UP A CREEK?

GUIDANCE ON HOW TO CONDUCT VULNERABILITY ASSESSMENTS FOR TIDAL CREEKS AND FLOOD CONTROL CHANNELS

This report describes an approach to assess the vulnerabilities and consequences of sea level rise on tidal creeks and flood control channels. While sea level rise alone may not immediately affect some areas, a higher downstream tide may exacerbate riverine flooding, such that smaller, more frequent flood flows cause overbank flooding and stormwater backups, particularly in low-lying areas that will no longer be able to effectively gravity drain. Planners need to work with flood managers using watershed-scale hydraulic models to evaluate various combinations of Bay water levels, sea level rise, and flood flows that could cause combined coastal-riverine flooding. This single-sector analysis fits into the multi-sector adaptation planning process developed by the Adapting to Rising Tides (ART) Program and provides a mechanism to improve coordination between community planning and engineering to ultimately identify feasible and appropriate sea level rise adaptation strategies.

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1. Introduction

The impacts of sea level rise will not be confined to direct coastal flooding along the Bay shoreline. Sea level rise will also affect every tidal creek and flood control channel that drains into the Bay, causing water levels in these channels to rise higher and the tide to push further (migrate) upstream. Since many of our creeks have been engineered to provide flood control assuming current Bay water levels, sea level rise will progressively reduce the capacity of these creeks to discharge riverine flows. Flooding in roadways and basements can occur when water levels in channels are too high to allow gravity-stormwater drainage into the creeks (Figure 1.1). Furthermore, overbank flooding can occur when riverine flows back up against high tides ('backwater effect'). And even before flooding, sea level rise will reduce available freeboard and levees may lose their Federal Emergency Management Agency (FEMA) accreditation, which would require residents and property owners in the floodplain to purchase flood insurance. Thus, sea level rise will exacerbate conditions in existing flood zones and may cause new areas to be designated as flood zones. While impacts of sea level rise will vary depending on the type and condition of the creek or channel and surrounding land uses, failure to address these vulnerabilities will have widespread consequences on homes, schools, businesses, transportation and utilities infrastructure, parks, and the environment. This guidance document lays out an approach for how to assess the vulnerability of tidal creeks and flood control channels to sea level rise and integrate the assessment outcomes into a multi-sector adaptation planning process.

Figure 1.1. January 1, 1997 flooding in downtown Martinez. Torrential rains and a high tide occurred at the same time. High water levels in the Bay caused Alhambra Creek to back up and kept adjacent areas from draining. The city and county flood control district spent $8.6 million in 2001 to widen the creek downtown. New Year's storms in 2006 rivaled the 1997 storm and Alhambra Creek overflowed upstream, where it had not been widened. Damage would have been much worse had the 2001 flood improvement project had not been completed. Martinez City manager reported, "The downtown would have been under water – we dodged the bullet."

1.1 Flood risk management and sea level rise adaptation

Flood risk management responsibilities are shared by a number of agencies. Conducting a vulnerability assessment of tidal creeks and flood control channels can strengthen relationships across these agencies and build the kind of broad community support that is needed to address existing flooding problems and the added challenge of sea level rise. For example, cities often own and manage the stormwater collection and drainage network, while the county may own and manage the flood control channels that the city network drains into. In other areas, private landowners and Joint Power Authorities may manage interconnected flood risk management assets. While most flood control channels were originally designed to provide protection in the most economical manner, which often resulted in narrow concrete channels lined with riprap, flood risk management now goes beyond "plumbing" (drains, culverts, etc.) and extends to the watershed as a whole (Avalon 2009). Many communities want flood control projects to provide wildlife and recreation benefits in addition to improved public safety. Like Redevelopment Plans, Watershed Management Plans, and General Plan Updates, Climate Adaptation Plans are a mechanism to address aging flood infrastructure, evolving community needs, and a changing Bay.

By planning now for sea level rise, communities can reduce the risk of costly damage from current and future flooding. While flood managers may be able to raise channel levees, install gates, add pumps, or even work with land managers to restore wetlands, protection of existing development and critical infrastructure is typically expensive and there will be tradeoffs between protecting certain properties and overall community benefits. Multi-sector planning processes will be needed to make these difficult decisions and vulnerability assessments of tidal creeks and flood control channels lay the foundation for developing, evaluating, and refining adaptation strategies that reduce flood risk to key community assets (e.g., Stein et al. 2014). The guidance that follows involves review of existing conditions, exposure analysis, and stakeholder engagement to understand the vulnerability and potential consequences from sea level rise on tidal creeks and flood control channels. This guidance is based on lessons learned in the Adapting to Rising Tides (ART) Program (www.adaptingtorisingtides.org).

Flood recovery vs. resilience

The dominant public urge post-disaster is often to recreate the same city, as quickly as possible. Traditional, single-objective solutions may be implemented unless there are already plans for more innovative solutions. Following Superstorm Sandy, a watershed coordinator in New Jersey described the struggle of balancing immediate recovery and long-term planning: *… the recovery period is a key opportunity to build back better rather than just building back to normal, and a big storm can be a key motivator for getting local governments and residents to take action on resilience projects that may have been on the back burner for years. But communities such as Sea Bright that were still removing mountains of sand and debris from the streets months after the storm might not be ready to look at sea level rise maps* (Howard and Goldstein 2014).

2. Scope and organize

This section describes the importance and the steps of scoping and organizing a vulnerability assessment, including identifying the project goals, study area, assets to be evaluated, and key participants that need to be involved to provide critical data and local knowledge.

2.1 Identify project area, assets, and key participants

Like flood risk management studies, vulnerability assessments for tidal creeks and flood control channels are typically conducted at the watershed scale. In county or city adaptation planning efforts with multiple watersheds, separate vulnerability assessments can be conducted on each of the main creeks and/or flood control channels. At this watershed scale, the creek and/or flood control channel can be divided into multiple reaches based on hydraulic and geomorphic characteristics, where emphasis is on the reaches subject to current tidal influence and predicted exposure to sea level rise (see Section 3). Associated stormwater collection and storage infrastructure, such as detention basins and pump stations, may also be assessed. While assessments conducted in a single watershed can more directly inform project planning and design decisions, assessments conducted on multiple watersheds can highlight similar management, regulatory, and funding challenges that may need to be addressed before reach-scale interventions can be initiated. Furthermore, vulnerability assessments of multiple tidal creeks and flood control channels can help to determine which watersheds should be prioritized for more detailed study. Ultimately, the selection of which assets to assess in depth will depend on the nature of the watershed and scope of the assessment, e.g., large-scale, county assessments are less likely to assess all individual assets than are small-scale, local assessments.

Watershed-scale assessments will need to include stakeholders from local public works and planning departments to provide information about flood control design, condition, and management. It is also important to consider adjacent landowners and regulators in the process because working with these individuals from the beginning will help build support for later discussions about adaptation opportunities and constraints, e.g., how to restore the connection between creeks and baylands and how to deal with infrastructure and development in the floodplain. The widespread consequences of sea level rise require the attention, expertise, and collaboration of diverse participants, some of whom have not had to work together in the past.

Stakeholder engagement on the Napa River

There have been 22 significant flood events in the City of Napa since 1862. In February 1986, the Napa River experienced one of the largest floods on record, damaging significant amounts of property downtown. USACE had already developed designs for construction of a traditional straightened, trapezoidal channel with riprap levee banks and floodwalls. The 1986 flood revitalized local concerns with the USACE traditional flood management design. A Community Coalition of 40 agencies and 400 individuals from organizations such as the Napa Chamber of Commerce, Sierra Club, Napa County Farm Bureau, and Land Trust of Napa County was formed to advocate for a more natural design. Coordinated by the Napa County Flood Control and Water Conservation District, the Community Coalition worked with USACE to develop a new "living river" design and rallied support for approval of a 20-year local tax to match USACE funds. The project will protect the community from the 100-year flood event and should be completed in 2015 as long as funding is received on schedule.

2.2 Set project resilience goals

The goal of flood risk management is often to provide current 100-year flood protection, as indicated by FEMA maps of the 100-year (1% annual chance) floodplain (Special Flood Hazard Area, SFHA). These maps underpin the National Flood Insurance Program, which requires property owners in SFHAs to purchase insurance if they have a mortgage from a federally regulated or insured lender. There is no solid basis of evidence, however, to justify a default 100-year design level of flood protection[1], especially given scientific projections that future flooding will be more frequent and intense due to climate change (e.g., NRC 2012). A default 100-year design level does not represent an attempt to achieve optimal balancing of risks and benefits, e.g., why provide the same level of flood risk reduction for both a densely populated urban area with large immovable structures and a low-density rural area with less value in harm's way?

