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California Coastal Management with a Changing Climate

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California is likely to face significant challenges to coastal management as a result of climate change, both along the ocean coastline and within the San Francisco Estuary. Some types of impacts - notably from sea level rise and increasing storm surges - are fairly certain, although there is uncertainty about the pace of change. Recent models predict roughly one foot of sea level rise by mid-century, and three or more feet by the end of the century.

Adaptation tools exist for dealing with the resulting coastal erosion and increased risk of flooding anticipated over this century, but they involve significant costs and tradeoffs. At one end of the spectrum, coastal armoring can protect developed coastal lands, at least for moderate levels of sea level rise, but it destroys beaches and habitat. At the other end, strategies involving retreat can lessen the damage to habitat and public coastal access, but at the price of losing development. The tradeoffs are perhaps less stark for new development – for which restrictions on where and how to build are the key adaptation tools – but the added costs of these measures for private property owners (or for the state when unavoidable takings issues arise) can make them unpopular.

Fortunately, California already has a set of policies and institutions that aim to balance the competing objectives for coastal development. Measures such as "no further armoring," which limits the rights of landowners to put in new protective devices, greater setbacks for new development, and planned relocation of stretches of the coastal highway, reflect the fruits of this policy focus.

However, coastal management agencies are at the very early stages of understanding what more needs to be done to facilitate adaptation to climate change. Both the California Coastal Commission and the San Francisco Bay Conservation and Development Commission have taken up the issue, as have a handful of local entities. But there has yet been little broad strategic thinking about whether and how the state's coastal policy should change to accommodate the anticipated climate impacts, or which new actions could facilitate a reduction in vulnerability. What steps should be taken as preventive measures, and which actions can wait until events unfold? Where are existing rules and procedures adequate to the task, and where are regulatory or legal reforms needed? Where do we need more information to guide these decisions?

The following priorities should be addressed to make progress in this direction: (i) inventorying coastal resources to provide a firmer basis for balancing decisions on property and habitat protection, (ii) identifying opportunities for coastal habitat migration, (iii) assessing the vulnerabilities of existing and planned coastal infrastructure, (iv) providing planning guidelines on sea level rise to agencies with coastal assets (including local governments, infrastructure providers, and environmental managers), (v) easing the rules on local funding of flood management investments, and (vi) experimenting with alternatives to armoring as a way of managing the changing coastline.

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Introduction

"Coasts are inherently dangerous places. The job of managers is to get things to operate somewhat rationally." California coastal manager, 2007.

California is endowed with a 1,250 mile ocean coastline, a dynamic and rich resource. It is also home to the San Francisco Estuary, the largest estuary on the Pacific side of the western hemisphere –– a network of interior bays with nearly 300 miles of coastline, connected on their eastern edge to some 700 miles of waterways that meander through the islands of the Sacramento-San Joaquin Delta. The ocean coastline is geologically diverse, with broad sandy beaches, primarily in southern California, and rocky cliffs, primarily in the central and northern parts of the state. The San Francisco estuarine coastline consists largely of low-lying earthen shores, in many places built upon landfill, often protected by earthen and rock levees.

These coastal environments are valued ecological resources, providing habitat for numerous aquatic and terrestrial species. Although large parts of the coastline are still relatively undeveloped, the coast was the state's historical growth corridor and is home to California's two largest population centers – in the south from Santa Barbara to San Diego, and in the nine-county San Francisco Bay Area. Coastal development has been accompanied by significant investments in public infrastructure, including roads, airports, and harbors. A network of state and federal parks run along the coastline, supporting a thriving recreational sector (Kildow and Colgan, 2005).

Balancing economic development, population growth, and habitat and environmental protection in the face of nature's dynamic forces makes management and planning on California's coast a constant struggle. In the 1960s and 1970s, the state established a regulatory framework to help meet these potentially competing goals, through coastal plans and permitting processes. Tradeoffs exist because one of the primary means of protecting buildings and infrastructure is to "harden" the coastline by erecting coastal armoring, which is detrimental to beaches, public access, and habitat.

In this report, we examine the challenges California's coastal managers will face as a result of a changing climate, the adaptation tools that are available, and the extent to which federal, state, regional and local institutions are prepared for changing conditions. We find that climate change will reinforce the management tradeoffs that are already present, bringing new challenges to the balancing act between nature and coastal development. We conclude with some priority areas for action to improve the state's preparedness.

Climate Change Risks to California's Coastal Areas

Potential Climate Impacts

Numerous dimensions of climatic change may affect the state's coastal areas, ranging from sea level rise, to changing ocean temperatures, to interactions with other climatic processes such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Among these, the only areas for which there is some certainty about impacts are sea level rise and increasing storm surges.

Sea Level Rise and Increases in Storm Surges

Sea level rise is perhaps the greatest single climate-related threat to California's coastline. Although sea level has been rising since the end of the last ice age, recent scientific predictions anticipate the onset of an accelerated pace – with some uncertainty about the rate of change.[1] One widely cited study, which factors in recent increases in the pace of sea level rise, projects 8 to 16 inches of increase by mid-century and 20 to 55 inches by the end of this century (Rahmstorf, 2007). Such a shift will have significant consequences for the California coastline, entailing increased bluff erosion, loss of beaches and wetlands, and threats to private and public structures and infrastructure from erosion and coastal flooding. The issue is not simply one of impacts from a gradual rise in the average water levels; higher averages also imply more frequent and more powerful storms and wave attacks, which will exacerbate erosion and shoreline retreat. Although these processes are well understood in general terms, it is very difficult to predict the precise patterns and pace of erosion along the ocean coastline.[2]

Within the San Francisco Estuary, which is protected from the most violent wave action, the incidence of coastal flooding is expected to increase considerably. Models indicate that a one foot rise in sea level (likely by mid-century) would shift the 100-year storm surge-induced flood event to once every 10 years (Gleick and Maurer, 1990). In effect, because so much of the interior coast within the Bay Area is so close to sea level, this area is likely to be hit far faster by sea level rise than many parts of the ocean coastline.

In addition to greater flood risks, low-lying coastal communities will face increasing difficulties draining off treated wastewater and stormwater, as they will no longer be able to rely on gravity flow to evacuate these waters. This problem will be exacerbated if climate change is accompanied by more extreme precipitation events, as some models predict. In the southern portion of the San Francisco Bay, flooding and drainage risks are compounded by continuing land subsidence. Saltwater intrusion into coastal wells, already a problem in many coastal areas, is also likely to increase.

Loss of wetlands is a concern for both the ocean and estuarine coastal areas. Wetlands tend to adapt to sea level rise by migrating upward and landward. Losses will be more severe

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[1] See the accompanying report by Luers and Mastrandrea (2008) for more details on the climate science discussed here.

[2] Some exploratory work on the identification of erosional hotspots is underway as part of the 2008 climate impacts assessment, with a focus on several areas in southern California (http://www.climatechange.ca.gov/research/2008_assessment/index.html).

for wetlands adjacent to land with steeper slopes or to areas that have already been "hardened" with structures or agricultural development, conditions that prevent migration. This direct conflict between the natural process of wetland migration and the maintenance of existing development is one of the key balancing acts for coastal management in the years ahead (Caldwell and Segall, 2007).

The loss of wetlands can also undermine other important water management goals. For instance, the northern California city of Arcata depends on coastal wetlands to provide flood protection, groundwater recharge, and water quality treatment, as well as wildlife habitat protection (Arcata General Plan, 2000). Arcata's system has been in place since 1986 and has become an international example of wastewater reuse and wetlands restoration (Kusler, 2007). Increased high tide peaks and storm events threaten to overwhelm the city-owned Marsh and Wildlife Sanctuary and the wastewater treatment facility, interfering with and preventing proper treatment of the city's wastewater (Andre, 2005).

Sea level rise and storm surge will also alter the salinity gradient within the San Francisco Estuary, pushing salinity further into the Sacramento-San Joaquin Delta, and altering habitat conditions throughout the system. These higher water levels, combined with higher flood risk associated with earlier winter runoff from the Sierra Nevada mountains, will compound the risks to the fragile Delta levee system (Lund et al, 2007, 2008). A catastrophic failure of this system would result in significant disruptions to the state's water supply, in addition to serious ecological consequences.[3]

Other Climate Impacts

Although it is likely that ocean water temperature changes, as well as interactions between long-term climatic changes and other climate processes, such as the ENSO and the PDO, will have significant impacts on ocean and coastal habitat, there is as yet little firm understanding of the underlying climate processes, let alone the impacts on the biological resources of the coast. There is also little sound information on the impacts on water quality of changes in water temperature, greater peak runoff events, or the mobilization of pollutants on fringe lands. This latter concern has been raised in the San Francisco Bay Area, where some old hotspots that have been cleaned up lie within the path of the rising waters.

