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Climate Adaptation and Sea-Level Rise in the San Francisco Bay Area

By Laura Tam

We have known about the perils of climate change for more than two decades. But global efforts to slow it down by reducing greenhouse gas emissions have largely failed. Even where major efforts are moving forward, such as California's Global Warming Solutions Act (AB 32), planned reductions will not even begin for 10 years, and they only represent a fraction of world emissions. In the meantime, the concentration of atmospheric greenhouse gases has continued to rise at an increasing rate.

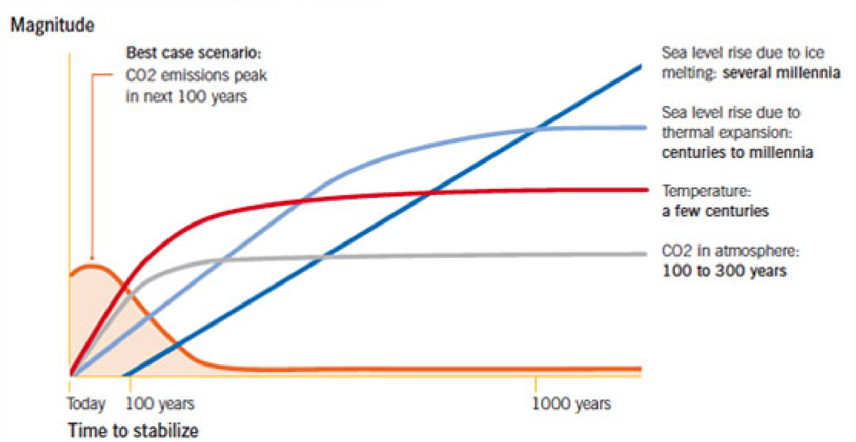
Even if we are somehow able to stop producing greenhouse gases tomorrow, the high concentration of carbon dioxide already in the atmosphere from historic emissions — since we began burning fossil fuels for energy in the 19th century — will cause the climate to continue to change (see Figure 1).

As a result we must not only intensify our efforts to reduce climate change both now and in the future, but we also must prepare for and adapt to its inevitable effects. These two planning efforts are referred to, respectively, as climate change mitigation and climate change adaptation.

Mitigation and adaptation are related. Without any mitigation, climate change impacts — higher temperatures, higher sea levels, changes in water availability — will be worse. Meanwhile, adaptation will be more difficult and more expensive, and more people are likely to suffer. Some policies or planning actions can support both goals. For example, restoring tidal wetlands both sequesters carbon (mitigation) and builds a buffer against sea-level rise (adaptation). Some actions, however, can pit these goals against each other. Desalination of seawater, for example, is an adaptation strategy for drought that is energy intensive, usually producing significant levels of greenhouse gas emissions. In selecting mitigation and adaptation strategies, it is important to consider trade-offs and try to achieve both ends if possible.

Figure 1: How long will it take our climate to stabilize?

Even if we succeed at reducing our emissions, it will take centuries for the climate—and the effects of global warming and sea level rise—to stabilize.



Source: Adapted from BCDC's "LIving with a Rising Bay," 2009. Based on data from IPOC.

Ideally, mitigation policy is implemented at an international or national level, where the scope of emissions is very large. Adaptation, however, must be implemented locally because the impacts of climate change are geographically variable, and vulnerabilities to these impacts are more variable still. Because of the local knowledge necessary to understand risks and reduce vulnerabilities, adaptation actions must be planned fairly close to home.

Planning with uncertainty

The process of adaptation planning identifies a set of actions to decrease a system's vulnerability, or increase its resilience, to the impacts of climate change. The main tool of adaptation planning is the vulnerability assessment: an evaluation of a system's risk compared to its adaptive capacity or ability to cope with climate change. Vulnerability assessments reveal where and which actions are needed to improve resilience to risk factors. They can be geographic or systemic in nature. For example, a vulnerability assessment for a city could include mapping future sea-level rise and areas at risk of urban heat-island effects alongside demographic information to reveal which populations may be most exposed to flooding or extreme heat. A vulnerability assessment for a wastewater system might model the system's performance under a range of predicted future storm intensities and sea levels to see whether infrastructure needs to be protected or moved and where urban flooding is most likely to occur. Vulnerability assessments can be used to set priorities for early-, medium-, and long-term actions, and to develop "trigger points" for decision making in the future.

