



Managing Floods in Mediterranean-Climate Urban Catchments: Experiences in the San Francisco Bay Area (California, USA) and the Tagus Estuary (Portugal)

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Abstract The San Francisco and Lisbon estuaries share many geographical similarities, but their different governance makes for interesting comparisons. Many tributaries to San Francisco Bay were channelized by the US Army Corps in the 1950s–1970s. The design flaws of these projects (such as their having ignored sediment) are manifest as local governments

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now struggle to maintain and operate them. Local agencies in the San Francisco region have used a range of innovative tools to solve these flood risk problems, such as creation of a new governance structure encompassing multiple jurisdictions around a stream, adoption of a 50-year plan to convert aging concrete channels into natural creeks, and implementation of projects that combine flood risk reduction with ecosystem and social benefits. Such a multi-purpose project built on the Ribeira das Jardas Stream near Lisbon has proven highly successful, especially as an urban social space.

Keywords San Francisco Bay region • Tagus estuary • US Army Corps of Engineers • Polis program • 50-year plan

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5.1 INTRODUCTION

Pedro Pinto and Anna Serra-Llobet

5.1.1 Urban Catchments in the San Francisco Bay Area and the Lisbon Estuary Area

The San Francisco Bay Area and Lisbon estuary area share several similarities including climate (Mediterranean climate) and topography, with both regions surrounding large “drowned-valley”-type estuaries. Smaller catchments, draining directly into the estuary, have been heavily built over in both regions, which contributed to increased exposure to urban flooding and further reducing the already short concentration times. The Mediterranean climate is characterized by extreme variability of precipitation patterns, and localized events of heavy rainfall are responsible for sporadic, but severe, flood events.

Despite these similarities, the urbanization of both regions had significant differences. San Francisco Bay (actually an estuary, not a “bay”) experienced very fast urban expansion within a very short time frame: from negligible urbanization in as late as the 1850s, the estuary was almost completely encircled by urbanization little over a century later. This development took place in an era of strong reliance on heavy flood control infrastructure. Most creeks in the region were confined to concrete canals and their former floodplains extensively built over. In contrast, urban expansion in Lisbon was a slow, multi-secular process and, unlike San Francisco, was only characterized by rapid suburban expansion in the last three to four decades. As such, large portions of the former countryside were left undeveloped until a time when modern environmental protection standards were beginning to be seriously considered. Although a few urban areas in the region were expanded so as to encroach on floodplains, most of the urban expansion took place over the surrounding hills and plateaus instead (Pinto and Kondolf 2016).

Perhaps more striking are the disparities in the way flood control/management is conducted in both regions. Portugal is a unitary state, with national government being directly responsible for most issues related with environmental standards, flood regulation, and, in most cases, even the conception and building of flood defense infrastructure. Municipalities have the local planning mandate and have great autonomy in terms of zoning decisions, but have almost continuously been able to uphold a rela-

tively strong public trust over stream banks. Except for a short period starting in the late 1970s and extending to the early 1990s, local plans have been reasonably effective in protecting floodplains from urban development, and it is the municipalities that are tasked with the day-to-day management of stream banks, including bank maintenance. However, they often lack the expertise and money and defer to the water agency, now a part of the Portuguese Environmental Agency, in the design and implementation of more complex flood detention or flood mitigation initiatives. Besides flood management, the agency is also responsible for wastewater regulation, water permitting, environmental protection, and habitat restoration. The agency also oversees the river basin management plans, including the one for the Tagus Basin, theoretically allowing very strong synergies in the coordination and management of these different issues.

In contrast, the San Francisco metropolitan region experienced rapid urban expansion, especially post-World War II, in a context of weak regional and local land-use regulations. Also, city governments had a very strong planning mandate but often not in direct articulation with flood control districts, which nowadays mostly share the same boundaries as counties (Fig. 5.1). These districts are in charge of flood management (stormwater and runoff) in urban areas. In general, they only do flood control, as wastewater treatment, water supply, water conservation, and so on are run by other districts with different boundaries. Typically, these flood control districts are reasonably well funded, especially when compared with the limited resources of the Portuguese Environmental Agency but, in contrast, are constrained by narrow mandates, which have discouraged the integration of local land-use solutions with flood management. Although recent budget constraints have virtually stalled large-scale public works, Portuguese agencies and local governments work within a more favorable legal framework, and the possibility of integrating flood defense with, for example, urban redevelopment or habitat restoration appears to be much facilitated.

In this chapter, Raymond Wong and Matt Kondolf review the many flood control projects built in tributaries to San Francisco Bay during the building boom of the 1950s, 1960s, and 1970s by the US Army Corps of Engineers (USACE) and turned over to local governments to operate. Unfortunately these projects suffered design flaws, such as ignoring the effects of the commonly high loads of sediment, whose accumulations posed unrealistic maintenance burdens on local governments. Jack Curley reviews the seven-decade-long history of flood control efforts on Corte Madera Creek in Marin County. Ralph Johnson describes the legacy of

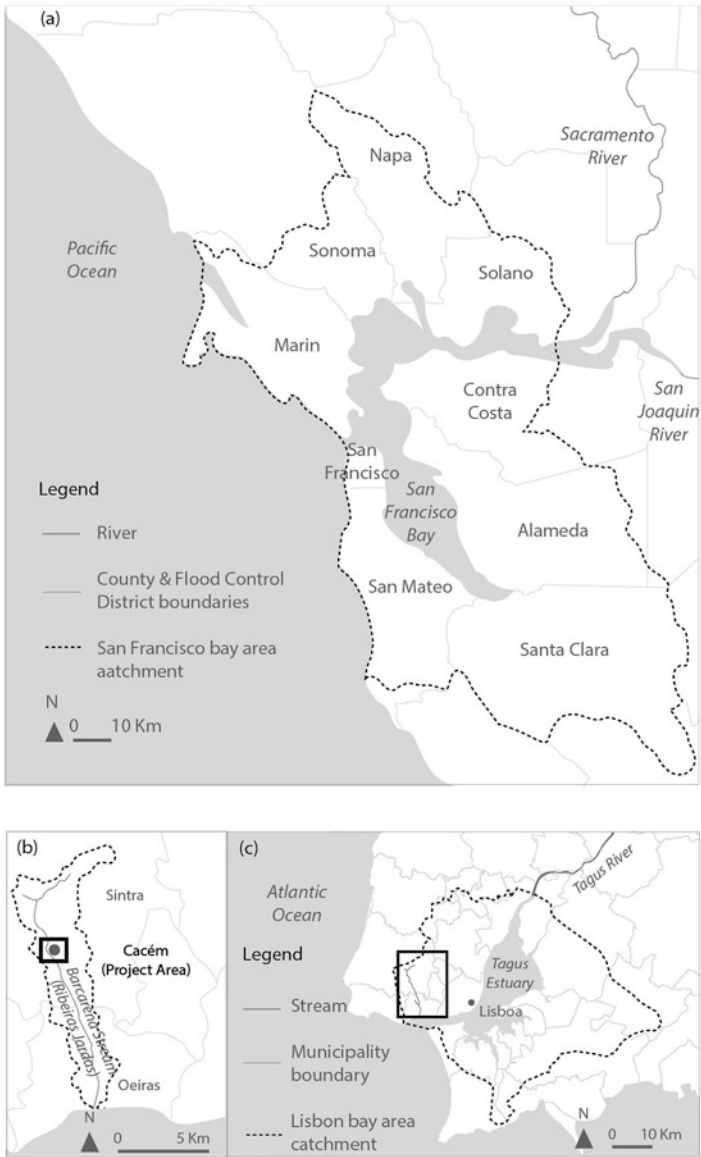


Fig. 5.1 San Francisco Bay Area catchment boundary in California (United States) (a). The Tagus estuary catchment boundary in Portugal and location of Ribeira das Jardas Project (b–c)

poorly sited development from the 1950s and 1960s and the efforts of Alameda County to improve predictions of flood-prone areas. Liang Xu illustrates the evolution of flood risk management with two projects in Santa Clara County, one of which (Guadalupe River) evolved over five decades into a multi-purpose project to provide flood protection and preserve habitats. San Francisquito Creek forms the border between multiple cities and counties, and thus was difficult to manage prior to the creation of a Joint Powers Authority (JPA) involving all relevant local government agencies, a creative solution to the governance problem. Len Materman reports on the JPA's challenges working within the lengthy US Army Corps process and how the JPA has been motivated to take some action on its own. As concrete channels age, they deteriorate and confront local agencies with difficult choices. Mitch Avalon describes Contra Costa County's innovative "50-year plan", which involves local communities to start the planning process now, to find ways so that at least some of the concretized channels can be converted back to natural creeks. Finally, switching estuaries to the Tagus in Portugal, Graça Saraiva reports on a successful project on the Ribeira das Jardas west of Lisbon, which converted a concrete culvert back into an open stream, reducing flood risk while creating a vibrant urban social space around the restored stream.

5.2 A HISTORY OF FLOOD CONTROL PROJECTS IN THE SAN FRANCISCO BAY REGION

Raymond Wong and G. Mathias Kondolf

5.2.1 *Introduction*

In the USA, the USACE is one of the leading federal agencies on flood management. The 1936 Flood Control Act established the USACE's flood control mission (Arnold 1988). When a local community experiences flooding problems beyond its ability to solve, the local agencies could partner with USACE, to benefit from the agency's technical expertise and to receive a financial subsidy for most of the project cost. Most commonly, the USACE would design and build the project, then turn it over to the local sponsor, who is then responsible for operation and maintenance (O&M) (Carter and Stern 2010). The 1986 Water Resources Development Act (WRDA) revised the "cost-sharing" policy, so that federal government covered a much smaller percentage of the total project cost than had previously been the case.



