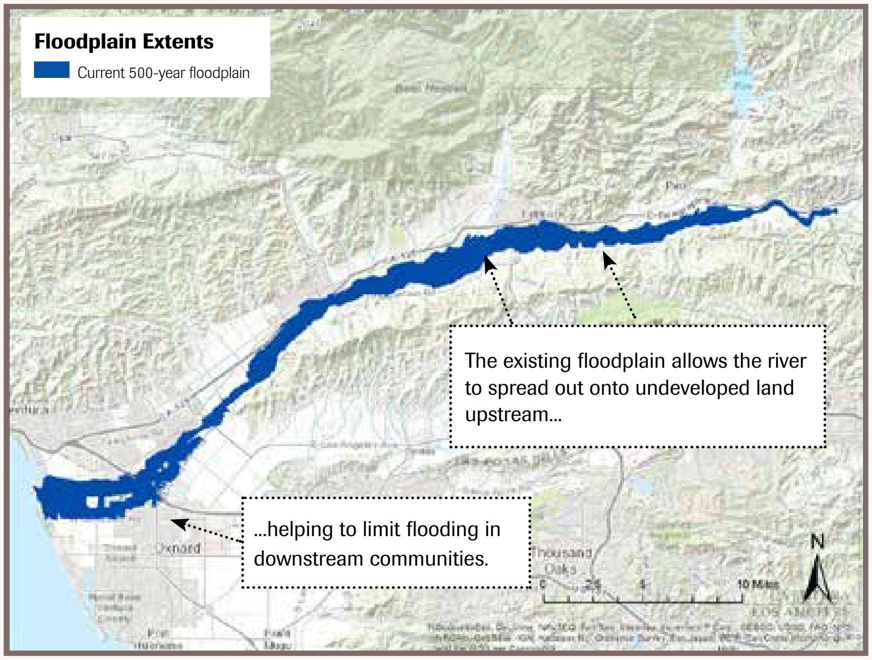
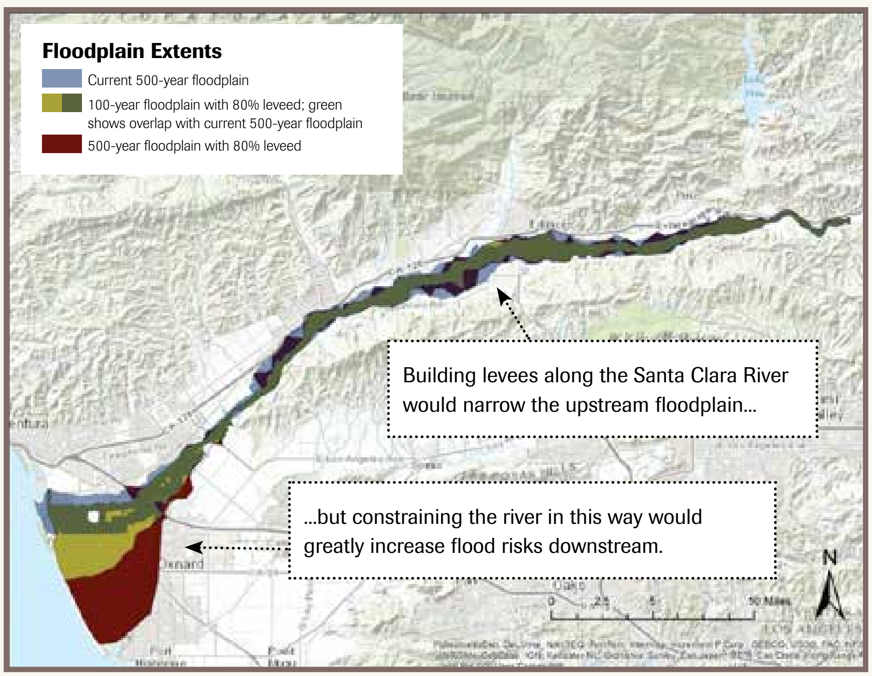
UCSB-TNC Santa Clara River Group Project
santaclararivergp.weebly.com

PHOTO: Santa Clara River © *Melinda Kelley*

23. *Ventura County Watershed Protection District, 2011. Hydraulic Impact Analysis of the Santa Clara River Floodplain Protection Program. http://www.water.ca.gov/irwm/grants/docs/Archives/Prop84/Submitted_Applications/P84_Round1_Implementation/County%20of%20Ventura/Att9_IG1_DReduc_2of2.PDF.*

24. *Watersheds Coalition of Ventura County Proposition 84 IRWMP Implementation Grant application, 2013. Page 9-5. http://portal.countyofventura.org/portal/page/portal/ceo/divisions/ira/WC/Prop84/Attachment%209%20Economic%20Analysis%20-%20Flood%20Damage%20Reduction%20Costs%20and%20Benefits.pdf.*





MAPS: © *Montgomery, J., L. Prahl, P. Schellenbarger and W. Wilkinson. 2013* Prioritization of Easements for Floodplain Conservation along the Santa Clara River. *Presentation of project results for the Master of Environmental Science & Management Program at the Bren School of Environmental Science and Management, University of California, Santa Barbara.*

The increased flood damages if the river is 80% leveed are estimated at $204 million for a 100-year flood and $1.04 billion for a 500-year flood. Conserving the existing floodplain avoids these increased risks.

