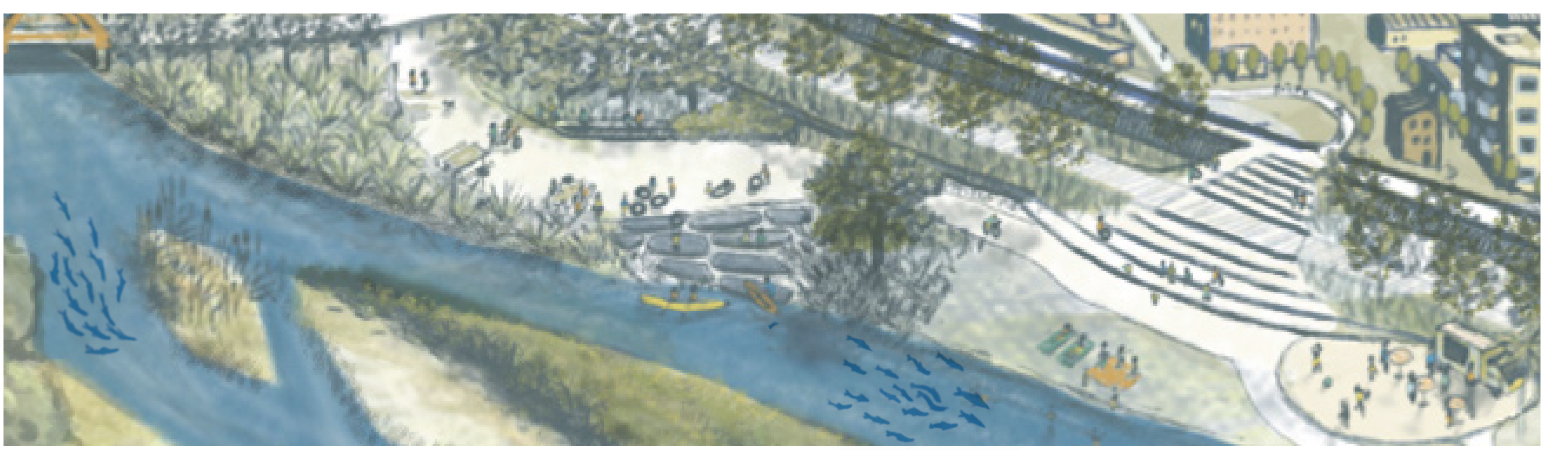


WALNUT CREEK WATERSHED RESTORATION OPPORTUNITIES

OCTOBER 2021



Contra Costa County's Fifty-Year Plan
Walnut Creek Watershed Opportunity Analysis

Realizing the Social + Ecological Potential of Creeks in Walnut Creek Watershed

OCTOBER 2021

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APPENDICES

I. THE FIFTY-YEAR PLAN: MORE BENEFITS TO MORE PEOPLE

In 2009, Contra Costa County Flood Control and Water Conservation District's "Fifty-Year Plan" defined a problem and vision, a set of challenges, and a planning approach. The **problem** is aging flood infrastructure, approaching its end-of-life, and in need of replacement across floodplains in the County. Since the District's inception in the 1950's, structural interventions to control floods have constrained streamflow within engineered channels, preventing inundation of historical floodplains through a interdependent system of earthen levees and concrete structures. This infrastructure allowed cities and suburbs to develop and prosper along low-lying valleys and up to the channel's edge. These structures also destroyed aquatic and riparian habitat, limited salmon migration and spawning, blocked public access to water and nature, and created an expensive — but unfunded — reconstruction project. Today, channel infrastructure is locked in place, surrounded by development, and increasingly prone to failure as individual components degrade.

The **vision** of the Fifty-Year Plan broadens the need for infrastructure replacement into an opportunity to restore multi-functional creek corridors as riparian ecosystems and shared public greenways that address rising flood risk while offering more benefits to more people.

Challenges emerge from intertwined physical and social constraints. The combination of aging infrastructure, unaccounted hazards of climate change and earthquakes, and increasing development pressure pose increasing risks to private investments and critical public infrastructure within historical floodplains, the reach of rising tides, and poorly drained neighborhoods. For people living and working in upland contributing areas, flood infrastructure has offered little value, but packs a high replacement cost.

Restoration of living, dynamic creeks expands the scale and scope of land use change required for the next generation of multi-functional flood management. In contrast to smooth and simplified flood control channels, the vegetation and irregular forms of restored streams require a widened floodable corridor. Roughness expands flow volumes, but private property abuts the existing contrained channels. Diverse stakeholders will hold different perspectives on the costs versus benefits of land use change along creek corridors. Floodplain parcel owners may prioritize continuing flood protection, but residents throughout the watershed express concern about droughts and water security, housing affordability, access to safe bike trails, and health effects of traffic and pollution. More than three quarters of adults in the County prioritize environmental protection over economic growth. Municipalities face tight fiscal budgets, growth pressure, and competition for jobs and tax revenue. Few are aware of rising flood risks or the opportunities presented by the Fifty-Year Plan.

To address these challenges, the Fifty-Year Plan proposes to re-integrate creek corridors into communities as vital public resources supporting health and well-being, civic engagement and education, wildlife habitat and everyday life. With this long-term vision for sustainable, community-serving creeks, the District continues its mission, but changes how it's done. A **planning process** can reconcile the services creeks offer to all inhabitants of the watershed.

II. SCOPE OF THIS REPORT

This report begins to outline and map the opportunities, constraints, and trade-offs facing communities as they plan the next generation of the County's flood management. The District asked Riverlab — an academic team of applied scientists and environmental planners at University of California, Berkeley — to explore the social and ecological potential for reviving altered channels as multi-functional, community-serving creek corridors in Walnut Creek Watershed. To inform this process, we reviewed and synthesized science and planning studies relevant to the vision, challenges, and context of the Fifty-Year Plan. Based on the latest restoration science, consultation with engineers in the District, interviews with municipal stakeholders in Pleasant Hill, and feedback from presentations of in-process work to local watershed planning committees, we defined a range of potential restoration strategies, developed suitability criteria for each strategy given available data, and mapped suitability for two major strategies at multiple scales in the watershed. The resulting *Walnut Creek Watershed Restoration Opportunity Atlas (Atlas)* represents a first step in raising stakeholder awareness of the potential for community connections to restored creek corridors in Walnut Creek Watershed. Maps in the *Atlas*, referenced throughout this report as (*Atlas Map)*[1], rank opportunities for pursuing various strategies based on potential benefits and partners.

This report presents our analysis, methods, and results. It outlines the underlying arguments, assumptions, and planning recommendations for the District to consider as they launch the planning and implementation of the Fifty-Year Plan. To support the District's commitment to communicate with stakeholders and encourage their participation in the planning and implementation of the Fifty-Year Plan, we present our analysis in an adapted journalistic structure, presenting in order *why*, *what*, *where*, and *how*.

- Section 1: **Why?** A Long-Term, Integrated Approach to Watershed Services. Details an argument for a holistic, integrated, and multi-scale approach to address rising flood risk and restoration of ecosystem services within the County's watersheds.
- Section 2: **What?** A Restoration Vision for Walnut Creek Watershed. Outlines a range of potential restoration approaches as options with trade-offs to be presented and weighed by stakeholders in the community.
- Section 3: **Where?** Mapping Opportunites for Restoration. Shares methods and analysis of on-the-ground restoration opportunities in Walnut Creek Watershed with references to resulting maps in the *Walnut Creek Watershed Restoration Opportunity Atlas*.
- Section 4: **How?** Principles, Strategies, and Tools for the Fifty-Year Plan. Discusses the planning process for watershed-scale restoration and introduces planning and policy tools that are further explored in Appendices.

[1] Maps in the *Atlas* are referenced by a unique identifer where the first letter represents the map scale, Watershed (W), Municipal (M) or Reach (R) followed by a number to support easy, ordered lookup.

1 WHY? A Long-Term, Integrated Approach to Watershed Services

1.1 AN OPPORTUNITY TO REVIVE CREEK CORRIDORS

About 1,200 miles of creeks flow through Contra Costa County (County) into the San Francisco Bay-Delta (SF Bay). Their combined drainage area covers 600 square miles, divided into nine major watersheds and 340,000 private parcels. Just over one million people reside within the nineteen municipalities and numerous unincorporated communities of the County. Upon establishment in 1951, the Contra Costa County Flood Control and Water Conservation District (District) adopted a mission to reduce flood risk within its booming suburbs. The District has since expanded its mission "to promote stormwater quality and to restore and enhance natural resources in an environmentally sensitive manner."

The District owns and manages 79 miles of flood control channels and 29 detention basins. Built over the past 65 years at an estimated cost of $1.2 billion[1] (*Figure 1-1*), this flood infrastructure has reduced the frequency of floods in historical floodplains, and development has flourished, now valued at $25 billion (Avalon, 2014). However, this infrastructure has a finite life. Recent assessments show that 25-65 years of 'service life' remain, but only with repair (*Table 1-1*). The system-wide cost to reconstruct flood infrastructure as-is could exceed $2.5 billion (Avalon, 2014) with additional costs for planning, permitting and design to meet current regulations, address community needs, and consider threats of climate change.

On top of gradual deterioration, many flood control channels no longer convey the intended return period floods. With revised calculations and improved hydrologic data, the 100-year flood is now larger than previously estimated. The capacity of some channels is repeatedly compromised by sediment deposition which reduces channel capacity (Pinto et al., 2018). As time wears on, the District foresees an increasing risk of failure, even from frequently occurring storms. Prior to 2009, no plans existed for infrastructure replacement or imminent failure.

In 2009, the District adopted the "Fifty-Year Plan", a vision to replace rigid, single-purpose channelized infrastructure with restored, multi-functional creeks wherever possible (CCC FCD, 2009). The approach aims to maintain flood conveyance capacity while integrating the management of water, land use and ecosystems to maximize public benefits over the long term. It recognizes the natural flow patterns of a watershed as services to leverage and engage rather than fight or control. It asks: for every dollar spent on the next generation of infrastructure, can communities gain much more? The Fifty-Year Plan continues the District's mission of flood safety, but restructures its imprint on the landscape to serve a broader public mandate, evolved values, and local to global concerns. Multi-functional approaches to flood management can help the County conserve water, improve water quality, address threats of climate change, restore habitat for native wildlife, support the well-being of residents, and promote equitable access to shared, self-sustaining community resources that serve future generations.

[1] Throughout the report, conversion of dollar amounts to 2019 values is based on the Consumer Price Index and calculator from the U.S. Department of Labor Statistics (Bureau of Labor Statistics, 2019).

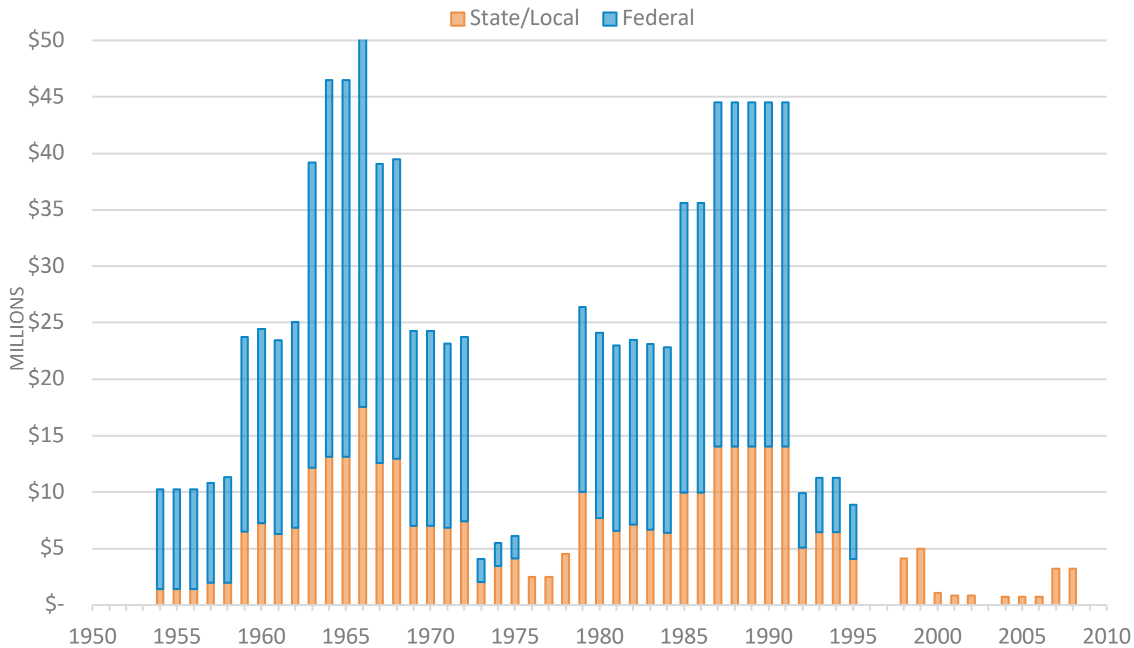

Figure 1-1. Dollar value of major flood infrastructure investments in Contra Costa County between years 1951-2010, adjusted to 2010 dollars. Colors distinguish federal versus local and state cost share. Total past capital investment sums to $1.2 billion and future capital replacement cost exceeding $2.5 billion, adjusted to 2019 dollars (Avalon, 2014).

Table 1-1. Summary of flood infrastructure service life assessment for a *subset* of flood infrastructure facilities in Walnut Creek Watershed as assessed by independent engineering firms for the District between 2015-2018 (citations available upon request). Red highlights assets with less than thirty years of service life (even with repair), orange shading highlights assets with less than fifty years, and blue highlights those with more than seventy-five years.

REACH	FACILITIES	YEAR BUILT	REMAINING YRS OF SERVICE LIFE (no repair)	REMAINING YRS OF SERVICE LIFE (repair)	REPAIR COST (in 1000s)
EAST FORK GRAYSON	Concrete U Channel	1957	30	40	$60
WEST FORK GRAYSON	Concrete U Channel	1960	20	65	$75
LAFAYETTE CREEK	Concrete U Channel	1955	20	65	$80
	Culverts (4)	1955	20	65	
SAN RAMON CREEK	Drop Structure 3		40	40	< $1
	Drop Structure 3A	1961	40	40	$5
	Drop Structure 4	1954	40	40	$10
	Drop Structure 5	1961	60	60	$5
	Drop Structure 6		50	85-100	$5-$10
	Drop Structure 7	1961	60	60	$5
	Drop Structure 8		60	60	$30
	Drop Structure 9		30	60	$30
	Drop Structure 10		30	60	$30
	Drop Structure 11	1958	60	60	$5
	Drop Structure 12	1958	60	60	$5
	Drop Structure 13		65-75	85-100	$5-$15
	RCB Culvert		50	50	
LAS TRAMPAS CREEK	Carol Lane Drop Structure	1941	5	25	$50
	Trapezoidal Channel	1962	25	75	$35
	Drop Structure 1	1954	20	50	$30
	Drop Structure 3		25	25	
TICE CREEK	Concrete Channel	1962	20	65	$75
PINE CREEK	Pine Creek Dam	1955-56	50	85-100	>$100

1.2 WHY INVEST IN CREEK CORRIDORS?

The threats posed by aging concrete channels, drop structures, and culverts spurred the District to consider impending flood facility replacement. After comparing broad alternatives, the Fifty-Year Plan reframes the problem of flood infrastructure replacement as an opportunity to revive creek corridors for multiple community benefits through a participatory watershed planning process. The District's initial vision (2009) calls for maintaining or improving flood risk protection while gaining benefits for the community, identified as:

- *Improved quality of life* as flood control channels redeveloped with natural creeks, recreational trails, civic amenities, and commercial opportunities;
- *Improved wildlife habitat;*
- *Improved water quality;*
- *Community reconnection with nature* for improved public health and childhood education;
- *Opportunity for civic involvement and community activities;*
- *Development of 'green jobs*' to reconstruct and maintain creek corridors with a local workforce.

The following section broadens and deepens the discussion of potential benefits of restoring creek corridors as part of multi-scaled, multi-functional public infrastructure that supports the ecosystem services of local watersheds, conserved lands, municipalities, floodplains, and neighborhoods. By understanding the potential social and ecological benefits of watershed restoration, communities can assess their values and needs to define the broad goals and measurable objectives of restoration. With community input and further study, potential benefits and trade-offs of specific approaches can be better quantified and weighed. To motivate participation, the community must first be aware of the risks embedded in the current state of flood infrastructure.

1.2.1 AN URGENT NEED TO ADDRESS RISING FLOOD RISK

1.2.1.1 Flood risk is growing, creating an opportunity to rethink flood risk management

Flood risk across the state of California remains insufficiently quantified, but is likely rising as the number of people, the value of property, and the probability of major floods outpaces funding sources and planning timeframes to protect people and property (California Department of Water Resources and US Army Corps of Engineers, 2013; Mount, 2017; Opperman et al., 2009). Costs to fund existing flood management projects at planning stages across California could exceed $50 billion. To protect the 1.4 million at-risk Californians from 100-year recurrence interval storms – those with a 1% probability of occurring in any given year – could cost another $50 billion. Thus California's Department of Water Resources "conservatively estimates $100 billion is needed to reduce risk statewide" (California Department of Water Resources and US Army Corps of Engineers, 2013, pp. 3–43).

Definition of Flood Risk

Damaging floods are a product of physical and social factors. Flood risk can be defined as a function of a hazard and its impact (Blaikie et al., 2004; Koks et al., 2015; Kron, 2005; Merz et al., 2010). The impact of a given hazard depends on society's exposure and vulnerability. Our collective or individual perception of risk affect our behavior, altering our exposure and vulnerability to hazards (Birkholz et al., 2014; White, 1945).

- Hazard is the probability and intensity of inundation (e.g. via river overbank flood, flash flood) often expressed in terms of frequency and intensity. Although floods are often described as a "natural" hazard, anthropogenic factors in urbanized watersheds influence runoff response to precipitation and subsequent flood flow volume, velocity and depth. Structural approaches to flood protection, such as the 1960s-era facilities constructed in Contra Costa County, often aim to reduce flood hazard by minimizing the extent of inundation (Merz et al., 2010).
- Exposure represents the value of assets subject to flooding and the population affected. Assets can include structures, land, agricultural crops, critical infrastructure (e.g. sewage treatment facilities and hospitals) or assets of cultural value. Factors affecting exposure to hazard include population density, land use, capital investment and reconstruction costs of development in flood-prone areas, but also indirect flood effects (e.g. disruption to the regional economy, long-term impact of contamination). For an exposed population, the degree and character of impact on each individual will vary (e.g. based on preparedness or access to resources), so a population count only provides a bundled, unrefined assessment of hazard impact.
- Vulnerability emphasizes the social capacity to cope with, adapt to and recover from floods. For individuals or populations, factors that influence vulnerability to flood hazards can include age, disability, income and savings, family structure, social networks, language and discrimination barriers, or access to resources. Vulnerability can be affected by awareness of hazard and exposure, preparedness, disaster and evacuation planning, insurance coverage, land use, design and condition of the local environment, or policy measures. Most often, vulnerability is not homogenous across a population (Koks et al., 2015), varies over time, can be conferred deliberately or inadvertently but often reflects social hierarchies and power structures, and remains difficult to measure (Adger, 2006).

Opportunities to Improve Risk Management

Historically, a focus on hydraulic engineering solutions to mitigate hazards tended to overlook social dimensions of exposure and vulnerability, leaving a legacy of unaddressed residual and compound risk (Birkholz et al., 2014), while allowing for expanded occuption of flood-prone lands. Today, we understand risk management as an evolutionary cycle through phases – from analysis, planning, design, operations, disaster response and recovery. As physical and social conditions change, so do risks, prompting a need to cycle through these phases of risk management (Plate, 2002). Planning each new generation of infrastructure represents an opportunity to learn how to better protect communities from risk.

The District's recognition of aging flood infrastructure and the opportunity for restoration prompts a major community reconciliation of risks across broad physical, social and ecological dimensions.

The call for long-term, community-based watershed planning (CCC FCD, 2009) represents an opportunity for social learning that can increase the ability of local communities to adapt to changing hazards, exposure, and vulnerabilities. In its communication with stakeholders, the District can pose the Fifty-Year Plan as a response to the following changes since the District's inception:

- Changes in the regional climate with impacts on natural hazards (Section 1.2.1.3);
- Lessons learned from 60 years of experience managing and maintaining conventional, engineered flood protection facilities across the U.S. (Section 1.2.2);
- Impacts of urbanization on watershed hydrology and ecosystems (Section 1.2.2.2);
- Social response to residual risk and ecological impacts of engineered infrastructure (Section 1.2.4);

Multiple Aspects of Risk

In complex and non-stationary systems, predicting change in flood risk may forever be uncertain. When considering integrated, interdependent components of urbanized watersheds, systemic risk can cascade and ripple in unexpected ways, defy attempts to quantify in simple terms of hazard and exposure, leaving many risks unaccounted (Renn et al., 2011). In Table 1-2, we highlight factors that likely influence flood risk over time in Contra Costa County. We consider trends, emerging concerns about compound hazards, and outline how potential exposure and vulnerability to flood hazards can influence the risk faced by residents, business owners, and managers of public infrastructure. By no means exhaustive, the summary begins to explore how the probability of an event interacts with predicted damage in terms of extent and character of flooding as well as social preparedness, cost, recovery and geographic distribution. This exploration can inform community deliberation about the degree, distribution, and uncertainty of risk, and debate about appropriate local, contextual approaches to flood risk management that are simultaneously objective, quantified, inclusive, deliberative, precautionary and pragmatic (Klinke and Renn, 2002; Merz et al., 2010).

1.2.1.2 Lack of awareness increases flood risk for residents

The sense of safety afforded by flood policies increases other aspects of risk

Federal flood policy, regional economic pressure and local land use zoning have encouraged people to live, work and build in floodplains. Across Contra Costa County, the value of assets in historical floodplains was recently estimated at $29.9 billion with 83% of these assets protected by flood infrastructure (Randolf et al., 2015, p. 40). Suburban development on floodplains in Contra Costa County was not designed to accommodate the processes that form and maintain creek channels and floodplains. As population growth and economic pressure propelled development, flood infrastructure locked streams into hardened, smooth canals designed to convey severe floods up to a designed maximum. By preventing frequent inundation of floodplains, this infrastructure encouraged further investment of flood-intolerant development on flood-prone land.

Known as the "levee effect", the protection afforded by flood infrastructure encourages floodplain development, increasing *exposure* to rare floods or infrastructure failure (Ciullo et al., 2017).

Table 1-2. Summary of factors influencing change in flood risk within Contra Costa County

RISK FACTOR	TREND	DESCRIPTION OF DRIVER AND IMPACT
HAZARDS	AGING INFRASTRUCTURE	• *Flood infrastructure failure.* As flood protection infrastructure ages beyond its design life, hazard of failure and inundation of the floodplain increases. • *Reduced capacity of flood infrastructure* over time due to design flaws, sedimentation, regulatory conflict, and revised flood frequency analyses.
	URBANIZATION	• *Rise in peak flows*. Expansion of impervious surfaces as urbanization intensifies and grows beyond urban limit lines likely exacerbates flood peaks, especially for frequent events, unless urban limit lines held and urban impacts mitigated.
	CLIMATE CHANGE	• *Projected sea level rise* of 1.6-10.2 ft (0.2-3.1 m) by 2100 within the San Francisco Bay will increase flood hazards as tides and wave heights rise, storm surges amplify (Griggs et al., 2017; Jevrejeva et al., 2014a; Parris et al., 2012) and riverine flooding responds to reduced channel capacity, higher base level, expanded tidal zones, and compound effects of winter rains in a swollen SF Bay (Cayan et al., 2008a; Moftakhari et al., 2017b). • *Extremes in Precipitation*. Trends and projections indicate increased variability and extremes in precipitation frequency and intensity with climate change (AghaKouchak et al., 2018; Dettinger, 2011; He and Gautam, 2016; Pierce et al., 2018; Russo et al., 2013; Swain et al., 2018; Yoon et al., 2015). • *Channel instability,* due to unprecedented range of flows, can alter patterns of erosion and sedimentation.
	COMPOUND HAZARDS	• *Earthquakes*. Fault rupture, violent shaking, or liquefaction has potential to undermine earthen levees, dams, and concrete infrastructure that protects broad, developed floodplains including critical water supply, sewage treatment facilities, energy, and transportation infrastructure (ABAG, 2014; Gafni, 2015; Tetra Tech, 2018). • *Fault Creep.* Lower Walnut Creek and eastern tributaries cross and adjoin the Concord-Green Valley Fault. At the time of flood control infrastructure design and construction, local seismic risks were not well-understood. Performance of infrastructure over decades of right-lateral creep remains uncertain. • *Landslides.* On steep slopes, slight perturbations, prolonged rainfall, earthquakes, or changes in vegetation, drainage, or roadcuts can all induce mass movement of rock and soil, posing threats to structure and people downslope. • *Drought.* Requires integrated water management to ensure diverse water supply portfolio (e.g. local groundwater sources) with sufficient water to support aquatic ecosystems (Mount et al., 2015). If sufficiently prolonged and severe enough to significantly change vegetation cover, drought can increase erosion rates, wildfire, landslide, and flood hazards. • *Fire.* As hazards increase with warming temperatures and extremes in precipitation, wildfire followed by rainfall can result in pulse of high flows, slope failure, debris flows, and channel sedimentation with cumulative effect of increased flood hazard. • *Hazardous Material Release.* Refineries, industrial operations and sewage treatment facilities in lower Walnut Creek pose hazard of toxic chemical release if flood damages lead to ruptures, leaks, or lost operations control (Gafni, 2015).