Fig. 5.2 Grayson Creek channel right after completion in 1957 (Courtesy of Contra Costa County Flood Control and Water Conservation District)

Historically, USACE flood management has been heavily skewed toward conventional structural approaches. Most projects were designed to provide predictable flow conveyance capacity in the smallest possible footprint. Ecological values were mostly ignored. In addition, many of these project designs were based on unrealistic assumptions; notably, they did not adequately account for sedimentation, resulting in massive sedimentation problems in the flood control channels (Williams 1990).

As a result, many local agencies cannot afford the significant O&M requirements they inherited with the projects. Many of these projects are plagued by chronic problems on sedimentation and inadequate level of flood protection. It presents a challenge to the local agencies on how to provide adequate level of services for flood protection, while balancing project life cycle cost.

In the San Francisco (SF) Bay region, many flood control projects designed and built by the USACE during the 1960s and 1970s included reaches of narrow concrete channels (Fig. 5.2). Some of these projects are now recognized as undersized and pose significant O&M challenges due to sedimentation. As these O&M problems emerged, they have been treated as independent problems unique to the individual projects. However, in reality these projects share commonalities in planning and design approaches, and in their resulting O&M problems (Samet 2007). Wong (2014) analyzed nine such projects in the SF Bay region and found

that the current channel sediment removal cost is about five times higher than the original estimate of the project design, adjusted to present value. Five of the nine projects have existing channel capacity data, but none of them has 100-year flow capacity due to a combination of watershed urbanization and channel sedimentation. Notably, six of the nine projects relied on “land enhancement benefit”, defined as the net incomes and property values of turning undeveloped floodplain into urban development, as a benefit to produce a positive cost benefit ratio. If the land enhancement benefit is removed from the cost benefit ratio, three of the six projects would have had cost benefit ratio below 1, meaning the projects would not be economically justifiable to proceed.

As an illustration of the challenges faced by local agencies as they attempt to maintain flood control function, we describe two case studies: San Lorenzo Creek and Walnut Creek.

5.2.2 *San Lorenzo Creek, Alameda County*

San Lorenzo Creek drains a 124 km² (48 mi²) catchment, flowing westward from Cull Canyon, Crow Canyon, and Palomares sub-catchments into SF Bay. To alleviate recurring flooding in the downstream floodplain, the 1954 Flood Control Act authorized San Lorenzo Creek Flood Control Project. The project, completed in 1962, included 8.4 km (5.2 mi) of concrete channels and earthen trapezoidal channel flanked by levees. The construction cost was \$4.28 million at the time (equivalent to about \$60 million in 2010 dollars), with a calculated 1.17 benefit cost ratio.

After the project was completed, urban development increased the 100-year peak flow from 227 m³/s (8016 ft³/s) to 468 m³/s (16,527 ft³/s). Since the project design flow is 275 m³/s (97,011 ft³/s), the project no longer has 100-year flow capacity.

Unrelated to the flood control project, in the 1960s the county constructed reservoirs on two tributaries, Cull Canyon and Palomares, funded by the Davis Grunsky Act, to provide recreation and water supply benefits. The reservoirs also provided some ancillary flood storage, but their capacities declined rapidly from sedimentation, both down to only 20% of their original capacities by 2003. Sedimentation in these reservoirs has reduced sediment delivery to the downstream flood control channel, although the third major fork of San Lorenzo Creek, Crow Canyon, still supplies sediment to the downstream channel without impairment.

The downstream reaches, within the engineered flood control channel, have relatively flat slopes and thus are natural sites for sedimentation. In the past, flood overflows would distribute the sediment load over the marsh plain, but with channel constriction and levees, the sediment is either carried into the bay or deposited in the channel. Since 1962, the county has spent \$4.1 million (2010 dollars) on sediment removal from the flood control channel. If the total cost were to include the estimated cost to remove all sediment in both reservoirs, it would increase to \$52 million (2010 dollars). It is an order of magnitude higher than the total O&M cost estimate in 1954, at \$3.5 million (2010 dollars).

5.2.3 *Case Study: Lower Walnut Creek, Contra Costa County*

Walnut Creek drains a 378 km² (146 mi²) watershed, from the headwaters of its Pine Creek tributary near the summit of Mount Diablo at 1173 m (3849 ft) above mean sea level, flowing northward and dropping to sea level at San Pablo Bay. The mean annual precipitation is 530 mm (21 in) (CCCFCWCD 2003). The Contra Costa County Flood Control and Water Conservation District (Contra Costa County) is responsible for Walnut Creek watershed planning and flood management. Repeated floods in the mid-twentieth century prompted the Lower Walnut Creek Flood Control project with USACE, authorized under the Flood Control Act in 1960 (USACE 1963). The project constructed in 1965 included 22.7 km (14.1 mi) of earth and concrete channel and levee sections, at the sections of Walnut Creek between Rudgear Road and the outfall at Suisun Bay. The project cost was \$31,500,000 in 1964 dollars, with 1.3 cost benefit ratio (USACE 1964).

The project was designed for a Standard Project Flood of 708 cms (25,000 cfs) at the bay. However, a 2008 reevaluation of the project by the USACE estimated the 100-year design flow as 884 cms (31,200 cfs), but channel flow capacity to be only 566 cms (20,000 cfs) (RDG 2013). Thus, the Lower Walnut Creek Flood Control project not only cannot convey the 100-year flow, but also did not maintain its original design capacity.

The Lower Walnut Creek Flood Control project was designed with a flat bottom and no low-flow channel. The project has been plagued with sediment issues since its construction in 1965. In 1972, USACE revised its estimate for sediment deposition in the flood control channel upward from that stated in the project General Design Memorandum, from

28,000 m³/yr (36,000 yd³/yr), out of an estimated sediment load of 138,000 m³/yr (180,000 yd³/yr), a 20% trap rate. The revision estimated the flood control channel would trap 122,000 m³/yr (160,000 yd³/yr) out of 192,000 m³/yr (250,000 yd³/yr) sediment supply, a 65% trap rate, and a more than fourfold increase in predicted sedimentation (USACE 1972).

Between 1973 and 1989, USACE and the Contra Costa County removed approximately 861,000 m³ (1,126,000 yd³) of sediment in the creek. In the early 1990s, the district estimated that 497,000 m³ (650,000 yd³) of sediment had accumulated in the area dredged by USACE in 1973. After significant efforts to secure regulatory permits for sediment removal, Contra Costa County concluded that the dredging work was unlikely to be permitted due to significant environmental impacts and that mitigation costs would far exceed the county's financial resources.

In 2007, the USACE released a nationwide evaluation of flood control systems and included Lower Walnut Creek in the deficient category. As a result, Contra Costa County implemented the Interim Protection Measures Project and removed 153,000 m³ (200,000 yd³) of sediment between BNSF Railroad and Clayton Valley Drain. Contra Costa County continues to evaluate options to sustainably maintain the lowest 4 km (2.5 mi) of Lower Walnut Creek, to balance ecological function and flood protection benefits, and meet the USACE maintenance requirements. The county concluded that there were significant permitting hurdles to continue the needed dredging operation at the lower reach. In addition, since the lower reach is away from the urban areas, the residual risk is relatively low. At the Contra Costa County's request, the lowest 4 km (2.5 mi) reach of the creek was de-authorized from the USACE Lower Walnut Creek flood control project (U.S. Congress 2014). As a result, Contra Costa County can redesign the lower reach with a different design frequency, as long as it does not impact the capacity of the upstream project.

5.2.4 Conclusion

San Lorenzo and Walnut Creek illustrate key attributes of USACE flood control projects in the region as borne out by Wong's (2014) study of nine such projects:

- Cost Benefit Analysis: A key USACE project planning tool, the benefit cost ratio for a project must exceed unity or the project is rejected.

This approach creates an incentive to select the lowest capital cost alternative to provide flood protection benefits, often at the expense of environmental and social values, as well as unrealistic and underestimated O&M requirements. Moreover, most of the projects built in the SF Bay region in the 1960s and 1970s relied on enhanced land values (which is to say, the anticipated value of houses built in the floodplain was induced by the flood protection promised by the project) to yield a positive benefit cost ratio.

- **Project Design:** The clear water and supercritical flow assumptions used in the designs implicitly assume that sediment does not affect flow hydraulics, which is manifestly incorrect. It was a fundamental design flaw in all studied flood control projects (Wong 2014). The basic geomorphic principle that sediment deposition would be expected on distal alluvial fan reaches was simply ignored. Thus, the sedimentation rate was underestimated, and as a result, channel capacity was overestimated.
- **Operation and Maintenance:** Federal appropriation only covers the capital project cost. Local sponsors must fund the O&M, but many projects were not designed for efficient maintenance, nor were maintenance requirements properly estimated in the original project documents. Inadequate O&M reduces project performance, a significant short fall whose consequences have fallen on the local sponsors, who have inherited projects they cannot afford to maintain. Consequently, project performance deteriorates over time, resulting in a false sense of security for residents “protected” by these projects.