Vulnerability to Climate Change

Coastal communities' vulnerability to climatic changes depends not only on the physical risks to the coastline – largely a function of its natural features – but also on a range of factors reflecting the level of coastal economic development, including the extent of fixed structures on coastal lands. Although there is as yet little detailed information on these risk factors, broad indicators suggest that they vary widely across California's ocean coastline.

[3] For more on the water supply effects of sea level rise, see the accompanying report by Hanak and Lund (2008).

The Coastal Vulnerability Index (CVI), developed by a team of scientists from the US Geological Survey, provides a general overview of physical vulnerability (Thieler and Hammar-Klose, 2001). The CVI is a relative measure of vulnerability that "combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions."[4] Figure 1 maps the CVI for California. Coastal areas rated as having "Very High" and "High" vulnerability to sea-level rise are in Humboldt Bay between the cities of Arcata and Eureka, along San Francisco and Marin Counties' coast, in Monterey Bay from Santa Cruz to Monterey, and along most of the coast from San Luis Obispo to the southern border with Mexico.

For the San Francisco Estuary, maps produced by the San Francisco Bay Conservation and Development Commission provide a rough indicator of physical vulnerability, by showing the extent to which coastal areas would be covered by water with a one meter (3+ feet) rise in sea level (anticipated by the end of this century) in the absence of protective infrastructure such as higher levees (Figure 2). Both of the region's airports and many neighborhoods face the prospect of permanent flooding.

[4] For each segment of coastline, the CVI combines six risk variables: (1) geomorphology, (2) slope, (3) relative sea-level change, (4) shoreline erosion, (5) average tide range, and (6) wave height. Values range from 1 to 5, increasing with vulnerability. The value ranges are based on previously defined ranges and regional historic trends in the Pacific Coast. The index is computed as the square root of the geometric mean of the ranked values.

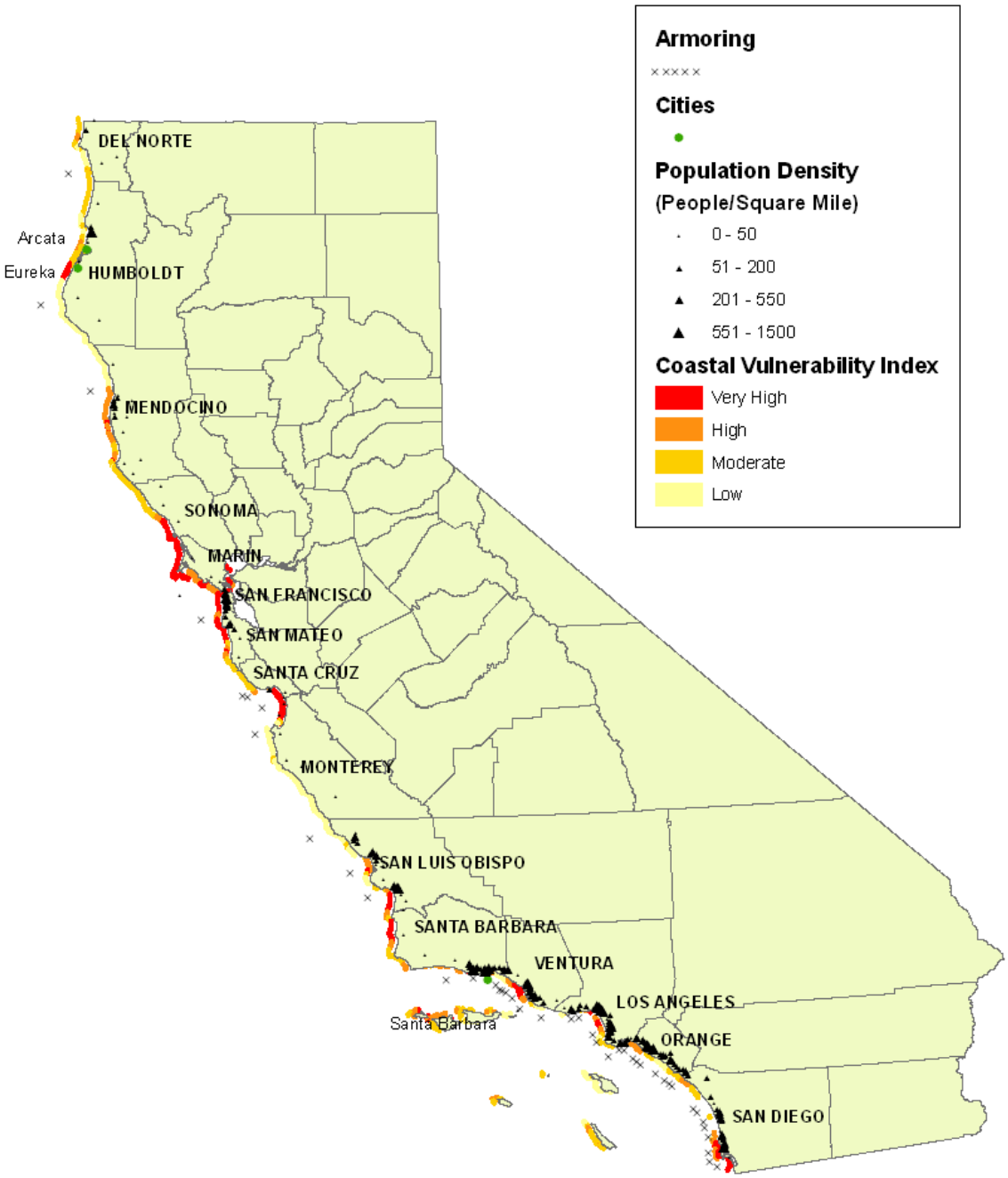

Figure 1. Measures of Vulnerability Along California's Ocean Coastline

Sources: CVI: Thieler and Hammar-Klose (2001); population density of census block groups bordering the coastline: US Census 2000; coastal armoring: Coastal Armoring and Bluff Erosion Geographic Information System created by Jennifer Dare, NOAA Coastal Management Fellow at the California Coastal Commission.