RISK FACTOR	TREND	DESCRIPTION OF DRIVER AND IMPACT
EXPOSURE	URBANIZATION	• *Damage to Critical Infrastructure*. Highways, transit, sewage treatment and energy networks often co-locate in floodplains. increasing exposure and potential damage from flood hazards. • *Public Health and Safety*. More people living near flood infrastructure increases risk that someone will be in/near flood facilities at the wrong time and be swept into fast-moving water. • *Compound Effects of Increased Frequency of Flooding*. As sea level rise increases the hazard of nuisance flooding, the damages wrought by repeated exposure could approach or surpass costs of extreme events (Moftakhari et al., 2017a). • *Priority Development Areas* promise to address housing affordability and promote transit use, but threaten to increase density of floodplain development near transit hubs. • *Homeless individuals*, estimated at 1,600 in the County, often form encampments in flood-prone areas (Richards, 2018).
	SECONDARY DAMAGES	• *Disruption of Critical Services*. In addition to direct threats of flooding, disruption of critical services, energy and water supply, transport, economic activity, or viability of ecosystems can threaten lives, cause trauma or crises for marginalized people, and incur financial cost at regional scales. • *Structural Inadequacy*. Buildings and structures on the floodplain may lack physical strength to withstand flood hazards if constructed prior to rigorous building code standards. • *Catastrophic Instability*. Building and structures encroaching on channel banks have increased risk of catastrophic instability if infrastructure failure instigates bank collapse or mudflows.
	RESIDUAL RISK	• *Public Health and Safety*. Overbank flow into developed floodplains, due to exceedance of design capacity or facility failure, exposes relatively unaware residents and workers to potentially dangerous inundation, high velocity flows, contaminants, and pathogens. • *Costs of uncertainty*. Sediment trapped in flood control channels decreases flow capacity, requiring frequent removal at unexpected cost, a rising concern with sea level rise, increased extremes in precipitation, heat, vegetation shifts and upland erosion (San Francisco Estuary Institute, 2016).
VULNERABILITY	AWARENESS	• *Lack of Preparedness*. Floodplains are not mapped to show the extent, depth, and velocity of floodwaters in the event of infrastructure failure, floods larger than design capacity, or compound hazard scenarios. Many residents are unaware of hazard and exposure (Ludy and Kondolf 2012). • *False Sense of Security*. Property owners outside FEMA-designated "100-year floodplain" but living within historical floodplains may be unaware of potential exposure to inundation if discharge exceeds the design capacity of flood protection system. A false sense of security decreases preparedness, responsiveness to emergency, urgency to address risk through policy change; hence it increases vulnerability (Birkholz et al., 2014; Leidy, 2007; Merz et al., 2010; Tobin, 1995). • *Federal flood maps are* based on historical data, and thus do not account for change in sea level rise, land use and runoff patterns, or climate impacts on precipitation, projected hazards or cumulative effects (Bedsworth and Hanak, 2010). • *Lost Connection to Nature, Lack of Community Knowledge*. As creeks were converted to off-limits flood control channels,

RISK FACTOR	TREND	DESCRIPTION OF DRIVER AND IMPACT
		communities have forgotten the effects of past floods, lost awareness of and access to ecosystem services, and lost knowledge of how floodplains and wetlands function. • *Marginalized populations* (e.g. low-income families, non-English speakers, elderly, children, people with disabilities) may be unaware of hazard or unable to afford missed work, protections or recovery cost, even for frequent nuisance floods (Walters and Gaillard, 2014). • *Homeless people,* residing between levees, in concrete channels or low-lying areas face disproportionate flood impacts to their belongings, health, community and security. Most often, homeless are not considered in hazard mitigation planning (including the County's Tetra Tech 2018 draft report) (Walters and Gaillard, 2014; Wisner, 1998).
	FUNDING AND POLICY	• *Lack of reliable, sustained funding* for flood management reduces opportunities for repairs, maintenance, integrated water management, habitat protection, and planning for future. • *Fragmented land and water management* across scales and sectors limits potential for integrated planning, permitting, funding, maintenance and operations even as issues and risks become more complex (California Department of Water Resources and US Army Corps of Engineers, 2013). • *Unresolved maintenance needs, costs and regulation*. Local maintenance costs were commonly underestimated during project design, leaving an unexpected burden on communities who face regulatory resistance to dredging channels, because of impacts on aquatic ecosystems (Pinto et al., 2018). • *Lack of local policie*s to protect people, property and ecosystems through non-structural flood management (e.g. limit development on floodplains or enforce flood-safe building practices) increase reliance on aging, inflexible infrastructure. • *Transit-Oriented Development* may incentivize more development, people, businesses, and assets in hazard zones.
	AGING INFRASTRUCTURE	• *Flood infrastructure must maintain ideal flow conditions* to function as expected. Wear increases risk of catastrophic failure. • *Increased in-channel roughness and sedimentation* decreases capacity of flood control channels over time (Pinto et al., 2018). • *Seismicity was not taken into account in flood infrastructure design*. Increasing knowledge of faults, creep and earthquakes reveal vulnerability. • *Bridges and culverts are often undersized and vulnerable to backwater flooding or failure*. River crossings may be critical for maintaining emergency access to certain neighborhoods (Tetra Tech, 2018). Bridges can trap debris and create debris dams, which can release dangerous flood waves when they fail.
	FLOOD INSURANCE	• *Limited flood insurance* is only required within FEMA-designated "100-year" floodplain. Outside of this area, most property owners do not carry flood insurance despite vulnerability to residual risk of flooding from extreme events (beyond the designed capacity of channels), infrastructure failure, compound hazards, or mapping error.
	PREPAREDNESS	• *Encroachment of private parcels* into and along channels limits access for the District to repair and maintain its facilities.

Where flood infrastructure offers a prescribed level of protection, as assessed via flood maps and flood frequency analysis, federal policies do not require risk disclosure or flood insurance to people living in former floodplains. Landowners, residents and businesses may assume they are safe, unaware of the danger of floods that exceed the design flow of engineered infrastructure (Ludy and Kondolf, 2012). Citizens' perception of safety and lack of awareness can engender further development on floodplains, reduce motivation to take individual measures or further invest in community flood protection, and thus increase *vulnerability* to unaccounted hazards and unacknowledged residual risk (Birkholz et al., 2014; Randolf et al., 2015). The lack of awareness of flood risk is attributable in large part to the success of the flood control infrastructure, which has been sufficient to manage most of the floods in recent decades. As a result, two generations of residents have not experienced the kind of flooding that originally motivated the flood control infrastructure. Unlike other, more visible infrastructure, the public usually becomes aware of flood control infrastructure only upon failure, such as overtopping, development of sinkholes over storm drains, etc.

Engineered flood protection addresses well-defined hazard scenarios, supporting a sense of safety at the expense of *awareness and preparedness* for unaccounted scenarios. Public-serving infrastructure that propels economic development in the County often lies in flood-prone areas: energy distribution networks, interstate highways, public transit, rail lines, sewer pipes and wastewater treatment. Flood protection infrastructure supports the function and reliability of these critical services. In turn, the security of critical infrastructure engenders development across entire watersheds. The subsequent increase in impervious surface area and stormwater connectivity generates greater storm runoff and increases peak flow in channels for all but the most extreme and prolonged storms (Randolf et al., 2015). Over time, downstream hazards increase with upstream development. For instance, in Walnut Creek, 1960s-era flood control channels were designed to convey a 100-year recurrence interval flood, estimated at 25,000 ft^3/s (708 m^3/s). In 2008, the US Army Corps revised its estimate of the 100-year flood to 31,2000 ft^3/s (884 m^3/s) and the flood channel capacity was downgraded to 20,000 ft^3/s (566 m^3/s) due to sedimentation (Pinto et al., 2018; Walkling, 2013).

Once constructed, the stability and durability of conventionally engineered flood infrastructure allows for constrained channels and encroaching floodplain development, but leaves little room to accommodate subsequent adjustments in design parameters. Changes in our understanding of seismicity or sediment loads, physical changes in watershed land use, or changes in precipitation patterns from climate change raise silent risks that often remain unacknowledged, increasing vulnerability to flooding. This "revenge effect" of design-limited technology can reap catastrophic consequences (Ciullo et al., 2017; Tenner, 1997). Without an awareness of risks, local communities' motivation and willingness to invest in non-structural approaches to flood management may languish, even as risk grows (Birkholz et al., 2014; Merz et al., 2010; Tobin, 1995).

The memory of past flood disasters has faded. Floods do not rate as a broad public concern. More than 85% of County residents self-reported that they have never experienced a flood (Tetra Tech 2018, online "hazard mitigation" survey of 662 residents in 2017). 72% of residents have no recollection of serious flooding in the County, according to in-depth telephone interviews (605 registered voters, as documented in Metz 2015). In the 2015 phone interviews, 30% of County voters perceived flooding as an individual risk. When asked if communities need more protection from flooding along local creeks and streams, 60% said “no” and 28% responded “yes” (Metz, 2015).

About 10% of online survey respondents in 2017 were “very” or “extremely” concerned about flooding – the same portion of respondents who live in a FEMA-designated floodplain or had flood insurance (Tetra Tech, 2018). In both online surveys and phone interviews, drought and earthquakes ranked as natural hazards of greatest concern. Of 605 interviewed County voters in 2015, only 7% found local flooding to be a very or extremely serious problem. Over 80% found current drought conditions as very or extremely serious (Metz, 2015). More than flooding, respondents across both surveys expressed concern about active shooters, cyber threats, epidemics, air pollution, hazardous material release, wildfire, terrorism or power failure. Less than 1% of online respondents mentioned climate change or sea level rise in open-ended prompts about “other” unlisted hazard concerns (Tetra Tech, 2018).

The two sources of survey data confirm that flooding does not rate as a strong concern for the majority county residents (*Figure 1-2*). Three quarters of online respondents agreed that the government is responsible for providing “education and programs that promote citizen actions that will reduce exposure to the risks associated with natural hazards” (Tetra Tech, 2018). About 40% of voters were familiar with the District. Of those who were, three quarters viewed the District favorably (Metz, 2015). About 40% of voters agreed that the District actively educates the public about flooding and pollution. Just over 60% ranked education as an important responsibility of the District – the second highest below protecting water quality (Metz, 2015). When asked about community priorities for the Fifty-Year Plan, voters also ranked water quality improvement as most important followed by groundwater recharge, infrastructure replacement and habitat restoration (Metz, 2015).

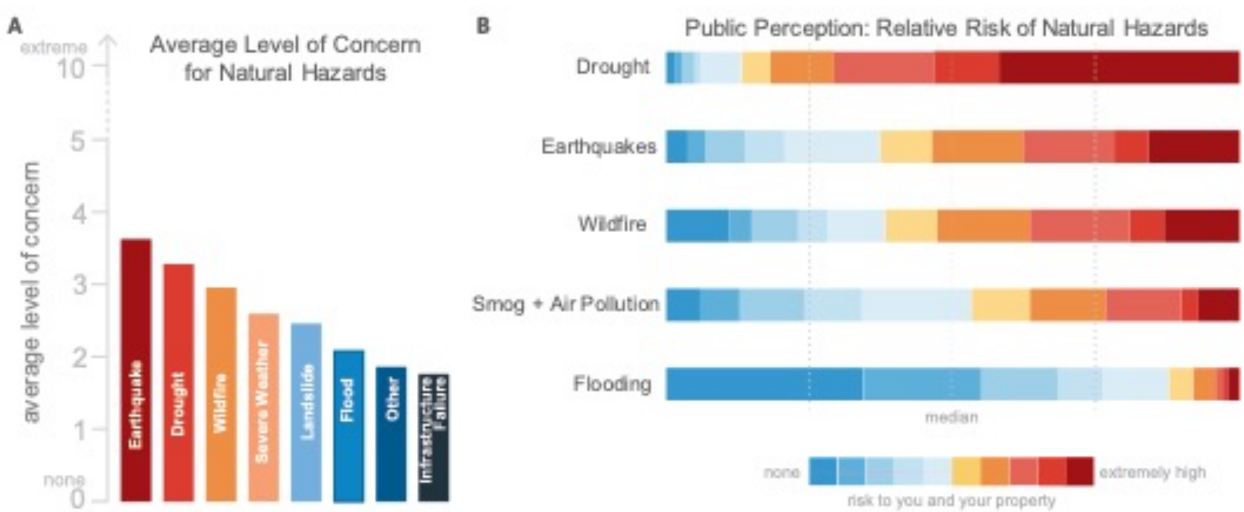

Figure 1-2. Public concern about natural hazards. (A) Results of 2017 online survey of county residents (Tetra Tech, 2018). (B) Results of 2015 telephone interviews of registered voters in the County (Metz, 2015).

1.2.1.3 Risks grow with climate change

Sea Level Rise

Since 1900, the global annual average temperature has increased by 1.8° F (1.0° C), primarily attributed to human-derived emissions of greenhouse gases (Wuebbles et al., 2017). With the accumulation of greenhouse gas in our atmosphere, oceans have warmed and expanded. Since 1900, the mean sea level at San Francisco's coast has risen over 8 inches, (20 cm) (Griggs et al., 2017) but the rate of regional sea level rise has at least doubled, if not tripled, since 1990 (Dangendorf et al., 2017; Jevrejeva et al., 2014b; National Research Council, 2012). Due to time lags, the rate of sea level rise we see today and the near-future reflects past decades of greenhouse gas emissions. Global efforts to reduce emissions in this century will influence sea level rise for hundreds of years, affecting the ability of local flood mitigation measures to manage risk as sea level continues to rise unabated by any heroic measures to reduce emissions in the next decades (Ackerly et al., 2018b; Jevrejeva et al., 2012). As highlighted in the Fourth National Climate Assessment: "With its long service life, urban infrastructure must endure a future that is different from the past (Maxwell et al., 2018, p. 439)."

Projections of future sea level rise remain uncertain, and will be influenced by our past and near-term emissions. Median sea level rise projections for the San Francisco Bay region between years 2000 to 2100 range from 1.6 to 2.4 ft (0.49 to 0.76 m) depending on well-defined scenarios for greenhouse gas emissions (*Figure 1-3*). These emissions scenarios, discussed as "representative concentration pathways" (RCP), represent plausible future conditions across a range of potential global climate policies and their anticipated effects (Moss et al., 2010; Parris et al., 2012). Scenarios of ambitious emissions reductions (e.g. RCP 2.6 tracks objectives of the United Nations 2015 Paris Agreement) coincide with the low end of the projected range in temperature and sea level rise whereas "business-as-usual" scenarios (e.g. RCP 8.5 continues current trends of energy demand and greenhouse gas emissions) coincide with high end.

Beyond the median projection, models demonstrate a 5 to 0.1% chance of sea level rise of 7.9 to 9.3 feet (2.41 to 2.87 meters) in California by 2100 (Griggs et al., 2017). Without drastic emission reductions in the next decade, instabilities in the Antarctic ice sheet, driven by processes not currently underway but considered plausible, may lead to a dramatic ice melt and acceleration in sea level rise to 10.2 feet (3.1 meters) by 2100 (see H++ scenario in Fig 1-3) (DeConto and Pollard, 2016; Griggs et al., 2017). In models of ice sheet collapse, this extreme rise in sea level represents a 5% probability in the RPC8.5 "business-as-usual" greenhouse gas emissions, but the models predict a *mean* rise of 6 feet (1.84 meters) by 2100 if Antarctic ice sheets destabilize (Bars et al., 2017). Scientific approaches to understanding processes, projection and prediction of sea level rise are rapidly evolving. "Extreme risk projections" of sea level rise will likely change as methods, policy and emissions adjust. For flood infrastructure projects with an expected service life beyond 2100, worst-case scenario projections can help identify and weigh the costs and benefits of more adaptable approaches to a continuous rise in sea level while mitigating risks to people and ecosystems (Ackerly et al., 2018b; Cloern et al., 2011).

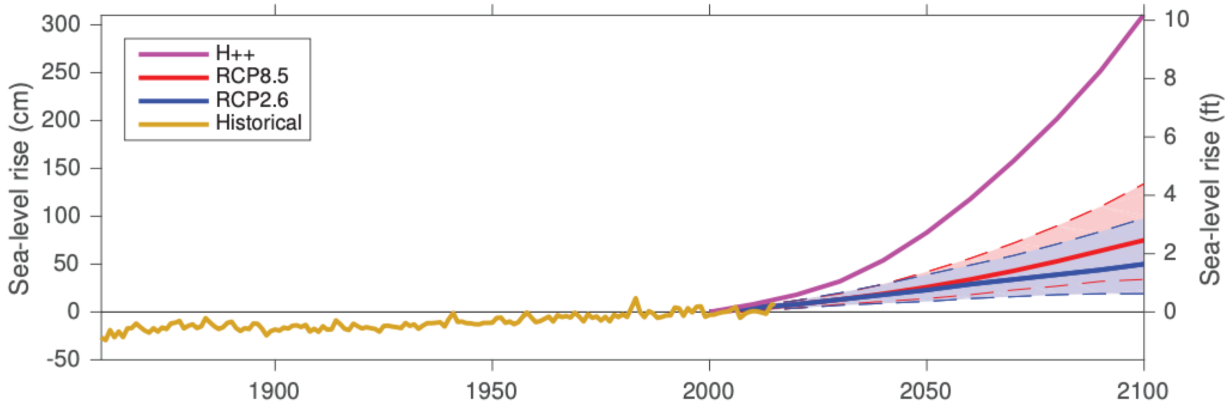

Figure 1-3. Projections of sea level in San Francisco, relative to year 2000 baseline. Colored lines represent a range of greenhouse gas emissions scenarios. RCP2.6 and RCP8.5 (scenarios of 'representative concentration pathways' of anthropogenic carbon in the atmosphere) represent a range of greenhouse gas emissions reduction. RCP2.6 corresponds to the UN 2015 Paris Agreement to achieve net-zero emissions by 2050, a "challenging" and aggressive target to achieve. RCP8.5 represents continuation of present-day "business-as-usual" emissions trends. H++ scenario represents an extreme acceleration in ice sheet mass loss, a process not observed today, but conceivable given potential for marine ice sheet instability (Griggs et al., 2017).

As the rate of sea level rise continues to accelerate, more land will be submerged along San Francisco Bay's coastline, and more assets near tidal zones will be subject to periodic flooding with much greater frequency (Sweet et al., 2017). With this rise, extreme tides and typical winter storms will increase the likelihood of backwater flooding affecting property, roads, infrastructure, economic activity, and public safety upstream of tidal influence (Cayan et al., 2008a; Griggs et al., 2017; Vandever et al., 2017). On lower Walnut Creek, inland floodplains upstream of tidal wetlands will be affected by sea level rise as the head of tide pushes upstream and increases compound flood hazards in Concord, Pacheco, and even Pleasant Hill (*Figure 1-4*). Even under ambitious emissions reductions scenarios (RCP 2.6), disruptive flooding of roads, property, and infrastructure will increase as water overtops creek banks during high tide or typical winter rains. With business-as-usual scenarios (RCP8.5), average daily high tide may approach or exceed the current 1% annual chance coastal flood (Fleming et al., 2018).

Predicting Change in Flood Risk with Sea Level Rise

Due to the complexity of contributing factors and lack of data, predicting change in flood risk is highly uncertain (Merz et al., 2010). Current methods used to assess flood hazard often fail to account for compound drivers, such as combined coastal and fluvial flooding. Risk assessments often fail to assess cumulative cost of frequent, nuisance level flooding with diffuse effects on property loss and lowered value, transport disruption, critical water treatment services, quality of life, and public health (Moftakhari et al., 2017a). Commonly used models for estimating economic loss and population vulnerability assume flood risk rises with population growth, increasing land value and economic investment in floodplains. They increasingly consider sea level rise and precipitation extremes.

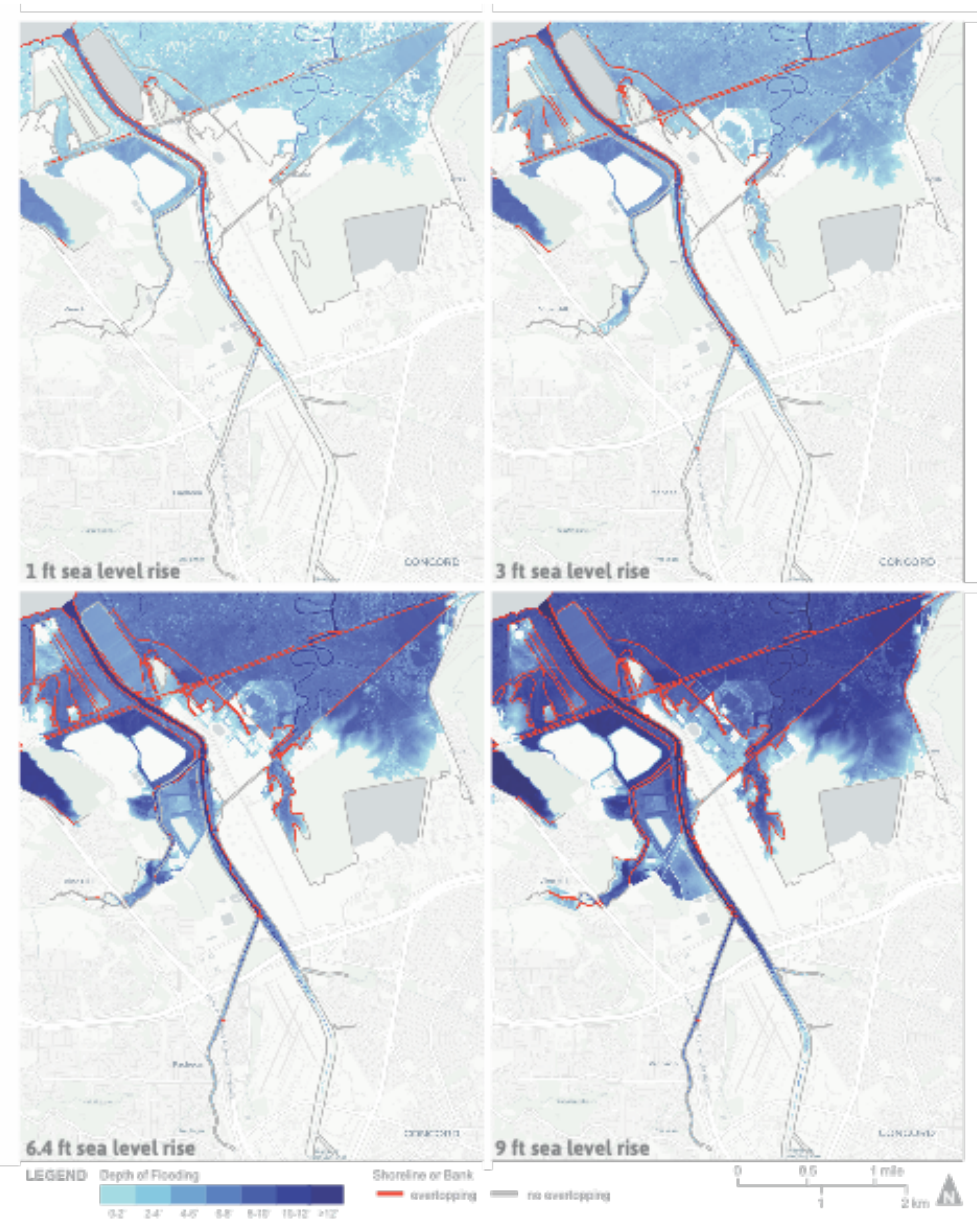

Figure 1-4. Projected sea level rise inundation depth and bank overtopping (red line) in Lower Walnut Creek and Grayson Creek as projected for a range of emissions scenarios. No riverine flood, tidal surge or wave effects are considered in the projections (San Francisco Bay Conservation and Development Commission, 2019). From top left, clockwise: a 1 ft rise by 2040-2050 in low emissions scenarios; a 3 ft rise by 2060-2100 in medium to low emissions scenarios, a 6.4 ft rise is the median projection for 2100 if Antarctic ice sheets destabilize. A 9 ft rise by 2100 remains a low probability, 'worst-case' projection for 2100 (San Francisco Bay Conservation and Development Commission, 2019). The projection shows a 3 ft sea level rise overtopping Grayson Creek banks near its intersection with I-680.

A simplified geospatial model for coastal California, based on HAZUS software from the U.S. Federal Emergency Management Agency (FEMA), projected impacts of sea level rise during a 100-year flood by adding 4.6 feet (1.4 meter) of sea level rise to FEMA's existing 1% annual-chance base flood elevation (Heberger et al., 2011). Using Contra Costa County's demographic data (based on 2000 U.S. Census) the model estimates increases in countywide flood risk with climate change as:

- *A nearly seven-fold increase in the flood-vulnerable population*, disproportionately impacting low-income and non-white communities;
- *A five-fold increase in replacement value of flooded buildings* on private parcels (not considering impacts on infrastructure and right-of-ways);
- *18 additional EPA-regulated sites (i.e. with hazardous substances)* subject to flooding;
- *100 miles of roadways subject to flooding*, a five-fold increase (Heberger et al., 2011);
- *22% loss of wetland area* (Heberger et al., 2009).

Increasing precipitation extremes

As increasing greenhouse gas concentrations alter the global climate, the *mean* annual and winter precipitation in California and the San Francisco Bay Area has remained stable over the past 80-120 years. Variability and extreme precipitation, however, have increased over this time (Russo et al., 2013). Multi-model climate projections for the next 80 years in California align with observed trends of more frequent extreme storms and drought (*Figure 1-5*) (He and Gautam, 2016). Across coastal California, we expect inter-annual variability in precipitation, but simulations project a 25-100% increase in extremes of precipitation within this century, described as a 'precipitation whiplash effect' on California's climate (Swain et al., 2018).

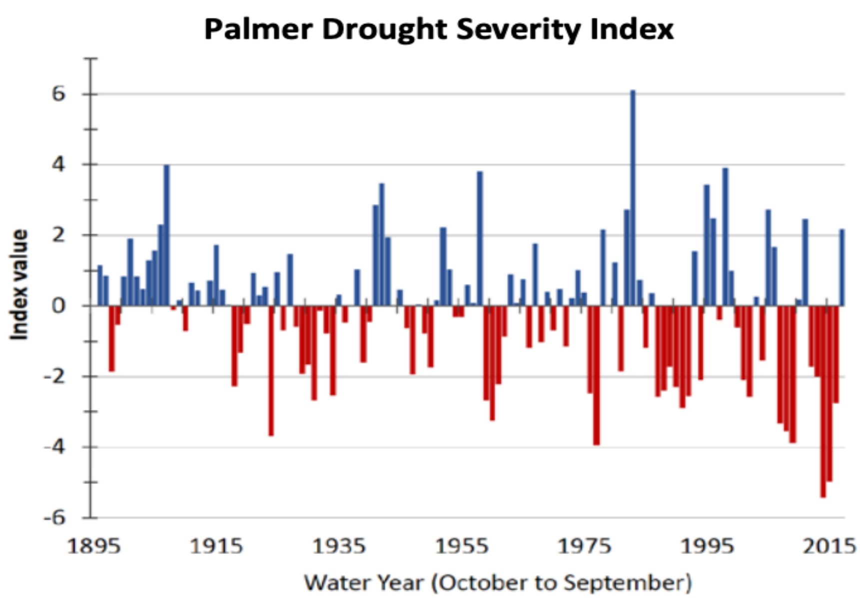

Figure 1-5. Increasing drought severity for California through the 20th century as indicated by the monthly Palmer Drought Severity Index (y-axis), a standard index that ranges between -10 (dry) and +10 (wet) using temperature and precipitation data in a water balance model. Trends show that California has become increasingly prone to drought, amplified by rising temperatures. Between 2007 and 2016, five of the eight years were categorized as "extreme" (below -3) with unprecedented drought in 2014-15 with no equivalent since instrumental recording in 1895 (Office of Environmental Health Hazard Assessment, 2018).