CASE STUDY 5:
Surfers Point Managed Retreat

Location: Surfers Point, Ventura

Summary: The project relocated erosion-damaged infrastructure inland as an alternative to the construction of a seawall. Natural shoreline processes were restored by replacing a 65-foot-by-900-foot stretch of paved beachfront land with a cobble berm covered by vegetated dunes.

Cost: $4.5 million.[25] A concrete-and-rock seawall would have cost an estimated $5,000 to $10,000 per linear foot,[26] or $4.5 million to $9 million for the 900-foot length of the project.

Vulnerability Addressed: The project removes and relocates infrastructure at risk of erosion—a bike path and a portion of a parking lot—and replaces it with a cobble berm and sand dunes that will provide sustainable protection for remaining structures.

THE PROJECT: In 1992, winter storms eroded a new beachfront bike path, owned by the California Department of Parks and Recreation, and damaged the adjacent parking lot for the Ventura County Fairgrounds. Local officials proposed the construction of a seawall to stop further erosion. The Surfrider Foundation and the California State Coastal Conservancy opposed the sea wall plan, which would have reduced the habitat and recreational value of the site and, by altering wave patterns, likely increased erosion rates on nearby beaches.

After much discussion, the many parties with an interest in the site agreed on a "managed retreat" approach for the site. In 2001, a plan was developed to relocate an 1,800-foot section of pathway and a parking lot 65 feet inland. In the retreat zone, a cobble berm beneath dunes and native vegetation is engineered to be resilient to erosion while restoring habitat and preserving the site's value for surfers and other beachgoers. Construction on Phase 1, covering a 900-foot reach, was completed in 2011.

STATUS: The constructed berm and dunes have resisted erosion through two winters; monitoring is ongoing. Phase 2 of the project is on hold, due in part to a lack of funding.

FOR MORE INFORMATION:

NOAA Managed Retreat Case Studies
tinyurl.com/ccr2wjz

Ventura River Ecosystem blog
venturariver.org

Los Angeles Times 2011 article
tinyurl.com/mbeg9sg

Paul Jenkin, Surfrider Foundation
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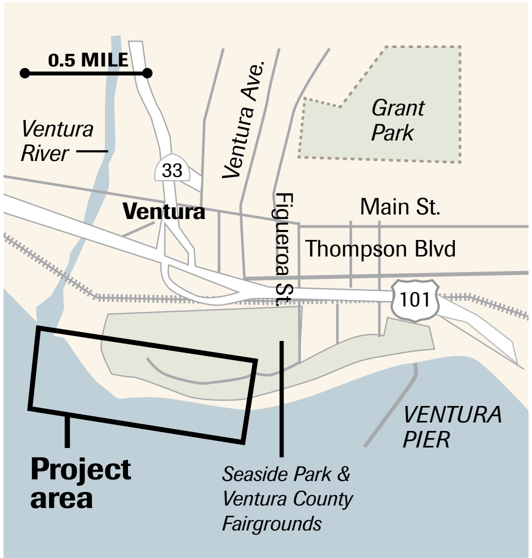
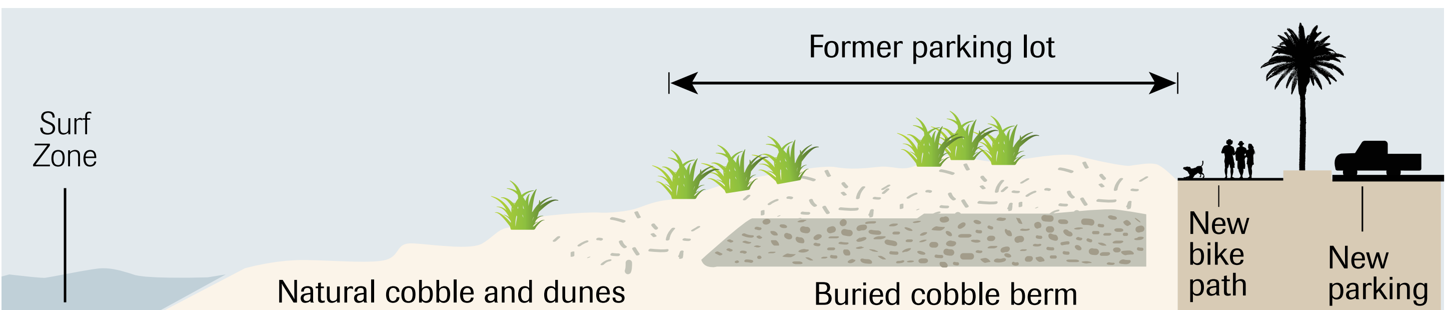
Joe McDermott, City of Ventura
jmcdermott@ci.ventura.ca.us