The acceptability of risk is more than a technical question -- it is a question of politics, economics, and values. While analyzing various levels of flood protection will typically be considered in subsequent feasibility studies, participants should discuss unacceptable levels of risk in the process of developing resilience goals. These goals inform the rest of the planning process and help to go beyond existing flood design criteria and intentionally consider all aspects of sustainability – society and equity, economy, environment, and governance. Example resilience goals for tidal creek and flood control channel vulnerability assessments at both the county- and watershed-scale are provided below:

[1] The 1% annual chance event was selected "because it was already being used by some agencies, and because it was thought that a flood of that magnitude and frequency represented both a reasonable probability of occurrence, a loss worth protecting against and an intermediate level that would alert planners and property owners to the effects of even greater floods" (Robinson 2004 in NRC 2014).

- **Regional:** Identify how sea level rise will affect county flood control channels and the future of low-lying communities, infrastructure, ecosystems, and economy; and
- **Watershed:** Protect utilities, homes, businesses, community facilities and services, and recreation from the current 100-year flood and projected sea level rise during the lifespan of the project in a way that does not preclude future adaptation options, while also preserving hydrologic and geomorphic functions to the fullest extent possible so that water quality, sediment transport, and habitat are maintained, enhanced, and self-sustaining (adapted from Flood Control 2.0 Project focus on Napa River, San Francisquito Creek, Novato Creek, Walnut Creek).

Range of flood design criteria

Different flood management agencies have different flood design criteria (ESA PWA 2012). For example, FEMA uses historic data rather than future projections for flood risk management, while USACE takes sea level rise into account according to a risk-based approach of assessing potential damages that may accrue during a range of flood levels to ascertain whether avoidance of these damages saves more than the construction costs of new levees. Recent Federal Executive Orders made a significant change by directing federal agencies to adopt stricter building and siting standards to reflect scientific projections that future flooding will be more frequent and intense due to climate change. While the new policy does not make changes to the National Flood Insurance Program, it will apply to federal projects or those using federal funds, thereby affecting some construction or capital improvements in flood-prone areas.

3. Conduct vulnerability assessment

Conducting a vulnerability assessment for tidal creeks and flood control channels involves developing sea level rise and storm scenarios, analyzing the impacts of these scenarios of flood infrastructure and surrounding low-lying areas, and summarizing the findings into clear statements that describe the vulnerabilities and consequences, if action does not result from the assessment and adaptation planning process.

3.1 Develop sea level rise and storm scenarios

Given the uncertainty about the magnitude and timing of future sea level rise, a scenario-based approach enables planners and engineers to understand how flooding could change with different conditions and over various timeframes. Scenarios for tidal creeks and flood control channels provide the opportunity to examine different current and future coastal and riverine flood conditions. Current FEMA Flood Insurance Rate Maps (FIRMs) do not consider future sea level rise; therefore the FIRMs do not illustrate a community's future flood risk. In addition, the FIRMs illustrate flood risk by overlaying the current 100-year coastal and riverine floodplains, where the 100-year tide condition sets the downstream, tidal-dominant floodplain and the 100-year riverine flow (at mean higher high water, MHHW) sets the upstream, riverine-dominant floodplain. Where the floodplains overlap, FEMA uses the higher of the two flood elevations as the Base Flood Elevation (BFE). FEMA does not model the coincident or joint probability of coastal and riverine flood events. As past flood events around the Bay have demonstrated, the worst flooding is likely to occur when peak riverine flows coincide with elevated tides. As sea level rises, models that consider the joint probability of coastal and riverine flood events will therefore be necessary to understand flood risk.[2]

While there are several online tools that map sea level rise inundation on the Bay shoreline by comparing water level and land elevations, there are limitations to using these coastal inundation maps to understand the future flood risk in tidal creek and flood control channels. For example, the NOAA Sea Level Rise (SLR) Viewer maps sea level rise inundation in one-foot increments from one to six feet above MHHW. The way these maps depict the future inland extent of the tides is only an *indicator* of future coastal flood risk because higher Bay water levels in tidal creeks and flood control channels will also reduce their capacity to discharge riverine flows. Overlaying NOAA SLR Viewer inundation maps showing future coastal flooding over FIRMs showing current riverine flooding suggests, but does not quantitatively evaluate how tidal creeks, flood control channels, and adjacent land uses will be exposed to future flooding.

[2] There are physical reasons to suppose that peak riverine flows are likely to coincide with high water levels in the Bay. The winter storms that lead to flooding in the creeks are associated with low barometric pressures and these low pressures lead directly to higher tides. However, the statistical significance of this correlation is controversial and whether coincident probability analysis is needed to resolve the relationship is subject to engineering judgment.

To better understand the transition between tidal and riverine conditions, the San Francisco Estuary Institute (SFEI) developed a protocol for mapping this transition and for predicting where this transition may migrate as sea level rises. The upstream boundary of this transition, referred to as the Head of Tide (HoT) zone, can be defined as the inland limit of the effects of average high tides on riverine flows and water surface elevation (SFEI 2014). The objective of the protocol was to combine desktop and field investigation methods, and as a result, the protocol only evaluated MHHW + 1 foot of sea level rise (predicted by 2050; NRC 2012) as this extent could be compared to field observed King Tide conditions. SFEI found that the future HoT zone location with one foot of sea level rise derived from the desktop investigation was similar to that determined based on field investigations in five of the six pilot HoT sites (Appendix A – Sulphur Creek, Alhambra Creek, Novato Creek, and Coyote Creek). This finding demonstrates that both desktop and field investigations are informative, and indicates that field observations of King Tides coupled with the location and condition of grade control structures and other flood infrastructure that affect HoT zone migration are needed to help ground-truth desktop results.

Protocol to delineate HoT zone

Desktop: The method interprets the NOAA SLR Viewer, which uses land elevations are derived from high resolution airborne LiDAR. This can be an issue for tidal creeks and flood control channels because LiDAR does not accurately capture ground surface elevations if either water or dense vegetation is present. The NOAA SLR Viewer includes an indication of “high” and “low” confidence inundation mapping based on the known error in the LiDAR-derived elevation data and the tidal corrections used to create the Bay water surface (Schmid et al. 2014). These high and low confidence results were used to define the current and future HoT zone. As such, this zone is based on the confidence in the mapping rather than natural variability that can be observed in the field, e.g., due to the height of the high tide and seasonal streamflow.

Field: This method involves observing King Tides, which are approximately +1 foot above MHHW, to document how much farther the tides migrate upstream of typical MHHW extent. With surveyed longitudinal profile data, grade control structures or other minor slope changes can be analyzed in terms of their distance from the current HoT zone and amount of sea level rise that would overtop them. In low gradient creeks and channels such as Coyote Creek, access to high-resolution longitudinal profile data was the single most important resource used to refine the location of the future HoT zone.

To improve vulnerability assessments of tidal creeks and flood control channels, watershed-scale hydraulic models are needed to calculate how sea level rise will exacerbate riverine flooding.[3] Models can evaluate numerous combinations of Bay water levels, sea level rise, and riverine flows to support a robust assessment (Table 3.1). For example, modeling for Damon Slough near the Oakland Coliseum, Alameda County showed that the combined impact of tidal and riverine flooding posed a greater risk than only considering permanent inundation from sea level rise (AECOM 2014). Without this joint coastal-riverine flood modeling, the potential for an increase in flood risk in the current 100-year floodplain due to sea level rise may be underestimated. Furthermore, this modeling may reveal new areas at risk that were not identified by sea level rise inundation maps.

Table 3.1 Possible scenarios for modeling joint coastal-riverine flooding.

Downstream tidal boundary condition	Upstream riverine boundary condition 10-year flow	Upstream riverine boundary condition 100-year flow
Existing MHHW	✔	✔ (large)
Existing 10-year tide	✔	✔
Existing 100-year tide	✔ (large)	N/A
Existing MHHW + SLR*	✔	✔
Existing 10-year tide + SLR*	✔	✔
Existing 100-year tide + SLR*	✔	N/A

Note that most county flood control districts currently analyze at least two scenarios (identified with large checks): 1) the 100-year peak riverine flow at MHHW and 2) the 10-year peak riverine flow at the 100-year tide level. Peak riverine flows can come stream gage data/hydrograph analyses, while 100-year tide level can come from FEMA hazard analyses/FIRMs. The 100-year tide level is not typically evaluated in combination with a 100-year peak riverine flow because this combination would represent an event that is extremely unlikely. NRC (2012) provides the best available science on SLR projections for the Bay at the time of this report writing. The SLR projection(s) selected depend on project planning horizon and thresholds of change, i.e., minimum SLR amount that causes flooding, tipping point where impacts become more severe (multiple seawalls/levees are overtopped), and worst-case scenario.