Across a range of emissions scenarios, projections of California's average precipitation change little through 2100, only +/- 10%, (Dettinger, 2011; Swain et al., 2018) but today's 'normal' storm becomes less likely to occur (Yoon et al., 2015). Simulations and ensembles share consistent projections of increased frequency of extremes in precipitation, either dry (up to two-fold increase) or wet (up to three-fold) (Swain et al., 2018; Yoon et al., 2015). Regional climate simulations project:

- *25-100% increase in occurrence of wet winters*, defined as 25-year recurrence interval cumulative winter precipitation, across California in high emissions scenarios (Swain et al., 2018);
- *daily extreme precipitation increase by 5-15%* in moderate emissions scenarios and up to 20% in high emissions scenarios (Pierce et al., 2018);
- *the frequency of what is now a 50-year recurrence interval 1-day storm to nearly double* in moderate emissions scenarios (AghaKouchak et al., 2018);
- *a 3-4 fold increase in the likelihood of what is now a 200-year recurrence interval 40-day storm (i.e. equivalent to atmospheric river duration and precipitation that occurred in 'The Great Flood of 1862')* in a large ensemble model given high emissions (RCP 8.5) scenario (Swain et al., 2018).

Models suggest that past drivers of major California floods, El Nino Southern Oscillation and atmospheric rivers, will strengthen and amplify over the next 85 years (Dettinger, 2011; Swain et al., 2018; Yoon et al., 2015). Models of medium-high emission scenarios through 2100 project an increase in the number of years and the season length when atmospheric rivers develop over California. With increases in water vapor and storm temperatures, "atmospheric river storms may increase beyond those that we have known historically (Dettinger, 2011)."

Increasing likelihood of extreme events beyond recorded history coincides with the end of service life for engineered channels. The District's aging flood infrastructure is increasingly likely to receive extreme runoff beyond designed capacity with potential to induce failure or lead to unanticipated flood hazards, increasing the urgency to expand the footprint of flood infrastructure. Attention to adaptive solutions can account for increasing extremes, uncertainty in emissions scenarios and projected flood risk. To date, hazard mitigation plans (Tetra Tech, 2018), flood models, and climate action plans (Contra Costa County, 2015) for the County acknowledge projections of increased precipitation variability and increased flood hazards, but proposed actions do not yet address opportunities to reduce risk with the next generation of flood infrastructure. Integration of planning efforts within the County can raise awareness of the Fifty-Year Plan and the opportunities to address multiple risks and emerging regulatory requirements with new investments along channel corridors.

Climate Change Worries Adults in Contra Costa

In contrast to surveys that reveal a modest level of concern for local floods (Section 1.2.1.2), survey data extrapolated from a national assessment (Howe et al., 2015) reveal that 70% (+/- 8% across the study) of adults in Contra Costa County are worried about global warming, almost 10% higher than the national average. Over three quarters of adults in the County believe that climate change will harm future generations. About half of adults believe they will be harmed personally.

When asked, "Who should do more?" county respondents selected corporations at 71% followed by citizens (69%), U.S. Congress (67%), and local officials (61%), and California's governor (57%) (Howe et al., 2015). Remarkably, a 2018 update to the study estimates that 76% of adults in Contra Costa County prioritize environmental protection over economic growth. The San Francisco Bay Area demonstrates the highest public support for this statement among all metro areas across the country (Howe et al., 2015; Marlon et al., 2018). The gap between concern for floods and concern for climate change represents an opportunity to build awareness and support for a new generation of adaptive, multi-functional approaches to flood infrastructure as restored watershed and ecosystem services (see Section 4, How?).

1.2.2 HEED THE LESSONS FROM PAST GENERATIONS OF FLOOD CONTROL

1.2.2.1 Single-purpose flood control infrastructure

For over 60 years, conventional flood and stormwater infrastructure has drained storm runoff away from flood-prone communities of Contra Costa County. The District has worked diligently to maintain and expand these inherited facilities as populations, hazards and exposure have grown. Today, the levees, concrete channels, and hydraulic controls of current flood infrastructure serve their damage-reduction purpose by containing and conveying all streamflow up to a specified design flow, typically the 100-year (or 1% annual probability) flood. By design, engineered channels contain flood flows up to a designated maximum (i.e. 1-2% annual likelihood) and rarely, if ever, overtop their banks. Over the past 60 years, floods have been constrained and controlled for the benefit of many, but not without unintended consequences for others.

Historically, prior to urbanization and flood infrastructure, self-formed stream channels overtopped their banks with much greater frequency, commonly once or twice every few years, spreading across floodplains, allowing fine sediment to drop from suspension as velocities slow, off-channel habitats inundate, and water infiltrates into the soil. Plants captured fine sediment and bits of organic carbon. These dynamics recharged aquifers, supplied fresh substrate and cycled nutrients for plant growth, filtered pollutants, and maintained habitat for fish and wildlife. The dynamics that influenced the evolution and adaptations of native species have been lost as riparian ecosystems were leveled for development and creeks were confined into conventional flood control infrastructure.

The extinction of Coho salmon within San Francisco Bay and the species' endangered status across central and northern coastal California reflects the degradation of riparian habitats within the multiple watersheds where they once thrived. Other endemic riparian species hang on, but require protection from multiple threats (e.g. see status of native fish in Walnut Creek's watershed in*Tables 2-1 and 2-3*). Since the post-war period when the past generation of flood control infrastructure allowed floodplain urbanization to encroach on channels with little regard for ecosystem impacts, changes in environmental law and water resource policy reflect lessons learned through periods of flood, drought, urban growth, land use and pollutant strain on fragmented, degraded and destroyed ecosystems. As we inventory loss and change to San Francisco Bay-Delta and its watersheds, we increasingly value wetland ecosystems and watershed processes for the services they provide (*Table 1-3*).

1.2.2.2 Limitations in design of conventional flood infrastructure

Conventional flood control structures have reduced floodplain inundation, serving their initial purpose to reduce human exposure to the disruption of damaging floods, but with unintended consequences. Rarely considered in cost-benefit assessments, constructed infrastructure degrades aquatic ecosystems, inhibits access to natural resources, and has a limited lifespan. Because of sedimentation, engineered flood control channels have been expensive to maintain. They are rigidly designed, with a narrow tolerance and lack of redundancy, giving rise to concerns about adaptability to the extremes and uncertainties of a changing climate.

- ***Geology, sedimentation and dredging maintenance not considered.***
  Steep, tectonically-active Coast Range basins of California's East Bay creep, slide and rupture (see *Atlas Map W-2*), delivering massive loads of sediment to lowland floodplains in wet years. Past designs for flood control structures in our region often failed to adequately consider seismicity and sediment transport. Once flood control facilities were constructed, their operations and maintenance were transferred to local flood control districts, who encountered decreased flood conveyance capacity from sedimentation over time. The need for repeated dredging of accumulated sediment has left local flood districts with a legacy of higher-than-expected maintenance costs to maintain flood protection levels – up to five times higher than original estimates (Pinto et al., 2018; Williams, 1990; Wong, 2014).

- ***Infrastructure performs within a narrow range of climatic variability.***
  California has predictable wet versus dry seasons but also high interannual variability in precipitation. Extreme floods (i.e. beyond the typical maximum capacity of flood infrastructure) while rare, do occur (*Figure 1-6*). Conventional flood control channels are built to convey water up to a single design flow, usually a 50-to-100-year recurrence interval as determined from historical flow records. Beyond this maximum limit, no protection is provided and risks are not well understood (or communicated) despite the substantial exposure from flood peaks beyond conveyance capacity.

  With climate change, variability in precipitation will increase beyond the observed historical range. Due to climate, geology, and urbanization, residents of Contra Costa County are exposed to multiple hazards such as earthquakes co-occurring with large floods, large floods causing landslides or bridge failure, release of toxic material into air or water with flood impacts in industrialized lowlands, or floods and mudslides occurring after drought and wildfire. The residual risk from compound hazards include disruption of critical services, dangerous levels of contaminants or pathogens in floodwater, or the sudden release of deep and life-threatening flows. These residual risks have only recently received consideration in County hazard planning (Tetra Tech, 2018). New investments in durable infrastructure can incorporate advances in multi-hazard prediction, risk management and engineering practice to reduce exposure to compound hazards and address residual risk (Zscheischler et al., 2018).

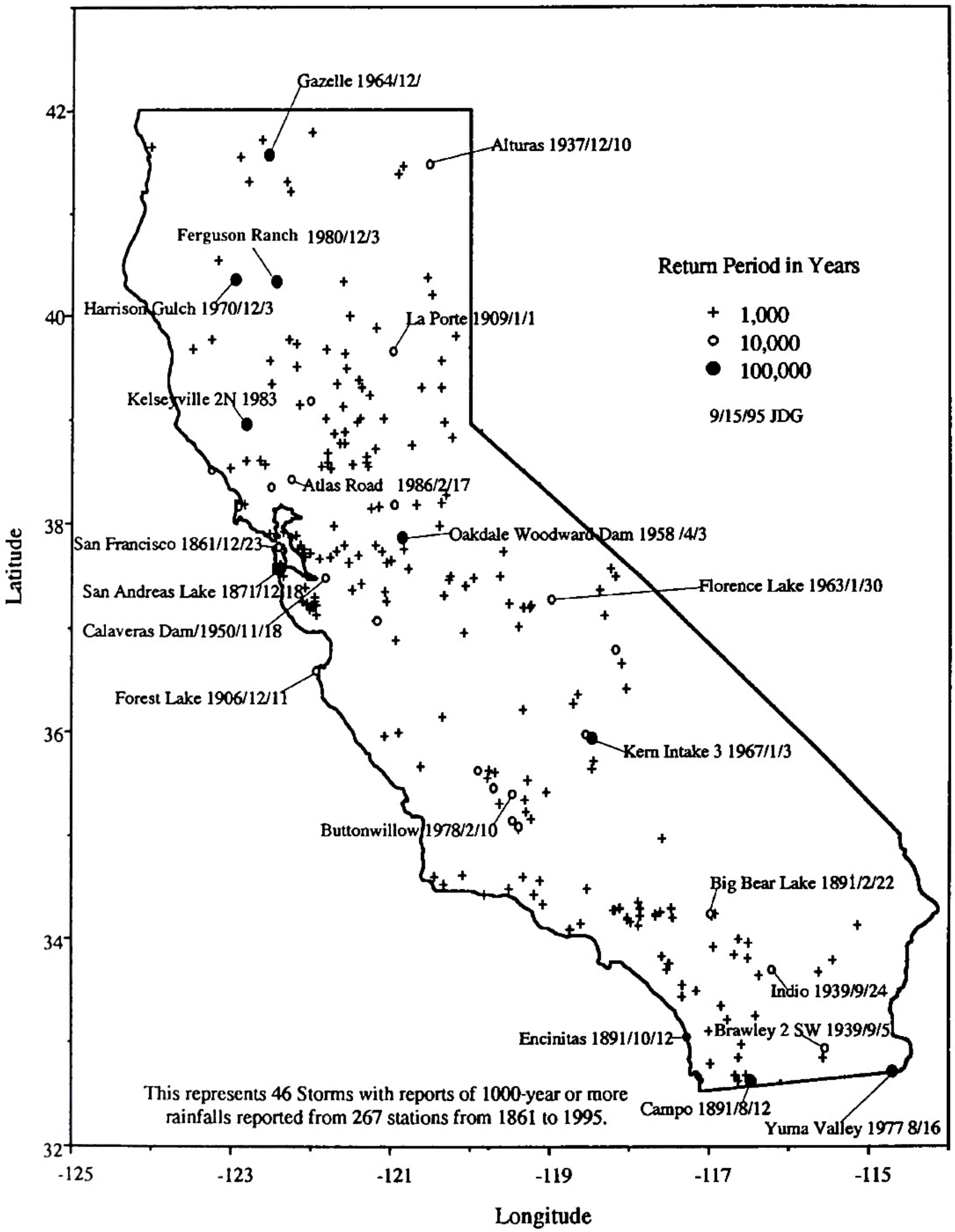

Figure 1-6 Rainfall records of 1000-year or greater recurrence intervals storms in California from 267 stations between 1861-1995 (California Department of Water Resources, 1997).

- ***Rigid design limits opportunities for adaptation to changing conditions.***
  Conventionally engineered flood infrastructure must maintain the precise, ideal flow conditions embedded in hydraulic engineering assumptions. The unexpected malfunction of just one component can lead to unpredictable, catastrophic failures – as witnessed during intense Bay Area storms when flows flanked and damaged structures (e.g. San Ramon Creek in 1995 as discussed in Avalon 2014) or when unaccounted-for sediment loads reduced channel conveyance capacity, overtopping channel banks unexpectedly (e.g. Corte Madera Creek in 1982 as discussed in Williams, 1990; Williams and Swanson, 1989).

  Existing water infrastructure and floodplain development were not designed to accommodate the hazards of climate change: changing extremes in precipitation and the associated risks of drought, wildfire, and landslides (Cannon and DeGraff, 2009). As the potential for property damage and social disruption increases across a range of hazards, risk management approaches that allow or engage a broad range of dynamic natural processes with reduced exposure can improve social adaptive capacity over hardened infrastructure suited to a limited range of conditions (Jones et al., 2012; Pahl-Wostl, 2007; Wobus et al., 2019). Investment in a new generation of flood infrastructure can reduce risk by incorporating flexibility and adaptability into design paradigms.

- ***Flood infrastructure contributed to loss of freshwater wetlands and riparian ecosystems.***
  Less than 15% of the world's natural wetlands remain intact as viable ecosystems (Davidson 2014). Wetlands include coastal marshes, inland floodplains, and seasonally inundated riparian forests. Wetland ecosystems buffer floods, increase residence time of flows, improve the quality of storm runoff (e.g., through inducing deposition of fine sediment or promoting nutrient cycling), and provide highly productive habitat. Despite the long-term value of wetland ecosystem services to humans, pro-development policies encouraged draining and filling of the world's wetlands, a process that accelerated after World War II.

  Through draining and filling land for agriculture, housing, industry, and infrastructure, California lost 90% of its wetlands, a greater portion than any other state (Dahl, 1990; Katibah, 1984). A global assessment of the resources, services and market value provided by wetlands found that the total economic value of a conserved, functional wetland ecosystem is greater than the value of the same land area in a conventional development development (Millennium Ecosystem Assessment, 2005).

  The wetlands that remain are commonly degraded by land use changes. Urban drainage patterns, constrained and culverted channels, and dammed reservoirs introduce new hydrologic and sediment regimes, disrupt hydrologic connectivity, and fragment habitat (Tockner and Stanford, 2002). As we discuss in Section 2 "What?", these human impacts threaten remaining wetlands and limit the potential for restoration of riparian habitat and wetland ecosystems.

- ***Disruption of people's connection to Nature and each other***
  Conventional engineered flood infrastructure provides an important service by reducing the magnitude and frequency of flooding, meeting essential human needs for safety and reliability. At the same time, engineered infrastructure often separates society from the dynamics and variability of climate, landscape and nature (Edwards, 2003). Not designed for public access, conventional flood infrastructure obscures public understanding and value of water in the landscape. This oversight represents a lost opportunity for a range of spontaneous, programmed, recreational, and educational uses of local waterways (Kondolf and Pinto, 2017; Kondolf and Yang, 2008). Without access to play, take a walk, or find solace within riparian corridors, people lose connection to the cycles of seasons, freshwater ecosystems, and nature more generally.

  As recent surveys (Metz, 2015; Tetra Tech, 2018) of local residents suggest, water and flood infrastructure becomes an invisible technological service. For most residents, channels remain empty, lifeless, fenced-off ditches crossed on a bridge in your car – an eye-sore, no man's land, a weedy ditch littered with garbage, forgotten, abandoned, dangerous. Devoid of public activity, drainage infrastructure invites illegal dumping, pollution, and encampments (Contra Costa County, 2019a; Richards, 2018). Without amenity, activity or visible means of ingress or egress, people feel not only unwelcome, but unsafe. Barbed wire and prominent warning signs remind people that hardened channels pose a hazard within neighborhoods. Current educational programs about local creeks center on the danger of flood control channels (Contra Costa County, 2019b). In meetings and decision-making about land use and development plans, citizens report that they remain unaware of, and thus uninspired by the potential for restoration.

- ***Fragmented water management reduces opportunities for conservation and adaptation***
  Safeguarding human investment with reliable, potable water and reduced flood risk was the primary goal for waterway management through most of the 20th century in California (Gleick, 1998). Early settlements relied on local water sources, but by the 1930s, East Bay Municipal Utility District (EBMUD) had dammed the distant Mokelumne River to supply the region, breaking the former local connection between the city and its water supply. In a parallel process, flooding of expanding, low-lying suburbs initiated the formation of the Contra Costa County Flood Control District. The District worked with federal partners, the Soil Conservation Service and the U.S. Army Corps of Engineers, to design and build flood infrastructure. Once constructed by federal partners, the infrastructure was turned over to the District for operation and maintenance (Pinto et al., 2018).

  Since the District was formed, ecological degradation, unaccounted maintenance costs, climate change, drought, and continued greenhouse gas emissions have emerged as unresolved risks to urban coastal regions. Over time, the District expanded its mission to include water quality and conservation, including a "One Water" public messaging campaign. As the District and community explores future flood protection investments, calls for holistic and integrative approaches to water management and sustainable urban design reach beyond the fundamental need for clean water and flood protection (Lloyd et al 2002, Walsh et al 2005). For example, scientists, policymakers and health professionals recognize broad and specific health benefits of access to "nearby nature" within urban regions (see literature reviews in *Appendix F*). Despite calls for integration, the institutions and planning processes for water use, land use, transportation, and hazard management remain independent, often operating at different scales, jurisdictions, and funding levels.

- ***It's the Wrong Scale: Watersheds drive flow volume, channels convey it.***
  In early phases of development, the most expedient approach to protecting societal investments from flooding was to prevent channel overbank flow by increasing channel capacity. This solution ignored the root of the problem and also exacerbated it: simplifying, smoothing, culverting, and increasing channel capacities prevented floodplain inundation but concentrated in-channel flows with greater discharge, deeper flood stages, and faster velocities. This engineering feat did not override a fundamental driver of floods: rainfall and runoff across a watershed.

  As urbanization paves over soils, the loss of vegetation and introduction of impervious surfaces influences the water cycle. Vegetation intercepts raindrops, encourages infiltration through opened pore spaces in soils, and transpires water into the atmosphere, increasing humidity and cooling temperatures. Once vegetation is removed, surface runoff increases. Runoff flows *over* paved and built surfaces rather than *soak into* soils. For the common storm conditions that shape channel form, peak flows and erosive forces increase, and degradation of riparian ecosystems ensues.

  When considering flood protection, water conservation, and ecological restoration, planning must cross scales, starting with the fundamental unit of the watershed. Without mitigating urbanization's effect on flows of runoff and pollutants, restored stream channels often remain degraded due to increased peak flows, decreased retention time, poor water quality and simplified aquatic habitat. Cumulatively, the effects of watershed land use, urbanized drainage, and altered flows contribute to degraded conditions known as 'urban stream syndrome' (Walsh et al., 2005). If restoration investments seek to decrease flood risk and improve habitat for sensitive native aquatic species, the sources of concentrated runoff must be addressed at the watershed scale, not in the channel.

- ***Flood infrastructure has limited lifespan and imposes a recurrent cost to rebuild that has not been considered (or funded) by local community.***
  Due to limits of materials and a low tolerance for degradation, engineered flood control infrastructure has a limited lifespan, or 'service life' during which the infrastructure can be expected to provide trouble-free service, typically about 75 years (Avalon 2014). Fighting against forces of nature with fixed, narrow and smooth channel boundaries of engineered flood protection structures requires a massive capital investment with benefits largely conferred to floodplain landowners. The District estimates in-kind replacement of existing engineered flood infrastructure at $2.4 billion. To finance a recurrent, centennial rebuild of channels, communities of Contra Costa County would need to set aside $24 million per year or $24 per County resident annually. Split among the 40,000 *people* in the FEMA-designated "100-year" floodplain would amount to annual per capita contribution of $600

(with no accounting for flood insurance or damage recovery for unmitigated risk). Split among the roughly 10,000 *properties (not residents)* in the 100-year floodplain would amount to $2,500 per year per property owner. No financing scheme has been implemented and only a few decades remain before the end-of-life for a growing list of facilities.

- ***Construction of concrete flood infrastructure contributes to carbon emissions.*** The production of concrete represents a financial cost and a carbon emissions cost. As a rule of thumb, the production of one metric ton of Portland cement emits one ton of carbon dioxide into the atmosphere (Naik 2008). In a lifecycle assessment of high speed rail in California, for instance, greenhouse gas emissions for construction were estimated at 3200 t CO^2_e per km (Chang and Huang, 2015). Once built, the corrosion rate of concrete is expected to increase with rising concentrations of atmospheric carbon (Stewart et al., 2011). As the District weighs timelines and strategies for reconstruction or removal of concrete infrastructure, lifecycle assessments should consider embodied energy of materials, construction, and maintenance into the future.

1.2.3 PROVIDE MORE BENEFITS TO MORE PEOPLE

1.2.3.1 Multiple Functions of Creeks Corridors

Single purpose, conventionally engineered flood infrastructure invests capital and human resources in a fight against natural processes to reduce exposure to specific types of floodplain hazards. Outside of flood protection, hardened infrastructure offers no benefits to the community. To the contrary, it detracts from everyday quality of life. Off-limits infrastructure blocks access to natural resources and recreation opportunities (Keeler et al., 2019; Kondolf and Pinto, 2017). Humans can benefit from the services provided by functioning ecosystems, and from the opportunity to interact with a bit of 'wild' nature in the urban environment, an important aspect of the social connectivity of urban rivers and streams (*Table 1-3*).

Lessons learned from the past generation of infrastructure can inform innovation and investments for the next generation. At the same time, innovations must address challenges of the 21^{st} century: increasing density of human populations in urban areas, inequities in access to natural resources, global climate change, and human impacts on biodiversity.

The District's focus on restoring altered creek corridors rests on the premise that creeks do more than convey flood flows. The restoration of creek corridors can support and harness natural processes of vegetation, soil, water, sediment and life. These biophysical processes support vital functions to aquatic and terrestrial ecosystems within a watershed, as they have co-evolved over time. In turn, functioning ecosystems provide benefits and values to humans as 'ecosystem services'. The challenge is how to restore ecological functions while maintaining at least current levels of flood protection. In this report, we assume that with long-term and integrated planning, the County's watersheds, riparian corridors, and wetlands can be managed and maintained as a multi-faceted, shared public resource that provide ecosystem services, including safely conveying frequent floods through wider, natural stream corridors (Frank, 2012).

Table 1-3. Ecosystem Services of Natural Channels, Riparian Corridors and Floodplain Wetlands[2]

SERVICE TYPE	ECOSYSTEM SERVICES *from process and function*	HUMAN BENEFITS
PROVISIONING	**Fish and Wildlife**	• Source of food; sustain fisheries and ecosystem food webs.
	Vegetation Growth *primary production and carbon sequestration*	• Source of food, fiber, wood and carbon; supply for fuel, light construction, soil amendments, medicinal, ornamental and health products; seed supply • Source of organic matter; improves soil fertility and water retention • Mitigate greenhouse gas emissions, meet regulatory goals
	Water Supply and Storage	• Store and retain precipitation; provide source of cool, clean water during drought via groundwater recharge • Supply freshwater for multiple uses; sustain vegetation, fish, wildlife
SUPPORTING	**Biodiversity Conservation** *sustain populations*	• Create habitat to support species' lifecycles; sustain populations • Promote genetic resistance to pathogens, local phenotypes and life history strategies; support recovery capacity and adaptation to change
	Nutrient Cycling *biogeochemical exchange*	• Support flow and exchange of nutrients through a watershed • Avoids eutrophication, toxic algae outbreaks, and water treatment
	Connectivity	• Support migration, dispersal and lifecycle needs for native species • Improve walkability, bike infrastructure and reduce carbon emissions
REGULATING	**Self-Sustaining Channels** *natural flow, sediment regime*	• Self-regulating sediment transport builds habitat, reduces dredging • Self-defined channels have no channel reconstruction cost • Riparian plants stabilize banks, protect soils, trap sediment
	Flow Conveyance *watershed hydrology and overbank to floodplains*	• Attenuate and reduce peak flow; slow and detain flows • Reduce flood risk, increase awareness of flooding • Adapt to change, disturbance, extremes • Natural flow variability reduces pests and invasive species
	Climatic Controls *shade, evapotranspiration*	• Moderate air and water temperatures; mitigate greenhouse gases • Regulate air circulation, humidity and precipitation • Cool the air; adapt to climate change and urban heat island
	Groundwater Recharge *infiltration and vegetation*	• Water storage and filtration, supplies cold summer baseflow for fish • Vegetation aerates soils, encourages infiltration, and reduces runoff
	Water Filtration and Treatment	• Retention and filtration of nutrients; oxygenate water • Trapping and removal of pollutants; bioremediation via plant uptake
	Air Filtration *photosynthesis, uptake*	• Vegetation oxygenates the air, draws down carbon dioxide • Dispersal and uptake of pollutants improves air quality
	Pollination	• Habitat for pollinators, a benefit to food production
CULTURAL	**Recreation and Active Transport**	• Safe, off-road trails for biking, hiking, running, playing • In-stream fishing, swim or wade, kayak, canoe, paddle board, tube • Passive: picnics, wildlife observation, exploration, geo-caching • Integrate and connect "nearby nature", neighborhoods, destinations
	Education	• Encourage exploration, cognitive development, local knowledge • Outdoor classrooms and science labs, art and health programs • Community tours, wildlife-viewing, stewardship; social capital • Promote citizen-based science, data collection, monitoring
	Local Economy	• Outdoor tourism and trail networks, new retail services, green jobs • Park corridors can increase quality of life; efficient, active commutes • Increase desirability, business diversity, sales tax, property values
	Health and Well-Being	• Promote exercise, relaxation, refuge from technology and social pressures. Assuage trauma, grief. Form social support networks. • Increase access to clean air and water, relief from heat
	Aesthetics	• Opens vistas, visual contrast to urban forms, multi-sensory experiences • Opportunities to incorporate public art and programming • Strengthen sense of place, distinct local culture, landscape legibility
	Spirituality and Inspiration	• Preserve, restore, and create sacred and inspiring community spaces • Reconnect citizens to iconic wildlife, landscapes, experiences • Promote transformative experiences and free expression

[2] Adapted from (Brauman et al., 2007; Millennium Ecosystem Assessment, 2005; Naiman et al., 2010; Schindler et al., 2014; Steiger J. et al., 2005). Elaboration of points and citations available in *Appendix G*.