25. *2011 construction cost.*

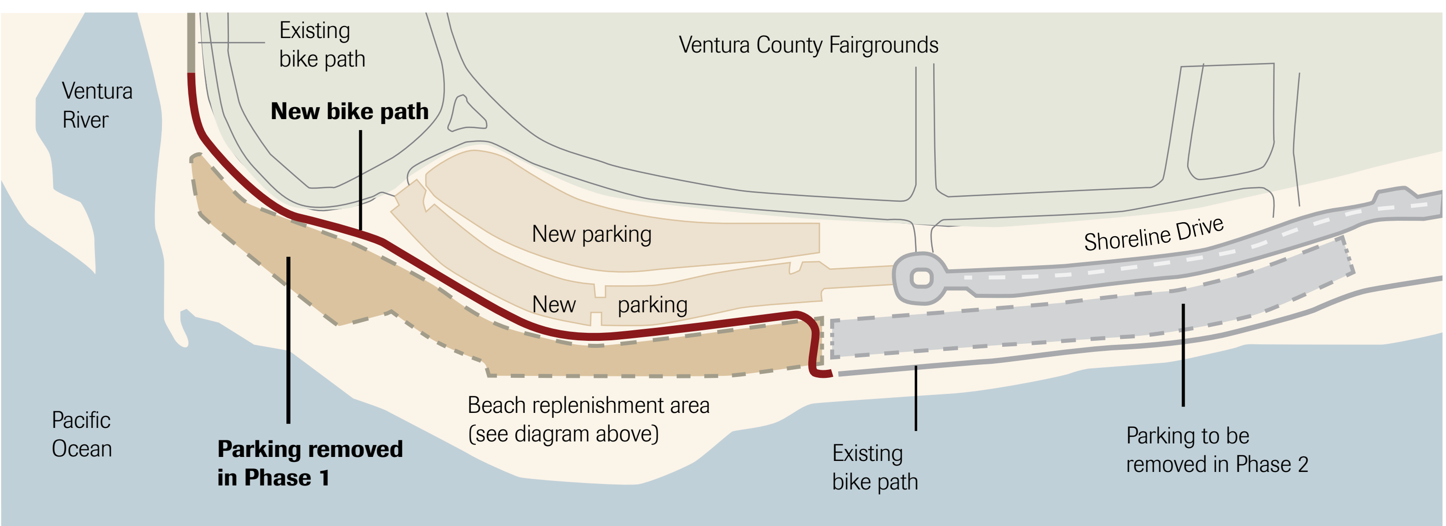
26. *Bob Battalio, Principal Engineer, ESA PWA, pers. comm.*



Before project construction: Coastal erosion had destroyed a bike path and damaged a parking area for the Ventura County Fairgrounds.



Under the managed retreat plan, the bike path and parking lot were relocated inland (below). An eight-foot-thick berm of cobblestones beneath vegetated dunes was built in place of the parking lot (above), restoring habitat and beach processes while providing erosion protection.



Surfers Point Managed Retreat: Phase 1 Construction (completed 2011)

CASE STUDY 6:

Aramburu Island Coarse Beach Restoration

Location: Aramburu Island, on the Mill Valley shore, San Francisco Bay

Summary: A 500-meter-long resilient coarse beach of gravel and oyster shells was built in 2011 and 2012 on the bayward side of the 17-acre island in Richardson Bay.

Estimated Cost: Beach construction totaled roughly $500,000; with other restoration measures, the project cost totaled $2.6 million.

Vulnerability Addressed: Rising sea levels will increase shoreline erosion and strain tidal ecosystems.

THE PROJECT: Coarse gravel and cobble beaches occur naturally in many places along the Pacific coast and in San Francisco Bay. In appropriate sites, engineered beaches of this type can provide erosion protection that is as effective as the traditional alternative—rock armoring—but less expensive to build, while also offering habitat and aesthetic benefits.