[3] The effect of climate change on precipitation timing, duration, and intensity is an active field of research and the results will affect how to account for future riverine flows in vulnerability assessments. Precipitation in particular is highly variable among climate change models, but even under drier climate futures, extreme rainfall events will occur and may be more intense than historical events. While this guidance does not account for precipitation changes due to climate change, the Terrestrial Biodiversity Climate Change Collaborative (TBC3) is working to help flood managers plan for these changes. TBC3 developed 18 future climate scenarios downscaled to 270-meter grid cell resolution covering all Bay Area counties and calculated six hydrologic variables across water years: annual precipitation, actual and potential evapotranspiration, soil recharge and runoff, and climate water deficit. TBC3 is currently creating daily data for parts of the Bay Area and aims to quantify future peak flows. In addition, the U.S. Department of Transportation recently released a tool called CMIP to process readily available downscaled climate data at the local level into relevant statistics for transportation planners. Metrics include extreme daily data such as “very heavy” 24-hour precipitation amounts (defined as 95th percentile precipitation, inches) and "extremely heavy" 24-hr precipitation amounts (defined as 99th percentile precipitation, inches).

3.2 Evaluate impacts

There are a variety of modeling platforms to evaluate sea level rise impacts on tidal creeks and flood control channels. While these impacts depend on site-specific conditions, e.g., frequency of maintenance dredging, they may include:

1. Reduced performance of gravity drained and pumped stormwater systems discharging into creeks and channels, causing backups in low-lying areas;
2. More frequent overtopping and overbank flooding of creeks and channels that already flood when rainfall coincides with high tides;
3. New overtopping and overbank flooding of channels and creeks not currently at risk; and
4. Changes in channel geometry due to changes in sediment transport (scour, sedimentation).

Flood managers commonly use HEC-RAS, a free one-dimensional model developed by USACE that is certified for FEMA hazard analyses, to calculate extreme event water levels in creeks and channels. These modeled water level elevations are then compared to channel bank and floodplain elevations to map flood extent. Most county flood protection agencies have models for larger tidal creeks and flood control channels, but they may not reflect the most up-to-date conditions, e.g., modified culverts or bridges. Additional field and bathymetric surveys may be needed to resolve certain reaches in larger creeks and channels or to capture the entirety of many smaller creeks and channels (Appendix A). Models should also be calibrated to measured flows to more accurately predict future flooding. Flood managers can perform sensitivity analysis to evaluate different sea level rise and storm scenarios by adjusting downstream tidal boundary conditions and/or upstream peak riverine flow boundary conditions. In addition, flood managers can adjust cross-section geometry to evaluate the potential for channel sedimentation to affect flooding. Using models to evaluate the sea level rise impacts and inform a vulnerability assessment does not obviate the need for more refined modeling, alternatives analysis, and engineering studies during subsequent feasibility and project design phases.[4]

Technical analyses can be supported and expanded by considering management, regulatory, and funding challenges since many of these must be addressed before physical interventions can be initiated. Assessment questions provide a framework for identifying asset vulnerabilities and consequences, and determining the key planning issues. Gathering answers to the assessment questions will be most straightforward for distinct segments of tidal creeks and flood control channels. The assessment questions

[4] As is the case with all models, results are limited by the quality of the input data, e.g., topographic accuracy, and by modeling assumptions, e.g., whether one-, two-, or three-dimensional aspects of flow are accounted for. Flood managers may pursue two- and three-dimensional modeling and integrate models with different strengths by passing the results between the codes as boundary conditions, e.g., linking HEC-HMS (rainfall-runoff model) with FLO-2D (creek and overbank flood model), PCSWMM (storm drain system model) and EFDC (tidal and sediment transport model) (KHE 2014). While these efforts often take more time, rewards can include more sophisticated simulation of the volume and movement of water through the watershed. For example, if geomorphic analyses indicate significant potential for sedimentation and scenario results show this results in significant flood risk, models specializing in tidal and sediment transport dynamics may be necessary to refine project designs. Alternatively, if large pump stations or gravity outfalls are located in the flood extent, hydraulic and pump curve analysis may be needed to assess the performance of stormwater drainage systems.

are grouped in six categories to help simplify the process of summarizing the information in a manner that ultimately leads to appropriate adaptation actions:

- Existing conditions questions describe the asset and highlight current conditions or stressors;
- Information questions determine if data is up-to-date, available, and accessible to other organizations and the public;
- Governance questions identify current management, regulatory, decision-making, and funding mechanisms and challenges;
- Physical questions highlight particular design characteristics that affect vulnerability;
- Functional questions consider asset operation and relationships with or dependence on other assets; and
- Consequences questions inform potential impacts on society, equity, the economy, and environment.

Answers are based on modeling scenario results, document review, and interviews with asset managers and topical experts (see ART Assessment Questions Guide for more details[5]). Appendix B presents an example of how assessment questions were answered for Wildcat and San Pablo Creeks in Contra Costa County. While Contra Costa County Flood Control and Water Conservation District (CCCFC&WCD) is completing a levee rehabilitation project to provide 100-year flood protection, ongoing sedimentation and sea level rise will reduce flood capacity over time, which could cause flooding in the West County Wastewater Plant and North Richmond community. While hydrologic and hydraulic analyses identify the type and location of physical vulnerabilities, the assessment questions highlight the need to address governance vulnerabilities related to a lack of funding and conflicting flood risk management and habitat goals that make it difficult for CCCFC&WCD to maintain and improve the creeks.

3.3 Summarize vulnerabilities and consequences

Once the assessment answers are gathered, the information needs to be summarized into clear statements that describe the vulnerabilities and consequences. The assessment categories make it easier to summarize the answers into brief statements and make it possible to identify similarities and differences among the assets (see ART Vulnerability and Consequence Statement Guide for more details[6]). For example, assets owned or managed by a single agency may have similar governance challenges and identifying this similarity can make the summarizing process more manageable, e.g., funding is a persistent problem for CCCFC&WCD. Depending on the project, assessment answers can be summarized into statements for individual assets, the flood risk management sector, the study area as a whole, or the agencies or organizations assessed.

[5] http://www.adaptingtorisingtides.org/wp-content/uploads/2015/08/ART-H2G-Assessment-Questions-Guide_web-aligned_V3.pdf

[6] http://www.adaptingtorisingtides.org/wp-content/uploads/2015/08/ART-H2G-VC-Statement-Guide_web-aligned_V2.pdf

The vulnerability and consequence statements are then used to create summary profile sheets that provide a concise narrative of the assessment findings (see ART Profile Sheet Guide for more details[7]). Appendix C presents an example profile sheet for the same reaches of Wildcat and San Pablo Creeks for which the assessment questions were answered in Appendix B.

[7] http://www.adaptingtorisingtides.org/wp-content/uploads/2015/08/ART-H2G-Asset-Profile-Sheet-Guide_web-aligned_V2.pdf

4. Transition to Adaptation

The transition from a vulnerability assessment to developing adaptation strategies involves identifying the key planning issues. The same process of reviewing assessment answers to develop vulnerability and consequences statements can be scaled up and used to identify key planning issues at the watershed, county, or even regional scale. These key planning issues are often vulnerabilities that are shared by many assets, those that have particularly widespread consequences, and those that will necessitate joint action. Below are example key planning issues based interviews with flood managers associated with SFEI's HoT protocol and on vulnerability assessments conducted for multiple tidal creeks and flood control channels in Contra Costa County:

- Issue 1: Pump stations that maintain existing flood protection require uninterrupted power and access. Back-up power or fuel supplies are needed to maintain operation for long durations, which can be problematic during storms where road access is disrupted. Pump stations can reduce, but not eliminate the risk of flooding and therefore may not be reliable for protecting valuable land uses and community assets. This raises questions about the long-term flood risk management strategy for existing infrastructure and communities in areas vulnerable to flooding and reliant on pump stations. The type and intensity of the existing and proposed development may need to change given the dynamic nature of the hazards.
- Issue 2: There is no framework for planning and permitting innovative, multi-benefit flood protection projects. Historically, flood risk management was single objective, but to confront today's challenges, we need improved agency coordination and collaboration to support programmatic, landscape-scale, integrated water management that makes efficient use of limited resources by achieving multiple objectives. This is difficult because each agency is constrained by its mandate and regulations. The prevailing model of fragmented regulatory decision-making and the legal system's discomfort with integrating and managing uncertain and changing conditions constrain innovative, multi-benefit flood protection projects.
- Issue 3: Flood managers confront aging infrastructure, deferred maintenance, and a lack of funding that inhibits their ability to deal with existing conditions, let alone with future sea level rise. While projects to address existing flooding can run into the tens of millions of dollars, future infrastructure maintenance costs will increase due to more frequent pump operation, expanded facilities, and exposure to higher salinity (for which standard construction is not designed to withstand). The ability of flood control agencies to fund projects has suffered from public opposition to additional property-based assessments, forcing agencies to compete for limited grant funding. Federal funding for all projects has also decreased. Furthermore, incentives for pre-disaster planning and land use strategies to improve resilience are particularly weak, e.g., hazard mitigation plans are rarely incorporated into local economic development, general plans, or other plans and regulations that direct land use and infrastructure investment decisions. There is a need to generate community support for funding capital replacement of flood protection infrastructure and then fund its ongoing maintenance. While flood protection systems save communities from disastrous losses during rare, heavy storm events, they are not foremost in people's minds. The ability of flood protection systems to provide benefits in addition to public safety, such as habitat and recreation opportunities, can help to demonstrate the importance of flood protection in relation to other necessary societal expenditures, hence the importance of addressing Issue 2 above.

Once the key planning issues are identified, then the appropriate response to address them can be considered. Adaptation responses lay a clear and transparent path towards implementation and almost always include multiple actions that together address the issue. Example actions that could be taken to address the key planning issues identified above include:

- Action 1: Review and support flood emergency preparedness and response protocols[8], e.g., obtain and maintain turn-key contracts for back-up power supplies, portable pumps, and sandbags and perform regular maintenance of drainage systems in flood-prone areas, especially when rainfall is predicted to coincide with extreme high tides;
- Action 2: Participate in multi-sector adaptation planning efforts to develop the institutional capacity needed to improve coordination between land use planning, public works, and hazard mitigation;
- Action 3: Engage in regional discussions to create a regulatory and funding framework that is equitable and transparent and rewards projects that are adaptable and provide multiple benefits; and
- Action 4: Propose flood control projects based on analysis of existing and future conditions as well as short- and long-term costs and benefits to communities, the economy, and the environment.

Planning for sea level rise can be difficult because it involves planning for phenomena that cannot be pinpointed exactly in scale or timing. As such, flood risk management projects should focus on flexibility and taking "multiple bites at the apple" rather than "getting it right" from the start. As stated by the Little Hoover Commission (2014), "the notion of stable, predictable geography in which to live, work and build permanent buildings will be off the table in decades ahead." The future of flood risk management requires adaptive management and ongoing maintenance, in which current investments are evaluated not *only* with respect to how they affect current conditions, but also whether the investment maintains or opens options and whether the investment allows for greater learning about future conditions, about the effectiveness of innovative strategies, and about processes for improved decision-making.

[8] Flood emergency preparedness, response, and recovery are often fragmented between local agencies and even within different departments of a single agency. Funds for emergency planning are also often reduced during difficult or contracting budget cycles despite the fact that flood emergency planning is a cost-effective, non-structural tool to reduce flood risk.

5. Conclusion

While some creeks already flood when storms coincide with extreme tides, a rising Bay will cause flooding during smaller, more frequent flood flows, particularly in low-lying areas that will no longer be able to effectively gravity drain. As such, sea level rise will exacerbate existing flood risk management issues, such as stringent regulatory requirements and limited funding. Assessing the vulnerability of tidal creeks and flood control channels to current and future flooding sets the stage to address these issues and plan for the future. Local flood control districts can use this guidance to inform improvements underway and participate in adaptation planning. There may be a limit to traditional engineering flood protection solutions in low-lying areas, at which point flood managers, planners, regulators, community groups, business owners, decision makers, among others, will need to leverage their collective expertise and resources to pursue land use planning solutions. Since flood risk management is a long-term investment, it can take decades to develop concepts, obtain funding, build public support, and design and permit plans before initiating a multi-phase project. Therefore, now is the time to start building resilience.

Collaborative planning is necessary to develop an understanding of the flood risk management physical as well as governance, information, and functional vulnerabilities that exist from the watershed to the regional scale. Since sea level rise is a region-wide issue with region-wide consequences, a regional vision for flood protection through improved structures, enhanced environmental stewardship, and creative land use and hazard mitigation planning to minimize flood damage is needed to protect public safety and support a vibrant Bay Area in the future (e.g., CDWR and USACE 2013). Such a regional effort would help local flood control districts plan, fund, and build a resilient future.

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Appendix A. Upstream migration of the zone of tidal influence, or Head of Tide (HoT)

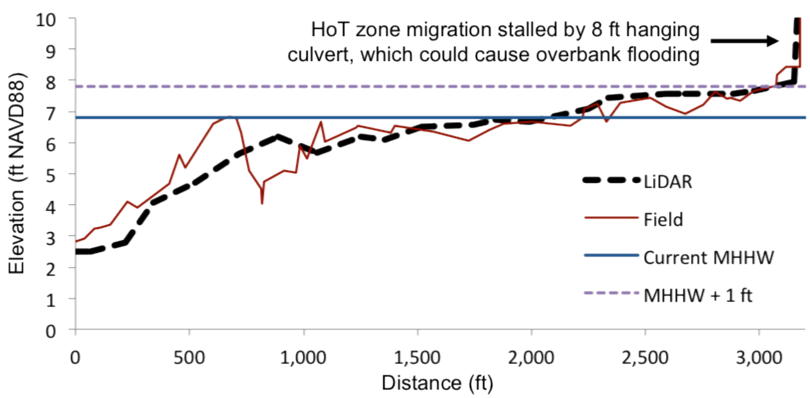
HoT Pilot Sites selected to develop qualitative desktop and field investigation methods for determining HoT migration given a broad range of physical conditions and management activities around the Bay (SFEI 2014).

Site	Management agency	Current flood protection within tidal reach	Current management activities
Sulphur Creek	Alameda County Flood Control and Water Conservation District	Engineered to 100-year event	None - recently installed concrete baffles to address erosion upstream of railroad bridge crossing
Wildcat Creek	Contra Costa County Flood Control and Water Conservation District	Engineered to 100-year event	Working on levee improvements around Richmond Parkway to increase flood capacity; ongoing sediment management (channel in transition since 2006 desilting effort)
Alhambra Creek	City of Martinez	Engineered to 100- and 10-year event (less protection upstream of Marina Vista Ave.)	None, though downtown Martinez is vulnerable to riverine flooding (sand bags available and pump stations regularly operate during storms)
Novato Creek	Marin County Flood Control and Water Conservation District	Engineered to 50-year event	Planning stages of flood protection improvements to reduce the need for channel maintenance dredging (costing around $1M every 3-4 years)
Sonoma Creek	Sonoma County Water Agency	Non-engineered	None, though Highway 121 vulnerable to riverine flooding with 2-5 year flows
Coyote Creek	Santa Clara Valley Water District	Engineered to 100-year event	Ongoing sediment management

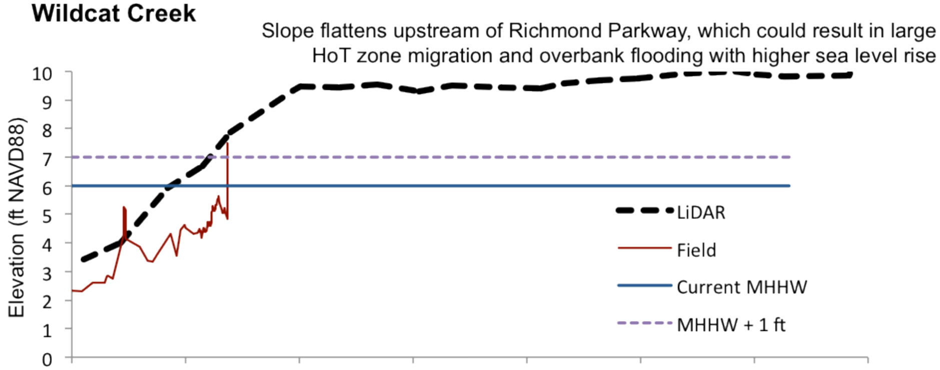
Channel slope largely controls HoT migration. Steeper slopes result in smaller migration distances. The plots below show airborne-derived LiDAR and field-surveyed elevation data with current and future mean higher high water (MHHW) elevations at the six HoT pilot sites. Aerial LiDAR can generally capture steep grade changes, such as at hanging culverts (Sulphur Creek) or transitions from canyons to alluvial fans (Alhambra Creek and Novato Creek) that would stall HoT migration; however, LiDAR-derived channel elevations can be slightly higher than field-derived elevations and therefore can underrepresent HoT migration. An extreme case where LiDAR inaccurately captured channel elevation is Sonoma Creek, where mapping of current MHHW reveals that the LiDAR was too inaccurate to be usable.