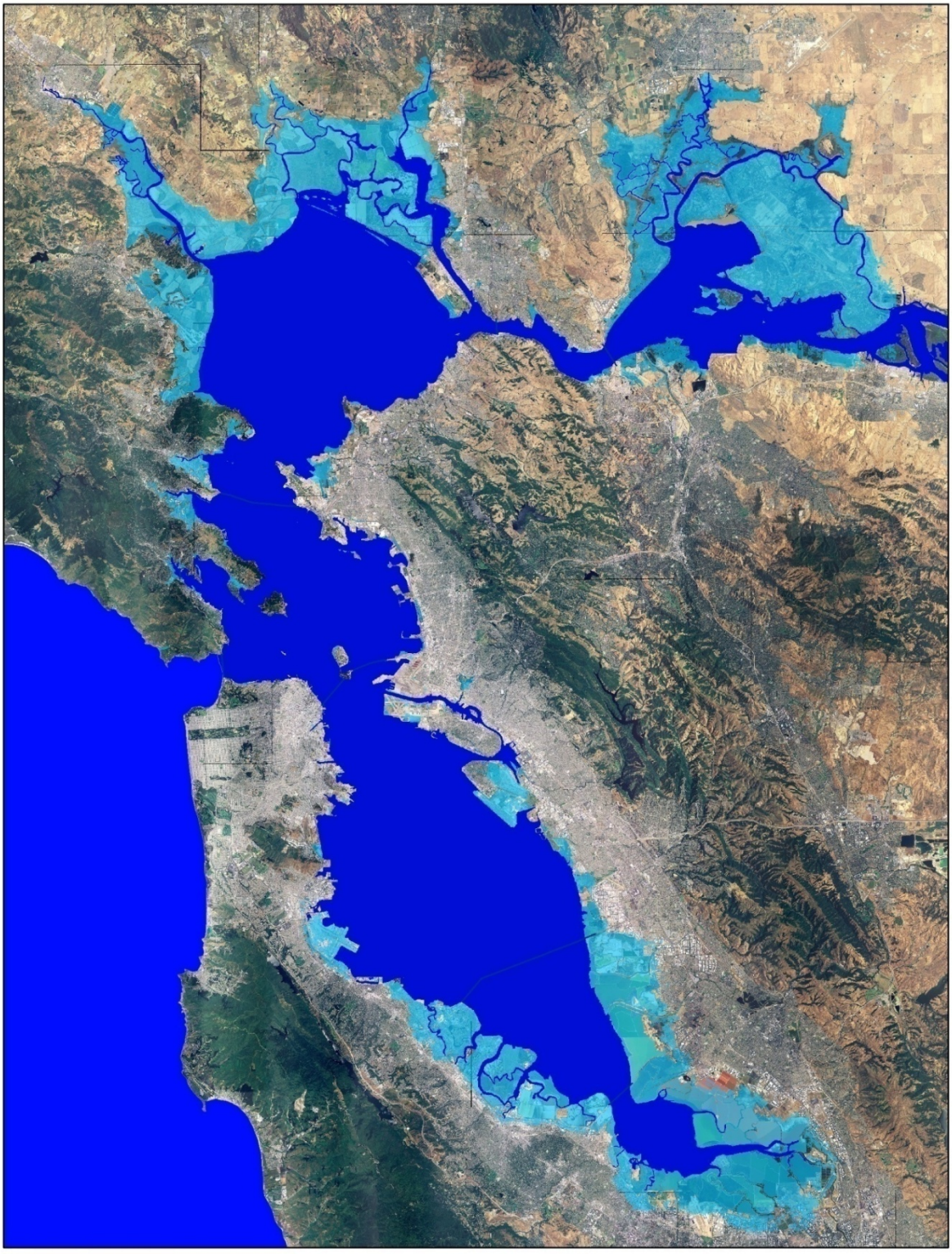

Figure 2. Central and South San Francisco Bay Sea Level Rise Scenarios

Source: San Francisco Bay Conservation and Development Commission, using elevation data from the U.S. Geological Survey and imagery data from the National Agriculture Imagery Program.

Note: The map is illustrative and depicts a potential inundation scenario with one meter (3.3 feet) of sea level rise (depicted in light blue). This level is within the range expected by the end of this century.

Risk to local communities also depends on the extent of development on the coast. In contrast to some coastal states, such as Maryland, California does not yet have an inventory of structures and activities that are susceptible to damage from coastal erosion and flooding. To provide a rough gauge, Table 1 provides some basic indicators, including population living in Census block groups bordering the coastline in 2000, miles of roads within one-quarter mile of the coast, and the value of economic activity attributed to the "ocean economy" by the National Ocean Economics Program (http://noep.mbari.org/).

Table 1. Indicators of Economic Vulnerability to Coastal Erosion and Flooding

Regions*	Coastal Population 2000 (1,000's)**	Coastal Share of Regional Population (%)	Roads Within 0.25 Miles of Coastline (miles)	Ocean Economy GDP 2004 (million $) ***	Ocean Economy Share of Regional GDP (%)
North Coast	36	14.9	440	235	4.1
Bay Area (Bay Side)	439	6.5	936	6,993	1.6
(Ocean Side)	37	1.7	798	-	
Central Coast	65	5.0	773	2,161	4.8
South Coast	169	1.1	1,678	18,587	2.5
Total	747	3.1	4,625	27,976	2.3

Notes:

*North Coast includes: Del Norte, Humboldt, Mendocino; Bay Area (Ocean Side) includes: Sonoma, Marin, San Francisco, San Mateo; Bay Area (Bay Side) includes these counties plus Napa, Solano, Contra Costa, Alameda, Santa Clara; Central Coast includes: Santa Cruz, Monterey, San Luis Obispo, Santa Barbara; South Coast includes: Ventura, Los Angeles, Orange, San Diego.

**Coastal population is the population in census block groups bordering the coastline. In densely populated areas, blocks extend 0.1 to 0.25 miles inland. In more rural areas, they can extend as far as 10 to 20 miles inland.

***Ocean economy includes establishments which are either: (1) in an industry whose definition explicitly ties the activity to the ocean or (2) in an industry that is partially related to the ocean and is located in a shore-adjacent zip code. Sectors include tourism and recreation, ship and boat building, transportation, living resources, minerals, and construction. For the Bay Area, the totals shown are for all 9 Bay Area counties. (There is no distinction in the data between ocean and bay side activity).

Sources: Authors' calculations using Census 2000 (population), National Ocean Economics Program (ocean economy), Tele Atlas North America (roads)

As Table 1 shows, in 2000, roughly three-quarters of a million people lived in close proximity to the coastline, with over half of this total along the shores of the San Francisco Bay. Over 4,600 miles of state highways and local roads border the coastline, with more than one-third of this total each in the Bay Area and South Coast regions. In 2004, nearly $30 billion of the state's gross domestic product resulted directly from ocean and bay-related activities, with

the leading sectors of transportation ($13 billion) and tourism and recreation ($11 billion). Southern California's preeminent role stems from the importance of the transportation sector, notably the Ports of Los Angeles and Long Beach. Although these numbers are large in absolute terms, they represent a relatively small share of the regional economies, particularly in the more densely inhabited regions of Southern California and the Bay Area. Given coastal topography, the population and transportation figures likely overstate the areas at physical risk, at least over this century. However, the economic estimates understate the dollar amounts at stake, as they only include the value of economic activity, not the value of at-risk assets such as buildings and infrastructure. Also, the estimates of at-risk roadways do not include roads within the Sacramento-San Joaquin Delta, which face higher risks of flooding as a rising sea level and higher winter flood flows put increasing pressure on fragile Delta levees (Lund et al., 2008).

For the ocean coastline, Figure 1 juxtaposes indicators of physical vulnerability as measured by the CVI with population density of coastal census blocks. Some population centers – notably the San Francisco Bay Area, San Luis Obispo, and parts of Southern California - coincide closely with the distribution of physical risks. In broad terms, it appears that many of the areas where the risks of property loss are greatest are also most likely to have the incentives and financial capacity to reduce vulnerabilities by implementing adaptation strategies. Smaller, more isolated coastal communities – with fewer resources at their disposal - may be more vulnerable to the effects of climate change.

Some areas of the coastline are also likely to be more vulnerable from the standpoint of coastal habitat, for reasons noted above. More detailed mapping of coastal areas, including measures of physical risk, an inventory of structures, and an identification of habitat areas that are particularly threatened or particularly valuable to protect, will be necessary to develop a clearer sense of coastal vulnerability and to determine where interventions may be warranted.

Adaptation Options and Tradeoffs

To a large extent, climate change will accentuate physical processes already underway – erosion of coastal beaches and bluffs, increased risk of coastal flooding and associated drainage problems, loss of coastal wetlands. Adaptation tools to respond to these threats already exist, although they are imperfect and involve difficult tradeoffs. In particular, there are conflicts between the primary physical solution to protect coastal properties and infrastructure – coastal armoring – and the range of other coastal uses, including beach access and coastal habitat. By accentuating these tradeoffs, climate change will likely spur the search for alternatives, including softer forms of coastal protection such as beach nourishment and planned retreat of development from the coastline.

Coastal Armoring

In many areas where storm surges and erosion have posed serious risks to private property and public infrastructure, investments have already been undertaken to harden the coastline, through construction of sea armor, such as sea walls, revetments, rip rap, breakwaters, and groins.[5] Over ten percent of the state's ocean coastline now has some form of armoring, with much higher shares in some counties, notably in Southern California (Table 2; Figure 1). Large parts of the interior coastline of the San Francisco Bay Area are also protected by levees.

Shoreline hardening can be effective in its principal goal of protecting property, at least over some period of time. It can also be put into place relatively quickly. However, the practice poses a number of other problems for coastal management. Shoreline hardening with armor such as sea wall and revetment diminishes or destroys coastal access by reflecting wave energy rather than dissipating energy as a beach does when in equilibrium (i.e. a beach that is not experiencing erosion). "Dissipative" structures such as rock riprap occupy beach space and constrain the beach's ability to establish equilibrium. Structures such as groins trap sand locally but increase down-drift erosion. [6] According to Griggs (2005), "Whenever a hard structure is built along a coastline undergoing net long-term erosion or retreat as a result of sea level rise, the shoreline will eventually migrate landward behind the structure."[7] This "passive erosion" is expected to worsen with accelerated sea level rise due to climate change, resulting in further loss of beaches for both recreational and ecological use (Caldwell and Segall, 2007).