Aramburu Island was created in the 1950s by the dumping of waste soil from dredging and upland excavation and was soon colonized by invasive vegetation. While birds and harbor seals used the island, habitat quality was generally low. In addition, fine sediment on the eastern shore of the island was exposed to waves from San Francisco Bay, and the island was eroding steadily. The Richardson Bay Audubon Center and Sanctuary and the County of Marin led a multifaceted restoration project, completed in 2012, that included an erosion-resistant coarse gravel beach as well as restoration of uplands and tidal wetlands to increase the island's resilience to sea level rise, enhance habitat for birds, harbor seals and rare salt marsh plants and establish native upland vegetation.

The beach slope and gravel type used for the beach restoration were selected based on observations of natural coarse beaches that exist at sites elsewhere in San Francisco Bay that have similar exposure to waves.

Building an erosion-resistant beach with gravel or cobbles can be significantly less expensive than installing riprap, due to lower materials costs and less need for heavy equipment during construction. For example, at Cape Lookout State Park on the Oregon coast, a 250-meter cobble berm and artificial sand dune coastal project was built in 2001 for $125,000, while the cost of a riprap revetment at the site was estimated at $500,000.[27/28]

STATUS: Construction on the Aramburu Island project was completed in 2012, with revegetation efforts scheduled to continue until 2015. The project is being monitored systematically, and results will inform the design of erosion-resistant restored shorelines elsewhere. Because few projects of this type have been built, pilot studies are needed to establish engineering parameters.

FOR MORE INFORMATION:

Richardson Bay Audubon
tinyurl.com/kouyg6j

Initial 2010 Project Study
bit.ly/1dQwHcR

Rachel Spadafore, Richardson Bay Audubon Center & Sanctuary
rspadafore@audubon.org

27. *Komar, Paul, 2007. The Design of Stable and Aesthetic Beach Fills: Learning From Nature. Coastal Sediments '07 (Proceedings of the Sixth International Symposium and Science of Coastal Sediment Process, New Orleans, May 13–17, 2007). http://ascelibrary.org/doi/pdf/10.1061/40926(239)32.*

28. *Allan, J.C. et al., 2006. The use of Passive Integrated Transponder tags to trace cobble transport in a mixed sand-and-gravel beach on the high-energy Oregon coast, USA. Marine Geology 232. 63–68.*

Pre-construction

Before construction (left), the eastern shore of Aramburu Island was eroding steadily and provided low-quality shoreline habitat. The coarse beach built in 2011 and 2012 (below), modeled after naturally occurring beaches elsewhere along San Francisco Bay, is more resilient to erosion and provides higher quality habitat.

Post-construction

PHOTOS: © *Richardson Bay Audubon Center & Sanctuary*

CASE STUDY 7:

The San Francisco Bay Living Shorelines: Nearshore Linkages Project

Location: Shorelines of San Rafael and Hayward

Summary: A variety of designs for engineered oyster habitat and restored eelgrass beds are being evaluated at two sites in San Francisco Bay.

Estimated Cost: Construction costs for a one-acre pilot site in 2012 were roughly $300,000. No detailed estimates are available for larger-scale projects. Full-scale engineered oyster reef projects on the Gulf Coast have been constructed at costs as low as $1 million per linear mile.[29]

Vulnerability Addressed: Rising sea levels will increase shoreline erosion and strain subtidal ecosystems.

THE PROJECT: Engineered oyster reefs are being installed in many coastal and estuarine locations in the eastern United States and along the Gulf of Mexico to restore oyster habitat and also, in some cases, to attenuate wave energy to reduce erosion. The Living Shorelines: Nearshore Linkages Project, led by the California State Coastal Conservancy, is testing similar approaches in San Francisco Bay. The San Rafael Bay site is located on property owned by The Nature Conservancy.

The project evaluates several designs for constructed native Olympia oyster reefs as well as restored eelgrass beds, which provide complementary habitat. Eelgrass and native oyster beds were once widespread in San Francisco Bay. They were selected for restoration because together they provide a variety of habitat features that support many species of invertebrates, fish and waterbirds. The San Francisco Bay Subtidal Goals Project has set a restoration target of 8,000 acres of oyster habitat and 8,000 acres of eelgrass beds.

The Living Shorelines Project is designed to see if the two habitat types also increase sedimentation and reduce wave energy, both of which reduce erosion and may facilitate the migration of subtidal habitats and the protection of adjacent tidal marshes as sea level rises. These physical effects may reduce the need to armor the shoreline of the bay as sea level rises.

For erosion control, a typical gray alternative to these habitat-oriented approaches would be a rock breakwater. Costs of both the green and gray approaches can be expected to vary widely by site due to variation in sediment and wave conditions. These variations influence the type and quantity of rock or oyster reef material appropriate for the site as well as the complexity and expense of construction.

STATUS: Researchers are evaluating the pilot sites to assess the performance of each design and to measure wave attenuation. The results will inform the design of future projects.