Note ½ scale for Coyote Creek.

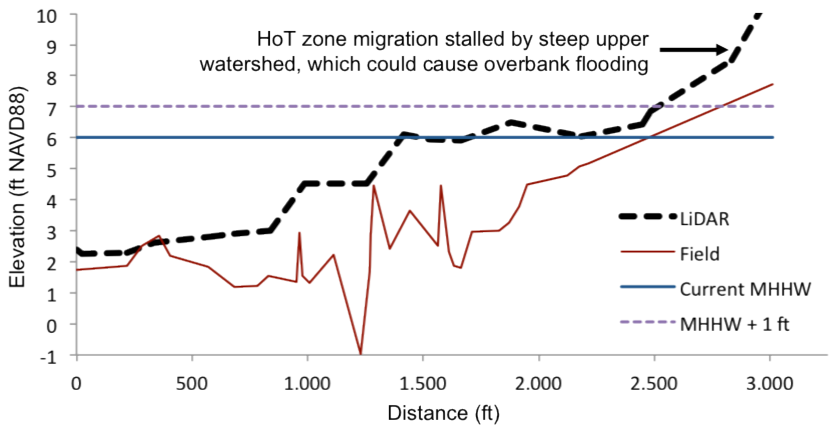
Sulphur Creek



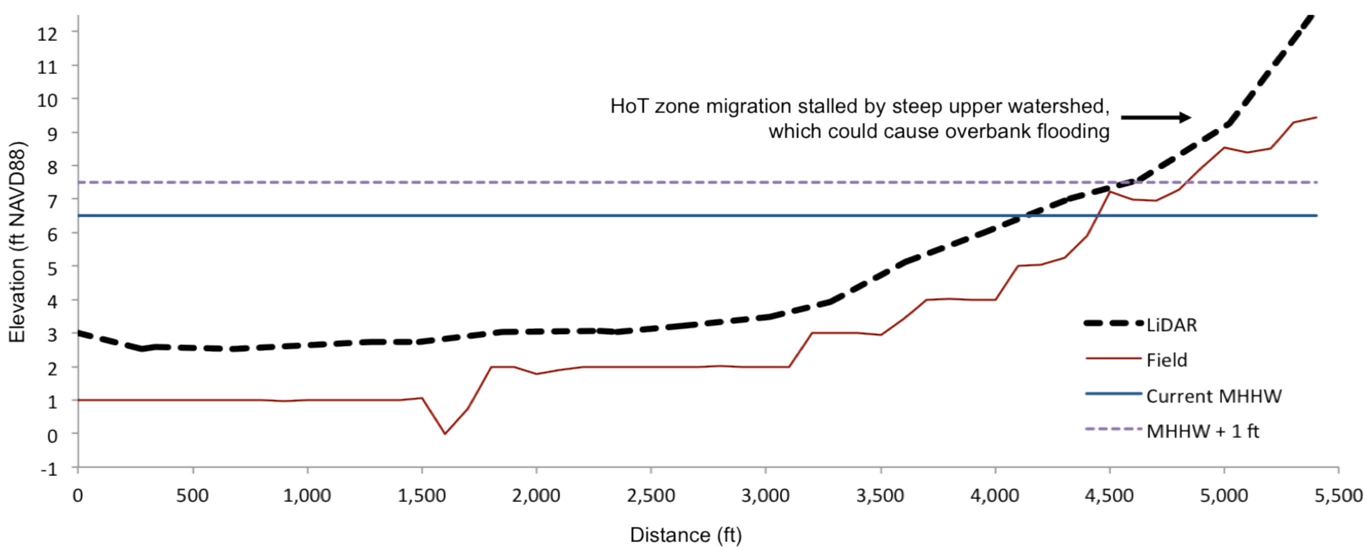
Wildcat Creek



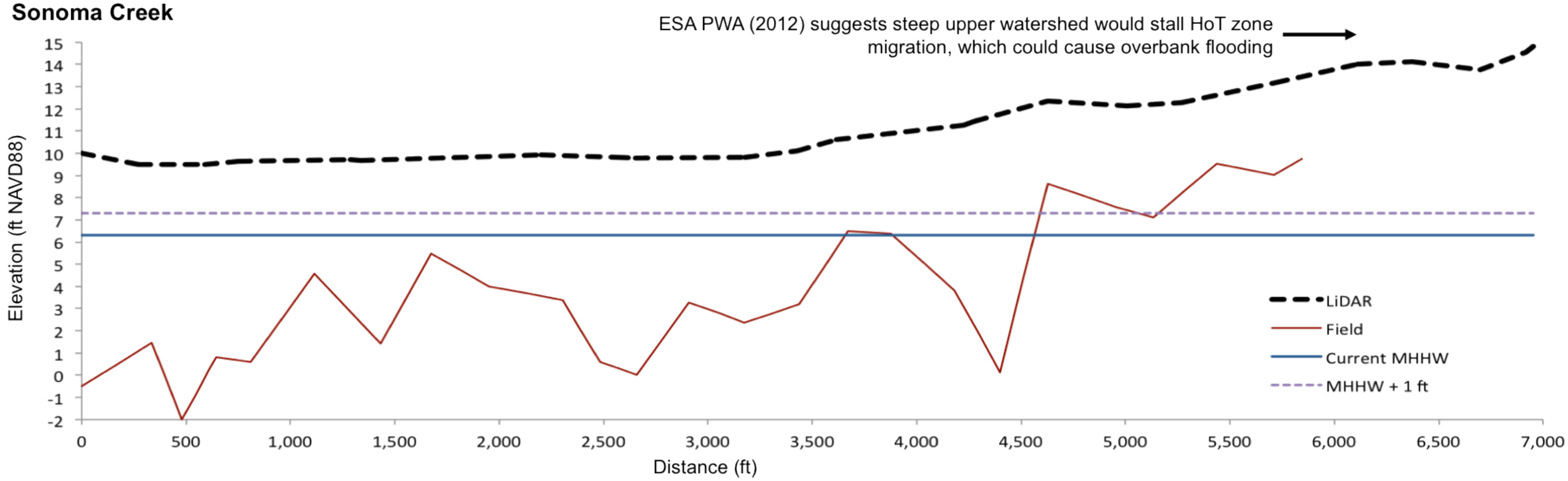
Alhambra Creek



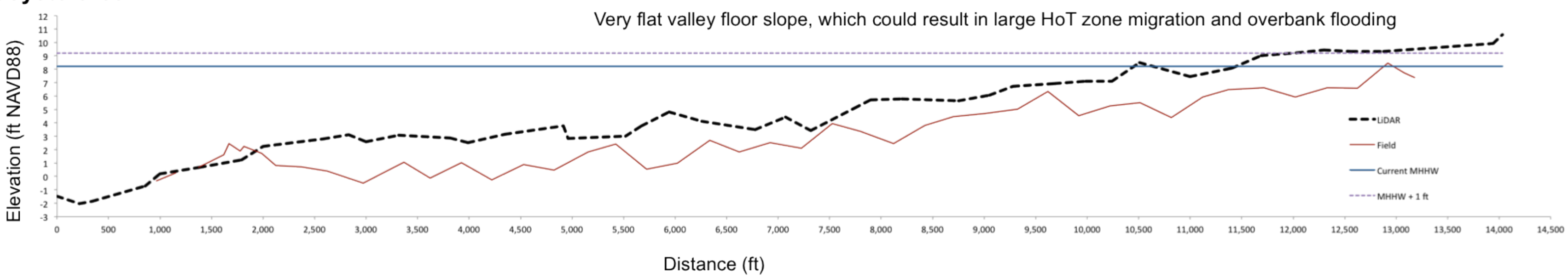
Novato Creek



Sonoma Creek



Coyote Creek



Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

EXISTING CONDITIONS describe the asset and highlight current conditions or stressors.	
Questions	**Answers (include data sources)**
1. Briefly describe the asset and its functions, e.g., collection, conveyance, storage, treatment or discharge, plus size of drainage or service area.	Wildcat-San Pablo Creeks drain 11 and 42 sq. mi., respectively, and are managed to provide flood protection through North Richmond.
2. Where is the asset located and what is its geographic extent? Attach maps or diagrams if necessary.	Wildcat-San Pablo Creeks share a low-slope floodplain (see Map 1).
3. Is asset located within a FEMA Special Flood Hazard Area (SFHA), e.g., within the current 100-year floodplain (1% annual chance event)? Is it located in the 500-year floodplain (0.2% annual chance event)?	Yes, see Map 2. CCCFC&WCD found that in some locations levees do not provide minimum FEMA freeboard requirement. HEC-RAS models indicate that the accumulated silt is causing the freeboard and channel bank deficiencies. Vegetation and trees are growing in the silt, which makes obtaining environmental permits to remove the silt difficult and expensive to mitigate. The levees were decertified in 2010 and recertification is required to remove the flood insurance requirements from the adjacent properties. Instead of removing vegetation and sediment, a raise-the-levee approach was selected. Levees are being raised to meet FEMA requirements, which are more stringent than the Corps' original design.
4. Has there been locally observed land subsidence that could potentially put the asset at greater risk of flooding? If yes, describe the location, amount of land motion, and the approximate timeframe over which the subsidence has occurred.	No
5. Who owns and manages the asset? Note if the owner and manager are different entities.	CCCFC&WCD

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
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6. What year was the asset built and what is its expected remaining service life?	USACE constructed flood control project (Phase 1) to protect development in the lower half of the plain (downstream of Union Pacific Railroad), starting in 1986 and finishing the upper reaches in 1991. Flood control channels typically have a design life of 50 – 75 years. Fun fact: BCDC denied permit application for bare-bones structural flood control project with no environmental amenities; by adding the objectives of public access and education, restoration of riparian habitat, and enhancement of aesthetic values to the original mission of flood control, a number of alternative sources of funding were available to implement the Consensus Plan that would not otherwise be available for single-purpose flood control projects (http://water.epa.gov/type/watersheds/archives/chap6wil.cfm).
7. When and what was the last major repair or improvement to the asset?	
8. What is the most frequent type of inspection/maintenance and how often is it conducted?	Sediment management (channel in transition since 2006 desilting effort)
9. Has the asset been disrupted in the past due to an unplanned event e.g., weather-related closure, emergency repair or improvement, or other event? If yes, how long did the disruption last and was the asset able to continue functioning either partially or fully?	No known storms or tides have caused damage since the channels were constructed. Note: Significant damage continues to occur upstream of the USACE project limits. USACE Phase II project was not originally constructed because of concerns about economic justification. Updated flow volume and frequency projections, FEMA floodplain maps, and a reconnaissance study completed in 2005 indicate that Phase II is now economically justified (http://www.spn.usace.army.mil/Portals/68/docs/Congress%20Maps/2015%20Maps/15_WildcatCreekSanPablo_I.pdf)
10. Is the asset currently under consideration for capital improvement or investment, or is it in an area that is planned for future development or redevelopment?	Levee rehabilitation project is expected to begin in 2016 (http://www.co.contra-costa.ca.us/DocumentCenter/View/29843).

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

Multi-hazard assessment	
Is the asset located in a state mandated "Zone of Required Investigation" due to proximity to an earthquake fault zone, liquefaction seismic hazard zone, or earthquake-induced landslide zone?	
Has a seismic assessment or other hazard assessment been conducted for the asset? If so, how does this inform asset maintenance or future capital improvements or investments?	

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

INFORMATION VULNERABILITIES describe if data is lacking, incomplete, poorly coordinated, or hard to obtain. (Difficulties encountered during this assessment may inform your answers.)	