[5] For depictions of various types of armoring, see http://www.kqed.org/w/coastalclash/armoring.html.
[6] Scripps Institution, http://coastalchange.ucsd.edu/st2_challenges/nourish.html
[7] See also Fulton-Bennett and Griggs, 1986.

Table 2. Armoring on California's Ocean Coastline, 2006

County	Miles of Seawall*	Share of Coastline (%)	Number of Levees, Breakwaters
Del Norte	2.2	4.6	3
Humboldt	1.8	1.1	1
Mendocino	0.7	0.5	1
Sonoma	0.9	1.5	0
Marin	1.9	1.9	0
San Francisco	2.4	45.1	0
San Mateo	4.9	8.3	2
Santa Cruz	11.3	24.8	0
Monterey	4.5	3.7	0
San Luis Obispo	6.5	5.7	4
Santa Barbara	14.3	12.4	1
Ventura	25.7	61.1	2
Los Angeles	17.5	15.9	4
Orange	16.7	36.8	2
San Diego	24.7	31.5	3
California	136.0	10.9	23

Note: * Includes: bluff walls, bulkeads, revetments, and seawalls

Source: Authors' calculations using Coastal Armoring and Bluff Erosion Geographic Information System created by Jennifer Dare, NOAA Coastal Management Fellow at the California Coastal Commission.

Property owners pursue these investments despite very high costs. Although simple riprap revetments can cost as little as $750 per linear foot, large sea walls coupled with bluff reconstruction and upper bluff retaining walls can run as high as $10,000 per linear foot – or $300,000 to $500,000 per property. Given the aesthetic value of oceanfront living and the absence of homeowners' insurance policies that cover property losses from coastal erosion, such investments can pay off for individual owners, even though they generate external costs. (For more on insurance, see below). Kriesel and Friedman (2003) find that while artificial shoreline stabilization may help protect individual waterfront property values, it lowers values of nearby non-waterfront properties. Furthermore, as more property owners stabilize their shoreline, neighboring shoreline properties also begin to lose value. Finally, despite high financial and

environmental costs, this approach is not always capable of stopping the advancement of coastal erosion.[8]

Similar issues arise when armoring is undertaken to protect public infrastructure of entire coastal neighborhoods, such as the large stretches of armoring in Ventura County to protect Highway 101 or the levee systems of Santa Cruz and Huntington Beach. Because of these conflicts, armoring is a targeted management activity under California's coastal policy.

Beach Nourishment

Beach nourishment, whereby sand is placed on beaches experiencing erosion, is a softer alternative to armoring with perhaps fewer environmental drawbacks, at least in terms of some recreational uses. However, it can still pose problems for natural ecosystems, both on and off-shore. It is also costly – rarely passing a cost-benefit test for federal funding except in limited, high-density areas (Heinz Center, 2000). It is not feasible in areas where the wave energy is very high, a common condition along California's coastline.

Although beach nourishment has been undertaken in various parts of the state, it has become the central tool of the regional shoreline preservation strategy in San Diego County, primarily with the goal of protecting the area's recreational resources. The first replenishment project occurred in 2001, and a feasibility study is underway to launch further activities, as replenishment is likely to be needed every five to seven years. Technical issues include finding enough high-quality sand, preventing rapid losses from storm events, and balancing the needs of the offshore biological resources and the recreational goals. This last point highlights the difficulties of evaluating the economic benefits of such projects when biological resources are at stake. Federal cost benefit guidelines – which consider recreational but not ecological benefits – would call for a wider beach in San Diego than state wildlife officials deem acceptable.[9] With sea level rise, replenishment is likely to become increasingly costly, because even smaller storms will become more erosive.

Living Shorelines

Another alternative to conventional shoreline hardening is to apply "living shoreline" principles – which maximize the ecological connectivity of the land/sea interface. In this approach, wetlands, natural stones, and sturdy plants along shore margins are used as components of a protective strategy. This approach has been fostered in both Maryland and Virginia, and has received much attention as potential tool for the Gulf region in the wake of Hurricane Katrina. It may provide superior wave protection by diffusing wave energy rather than absorbing it, as hard barriers do (Lutz, 2005). As with beach nourishment, it is not feasible in areas subject to high-energy wave action, as experienced along much of California's ocean coastline, and is likely to be more effective in bays or estuaries where wave forces are smaller.

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[8] For instance, roughly $7 million was spent to protect Stillwell Hall, an officer's club on the former Fort Ord military base on the Monterey Bay shoreline, with a large rock wall. In the end, the building had to be demolished.

[9] See Kildow and Colgan (2005) for some estimates of the net benefits of beach nourishment in support of the local recreational sector.

As illustrated by the Arcata example noted above, wetlands are an important component of coastal management in some regions of California. The Department of Parks and Recreation has also shown that stabilizing shorelines with methods such as vegetating dunes can be effective in protecting some coastal parks. Living shoreline principles are also being considered within the San Francisco Estuary as part of the South Bay Salt Ponds restoration project, discussed below.[10] To our knowledge, however, the use of living coastline principles as part of a strategy to protect private property or public infrastructure against coastal erosion and its consequences has not yet been applied to any significant extent in California.

Building Standards and Other Physical Solutions

Other physical solutions are available to keep coastal development in place, at least under moderate levels of sea level rise. Raising building pads for new development and instituting "low impact" methods of on-site run-off retention can minimize drainage problems and reduce flood risk exposure for these properties. [11] Pumping out stormwater and treated wastewater from areas that can no longer rely on gravity flow, in combination with dikes or levees, is a time-honored alternative for low-lying communities ranging from New Orleans to the Netherlands. Along the California coastline, several communities (Millbrae and Palo Alto in the San Francisco Bay Area; Huntington Beach in Orange County) are already pumping stormwater out of some neighborhoods that lie below the hydraulic grade. Within 30 to 50 years, many Bay Area communities will probably need to adopt this technology, which comes with a downside of added energy costs, in addition to the loss of habitat and coastal access often associated with coastal levees.

Insurance

An alternative or complement to these physical solutions is insurance. Although private insurers will not underwrite policies to protect homes from foreseeable coastal erosion events, such as bluff collapses, federal flood insurance is available to properties subject to periodic coastal flooding under the National Flood Insurance Program (NFIP), under the Federal Emergency Management Agency (FEMA). In principle, rates for structures built since 1974 are set to be actuarially fair, with higher rates in the "Special Flood Hazard Areas" facing more than a 1 percent annual chance of flooding. (Those built earlier get subsidized rates). Homes within the 100-year tidal floodplain (areas with at least a 1 percent chance of flooding in any given year) are generally required to hold insurance if they are mortgage-backed, although this policy is not always enforced (Troy and Romm, 2004; Chivers and Flores, 2002). Flood insurance subscriptions are generally far less prevalent in areas that are beyond this line of demarcation, even when higher levels of flood protection are afforded by levees, which are subject to overtopping and collapse.

Going forward, there are questions about the role of flood insurance as an adaptation tool for coastal California. First, there is some concern the program actually subsidizes development in high-risk areas, because flood insurance rate maps may understate flood risks. These maps are often based on hydrologic data that is at least twenty years old, and they do not incorporate two dynamic factors which point to increasing risk: sea level rise and upstream

[10] http://www.southbayrestoration.org/

[11] For a discussion of low impact development techniques, see U.S. Environmental Protection Agency, 2007.

development.[12] On the other hand, the insurance limits (currently $250,000 for dwellings, $100,000 for contents) preclude full insurance for many (if not most) coastal homes.

Retreat, Relocation, and Abandonment

The remaining alternatives involve moving back from the encroaching shoreline, a process that can occur in a more or less planned fashion. California's ocean coastline is already dotted with examples of structures and public infrastructure that have been lost to erosional forces – ranging from homes in San Mateo and Sonoma Counties to public beach infrastructure in San Diego County, to assorted portions of the coastal trail. Even with modest sea level rise, there will be an increasing number of cases where retreat is the best option, given rising costs of protection to defend coastal structures. This is especially true if the costs to the ecosystem and to public coastal access are factored in.

Retreat can be incorporated into a coastal management strategy in several different ways: with planned abandonment, a decision is made to let an asset go when nature takes its course; with planned relocation, assets deemed too valuable to lose are moved further inland. For new development, planned retreat can include requiring greater setbacks, to take into account accelerated rates of erosion, although rolling setbacks and other relocation strategies discussed below will eventually need to come into play as well.