5.3 CORTE MADERA CREEK IN MARIN COUNTY

Jack Curley

5.3.1 *Introduction: The Ross Valley Catchment*

The Ross Valley Catchment is located approximately 32 km (20 miles) north of San Francisco in Marin County. The Ross Valley contains over 70 linear km (44 mi) of stream channels and covers an area of approximately 72.5 km² (28 mi²) (MCFCD 2017a). The catchment starts in the hills above the Town of Fairfax, where the stream is called Fairfax Creek until the confluence of the tributary San Anselmo Creek coming out of the northwest hills. It then becomes San Anselmo Creek after a major conflu-

ence in downtown San Anselmo where it is joined by Sleepy Hollow Creek and Sorich Creek. It flows into the Town of Ross and is called Corte Madera Creek after the confluence with Ross Creek and then to San Francisco Bay at City of Larkspur.

The Ross Valley Catchment is one of eight flood risk management zones managed by the Marin County Flood Control and Water Conservation District (the District). The District was created in 1953 and its geographical boundaries coincide with those of Marin County. This district, under the authority of the Marin County Board of Supervisors, is responsible for enacting measures that reduce the risk of flooding (MCFCFD 2017b).

5.3.2 *History of Flooding*

The Corte Madera Creek catchment in Marin County, known as Ross Valley, has a long history of large floods. Damaging floods occurred in the catchment in calendar years 1914, 1925, 1937, and 1942. Since 1951, when a USGS gauge was installed on Corte Madera Creek in the Town of Ross, flood flows have been recorded in calendar years 1951, 1952, 1955, 1958, 1967, 1969, 1970, 1982, 1983, 1986, 1993, and 2005. Of these, the two most severe floods occurred in 1982 and 2005, with peak discharges of approximately 200 m³/s (7200 ft³/s) and 190 m³/s (6800 ft³/s) respectively, the percent-annual-chances (i.e., probabilities) of which were approximately 0.6% and 1%, respectively. The 1955 flood was an approximate 4-percent-annual-chance flood (Stetson Engineers 2011).

Residents of the valley have been working to find a solution to the chronic flooding since early in the twentieth century. In January 1934, the Kentfield Chamber of Commerce called on federal officials to help fix flooding problems along Corte Madera Creek. They warned that the damage caused by the 1925 flood could not be allowed to happen again. A survey of Corte Madera Creek was authorized under the Flood Control Act of December 1944, and the USACE completed a preliminary examination report in 1946. Another round of serious flooding in the early 1950s amplified the calls for action by the local communities. After the December 1955 flood, Ross Valley residents stormed the county supervisors' chambers, demanding formation of a flood control entity for Ross Valley in April 1956. Finally, in the Flood Control Act of 1962, the US Congress authorized the design and construction of the Corte Madera Creek Flood Control Project.

5.3.3 *Corte Madera Creek Flood Control Project*

The estimated federal cost share for the project was 97% or \$5,534,000 (in 1960s' dollars) with local interests contributing \$158,000. The project was conceived to consist of six units with a concrete-lined channel extending approximately 6.5 miles from the SF Bay upstream into the Town of Fairfax. It was designed to convey approximately 215 m³/s (7600 ft³/s) or a 250-year flood event. Following two flood events in 1962 and 1963, Congress amended the project under the Flood Control Act of 1966 to reduce the local cash contribution from 3% to 1.5%. In 1968, the USACE completed Units 1 and 2. Together they consisted of a dredged, earthen trapezoidal channel extending 4.8 km (3 mi) from SF Bay to Bon Air Road in Kentfield, a 365 m (1200 ft) settling basin and a concrete-lined channel in the upper 457 m (1500 ft) of Unit 2. After another flood in 1969, work continued on the 1066-m (3500 ft)-long Unit 3, creating a combined 1524 m (5000 ft) of concrete channel, terminating 182 m (600 ft) downstream of the Lagunitas Road Bridge in the Town of Ross.

With Units 1, 2, and 3 constructed, work was halted in 1974 after the settlement of the litigation brought by the Town of Ross and by growing environmental concerns of property owners whose residences/businesses were directly adjacent to the creek. Efforts to find a preferred local solution continued but local support diminished. After the highest flood of record occurred in 1982 and other large floods in 1983 and 1986, Congress authorized the project again in the WRDA of 1986, still limiting the extents of the project to the upstream end of the creek in the Town of Ross, half the distance to the upstream end of the catchment.

After the flood of 1982, local concern grew about the efficacy of the existing project design and was reflected in comments to the supplemental environmental impact documents. During the 1982 event, a storm that delivered 30 cm (12 in) of rain in 32 hours to the valley, local people saw that the concrete channel was unable to pass the peak flow of 203 m³/s (7200 ft³/s), which was less than the design flood peak, that is, the 250-year flood event with a peak flow of 220 m³/s (7800 ft³/s). Damages were estimated at \$80 million in the Ross Valley with more than 35 homes destroyed.

Due to those concerns and the results of engineering studies by private sector consultants hired by the local sponsor, an extensive sedimentation study was carried out by the USACE Waterways Experiment Station (WES) (now the USACE Engineer Research and Development Center

[ERDC]) in 1989. It determined that the flow capacity of the existing concrete-lined channel was significantly less than the 100-year flood event flow. Discussion continued, and the project was reclassified from active to deferred status pending an endorsement of a new consensus plan by the local sponsor. It was determined that building a project to the 100-year level of protection was environmentally unacceptable, and the community agreed on building to a flow capacity of 152 m³/s (5400 ft³/s), approximately the 25-year flood level of protection. The project was reactivated in 1998, and efforts have continued since then to find an acceptable design for completing Unit 4, that is, the last 182 m (600 ft) of the project. The project is moving forward albeit very slowly due to lack of federal funding.

Unit 4 remains an authorized project. In February 2014, the District signed an agreement with the USACE to share the costs of a feasibility study to reevaluate the authorized project (MCFCD 2017c). Under this agreement, the USACE will contribute 50% and Marin County Flood Control will contribute 50% of the cost.

In December 2015, the environmental review process began with the “Notice of Preparation/Intent” and the “Notice of Scoping Meeting” for a joint Environmental Impact Statement/Report (EIS/EIR) for the project (MCFCD 2017d). The Scoping Meeting was held in February 2016.

In August 2016, the USACE project team presented a list of possible alternatives at a public meeting in the Town of Ross to reduce the risk of flooding. Alternatives include top of bank flood barriers, setback flood barriers, and expanding or widening along sections of the earthen and concrete channels. An alternative for an underground bypass channel is also being considered. Removal of the existing fish ladder at Town of Ross is also included (MCFCD 2017e) (Fig. 5.3). USACE is currently modifying the hydraulic model to fully analyze these alternatives. The preliminary cost estimate for the project is \$14 million, but this estimate is subject to change based on the results of the feasibility study and the EIR/EIS (MCFCD 2017d).

On December 31, 2005, a New Year’s Eve flood devastated the Ross Valley, renewing calls for flood control measures. Flood waters in downtown San Anselmo were nearly 1.2 m (4 ft) high. Damages were estimated to be above \$90 million valley-wide. The town halls of Fairfax and San Anselmo required extensive and lengthy rebuilding. Some long-standing local businesses closed for good. Fairfax Creek topped its banks and water flowed through downtown along the historic creek path now developed into a busy downtown and residential area.



Fig. 5.3 Boundary between Unit 3 and Unit 4 in Ross Creek. Fish ladder separating concrete channel from earthen channel. Unit 4 extends 180 m (600 ft) upstream of this fish ladder (Courtesy of Marin County Flood Control District)

All of the tributaries of the upper half of the catchment come together in downtown San Anselmo at Bridge Street. Topping the banks there, the floodwaters flowed through the streets in San Anselmo, the Town of Ross, through Kentfield, finally returning to the main channel in lower Kentfield. The earthen channel, with its 344,050 m³ (450,000 yd³) of sedimentation, passed this flood, later determined to be a very close approximation of the 100-year flood.

Since the flood of 2005 was contained in the earthen channel, the District is altering its approach to the maintenance of the channel and proposing to dredge to the 100-year level in future years. Under the original agreement, the District is required to dredge to the 250-year level. This must be negotiated with the USACE after the completion of Unit 4 as part of the revision of the Operations and Maintenance Manual. For the very long term, the program looks to increase tidal prism as a means to increase flushing of sediment and as a potential buffer for sea level rise.

The District continues to partner with the San Francisco District of the USACE to complete Unit 4. In 2006, the District launched a catchment-wide flood control program to increase capacity to the 100-year level throughout the catchment. The success of the measures in the upper catchment is dependent on the completion of the federal project which is

the furthest downstream project in the catchment. The District has provided updated geometry for the catchment HEC-RAS model to the USACE and a local non-profit, the Friends of Corte Madera Creek, provided state-of-the-art fish passage designs for the Unit 4 reach through a grant from National Fish and Wildlife Foundation. The Flood Control District has provided detailed suggestions to the USACE on a number of measures that would integrate the upstream end of Unit 4 with the local catchment program in the Town of Ross.

Despite its lengthy history, there is optimism that Unit 4 can be completed, and local leaders are working to find a way to help the USACE San Francisco District complete the design and environmental process. In the meantime, the local effort is under way in the rest of the catchment. The Flood Control District recently received a grant from the California Department of Water Resources through the Proposition 1E Stormwater Flood Management program for \$7.6 million (50% of the project cost) to retrofit the local water supply reservoir, Phoenix Lake, to function as a detention basin during the 100-year event. The Phoenix Lake project alone could reduce the peak 100-year flow by half, 18.4 m³/s (650 ft³/s) of 38 m³/s (1340 ft³/s) at Ross gauge, and deliver the flow to Unit 4 that it is expected to be built to handle, that is, 150 m³/s (5400 ft³/s).