Adaptation strategies should be implemented according to future conditions, regular assessment, and recalibration. This process, called adaptive management, is necessary because there is great uncertainty about how fast the climate is changing and when the predicted effects may occur. Natural-resource managers have long used adaptive management to plan for uncertainty in the environment. It is an iterative process in which managers and scientists work together to consider management strategies, predict their outcomes, implement actions, monitor conditions, and adjust future actions accordingly.[1]

As an example of why this approach is valuable, consider that sea levels in San Francisco Bay are predicted to rise about 16 inches by 2050, but that the international scientific community constantly revises sea-level rise, usually upward. Although it is possible that sea levels may not increase 16 inches by mid-century, it is even more likely that we will see that much sea-level rise 10 or 15 years sooner. Because of this uncertainty, it is important to monitor changing conditions to determine when to take the prescribed course of action developed through vulnerability assessment. Without this, we may adopt the wrong adaptation strategy, pay too much for one — or pay too little. The adaptive-management approach is one that can be used by local governments and planners to outline the expected impacts of climate change, create scenarios, and take action in the face of uncertainty.

In the near term, some adaptation strategies have benefits that can be realized today, and may be things we are already working on to achieve other policy goals. Two examples of these "no-regrets" adaptation strategies include energy efficiency and water conservation, both activities that are valuable today and may be even more valuable in the event of future climate change. In a way, agencies and utilities working in these areas are doing climate adaptation planning already. But the severity and trajectory of climate change will require a thorough examination of goals, targets, and programs in these areas to ensure that they are effective in the future under changed conditions.

The state of California has been proactive in developing climate change mitigation and adaptation strategies, but there has been less guidance for local governments, which may be the lead agencies going forward due to the geographic nature of climate risks. Without proper planning, local governments may resort to more ad hoc approaches, even emergency responses. Such approaches are not only more risky, but they are usually much more expensive and do not build long-term resilience.

Climate change impacts in the Bay Area

Increasing concentrations of greenhouse gases in the atmosphere will cause three principal climate changes that are expected become more severe in the Bay Area over time:

1. higher temperatures and heat waves
2. changes in the hydrological cycle, including drought, flooding, and wildfire
3. sea-level rise due to thermal expansion of the oceans and melting land-based ice

Higher temperatures and heat waves

Temperature changes are the primary marker of climate change, and they are also the key driver of changes in other natural systems such as sea levels and hydrologic cycles. California projects a rise of four to nine degrees Fahrenheit by 2100, the higher end of the range corresponding to United Nations' Intergovernmental Panel on Climate Change's model scenarios of world development with higher emissions.[2] Temperature increases will be more pronounced in the summer months and at night. Heat waves are expected to increase in frequency, with individual heat waves becoming longer and extending over a larger area. Inland areas are likely to experience more warming than coastal regions.

There will be an increase in the number of "extreme heat days" — days that exceed the region's 90th-percentile average temperature. From a 20th century baseline of an average 12 extreme heat days per year in San Francisco, we may expect to see 20 such days annually by mid-century and 70 to 94 days by the end of the century — an eightfold increase from today. This will increase the likelihood of heat-related illness and deaths, burdens that will fall disproportionately on vulnerable communities, especially the poor, the elderly, and young children.[3]

Water uncertainty: droughts, wildfire, extreme storms, and flooding

Toward the end of the century we are likely to experience more prolonged shortages in freshwater supplies, as well as extreme weather that could increase local and urban flooding from severe storms.

The Sierra snowpack — which provides natural water storage essential for many Bay Area water agencies — is likely to melt earlier in the year and more rapidly than in the past. Longer and drier droughts are predicted before the end of the century, leading to increasing frequency and magnitude of water shortages, and exacerbating conflict over an already stretched resource. Across the state, more precipitation will fall as rain instead of snow, leading to water-storage challenges in the dry season. Higher temperatures will also increase water demand across all sectors: domestic, agricultural, commercial, and industrial. As droughts are expected to increase in frequency — because the dry season will start earlier and end later — wildfires are expected to increase in both frequency and intensity.

Groundwater basins used for water supply are threatened with decreased replenishment from lowered precipitation and increased evaporation. They are also at risk of increasing extraction to meet growing supply needs. For coastal aquifers, this may increase their vulnerability to saltwater intrusion from sea-level rise. Saltwater intrusion into coastal aquifers would make some of the freshwater unusable without more intensive treatment. A combination of increased storm intensity and saltwater intrusion in the Sacramento–San Joaquin Delta could increase the risk for flood-caused levee failures, which potentially could destroy low-lying areas and contaminate freshwater supplies stored and conveyed in the delta.