Planned relocation is the strategy currently under consideration for portions of Highway One, in San Luis Obispo, San Mateo, and possibly also Sonoma Counties. In these cases, the state Department of Transportation (Caltrans) will get temporary permission to put in place protective armoring, while it builds the new alignment. Planned retreat was pursued in Pacifica (San Mateo County), where some homeowners benefited from an NFIP program that retires homes facing high repetitive flood risk. Going forward, California may need to consider expanding this type of buy-out program, either as transitional assistance to lower income households in vulnerable areas, or as compensation when armoring is restricted to foster inward expansion of coastal habitat.

[12] FEMA is currently engaged in pilot work in some parts of the Bay Area to develop more detailed maps, but these will use current hydrology, rather than incorporating sea level rise.

Institutional Adaptation Capacities and Constraints

The cast of characters involved in California's coastal management is long indeed: private landowners, cities and counties, local, state and federal flood management authorities, port, airport and state and regional transportation authorities, state and federal wildlife protection agencies and park systems, the State Lands Commission, and no doubt others. Two central institutions were established several decades ago to help balance the competing needs and uses of the state's coastal areas: the San Francisco Bay Conservation and Development Commission (BCDC) (1965), and the California Coastal Commission (1972).

Both commissions play a role in overseeing development and the protection of environmental and public uses, and both have permitting authority over alterations to the coastline such as armoring. The Coastal Commission operates under the authority of the Coastal Act of 1976. It shares permitting authority with cities and counties within the legally designated Coastal Zone, an area of about 1.5 million acres of ocean coastline stretching from Oregon to Mexico.[13] The BCDC was created to prevent further infill of the San Francisco Bay – a trend which had emerged as a key problem by the 1960s. It has permitting authority over land uses within 100 feet of the shoreline within the San Francisco Bay. Under the federal Coastal Zone Management Act, both commissions have authority over activities permitted, conducted, or funded by the federal government that risk harming coastal resources.

Two other state bodies also support the broader goals of California's coastal policy. The California Coastal Conservancy (1976) acquires coastal lands to foster public access and ecosystem protection. The recently created Ocean Protection Council (2004) is charged with coordinating the activities of ocean-related state agencies as well as the collection and sharing of scientific data on ocean and coastal issues.

Thus, California already has an institutional set up for coastal management that should facilitate the planning of adaptation responses. Regional and state structures exist to regulate coastal investments, to develop and disseminate information, and to acquire sensitive lands. Both the Coastal Commission and the BCDC have put climate change on their agendas, and have begun to take actions to foster adaptation planning.[14] But, as the following discussion will show, both commissions face significant constraints on the exercise of their authority. The Coastal Commission also faces a severely restricted budget. In addition, there are wide gaps in response capacity among other agencies with coastal management responsibilities.

Management of the Ocean Coastline

Shared Responsibilities: The Role of Local Coastal Plans

Central to the reach and limits of the Coastal Commission's authority is its shared responsibility for oversight of the Coastal Zone. The Coastal Commission establishes partnerships with local governments (the 75 cities and 15 counties bordering the ocean

[13] The Coastal Zone reaches from 3 miles at sea to an inland boundary varying from a few blocks in urban areas to several miles in less developed regions. For maps by region, see Local Coastal Program status maps at http://www.coastal.ca.gov/pubs.html.

[14] See California Coastal Commission, 2001, for an early assessment of the issues for coastal management.

coastline) through Local Coastal Programs (LCPs). Local governments prepare the LCPs, which specify local land use plans, development goals and policies, and zoning ordinances necessary for implementing the plans. Rather than covering the entire coastal area within a city or county, LCPs sometimes divide the jurisdiction into segments. Once the Commission approves an LCP, it delegates permitting authority to the local government. Decisions made by local governments are appealable to the Commission, which retains authority to repeal certain local government decisions as well as jurisdiction over development on tidelands, submerged lands, and public trust lands. Amendments to approved LCPs must be submitted for Commission review and approval.

Table 3 lists the LCP status by county. At this point, cities and counties directly manage approximately 88 percent of the geographic Coastal Zone, within 92 certified segments (out of a total of 128 segments). The Commission has direct authority over the remaining areas, which are concentrated in Monterey County and the South Coast. Eighty percent of the communities with permitting authority developed their plans in the 1980s. Although the plans are subject to Coastal Commission review every five years, local governments are not required to update them. As the following discussion highlights, the lack of a legal obligation to update the LCPs is a constraint on the introduction of more climate-sensitive standards for new development.

Table 3. Local Coastal Plan Certification Status, 2007

County	Total LCP Segments	Certified and Issuing Permits	Certified but Not Issuing Permits	No Plan or Plan Rejected
Del Norte	6	5		1
Humboldt	9	9		
Mendocino	5	4		1
Sonoma	1	1		
Marin	2	2		
San Francisco	2	1		1
San Mateo	4	4		
Santa Cruz	4	4		
Monterey	14	7	7	
San Luis Obispo	4	4		
Santa Barbara	6	5		1
Ventura	4	4		
Los Angeles	22	10	8	4
Orange	17	9	4	4
San Diego	28	23	4	1
Total	**128**	**92**	**23**	**13**

Note: Data reflects plan status as of October 25, 2007

Source: Authors' calculations, using California Coastal Commission, 2007

Evolving Standards on Setbacks

Since its inception, the Coastal Commission has promoted a dynamic approach to planning for new development, consistent with its mandate to ensure the geologic stability of new structures. Setbacks are the primary tool used to protect structures from erosional forces over some period of time. Two factors are central to determining the appropriate size of setbacks: the length of life of the structure and the time path of exposure to coastal hazards (erosion and flooding). Over time, the way in which the coastal program evaluates these factors has evolved.

Initially, planned structure life was typically 35 to 50 years – long enough to pay off a mortgage plus some margin. Coastal managers found that people wanted homes to retain value for longer periods, requiring a longer planned structure life. Today, the Commission generally applies a 75 to 100-year life to new development within its jurisdiction. Most LCPs now also use 75 to 100 years, although some of the older ones still incorporate a 50-year standard. It is also worth noting that the calculations relied on by some LCPs have proven faulty, with the result that erosion at some locations is occurring at a faster pace than anticipated, threatening structures much sooner than expected. There is also a great deal of variation in local government treatment of hazards and setbacks. Notably, with many LCPs now 20-plus years old, even the 50-year planning horizons are approaching their upper limits, especially in light of sea level changes.

The time path of exposure to coastal hazards involves different calculations for bluff and beach fronts. For bluffs, building can occur at locations considered stable (in terms of slope stability) and safe from bluff erosion and flooding over the planned life of the structure. The calculations determine a setback from the bluff edge that takes into account erosional pressures, storm surge, localized geology, and other factors. This is not an exact science, however, and erosion rates are not constant.

For beach fronts, the calculations have historically considered the evolution of both land erosion and flooding hazards under 100-year storm conditions. Initially, these processes were calculated using information on historical trends in erosion and sea level rise. Additional factors have begun to be evaluated, such as wave uprush (the rush of water from a breaking wave onto a beach).

How best to incorporate changes in erosional trends resulting from climate change, and particularly sea level rise, poses a challenge for Commission staff analysts. With dependable information on changing climatic conditions, it should be relatively straightforward to incorporate factors such as sea level rise into studies of beach erosion, despite considerable localized variation along California's coastline. Recently, Commission staff has generally begun recommending that accelerated rates of sea level be factored into erosion and flood hazard calculations, based on peer-reviewed estimates of sea level rise for the next 50 to 100 years, such as those of the IPCC.[15] Although it is likely that climate change will also affect the rate of

[15] Although changes in storm surge patterns are also likely to affect the "design wave" of a 100-year storm, this has not generally entered the new calculations. This omission may be due to the more limited data on this phenomenon, as well as the role played by FEMA, which has resisted incorporating climatic changes in 100-year floodplain determinations.

erosion of coastal bluffs, predictive modeling of bluff erosion is more difficult, and there is concern that the results may not be adequately defensible until a sounder scientific basis is developed. Generally, the Commission projects the greatest long-term historical erosion rates recorded for an area (rather than the average) to allow for some increase in erosion rates due to sea level rise.

The application of any forward-looking policy will be limited unless local governments elect to incorporate the improved methodologies into their updated LCPs. At present, the Commission has no legal authority to require local governments to update these plans in light of new scientific information or changed circumstances.