5.4 EVOLUTION OF FLOOD MANAGEMENT IN ALAMEDA COUNTY

Ralph Johnson

5.4.1 *Introduction*

Much of Alameda County is in a floodplain. Until the 1950s and 1960s, many parts of the County were subjected to repeated flooding that closed businesses and schools, damaged agricultural crops, interrupted transportation and utility services, destroyed homes, and took lives.

At the request of Alameda County residents, the California State Legislature created the Alameda County Flood Control and Water Conservation District in 1949. Throughout the 1950s and 1960s, cities and unincorporated areas joined the Flood Control District to receive protection from devastating floods. The cities and unincorporated areas were grouped into “zones” which generally corresponded to catchment bound-

aries. There are now ten individual flood control zones, and since 1949, the Flood Control District has steadily constructed strategic flood control improvements. Each zone or catchment has a “master plan”, and projects were constructed generally from downstream to upstream, always following the “master plan”.

Even though few in the 1950s could have imagined the magnitude of development that has occurred in Alameda County, the flood control system was constructed assuming full build-out of the land. This system includes pump stations, reservoirs, and hundreds of miles of pipeline and channels. Recent estimates placed the value of the flood control infrastructure at over \$850 million. The system components have been paid for with a combination of property taxes, benefit assessments, special federal and state project funding, and developer fees.

5.4.2 The Concept of Wise Use of Floodplains in the 1950s and 1960s

During the 1950s and 1960s we were convinced that our concrete and steel engineering could manipulate the earth as we desired without any adverse impacts. We moved streams, covered creeks, changed shorelines, and replaced floodplains with cities. Our engineering produced a vast network of earthen and concrete channels, underground pipes, and culverts.

Benefit cost ratios were used to justify constructing flood control projects, provided that anticipated benefits exceeded project costs. In this era, the calculated “benefits” included the value of the land made available for new development by protection against flooding (see Sect. 5.2). Removal of the threat of floods also permitted more comprehensive local planning for future development and allowed freeway construction to proceed. As the freeways were part of the National Defense Highway System, major benefits could be included.

So as long as the risk to life and property could be mitigated at a reasonable cost, then the development of the floodplain was viewed as “wise”. If locating development in the floodplain disrupted the natural functions of the floodplain, this was not viewed as a problem, probably because it was thought that there were always other natural floodplains left.

The work of the Flood Control District is far from complete. Aging facilities must be replaced and (as noted in Sect. 5.2) efforts to keep flood control channels clear of silt and debris never cease. Increased focus on

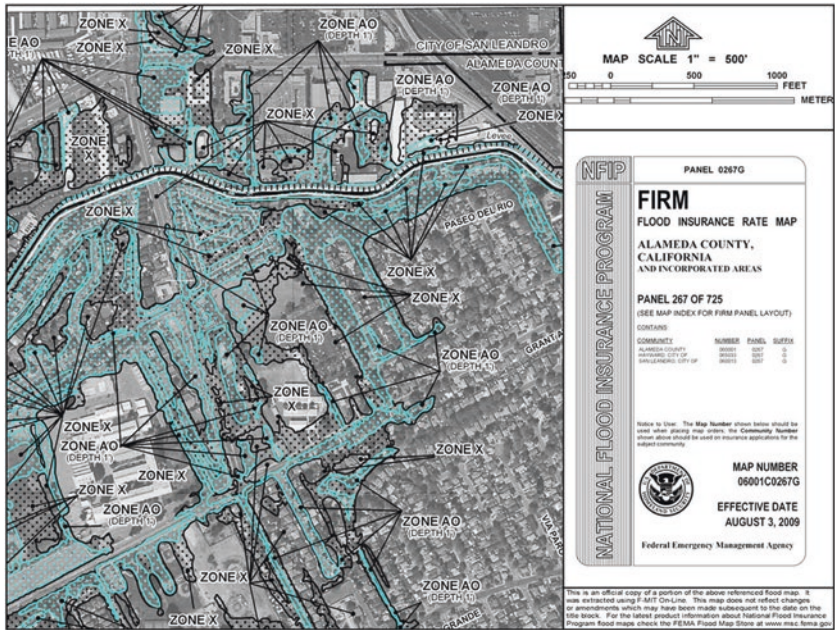


Fig. 5.4 The 2009 Flood Insurance Rate Map of northwest San Lorenzo, California, showing San Lorenzo Creek, Zone AO (the 100-year regulatory floodplain) and Zone X (other areas considered moderate or low risk) (Source: US Federal Emergency Management Agency)

controlling stormwater pollution and restoring stream habitat is the new challenge for the District.

5.4.3 Appeal of FEMA Floodplain Mapping in 1999

A FEMA remapping project completed in 1999 placed over 19,000 new parcels in Alameda County within a 100-year floodplain (Fig. 5.4). Homeowners in Alameda County were faced with paying millions of dollars of flood insurance. Additionally, the Flood Control District was faced with paying for a whole new set of flood capital improvement projects.

Using a new sophisticated hydrological computer model, District engineers more accurately predicted how much rain would fall in a major storm and how much would run off into the District’s creeks. Then, they evaluated the flood water levels caused by this runoff. Finally, they used

their own digital mapping and extensive knowledge of local hydraulics to map the probable extent of flooding.

As a result, the District was able to successfully remove over 12,000 of the 19,000 parcels from the floodplain. The Alameda County Flood Control District's advocacy on behalf of these homeowners means that they do not have to buy expensive flood insurance, which typically costs over \$1000 per year. This was the first time a local agency has so thoroughly and successfully appealed FEMA's flood studies. The technical quality of the District's reanalysis was so high that FEMA initiated a new program that allows local jurisdictions to oversee future floodplain analyses.

5.4.4 Strategic Plan for the Twenty-First Century

Using the experience gained during the 1999 appeal, the Flood Control District has updated floodplain mapping throughout the County to better inform County residents of the risks they have of living in a floodplain and to guide a maintenance and capital construction program that works toward minimizing the risks of living in a floodplain. This work has influenced the District to adopt a strategic plan for use of floodplains for the twenty-first century that includes sustainable Flood Control management, responsible environmental restoration, and clean water collaboration.

5.5 FLOOD PROTECTION PROJECTS IN SANTA CLARA VALLEY

Liang Xu

5.5.1 Introduction

Flood protection projects in urban streams must balance land use, right-of-way limitations, and preservation or enhancement of existing riparian habitat corridors while providing protection against the 100-year flood. This section describes two large projects in Santa Clara Valley, the Guadalupe River in the city of San Jose, and Permanente Creek in Mountain View. Both projects demonstrate how the Santa Clara Valley Water District (SCVWD) has dealt with the challenges of providing flood protection and generating community support. SCVWD is the largest multi-purpose special district in California, providing water supply, flood

management, and catchment stewardship to a population of 1.9 million, including Silicon Valley.

5.5.2 *The Guadalupe River Park and Flood Protection Project*

The Guadalupe River drains 360 km² (140 mi²), flowing north through Santa Clara Valley and the center of San Jose to debouch into the southern end of the San Francisco estuary. The Guadalupe River Park and Flood Protection Project (or Downtown Guadalupe River project) extends from Interstate 880 to Interstate 280 in the city of San Jose. This \$350 million multi-purpose project was completed in 2005 to provide flood protection to the city's technology and commercial industries and established residential neighborhoods; protect and improve the water quality of the river; preserve and enhance the river's habitat, fish, and wildlife; and provide recreational and open space benefits. The SCVWD served as the local sponsor, working with the USACE.

Persistent flooding problems initially led to calls for a river improvement project in the early 1960s, but for three decades the city of San Jose adopted a vision for the river based on the San Antonio River Walk, a well-known 1.2-km (0.74 mi) reach of the San Antonio River in San Antonio, Texas, along which a paved walkway, cafes, restaurants, and hotels are located. Early proposals included damming the Guadalupe River in a series of lakes to create stable, perennial water (despite the seasonal runoff in the Mediterranean climate), but the dams would have blocked migration of steelhead trout (Kondolf et al. 2013).

The project evolved considerably over the years, with modifications to the project design including channel widening, bridge replacement, and incorporation of a river walk, maintenance roads, and recreation elements, along with extensive planting for environmental mitigation (Fig. 5.5). The listing of two endangered species required added environmental study. The history of the project is long and complex and will not be recounted here, but many modifications and mitigations were undertaken in response to litigation brought by environmental groups and Guadalupe-Coyote Resource Conservation District (Roos-Collins 2007). The modified project included an underground bypass box culvert to carry flood flows around important environmental resources in the natural channel, stream-bed erosion protection features, terraces, and environmental mitigation to enhance habitat for steelhead trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) (required by the Endangered Species



Fig. 5.5 Guadalupe River flood control project looking upstream at outlet of Woz Way Bypass, downtown San José, California (Courtesy of Marin County Flood Control District, 2006)

and Clean Water Acts), with the goal of maintaining cooler water temperatures.