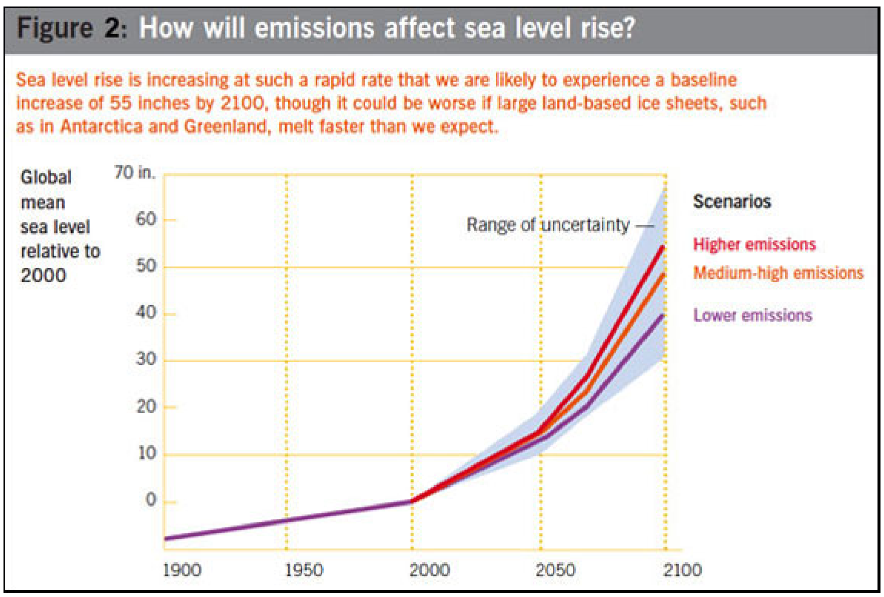
In the winter, heavier downpours and increased runoff could contribute to sewer overflows. Urban flooding from extreme storms could threaten public health and safety, damage property, and impair coastal water quality.

There are 22 wastewater treatment plants on the Bay Area's shoreline that are vulnerable to a 55-inch rise in sea level, the upper end of projections by 2100.[4] Many treatment plants rely on gravity to discharge treated water to the bay. As bay water levels rise, this mechanism could fail and significantly affect facility operations.

Sea-level rise

Sea-level rise occurs because of two natural processes that have been occurring since the last ice age ended approximately 10,000 years ago. The first is the expansion of the oceans, which increase in volume as they absorb atmospheric and land-generated heat. The second is the melting of land-based ice, such as glaciers and ice sheets that occupy vast areas of Greenland and Antarctica.

In the past 10 to 15 years, the rate of global sea-level rise has increased by about 50 percent and is now averaging three millimeters per year. Human-induced global warming is a major contributor to this accelerated rise. In California, we are likely to experience a sea-level rise of about 16 inches by 2050 and about 55 inches by 2100 — and much more after that.[5] These estimates are based on ranges that correspond to several global greenhouse gas emissions scenarios. In the highest-emission scenario, the range of estimated end-of-century sea-level rise is between 43 and 69 inches.[6] (see Figure 2)



Source: Cayan et al., 2006, in California Climate Adaptation Strategy, 2009, p. 80.

The degree of sea-level rise in the region depends on land subsidence or tectonic uplift. Some communities of the South Bay, which heavily extracted groundwater up through the 1960s, have sunk below today's sea level by as much as 13 feet. Parts of the Sacramento–San Joaquin Delta that have been heavily channelized, diked, eroded, and oxidized are now 25 feet below sea level. Areas that are sinking or losing land area or wetlands to erosion will experience the impacts of sea-level rise sooner and perhaps with greater intensity.

Most of the near-term damage we expect on developed areas will be from storm conditions that occur at the same time as high tides. Storms cause extreme lows in air pressure, allowing the sea level to instantaneously rise above predicted tides. Storms also increase winds, especially onshore winds, that cause bigger, more erosive waves. Finally, they bring rain, which increases water volume in creeks and rivers. Approximately 40 percent of California's land drains to San Francisco Bay, which means that storm floods will last longer here than in higher-elevation regions. Under existing conditions, the combination of high tides, storm surges, and river flooding can raise water levels in the delta by 51 inches for as long as a day.[7] As sea levels rise, low-lying areas protected by already fragile levees will face even greater risk.