Questions	**Answers (include data sources)**
1. Is planning-level or project-level information available to assess vulnerability, e.g., existing conditions reports, as-built drawings, monitoring or inspection reports, etc.?	Yes, e.g., planning-level information available online (USACE Flood Control Project Case Study) and project-level information from the CCCFC&WCD (HEC-RAS study reports, Levee evaluation reports)
2. What mechanisms exist to share information between departments within the managing agency? What mechanisms exist to share information with partner agencies, non-governmental organizations, and the public? Are these mechanisms adequate?	CCCFC&WCD responds to BCDC information requests and shares information with the public.

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

GOVERNANCE VULNERABILITIES describe challenges with management, regulatory authority, or funding.	
Questions	**Answers (include data sources)**
1. Is the asset managed to achieve multiple goals or objectives e.g., habitat, water quality, flood control, recreation, shoreline access, etc.? If yes, are their conflicts among them?	Yes, flood protection and habitat goals conflict – USACE project was constructed to include significant vegetation (not only for mitigation, but as a sustainability feature) and subsequent USACE policy disallowing vegetation on any part of flood control levees, where violation results in the loss of USACE funding, has caused problems in terms of how to maintain flood capacity (precludes(http://ca-contracostacounty2.civicplus.com/DocumentCenter/View/5357).
2. If the asset owner and manager are different, what is the relationship between them, e.g., a legal agreement such as a lease, right-of-way, access easement, JPA, MOU or MOA?	NA
3. Describe any plans that are relevant to asset management or improvement, e.g., Master Plan, Capital Improvement Plan, and if/how they consider sea level rise.	CCCFC&WCD performed sensitivity analysis as part of levee rehabilitation project and found the raised levees can accommodate approx. 2' SLR on top of MHHW without overtopping.
4. If the asset is protected from flooding by land or assets owned or managed by others (e.g., natural areas, structural protection, roadways), what is the relationship between the asset owner/manager and these entities? Do they coordinate information, funding or decision-making?	NA
5. What types of permits (and from which agencies) are necessary to maintain, repair or improve the asset? Are there special processes for emergency repairs?	Permits from local, state, and federal agencies are required, e.g., BCDC, RWQCB, CDFW, NMFS, USFWS and USACE, both to complete maintenance dredging and capital projects.
6. What funding sources currently exist that can be used to assess hazard risk or vulnerability to climate change? To improve asset resilience?	Prop. 13 froze property tax rates from which maintenance/capital improvement funds are generated, such that CCCFC&WCD receives 8% of necessary funding (Zones 6 & 7), forcing the district to compete for limited grant funding. Federal funding has also decreased over time.

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

PHYSICAL VULNERABILITIES describe challenges with particular design characteristics.	
Questions	**Answers (include data sources)**
1. To what extent is the asset exposed to tidal, wind or wave erosion or scour?	NA
2. What water or salt sensitive components of the asset are at-grade or below-grade, e.g., mechanical or electrical equipment, pumps, utilities, building heat, ventilation or power systems?	NA
3. For stormwater infrastructure and flood control channels what recurrence-interval rainfall event and Bay tide level (if considered) was the system designed for? Is the asset currently at capacity or does it have additional capacity to meet future conditions, e.g., projected higher Bay water levels, combined riverine and higher Bay water levels, or elevated groundwater?	Wildcat-San Pablo Creeks were designed by USACE to provide flood protection for a 100 year storm event against a MHHW tide. Currently, there is deficient freeboard in locations because of sediment in the floodplain benches of the channel that is heavily vegetated.
4. For flood control channels, what is the current extent of tidal influence, e.g., how far inland does high tide currently reach? If the tide migrates upstream are there protections in place that would prevent adjacent areas from flooding?	HOT in USACE Phase I reach (downstream of UPRR) between grade control structure (sewer crossing; partial fish barrier) and Richmond Parkway. HOT migration with +1 ft SLR is predicted to remain downstream of Richmond Parkway (NOAA SLR Viewer); however, since the slope flattens upstream of Richmond Parkway, relatively large HoT migration could occur with higher sea level rise (>2' accommodated based on CCCFC&WCD sensitivity analysis).
5. For flood control channels and stormwater outfalls, is there a mechanism to control inflow to the system from the Bay such as a flap gate, tide gate, check valve, etc.? Can these water control structures be adjusted to maintain system function as sea level rises?	No