Public access was also incorporated into the project, as the Guadalupe River Park, a 3-mile ribbon of parkland running along the banks of the Guadalupe River in the heart of downtown San Jose, was a resource of regional importance to the people of Santa Clara County and the SF Bay region. In 2009, SCVWD began to work on the Upper Guadalupe River project to provide flood protection for an additional 10 km upstream. Key components of this project have been built, but the project is not yet complete.

5.5.3 *Permanente Creek Flood Protection Project*

Another project on Permanente Creek is part of the voter-approved Clean Safe Creeks Program. The objectives for the project are to provide flood protection to homes downstream of El Camino Real. The uniqueness of the project is to have multiple offstream detention basins using the city and county parkland to reduce the peak flow. By using detention basins, we can maintain existing right-of-way in urban areas and reduce costs and impacts to communities along the creek (SCVWD 2008).

After reviewing the feasible alternatives using Natural Flood Protection objectives, engagement with the community, and feedback received from citizens, the Permanente Task Force, City staff, and elected officials, the District staff has identified the following elements for the project. This alternative is composed of the following project elements:

- Offstream flood detention facilities in Rancho San Antonio Park and McKelvey Park
- Bypass channel along Hale Creek
- Channel widening along reaches of Permanente Creek and Hale Creek
- Floodwalls north of Highway 101 on levee channels

There will be an opportunity for restoration, habitat enhancement, and trail extension upstream of Highway 101 when designing the project. The project is currently under construction.

5.6 SAN FRANCISQUITO CREEK IN SAN MATEO COUNTY

Len Materman

5.6.1 *Introduction*

San Francisquito Creek is located approximately (48 km) 30 miles south of San Francisco in the heart of Silicon Valley. It drains a catchment of approximately 116 km² (45 mi²), flowing eastward from the crest of the Santa Cruz Mountains down to the San Francisco estuary. In its course, it is crossed by major highways, rail lines, and infrastructure corridors. The largest landowner in the catchment is Stanford University, which owns much of the headwaters, including a nineteenth-century dam now filled with sediment. San Francisquito Creek itself is about 20 km long (and forms the boundary between San Mateo and Santa Clara Counties). With its tributaries, the stream system provides over 100 km (60 mi) of channels, the last relatively unaltered creek system in the southern part of SF Bay. This creek's fluvial floodplain overlaps with the SF Bay tidal floodplain: of the approximately 8500 parcels in both floodplains, about 42% are in the fluvial floodplain only, about 32% in the tidal floodplain only, and about 26% in both simultaneously. The 14-mile main stem of San Francisquito Creek forms the boundary between San Mateo and Santa

Clara Counties in the lower catchment, where its floodplain extends almost 8 km (5 mi) from northern Menlo Park to south Palo Alto and about 4 km (2.5 mi) from the Bay on the east to Middlefield Road in the west.

The 1998 flood (the largest flow since measurements began in 1930, an approximately 80-year flood) caused \$28 million in documented damage to over 1700 properties in Palo Alto, East Palo Alto, and Menlo Park, and closed the major freeway between San Francisco and Silicon Valley. Other recorded flooding and high flow events have occurred in 1955, 1958, 1982, 2002, 2005, 2012, and 2017. The USACE has estimated that damages from a 100-year or 1% flow event on San Francisquito Creek would cause 25 times the financial damages experienced in 1998 and would pose a far greater threat to lives, property, and regional commerce. Following substantial planning efforts in previous decades by government agencies and stakeholders, the 1998 event compelled five Silicon Valley jurisdictions the following year to form a new regional government agency named for the physical features that unites and divides them, the San Francisquito Creek Joint Powers Authority (SFCJPA).

The San Francisquito Creek catchment encompasses the cities of East Palo Alto, Palo Alto, and Menlo Park, among others, and thus the SFCJPA was founded by these three cities, as well as the two countywide flood protection entities on both sides of the waterway: the SCVWD and San Mateo County Flood Control District. The SFCJPA Board of Directors is composed of an elected official from each of these jurisdictions—in 2017, it is the mayor or vice mayor of each city, a county supervisor, and water district director. In addition to its work on the creek, the SFCJPA is addressing flooding, ecosystem, and trail opportunities along the shoreline of SF Bay with its project known as the Strategy to Advance Flood protection, Ecosystems, and Recreation along the Bay (or SAFER Bay), the largest multi-county effort to protect against sea level rise in California in an area with internationally significant assets at risk of tidal flooding today.

In the past five years, the SFCJPA has secured over \$83 million in commitments for its projects from its local partners, state and federal governments, and the private sector. The small SFCJPA staff advances its multi-jurisdictional, multi-benefit capital projects with the help of consultant teams and the expertise of staff from the five agencies that established it. While this creek is a boundary between these jurisdictions, it is also what unifies them, and the framework of the SFCJPA has provided a

forum for these communities to pursue other activities that cross their borders.

5.6.2 *San Francisquito Creek Flood Damage Reduction and Ecosystem Restoration Project*

In 2002, the SFCJPA initiated an effort to plan the implementation of its first flood protection project. After cataloging project concepts proposed since the 1950s by the USACE and local agencies, the SFCJPA developed a project and sought formal federal participation by the USACE through a federal catchment-wide Feasibility Study, with the SFCJPA as the local sponsor. In 2005, the SFCJPA Board of Directors elected to put the local project on hold to concentrate on working with the USACE.

The annual appropriations bill or a USACE Work Plan provides the federal government's 50% share of funding for Feasibility Studies. As is the case with many such studies, in the years since the San Francisquito Study began, federal funding has been inconsistent and inadequate to meet the schedule originally envisioned by the USACE. At various times since 2005, the SFCJPA has taken on significant portions of the study's technical analysis with the USACE focused on reviewing conformance with federal standards, and the SFCJPA has provided local funds to the federal study ahead of federal appropriations.

Another area where local resources advanced the overall effort has been in the planning and design of a so-called early implementation project in the furthest downstream reach of the catchment from SF Bay to US Highway 101. In this area, where there is substantial overlap between fluvial and tidal floodplains, the poorest community on the San Francisco Peninsula—East Palo Alto—lies below sea level and is “protected” from creek and tidal flooding by an uncertified levee that has seeped water during recent high flow events (Fig. 5.6). This is perhaps that part of the San Francisco Bay most vulnerable to sea level rise.

In the summer of 2009, a consultant to the SFCJPA produced an analysis of project alternatives in this reach between SF Bay and Highway 101, the most downstream area that would need to be constructed first. That August, the SFCJPA combined this analysis with other studies, including some done by the USACE, and formally requested federal credit for local resources spent on this aspect of the overall federal plan. In 2010, other SFCJPA consultants began the process to complete plans and specifications on this project and to complete the environmental reviews necessary



Fig. 5.6 San Francisquito Creek Area projects and floodplains (Courtesy of San Francisquito Creek Joint Powers Authority, 2017)

to begin construction. In the late spring of 2011, the USACE notified the SFCJPA that its 20-month-old application for credit could no longer be entertained because a new crediting policy was being put into effect.

In 2013, given the SFCJPA's progress to complete design and secure local and state funding for this project, the agency had a decision to make regarding whether its SF Bay-Highway 101 project should remain part of the USACE Feasibility Study. While the SFCJPA celebrated having completed environmental documents and submitted its permit applications, it had a dilemma:

- Should it remove the SF Bay-Highway 101 project from the USACE Feasibility Study and ask the USACE to complete a smaller study more quickly so that the SFCJPA could begin construction in the critical area closest to the Bay and then apply to receive credit later, and so that the existing project conditions are maintained.
- Should the SFCJPA delay construction in the Bay-Highway 101 reach and thus jeopardize state funding for construction and keep that project within the USACE Study, and should the SFCJPA ask the USACE to include tidal flooding in the study in order to increase

its benefit-to-cost ratio (BCR) and its chances of receiving federal funding—all of which would add time and cost to the federal study.

In 2012, the USACE Headquarters produced new guidance aimed at reducing the number of—and time to complete—federal Feasibility Studies. In this new guidance, USACE District offices were directed that current and future studies could be completed within three years and for \$3 million. To ensure that the San Francisquito Study met these criteria, the SFCJPA was asked to fund a two-day charrette to set the future course of the seven-year long effort. This charrette confirmed the agreement between the USACE and SFCJPA that they would pursue a reduced scope of the federal project by eliminating the Bay-Highway 101 project from the study, a result that matched the SFCJPA's decision to—13 years after the flood of record—no longer wait to fulfill its responsibilities to provide flood protection.

In late 2012, the SFCJPA Board certified the EIR for the Bay-Highway 101 project, and in the spring of 2013, the agency submitted applications for state and federal environmental regulatory permits to begin construction. The permitting process took 35 months, largely due to difficult discussions with the Regional Water Quality Control Board (a state agency). This protracted permitting process increased the project's environmental enhancements but did not change its fundamental features, alignments, and benefits, which include protecting against a 100-year creek flow and 60 cm (2 ft) of freeboard during an extreme tide after 90 cm (3 ft) of sea level rise, which, in total, is about 2.7 m (9 ft) above the higher of daily high tides. This project will also create new marsh habitat from golf course lands and new trail connections, recreate a natural mouth in the adjacent National Wildlife Refuge to this alluvial system for the first time since it was channelized over 75 years ago, and replace a gas pipeline adjacent to East Palo Alto homes dating back to 1931. In February 2016, the SFCJPA's construction manager of the levee and floodwall portion of the project, the SCVWD, put the contract to construct those features out to bid. Construction of those features, as well as enhancements of major utilities led by the SFCJPA, began in the summer of 2016, with work scheduled for completion in late 2018.