Climate vulnerabilities and adaptation strategies for the urban Bay Area

Climate change hazards, especially sea- and bay-level rise, threaten public health, infrastructure, ecosystems, and coastal zones. Sea-level rise is the most significant and unprecedented challenge for planners. It stands to dramatically transform the region's relationship with its most defining geographic features.

Physical strategies for sea-level rise

There is a continuum of strategies we can use to manage changing sea levels, ranging from armoring the shoreline — keeping the sea out — to abandoning low-lying development altogether.

Among them:

- barrier(s) or tidal barrage(s) to manage tidal flows in and out of San Francisco Bay (at the Golden Gate or in smaller, strategic parts of the bay)
- coastal armoring with linear protection, such as levees and seawalls, to fix the shoreline in its current place
- elevated development in which the height of land or existing development is raised and protected with coastal armoring
- floating development on the surface of the water, or that which may be floated occasionally during a flood, making it largely invulnerable to changing tides
- floodable development designed to withstand flooding or to retain stormwater
- living shorelines with wetlands that absorb floods, slow erosion, and provide habitat
- managed retreat that safely removes settlement from encroaching shorelines, allowing the water to advance unimpeded, and bans new development in areas likely to be inundated

Some of these strategies are familiar and reliable. For example, the Netherlands has used dikes and levees to keep the ocean at bay for hundreds of years, and most of that country's population lives below sea level. Other strategies, such as large-scale wetland restoration projects in the Chesapeake Bay and the southern San Francisco Bay, are ongoing experiments to determine wetlands' ability to absorb waves, attenuate flooding, and protect developed areas while improving the environment. Not all strategies are financially, politically, culturally, or environmentally appropriate for all areas. The essence of planning for sea-level rise is matching the right strategies to the right locations and conditions.

Appropriate and resilient strategy selection may require thinking about a much longer planning horizon than we are accustomed to. We may also have to work more in concert with, rather than in opposition to, natural processes. Today, permitting agencies — such as the California Coastal Commission and the Bay Conservation and Development Commission — assume for permitting purposes that new development will have a 50- to 90-year life. But we don't really know if that time frame is appropriate, given the permanent changes that sea-level rise will bring. Is it a good idea to build new development in the water's path, knowing that flooding won't be likely for 100 or 300 years, but will very likely happen eventually? Or is there a way to keep water from encroaching on some places forever? If we look far enough into the future, it is possible that San Francisco, along with every other coastal city, will have to be abandoned. How long should we be planning for? Uncertainty about when rising seas will make their impact felt raises numerous questions about what the appropriate planning horizon should be.

The San Francisco Bay of the future is going to need to be designed around more than one of these strategies. We will not be able to recreate the ecological intactness of San Francisco Bay before it was developed — even if we fully retreat from its shore — just as we will not be able to hold the shoreline at current levels to protect all existing and planned development. The shape of the bay will become the product of our choice of strategies.

On the ocean coastline, we have less control because the shoreline is much more rugged and less developed — so fewer strategies are realistic. The coastlines of Marin and San Mateo counties, while home to towns and cities such as Stinson Beach and Pacifica, are uninhabited in many places. San Francisco has medium-density residential areas that were built right over sand dunes to the very edge of the beach. Although most of our region's population and urbanized area is concentrated along the bay shoreline, we will still need to figure out what to do about development on the ocean coast, especially where critical infrastructure is concerned.

Governance of sea-level rise

Many public agencies have responsibility for managing the challenges of climate change. Water supply and wastewater agencies will have to deal with changes in flow, facilities at risk, and saltwater intrusion into intake systems. Airports and ports will have to deal with shoreline infrastructure that is not at the right height. Transit and transportation agencies will have to deal with roads, railways, and subways that are vulnerable to flooding. Parks, planning, and redevelopment agencies will have to figure out how to deal with floodwater in residential neighborhoods, especially in those neighborhoods that are least prepared to cope with new risks.