1.2.3.2 A Diverse Range of Public Benefits Serve People Beyond the Floodplain

A multi-functional riparian wetland ecosystem can manage floods within wider stream corridors, connect destinations via off-road trail networks, diversify recreational opportunities, and improve community aesthetics with natural spaces, cooler summer temperatures and cleaner air, and improved water quality. By integrating these services into the urban fabric, as appropriate to local conditions, neighborhoods can embrace creek corridors and develop an active, safe, and connected sense of place. The transformation of off-limits concrete channels to public creek corridors can open and connect the community to the health and recreational benefits of urban green space. Cascading benefits from this investment can include increased community desirability, business and educational opportunities, sales tax revenue and property values, and a strengthened sense of community identity (*Appendix F*, literature review of restoration benefits).

1.2.4 SERVE FUTURE GENERATIONS WITH ADAPTABLE INVESTMENTS

1.2.4.1 Change in Values over Time: Conflicting Laws and Policies

Laws and policies have changed over the 60 years since flood infrastructure was developed in the County. Environmental regulations no longer support conventional flood infrastructure. The Clean Water and Endangered Species Acts, along with state statutes, may preclude in-kind replacement of concrete channels due to regulated beneficial uses of streams and threats to native species. North-central California is unique in having both a Mediterranean climate and salmon populations (Deitch and Kondolf 2015). With increasing temperatures and extremes in precipitation and drought, threats to socially-significant species will increase, prompting regulation to restore, reconnect, and repopulate degraded freshwater habitat (Herbold et al., 2018).

1.2.4.2 Adapt to Emerging and Accelerating Social Pressures

Population Growth and Rising Cost of Living

Regional plans seek to accommodate population growth, but also maintain urban limit lines, ensure housing affordability, decrease greenhouse gas emissions, and maintain a strong economy (Mackenzie et al., 2017). To balance these goals, regional strategies seek to increase the density of people living and working along transit corridors. The delineation of "Priority Development Areas" across the San Francisco Bay Area focuses development in walkable, mixed-use zones around transit centers that can support daily life without frequent car trips. Within Contra Costa County, several Priority Development Areas lie along valley bottoms, in flood-prone areas (*Atlas Map W-3*) (Mackenzie et al., 2017).

The transformation of land use within Priority Development Areas poses both opportunities and potential threats. Without integrated planning and consideration of aging flood infrastructure, intensified development of floodplains will likely adds to long-term flood risk by increasing exposure of people and structural assets in the floodplain. With care and attention, communities may instead seek to embrace creek corridors as critical public amenities. Public greenways within widened riparian corridors can simultaneously set aside room for flooding and provide increasingly dense communities with nearby access to nature and connect people to destinations via active forms of transport (i.e. walking, biking) on safe and inviting trail networks. The development of affordable housing along public greenways may help avoid the displacement of marginalized communities that can arise with gentrification of amenity enriched neighborhoods. Trails and public open space provided by restored riparian corridors can further decrease cost of living in adjacent neighborhoods by offering recreation opportunities, low-cost transport, and health benefits. Addressing these social pressures can only be incorporated into plans for regional growth, floods, and ecological restoration if acknowledged by the community and addressed in goals and objectives of overlapping plans and projects. The dual stressors of population growth and high housing costs will pose challenges to setting aside land for riparian corridors in low-lying urban areas. Once established and functioning, the creek corridor would offer definite public benefits (*Table 1-3*), but quantifying the benefits versus costs remains a challenge.

Beyond Floods: Multiple Threats of Climate Change

Current summer temperatures average 85° F in Walnut Creek. By 2100, multi-model climate simulations across greenhouse gas emissions scenarios (low at 550 ppm CO_2, high at 970 ppm CO_2) project average temperature increases of 3° to 15° F across California (Cayan et al., 2008b; Hayhoe et al., 2004) and doubling of heatwave frequency and season length for Sacramento (Hayhoe et al., 2004). Heat-related mortality could increase by 2-4 times in Contra Costa County by 2090 (Sheridan et al., 2012), depending on emissions scenarios.

Strategies to address climate change include measures to reduce greenhouse gas emissions, increase carbon storage (e.g. in plants, soils and water bodies), and adapt to rising temperatures, prolonged drought, and changing flood risk.

Mitigation of Greenhouse Gas Emissions with Multi-Functional Flood Management

In recognition of threats of climate change on public health, flood hazards, and natural resources, the passage of California's Assembly Bill (AB) 32 of 2006 requires reduction of greenhouse gas emissions to 1990 levels by 2020 across the state, as regulated by the California Air Resources Board through a market-based system known as cap-and-trade. By 2016, emissions in the state met AB 32 targets for 2020 despite 3% growth in gross domestic product and a slight increase in emissions from transportation (California Air Resources Board, 2018). That same year, California's Senate Bill (SB) 32 set longer-term targets to reduce of greenhouse gas emissions to 40% of 1990 levels by 2030 (see *Table 1-4* for summary of state targets).

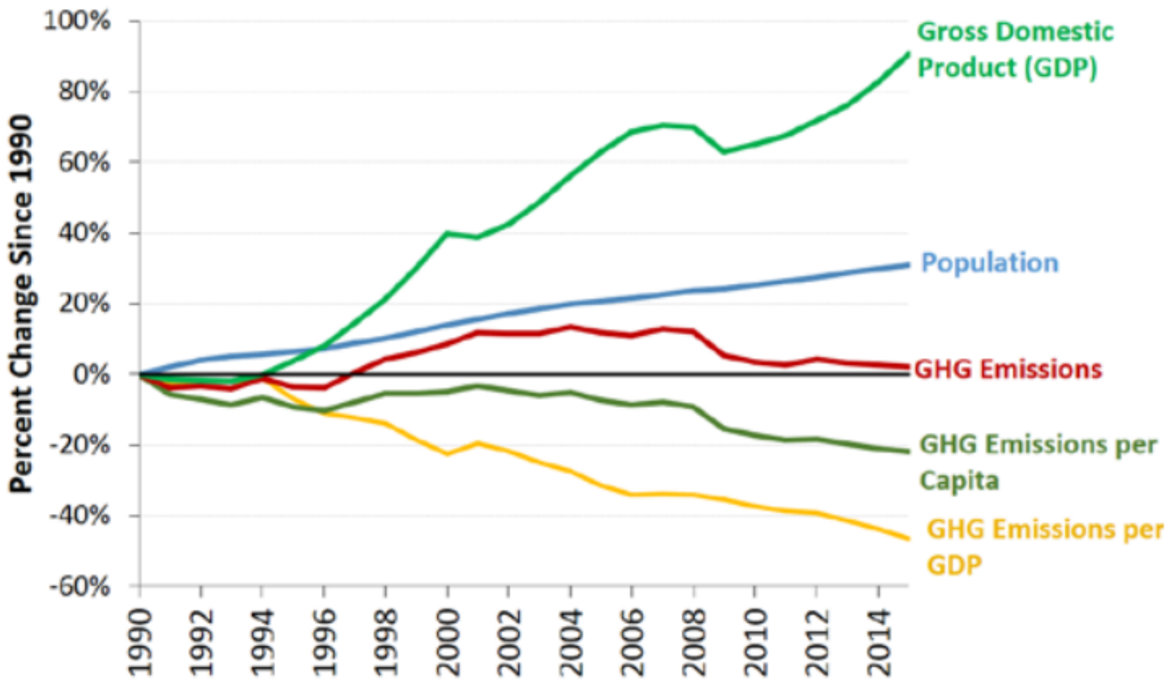

Figure 1-7 Trends in California compared to greenhouse gas (GHG) emissions (Office of Environmental Health Hazard Assessment, 2018). As population steadily rose, per capita GHG emissions decreased year-over-year since 2007. Gross Domestic Product has nearly doubled since 1994, but GHG emissions per GDP have declined by 50% in that same time. Overall, GHG emissions (in red) approach 1990 levels (AB 32 target for 2020), but SB 32 requires much deeper cuts to reach target of 50% below 1990 levels by 2035. Former Governor Brown's 2018 executive order (B-55-18) targets carbon neutrality by 2045.

Table 1-4. Carbon Dioxide Emissions Targets in California

CALIFORNIA LEGISLATION	EMISSIONS REDUCTION TARGET	EMISSIONS REDUCTION DEADLINE	STATUS[3]
ASSEMBLY BILL 32 (2006)	to 1990 levels	2020	2020 Target Met
SENATE BILL 32 (2016)	40% of 1990 levels 50% of 1990 levels 80% of 1990 levels	2030 2035 2050	Current strategies unable to meet targets
SENATE BILL 375 (2018) SFBAY TRANSPORTATION	10% of 2005 levels 19% of 2005 levels	2020 2035	Current strategies unable to meet 2035 targets
EXECUTIVE ORDER B-55-18	Carbon neutrality (net zero carbon emissions)	2045	(no known evaluations, bills introduced)

Transportation ranks as the largest source of greenhouse gas emissions in California (California Air Resources Board, 2019a; Escriva-Bou et al., 2018). In Contra Costa County, road and highway transportation contribute about half of the local, *non-industrial* greenhouse gas emissions (i.e. excluding refineries and power plants regulated by federal and state authorities) (Contra Costa County, 2015). Roughly 60% of Contra Costa County commuters drive to work alone, a pattern resulting from the county's sprawling land use that limits the potential for people to use

[3] (California Air Resources Board, 2018; Cameron et al., 2017)

alternative transport modes, such as walking and biking or even public transit, due to distances between destinations and the design of transport corridors (Mackenzie et al., 2017).

To support California's emission reduction goals, the Sustainable Communities and Climate Protection Act (SB 375) was introduced to regulate and coordinate transportation and land use strategies via regional targets (Boswell and Mason, 2018). The California Air Resources Board defines targets and approves transportation plans for the San Francisco Bay region.[4] For Contra Costa County and the District, the time horizon, and scope of these statewide emissions goals overlap with the Fifty-Year Plan.

Plans and strategies to meet the state's emissions targets focus on replacing fossil fuels with new sources of renewable energy, but also reducing energy use in ways that sequester carbon, improve air quality and public health, address inequities in disadvantaged communities, adapt to threats of climate change, and restore ecosystem function. To meet ambitious goals over the next decades, reductions in carbon emissions will increasingly emerge from strategic and systematic changes in land use and circulation. Communities have an opportunity to define how to implement these changes in ways that address local issues and achieve more benefits for the most people. As a promising start, Contra Costa County and several local municipalities (e.g. Concord, Walnut Creek, Lafayette) have developed their own climate action plans.

In Contra Costa County, around 90% of the total carbon dioxide emissions are generated from oil refineries and power plants (Contra Costa County, 2015). The Shell Oil refinery in Martinez is the second largest emitter in the state of California, and the Marathon refinery near Concord is the ninth largest (Contra Costa County, 2015). Due to the scale of these "stationary" contributions to global greenhouse gas emissions and regional air quality concerns, they are regulated by the California Air Resources Board through a "cap-and-trade" program designed to limit emissions and fund mitigation, especially in local communities affected by emission of industrial pollutants (California Air Resources Board, 2019b).

The County's Climate Action Plan does not target these dominant sources of stationary, industrial and regional-serving carbon emissions, but focuses on limiting local community contributions to atmospheric carbon through energy efficiency, water conservation, land use policy, tree planting, and shifts in transportation patterns (Contra Costa County 2015). Together, state and local strategies promise to meet the short-term target of limiting the County's greenhouse gas emissions to 1990 levels by 2020 (not counting the out-of-scope impacts of stationary, industrial contributions).

Relevant to the Fifty-Year Plan, longer-term strategies for reaching 2035 County emission goals fail to bridge the gap between state-supported reductions (13% below 1990 levels) and the SB 32 target (50% below 1990 levels). Local strategies related to the Fifty-Year Plan's watershed restoration efforts include reduced water use (by 20%), doubling the number of weekday bike trips (to 67,200) and planting 1,000 trees by 2035. These three specific proposals offer modest

[4] Transportation plans developed and adopted by Metropolitan Transportation Commission (MTC) and Association of Bay Area Governments (ABAG).

emissions reductions *of less than 0.5% of 1990 levels* (Contra Costa County 2015). The total proposed state and County strategies strategies only reach about halfway to 2035 targets. If projections hold true, they reduce emissions by just 22% of the 1990 baseline (not 50%), leaving an excess of 513,000 $MtCo^2{}_e$ released into the atmosphere (Contra Costa County, 2015, pp. 38 and 74). Since the County's Action Plan was published, former Governor Jerry Brown upped the ante with a 2018 executive order that pushed state targets to "carbon neutrality" or net-zero carbon emissions by 2045. Aggressive state targets beg the question: Can the Fifty-Year Plan help to neutralize emissions?

With focused planning, watershed green infrastructure that includes re-integration of multi-functional creek corridors through urbanized floodplains can help overcome the limitations of current land use patterns on County-wide greenhouse gas emissions by increasing tree cover and carbon capture, reducing runoff and conserving water, limiting the urban heat island effect and ameliorating threats of rising temperatures, reducing the use of concrete-intensive structures and need for periodic sediment removal, decreasing pressure to rebuild flood-damaged buildings, encouraging local recreation, and supporting non-carbon-emitting transportation options for residents and commuters. The County needs an integrated effort to account for potential impacts.

Managing Watersheds with Equitable Green Infrastructure. By 2045, the state of California aims to achieve carbon neutrality in ways that improve air quality, support low-income and disadvantaged communities, protect water and native wildlife. These measures serve a dual-purpose by also supporting California residents to adapt to climate change (Executive Order B-55-18). To achieve carbon neutrality, emissions of greenhouse gases must be offset by drawdown of carbon dioxide from the atmosphere, to be stored as organic carbon in vegetation, soils, and sediment (Ackerly et al., 2018a). Managing rangelands, forests and wetlands to store carbon is highlighted as one of six pillars in California's greenhouse gas reduction goals (California Air Resources Board, 2016). The people of Contra Costa County have an opportunity to help achieve that goal through conservation of undeveloped watershed land, integration of green infrastructure into urban areas (especially for under-served communities), and restoration of self-sustaining creeks, their forested riparian corridors, and floodplain wetlands as part of a public greenway network.

Increasing carbon storage. Trees and plants store carbon as biomass. Through photosynthesis, vegetation draws carbon dioxide out of the atmosphere and converts it to organic carbon, powered by sunshine. Remnant creeks and floodplains support dense riparian forests and wetlands, which sequester carbon (Matzek et al., 2015). As plants shed leaves and die, much of their biomass incorporates into soils (D'Elia et al., 2017), a dominant store of the Earth's land-based carbon. As a connected system, rivers capture organic carbon from plants, sediments and solutes (i.e. dissolved forms in water), and eventually deposit carbon in wetlands, deltas, and the ocean floor where it can be stored for millennia. Where floodplains have been drained and converted to urban land uses, the result is a loss in carbon storage (Pendleton et al., 2012). Land conservation, urban forests, and wetland restoration can contribute to reductions targets, but have not been integrated into increasingly aggressive state emissions targets and local climate action plans (Cameron et al., 2017). Given the county's gap in carbon offset targets and potential for funding restoration through California's carbon emissions policies, the potential carbon storage of restored channels and floodplains within Walnut Creek should be quantified, though calculations remained out of scope for this report.

Promoting biking and walking. The expansion of bicycle and pedestrian trail networks along shaded, off-street, forested paths within creek corridors presents an opportunity to promote safe, low-carbon transport that can help break barriers for people who do not currently own or ride a bike due to concerns about safety and comfort. Over the long-term, dramatic improvements to bicycle and pedestrian infrastructure and facilities, as part of a net-zero-emissions overhaul of the built environment, provide many co-benefits related to public health and equitable access to resources. Strategies to promote a diversity of low-cost, active transport options, when presented to County residents, garnered "extremely high public support" (Contra Costa County 2015, p. A-22). Pursuing multi-benefit restoration of creek corridors over the next decades can spur the changes in land use and circulation needed to achieve local emission reduction targets in ways that benefit future generations within the community and beyond.

Climate Adaptation: Overlapping Benefits of the Fifty-Year Plan

Rising Temperatures and Heat Stress. Widened creek corridors that make room for floods can also support the shade and humidity of riparian forests, recharge floodplain aquifers, connect groundwater and soil moisture to the atmosphere, and thereby moderate local temperatures. Dense riparian forests act as natural air-conditioners as they maintain cool air pools along valley bottoms, providing shade and emanating water vapor. In urban areas, vegetated parks can mitigate the heat island effect and cool air temperature up to 22° F (Bowler et al., 2010; Feyisa et al., 2014; Jenerette et al., 2011; Tan et al., 2016) with effects reaching 250-1000 feet into urban areas (Feyisa et al., 2014; Lin et al., 2015). Streamflow itself can cool urban air by several degrees depending on temperature and humidity gradients (Hathway and Sharples, 2012). In Walnut Creek, summer baseflows are limited, but moist sediments are sealed beneath cement, blocking potential for vegetation growth and evapotranspiration. More than nice-to-have amenities, restored creek corridors can connect communities (and wildlife) to cool, safe public spaces that offer relief and refuge from threats of extreme, prolonged heat. To influence policy, the potential for local benefits should be quantified.

Mitigating Drought and Threats to Water Supply. In anticipation of increased but uncertain variability and extremes in precipitation frequency and intensity, a diverse and broad range of strategies can improve the County's adaptive capacity to withstand disruptions to freshwater supply and intensified flooding (Cloern et al., 2011; Hayhoe et al., 2004; Yoon et al., 2015). Today, Contra Costa Water District (CCWD) supplies water to much of central and eastern Contra Costa County, while East Bay Municipal Utility District (EBMUD) serves the south and western portion of the county. The 500,000 residents served by CCWD receive water from the Sacramento-San Joaquin Delta; those served by EBMUD receive water from the Mokelumne River watershed in the Sierra Nevada Mountains. While the Delta and Mokelumne River have provided reliable drinking water, the reliability has come at the cost of flow for rivers and fish. Moreover, these resources may not continue to provide reliable water as sea level rise, salinity, drought, and reduced snowpack increasingly affect the Delta and Sierra Nevada headwaters.

Local groundwater is not a major source of the County's current water supply, but it has potential to serve as a buffer against drought-induced supply limits where groundwater basins remain uncontaminated. Improvements to groundwater storage and management are widely recognized as a low-cost and robust "no-regrets" approach to climate adaptation in California (Bedsworth and Hanak 2010). Recognizing this potential, the state is investigating further institutional, regulatory, and legal means to promote aquifer recharge and increase groundwater storage as a promising adaptation strategy to bolster water supplies (Bedsworth et al. 2018). Given the projections of more severe and prolonged droughts, what appears forward-thinking today may soon become the regulated norm.

Across the state, the Sustainable Groundwater Management Act (SGMA) mandates that high and medium priority groundwater basins form Groundwater Sustainability Agencies (GSAs) and develop Groundwater Sustainability Plans (GSPs) to address groundwater overdraft and plan for sustainable groundwater use. No high or medium priority groundwater basins have been designated in Contra Costa County. Similarly, the Municipal Regional Stormwater Permit (MRP) 2.0 does not currently require jurisdictions' Green Infrastructure Plans to address groundwater recharge.

The county's holistic 'One Water' framework and the long-term planing horizon of the Fifty-Year Plan, however, align with the future direction of SGMA and GSPs. A forward-thinking GSP would determine existing groundwater storage, safe groundwater withdrawal rates and volumes, and agreement for who can use the groundwater (Contra Costa 2015-2016 Grand Jury Report 1602). As part of green infrastructure plans, cities and counties often identify opportunities to restore floodable areas and employ distributed infiltration facilities (e.g. deep infiltration wells for stormwater mitigation in Portland, discussed in *Appendix C*4) to reduce flooding in frequent storms, filter pollutants, and promote groundwater recharge. Infiltration can be targeted in coarse, permeable alluvial soils of alluvial fans and historical losing (influent) stream reaches. For example, analysis of infiltration opportunity areas in Walnut Creek shows that 23% of the watershed is underlain by permeable soils or coarse subsurface alluvium (e.g. fans that cross North Calavaras Fault and its extensions) outside hazard zones, creating opportuinties for shallow or deep infiltration (in *Atlas Map W-5*, explained in *Section 3.5.2* and *Appendix A3*).

Even if groundwater recharged for urban areas is not suited as potable water, it may still play an important role in irrigation (and thus offsetting imports of water supply) and cool summer baseflow for fish, macroinvertebrates and riparian species. Given the threats of drought and sea level rise to reliable freshwater supply over the next fifty years, we recommend that potential benefits of groundwater recharge be investigated and quantified so they can be incorporated into planning and policy appropriately.

Adaptation to Increased Peak Flows. By moving investments out of a widened flood corridor, creeks and floodplains can convey floods with less threats to infrastructure, less danger for people and reduced stress on natural resources. As opposed to deep and fast flows within rigid, narrow and constrained channels, wider natural channels and floodplains promote slower and shallower flows, but over larger areas. Making room for floods requires moving structures and buying properties, a non-trivial task with complex considerations for local communities, but this approach has achieved multiple benefits for pioneering cities in California, has been promoted by state and federal programs across urban flood-prone regions of the U.S., and has become a best practice in flood management across the globe (see *Appendix E* for precedent studies). Making room for floods can increase a community's capacity to adapt to a wider range of climatic extremes and watershed conditions, while also integrating natural areas into cities, supporting recovery of lost habitat, promoting a regional outdoor recreation economy, and providing an array of ecosystem services that support public health and community life.

To adapt to predicted increase in precipitation extremes, wider floodplain corridors may accommodate higher flows with less risk if creek corridors can be re-imagined with:

- ***A widened footprint*** which will likely require willing buyer programs to acquire properties in targeted reaches and bypass channels integrated into public right-of-ways;
- ***Reduced reliance on the performance of individual structural components*** where a single failure or threshold-exceedance can lead to unpredictable, cascading failures;
- ***Expanded range of flow capacities*** (i.e. beyond 100-year flood) without threat to lives;
- ***Self-maintenance of deposition and scour*** without need for regular dredging to ensure flood protection or the periodic reconstruction of expensive flood infrastructure;
- ***Increased awareness*** of creeks, flood benefits and hazards, and the need for preparation, disaster planning, and reduced exposure by staying out of harm's way.

1.3 WHY FIFTY YEARS?

The Fifty-Year Plan seeks to address aging infrastructure, rising flood risk, innovations in flood management, emerging threats and community concerns. Billions of dollars are at stake. Complexity confounds the engineering, science, politics, and management of on-the-ground change across multiple jurisdictions, land uses, institutions, and individual properties. The fifty-year planning horizon acknowledges these risks, challenges, uncertainties. The extensive time scale opens an opportunity for local residents, businesses, politicians and institutions to re-imagine creek corridors, floodplains, and watersheds as vital, multi-functional community resources. The long time horizon allows communities to look beyond the constraints that lock-in the status quo of single-purpose, rigid flood infrastructure.

In its call for long-range planning, the District recognizes that the response to aging infrastructure cannot rely on a series of reactive, emergency fixes. Such a short-sighted approach would increase the risks of unexpected, unpredictable, catastrophic flooding by leaving the failure of infrastructure components to chance. Waiting until disaster strikes would be a wake-up call for the community, a way to raise community awareness of the risks of aging infrastructure and the rising likelihood of extreme storms. Catastrophic damage would open pathways for quick permitting and disaster-recovery funding to replace infrastructure components while bypassing costly regulatory oversight and community deliberation. In these ways, reactive planning is incentivized. Without foresight, disaster recovery policies can further engrain the status quo by failing to confront the unmitigated risk of legacy infrastructure that no longer aligns with policies, regulations, stakeholder values, watershed conditions, and the unexpected instability of Earth's climate. Instead, proactive planning can carefully consider post-disaster response in light of

District and community goals for flood management, watershed green infrastructure, and riparian corridor restoration. With upfront planning investments, post-disaster funding can instead help implement critical, vetted restoration strategies.

Long-standing public infrastructure supports economic stability, but can also lock in the status quo and "create inertia to change (Unruh, 2002, p. 318)." As durable infrastructure (e.g. energy grids or transportation networks) co-evolves with society and governing institutions, any maladaptive policies and investments (e.g. carbon emissions) that are enabled by that infrastructure can bind communities to problematic consequences (Unruh, 2002). In the case of aging flood infrastructure, the channelized creeks and current land use our bound to each other. Flood infrastructure created conditions to support floodplain development and now floodplain development, built up to the channel edge, precludes change to flood infrastructure. With a fifty-year timeframe, the District can help unlock communities from past decisions by calling for a community reconciliation of flood protection, water conservation, and ecosystem services.

Past decisions (land use, channel alteration, economic growth, and resource stewardship) and emerging threats (climate change, resource distribution, affordable housing, compound hazards, or ecosystem collapse) can be integrated into a democratic planning process. Reframing problems, defining goals, exploring uncertainty, deliberating trade-offs, modeling scenarios, and testing a range of solutions will take time, partnerships, and collaboration. Citizens may have concerns, memories, knowledge, courage, and resolve to protect California's aquatic ecosystems, but at present, most residents remain unaware of the opportunities presented by the Fifty-Year Plan. As multiple pressures influence land use decisions-making in the region, planners expect infill development of floodplains to accelerate. The lack of public awareness about the Fifty-Year Plan, and the opportunities it presents, threatens to stymie land use change that supports flood safety, water conservation, and ecosystem services as well as housing affordability and climate change policy.

Local communities may have decades to take action to address aging infrastructure, but in the meantime, parcels in the floodplain are bought, sold, and further developed under the assumption of continued flood protection. As land values rise, urgent action to address regional affordability with increased housing supply may overwhelm nascent efforts to open space for flooding, groundwater recharge, and habitat. California's climate change legislation adds pressure to intensify development in the low-lying transit corridors that overlap with historical riparian floodplains. With some degree of restoration, these same corridors can again support legally protected aquatic species. Conversely, efforts to re-integrate nature into urbanized areas can appear to serve goals for public health and long-term sustainability but lead to displacement of marginalized communities (Bryson, 2013; Checker, 2011; Dooling, 2009; Wolch et al., 2014).