Upstream of this reach, the California Department of Transportation (Caltrans) is designing a new Highway 101 bridge over the creek to the

SFCJPA's creek flow specifications—100-year creek flow during an extreme tide and 90 cm (3 ft) of sea level rise at a location that is already influenced by the daily high tide. It is not until the SFCJPA modifies two more bridges and widens the channel in three locations further upstream that the areas upstream (or west) of Highway 101 can be protected against a repeat of the largest flow ever seen, the 80-year flood of 1998. The SFCJPA and its member agencies are in the process of designing these improvements and planning additional work such as bank stabilization and revegetation of riparian habitat, fish passage barrier removal/modification, bike and pedestrian trails, and interpretive signage. And in conjunction with a Corps of Engineers' Environmental Impact Statement and Feasibility Report, the SFCJPA is developing an Environmental EIR to analyze these improvements and alternatives to them that either detain a storm's peak flow in an upstream basin adjacent to the channel on Stanford land, redirect high flows around the floodplain by way of an underground bypass culvert, or contain more water within the channel through new floodwalls. This EIR will tie together the entire project and complement the work of UC Berkeley graduate students who, in the spring of 2012, developed innovative ideas for making SFCJPA projects more sustainable and these communities more livable. Achieving the SFCJPA's stated goal of 100-year flood protection upstream of Highway 101 to remove properties from the flood insurance requirement will require a combination of these four alternatives.

Each of these alternatives comes with difficult political, right-of-way, environmental, and financial issues. No matter which option is chosen by the SFCJPA, the agency believes that the USACE would find a BCR that would support federal investment in this work. A USACE preliminary analysis of economic damages found that there is a likely federal interest in a fluvial-only project or a project that includes both creek and coastal elements, but the BCR is higher with coastal elements.

The SFCJPA has taken a leadership role in the Bay Area by moving forward with a multi-jurisdictional, multi-benefit project that adapts to rising sea level. Beginning in 2012, the agency received grants from state, local, and federal sources, and then funding from Facebook, whose headquarters is surrounded by marsh, to design and complete an EIR for a new 17.7-km (11 miles) Bay coastal system from San Francisquito Creek north to the Redwood City border and from the creek south to the Mountain View border. This project, known as the Strategy to

Advance Flood protection, Ecosystems, and Recreation Along the Bay (SAFER Bay), provides protection against a 100-year tide with 60 cm (2 ft) of freeboard after 90 cm (3 ft) of sea level rise. Protection afforded by the SAFER Bay project will reduce the risk of flooding from rising tides to assets ranging from the headquarters of both Facebook and Google to 19.3 km (12 miles) of state highway, including the main artery between San Francisco and Silicon Valley, to a regional water treatment plant, electrical substation, airport, and postal service facility. SAFER's new infrastructure will enable the restoration of over 400 ha (1000 acre) of marshland by opening these lands to tides along SF Bay and can enhance the heavily trafficked San Francisco Bay Trail.

The SFCJPA believes that strength of the SAFER Bay project lies in the number of assets protected or enhanced, which has brought on multiple partners and multiple benefits for those partners. This extends to construction funding as well, for the diversity of assets protected should dictate the diversity of funding sources paying for protection. Thus, like its funding for planning and design, the SFCJPA has a multi-pronged strategy to fund SAFER Bay's construction, which is likely to exceed \$150 million. These sources include traditional opportunities for public works funding like the State of California and federal government, and a new special tax or assessment district passed by properties that would be protected and see flood insurance premiums reduced. But the SFCJPA is equally focused on non-traditional sources of funding for such projects, including a new regional agency called the San Francisco Bay Restoration Authority, which recently secured \$500 million over 20 years to support projects such as SAFER, on the private sector that will rely not just on the direct protection of its assets but also on the protection of roadways to access its assets and electrical and water infrastructure to support it, and finally on opportunities to aggregate flood insurance community wide through private companies and utilize the savings for capital improvements.

Several of these strategies may also bear fruit for the SFCJPA's work along the creek upstream of Highway 101, where it maintains its partnership with the USACE for potential benefits related to federal funding and permitting support. Thus, while local residents are not ready to abandon a federal process that has—after 12 years—not produced tangible results to provide protection almost 20 years after the flood of record, the agency that represents them in this process, the SFCJPA, is exploring all available opportunities to complete this work locally.

5.7 FROM CHANNELS TO CREEKS IN CONTRA COSTA COUNTY

Mitch Avalon

5.7.1 *Introduction*

This chapter describes the approach that our Flood Control District is taking to ensure long-term, sustainable flood protection for its residents and commercial centers. This approach combines the need for capital replacement of flood protection infrastructure with the natural desire of people to reside in communities with natural creeks rather than traditional flood control channels.

5.7.2 *Infrastructure Replacement*

Most of our infrastructure was designed and built by the USACE with federal funding during the 1960s and 1970s, a period of rapid development in the County. To receive federal funding, the County had to pay all right-of-way costs, which often resulted in relatively narrow concrete and rip-rap lined channels. There are three reasons why this infrastructure may need to be replaced. First, at some point it will exceed its service life of between 75 and 100 years. Second, the infrastructure has become inadequate to provide the level of flood protection necessary for the community. This could be due to changing land uses within the catchment (e.g., changing from an agricultural land use to an urban land use) or a desired increase in the level of service (e.g., from a 50-year level of protection to 100-year level of protection to meet the US Federal Emergency Management Agency (FEMA) flood insurance requirements). Third, the infrastructure was built with design assumptions that no longer work today. An example would be the past practice of the USACE to design steeper than natural grades in the lower portion of creek channels so they ended up below sea level at the outlet. This was an acceptable design practice at the time because dredging was a standard maintenance operation that was easy and inexpensive. Today, however, flood protection agencies effectively cannot get permits to dredge lower creek channels and the channels fill up with silt, reducing flood flow capacity.

We have an estimated \$1.0 billion in infrastructure that we need to replace over the next several decades. Compounding our problem is a

severe shortage in funding that barely covers routine maintenance costs. After the passage of a California tax reform measure in 1978, our tax revenue was reduced by 58%. Another measure passed in 1996 requires a vote of all registered voters within the service area, or alternatively all property owners, in order to establish or raise a property tax or assessment. When our infrastructure was originally built by the USACE, federal funding covered up to 90% of the project planning, design, and construction costs. Working with the USACE today to rebuild our infrastructure, only 50% of the overall planning and design costs and between 50% and 65% of the construction costs are covered. In addition to the increase in costs to the local flood control district, there is an order of magnitude higher costs overall in planning, designing, and building a flood control project today compared to a project in the 1960s or 1970s. How will we pay for future projects? We must bring our communities in to help fund infrastructure replacement projects and to provide influence and advocacy at the state and federal levels for increased state and federal funding.

Another consideration in a capital replacement program is life cycle costs. These vary by facility and channel reach. Concrete channels tend to have high initial construction costs, very low ongoing maintenance costs, and high replacement costs. Natural channels require increased right-of-way width (and cost) and generally higher ongoing maintenance but low or zero replacement costs. Natural channels also tend to be more adaptable to changes in the landscape or to climate change impacts than hard facilities. Taking the long view, the costs of natural channels will be less compared to the costs of multiple life cycles for concrete channels.

Our major infrastructure has a remaining service life of 30–50 years. We need to embark now on a planning process for long-range replacement of this essential infrastructure. The question for our communities is this: what type of infrastructure should it be replaced with? Should we simply rebuild our concrete or rip-rap channels, or should they be replaced with more natural systems of vegetation and riparian habitat in a manner that allows natural processes to maintain essential flood protection and water quality improvement functions, recreational and aesthetic values, and flexibility to respond to climate change? Our experience indicates there will be much more public support for replacing existing infrastructure with natural systems. If we pose this question openly, then the answer becomes a community design issue, resulting in community involvement, and ultimately community buy-in and support. This long-range process to engage

the community and develop a “creek enhancement plan” was termed the “50-year plan” simply to illustrate the long-range aspect of the process (CCCFCWCD 2009).

5.7.3 *Creek Enhancement Planning*

The Flood Control District has 116 km (72 mi) of engineered, or historically termed “improved”, channels that no longer have the natural features of the original creek. Funding will likely become available to restore some natural features to these channels. In today’s world, there is much more funding available, and the award of funding much more likely, for an environmental creek restoration project than for a concrete flood control channel replacement project. As our communities age and land uses change, we will have the opportunity through “redevelopment” of the community to implement more natural flood protection facilities integrated into the new urban landscape (Figs. 5.7 and 5.8).

The Flood Control District can develop Creek Enhancement Plans to, for example, plant riparian vegetation in an earthen channel and still maintain flood protection, if the drainage system is looked at from a catchment perspective, to offset the loss in capacity due to the vegetation planted in



Fig. 5.7 Grayson Creek channel just upstream of Taylor Boulevard, Pleasant Hill, California (Photo by Mitch Avalon 2000)



Fig. 5.8 Remnant of the natural Walnut Creek after Corps project, now referred to as Ellinwood Creek, Pleasant Hill, California (Photo by Mitch Avalon 2000)

the channel. If the goal is to convert a flood control channel to a natural creek, then some Creek Enhancement Plans will need extremely long planning horizons of 50 years or more to achieve all of their objectives. Some plans may be as simple as providing a bypass pipe or an upstream detention basin or increased upstream infiltration to allow a creek section to be natural, while other plans may call for purchasing a row of houses in order to replace a concrete channel with a natural looking creek. These kinds of objectives are achievable and can be implemented without unreasonable disruption to a community if a long-range “50-year” creek enhancement plan is adopted. The Flood Control District will develop these plans if our communities are interested in a more natural environment in our flood protection facilities.