In the Bay Area, there are two special-purpose government agencies with jurisdiction over the water that surrounds us: the San Francisco Bay Conservation and Development Commission and the California Coastal Commission. These agencies have severely limited authority to implement strategic decisions about adapting to sea-level rise. BCDC issues permits for filling, dredging, and changes in use in the San Francisco Bay, salt ponds, managed wetlands, and on the shoreline. It makes these permitting decisions in concert with the policies in its long-term guidance document, the San Francisco Bay Plan, which, among other things, specifies which areas along the shoreline should be used for ports, recreation, wildlife refuges, and other purposes. However, BCDC's shoreline jurisdiction to regulate development only extends to 100 feet upland from the bay. In many places, 100 feet inland is well within the elevation that will be flooded by a sea-level rise of 1.4 meters. Many people have recently suggested that state law be amended to broaden BCDC's scope of authority to allow better management of rising seas.

Along the ocean coastline, the California Coastal Commission shares responsibility for developing coastal plans with 60 cities and 15 counties. Local coastal plans set ground rules for the location and type of land uses that can take place in the coastal zone, as described by law. Typically, LCPs are developed by local governments and certified by the CCC, at which time the commission transfers permitting authority for most new development to the local government. The CCC retains appellate authority over development within 300 feet of the high-tide line or the first public road, whichever is landward. About 90 percent of the state's coastal zone falls into an LCP. However, most of these plans were developed in the 1980s, before sea-level rise became a well-known concern, and there is no legal requirement for them to be updated.

One of the big gaps in our waterway governance system is an entity to manage the Sacramento–San Joaquin Delta, where two major climate adaptation issues have come to a head: water supply and sea-level rise. The delta is the largest estuary on the West Coast, and supplies drinking water to two-thirds of California. It is home to half a million people, and hundreds of species of plants and wildlife — including numerous endemic species. Over the years, a lack of cohesive planning and a lack of clear management have left the delta in crisis. Agricultural and developed areas are severely threatened by sea-level rise and by old, unmaintained levees. Delta water is not being managed or supplied well enough to meet growing demand from human uses and ecological restoration. Today's challenges in the delta give us a glimpse of the extreme vulnerability the Bay Area could face in the future if we don't give our institutions the powers they need to manage the changes coming our way — with the whole region's best interests in mind.

Local governments in the Bay Area are just beginning to consider planning for projected sea-level increases. Local governments do all of the planning and most of the permitting in areas that are at risk from sea-level rise, erosion, and storm surge, but they need resources or decision tools for determining what to protect and where. But local planning efforts are generally underfunded, and sea-level rise is perceived as a new threat that will not cause significant harm or require emergency response for years, if not decades. There is no public consensus around how to plan for sea-level rise, or the most appropriate risk, financial, and land-use management strategies for local governments to adopt. There is also a hope that federal, state, or even regional organizations will step up with resources and planning tools that local governments will need to negotiate the problem — and also work to phase out programs and policies that can increase future risks for sea-level rise, particularly in existing flood-prone areas.

If we don't make changes in how our shorelines are governed, we will end up with an unplanned and ineffectual solution. Most communities will want shoreline armoring to secure property tax bases and to protect coastal infrastructure in the short term. But these structures diminish ecological and recreational values. If every project or jurisdiction, particularly on the bay side, hardens its shoreline, we will not build enough flood-attenuating wetlands. We do not want to set ourselves up for tragedy in the future because we have invested too heavily in constructing levees but not spent enough on maintaining them. We need the right combination of approaches to produce an answer that is sustainable, cost-effective, and resilient to whatever change in sea level the future brings.

As a first step forward, local governments and regional agencies can undertake a shoreline risk assessment and prepare coast inundation maps. These assessments should be based on estimated 100-year flood elevations that take into account the best available scientific assessments of future sea-level rise (currently about 55 inches) and current or planned flood protection. These maps should be updated regularly, about every five years. Local governments should also update their coastal plans at this frequency, even though it would take a change of state law, the Coastal Act, to require it. Safety Elements within General Plans, which are required, should be updated to reflect climate change hazards and include planned approaches to reducing their potential damage. One way that local governments can prevent future damage is to prohibit new development in extremely hazardous areas unless the project is very small or temporary, or is in an infill location surrounded by other development and supporting infrastructure. Dense, urban places and critical infrastructure are some of the best candidates for flood protection resources should they become available. Planning departments, redevelopment agencies, and other local agencies should use local risk assessment and inundation maps to prioritize flood protection resources and select strategies. Nonstructural measures, such as wetlands, should be used wherever feasible because of their climate mitigation, habitat, scenic, and other benefits.