Communities need time to determine goals and requirements for the next generation of flood management, but further investment in intensified, durable development can limit opportunities before integrative planning can begin. Despite the remaining decades of service-life for flood infrastructure and the uncertainty of what lies ahead, waiting to take action may not be the most conservative option for the District. Instead, "no regrets" strategies to make room for restored creeks can reduce rising flood risk and buffer impacts of intensified urbanization on storm runoff, water quality, threatened species, and even public health. By promoting awareness of land use trade-offs in the near term, communities can have the foresight to deliberate strategies for meeting complex goals prior to instituting difficult-to-reverse land use policy.

1.3.1 NEED FOR COMMUNITY-BASED, INTEGRATED AND ADAPTIVE PLANNING

The challenges and constraints presented by current watershed land use calls for community participation, creative collaborations, and adaptive management of watersheds. As seen in other restoration contexts, direct engagement of stakeholders and citizens through a participatory planning process helps formulate community-driven goals, consider local context, address diverse needs, and develop the trust and coalitions needed to transform infrastructure paradigms and resource use throughout the watershed (Golet et al., 2006). To fund projects, the District recognizes that local communities must not only support restoration initiatives, but also advocate for them through outreach to state and federal agencies and representatives (Pinto et al., 2018). This level of commitment takes not only engagement, but a sense of ownership in the process and outcomes, as seen across precedent studies (*Appendix E*).

An adaptive approach to planning and management addresses risk and uncertainty through systematic learning where goals and interventions are expressed as hypotheses and experiments, allowing evaluative criteria and monitored results to inform either iterative adjustments or novel approaches (Doremus et al., 2011; Pahl-Wostl, 2007). Modeling tools that investigate a range of management strategies across hydrologic, social and ecological variables can help quantify and weigh risks, costs and benefits to inform on-the-ground investments (Ciullo et al., 2017; Levy, 2005). At the same time, participatory (or bottom-up) approaches to assessment, planning, implementation, and monitoring can develop and refine objectives, evaluate and interpret plans and models, adjust the scope and priorities of restoration planning and risk management in ways that overcome limitations of top-down, technical approaches to "management as control" (Knighton et al., 2018; Pahl-Wostl, 2007). The fifty-year planning timeframe recognizes this opportunity for collaborative, polycentric (i.e. top-down, bottom-up, interdisciplinary) approaches to adaptive planning and management of risk and public resources.

1.3.2 ADDRESS RISKS, CHALLENGES, AND UNCERTAINTY

Communicating the risks, challenges, and uncertainties of planning alternatives can help communities raise unacknowledged concerns, steer priorities, balance trade-offs, and weigh costs versus benefits to initiate the most certain opportunities and no-regrets strategies for restoration of multi-functional creek corridors. *Table 1-5* presents an overview of potential risks, uncertainty, and challenges associated with alternative approaches to floodplain management.

Regulatory structures often fail to sufficiently characterize, quantify, and communicate risks of floods, water security, and climate change. Tools to assess risk across scenarios of land use transformation in urban watersheds may not adequately address uncertainty, leaving institutions charged with reducing risk to rely on *principles* of adaptation, inclusion, and innovation in their planning, policy, investments, and management (Renn et al., 2011). Institutions committed to reduce risk and ensure water security often resist innovation (i.e. the creation of new standards, approaches, and guidelines) without proof of performance or a legislative mandate. Without organizational support for in-house strategic planning and collaborations between institutions, this innovation trap becomes a secondary risk and challenge (Kiparsky et al., 2013; Roy et al., 2008).

Following the "precautionary principle" through preventative action and avoidance of hazards remains a pragmatic, common-sense approach to mitigating uncertainty (Cutter, 2003; Kriebel et al., 2001), but urbanized floodplains preclude precaution (i.e. staying out of harm's way) without major land use transformation. Modeling a range of scenarios, including worst-case scenarios and fail-safe design, can help raise awareness, inform decision-making (Quay, 2010) and minimize catastrophic surprises (Merz et al., 2010). We discuss planning principles, strategies, and tools to address risk and uncertainty further in Section 4, "How?"

Table 1-5. Risks and Challenges of Structural Flood Control Replacement and Creek Corridor Restoration

	IN-KIND REPLACEMENT OF STRUCTURAL FLOOD CONTROL	MULTI-FUNCTIONAL CREEK CORRIDORS
RISKS	• Minimal community benefit; creeks do not meet beneficial use requirements • Continued habitat and ecosystem degradation • Species extinction; lost opportunity to expand and restore habitat • Inflexibility of flood control channels; limited community tolerance of extreme heat, drought, and flood of climate change • Lack of agency and public support for replacement; delay and squandered response time to address the growing risk of infrastructure failure. • Abrupt, catastrophic failure • Litigation • Loss of trust in governance • Infill development directed to floodplain-based transit centers, putting more people and investment at risk. • Lack of funding for replacement and no plan to address long-term costs of recurrent replacement.	• Delayed action leads to lost opportunity to conserve most strategic parcels for restoration or prevent further high-risk development within floodplains. • Conflicts between stakeholders lead to deadlock, lasting divisions, a piecemeal approach, or lost opportunities • Insufficient planning and fragmented decision-making prevents effective action, misses opportunities for integrated and sustainable solutions (Beechie et al., 2012). • Stakeholders left out of the planning process; inequities may be exacerbated despite good intentions; solutions seen as unjust. • Channels restored but watershed constraints not addressed, leading to unmet expectations. • Institutions supporting infrastructure with a long design life may not have capacity for in-house strategic planning; out-sourcing can dampen innovation "by perpetuating established technologies (Kiparsky et al 2013)." • Ecosystem services and benefits of non-structural approaches undervalued (i.e. defy monetization) or unexpectedly maladaptive, leading to higher than expected social costs over long term (Jones et al., 2012) • Lack of funding and support to implement, maintain, and monitor restoration • Lack of regulatory drivers allows economic pressures to override community consensus. • Undersized and disconnected corridors lead to flooding, erosion, property damage, and unmet habitat needs • Additional maintenance required to manage debris and sediment • Climate change acceleration follows worst-case scenarios with unprecedented extremes in precipitation and temperature, reducing viability of habitat, vegetation and wildlife despite restoration
UNCERTAINTIES	• Long term effect of channels on ecosystem and species at regional scales • Effect of intensified and expanded urbanization on peak flows and sediment loads	• Effect of highly urbanized areas on downstream hydrology, geomorphology, ecology • Degree of restoration required to provide ecological benefit

	IN-KIND REPLACEMENT OF STRUCTURAL FLOOD CONTROL	MULTI-FUNCTIONAL CREEK CORRIDORS
	• Effect of climate change and increased precipitation intensity on rigid channel infrastructure • Permitting, likely not possible except for emergency repairs • Negative consequences of structural flood control on the environment and public health; unaccounted costs to society (Gómez-Baggethun et al., 2013).	• Ability of watershed green infrastructure approaches to manage and treat stormwater prior to entering restored stream channel • Impacts of climate change on flood hazards, water management, and land use • Time and cost of permitting process • Value of ecosystem services and their benefits, especially when they are indirect, not marketable, and difficult to quantify in conventional economic terms (Gómez-Baggethun et al., 2013)
CHALLENGES	• High cost to many with limited benefit to specific group of stakeholders • Require perpetual maintenance and recurrent replacement • Narrow, smooth, hardened channels and parcel encroachment leave few alternatives (i.e. anything other than concrete) or even minor enhancements without land use change.	• Restored channels require larger width than concrete channels • Current land uses limit land available for restoring channels and watershed process • Restoration objectives and strategies must be negotiated, not able to return to historical conditions • Jurisdictional boundaries make watershed-scale planning and land use change difficult; process-based restoration requires integrated strategies across multiple scales and institutional sectors. • Potential for conflicting interests between private property owners, municipalities, and regulators • Complexity of both flood control facilities and natural systems • Watershed-wide restoration requires strategic planning, sustained political leadership, a unified vision, and negotiated objectives. • Results derived from connecting multiple projects over many years, measurable benefits of ecosystem services may not accrue for many decades. • Monitoring often unfunded and not sufficiently robust to inform strategic decision or incremental change.

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2 WHAT? A Restoration Vision for Walnut Creek Watershed

2.1 WHAT IS WALNUT CREEK WATERSHED'S POTENTIAL?

In the Fifty-Year Plan, the District invites communities to imagine local creeks as more than a series of pipes, ditches, dams, and drop structures. The plan turns the expensive and dangerous problem of aging flood control infrastructure into an *opportunity*. It asks: can local creeks do more for more people? Given threats of extreme flood and drought, depleted fisheries and species extinction, pollution and disease, what can restoration achieve? Can it support local water supply, improve air and water quality, revive freshwater ecosystems, and improve health and habitat for people and wildlife? Given the limited lifespan and recurrent cost of structural approaches to flood management, can the watershed's conveyance system – the valleys, floodplains, and channels that distribute flows – be self-sustaining for future generations?

Over the past sixty years, the County's engineered flood infrastructure has served its singular purpose, but to the detriment of other stream functions. When not constrained, stream channels self-form and sustain themselves as water converges, storm after storm, flowing from ridgetops to the Bay, eroding and depositing sediment. Unarmored creek banks and beds continually adjust to flow dynamics, exchanging and sorting sediment in response to both watershed and local conditions, setting the stage for riparian-adapted species to cycle through their life stages. These biophysical processes inform the structure and function of riparian ecosystems as a dynamic, self-sustaining expression of a watershed's geologic formation, climate and land cover.

In contrast, engineered channels have a static form and limited lifespan. Concrete channels must be rebuilt every 60-100 years. Their rigid engineered form and function assume stable watershed and climatic conditions. Their impacts on ecosystem function propagate upstream and downstream. Although the Fifty-Year Plan proposes the replacement of channelized flood infrastructure with restored stream channels, it is impossible to separate a channel from its watershed. The creeks we seek to restore are not separate from the ridges, hills, highways, wetlands, homes and floodplains they drain. Given the extent of urbanization and modification of runoff processes in the District's watersheds, restoring the footprint of historical stream conditions would lead to inundated floodplains and intolerable economic cost. Without attention to watershed stressors, symptoms of 'urban stream syndrome' would prevail as habitat simplifies, limited by pollutants and urban drainage conditions (Walsh et al., 2005).

This chapter outlines the opportunities and constraints of restoring Walnut Creek's *watershed*. *To restore self-sustaining aquatic ecosystems, creek restoration must be tied to watershed restoration*.

2.1.1 SYNERGIES OF SOCIAL AND ECOLOGICAL POTENTIAL

This report aims to characterize the opportunities and constraints of creek restoration in terms of a watershed's social *and* ecological potential. Although distinct, the two are not independent. When considered together, the two present opportunities for synergistic effects (*Figure 2-1*).

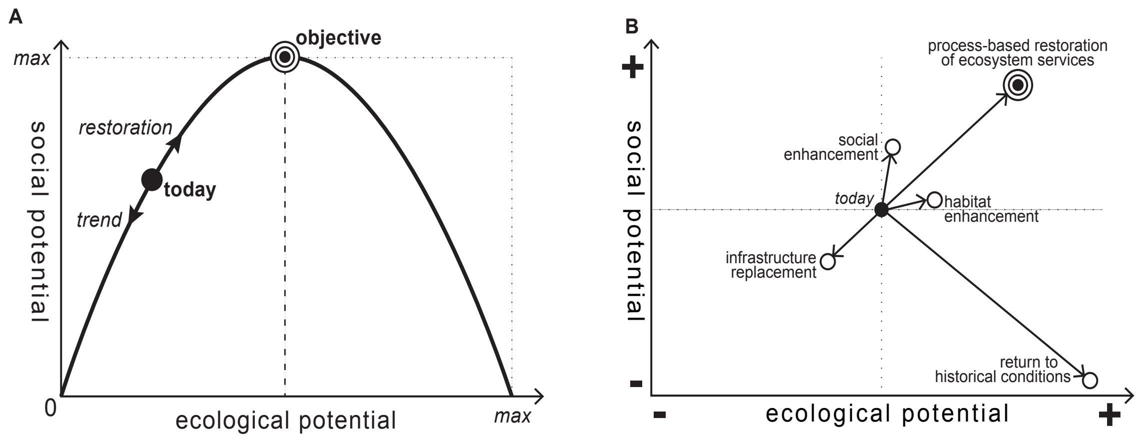

Figure 2-1. Social and Ecological Potential of Next Generation Flood Management. (A) Restoration can increase the social and ecological potential of communities. To maximize both, approaches must consider potential synergies of compounding benefits, such as self-sustaining services of ecosystems, versus costs, including capital required for maintenance and replacement. (B) Various approaches, played out to extremes, may push the ecological and social potential in positive or negative directions. Wholesale infrastructure replacement or a return to historical conditions would degrade social potential beyond community tolerance. Opportunistic "spot" enhancements could nudge the system in a positive direction but have limits. Restoration that sustains the critical services of functioning riparian ecosystems can connect people to stream corridors as multi-functional public resources for generations to come.

2.1.2 THE SOCIAL VALUE OF NATURAL CAPITAL

The productivity and functions of ecosystems underpin human well-being. Humans depend on natural capital, the life-sustaining biophysical processes that renew resources and evolve diverse forms of life (*Figure 2-2*). This dependence binds the social potential of communities to the ecological potential of our planet, oceans, and watersheds. Without efforts to steward the natural capacity of local watersheds to serve current and future generations, urban communities rely on import of resources and export of waste, at a cost to natural capital that has not been reconciled via conventional economics. These 'externalities' expand human impacts across an ever-widening array of Earth's ecosystems (Folke et al., 1997; Grimm et al., 2008). In contrast, reinvestment in local natural capital through restored ecosystem function supports multiple human benefits that can be measured in terms of social capital (Rosenzweig, 2003) (*Figure 2-3*).

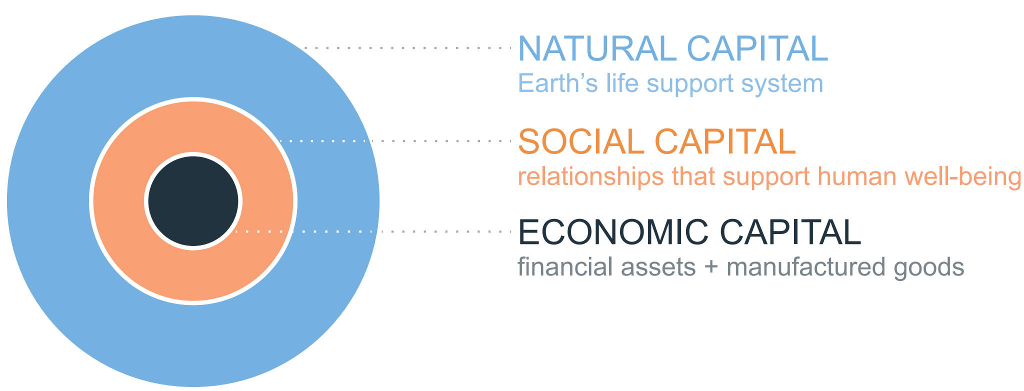

Figure 2-2. Concepts of sustainable development recognize that a thriving global society depends on stewardship of Earth's self-regulating systems: the atmosphere, oceans, forests, waterways, biodiversity and nutrient exchange. Human well-being and market economies depend on and benefit from the "natural capital" of stable ecosystems that provide reliable sources of food, water, and building material. Figure adapted from Griggs et al (2013).

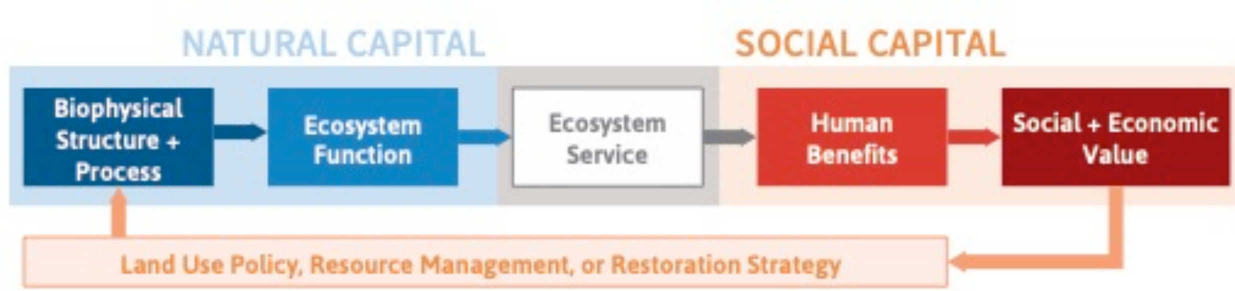

Figure 2-3. A conceptual model of ecosystem services illustrating how natural capital can support social capital. Humans derive food, materials, and myriad benefits from the biophysical processes that drive the production, filtration, and regulating functions of ecosystems. The *ecosystem services* that derive from this natural capital sustain society and support human well-being. Over time, laws, land use policy, management schemes, and technology (bottom) evolve to conserve and restore *natural capital*. As society progresses through this cycle, we can better sustain and even improve quality of life and well-being for future generations. The Fifty-Year Plan represents a new iteration of flood and watershed management that re-invests in the balance of natural and social capital in Walnut Creek's watershed. Figure adapted from de Groot et al (2010).

2.1.2.1 Management of Natural Capital in the San Francisco Bay-Delta Region

For the people and commerce of the San Francisco Bay region, competing demands for all types of capital – natural, human, and economic -- strain water supply, fisheries, aquatic ecosystems, and attempts to cap greenhouse gas emissions. Flood control, water diversions, wastewater discharge, and irrigated agriculture have transformed the San Francisco Bay-Delta Estuary (SF Bay) – the largest estuarine wetland on the Pacific Coast of North America and an international biodiversity hotspot (Myers et al., 2000), noted for its large number of limited-range species (*Figure 2-4*) (Stein et al., 2000). Formerly abundant wetlands of SF Bay have been simplified if not filled or excavated. The food chains and diversity of remnant aquatic ecosystems now face collapse due to fragmented and degraded habitat (McCreary et al., 1992), water infrastructure (Mount et al., 2012), contaminants (Healey et al., 2016b, 2016a), accelerating species invasion rate (Cohen and Carlton, 1998), and precipitous declines of endangered fish (MacNally et al., 2010), such as the loss of species such as Coho salmon (Oncorhynchus kisutch) within SF Bay (Leidy et al., 2005a). By serving diverse demands across the state of California, SF Bay has been described as "the most impacted urban estuary on the West Coast (McKee et al., 2013, p. 57)" and the most invaded by exotic species (Leidy et al., 2011). Non-native fish constitute 42% of all freshwater fish species in the basin (Leidy et al., 2011). Problems in the Bay-Delta are so complex that they "cannot be solved, only managed (Healey et al., 2016a, p. 2)" (Mount et al., 2012; Sommer et al., 2007).

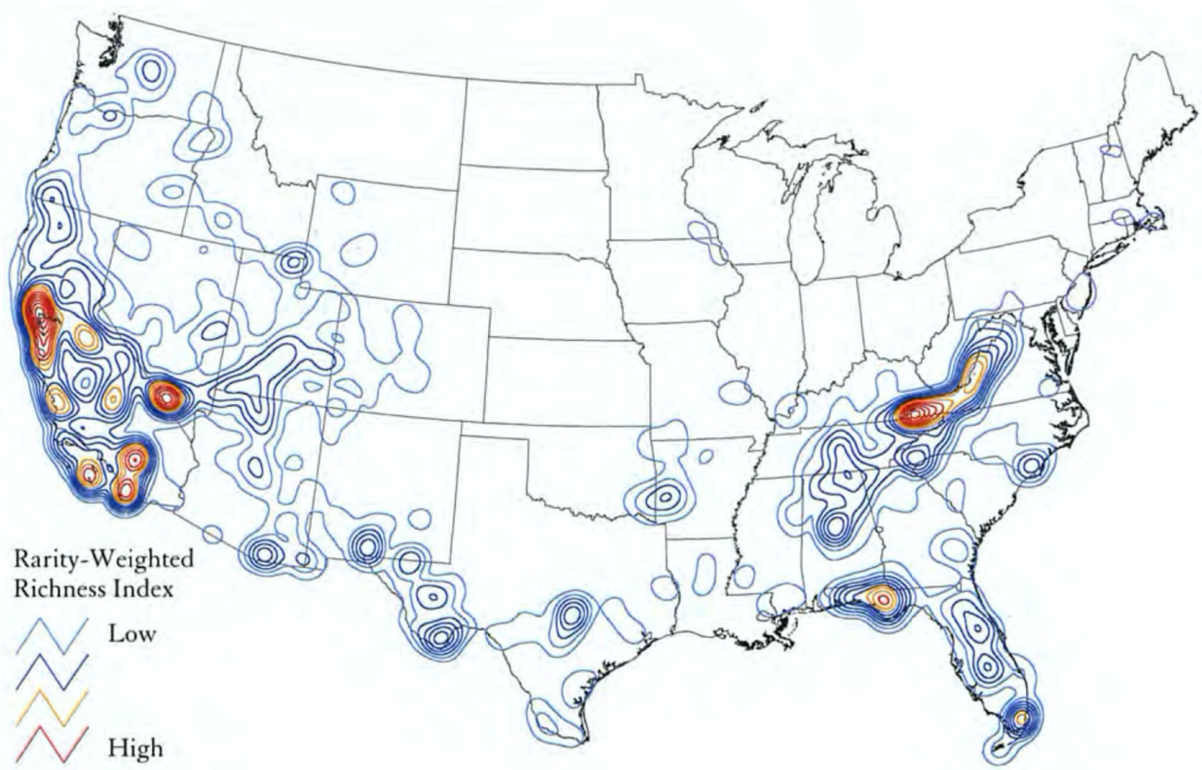

Figure 2-4. Biodiversity Hotspots in the U.S. rated according to a "rarity-weighted richness index". Rarity refers to restricted-range species that are endemic to a specific area. Richness refers to the number of imperiled species (e.g. federally-listed as endangered or threatened, or with a vulnerable or greater global conservation status) per unit area. Figure from Stein et al. (2000, p. 173)

2.1.2.2 Regional Natural Capital Depends on Watershed Function

For SF Bay, the streams and rivers that contribute to its core ecosystem processes and functions are strongly influenced by water demands and land uses of urbanized watersheds. Human need for clean, safe water supply redirects water from protected headwaters and the Delta. Urbanized watersheds of SF Bay contribute freshwater, sediment, nutrients, migration pathways for fish, but also pollutants and invasive species that have emerged from highly altered land cover and use (Leidy et al., 2011). Restoration and management of SF Bay's ecosystems, the natural capital that sustains our lives and economies, must consider human impacts from upstream to downstream, winter to summer flows (Kaushal and Belt, 2012; Paul and Meyer, 2001). Addressing the source of impacts that emanate from urbanized watersheds constitutes a critical strategy for improved management of SF Bay, its headwaters, wetlands and riparian corridors. As part of this reconciliation of human impacts on ecosystems, the regulation and management of flood and stormwater infrastructure increasingly recognizes the connectedness of land use, disaster planning, economic sustainability, ecosystem services, uncertainty and adaptation to extremes in precipitation (Albert et al., 2019; Batker et al., 2005; Brown, 2018; Merz et al., 2010). To adapt to current and future watershed conditions and climate trends, restoration goals and strategies should be informed by an understanding of past, present, and projected evolution of the watershed (Iacob et al., 2014).

2.1.2.3 Walnut Creek's Watershed Function

When flood infrastructure was built in Contra Costa County, past land use had already changed land cover, introduced invasive species, and "improved" channels for better drainage, increasing drainage density, compacting and paving surfaces, reducing in-stream shade and floodplain complexity, and exposing soils to erosion.

By the 1950s, suburban houses and commercial development encroached on creek channels and active floodplains. To protect these investments and allow for new ones, engineered flood infrastructure was imposed on creek channels after two major floods, in 1955 and 1958. At the time, national programs and expertise promised safety and protection via engineered control of natural hazards. Few alternatives were considered. Risks, costs and benefits were simplified and considered over short time frames. Assumptions were not offered for debate. Prior to enactment of environmental regulations, impacts to fish and ecosystems were not a factor in decision-making. With 80-90% of funding from the federal government and recent floods inundating freshly-built suburbs, flood control projects garnered public support (Avalon, 2014).

In the Walnut Creek Watershed, constrained channels no longer form and maintain themselves. Hardened flood infrastructure and piped drainage systems, when applied at scales that substantially disrupt the flow of water, sediment, nutrients, and organisms within a watershed, suppress the ability of connected ecosystems to sustain themselves. This decreases ecosystem services – the social benefits derived from biophysical processes and ecosystem functions (*Figure 2-3*). This cost is not traditionally weighed against flood protection benefits as watersheds are parceled, developed, and then protected from natural hazards.

As introduced structures wear and lose their functional integrity, they require not only maintenance and repair to serve their flood control purpose, but wholesale replacement, a lifecycle cost not previously considered in economic analysis. In contrast, by allowing channel-forming processes to sustain habitats and water purification processes, society may gain multiple benefits, including greater capacity to adapt to an unstable climate (Jones et al., 2012). Dynamic, self-maintaining channels require space for water to flow, sediment to move, and vegetation to grow over lands currently occupied by thousands of private parcels and structures in the floodplain.

2.2 WHAT TO RESTORE?

2.2.1 BENEFICIAL USES OF WATER, A REGULATED PUBLIC RESOURCE

The beneficial uses of water in Walnut Creek's watershed are protected by the state of California. The California Water Code (Section 201) asserts that, "all water within the State is the property of the people of the State, but the right to the use of water may be acquired (State Water Resources Control Board, 2019, p. 4)." The California Constitution (Article X, Section 2, ca. 1976) further requires "water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare (State Water Resources Control Board, 2019, p. xxii)."

Walnut Creek is a "fully appropriated stream" (between May 01 to November 30) from its confluence with Suisun Bay upstream into all tributaries where hydraulic continuity exists (State Water Resources Control Board, 1998, p. 7 Decision No. 58). The California Water Code defines "fully appropriated streams" in Section 1205 (b): "A declaration that a stream is fully appropriated shall contain a finding that the supply of water in the stream system is being fully applied to beneficial uses where the Board finds that previous water rights decisions have determined that no water remains available for appropriation (State Water Resources Control Board, 2019)."