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

FUNCTIONAL VULNERABILITIES describe asset relationships with or dependence on other assets.	
Questions	**Answers (include data sources)**
1. Is the asset part of a networked system such that damage to other parts of the system would affect the asset's ability to function? Describe what alternatives exist that could help maintain continuity of service if parts of the system are disrupted.	No, while a watershed approach to flood protection and stormwater management is helpful, interior drainage due to high tailwater conditions is not an issue because there is not much direct outfall in the lower reaches of Wildcat and San Pablo Creeks. The West County Wastewater District facility has a host of issues (FEMA V Zone), including the North Richmond Pump Station that should receive first flush low flows but 1/4 pumps working, funding challenges, etc. (Paul Detjens, pers. comm., 4/22/15). Note: In reach upstream of flood control project, years of flood observation, geomorphic assessments and recent hydraulic modeling studies suggest that insufficiently sized and poorly designed in stream structures constrict storm flows, creating backwater conditions that lead to over bank flooding and in-channel sedimentation (Urban Creeks Council 2010).
2. If the asset is disrupted or damaged, what redundant assets exist that could help maintain the capacity, function, or level of service that is normally provided by the asset?	None.
3. What external services, such as power, roads, fuel supplies or materials does the asset rely on? What is the relationship between the asset manager and the organizations that provide these external services? If these external services were interrupted, are there back up supplies ready and in place, and how long would they last?	NA
4. Does the asset provide or protect habitat for threatened or endangered species? Is this habitat scarce in the region? Could this habitat be established in other areas?	Yes, Wildcat Marsh at the mouth of the creek supports endangered and threatened species, e.g., Ridgway Rail and Salt Marsh Harvest Mouse, and the creek hosts two native species – stickleback and steelhead (though the sediment chute downstream of Union Pacific Railroad is an impassable barrier for steelhead).

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

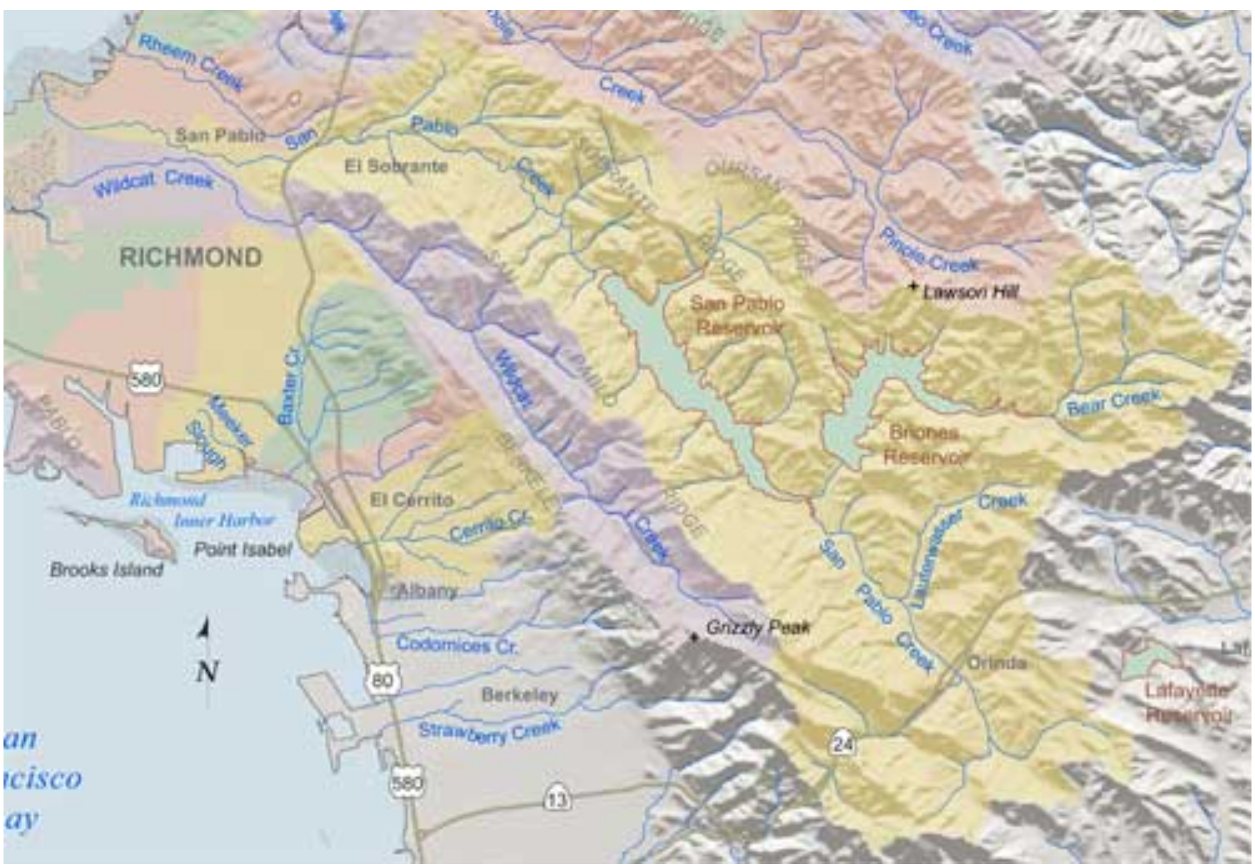
CONSEQUENCES describe potential impacts on society, equity, the economy, and the environment.	
Questions	Answers (include data sources)
1. What degree and scale of economic disruption would occur if the asset was damaged, disrupted, or failed? Local, regional, state, or national? If based on a past weather event or an unplanned disruption, describe the type and duration of that disruption.	Damage to the West County Wastewater treatment plant and residential development would result in local economic damage.
2. If the asset was damaged, disrupted or failed, how much direct revenue would be lost? For how long?	NA
3. What would the water quality impacts be if the asset was damaged, disrupted, or failed, e.g., release of hazardous materials or pollutants?	NA
4. What habitat or species benefits would be lost if the asset was damaged or lost? What would the effect of this loss have on local and regional biodiversity and ecosystem health?	NA
5. If the asset was damaged, disrupted, or failed, would there be a loss of flood protection benefits? If yes, what would the affect of this loss be on adjacent assets or communities?	Yes, flooding to adjacent assets and communities could disrupt wastewater services and disrupt communities.
6. If the asset was damaged, disrupted or failed, would there be a loss of public access to the shoreline? Of recreational, educational or interpretation opportunities?	

Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
Asset name: Wildcat/San Pablo Creeks

7. What critical emergency services would be affected if the asset was damaged, disrupted or failed?	See Javi Map
8. How would the community, particularly at-risk members, be affected by damage, disruption, or loss of asset function?	
9. If the asset was damaged, disrupted or failed, how many and what type of jobs or employment centers would be affected? For how long?	?