5.7.4 *Benefits for the Community*

The community gains many tangible benefits to a natural flood protection system in addition to continuing flood risk reduction. Having a natural creek system flow through a neighborhood rather than a concrete channel looks and feels better to the surrounding residents resulting in increased property values. The community can plan and design its public spaces and retail/commercial areas to take advantage of the attraction of a natural

system and have a recreational and aesthetic focus along the creek. This can enhance economic activity and investment in the area. A natural creek can provide wildlife linkages between urban ecosystem fragments and open space areas and filter storm runoff to reduce pollutants in the storm-water. As our landscape becomes more urbanized and we have more technological diversions, our children have less opportunity and spend less time interacting in a natural environment. Reestablishing natural creeks in an urban setting will increase opportunities for children to interact with nature, a healthy alternative to the “concrete jungle” (Louv 2008).

The community will have an opportunity for citizens to get involved in creek-related activities, such as clean-ups, water quality monitoring, and fish surveys, or for youth groups to help actively manage portions of the creek by, for example, removing invasive species or trimming vegetation. These activities increase citizen involvement and increase their sense of community. The community can also develop and retain a skilled workforce restoring and maintaining public and private natural creeks. This could include revegetation and soil bio-engineering project work, water quality monitoring, and coordination of erosion prevention/stabilization on private property and stream stewardship training for private property owners. These would be new jobs for the community that can't be outsourced overseas and help the community's economic sustainability.

5.7.5 *Opportunities*

There are many opportunities to include long-range planning for the replacement of vital flood protection infrastructure within existing community planning and implementation activities. Each city and county must update its general plan every 20 years. In addition, many cities and counties prepare general plan amendments or specific plans to establish a vision for development of a neighborhood within the city or a county or unincorporated community. Large development projects are required by state law to mitigate their impacts on the surrounding community. Development mitigation measures could include short pieces of channel or creek enhancement with their land-use entitlements. These are all opportunities to include catchment and systemwide creek infrastructure planning into a city's fundamental and foundational planning documents.

There are other drivers for long-range planning that could include flood protection infrastructure on a catchment or systemwide basis. Integrated Regional Water Management Planning in California is a col-

laboration primarily of water supply, wastewater, and flood protection agencies that could provide funding or cost share contributions to alternative stormwater management approaches that, for example, retain and “harvest” rainfall, thereby enhancing local water supplies for landscape irrigation and reduction of flood peaks. There are also opportunities to develop catchment or creek enhancement plans and/or implement portions of improvements as an offset to or in lieu of stormwater (NPDES, National Pollutant Discharge Elimination System) or regulatory permit requirements. FEMA is continually updating their floodplain maps and adding properties to the flood hazard area, which triggers the need for flood insurance. This is always a driver for increased public awareness and interest in reviewing catchment or creek infrastructure needs within floodplains. Climate change and sea level rise will also be a trigger for long-range creek planning, especially with the expansion of floodplains and exposure of more properties to flood risk.

5.8 THE RIBEIRA DAS JARDAS STREAM: AN URBAN FLOODPLAIN IN LISBON

Graça Saraiva

5.8.1 *Evolution of Flood Management Strategies in Portugal*

Floodplain management in Portugal has a long tradition, driven by the unbalanced seasonal distribution of precipitation and runoff of its Mediterranean climate. International Iberian river basins, such as Tagus and Douro, as well as smaller basins entirely within Portugal and small, highly urbanized catchments, have been affected by floods, causing extensive economic damages and, in extreme situations, loss of human lives.

Flood control measures and legislation have been implemented since the beginning of the twentieth century, initially with a strong emphasis on structural measures. The “water sector” was responsible for building flood control structures, namely dams and levees/dikes.

In the 1980s, a non-structural approach for floodplain management emerged, mainly coupled with land-use planning regulations, such as floodplain zoning and development constraints, integrated on the spatial planning process at the local (municipal) level. The fact that very severe flash floods occurred in the highly urbanized region around Lisbon in

1967 and 1983, with many casualties (around 400 in 1967), was an alert for the need to consider flood risks in spatial planning and development control. However, the current trends of urban growth and metropolization have increased flood hazards in the most developed areas, such as the Lisbon region and in the Algarve, where tourism has promoted intense urban sprawl.

At the time of Portugal's joining the European Community in 1986, EU environmental policy concerning water resources emphasized mostly solving water quality problems, with a set of directives that intended to achieve water quality standards. With the adoption of the Water Framework Directive (WFD) in 2000 (Directive 2000/60/EC of October 23, 2000) (EU 2000), member states were required to organize themselves under river basin districts governed by river basin commissions, charged with preparing River Basin Management Plans. In Portugal, the WFD was transposed into national legislation in 2005, through the Water Law (Law no. 58/2005 of 29 December) and related legislation.

However, the WFD didn't specifically address the risk of flooding and the effect of future climate change. The European Commission then developed an approach to manage flood risks at the community level, taking into account the uncertainty of climate change and reinforcing flood prevention as well as flood protection and mitigation. The Floods Directive (adopted in 2007) proposed to "establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community" (EU 2007).

Under this Directive, floods also must be managed at a river basin scale, with international cooperation for rivers crossing two or more countries. Three distinct steps are required by the Directive: (1) preliminary flood risk assessment, based on an analysis of past floods with significant adverse consequences—these assessments were due in 2011; (2) preparation of flood hazard maps and flood risk maps, at the level of river basin districts, including several scenarios of probability (low, medium, and high), showing the number of inhabitants and type of economic activity potentially affected—these maps were due in 2013; (3) preparation of flood risk management plans to reduce potential adverse consequences of flooding, including prevention, protection, preparedness, flood forecast, and warning systems. These plans were encouraged to include sustainable land use practices and the improvement of water retention—the plans were due by the end of 2015.

A key feature of the Floods Directive was its implementation within the framework of the WFD (again transposed into national law), so that flood risk management plans were developed by the same competent authorities already established to develop and implement the River Basin Management Plans to encourage consistency with WFD goals.

Portugal adopted this Directive in 2010 (Decree-law no. 115/2010 of 22 October). Each of the ten river basin districts of mainland Portugal adopted a flood risk management plan in 2016, following requirements of the Directive, with information accessible to the general public (APA 2016). Thus, overall responsibility for flood management lies with the Ministry of Environment through the Environment Agency, which oversees the River Basin Districts and River Basin Management Plans (The Ribeira das Jardas/Barcarena is included in the Tagus Basin District).

Climate change scenarios for main river basins forecast the concentration of precipitation in winter and the concentration of heavy precipitation events which are likely to increase flood magnitude, frequency, and risks (Santos et al. 2001). This argues for associating flood protection measures with best environmental options, such as natural retention of floodwaters and green infrastructure to reduce runoff. This strategy can strengthen natural flood management, contributing to the protection and restoration of floodplain and coastal ecosystems, which can function to mitigate climate change impacts. Green infrastructures can be broadly described as approaches that work with nature to reduce flooding and restore natural ability to store or slow down flood waters, planned at a basin or catchment scale (EC 2011).

Green infrastructure concepts have been integrated in the spatial planning process in Portugal at the municipal level since 1999, with the objective to develop continuous “green or ecological networks” or “municipal ecological structure”. This structure includes rivers and streams, floodplains, steep areas, and other environmentally sensitive areas, aiming to ensure land uses compatible with environmental and hazard protection. These areas are mapped in the municipal plans and should be developed within these constraints, namely, as green infrastructure corridors, or green areas for leisure and recreation. Among areas recognized for good green infrastructure practice are the cities of Porto and Lisbon, and municipalities along the Ribeira das Jardas/Barcarena west of central Lisbon (Silva et al. 2012).

5.8.2 *Revitalizing the Ribeira das Jardas (Cacém, Portugal)*

Urban streams in the Lisbon region have been very vulnerable to flash floods in recent decades (1967, 1983, 1997, 2008, and 2011), largely because urban growth pressures in the twentieth century allowed dense settlement areas to spill into floodplains. The north bank of the Tagus estuary west of central Lisbon is drained by a series of small streams flowing from north to south, crossing densely developed areas, still maintaining, in some cases, deeply incised valleys within which many stream reaches have retained relatively natural characteristics. This is the case of Ribeira das Jardas stream, whose catchment covers an area of approximately 35 km² and originates in the mountainous slopes of vale de Lobos, in the municipality of Sintra, flowing into the municipality of Oeiras and discharging into the Atlantic (Fig. 5.1 b–c). In its 18.8 km, the Ribeira das Jardas flows through the cities of Cacém and Barcarena, before debouching into the Tagus estuary. In its northern upstream reach, it is called the Jardas; below the town of Barcarena, it is known as the Barcarena.