The "No Further Armoring" Policy

Of course, stricter setback rules are only helpful for making *new* development more resilient to changing climate conditions. In many areas, the coastline is already largely developed, often with smaller setbacks. For many individuals and communities facing increased erosion and greater flood risk exposure, the first line of defense will be to seek permits to erect armoring. Here is where the direct conflicts emerge in the goals of the Coastal Act, which simultaneously charges the Commission to protect threatened structures and coastal resources as well as such things as public access, environmentally sensitive habitat, and scenic resources. In striking that balance, there is often an impression that protection of endangered structures gets the upper hand. As one observer noted, "California has the most comprehensive coastal act in the nation, but also one of the most permissive with respect to armoring."

Since the late 1990s, the Commission has generally attempted to manage property owner expectations with the application of a "no further armoring" condition on permitted development. Under this approach, permits for new structures include a prohibition against future armoring (or no expansions to the existing armoring). The approach is applied through case-by-case reviews of individual permits. Since it is not the result of a change in law, it could be modified by future commissions.

By clarifying expectations from the outset (particularly for new development), this approach may reduce the pressures on the Commission to allow shoreline hardening. To date the restriction has not been subject to legal challenges, although exemptions have been granted (Caldwell and Segall, 2007). However, when high value property is threatened by more severe or more frequent storms, it may still be difficult for the Commission to resist granting exemptions, even if they conflict with other coastal management goals.

Rolling Easements

Following up on an idea popularized by James Titus (1998) of the U.S. Environmental Protection Agency and others, former Coastal Commissioner Meg Caldwell has proposed to take the armoring restriction policy further with the introduction of "rolling easements" (Titus, 1998; Caldwell and Segal, 2007). The term stems from a legal feature of coastal lands, which have a public easement up to the mean high tide line. Given coastal erosion, this easement would naturally roll inland, unless it is prevented from doing so by coastal armoring. By this reasoning, armoring violates the public trust, and no properties have the right to erect armoring, because the public trust doctrine takes legal precedence over armoring provisions in the Coastal Act.

In practice, Caldwell and Segall propose a more pragmatic set of measures. They acknowledge that more armoring is likely to be necessary to protect economic values in heavily developed areas. The target would instead be rural areas and homes on the urban fringe. Although litigation could be one strategy for preventing further armoring, they also suggest a grandfathering principle to compensate property owners for rolling easements if their structure is not subject to a "no further armoring" permit condition. Efforts would focus on allowing inward migration of the coastline in ecologically sensitive areas, where appropriate uplands are available to accommodate the shifts. Armoring, where legally necessary or prudent, would follow living shoreline design principles.

As Caldwell and Segal acknowledge, a precondition for implementing this approach is detailed surveys of the coastline, to determine vulnerabilities and areas where allowing natural landscape migration would be the most beneficial. There are clearly also legal and financial considerations. If litigation is used against those who now consider themselves to have armoring rights, the cases could be tied up in the courts for years as a takings issue. If instead the approach is to favor compensation, there are likely to be battles over property valuation (for instance, with or without armoring rights?) Substantial financial sums would also need to be identified to support a buy-out policy.

Management of Coastal Resources in the San Francisco Estuary

In the Bay Area, the BCDC has been conducting an awareness campaign about the region's vulnerability to climate change. A simple, yet impressive tool is a set of maps showing what the region will look like with one meter of sea level rise, in the absence of additional armoring (such as Figure 2, displayed above). A recent PPIC survey of cities and counties suggests that this outreach effort has been effective (Hanak et al., 2008). The Bay Area is the only region in the state where assessments of the impacts of climate change are being conducted on a broad scale (60% of all communities surveyed, covering 76% of the region's population), and sea level rise is widely identified as an important risk.

Commission staff fully expects the need for additional armoring, given the high property values at stake. A 1990 study by Gleick and Maurer estimated the value of property at risk from a one meter rise in sea level at $48 billion. While waiting for an update to this study, now underway, the BCDC estimates that the total value today would easily exceed $100 billion.

A New Approach to Planning for the Bay

The concern is how to proceed with armoring plans in a reasonable manner, given the implications of climate change for the region's ecological resources: loss of wetlands to sea level rise, shifts in salinity and changes in water temperatures affecting habitat conditions throughout the estuary. BCDC's Executive Director points to the need for a new approach to planning for the Bay to anticipate these changes and determine where to place an emphasis on ecosystem support. Planning for the Bay in the late 1960s was focused on keeping the Bay from shrinking; a new approach would instead guide the Bay's enlargement as the sea encroaches.

No process has yet been launched to develop a new plan, which would need to involve a wide swath of federal, state, regional, and local officials as well as the public. As in the case of the ocean coastline, better information about the nature of risks to wildlife and habitat and opportunities for fostering productive transitions will be an essential ingredient to this process.

Early Adaptation Efforts

In the meantime, some Bay Area communities have begun taking steps to adapt to sea level rise. In San Francisco, the focus of efforts has been on managing the consequences for the wastewater and drainage system, where impacts are already being felt. In the South Bay, efforts are in place to address the growing tidal floodplain risks. Both experiences highlight the importance of interagency coordination to successful adaptation planning.

San Francisco's wastewater system, designed in the early 20th century, has started to experience problems of saltwater backflow into its overflow weirs at high tide (Franza, 2007). In the short term, there is a relatively easy technical fix to the backflow problem, which can disrupt the system's biological treatment processes: placement of duckbills on the weirs. In the longer term, wastewater management officials anticipate the need for a combination of dikes and pumps to handle drainage that will no longer be able rely on gravity flow. They also would like to see more resilient design principles introduced for new construction, such as raising building pads and incorporating low impact development principles for runoff management. A missed opportunity was Mission Bay, a new neighborhood on the bay's edge, where officials belatedly recognized that higher building pads would have improved drainage. Instituting changes will require the cooperation of the planning department, which issues building permits. Coordination has improved through the city's "Better Streets" initiative, and an interdepartmental working group is looking into a possible ordinance requiring low impact development.

Flood management is a longstanding concern in the South Bay, large areas of which lie within a tidal floodplain. Parts of the shoreline are protected by levees built for commercial salt ponds, which were slated for conversion into wetlands under a multi-million dollar restoration project. As plans for the restoration project advanced, the local flood management authority for Santa Clara County pushed to have the project's flood risk implications assessed. The result has been a pair of collaborative studies for the restoration project and for broader flood management issues along the shoreline, involving federal, state, and local agencies.[16] For the flood management study, the local partners convinced the Army Corps of Engineers to consider the effects of accelerated sea level rise. This may be a first for the Corps, which has been slow to take climate change into account in its flood risk analysis (Hanak and Lund, 2008). Local officials acknowledge that the restoration project presented a fortuitous opportunity to reassess flood risks in light of a changing climate; a few years earlier, they might not have thought to incorporate sea level rise in the analysis.

More broadly, the flood management experience in the South Bay offers insights about regional coordination processes that will become more important with climate change. The Santa Clara Valley Water District, which has countywide responsibility for flood management, water supply, and water quality in local streams, has played a pivotal role in bringing local governments into the process. This integration is necessary, because both flood and water quality management depend on land use decisions under the jurisdiction of local governments. To foster better management, the district led a successful multi-year collaborative effort that has resulted in coordinated regional planning.

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[16] The South Bay Salt Pond Restoration Project (http://www.southbayrestoration.org/) and the South San Francisco Bay Shoreline Study (http://www.southbayshoreline.org/), respectively.

As consideration of the effects of climate change in the Bay Area proceeds, there is a question of whether more formalized regional coordination will be needed on such issues as levee planning and the designation of areas to protect for habitat and for public access to the coastline. A new Bay Plan clearly would serve as a useful planning tool. Is there also a need for an institutional authority to oversee this process? If the BCDC is to play that role, its jurisdiction may need to be extended beyond 100-feet from the shoreline, since a key issue will be how and where to allow this shoreline to recede.

Local Government Tools and Challenges

A few other cases exist where local governments in coastal areas are explicitly integrating climate change into infrastructure and land use planning. The City of Santa Cruz is incorporating projections of accelerated sea level rise into its General Plan update. The City of Solana Beach, which has been subject to significant beach and bluff erosion, is requiring consideration of sea level rise in a new master environmental impact review for the coastal area. More generally, however, a recent survey of local coastal managers found that adaptation to climate change is not a planning consideration, even though awareness of the potential impacts is fairly high (Moser and Tribbia, 2006/07 and 2007). Our interviews revealed that explicit climate-based planning is even absent in cases where communities are implementing adaptive measures. For instance, sea level rise has not been a part of the discussion in the San Diego shoreline preservation workgroup which is coordinating regional beach nourishment efforts.