Managing public health

Public safety and health are vulnerable to climate change in several ways. Increases in extreme heat, particularly during heat waves, could kill more people than all other climate change impacts combined.[8] Warmer days also worsen air quality, create urban heat islands, and can increase people's risk to vector-borne and infectious diseases such as West Nile virus and Lyme disease. Public safety and health could also be compromised by storm-related flooding in residential areas and by wildfire, both because of fire's direct threat at the urban-wildland interface and because it significantly impairs regional air quality. While the Bay Area may not experience the same severity or frequency of extreme heat days as other parts of southern and central California, by mid-century we may see three to four times as many extreme heat days as we do today, and six to eight times as many by 2100.

In milder climates, such as along the California coast, people are much less prepared for and acclimatized to hot weather. In California's 2006 heat wave, rates of emergency department visitation and hospitalization were far greater in coastal counties, including San Francisco, than the state average, although some parts of the state were objectively hotter and suffered more heat-related deaths.[9] Only about 11 percent of housing units in the San Francisco metropolitan area have air conditioning.[10] Although some San Franciscans might welcome a few more warm summer days, an important part of adaptation planning will be preparing for regionwide heat emergencies that could otherwise overwhelm hospitals and health providers. Heat waves that are longer and that occur earlier in the season will increase our region's vulnerability to this aspect of climate change. San Francisco and Alameda counties contain eight of the 13 census tracts most vulnerable to heat in the entire United States.[11]

Urbanized areas around the bay may be especially vulnerable to the phenomenon known as "urban heat island," where heavily urbanized areas can become and remain significantly warmer than nearby areas because of the prevalence of heat-retaining materials like concrete and asphalt. Urban heat islands may be five to eight degrees warmer than surrounding areas experiencing the same weather systems. Impervious ground and roof surfaces limit natural cooling that takes place when plants and soil release water vapor into the air, a problem compounded by lack of shade. They also release heat more slowly at night, so when extreme heat occurs, cities have more trouble cooling off than other places do. This increases energy demand for cooling and impacts health: Heat waves are more dangerous for people when the body cannot cool off at night. Heat-related illnesses and deaths are considered entirely preventable if appropriate strategies are taken by residents, planners, and health providers.

While every sector of the population will have to deal with flooding, warmer temperatures, extreme weather, impaired air and other economic and health issues, some social groups will be more vulnerable than others to these changes. It has been widely known for a long time that on a global scale, the low-income, the very young, and the elderly are the populations most vulnerable to climate change impacts. In large part, these groups' vulnerability stems from having less ability to anticipate, cope with, and recover from a disaster.[12] Often, these vulnerable groups reside in locations where heat-related and other pollution is already problematic.

The burdens of higher temperatures and heat waves will fall disproportionately on the poor, the elderly and young children. People with preexisting health conditions such as asthma, respiratory disease, allergies, diabetes, or heart conditions are also more susceptible to the impacts of climate change due to deteriorated air quality and heat-related illness or death. Low-income neighborhoods are also more vulnerable to urban heat-island effects because they generally have less tree coverage and more impervious ground surfaces. People who live alone are especially vulnerable to heat waves and heat-related illness.

The costs of disaster insurance, healthy food, water, and heating and cooling are expected to rise as a result of climate change. People in low-income communities will spend a larger percentage of their incomes than those in middle- and high-income communities to prepare for and respond to these impacts. Households without an adult English speaker are also more vulnerable than others. Low-income and linguistically isolated people are less likely to be able to afford emergency supplies or sufficient insurance. They are also less likely to be able to evacuate during a disaster, either to go to cooler places or to escape flooding.

To prepare for the public health impacts of climate change, county health agencies should work with city planning, housing, and emergency-services agencies to identify geographic areas and populations vulnerable to specific climate change threats such as sea-level rise, flooding, fire, and urban heat islands. Susceptibility factors that should be part of the vulnerability analysis include housing quality, transportation access, age, poverty, and access to health care. These analyses should be used to develop countywide climate-preparedness plans that include actions to reduce vulnerabilities and target health outreach and emergency measures for susceptible people. City agencies should also develop robust and comprehensive heat response plans that identify cooling centers, reach out to facilities that serve vulnerable groups such as the elderly and young children, and plan transportation. Agencies responsible for the built environment should seek to reduce the urban heat-island effect through expanding urban forestry, switching to light-colored pavement, and promoting white roofs.