FOR MORE INFORMATION:
Project Description
tinyurl.com/ljsfkev

San Francisco Bay Subtidal Habitat Goals Project
sfbaysubtidal.org

Marilyn Latta, Project Manager,
State Coastal Conservancy
mlatta@scc.ca.gov

OPPOSITE PAGE: The Living Shorelines: Nearshore Linkages project is testing several alternative designs for engineered oyster reefs in San Francisco Bay. The reefs reduce wave energy while providing habitat. © *California State Coastal Conservancy*

29. *Timm Kroeger and Jeff DeQuattro, The Nature Conservancy Alabama, pers. Comm.*

CASE STUDY 8:
The Horizontal Levee Concept

Location: Concept for San Francisco Bay

Summary: The Horizontal Levee concept integrates the natural flood risk reduction properties of tidal marshes into a shoreline management strategy. This strategy would meet marsh restoration and flood management objectives, while also addressing water quality issues in the bay.

Cost: Capitalizing on the capacity of tidal marshes to reduce the height of storm waves could reduce levee construction costs by 50 percent.

Vulnerability Addressed: In San Francisco Bay, rising sea levels threaten to overwhelm the flood protection capacity of existing levees and drown tidal marshes. Wastewater treatment infrastructure is particularly at risk.

THE CONCEPT: The Horizontal Levee strategy envisions abandoning existing bayshore levees (bayward of the constructed salt ponds that exist along much of the eastern shoreline of the bay) in favor of smaller inland levees behind restored tidal marsh (Figure 1). Because the restored marsh would substantially reduce wave energy, a smaller inland levee could provide the same level of flood protection as a large bayshore levee. The strategy would complement ongoing tidal marsh restoration efforts in San Francisco Bay begun in the 1980s while providing necessary flood protection for homes and businesses close to the shore.

Where appropriate for the bay's ecology and development, the Horizontal Levee concept could be extended to include additional multiple-benefit features (Figures 2 and 3). The tidal marsh could transition into gently sloping upland (potentially built using material dredged from local flood channels), which would facilitate landward migration of tidal habitats as sea level rises. These upland areas could also be used to address issues associated with the disposal of effluent from the many wastewater treatment plants along the shore of the bay. Treated effluent from these facilities could be used to irrigate native freshwater marsh vegetation, a strategy that would reduce the flow of nitrogen to the bay while also reducing the costs wastewater treatment plants incur to pump and discharge effluent.

The study compared the cost of the Horizontal Levee with upgrading existing levees, assuming 14 inches of sea level rise over 50 years. The study found that the cost of raising and maintaining an existing bayshore levee was twice that of the cost to build and maintain a smaller levee behind a roughly 150-foot-wide restored marsh. The reduced cost stems from the difference in size between the two levees, which translates into large savings on construction costs for the smaller levee. The study did not account for land acquisition costs or other complications associated with moving the levee inland; the assumption is that Horizontal Levee implementation would be coordinated with ongoing salt pond restoration efforts.

FOR MORE INFORMATION:

2013 Horizontal Levee study for The Bay Institute
bay.org/publications/the-horizontal-levee

2013 Innovative Wetland Adaptation Techniques Project for the San Francisco Bay Conservation and Development Commission
tinyurl.com/kwnroqs

2010 Sea Level Rise study for the Hayward Area Shoreline Planning Agency
tinyurl.com/7jd8vza

> The study found that the cost of raising and maintaining an existing bayshore levee was twice that of the cost to build and maintain a smaller levee behind a roughly 150-foot-wide restored marsh.

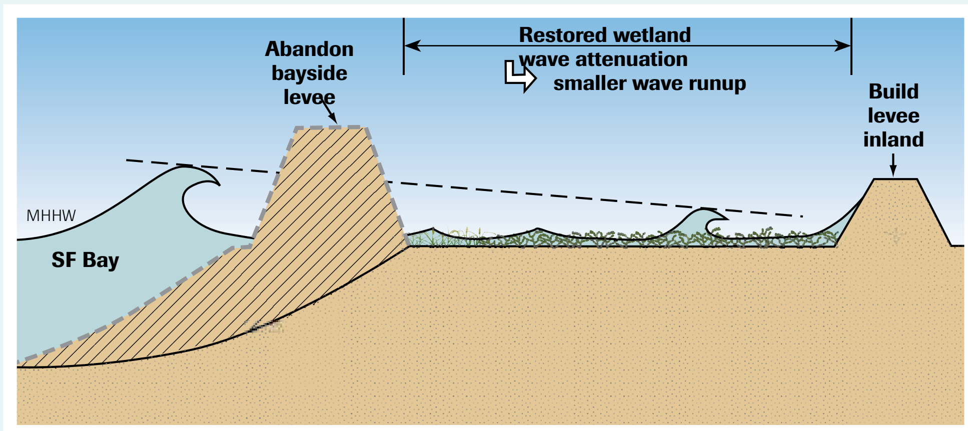


Figure 1: Tidal marshlands reduce wave energy substantially. Modeling results indicate that it would be cost-effective to abandon deteriorating bayshore levees in favor of smaller levees built landward of restored tidal marshes. This strategy would meet both ecological restoration and long-term flood risk management goals.