Map 1



Appendix B. Wildcat and San Pablo Creeks Assessment Questions

ART Assessment Questions: Stormwater/Flood Control Infrastructure
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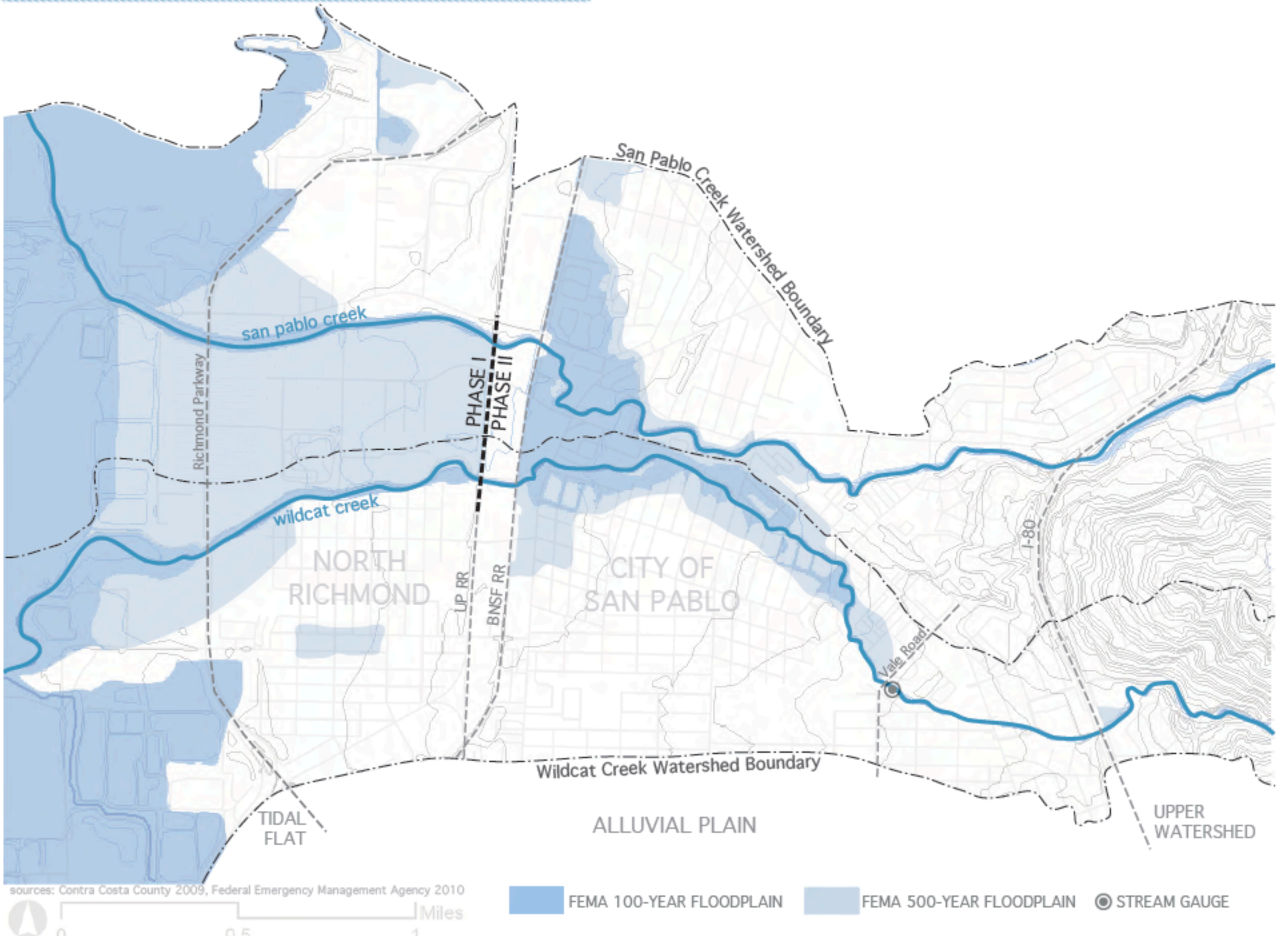
Map 2

WILDCAT CREEK RESTORATION ACTION PLAN | URBAN CREEKS COUNCIL | APRIL 2010 1. INTRODUCTION

FIGURE 1-4: WILDCAT AND SAN PABLO CREEK SHARED FLOODPLAIN



Appendix C. Wildcat and San Pablo Creeks Profile Sheet

WILDCAT AND SAN PABLO CREEKS

(Tidal reach from the mouth to Garden Tract Rd. and Richmond Parkway, respectively)

Key Issue Statement

After the levee rehabilitation project is completed, lower Wildcat and San Pablo Creeks will provide 100-year flood protection. However, ongoing sedimentation and sea level rise will further reduce flood capacity, which could cause flooding at the West County Wastewater Plant and North Richmond community. Lack of funding and conflicting flood management and habitat goals also make it difficult for CCCFC&WCD to maintain and improve the creeks.

Asset Description

Wildcat and San Pablo Creeks drain approximately 11 and 42 square miles, respectively. Once the creeks exit the upper watershed canyons, they flow westward and parallel to each other through San Pablo, Richmond, and North Richmond passing through an area of mostly industrial land uses before reaching Wildcat Marsh. From 1987 to 1992, U.S. Army Corps of Engineers (USACE) constructed a flood control project (referred to as Phase I[1]) on Wildcat and San Pablo Creeks to provide protection to development downstream of Union Pacific Railroad for the 100-year riverine flow at mean higher high water (MHHW). As the local sponsor, the Contra Costa County Flood Control and Water Conservation District (CCCFC&WCD) owns and maintains the channels as part of Flood Control Zones 6 and 7.

CCCFC&WCD is currently planning a levee rehabilitation project on Wildcat and San Pablo Creeks expected to begin in 2016. CCCFC&WCD found that in some locations the channel levees do not meet minimum Federal Emergency Management Agency (FEMA) freeboard requirements. Observations and modeling indicated that accumulated silt, despite the 2006 desilting effort, causes freeboard and channel bank deficiencies. Due to the difficulty in obtaining environmental permits and paying for mitigation for silt and vegetation removal, CCCFC&WCD decided to raise the levees to meet FEMA requirements, which are more stringent than the USACE original design. The levees were decertified in 2010 and recertification is required to remove the flood insurance requirements from the adjacent properties, including the West County Wastewater Plant and low-income North Richmond neighborhood. CCCFC&WCD receives only 8% of the funding necessary to maintain Wildcat and San Pablo Creeks due to funding restrictions associated with Propositions 13 and 218. As such, CCCFC&WCD applied for and received a Local Levee Critical Repair grant from the Department of Water Resources for the levee rehabilitation project.

Exposure to Flooding

Sea level rise will exacerbate riverine flooding. Tidal influence in Wildcat and San Pablo Creeks is within the USACE Phase I project and current levee rehabilitation project, currently extending to Garden Tract Road in Wildcat Creek and to Richmond Parkway in San Pablo Creek. Sea level rise will cause the tides to extend further ('migrate') upstream and raise water levels in the creek. This will progressively reduce the capacity of

[1] Significant flooding occurs upstream of Phase I; numerous efforts to initiate a Phase II flood control project have thus far been unsuccessful.

the creeks to discharge riverine flows, such that smaller, more frequent storms will cause overbank flooding and stormwater backups, particularly in low-lying areas that will no longer be able to effectively gravity drain against the higher downstream tidal condition. However, even before flooding, sea level rise will reduce available freeboard and levees may lose their FEMA accreditation, which would require residents and property owners in the floodplain to purchase flood insurance.

Map of current FEMA flood zones overlain with +6 feet sea level rise above MHHW (NOAA SLR Viewer; bright green indicates disconnected, low-lying areas and increasingly dark shades of blue indicate increasing flood depth).

While overlaying FEMA Flood Insurance Rate Maps (FIRMs) and sea level rise inundation maps suggests the risk of joint coastal-riverine flooding, it may underestimate the potential for an increase in flood risk in the current 100-year floodplain due to sea level rises. Furthermore, simply overlaying FEMA FIRMs and sea level rise inundation maps may overlook areas at risk from joint coastal-riverine flooding. CCCFC&WCD performed sensitivity analysis as part of levee rehabilitation project hydraulic modeling and determined that the designed raised levees as can accommodate approximately 2 feet of sea level rise above MHHW before overtopping. Further analysis is needed to better understand the extent of flooding caused by combinations of Bay water levels, sea level rise, and flood flows.

Vulnerabilities

INFO: FEMA FIRMs do not factor in sea level rise, which make it difficult for flood managers and communities to prepare for future flooding. Furthermore, FEMA FIRMs show the overlay of the 100-year riverine and coastal floodplains, whereby the 100-year riverine flow sets the upstream and the 100-year tidal condition sets the downstream flood extent. The joint probability of riverine and coastal events likely increases the elevation and extent of the 100-year floodplain, but FEMA FIRMs depict riverine and coastal flooding as independent events and use the higher of the two flood elevations where riverine and coastal floodplains overlap.

GOV1: CCCFC&WCD has to compete for grants to maintain flood control channel condition and capacity. A reliable financing mechanism is needed to address outstanding maintenance, capital improvement, and long-range flood management planning.

GOV2: Since Wildcat and San Pablo Creeks are federal facilities, improvements must be consistent with USACE policy to remain eligible for federal disaster relief. The USACE original design was constructed to include significant vegetation (not only for mitigation, but as a sustainability feature). However, subsequent USACE policy prohibits vegetation on any part of flood control levees. These conflicting vegetation goals make channel maintenance difficult.

PHYS: Wildcat and San Pablo Creeks will offer 100-year flood protection, but sea level rise will diminish its capacity to discharge flood flows over time.

Consequences

Society and Equity: Increased flooding in Wildcat Creek could result in extreme burden for North Richmond community members because they have limited resources to pay for flood insurance as well as prepare for, respond to, and recover from flood events.

Environment: Increased flooding in Wildcat Creek could affect marsh habitat and endangered rail and saltmarsh harvest mouse populations in Wildcat Marsh. Increased flooding in Wildcat and San Pablo Creeks could also mobilize industrial substances and introduce contaminants to surrounding areas.

Economy: Increased flooding along Wildcat and San Pablo Creeks could lead to disruptions to wastewater and transportation services, affecting the regional economy.