California pioneered water quality governance with the The Porter Cologne Water Quality Control Act (1969), giving state-wide and regional water quality control boards responsibility to protect, restore and enhance the beneficial uses of waters of the state. Today, regional boards enforce standards of the U.S. Clean Water Act (1977), the California Water Code, and regionally appropriate water quality protection policies. The State of California San Francisco Bay Regional Water Quality Control Board (SF Regional Board) designates beneficial uses for Walnut Creek and its tributaries through its *Water Quality Control Plan for the San Francisco Basin* (2010) (*Table 2-1*).

Within each basin plan, water quality objectives are defined to protect designated uses for a creek and inform discharge permits to protect fish, wildlife, recreation, and scenic enjoyment (Whyte, 2019). To protect "fish migration" as a beneficial use, for instance, water quality criteria may address barriers to migration: thermal (i.e. cold vs warm water), physical (i.e. allow passage between habitats needed to complete migratory lifecycle), or chemical (i.e. pollutants, salinity). Where protected species exist under federal or state law, more specific criteria and management regimes may be required and enforced by the California Department of Fish and Wildlife, the National Marine Fisheries Service, or the U.S. Fish and Wildlife Service.

In considering the question, "What to Restore?" the District and community might first consider the designated, protected beneficial uses that were determined via a review of scientific evidence and justified in public hearings of the SF Regional Board. The jurisdiction of the SF Regional Board covers the entire watershed, but its regulatory mandate to enforce restoration of creeks and watersheds remains limited (see *Section 4.1.1*). Much of the flood and stormwater infrastructure in Walnut Creek's watershed was constructed prior to enactment of laws and policies designed to protect beneficial uses of creeks. Although no specific prescriptions for restoration appear in the basin plan for Walnut Creek (SF Regional Board, 2010), the designated beneficial uses represent one of the most direct regulatory drivers for restoration of altered channels and urbanized watersheds. Although these uses are not explicitly identified as ecosystem services, they form the current basis for understanding and communicating the multiple potential functions of creek corridors that are protected within the watershed. Planning to support the Fifty-Year Plan can further inform that basis with local concerns, community objectives, scientific inquiry, and an adaptive outlook to future needs.

Table 2-1. **Designated existing beneficial uses of streams in Walnut Creek Watershed** (San Francisco Regional Water Quality Control Board, 2010). FT = Federally listed Threatened Species, FSC = Federal Species of Concern.

CREEK	COLD FRESHWATER HABITAT	FISH MIGRATION	THREATENED SPECIES	FISH SPAWNING	WARM FRESHWATER HABITAT	WILDLIFE HABITAT	WATER-CONTACT RECREATION	NON-CONTACT RECREATION	CURRENTLY PRESENT PROTECTED SPECIES
WALNUT	■	■	■	■	■	■	■	■	CA Central Coast Steelhead (FT) Central Valley Fall-Run Chinook (FSC)
PACHECO					■	■	■	■	
GRAYSON	■	■	■		■	■	■	■	CA Central Coast Steelhead (FT)
PINE	■	■	■	■	■	■	■	■	CA Central Coast Steelhead (FT) CA Tiger Salamander (FT) CA Red-Legged Frog (FT)
GALINDO	■				■	■	■	■	
SAN RAMON					■	■	■	■	
BOLLINGER	■			■	■	■	■	■	CA Central Coast Steelhead (FT)
LAS TRAMPAS	■		■		■	■	■	■	CA Central Coast Steelhead (FT) Alameda Whipsnake (FT) CA Red-Legged Frog (FT)
TICE CREEK			■		■	■	■	■	Alameda Whipsnake (FT) CA Red-Legged Frog (FT)
LAFAYETTE	■				■	■	■	■	CA Central Coast Steelhead (FT)

2.2.2 PACIFIC COAST SALMON RUNS

2.2.2.1 Threats to native anadromous salmon along the Pacific Coast

Migratory salmon play a critical role in the marine and freshwater food webs of the entire Pacific Coast. Although Pacific salmon have evolved diverse life history strategies that allow populations to survive across a wide range of watershed habitats, human activities have reduced salmon populations substantially (Bottom et al., 2009; Greene et al., 2010; Hilborn et al., 2003). Over 30% of the 1,400 historical salmonid populations across the western U.S. no longer exist (Bottom et al., 2009). Of the 49 remaining species of Pacific salmon identified along the Pacific Coast of the U.S., more than half require protection as threatened or endangered species (NOAA Fisheries, 2019a). Prior to flood infrastructure investments throughout Walnut Creek, three of those species historically occurred in the watershed:

- *Central California Coast Coho salmon*, a federal Endangered Species (2005) in serious danger of extinction in the next 50 years if trends continue (Moyle et al., 2017).

- ***Central California Coast Steelhead***, a federal Threatened Species (1997) under severe threat of extirpation within 50 years "unless large-scale restoration actions are coordinated and implemented (Moyle et al., 2017, p. 210)."
- ***Central Valley Fall-run Chinook Salmon***, a federal Species of Concern under severe threat of extinction in the next 50-100 years (Moyle et al., 2017), and a primary food source of the endangered southern resident killer whales who feed off San Francisco Bay (NOAA, 2018).

Walnut Creek is not alone. Across the U.S. West Coast, modification of both riparian habitat and seasonal flow regimes (i.e. winter floods and summer drought) to serve human development of land and water supply have destroyed, blocked, simplified and polluted salmon habitat (Beechie et al., 2010, 2001; Crozier et al., 2019).

In California, native salmon populations persist at the southern end of their range as they contend with extensive alterations of rivers and competition for freshwater supply (Kondolf et al., 2012; Moyle et al., 2015). Across the state, trends in populations, habitat status, and climate suggest that 78% of salmon species face extinction in coming decades without "bold changes in management policy (Katz et al., 2013, p. 1171)." A rapid demise is possible, as witnessed by declines in California's Coho salmon over the past 50-60 years.[1] The number of adults returning to natal streams fell to zero in many systems, including Walnut Creek. Across all of California, the total number of individuals has plummeted to mere hundreds (Katz et al., 2013; Leidy, 2007a; Leidy et al., 2005a; Moyle et al., 2017). Central California Coho salmon are now extinct from SF Bay, were first federally listed as threatened in 1997 under the U.S. Endangered Species Act (ESA), then listed as endangered in 2005.

Observations of Coho and steelhead in Walnut Creek's watershed occurred in upper Pine Creek and its tributaries in the 1950s, and last occurred in Pine and Arroyo del Creek creeks in the 1960s (Leidy, 2007a, 1983). Coastal rainbow trout, resident steelhead trapped upstream of flood infrastructure, have been reported in Bollinger Canyon in the last decade (Alexander, 2001). Chinook salmon were surveyed below Drop Structure Number 1 on lower Walnut Creek in 2005 (Kozlowski, 2006).

Of all Pacific salmon under threat of extinction, Chinook and Coho of central California ranked highest in a recent vulnerability assessment of combined sensitivity and exposure to climate change. In our region, projections of increased precipitation extremes (i.e. intensification of atmospheric rivers in winter alternated with extended drought) increase the vulnerability of early-season migrants (fall and winter). Steelhead tend to spawn in late winter to spring, so ranked less sensitive to fall and winter precipitation extremes. The threat of increased water temperatures with climate change may particularly affect California's salmon because they already survive at the the southern end of their range (Crozier et al., 2019), never mind the temperature impacts of urbanization and the elimination of riparian forest shade and evaporative cooling.

[1] Coho salmon is native to Walnut Creek and several of its tributaries. Individuals were last observed in Pine Creek and Arroyo del Cero Creek prior to 1970, but Coho is now extinct from San Francisco Bay (Leidy, 2007a; Leidy et al., 2005a).

2.2.2.2 Salmon as an anchor species across ecosystems and economies

The loss of Pacific salmon echoes through freshwater, estuarine, and marine ecosystems. Anadromous fish travel thousands of miles between oceans, mainstem rivers and headwater tributaries to complete their lifecycles (*Figure 2-5*). Across their wide-ranging, cyclic migration, they serve as both predator and prey, affecting food webs from oceans to streams to forests. Because they connect nutrient sources across ecosystems and organisms, anadromous salmon are considered a keystone species – their presence or absence defines the community structure of entire ecosystems (Bottom et al., 2009; Budy and Schaller, 2007; Gende et al., 2002; Power et al., 1996; Willson and Halupka, 1995). They're also considered an umbrella species – restoring the processes that sustain habitat for salmon supports other native species. Their keystone role across ecosystems and their vulnerability to watershed alteration connects the future management of aging flood infrastructure in SF Bay's watersheds with the fate of California's salmon populations, as well as:

- ***the fate of other endangered species***, such as the southern resident killer whale (*Orcinus orca)* that feed on large, fatty Chinook salmon off major estuaries of the California coast (NOAA, 2018),
- ***regional jobs and revenue*** generated from commercial fisheries and the seafood industry,
- ***the growth of outdoor recreation and ecotourism*** as a regional economic engine that builds on public investment in multi-use trails, water access, and wildlife conservation (see *Appendix F*),
- ***a regional identity and connected sense of place*** as salmon connect local people to their rivers and watersheds, the SF Bay-Delta Estuary, and the biodiversity of the Pacific Coast.

California's commercial fishery generates over $22 billion in annual seafood industry sales. In good years, salmon landings alone can generate over $22 million in revenue across the state (NMFS, 2018). When the state's commercial salmon fishery closes due to declining populations and environmental conditions, as occurred in 2008-2009, revenue drops to none, leading to the loss of thousands of jobs and over $100 million in associated income (Zavaleta and Mooney, 2016). Recreational anglers, whose numbers averaged over one million in California in the past decade, add more than $2 billion to the state economy in trips, durable good, and travel expenditures per year. The recreational angler industry supports 20,000 jobs across California (NMFS, 2018). If upstream habitat were restored, 76% of surveyed Sacramento River anglers would be interested in new fishing grounds (NOAA Fisheries, 2019b).

2.2.2.3 Regulatory protections and recovery strategies

As regulated by NOAA Fisheries (NMFS), current ESA policies "protect the best" watersheds by investing in the conservation of remaining, independent salmon populations (e.g. in rural or conserved areas where salmon continue to spawn, rear, and out-migrate). Regional conservation plans echo this approach (*Figure 2-6*). Increasingly, a singular focus on conservation has been deemed inadequate as California's salmon populations continue to decline (Golet et al., 2006; NMFS, West Coast Region, 2016). The survival of salmon in California may require reintroducing species into historical habitats where flow regimes, geomorphic processes, and migratory passage are restored and populations can recolonize (Bisson et al., 2009; Bottom et al., 2009; Greene et al., 2010; Herbold et al., 2018; Leidy et al., 2011). Because in-migrating adults return to

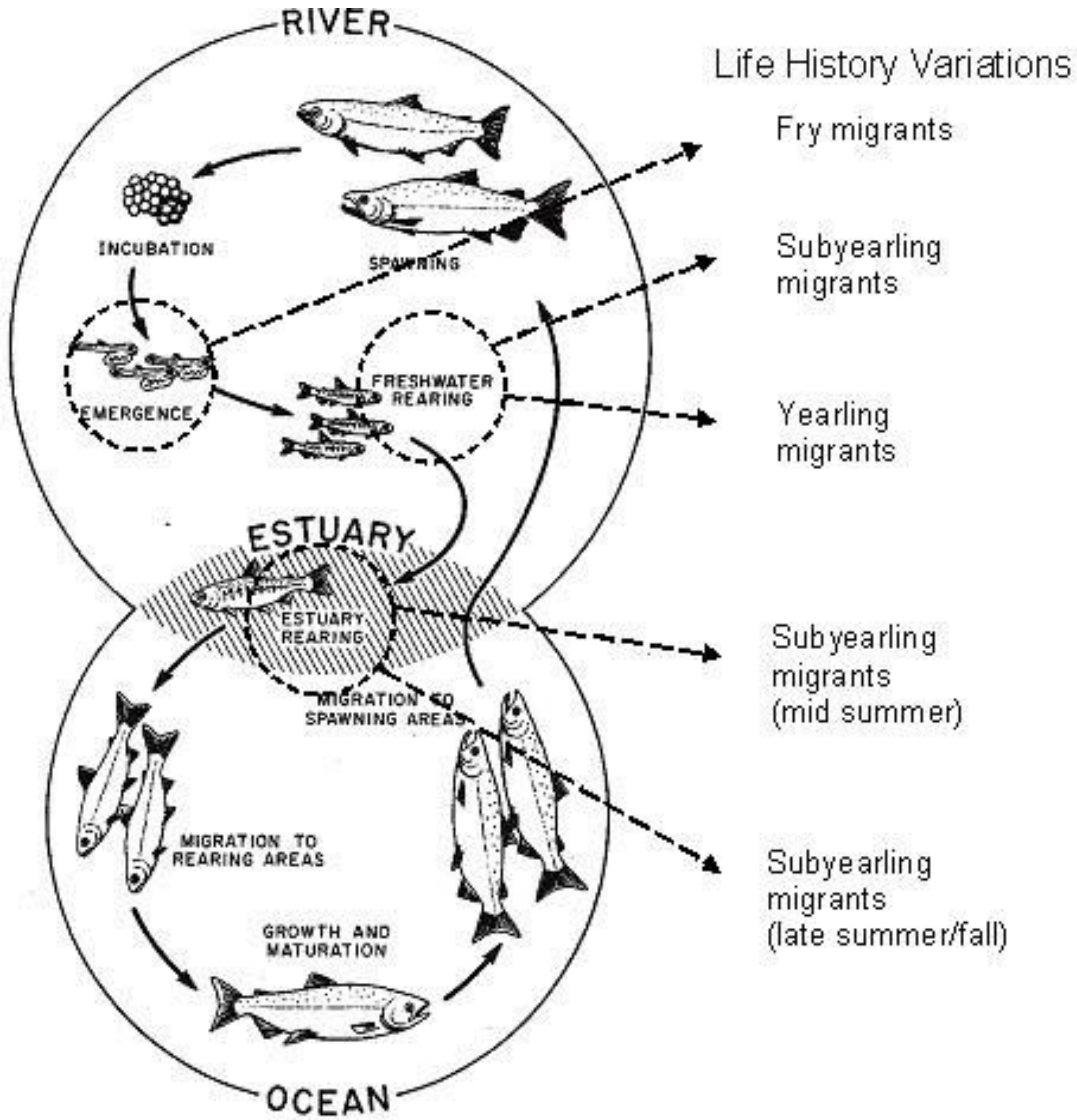

Figure 2-5. Life history variations of anadromous salmon migration between ocean, estuary and river. The life cycle of anadromous salmon generally follows pattern of incubation and emergence in cool freshwater habitat, rearing, marine maturation, and return to natal stream to spawn and die. Variations in life history often arise in patterns of residency, rearing (e.g. in freshwater or brackish estuaries) and timing of migration (e.g. fall, winter, spring) dependent on population-specific adaptations to watershed, estuary or ocean conditions. Figure from Bottom et al. (2009, p. 5)

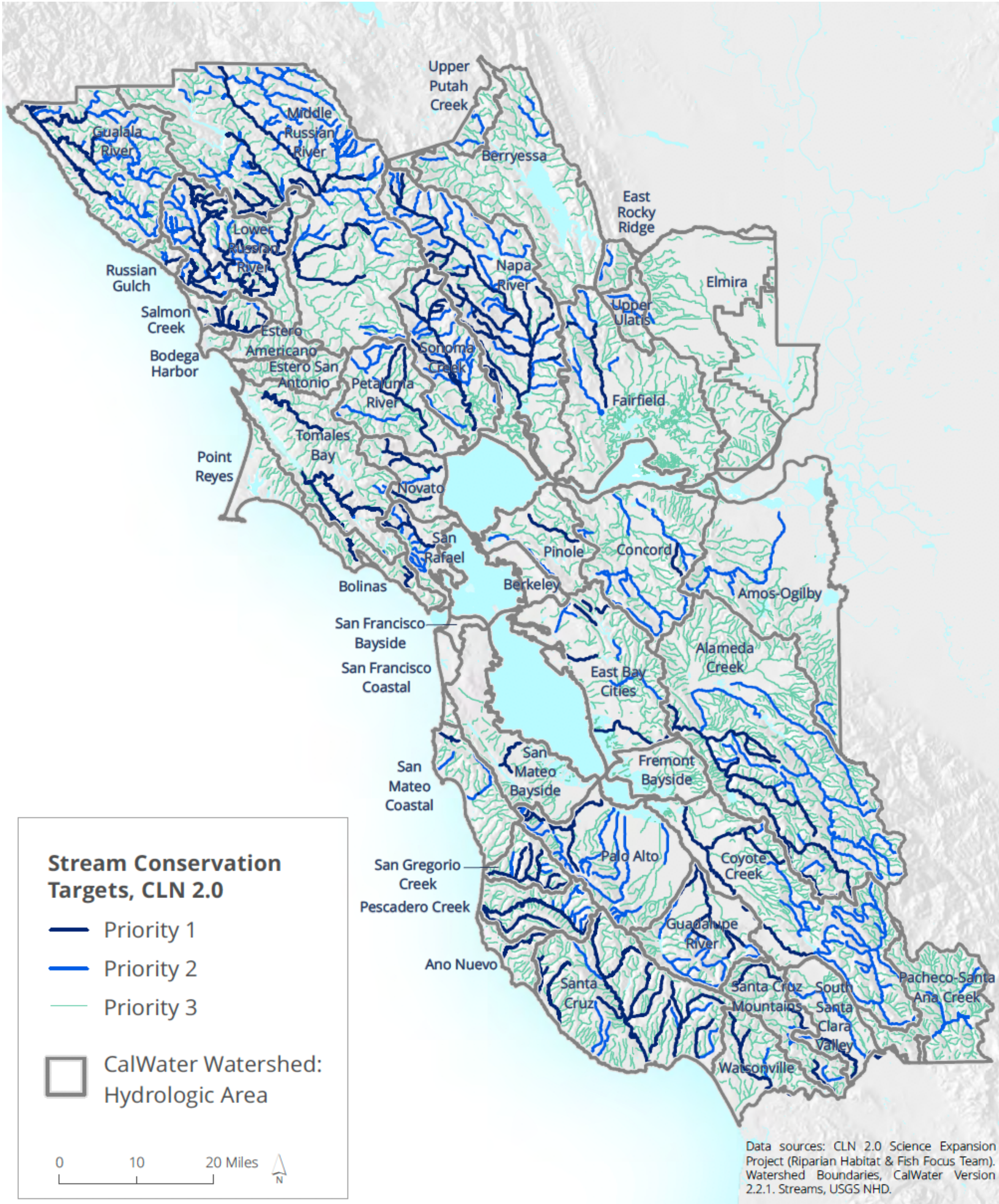

Figure 2-6. **Stream Conservation Priorities for San Francisco Bay Area** as designated by the Conservation Lands Network (Bay Area Open Space Council, 2019, p. 99). Priority 1 (dark blue) streams identify the presence of Coho salmon and Steelhead, a total of 387 creeks. Priority 2 (blue) streams identify where native fish remain. In Contra Costa County, a total of 21 miles of Priority 1 creeks were identified and 116 miles of Priority 2 creeks. The analysis used riparian vegetation and species occurrence to create a linear network. The urbanized portions of Walnut Creek left were not considered as critical mainstem connections to conserved upland stream habitat. The Fifty-Year Plan opens opportunities to restore riparian connectivity through urbanized reaches for native fish. The need to replace aging flood infrastructure across the Bay Area may open more upland fish habitat for threatened species and may be increasingly considered as an opportunity in regional analyses, conservation planning, and watershed management.

home streams to spawn, their dispersal is slow. Over time, wild salmon runs develop unique adaptations to local conditions of their natal streams.

Strategies to sustain California's salmon populations can leverage the power of 'biocomplexity', an emergent property of anadromous fish and their habitat across watersheds in a region. Biocomplexity develops as distinct sub-populations of salmon species adapt to the conditions and variability of their natal watershed, increasing the resilience of the larger regional population (Hilborn et al., 2003) (*Figure 2-5*). This occurs because habitat diversity across watersheds in a region leads to diverse life history adaptations within that region (Fausch, 2018). The combination of geographic and genetic diversity promoted by biocomplexity spreads the risk of a singular disturbance location, event, or stress from wiping out an entire regional population (Greene et al., 2010; Hilborn et al., 2003). Improving biocomplexity for California's salmon by supporting migration through urbanized mainstem reaches into conserved, cool-water upland tributaries can support more resilient regional populations in watersheds where flow regimes, water quality and food availability are restored to support the full lifecycle of salmon species (Bisson et al., 2009). In contrast, engineering habitat in place along individual reaches of former habitat fails to address the variability and complexity of watershed processes required to support migratory salmon (Bisson et al., 2009).

Given the critical role of anadromous salmon across the ecosystems, economy and livelihoods of the Pacific Coast, recovery plans increasingly look beyond conservation of existing habitat, calling for the restoration of fish passage, larger habitat areas, improved habitat quality and watershed management to protect threatened and endangered species across the food chain (NMFS, West Coast Region, 2016). As such, salmon should be considered a keystone species driving restoration efforts across SF Bay watersheds, especially where free-flowing streams connect to diverse, extensive and suitable habitat. Although Walnut Creek has dozens of flood infrastructure components blocking salmon migration to upstream habitat, its large watershed size and conserved uplands represent the restoration potential for native keystone species of the watershed, the SF Bay and Pacific Coast.

2.2.3 THE ECOLOGICAL POTENTIAL OF WALNUT CREEK'S WATERSHED

As one of the last remaining watersheds with a variable flood pulse, sediment delivery into SF Bay, and conserved upland riparian corridors, Walnut Creek has potential to support regional biodiversity and beneficial public uses if riparian corridors throughout the watershed can be:

- **Widened** to safely accommodate floods with more dynamic channel boundaries to sustain riparian ecosystems;
- **Connected** from conserved hills and headwaters to Suisun Bay to support migration of native fish and wildlife;
- **Protected** from impacts of urbanization throughout the watershed through measures to reduce, intercept, infiltrate, retain, detain and filter urban runoff.

2.2.3.1 Ecological Role of Walnut Creek within SF Bay

The ecological potential of Walnut Creek's watershed can be understood by relating its size, condition, and functions to other watersheds in the region. Walnut Creek retains the fourth largest undammed area of all basins flowing into SF Bay (*Table 2-2*), an indication of its potential habitat area and diversity of species. Today, only 4% of the watershed lies behind dams, but 96% of in-stream habitat remains impassible to anadromous salmon. Fish, especially salmon, thrive with movement. Native, wild, anadromous salmon have evolved to move in response to seasonal disturbance of California's climate to fulfill the diverse needs of their lifecycle. Dams disrupt movement by fragmenting habitat and disrupting flow regimes, sediment supply, and temperatures. As 52% of the watershed area draining to SF Bay lies behind dams, Walnut Creek is distinguished by its undammed status.

Table 2-2. **Major Watersheds of San Francisco Bay** (SF Bay), sorted by drainage area unblocked by dams[2]. Walnut Creek is the sixth largest watershed, but it ranks as the fourth largest basin in terms of below-dam drainage area. The drainage area below a dam represents the area that influences frequent flooding, downstream sediment delivery, and the potential stream length available to migratory aquatic species. Compared to Walnut Creek, only Sonoma Creek and Petaluma River are less affected by dams, but the three represent outliers in SF Bay (red text). All other watersheds with greater than 100 km^2 total drainage area have at least 29% of their catchment area blocked by a dam. At this level, dams affect keystone processes that sustain native species of riparian ecosystems.

WATERSHED NAME	BELOW DAM DRAINAGE AREA (km^2)	TOTAL DRAINAGE AREA (km^2)	# OF NATIVE FISH SPECIES PRESENT[3]	AVG ANNUAL SUSPENDED SEDIMENT YIELD (t/km2/yr)[4]	% AREA UPSTREAM OF DAM
Sacramento San Joaquin	80,080	154,000	28	5.8	48%
Alameda Creek	927	1,664	19	68	44%
Napa River	523	738	23	422	29%
Walnut Creek	364	378	14	232	4%
Coyote Creek	330	833	19	9.9	60%
Guadalupe River	268	446	18	18	40%
Sonoma Creek	241	241	15	847	0%
Petaluma River	122	122	19	213	0%
Suisun Creek	93	137	13	224	32%
San Francisquito Creek	80	118	9	340	32%
San Lorenzo Creek	63	125	7	135	50%
San Pablo Creek	23	106	7	58	78%
San Leandro Creek	21	128	6	45	84%

Barriers to movement, habitat degradation, and pollutants from urban runoff have reduced the species richness and abundance of native fish populations across SF Bay watersheds (Moyle et al., 2017; NMFS, West Coast Region, 2016). Across California, at least 80% of native freshwater fish are extinct or imperiled with climate change exacerbating their vulnerability to extinction (Moyle et al., 2011). Similarly, in Contra Costa County, at least three fish species (18%) have been

[2] (McKee et al., 2013)

[3] (Brown and Moyle, 2005; Leidy, 2007b)

[4] Represents yield to SF Bay, based on regression relationships from USGS data spanning at least five water years, then calculated based on total watershed area (upstream + downstream of dams)

extirpated and another nine (53%) are imperiled. Historically, Walnut Creek's basin supported 17 species of native fish, the sixth highest diversity of all basins flowing into SF Bay and the most of all streams in the County (*Table 2-3*) (Leidy et al., 2005b; Leidy, 2007). Today, 14 native fish species still occupy its waters.[5] In Walnut Creek's waters today, introduced fish species outnumber native fish, about 1.4 exotics to every native fish.

2.2.3.2 Conserved Natural Capital of Walnut Creek Watershed

For riparian ecosystems of Walnut Creek's watershed, the highest potential for ecological recovery lies in the least disturbed creeks (*Opportunity Atlas Map W-3*) and subwatersheds (*Map W-4*), but only if habitat is accessible. Historically, steelhead migrated up Walnut Creek, Mount Diablo Creek, Pine Creek, San Ramon Creek and probably Las Trampas and Lafayette Creek (Leidy et al., 2005b) (*Map W-2*).