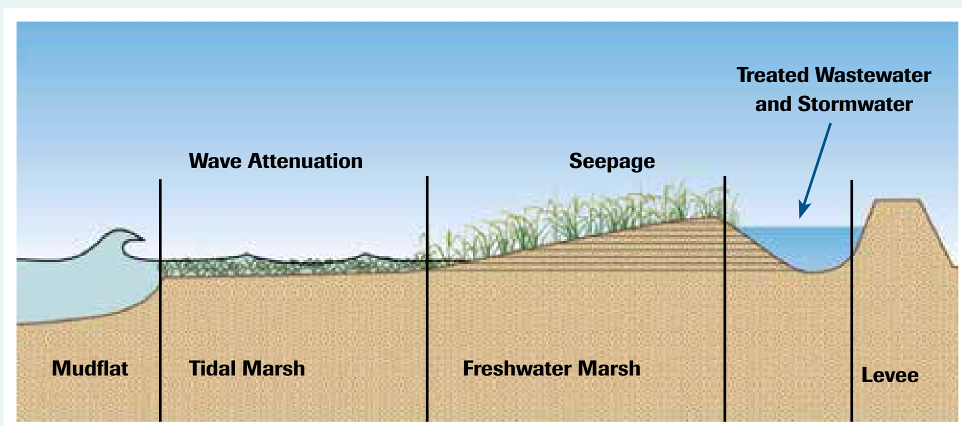


Figure 2

Figures 2 and 3: These illustrations show cross-sections of a conceptual, multiple-benefit Horizontal Levee design, showing four zones: 1) tidal mudflat habitat; 2) a tidal marsh, which attenuates waves in addition to providing habitat; 3) a sloping, vegetated freshwater habitat zone irrigated with treated wastewater and stormwater, which would help to address water quality issues associated with discharges into the bay; and 4) a flood risk management levee. As sea level rises, the sloping profile facilitates landward migration of tidal habitats.

Figure 3

ILLUSTRATIONS: *© ESA PWA 2012*

CASE STUDY 9:

Monterey Bay Coastal Erosion Mitigation Alternatives Study

Location: Southern Monterey Bay coast

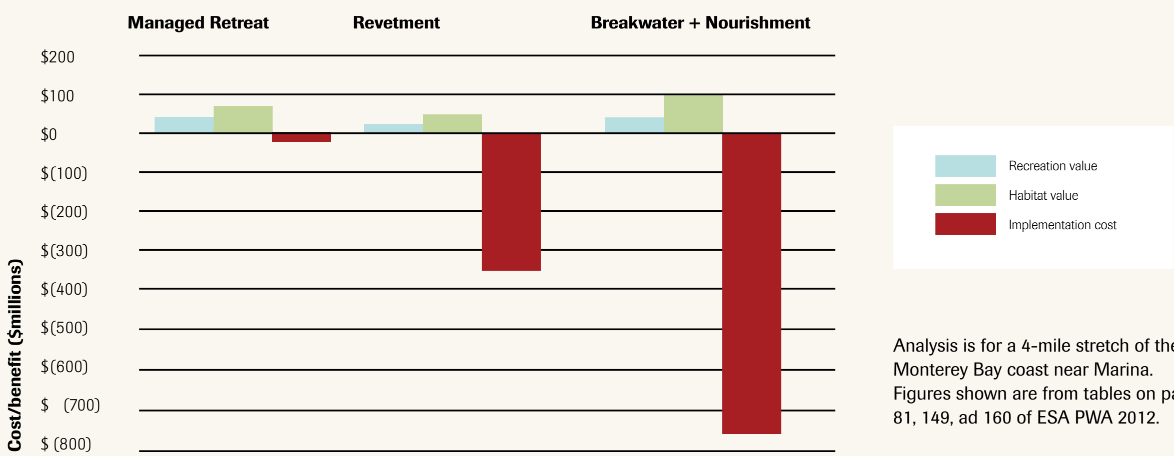
Summary: An analysis[30] of the Monterey Bay coast compared the costs and benefits of revetments (rock armoring), off-shore breakwaters, managed retreat (acquiring easements to allow natural shoreline erosion to proceed), and other erosion mitigation alternatives. For one 4-mile coastal reach, the study found that a managed retreat approach would deliver habitat and recreation benefits nearly four times greater than project implementation costs. By contrast, the cost to build revetments or breakwaters at the same site would be much greater than the value of the benefits provided by either of those strategies.