The tremendous potential for restoration of the Ribeira das Jardas for both ecological and social values has been recognized (Saraiva et al. 2001; Silva et al. 2004; Kondolf et al. 2010), and it was here that the first river rehabilitation project in Portugal under the concept of green infrastructure was implemented (Fig. 5.9). A large program of urban renewal, the Polis program, was launched by the Ministry of Environment in 2000, with goals of urban rehabilitation and environmental regeneration in cities and to improve their quality of life. This program was applied in the city of Cacém in 2005 to rehabilitate the Jardas stream and create a greenway along its banks. The Polis program reinforced the coordination between central institutions, notably the Water Agency, in charge of water and river management (now subsumed into the Environment Agency) and local authorities (municipalities), encouraging coordination, shared decision making, and providing special funding (Partidário and Nunes Correia 2004).

Prior to the project, the Jardas was highly altered and degraded, canalized within concrete walls, and consequently, with low habitat complexity and reduced amenity and recreational values (Kondolf et al. 2010). With the selection of the city of Cacém for inclusion in the Polis program, a master plan was developed, establishing the aims of achieving identity, mobility, and sustainability, as well as of creating urban quality of life. The master plan called for a public green area along Jardas stream and the



Fig. 5.9 Ribeira das Jaldas rehabilitation project in downtown Cacém, Portugal (Photo by Graça Saraiva 2008)

rehabilitation of the concrete channel in the city center into a green corridor. Importantly, the sewage system treatment was upgraded, and consequently, water quality improved, creating conditions favorable for restoring some ecological functions.

The river rehabilitation project had goals of providing flood protection, regenerating aquatic and riparian habitat, providing space for leisure and recreation, and enhancing scenic and aesthetic values. Continuity along the river corridor was pursued, leading to the demolition of some buildings that had been restricting the floodplain. In addition, measures were implemented to increase permeability and restore riparian vegetation (NPK 2011).

Due to the highly constricted space available, the park was conceived as a set of overlapping systems at different levels, such as riparian vegetation, the circulation network, the green and permeable areas, and the bank structures. Given the lack of space and the extent of prior disturbance, there was no attempt to restore a natural channel. A system of gabions provided flexibility to increase flood conveyance capacity to accommodate the 100-year flood, and to eliminate flow restrictions, and also to create diversity and enhance physical habitats.

Banks and terraced floodplains became permeable land, with riparian vegetation planted to restore a riparian ecosystem. Multiple terraces made

possible the creation of detention areas. A network of trails, cycling lanes, and paths has attracted people from the surrounding dense neighborhoods to meet together near the “rediscovered” stream.

One of the major benefits of this project was its successful engendering of public use and recreation. Before the project, the area around the Jardas was derelict, the concrete channel hemmed in by fences, hidden between buildings, ignored by the residents, and collecting litter. After the rehabilitation, social uses of the greenway were the most visible benefits. In a survey conducted in 2009 (Kondolf et al. 2010), results showed that 77% of the respondents felt positively about the intervention, considering improvements on river accessibility, pollution, and urban aesthetic quality. Survey responses pointed to the need for more shaded area, as the trees had been only recently planted, as well as more recreation facilities. One ironic result of the survey was that respondents were more critical of the water quality than had been the case prior to the project. In reality, the water quality had measurably improved thanks to the upgraded waste water treatment facilities, but the improved visibility of the stream evidently drew public attention to the water quality (Kondolf et al. 2010).

REFERENCES

- APA. 2016. *Planos de Gestão dos Riscos de Inundação*. In: <http://www.apambiente.pt/index.php?ref=16&subref=7&sub2ref=9&sub3ref=1250>.
- Arnold, J. 1988. *The Evolution of the 1936 Flood Control Act*. Fort Belvoir/Washington, DC: Office of History, US Army Corps of Engineers.
- Carter, N.T., and C.V. Stern. 2010. *Army Corps of Engineers Water Resource Projects: Authorization and Appropriations*, Congressional Research Service Report for Congress. R41243.
- CCCFCWCD (Contra Costa County Flood Control and Water Conservation District). 2003. *Contra Costa County Watershed Atlas*. Martinez: CCCFCWCD (Contra Costa County Flood Control and Water Conservation District).
- CCCFCWCD (Contra Costa County Flood Control and Water Conservation District). 2009. *The 50 Year Plan “From Channels to Creeks”*. Contra Costa County Flood Control and Water Conservation District.
- EC (European Commission). 2011. *Towards Better Environment Options for Flood Risk Management*. DG ENV D.1. 236452, European Commission.
- EU (European Union). 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*. Brussels.

- . 2007. *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks*. Brussels.
- Kondolf, G.M., K. Podolak, and A. Gaffney, eds. 2010. *From High Rise to Coast: Revitalizing Ribeira da Barcarena*. Berkeley: Department of Landscape Architecture & Environmental Planning, University of California.
- Kondolf, G.M., K. Podolak, and T.E. Grantham. 2013. Restoring Mediterranean-Climate Rivers. *Hydrobiologia* 719: 527–545. <https://doi.org/10.1007/s10750-012-1363-y>.
- Louv, R. 2008. *Last Child in the Woods: Saving Our Children from Nature Disorder*. Chapel Hill: Algonquin Books.
- MCFCDD (Marin County Flood Control District). 2017a. http://www.marinwatersheds.org/ross_valley.html. Accessed 30 Jan 2017.
- . 2017b. http://www.marinwatersheds.org/flood_stormwater.html. Accessed 30 Jan 2017.
- . 2017c. http://www.marinwatersheds.org/documents_and_reports/documents/CorteMaderaCreekFCSASigned_000.pdf.
- . 2017d. http://www.marinwatersheds.org/documents_and_reports/USACE_CorteMaderaCreekProject.html.
- . 2017e. http://www.marinwatersheds.org/documents_and_reports/documents/CorteMaderaCreekProjectupdateflyerNovember2016.pdf.
- NPK Consultants. 2011. *Ribeira das Jardas Linear Park in Cacém, Portugal*.
- Partidário, R., and F. Nunes Correia. 2004. Polis—The Portuguese Programme on Urban Environment. A Contribution to the Discussion on European Urban Policy. *European Planning Studies* 12 (3): 409–423. <https://doi.org/10.1080/0965431042000195001>.
- Pinto, P.J., and G.M. Kondolf. 2016. Evolution of Two Urbanized Estuaries: Environmental Change, Legal Framework, and Implications for Sea-Level Rise Vulnerability. *Water* 8: 535. doi:<https://doi.org/10.3390/w8110535>. Online at <http://www.mdpi.com/2073-4441/8/11/535/pdf>.
- RDG (Restoration Design Group). 2013. *Walnut Creek Watershed Inventory*. Prepared for the Walnut Creek Watershed Council. Berkeley: RDG (Restoration Design Group).
- Roos-Collins, R. 2007. Bankside San Jose. In *Rivertown: Rethinking Urban Rivers*, ed. P.S. Kibel, 111–141. Cambridge, MA: MIT Press.
- Samet, M. 2007. Bankside Federal. In *Rivertown: Rethinking Urban Rivers*, ed. P.S. Kibel. Cambridge, MA: MIT Press.
- Santos, F.D., K. Forbes, and R. Moita. 2001. *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures: Executive Summary and Conclusions*. Lisboa: Fundação Calouste Gulbenkian.
- Saraiva, M.G., P. Simões, J. Alves, G.M. Kondolf, and K. Morgado. 2001. *Estudo de Requalificação Paisagística e Ambiental das Ribeiras da Costa do Estoril*. SANEST, Saneamento da Costa do Estoril, SA.

- SCVWD (Santa Clara Valley Water District). 2008. *Permanente Creek Flood Protection Project Planning Study Report*, Santa Clara Valley Water District, July.
- Silva, J.B., M.G. Saraiva, I. Loupa-Ramos, F. Bernardo, and F. Monteiro. 2004. *Classification of the Aesthetic Value of Jardas Stream*, Deliverable 4-3, URBEM (Urban River Basin Enhancement Methods) Project, EVK-CT-2002-00082 CESUR, IST, Technical University of Lisbon.
- Silva, J.B., M.G. Saraiva, I. Loupa-Ramos, and F. Bernardo. 2012. Improving Visual Attractiveness to Enhance City-River Integration—A Methodological Approach to Ongoing Evaluation. *Planning Practice & Research* 28 (2): 163/185. <https://doi.org/10.1080/02697459.2012.704734>.
- Stetson Engineers. 2011. *Capital Improvement Plan Study for Flood Damage Reduction and Creek Management for Flood Control Zone 9/Ross Valley*, Report to Marin County Flood Control and Water Conservation District, May.
- U.S. Congress. 2014. *Water Resources Reform and Development Act of 2014*, Public Law 113–121.
- USACE (US Army Corps of Engineers). 1963. *Design Memorandum No.1, Walnut Creek Project, Contra Costa County, California, Channel Improvement, General Design and Basis of Design for Reach I (Suisun Bay to Willow Pass Road)*. Sacramento.
- . 1964. *Design Memorandum No.2, Walnut Creek Project, Contra Costa County, California, Channel Improvement, Basis of Design—Reach II, Willow Pass Road to Rudgear Road*.
- . 1972. *Walnut Creek Project, Contra Costa County, California—Letter Supplement No.3 to Design Memorandum No.1*, Prepared by Diversion Engineer, South Pacific.
- Williams, P.B. 1990. Rethinking Flood-Control Channel Design. *Civil Engineering* 60 (1): 57–59.
- Wong, P.L.R. 2014. *Federal Flood Control Channels in San Francisco Bay Region—A Baseline Study to Inform Management Options for Aging Infrastructure*, PhD Dissertation. University of California Berkeley.