Leidy et al. (2005b) identified suitable habitat for steelhead (defined as remnant reaches with well-shaded pools, cool water, and complex cover) in Upper Pine and Little Pine Creek, Arroyo del Cero Creek, San Cantanio, and Bollinger Canyon creeks. Rainbow trout (O. *mykiss*, but non-migrating residents) have been reported in Lafayette and Bollinger Canyon creeks (Leidy et al., 2005b). Field surveys in 2005 revealed abundant canopy and shading on Bollinger, Las Trampas, Tice and Upper Sycamore creeks (Kozlowski, 2005). Summer temperatures exceed 70 F in unshaded mainstem reaches of Walnut and San Ramon creeks, but remain below the 65 degree optimal temperature for steelhead rearing in Las Trampas and Bollinger Creeks, where flows and pools persist (Kozlowski, 2005).

2.2.3.3 Need for Connectivity

Walnut Creek watershed's dams remain confined to headwater reaches. Unlike other salmon habitat connected to SF Bay, mainstem reaches retain a flood pulse. Under state law, Walnut Creek's waters are "fully applied to beneficial uses" (discussed in *Section 2.2.1*), but flood infrastructure physically confines mainstem reaches, limiting the beneficial uses of streamflow. For fish, infrastructure disconnects Suisun Bay from historical headwater spawning habitat (*Opportunity Atlas Map W-3*). Today, at least 30 drop structures block fish passage to unaltered stream channels with cool-water habitat. Long and dark culverts, confined and straightened channels promote intolerable flow velocities, insufficient flow depth or refugia (Kozlowski, 2005). These conditions also deplete food sources for migratory salmon.

As suggested by Peter Alexander (2001), Fisheries Program Manager for East Bay Regional Parks, the conserved uplands and flow regime of Walnut Creek watershed offer an opportunity to create safe passage for salmon through urbanized reaches into suitable, potentially extensive and well-

[5] The three native species no longer found in Walnut Creek's watershed include thicktail chub (*Gila crassicauda)*, Coho salmon (*Oncorhynchus kisutch)*, and Sacramento Perch (*Archoplites interruptus)* (Leidy et al., 2005b). Thicktail chub is listed as Extinct and Coho salmon is federally-listed as Endangered (CA Department of Fish and Wildlife, 2019). Sacramento Perch is extinct in its native range (CA Department of Fish and Wildlife, 2015).

Table 2-3. **Relative Fish Diversity in large Contra Costa County Watersheds**. Abbreviations: Federal Endangered (FE), Federal Threatened (FT), Federal Species of Concern (FSC), State Delisted + Extinct (SDE), State Endangered (SE). Moyle et al. (2015) designated California conservation status as Critical (red), High (dark blue), Moderate (light blue) or Low (green). San Francisco Bay Conservation Targets (left column) defined by Weiss et al (2010); used to define Priority 2 streams in the Open Lands Network 2.0 report (*Figure 2-6*) (Bay Area Open Space Council, 2019). "?" indicates native species with uncertain presence. Source of fish identification per watershed by Leidy et al (2007a)

	WALNUT	MARSH	SAN PABLO	PINOLE	WILDCAT
Watershed Size (mi^2)	146	94	43	15	11
Total Channel Length (mi)	310	167	109	47	22
# of native species	14	9	6	5	5
# of introduced species	19	4	5	10	11

SAN FRANCISCO BAY CONSERVATION TARGET	STATUS	Endemic to SF Bay	Anadromous or Resident	COMMON NAME	WALNUT	MARSH	SAN PABLO	PINOLE	WILDCAT
					(N)ative, (I)ntroduced, or (E)xtinct				
SAN FRANCISCO BAY CONSERVATION TARGET	SDE 1980	Endemic	Resident	Thicktail chub	E	E			
SAN FRANCISCO BAY CONSERVATION TARGET	FE 2005 SE 2005 *Critical*		Anadromous	Coho salmon	E		E		
SAN FRANCISCO BAY CONSERVATION TARGET	FT 1993 SE 2010 *Critical*	Endemic	Resident	Delta smelt	N?				
SAN FRANCISCO BAY CONSERVATION TARGET	FT 1997 *High*		Both	Steelhead	N	N?	N	N	N
SAN FRANCISCO BAY CONSERVATION TARGET	FSC *High*		Anadromous	Chinook salmon	N	N			
SAN FRANCISCO BAY CONSERVATION TARGET	*Critical*	Endemic	Resident	Sacramento perch	E	E			I
SAN FRANCISCO BAY CONSERVATION TARGET	*High*		Resident	White sturgeon	N				
SAN FRANCISCO BAY CONSERVATION TARGET	*Moderate*	Endemic	Resident	Sacramento splittail	N	N	N?		N?
SAN FRANCISCO BAY CONSERVATION TARGET	*Moderate*		Anadromous	Pacific lamprey	N?				
SAN FRANCISCO BAY CONSERVATION TARGET	*Moderate*	Endemic	Resident	Hitch	N	N			I/E
SAN FRANCISCO BAY CONSERVATION TARGET	*Moderate*	Endemic	Resident	California roach	N	N	N	N	
SAN FRANCISCO BAY CONSERVATION TARGET	*Low*		Both	Threespine stickleback	N	N	N	N	N
SAN FRANCISCO BAY CONSERVATION TARGET	*Low*	Endemic	Resident	Sacramento pikeminnow	N	N	N	N	N
SAN FRANCISCO BAY CONSERVATION TARGET	*Low*	Endemic	Resident	Sacramento blackfish	N	N			
SAN FRANCISCO BAY CONSERVATION TARGET	*Low*		Resident	Prickly sculpin	N		N	N	
SAN FRANCISCO BAY CONSERVATION TARGET		Endemic	Resident	Sacramento sucker	N	N	N	N	N
SAN FRANCISCO BAY CONSERVATION TARGET		Endemic	Resident	Hardhead		E	E		E
			Resident	Staghorn sculpin	N				
				Yellowfin goby	I			I	
				White catfish	I			I	
				Western mosquitofish	I	I	I	I	I
				Striped bass	I	I			
				Shimofuri goby	I				
				Redear sunfish	I				I
				Rainwater killifish	I			I	
				Pumpkinseed	I				
				Largemouth bass	I		I		I
				Inland silverside	I			I	
				Green sunfish	I	I		I	I
				Goldfish	I			I	
				Golden shiner	I			I	I
				Fathead minnow	I				
				Common carp	I		I	I	I
				Chameleon goby	I				
				Bluegill	I	I	I		I
				Black crappie	I				I
				Black bullhead	I				

vegetated riparian habitats. Extensive urbanization throughout the watershed, however, likely increases peak flows for the most frequent, geomorphically effective storms. Even if fish passage were restored, the land-based impacts of watershed-scale urbanization may be a more insidious threat to restoration of salmon-bearing habitat.

2.2.3.4 Mitigating Impacts of Watershed Urbanization

While the Fifty-Year Plan opens opportunities to reconsider constraints on salmon habitat imposed by flood infrastructure, the watershed's ecological potential remains limited by urban runoff patterns and lack of habitat connectivity *across the entire watershed*. Outside of concrete channels, earthen channels in urbanized reaches of Walnut Creek suffer from effects of urban land use and impervious surfaces on the flow regime, water pollutants, stream temperature, extreme nutrient inputs, and reduced groundwater exchange (Leidy et al., 2011) (*Opportunity Atlas Map W-4*).

Grayson Creek, for instance, sits in an urbanized subwatershed of Walnut Creek. With 34% impervious cover, only a small corner of land in this subwatershed remains protected and conserved as open space (*Opportunity Atlas Map W-4*). Despite its urbanization, Grayson Creek remains accessible to in-migrating Chinook salmon. Drop Structure #1 on Walnut Creek lies about five miles *upstream* of the Grayson Creek confluence (*Map W-3*). Chinook salmon amass at the upstream drop structure in early winter, yet downstream in Grayson Creek, exotic mosquitofish and inland silversides dominate measures of fish abundance. Grayson Creek's streambed, confined between levees and periodically dredged, lacks a diversity of food. Oligochaete worms dominate streambed biota with some chironomid midges present, a strong indication of disturbed, urbanized and high-nutrient conditions, as confirmed by "harmful" levels of nitrate, non-ionized ammonia, and dissolved oxygen (Hagar and Demgen, 1987). Monitoring of benthic macroinvertebrates shows consistently poor conditions between 2001-2011 (Walkling, 2013). Although native threespine stickleback and hitch occur in Grayson Creek, the species diversity of this urbanized and channelized reach appears bolstered by exotic, generalist species tolerant of urban conditions who have outcompeted native fish.

The lack of salmon in lower Grayson Creek, despite no in-migration barriers, suggests that the effects of urbanization are a larger impediment to salmon recovery than migration barriers, especially in highly urbanized drainages. Across Walnut Creek's five major subwatersheds (Clayton Valley Drain, Pine, San Ramon, Las Trampas and Grayson), percent impervious cover generally correlates with biotic integrity scores from surveys of benthic macroinvertebrates (Walkling 2013, p. 28). At 34% impervious cover, Grayson Creek fits in the "non-supporting" category for sensitive freshwater organisms, as confirmed in biotic field surveys (*Opportunity Atlas Map W-4* and *Figure 2-12*). Remnant assemblages of native fish in patches of Walnut Creek and San Ramon Creek, however, indicate the potential for *watershed-scale restoration* to mitigate urban hydromodification, expand habitat area, and allow natural patterns of flooding (a requisite or "keystone" disturbance process) to support native fish and reduce competitive pressure of exotic generalists.

Restoration to reinvigorate persistence of salmon populations in Walnut Creek's watershed would at least require removing barriers to movement, reducing storm flow velocities and reducing excessive peak flows, establishing of refuge habitat for salmon to rest and feed as they migrate through freshwaters, and disconnecting sources of pollutants (Herbold et al., 2018). This general list serves as minimum requirements, but the thresholds and optimum locations of change required to support salmon remain unknown and deserve further consideration through an adaptive management process (discussed in Section 4, *How?*).

2.2.4 THE EVERYDAY VALUE OF RIPARIAN CORRIDORS TO PEOPLE

On an everyday basis, access to the sensory experiences of nature can improve the physical and mental health of people. A broad literature review (*Appendix F*) compiles evidence that the "nearby nature" of riparian corridors can improve air and water quality, cool local air temperatures, dampen urban noise, provide cognitive and emotional benefits critical to children's development, reduce biomarkers of stress, restore attention, improve productivity and job satisfaction of workers, encourage physical activity, improve cardiovascular health, reduce risk factors associated with chronic disease, and limit greenhouse gas emissions of a community by reducing vehicle trips and miles. When nature is nearby, these benefits become available to those without a car, without the income to vacation in a far-off oasis, or without the ability to hike for miles. If edges and trails are designed with access and safety in mind, they become available to the infant and elder, the sick and disabled, the grieving or stressed, the observant explorer or artist, the students in an outdoor science lab or free ramblers on summer vacation.

Accounting for the potential synergistic social benefits of restored ecosystem requires analyzing costs and benefits beyond the metrics of near-term economics across the full lifecycle of flood infrastructure and life stages of a diverse surrounding community. At this opportune moment of planning for major re-investment in flood management and natural capital, the community deserves to consider the value of nearby nature to public health and well-being, the inherent value of self-sustaining freshwater ecosystems within their own neighborhoods, and the externalities of living in a watershed connected to the biodiversity and productivity of the largest estuary on the Pacific Coast. These potential benefits must be weighed against the degree of transformation and investment required to integrate restored creek corridors into existing neighborhoods, commercial areas, and transportation corridors that provide critical services to communities. Displacement of existing uses may incur financial, social and psychological costs, especially for residents or small businesses with few resources.

2.2.5 DISTURBANCE: THE VALUE AND CONTROL OF FLOODS

2.2.5.1 Social Value of Existing Flood Infrastructure

Floods represent a disturbance to ecosystems and society. On urbanized floodplains, sediment-laden flows threaten damage to structures. A series of floods between 1950-1958 occurred as suburban communities of Walnut Creek's watershed grew rapidly with the post-war economy. In December 1955, a flood with a 22-year recurrence interval inundated downtown Walnut Creek in two to three feet of water. Families were evacuated; over 1,000 homes and about 50 businesses were damaged by inundation or bank erosion (U.S. Geological Survey, 1963), a result of land-use zoning that allowed new development to encroach on channels and floodplains, and thereby increase exposure to flood hazards. Another major flood occurred in 1958. For each of these two floods, recovery costs in the watershed were estimated between $8.5 to $15 million (in 2019 U.S. dollars) (U.S. Geological Survey, 1963; Walkling, 2013).

In response to these events, numerous agencies worked to design and adapt a flood protection system, constructed between 1964-1992 (*Table 2-4*).The system relies on engineered, narrow, low-roughness channel structures that convey and contain extreme flood flows (of 50-120 year recurrence interval) at high velocities without overbank onto floodplains (Contra Costa Soil Conservation District, 1966; Pinto et al., 2018; Wong, 2014).

About 30% of channels in Walnut Creek Watershed have been altered for flood protection (*Opportunity Atlas Map W-3*). Most occur uninterrupted through the broad alluvial floodplains that run parallel to active regional faults, the Concord-Green Valley Fault and Calavaras Fault (*Map W-1*). Of these altered channels, 55% are constructed of reinforced concrete, usually open box channels but also tunneled culverts that flow belowground, often beneath developed structures. About 40% are constructed earthen channels constrained by levees. And the remaining 5% are constructed of riprap (in some cases grouted), usually as trapezoidal channels. To reduce channel slopes and dissipate energy, numerous weirs, drop structures, detention basins, and spillways were integrated into the channel network. Drop structures control the channel gradient to keep velocities down, thereby ensuring flow conditions follow predicted hydraulic behavior through constrained channels. The degradation, failure, or removal of any one piece of this infrastructure will likely have consequences to the function of other components, a critical consideration in planning the future of flood management and creek restoration in Contra Costa County. Issues regarding the rigidity, inflexibility, and lack of redundancy in this system, especially given uncertainty of climate change and unmitigated risks (including and beyond flooding), is discussed in Section 1 *Why?*.

Since the 1958 flood and introduction of flood infrastructure, the watershed has experienced two major floods of at least a 20-year recurrence interval. Both led to FEMA disaster declarations in Contra Costa County. In January 1982, the peak flow of a 20-year flood recorded on Walnut Creek at Concord reached 13,300 cubic feet per second (cfs) (Randolf et al., 2015), followed in 2006 by a 50-year storm centered over Danville that also produced high flows in Walnut Creek. As discussed further in Section 4 *How?*, a lifecycle accounting of the costs versus benefits of the current infrastructure may help communities weigh investment decisions, but with recognition of trends and projected changes in flood likelihood, the impacts on community life, and ecosystem degradation.

Table 2-4 **History of Walnut Creek Watershed Flood Infrastructure Construction** (Copeland, 2012)

Creek	Limits	Year Built
Walnut Creek	Suisun Bay (Sta. 0+00) to Grayson Creek (Sta. 187+50)	1964
Walnut Creek	Grayson Creek (Sta. 187+00) to Drop Structure #1 (Sta. 354+90)	1965
Walnut Creek	Drop Structure #1 (Sta. 353+90) to Drop Structure #2 (Sta. 460+70)	1966
Walnut Creek	Drop Structure #2 (Sta. 459+25) to Geary Rd. (Sta. 497+70)	1967
Walnut Creek	Waterfront Rd. (Sta. 66+30) to Grayson Creek (Sta. 187+50)	1967
Walnut Creek	Treat Blvd. (Sta. 490+88) to School Foot Bridge (Sta. 562+80)	1968
Walnut Creek	School Foot Bridge (Sta.562+80) to SPRR Bridge (Sta. 585+00)	1970
Walnut Creek	Mt. Diablo Blvd. (Sta. 4+27) to Capwells Culvert (Sta. 18+50)	1971
Pine Creek	Existing concrete lining to Walnut Creek	1978
Pine Creek	Market St. (Sta. 36+00) to Monument Blvd. (Sta. 88+95)	1981
Pine Creek	Monument Blvd. (Sta. 88+95) to Detroit Ave. (Sta. 135+71)	1982
Galindo Creek	Detroit Ave. (Sta. 8+53) to Albert Ln. (Sta. 45+00)	1982
Upper Pine	BART (Sta. 134+90) to Oak Grove Rd.(Sta. 279+30)	1989
Upper Pine	Perada Dr. (Sta. 289+62) to Detention Basin (Sta. 305+62)	1990
San Ramon Creek	Bypass	1985-1992

2.2.5.2 Embracing the Value of Floods

Floods structure, connect, and rejuvenate ecosystems

In our Mediterranean climate, winter rains produce high flows in creeks and rivers, especially when atmospheric rivers pull water from the Pacific Ocean in multi-day, prolonged deluges. A series of wet years are often followed by drought, a pattern that is projected to amplify with climate change. Rainfall drains from watershed land into the channel network where flow characteristics are influenced by slopes, subsurface geology, soil moisture and infiltration rates, vegetation cover, land use, the structure of conveyance networks, as well as rainfall characteristics (e.g. intensity over space and time). Ecosystems have evolved with and adapted to natural patterns of flooding, which serve as a seasonal ecological disturbances that shape habitat. Floods sustain the functions and biodiversity of freshwater ecosystems in four major ways:

1. *Floods convey freshwater, sediment, and nutrients* from uplands to SF Bay and provide connectivity and seasonal cues for migratory species;
2. *Floods connect low-flow channels with oxbows and floodplains,* off-loading flow volumes and sediment while providing refuge and productive feeding grounds for organisms;
3. *Overbank flows prolong retention time* of water in the watershed, supporting nutrient cycling, pollutant breakdown, and groundwater recharge;
4. *The erosive forces of floods re-work sediments*, organic matter, solutes, nutrients, and provide fresh substrate for organisms to regenerate.

As floods sustain not only channel form but also riparian ecosystems and water storage, they also have potential to provide social benefits or "ecosystem services" (*Table 2-5*) that have been largely voided with the introduction of flood infrastructure.

In Walnut Creek, flood infrastructure has confined flows through hardened channels and degraded habitat, but the *variability* of the flow regime still exists, as seen in distinct flood pulses in hydrographs of gauged streams. Undammed flows are relatively rare among large tributaries to SF Bay. This leaves local communities with the question: can floods become valued, not just controlled?

2.3 A RANGE OF POTENTIAL RESTORATION APPROACHES

Increasingly, the regulated beneficial uses of creeks can be understood as the ecosystem services of a watershed. The benefits and values we can restore to public riparian corridors in local neighborhoods and freshwater aquatic ecosystems that drain to SF Bay emerge from the restoration of ecosystem function. In human-dominated landscapes, these functions are largely controlled by land use policy, flood and resource management, and restoration strategies. Our policies manifest within a watershed in terms of land use and vegetation cover, habitat fragmentation, pollutant loads, stormwater management, and flood control channels. In turn, these changes impact biophysical processes and functions of freshwater ecosystems in a full circle (*Figure 2-3*). Restoration represents an intervention into this system, a reconciliation of the services we value and the policies that influence ecosystem function. When restoration strategies target the structure and processes of watersheds (and their drainage networks) at the appropriate scale, re-investment in natural capital along with change to resource management policy and practices can aim to sustain the benefits we derive from restored ecosystem function. This reconciliation approach to restoration raises new challenges and promise for communities, politicians, land and water managers, engineers, and scientists (Rosenzweig, 2003). In order to sustain lasting public benefits for current and future generations, what structure and processes need to change, where, and to what degree?

2.3.1 RECONCILIATION OF GOALS AND TRADE-OFFS

Consensus on the goals and objectives of restoration can be stratified across the diverse interests of stakeholders in a watershed. Understanding the feasible restoration approaches available and tradeoffs involved with each is essential to negotiating and prioritizing objectives of restoration in terms of critical functions of the watershed (*Figure 2-7*).

While replacing concrete channels in their current incarnation would likely be opposed by regulatory agencies and surrounding communities, it is also not possible to completely restore the historical drainage network. Ecosystem recovery to support historical assemblages of species would require dismantling of built structures at scales that disrupt existing communities and the economy. In between these unreasonable extremes, the community must begin to weigh trade-offs between the desired functions of their watershed and the degree of change required to meet objectives.

Table 2-5. **Ecosystem Services of Floods.** Floods structure and disturb creeks, riparian forests and seasonal wetlands in ways that support the critical processes and functions of freshwater ecosystems. Through a cascade of biophysical processes, habitat created and rejuvenated by floods is vital to California's threatened salmon fisheries.

ECOSYSTEM FUNCTION	ECOSYSTEM SERVICE	SOCIAL BENEFIT
Floods connect stream channels with their floodplains, allowing channels to off-load flow volumes and sediment load while retaining scouring forces of in-channel flow.	**Sustain channel form and conveyance capacity** when flows allowed to connect with riparian and floodplain corridors.	**No channel reconstruction costs**, channels sustain themselves.
	Reduce downstream flood peaks when flows overtop banks and spread over expansive floodplains.	**Reduce flood hazard** downstream of floodplains that store floodwaters.
Floods convey freshwater from terrestrial uplands to the SF Bay; promoting estuary mixing (due to salinity and density gradients) and supplying detritus (a major food source), nutrients, and solutes to fuel growth of organisms.	**Regulate estuary habitat with freshwater inflow** by influencing turbidity patterns and light availability, salinity, food resources, nutrient cycling, sediment and waste flushing.	**Support native estuarine species and populations**, conserving biodiversity. **Sustain regional fisheries**, promote conditions needed for migration, spawning and rearing of salmonids. **Reduce cost to control invasive species**
Overbank floods slow as they spread over broad, rough surfaces.	**Capture materials that fuel life** and support floodplain productivity through supply of fine sediment, organic matter, solutes and nutrients.	**Reduce sedimentation** of downstream channels and habitat. **Replenish floodplain fertility** with silt, organic matter and nutrients. **Sequester carbon** in floodplain soils.
	Provide refuge for organisms during high flows.	**Reduce danger to human life** as slower flows, eddies and shallow banks interact with bars, islands and tree branches. **Promote ecosystem resilience** by supporting recovery of populations from disturbance.
	Filter flows through vegetation, sediments + organic matter.	**Improve water quality**
Floods convey and re-work sediments, organic matter, solutes, nutrients, organisms + seed from steep terrestrial uplands to low-slope downstream reaches (*longitudinal connectivity*) and also from in-channel to floodplains (*lateral connectivity*).	**Sustain elevations** of valley floodplains and tidal marsh, even as sea levels rise.	**Protect coastal zones** from wave action, tidal surges and inundation with rising sea levels.
	Refresh substrates that support life. Floods supply, sort and filter substrates (bed sediments, soils), promoting disturbance and re-assembly of organisms that favors native species.	**Create + sustain habitat to support lifecycles of diverse life forms,** ensuring conservation of biodiversity without human intervention to support threatened species. **Conserve biodiversity**
	Distribute resources across terrestrial, aquatic and marine ecosystems, creating gradients and exchange.	**Reduce cost to control invasive species**
	Disperse organisms, promote gene flow between populations, and	**Sustain regional fisheries**, promote conditions needed for migration, spawning and rearing of salmonids.

	distribute species to overcome urban patterns of habitat fragmentation.	**Mitigate urban habitat fragmentation**
	Fuel riparian productivity in a post-flood flush of growth that cascades up the food chain.	**Feed** wildlife, fish and people.
		Offer recreational and educational resources after floods subside through wildlife observation, fishing, teaching, nature-based programming, and tourism.
		Diversify local economies with visitor and experiential services, recreational retail.
	Regenerate riparian forests by synchronizing seed release, flood and germination times. If provided with room to flood and grow, riparian forests offer further habitat, ecosystem functions, and services.	**Mitigate greenhouse gas emissions** by drawing down carbon dioxide from the atmosphere through photosynthesis by plants and aquatic autotrophs.
		Cool summer temperatures (via shading, evapotranspiration of plants) + mitigate urban heat island effect.
		Improve air quality, mitigate pollution impacts from nearby refineries and power plants.
		Provide access to nearby nature, supporting public health and human well-being, especially in lowland disadvantaged neighborhoods.
Overbank floods prolong retention time of water, promoting nutrient cycling, chemical reactions, uptake and breakdown of pollutants by microbes and plants, and a flush of productivity fueled by post-storm light availability.	**Breakdown trapped pollutants**	**Improve water quality** in downstream reaches and SF Bay.
		Improve in-stream habitat for sensitive species and benthic macroinvertebrates, feeding the entire food chain.
		Conserve regional biodiversity by supporting conditions needed for most sensitive species.
	Recharge groundwater, which provides other ecosystem functions, services and benefits.	**Recharge + diversify local water supply**
	Fuel riparian productivity in a post-flood flush of growth that cascades up the food chain.	**Ensure cool, clean summer baseflows** supporting temperature-sensitive species, such as salmonids.
	Create and sustain off-channel pools with conditions that promote high productivity, growth and survival of rearing fish.	**Sustain regional fisheries**, promote conditions needed for migration, spawning and rearing of salmonids.

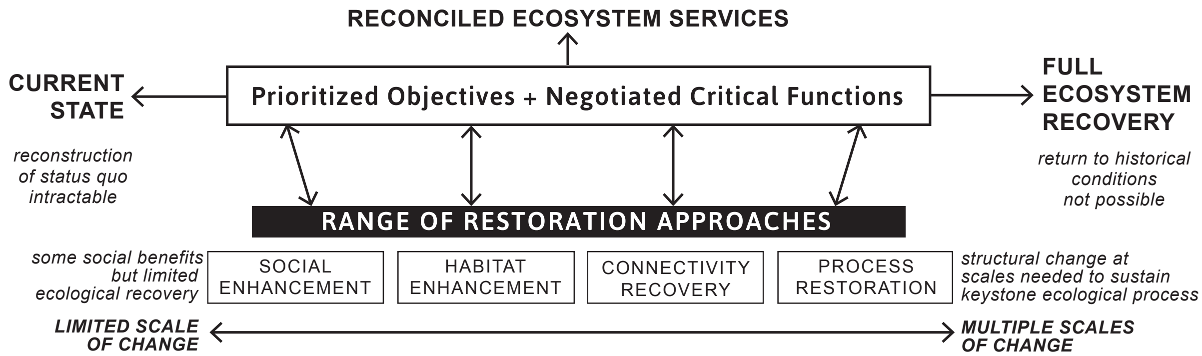

Figure 2-7. A Range of Restoration Approaches may be combined to meet restoration objectives as negotiated by a broad range of stakeholders. One extreme outcome, as-is reconstruction of the current infrastructure, does not reflect current laws or values, making this an unlikely option. At the other extreme, a return to historical conditions is not possible.