Moser and Tribbia cite numerous factors – lack of time, funds, information, dedicated and/or trained staff, technical assistance, and leadership – as factors preventing more proactive approaches. It is our sense that local managers may also need a regulatory boost toward planning for increased resiliency. Particularly in communities where there is not already a strong environmental sensibility, it can be difficult for local officials to argue for changing the status quo. Several persons we interviewed suggested that guidelines or regulations from the state would facilitate local actions. What quantitative guidelines should be used on sea level rise, erosion rates, and changes in flood risk, over what time period? With this information and authority in hand, local governments can go back to their master plans for flood channels, require higher elevation of building pads, change the base flood elevation in flood maps, and modify their capital improvement programs.[17] Without the backing of a higher authority, local governments risk litigation, because all of these measures entail some costs, either to individuals or to local taxpayers.

These types of local infrastructure planning decisions are largely beyond the sphere of the Coastal Commission or the BCDC. Instead, they fall under the rubric of general and environmental planning law. New directions would need to come from the Governor's Office of Planning Research (OPR), which issues guidelines on the implementation of general plans and all projects subject to review under the California Environmental Planning Act (CEQA). Recent legislation provides a framework within which OPR can take steps in this direction. Under Senate Bill (SB) 97, signed into law in August 2007, OPR is required to develop CEQA guidelines by mid 2009 for mitigating greenhouse gas emissions and for taking into account the effects of climate change. In this update, OPR should identify the types of climate-related issues that local governments should address. State technical agencies, such as the Resources Agency,

[17] Some of these actions require the cooperation of other agencies. For instance, flood maps are approved by FEMA.

should provide complementary information to local governments on the numbers: for instance, what level of sea level rise to plan for by 2050.

Climate Planning Issues for Large Infrastructure Providers

In discussions about the effects of sea level rise, attention is often turned to large public infrastructure – roads and bridges, ports and airports: what will be the impacts on this infrastructure, and how can it be protected?

Caltrans

As noted above, more than 4,600 miles of roadways lie within one-quarter mile of the coast, and additional roadways are at risk of flooding from levee failures within the Sacramento-San Joaquin Delta. Although many of these roads are managed locally, the total includes several major highways (e.g., Highway 101, Highway 1, Route 92) and bridges under the purview of Caltrans. Although Caltrans has traditionally based infrastructure plans and designs on historical rates of coastal erosion, the agency has already faced challenges to the geologic stability of coastal roadways. Coastal armoring has been the standard response (e.g. in Ventura County). A recent innovation, noted above, has been to consider relocation of stretches of roadway; these solutions have been negotiated with the Coastal Commission, which is aiming to wean Caltrans from armoring when possible. So far, the relocation has concerned rural stretches of Highway 1, and it has come up on a case by case basis, in response to erosion events that require emergency armoring permits.

The bigger question before Caltrans is how to develop a better sense of exposure to risks and the implications for infrastructure planning. Although Caltrans officials are aware that accelerated sea-level rise, climate variability and new patterns of erosion due to climate change will affect the transportation network, there is as yet no formal process for assessing the system's vulnerability. One obstacle cited by Caltrans staff echoes the concerns of some local government officials: with uncertainty over the pace of climate change, it is difficult to plan for it. With large backlogs of projects in the pipeline, and a customer base frustrated by problems of congestion, such long-term issues may seem low priority. Transportation planning also may be particularly unsuited to adaptation, because it is highly inflexible. Many components of current investment plans were developed decades earlier, and it is difficult to change them in mid-course.

By the same token, however, the long-term nature of transportation investments suggests that it would be prudent to understand vulnerabilities and see where new investments might be made more resilient. In some cases, the best solutions may involve road realignments. For instance, given the very high risks of Delta levee failures, realignment of some stretches of Highways 4 and 12 may prove more prudent (and cost-effective over the long-term) than making planned improvements within the existing alignment.[18] In other cases, modified design standards within the existing alignments might improve the capacity to accommodate increases in runoff from extreme precipitation events, for instance. Long term planning could also minimize the costs of future realignments through acquisition of easements in high-risk areas.

[18] Such an approach has been explored by some water agencies and other infrastructure providers concerned with the risks of catastrophic failure of Delta levees. The idea would be to realign various pieces of infrastructure in an "infrastructure corridor."

A first step will be developing a sense of the vulnerabilities under different scenarios of climate change. State efforts to produce the basic scientific information will be key to this effort.

Seaports

In addition to a number of small ports and harbors, the California coastline is home to several large seaports. The twin Ports of Los Angeles and Long Beach handle about 44percent of all imported marine freight in the US; the Port of Oakland, though smaller, is also a significant economic asset. In the context of rapid growth in sea freight and concerns over the air quality impacts of port operations, much recent attention has focused on improving environmental management of the ports. In this context, the ports have also begun to consider the ways in which their practices can reduce greenhouse gas emissions.

Although casual observers often highlight the ports as a particularly vulnerable target of sea level rise and increased storm surges, this aspect of climate change is not on the planning radar of port authorities. That said, the current set-up may be fairly resilient, at least to modest increases in sea level rise. The most important risk for the ports is that rising tides may compromise the ability for shippers to load and unload cargo in the container terminals. Currently, the container terminals at LA-Long Beach are six feet above mean high tide.[19] Rather than raising the terminals in response to sea level rise, a more cost-effective adaptive strategy could be to build dikes and enhance the existing breakwater that protects the harbors. Although further study is needed, these actions could likely be undertaken relatively quickly if the need arose, in a matter of a couple of years; the biggest constraint would be congressional approval for funding. As one observer noted, a severe storm could motivate Congress to speed up this process.

Airports

As noted earlier, both the San Francisco and Oakland Airports are highly vulnerable to sea level rise. Although neither airport has actively considered these potential climate change impacts, SFO has recently completed a levee upgrade program, and Oakland is in the midst of one, which should postpone flooding problems for some time. These permits have been accompanied by restrictions on the extent of armoring, to protect the shoreline. Given the vast assets at stake, the airports will likely pursue further levee investments as conditions change.[20] Other coastal airports, such as San Diego, could be well-served to examine their vulnerability to sea level rise.

Funding Adaptation

Planning and implementing adaptation strategies will require financial resources. To what extent is this likely to be a constraint, and what innovations might be possible? Across coastal management entities, there is currently considerable variation in the ability to finance adaptation measures, largely depending on the legal and regulatory framework for raising funds.

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[19] For interior ports, including the Port of Oakland, another potential issue is reduced air clearance under bridges for container ships as a result of sea level rise.

[20] As a point of comparison, Schiphol Airport, in Amsterdam, lies more than 10 feet below sea level.

Among large infrastructure providers, airports are relatively well positioned, as they can use their general allocation of Federal Aviation Administration funding (a function of passenger count) for infrastructure investments, and they can raise funds from the airlines for any additional needs. In contrast, both Caltrans and the seaports face constraints on the use of available funds and are limited in their ability to raise new revenues. For instance, although introduction of a toll to fund road network improvements is not unheard of – Bay Area bridge users pay fees to help cover seismic retrofits – it involves significant institutional hurdles, including voter approval and/or approval by Congress and the state legislature.

By the same token, the state's two key coastal management bodies – the California Coastal Commission and BCDC – will surely face resource limitations for conducting analysis, outreach, and technical support, given current state budget difficulties. Budget limitations have already posed constraints to the Coastal Commission's activities to address climate change.

For coastal armoring and beach nourishment, one of the big questions will be federal funding availability. At present, the Army Corps of Engineers funds between 50 and 65 percent of authorized projects (those that pass a cost-benefit test and receive congressional authorization). In the most recent authorization for Corps activities, passed into law in November 2007, California received around 4 percent of the funds – a low share relative to flood risks, population, or GDP. California should expect stiffer competition in the future, given the even greater risks from sea level rise facing coastal regions in the eastern U.S. and along the Gulf of Mexico. The state could help meet the gap through infrastructure bonds, although it faces severe budget constraints of its own. In November 2006, state voters approved nearly $5 billion in flood bonds, mostly for the Central Valley. There may be more justification for state contributions to Central Valley flood works than for coastal flood management, since state taxpayers are legally liable for flood damages in this region.[21]

In the context of limited federal and state sources, the constraints to funding local flood works appear particularly problematic. Following the passage of Proposition 218 in 1995, the California constitution has required local flood and stormwater management agencies to earn a two-thirds majority of the popular vote or approval of at least half of all property owners to pass new measures. Even in Santa Clara County, where there was broad local government involvement and public participation in the planning process, the last local measure, passed in 2000, squeaked by with 66.68 percent of the vote. In recent years, several legislative proposals would have put flood and stormwater management agencies on the same footing with local water and wastewater utilities, which do not face such stringent voter requirements. As of yet, none of these measures have made it through the legislature.