Vulnerability Addressed: The southern Monterey Bay coastline is on average the most erosive sandy shore in California.[31] Sea level rise is expected to accelerate coastal erosion.[32]

THE STUDY: Options for mitigating coastal erosion influence habitat and recreation values and carry a wide range of economic costs. A 2012 study by ESA PWA for the Monterey Bay Sanctuary Foundation and the Southern Monterey Bay Coastal Erosion Working Group evaluated the costs and benefits of more than 20 potential strategies for responding to the high rate of erosion in Monterey Bay.

The chart below compares the net present value of the costs and benefits over 100 years of two engineered approaches—revetments and the combination of off-shore breakwaters and beach nourishment (sand addition)—as well as managed retreat (see illustration below) facilitated by the acquisition of easements that would allow for the erosion of coastal property. The figures shown are for a 4-mile section of coast near the towns of Marina and Seaside.

100-year Benefits and Costs of Erosion Mitigation Alternatives, Marina Study Area



Analysis is for a 4-mile stretch of the Monterey Bay coast near Marina. Figures shown are from tables on pages 81, 149, ad 160 of ESA PWA 2012.

ILLUSTRATION: *© Data from ESA PWA 2012*

30. *ESA PWA 2012, Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay. Report prepared for the Monterey Bay Sanctuary Foundation and the Southern Monterey Bay Coastal Erosion Working Group. May 30, 2012. Available at http://montereybay.noaa.gov/research/techreports/tresapwa2012.html.*
31. *Hapke, C., D. Reid, B. Richmond, P. Ruggiero, and J. List, 2006, "National Assessment of Shoreline Change, Part 3: Historical Shoreline Change and Associated Land Loss Along Sandy Shorelines of the California Coast." Santa Cruz, California: U.S. Geological Survey Open-file Report 2006-1219, p.#79.*
32. *The analysis in this study is based on current rather than projected future erosion rates.*

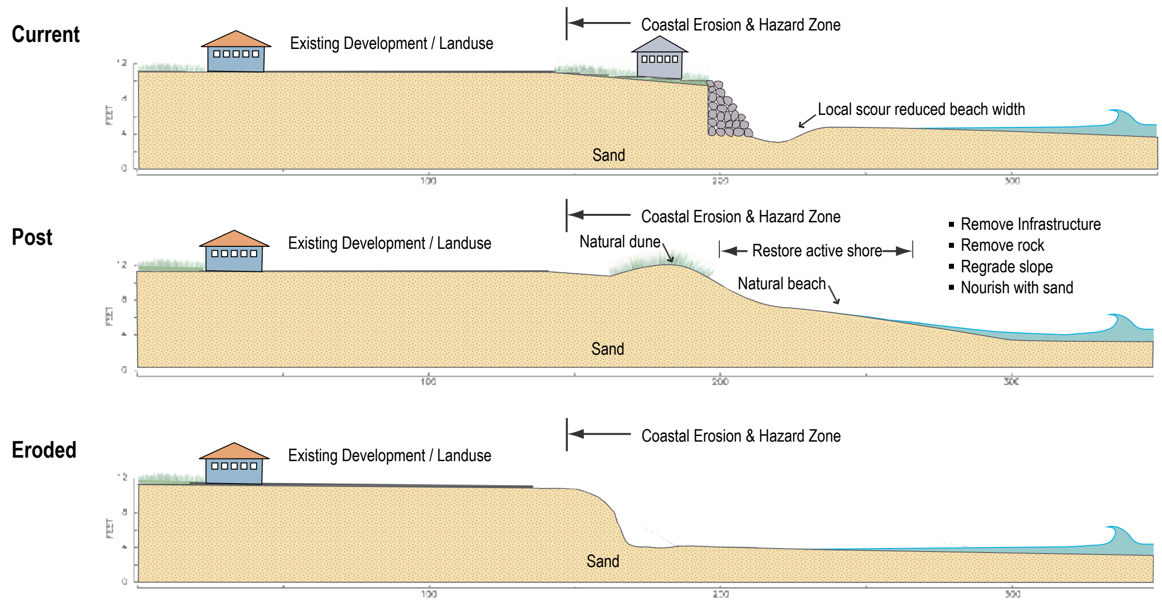


ILLUSTRATION: In appropriate locations, managed retreat can be a cost-effective way to preserve coastal habitat and recreation benefits on erosion-prone coastlines. © *ESA PWA*

The construction and maintenance costs of the engineered structures greatly exceed the easement cost of the land required for the managed retreat strategy. Habitat and recreation values are lowest for the rock revetment strategy, because it would result in the least amount of beach area. The breakwater option would be implemented with a beach nourishment program that would provide for a broad beach, so it provides greater habitat and recreation than managed retreat.