Managing infrastructure

Infrastructure — the physical fabric of functioning cities — is at risk from climate-change hazards, especially sea-level rise. Roads, mass transit, airports, bridges, ports, energy generation and distribution facilities, sewer systems, and water systems suffer already from underinvestment, making certain assets even more at risk of weather and climate-related events. In the Bay Area, shoreline infrastructure is among the most vulnerable, where it is in the path of sea-level rise and storm surges. Yet the shoreline is also where some of our most significant public assets, including our airports, major highways, railroads, and wastewater treatment facilities, are located.

Transportation. Climate change will affect transportation systems at all levels, including planning, design, construction, operation, and maintenance. Potential economic impacts of climate change on transportation include: lost worker productivity from delays; impeded and more expensive movement of goods through ports, airports, and rail systems; and increased costs of repairs and maintenance of transportation systems. Climate change could also impair the safety of travel. The Bay Area contains about half of the roads at risk of inundation in the state of California and 60 percent of the state's railroads at risk in a 100-year flood event. Several factors contribute to the susceptibility of transportation infrastructure to climate change impacts, including age, condition, proximity to other infrastructure elements, and current level of service.

San Francisco International Airport and Oakland International Airport could be significantly affected by sea-level rise because of their low elevation. Ninety-three percent of the land they are built on is vulnerable to storm-surge inundation with a 55-inch sea-level rise. The runways at SFO were built on landfill, but will be protected at least through the middle of the 21st century by a partial seawall and new planned levees. Beyond mid-century, levees around the runways or new raised runway elevations may be required.

Transportation planners should assess and regularly monitor regional transportation system vulnerabilities to climate impacts, design new transportation projects to be resilient to end-of-century sea-level rise, and prioritize retrofits for existing infrastructure for assets that are of significant regional economic value or are irreplaceable, and those that cannot be relocated and would not otherwise be protected.

Energy. California's energy system is vulnerable to climate change in four principal ways:

1. Warmer temperatures and severe storms could reduce electric-grid reliability.
2. Energy demand, particularly for cooling, may dramatically increase.
3. Changing precipitation patterns could affect hydroelectricity supplies.
4. Sea-level rise and increased storm surges could potentially affect energy infrastructure.

As temperatures in California are expected to increase more in summer than in winter, buildings in general will exhibit higher demand for summertime cooling. This demand for cooling will rise at the same time of day as higher temperatures threaten important electrical infrastructure, straining local and statewide electric grids. As energy demand increases and electric grids become more vulnerable, local on-demand "peaker" power plants and backup generators may be switched on, increasing both greenhouse gas emissions and localized air pollution. Higher temperatures and changes in humidity also decrease the efficiency of fossil-fuel burning power plants, some types of renewable power plants (including solar photovoltaic), and energy transmission lines, thus requiring either increased production or improvements in the efficiency of power generation and transmission.

Many Bay Area communities currently suffer power outages during extreme winter weather events as a result of downed power lines or flooded infrastructure. This could increase if extreme weather events increase in frequency or magnitude because of climate change. Projected sea-level rise along California's coast may result in higher flooding potential for coastal energy infrastructure, such as natural gas pipelines and compressor stations, electrical substations, electric transmission lines, and power plants.

To prepare for climate change, energy utilities and planners should conduct vulnerability assessments for energy system assets at risk from the effects of climate change, and evaluate existing energy efficiency and demand-response programs for their effectiveness at shaving peak electricity demand in more frequent and prolonged hot weather.

Water and wastewater systems. For more than a century, water development and management has been one of the most enduring and complex policy issues in the western United States. Monumental investments in infrastructure built to move water around California — particularly from north to south and east to west — have enabled the state's agriculture sector to grow and cities to exist in Southern California and the Bay Area. Even in the absence of climate change, demands on limited water resources by every sector have caused environmental damage and are the subject of ongoing conflict, problems that will only grow as the state's population increases by more than 50 percent by mid-century. Climate change will not only exacerbate the challenge of meeting demand, but it directly threatens the viability of water infrastructure through extreme events and sea-level rise.