In the face of these rules restricting local funding, one question that is already beginning to surface is how broadly to cast the funding net: should adaptation to coastal processes be paid for strictly by the communities and neighborhoods that are directly affected, or should the wider region contribute? In the Santa Clara case, funding was countywide, even though the coastal areas benefited most directly. In San Diego, the council of governments is exploring ways to get inland communities to help fund beach nourishment programs, on the grounds that they benefit the wider regional economy.

[21] For a discussion of the legal issues, see Department of Water Resources, 2005.

Another question is whether and how to mobilize mitigation funds from those who benefit from coastal armoring, given the negative externalities it generates. The Coastal Commission, where warranted, has begun charging modest mitigation fees for armoring projects. Expanding on this practice, the City of Solana Beach recently introduced a policy requiring anyone permitted to put in armoring to pay into a mitigation fund for beach nourishment activities. Pending a detailed funding study, the provisional amount charged is $1,000 per linear foot, about a ten percent surcharge. As pressures increase to augment armoring along the ocean and bay coastlines, this approach could be applied more broadly as a way of funding the protection of habitat and public coastal access and even relocation. However, significant taxpayer resources will also be needed to compensate private landowners if a decision is made to protect large areas of the coastline through rolling easements.

Improving Adaptation Capacity

This review suggests several broad conclusions. First, California is likely to face significant challenges to coastal management as a result of climate change, both along the ocean coastline and within the San Francisco Estuary. Some types of impacts - notably from sea level rise and increasing storm surges - are fairly certain, although there is uncertainty about the pace of change.

Second, adaptation tools exist for dealing with the resulting coastal erosion and increased risk of flooding over this century, but they involve significant costs and tradeoffs. At one end of the spectrum, coastal armoring can protect developed coastal lands, at least for moderate levels of sea level rise, but it destroys beaches and habitat. At the other end, strategies involving retreat can lessen the damage to habitat and public coastal access, but at the price of losing development. The tradeoffs are perhaps less stark for new development – for which restrictions on where and how to build are the key adaptation tools – but the added costs of these measures for private property owners (or for the state when unavoidable takings issues arise) can make them unpopular.

Third, California already has a set of policies and institutions that aim to balance the competing objectives for coastal development. Measures such as "no further armoring," which limits the rights of landowners to put in new protective devices, greater setbacks for new development, and planned relocation of stretches of the coastal highway, reflect the fruits of this policy focus.

Fourth, coastal management agencies are at the very early stages of understanding what more needs to be done to facilitate adaptation to climate change. Both the Coastal Commission and the BCDC have taken up the issue, as have a handful of local entities. But there has yet been little broad strategic thinking about whether and how the state's coastal policy should change to accommodate the anticipated climate impacts, or which new actions could facilitate a reduction in vulnerability. What steps should be taken as preventive measures, and which actions can wait until events unfold? Where are existing rules and procedures adequate to the task, and where are regulatory or legal reforms needed? Where do we need more information to guide these decisions? In the short term, several steps seem essential to progress in this direction.

Better Information on Climate Impacts and Vulnerabilities

Although a few local agencies are comfortable making investment and land use plans based on broad scientific projections for sea level rise, the lack of better information on what to expect is a constraint for many local governments and infrastructure providers. More detailed analysis of the implications of sea level rise for coastal flooding and erosion under different scenarios of sea level rise will be a valuable planning tool. At the regional level, some early steps in this direction are already serving an important awareness-raising function. This includes the BCDC maps for the Bay Area noted earlier, as well as a regional flood risk mapping exercise for San Diego being undertaken by researchers at the Scripps Institute of Oceanography (e.g., Guza et al, 2007). A broader effort of this nature, under the coordination of the Ocean Protection Council, was proposed in the last legislative session (AB 1066, Laird).

In addition, more detailed mapping of coastal areas, including measures of physical risk, an inventory of structures, and an identification of habitat areas that are particularly threatened or particularly valuable to protect, will be necessary to develop a clearer sense of coastal vulnerability and to determine where interventions may be warranted.

Guidelines on Preventative Investment Strategies

For long-lived investments, it already makes sense for local governments and infrastructure providers to take climate change into account, through such steps as increased setbacks, higher building elevation, low impact development, and higher capacity for wastewater and drainage systems. In addition to more detailed information on climate risks, it may be necessary for state agencies to provide guidelines, or even regulations, to foster the adoption of more climate-sensitive general plans, building codes, investment plans, and LCPs. Key questions include not only what level of sea level rise to plan for, over what time horizon, but also what rates of accelerated erosion to consider, particularly for coastal bluffs. Because this effort to pin down numbers will push the limits of the science, it will be important to consider the tradeoffs between using more or less conservative estimates.

To better understand the risks and opportunities for preventive strategies in the transportation sector, Caltrans should be required to conduct scenarios-based analysis of climate risks. The state's flood management authorities were issued such a mandate with the passage of SB 5 in the fall of 2007. Like flood management, transportation is a sector where the costs of not taking into account a changing climate are potentially great, given the high costs and long lives of capital investments.

An Inventory of Opportunities for Coastal Habitat Migration

A key planning issue that requires early thinking is what to do about coastal habitat. For both the ocean coastline and the San Francisco Estuary, inventories are needed to determine where the best opportunities exist for fostering inward migration of coastal habitat, as a basis for determining where to focus development and armoring restrictions and habitat acquisition efforts. To the extent possible, this analysis should include information on possible effects on biological processes of changes in water temperature. It will also be important to acknowledge that this type of planning comes with great uncertainties about likely success, given the limits in our knowledge about how natural systems will respond to climate change.[22]

Pilots on New Adaptation Techniques and Alternatives

Because there is still some time before the more dramatic changes take place, there is an opportunity to experiment with new technologies and institutional approaches to adaptation that may lessen some of the tradeoffs and constraints. Pilot studies using "friendlier" techniques for coastal protection are warranted, including less invasive armoring, more habitat-friendly beach nourishment, and the use of living shoreline principles in areas where wave energy does not pose too great a constraint. Pilots can also be used to explore institutional innovations such as rolling easements, perhaps picking some cases along different parts of the

[22] See the accompanying report by Barbour and Kueppers (2008) for a more in-depth discussion of ecosystem conservation challenges in the face of a changing climate.

coast, with different types of habitat and developed land. Innovations in finance should also be pushed – such as the use of armoring mitigation fees to support public coastal values.

Conclusions

Climate change will pose significant challenges to the management of California's diverse and valuable coastline, heightening the tradeoffs between social goals that are frequently in conflict under today's conditions. Over ten percent of the ocean coastline is already armored to protect private structures and public infrastructure, as are significant portions of the coastline in the San Francisco Estuary. These structures – including seawalls, levees, and breakwaters - raise the difficulties of maintaining recreational values and public access and of protecting aquatic and coastal species. With the anticipated acceleration of sea level rise and increasingly frequent and intense storm surges, the pressures to continue armoring the coastline will be great. Less invasive forms of coastal protection, such as beach nourishment and living shorelines, are less well-known, and not always physically feasible. Behavioral alternatives, such as planned retreat, will face significant financial and political hurdles to the extent that they are perceived as conflicting with private property rights.

Fortunately, a set of institutions exists to help negotiate these tradeoffs, and the two lead agencies – the Coastal Commission and the San Francisco Bay Conservation and Development Commission – have begun to address the implications of climate change in their planning and outreach efforts. However, much remains to be done to put coastal managers on firmer footing in dealing with the coming challenges. Priorities include inventorying coastal resources to provide a firmer basis for balancing decisions on property and habitat protection, assessing the vulnerabilities of coastal infrastructure, providing planning guidelines on sea level rise to agencies with coastal assets (including local governments, infrastructure providers, and environmental managers), easing the rules on local funding of flood management investments, and experimenting with alternatives to armoring as a way of managing the changing coastline.

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