The study does not account for reductions in property tax revenue due to the loss of land to erosion. On the other hand, it does not account for increases in sales tax revenue associated with coastal recreation value.

FOR MORE INFORMATION:
2012 ESA PWA Study
tinyurl.com/nxylahc

Conclusion

Green infrastructure is already working across California to protect communities from the effects of rising sea levels and more extreme weather. The case studies presented here illustrate that several key features of green infrastructure make it a competitive strategy for adapting to climate change in a wide range of settings:

Cost: By working *with* natural river and coastal processes instead of against them, green infrastructure designs can avoid the high capital costs of defensive strategies like rock armoring, can have lower long-term maintenance costs and can take less time to implement. In some cases, the cost savings for natural infrastructure can be quite significant.

Diversity: These projects have been developed successfully in a wide range of California climates, habitat types and topographies. In each case, attention to the workings of local natural systems has guided the green infrastructure design.

Flexibility: Many green infrastructure projects are designed with the capacity to adapt to changing river flow and sea level conditions.

Multiple Benefits: The natural systems at the heart of protective green infrastructure can also provide habitat, support recreation, improve water quality and deliver economic and other societal benefits.

Community Value: By conserving and restoring natural landscapes and habitats, green infrastructure projects tend to be popular with communities, which can be critical to raising project funds and building political support. Furthermore, green infrastructure projects often enhance existing restoration and conservation efforts.

Recommendations

CONDUCT ECONOMIC ANALYSES: ***Project proponents should conduct rigorous economic analyses on current and future green infrastructure projects.***

Lack of information often complicates the economic comparison of green and gray options. For instance, the value of benefits provided has not been quantified for most projects; and detailed, publicly available comparisons of the costs and benefits of the gray alternative (that is, the project that was *not* built) to a green project often do not exist.

To better evaluate the economic case for green infrastructure, rigorous analyses are needed and should include the following elements:

- *A description*—including construction, permitting, mitigation, and long-term operations and maintenance cost estimates—of the most likely alternative gray infrastructure approach at the site that would provide equivalent risk reduction.
- *An assessment*—as quantitative as possible—of the value of ecosystem services provided by the green project and its gray alternative.
- *An analysis* of the costs and benefits of both projects.

STRENGTHEN PUBLIC SECTOR SUPPORT: ***Because of the multiple benefits of green infrastructure, federal, state, and local governments should provide policy support and facilitate research to advance the field.***

Policy support: State and federal policymakers should:

- Direct implementing agencies to consider green infrastructure alternatives for all coastal and flood protection projects
- Encourage the incorporation of natural flood protection processes, such as the reduction of storm wave height by tidal marshes, into flood-control infrastructure standards.

Research support:

- Research and pilot projects are needed to better understand the tradeoffs involved in green infrastructure strategies. For instance, the construction and monitoring of pilot projects is key to the development of engineering standards for coarse gravel and cobble beaches, a natural approach to coastal erosion protection. While modeling indicates that these approaches will be effective, empirical evidence under a variety of conditions is needed before such projects can be implemented on a large scale.

MAKE GREEN INFRASTRUCTURE A PART OF THE PLANNING PROCESS: ***Local planners should consider green infrastructure in climate adaptation planning.***

Where feasible, green infrastructure can be a cost-effective way to provide necessary flood and coastal protection while advancing other conservation, environmental quality, and recreational objectives. It should be evaluated alongside other options as local governments prepare for sea level rise and more extreme weather, for instance through the Local Coastal Plan update process.

By fostering the spread of green infrastructure, California can prepare for the effects of climate change while enhancing natural habitats and reducing flood risks for communities.

TOP PHOTO: A family picnics on the shore of a lake © *Pete Spiro*
BOTTOM PHOTO: Flooded pedestrian boardwalk, San Francisco marina © *Matt J Richardson/California King Tides Initiative*

"We're going to need to get prepared. And that's why this plan will also protect critical sectors of our economy and prepare the United States for the impacts of climate change that we cannot avoid. States and cities across the country are already taking it upon themselves to get ready... And we'll partner with communities seeking help to prepare for droughts and floods, reduce the risk of wildfires, protect the dunes and wetlands that pull double duty as green space and as natural storm barriers."

– President Barack Obama, June 25, 2013

FACT SHEET: Executive Order on Climate Preparedness—November 1, 2013
1.usa.gov/1dhWwOg