Climate change adaptation planning is part of the job that regional water utilities already do. They are required to file five-year urban water management plans detailing how they will ensure that supply meets projected demand. State legislation from 2008 requires even greater water conservation efforts: a 20 percent reduction in per capita urban water use by 2020. In part, this helps the state deal with the existing challenge of water scarcity, but it also builds resilience for loss in snowpack, long-term drought, and other water-cycle changes that will be exacerbated by climate change.

Water utilities serving the Bay Area, including the East Bay Municipal Utility District and the San Francisco Public Utilities Commission, have undertaken water supply modeling to understand shifts in the quantity and timing of runoff that may occur due to climate change. Both have found that because of the high altitude and capacity of their storage reservoirs, along with other factors, climate change may not significantly affect water deliveries through about 2020 to 2030. But these utilities are in the process of factoring in net changes in precipitation, the impact of which may be much more significant by mid-century and beyond. While many Bay Area water customers are much more significant by mid-century and beyond. While many Bay Area water customers are lucky to have water supplies not immediately threatened by climate change, this security is relative and may be short-term.

Water supply planners should evaluate alternative water supply opportunities and demand management strategies, such as water conservation, water recycling and desalination, and prioritize investment in these strategies according to cost, reliability, and environmental benefits.

Wastewater utilities are vulnerable to saltwater intrusion into collection systems, which could exacerbate flooding problems and compromise biological treatment processes. To prepare for the effects of climate change, wastewater agencies should retrofit ocean and bay outfalls with backflow prevention as a short-term measure, and over the long term, create new design standards for infrastructure that accommodate increasing storm sizes and more frequent storm surges. They should also expand investment in "green infrastructure" which, through engineered surface treatment of stormwater, may attenuate floods, increase groundwater recharge, and reduce urban heat islands. Examples of these strategies include permeable pavement, rain gardens, constructed wetlands, grassy swales, rain barrels and cisterns, and green roofs.

In conclusion

Climate change is one of the greatest challenges the world has ever faced. We need to begin reducing greenhouse gas emissions immediately to stave off its worst effects. But we also need a plan to respond because some climate change will occur regardless, as the result of historic and ongoing emissions. Climate change is not a disaster like an earthquake, which could be imminent and massively destructive. Rather, it is a disaster that is here already and will slowly unfold for the rest of our lives, and for probably much longer after that.

Climate change adaptation will need to be dealt with at all levels of government. Yet it is at the local and regional levels where vulnerability can best be understood and addressed. Although there is some uncertainty around when we will experience various climate changes, planners can today anticipate their trajectories and begin thinking ahead about how to prevent catastrophic impacts. We know some of what the flooding risks are for parts of San Francisco Bay and the ocean in 50 and 100 years and beyond. We also have a broad array of management tools. We can try to stop floodwaters from encroaching on developed areas. Retrofit our developed areas to accommodate floodwaters. Build things that float. Make room for sponge-like wetlands to try to solve our flooding problem and restore the bay at the same time. Or retreat from shorelines altogether.

The Bay Area is fortunate to have institutions that are increasingly aware of these vulnerabilities and are beginning to plan ahead. But there is much more we need to do within specific areas of planning and governance to consider long-term impacts and, as much as possible, prevent foreseeable damage, loss, and misery. Local government agencies in particular need a starting place.

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This paper is largely based on the May 2011 SPUR report, Climate Change Hits Home, *which was principally authored by Laura Tam and is the product of a SPUR blue-ribbon task force on climate change adaptation. SPUR is a public policy think tank and member-supported nonprofit organization dedicated to good planning and good government in San Francisco and the Bay Area.* ***www.spur.org***

Notes

1. According to the U.S. Geological Survey; see **http://ecosystems.usgs.gov/wter/adaptive_mngmt.html**.

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4. Heberger, Matthew, Heather Cooley, Pablo Herrera, Peter H. Gleick, and Eli Moore. Pacific Institute 2009. *The Impacts of Sea-level Rise on the California Coast. A Paper from the California Climate Change Center* (Report No. CEC-500-2009-024-F); available at **www.pacinst.org/reports/sea_level_rise/report.pdf**.

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6. Based on a 2000 baseline in the "California Sea Level Rise Interim Guidance Document." Developed by the Coastal and Ocean Working Group of the California Climate Action Team. October 2010.

7. BCDC, *Living With a Rising Ba*y, 2009, supra note 5.

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9. Knowlton, K., et al. 2009. "The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits." *Environmental Health Perspectives* 117:61–67.

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12. Morello-Frosch et al., supra note 3.