With minimal land use change, restoration strategies can focus on *social or habitat enhancements*. Social enhancement might include an overlook on a bridge with an interpretive sign, a water-view bench at a park with a tree, a stretch of greenway trail along a levee, an access ramp for kayaks, grade control and energy dissipators constructed of aesthetically pleasing natural materials, such as boulders and anchored log jams, and redesigned to permit passage by fish and kayaks (*Figure 2-12*). Habitat enhancements might include trees planted along the top of bank that can provide habitat for birds, ramps can allow fish passage over drop structures, inset channels with baffle structure may allow fish to swim and survive through high-velocity concrete or culverted reaches. Restoration approaches that construct habitat features are common in heavily developed floodplains, but they may be ineffective because they treat symptoms of ecosystem degradation in isolated channel reaches. This limits ecological recovery as effects of watershed-scale alteration continue and in-stream habitat structures are often flanked, filled, or fail over time (Beechie et al., 2010; Bernhardt and Palmer, 2011).

Examples of potential direct, creekside social and habitat enhancement can be found in the City of Lafayette's Downtown Creeks Preservation, Restoration and Development Plan (2016). Perhaps because local municipalities and residents lack awareness of the Fifty-Year Plan, however, the proposed restoration opportunities for Lafayette Creek assume that concrete channels will remain in place. Moreover, many grants do not allow the funds to be used for right-of-way acquisition if done by condemnation so this limits use of grant funds to acquire parcels to expand creek corridors. Reach-by-reach assessments detail in-stream habitat conditions, vegetation, and potential for improved aesthetics, but visions for public access and habitat restoration remain constrained to a narrow edge between the top of bank and private property (e.g. removal of ivy, a bench overlook, a walkway). As social and habitat enhancements, the scale and potential for restoration remains limited (*Figure 2-1*) unless social and habitat connectivity can be addressed by changes to the channel and adjacent floodplain land use, in addition to the watershed-scale mitigation of urban hydroregime and pollutant loads (as recognized in Lafayette's plan).

Restoration approaches in urban streams often enhance aesthetics, access and recreation, or introduce static habitat features, but fail to address the systemic causes of ecosystem degradation

(Beechie et al., 2012a; Bernhardt and Palmer, 2011). These approaches offer social benefits, but rarely result in restoration of processes that sustain the functions of lost riparian ecosystems, especially for threatened species – such as Steelhead, California red-legged frog, or California tiger salamander of Walnut Creek's watershed – whose populations have declined along riparian corridors affected by urbanization. Isolated aesthetic enhancements fail to consider the potential of riparian corridors to integrate into everyday urban life in ways that enhance circulation and public health.

If community priorities and critical functions include access to the experience of creeks as a corridor through the landscape, restoration strategies can focus on increased social connectivity to a public greenway corridor. More than intermittent and enhanced views along the channel, a near-continuous public right-of-way of sufficient width can accommodate land-based trails, access points to creeks as water-based trails, and well-spaced park-like amenities that support a range of human uses from passive to active, programmed to spontaneous (Kondolf and Yang, 2008). Attention to viewsheds, access points, well-spaced nodes of human activity, and multi-modal circulation along the corridor can help engender a sense of safety. This approach cannot be realized without substantial land use change along the channel and attention to amenities and circulation in ways that welcome and connect people to riparian corridors as public greenways.

If community priorities and critical functions include restoration of viable salmon runs that sustain a distinct population in Walnut Creek, strategies must contribute to *restoring biophysical processes through structural change at appropriate scales and locations* (*Figure 2-8)*. A widened right-of-way, elimination of migration barriers, and mitigating urban runoff through watershed-wide green infrastructure can begin to restore flow regimes and connectivity. This approach cannot be realized without removing barriers to migration, substantial land use change along the channel and significant interventions to mitigate urban hydromodification, especially within the urban limit line. Because salmon are both keystone and umbrella species of Walnut Creek's watershed, the investment in the multi-scaled restoration of watershed processes promises to restore and sustain other at-risk native species, disrupt the conditions that favor exotic species, and limit the maintenance required to keep invasive species at bay. These types of win-win, low regrets restoration strategies can inform a reconciliation approach to restoration that targets processes and functions required to sustain valued ecosystem services.

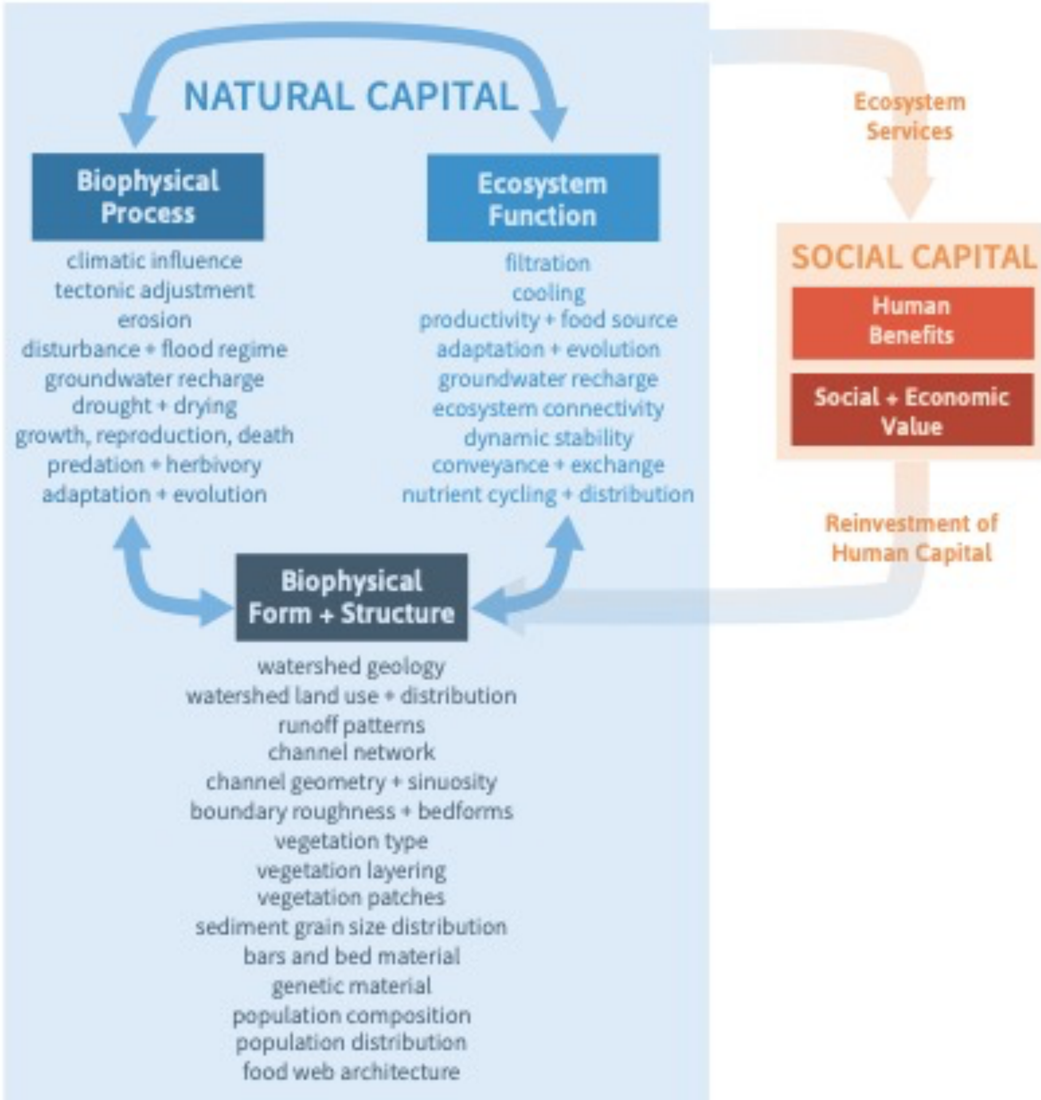

Figure 2-8. **The restoration of natural capital requires consideration of the biophysical form, structure and processes that interact to influence ecosystem function**. The degree that ecosystem function can be restored influences the social benefits derived natural capital. Structural and policy change, resulting from investment of financial and human capital, can be targeted to sustain ecosystem services of a watershed. Section 4 *How?* discusses this feedback loop as adaptive management.

2.3.2 KEYSTONE PROCESSES OF RIPARIAN ECOSYSTEMS

2.3.2.1 Keystone processes to restore Walnut Creek's watershed

Restoring wild salmon runs requires restoring the biophysical processes that support the full lifecycle of Chinook salmon and steelhead. These processes support other native species, whether flora or fauna. More robust populations of native species, adapted to the biophysical processes of unaltered watersheds, should be better able to outcompete exotic species, which are adapted to and more tolerant of degraded conditions of urban watersheds. Without restoration of natural disturbance processes (which tend to favor native species), restored channels whose form is mechanically restored will be vulnerable to invasion by exotic species.

Invasive species can alter aquatic and terrestrial food chains, water quality, flood behavior, often in unpredicted ways that can lead to species extinction and unforeseen management challenges and costs (Fausch and Garcia-Berthou, 2013; Moyle, 2001).

In Walnut Creek's watershed, restoration approaches should consider the keystone processes that sustain riparian ecosystems: appropriate hydrologic connectivity across the watershed and seasons, a natural flow regime, stream power and sediment load (*Figure 2-9*).

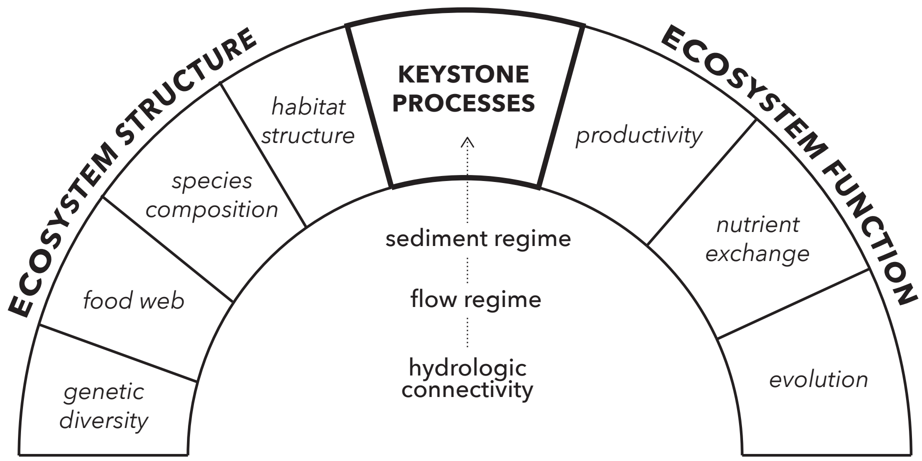

Figure 2-9. **Keystone Processes of Freshwater Ecosystems** have an outsized influence on riparian ecosystems. In this conceptual model, the keystone processes uphold ecosystem structure and function. Without the keystone process, components of the ecosystem will collapse (adapted from Ganguli et al., 2008).

2.3.2.2 Natural Flow Regime

The range of flows conveyed by a channel over time is driven by the hydrology of the contributing watershed and characteristics of the channel system (*Figure 2-10*). Flows across a watershed also erode, transport, and deposit sediment, forming channels, floodplains and terraces, which in turn influence the assemblages of life – flora, fauna and human occupation – within a watershed.

Streamflow can be characterized by magnitude, duration, frequency, timing, and rate-change of flows (Naiman et al., 2008; Poff et al., 1997). The range of flows that act upon a channel is influenced by the regional climate and geology, soils, vegetation, drainage patterns, and land uses throughout the watershed. As any of these elements change within a watershed, so does the flow regime and thus the forces exerted on a channel, the reach of flood flows, and the transport and sorting of sediment through a watershed's conveyance network. Channel form can shift in subtle or dramatic ways, depending on the extent and character of changes to the flow regime and the ability of the channel to adjust.

In many streams, the flow regime has been altered by dams (for water storage, flood control, or hydropower), diversions of streamflow (for water supply), and urban land uses that tend to convert formerly vegetated, infiltrative soils into paved and built surfaces that directly drain into pipes and confined channels (Kondolf et al., 2012). Freshwater ecosystems have evolved with and are shaped by historical patterns of water flow. Flow modification, whether by dams or urbanization, has cascading effects on the process, structure, and function of rivers (Poff et al., 1997; Richter et al., 2003). Across California, groundwater drawdown, reduced baseflows, increased stream temperatures, accelerated erosion and sedimentation, simplified in-stream habitat, and migration barriers, have resulted in collapsed fisheries, increased invasive species, and led to multiple species extinctions (Mount et al., 2012; Moyle et al., 2017, 2011).

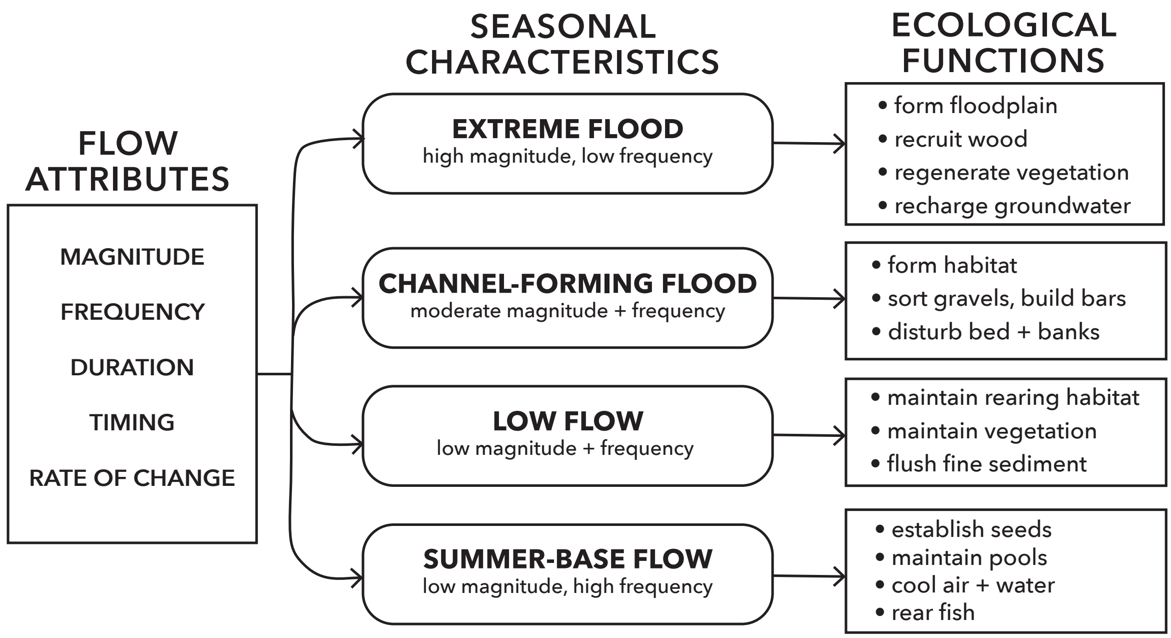

Figure 2-10. **Attributes of the Natural Flow Regime** and their influence on ecological function (adapted from Beechie et al 2013 and Poff et al 1997).

2.3.2.3 Natural Patterns and Functions of Riparian Ecosystem Connectivity

Ecosystem productivity is primarily driven by access to light, water, and nutrients -- often occurring in seasonal patterns with episodic disturbance over time. The availability and flow of water and sediment through a watershed regulate the transfer of energy, nutrients, and organisms. These paths form networks, which may be continuously or periodically connected. This network of water, nutrients, and organisms can be described in terms of connectivity in three spatial dimensions: longitudinal, lateral, and vertical connectivity (Kondolf et al., 2006).

Longitudinally, the drainage network of perennial stream channels forms a connected flow path from channel headwaters to the river mouth. The delivery of nutrients into estuarine deltas fuels primary productivity, supporting the base of the food chain. Longitudinal connectivity supports the upstream migration of salmonids, who deliver marine-derived nutrients into terrestrial ecosystems. In contrast, intermittent or episodic channels support seasonally disconnected flow-path that can isolate organisms but also support a unique assemblage of endemic, adapted species. Flood pulses introduce disturbance along longitudinal flow paths. Longitudinal connectivity can be interrupted by dams, weirs, undersized culverts, or even bridges. Migration can also be blocked by extremes in flow velocity, insufficient flow depth or oxygen, lethal stream temperatures, or reaches where organisms would be subject to stress, such as increased predation, extreme exertion, or insufficient food.

Laterally, flood pulses intermittently connect materials, organisms and nutrients between stream channels, oxbows, floodplains and riparian forests. Alluvial channels typically flow overbank with relatively frequent floods (e.g. less than five-year recurrence interval), creating a regular lateral connection with off-channel habitat, filtering water through sediment and vegetation but also providing refuge and food sources for aquatic organisms.

Vertically, exchange of stream flow with groundwater and the hyporheic zone (shallow water interstitial to streambed gravels) influence temperature, nutrient cycling, primary productivity, and thus, habitat. Upwelling regions of streambeds, often cool flows, providing important temperature refugia for salmon, and are hotspots of productivity, fueling microbes, benthic invertebrates, and interstitial fauna (water mites, isopods, amphipods) with food and nutrients (Sophocleous, 2002). In unaltered channels, vertical connectivity of in-stream flow is enhanced by hydraulic gradients created by bedforms, heterogeneous sediment permeability or upwelling groundwater. Water table draw down, incision of stream channels, and simplifying or silting of streambeds suppress vertical connectivity (Boulton et al., 2010; Woessner, 2005). Concrete beds eliminate it. Reduced opportunities for in-channel hyporheic exchange can increase water temperatures and reduce dissolved oxygen. These critical variables control the fate of salmon spawning, egg incubation, rearing of young, and survival in locally-cooled thermal refugia from high summer temperatures (Baxter and Hauer, 2000).

More broadly, vertical connectivity affects decomposition rates of organic material in soils and streams, and even flow stage (Baxter and Hauer, 2000; Kondolf et al., 2006). In urbanized watersheds, limited inundation area, residence time, and infiltration can reduce groundwater recharge with subsequent influence on baseflows, stream temperature, and solute delivery to streams. Although imperceptible and often disregarded in engineered flood infrastructure (and even stream restoration), disrupted vertical connectivity presented by hardened and simplified channel beds, concrete culverts, placement of over-sized gravels, and excessive fine-grained sedimentation affect the assemblages of in-stream biota, altering food chains and creating homogenized conditions that may favor invasive species (Boulton et al., 2010) with potential regional implications for the SF Bay and the Pacific Coast as species migrate and organisms disperse with flows and our region's strong ocean currents.

2.4 WHAT IS POSSIBLE?

2.4.1 SUITABILITY OF RESTORATION APPROACHES

For a given stream reach, key factors that determine what is possible to restore include the degree of channel alteration and urban encroachment. These human interventions constrain the lateral connectivity between the channel and its floodplain, the longitudinal connectivity of the reach to SF Bay, and the capacity of the stream to convey and rework sediment. Depending on the degree that constraints of encroachment and connectivity can be overcome, some restoration approaches may be more suitable than others (*Figure 2-11*).

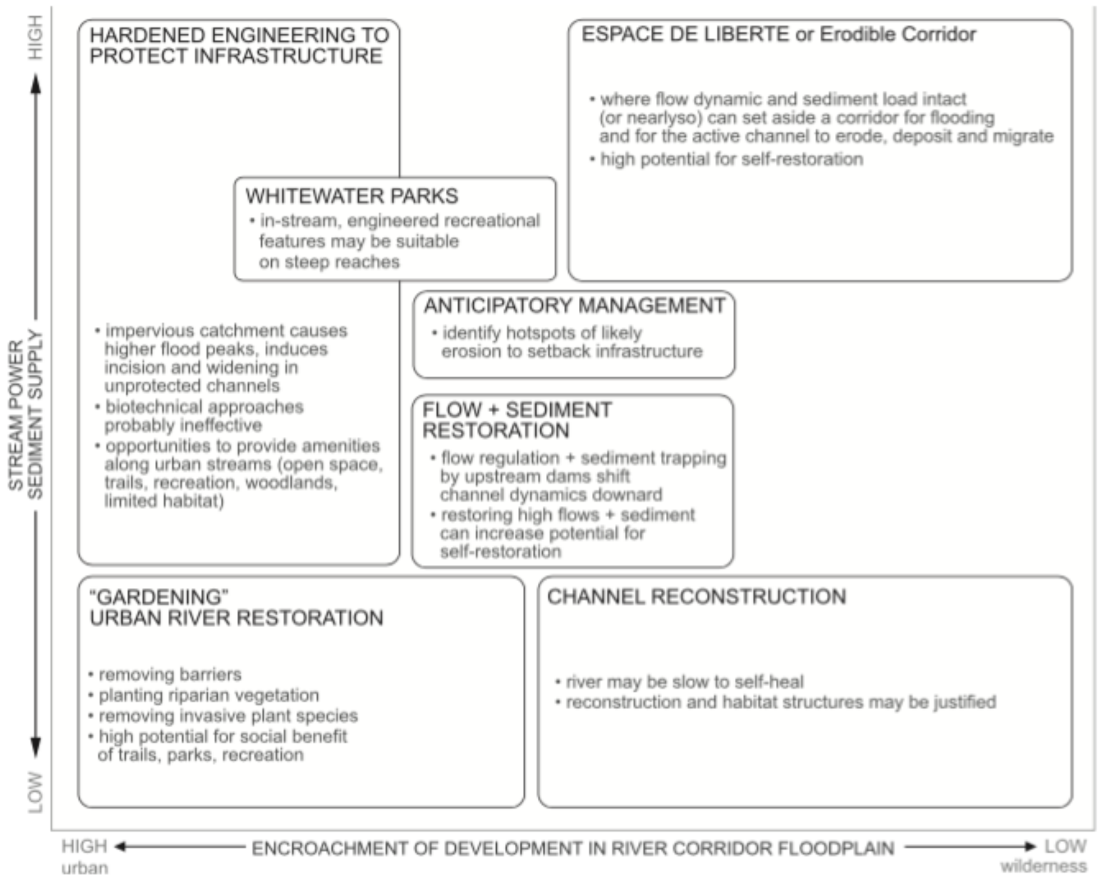

Figure 2-11. **Suitability of Restoration Approaches** organized by process-based opportunities (y-axis) against constraints of land use and urban infrastructure (x-axis). Figure from Kondolf et al. (2011)

Where a dynamic flow regime, high stream power, and sediment loads remain unaltered by dams ("high" on y-axis), approaches to process-based restoration have more potential for synergistic social and ecological benefits. Where constraints encroach on channels and floodplains ("high" on x-axis), approaches often focus on social enhancements to provide amenities (lower left) and engineering infrastructure to protect urban investments (upper left). Relaxing constraints of encroachment by opening accommodation space for dynamic processes of flooding (moving x-axis to the right) can increase opportunities for process-based restoration. If stream power is low (e.g. due to influence of dams) and urbanization constraints remain, social and habitat enhancements may be the only recourse.

Where dams have not impacted the flow and sediment regime, channel reconstruction may allow natural processes to sustain riparian ecosystems (lower right), especially when the impacts of urbanization on flow and sediment regimes are mitigated at the watershed scale (center). Where stream power has capacity to deliver and rework sediments and there's room for natural processes drive channel dynamics, some reaches may retain capacity to restore and sustain themselves (top right). Rather than using drop structures to manage energy of streamflow, steep reaches in urban areas can be managed for fish passage, recreation and aesthetics.

2.4.2 CONSTRAINTS TO PROCESS-BASED RESTORATION OF RIPARIAN ECOSYSTEMS

Though the Fifty-Year Plan promises to change the imprint of flood infrastructure, encroaching structures, maladapted floodplain land use, and urbanized watersheds remain primary constraints on restoration opportunities. They present barriers to increasing connectivity because built structures not only take up space, but create a network of impervious surfaces and require flood protection. To explore opportunities to unravel this dilemma, we outline the specific ways that human alterations to channels, floodplains and the watershed limit the keystone processes that sustain freshwater ecosystems of Walnut Creek.

2.4.2.1 **No lateral connectivity of flood flows** with floodplains or off-channel habitat.

Flood control channels are designed to convey high flows, without overbanking to allow urban development on the floodplain. This means overbank flows cannot spread out on floodplains, so we lose the effect of reducing downstream peak flows and deposition of sediment and nutrients in floodplains and riparian zones. Potential off-channel habitat exists on Ellinwood Creek, but is hydrologically and physically disconnected from mainstem Walnut Creek by I-680.

2.4.2.2 **Flood control structures confine and harden channel boundaries into homogeneous, smooth and immobile surfaces**.

Armored channel beds protect channels from erosive flows. They also reduce or eliminate the influx of groundwater into stream channels, reducing potential for recharge or for creating thermal refugia, a critical issue for fish, as stream temperatures in the lower reaches of Walnut Creek exceed 70 degrees Fahrenheit each summer (beyond the lethal threshold for native salmon species). The smooth surfaces of concrete channels allow for high velocity flows and narrowed channel footprints. High velocities also flush fish downstream and out of the channel. Flood infrastructure not only degrades or eliminates habitat for native species, but it also creates conditions that favor exotic species and likely reduces the abundance wildlife by paving over substrates and flushing water out of the watershed.

2.4.2.3 **Urban hydromodification across the watershed alters the flow regime and geomorphic processes** by intensifying overland flow and flood peaks, and reducing water retention, storage, infiltration, and groundwater recharge – especially for frequently-occurring storms.

Unlike many of the larger rivers contributing to SF Bay, Walnut Creek's hydrograph retains a flood pulse. With few dams limiting contributing areas, flow variability and floods exist. The flow regime is modified, however, because impervious surfaces of roads, buildings, sidewalks, and parking lots prevent interception and infiltration of rainfall (*Opportunity Atlas Map W-4*). Without access to soils and vegetation, precipitation quickly accumulates on built surfaces, producing runoff. Local stormwater drainage systems often directly convey this runoff into creeks, increasing peak flows for common storms (all but the most saturated watershed conditions), and connecting diffuse sources of pollution directly to channels.

Up to 70% of Walnut Creek's watershed remains unprotected from development (Walkling, 2013). At full build-out of all land within the urban limit line, the watershed's total impervious cover could reach 30% (Walkling, 2013). At this degree of urbanization, stream habitat quality degrades, sensitive species cannot survive and the abundance of aquatic life may decline, though tolerant exotic organisms may persist, even if channels are restored to 'look natural' (*Figure 2-12*) (Schueler, 2000). Impervious surfaces of buildings and pavement reduces interception of rainfall by trees and soils, and blocks the infiltration of water into soils and aquifers. When runoff pathways connect, as directed by downspouts and gutters, street drainage and storm pipes, flows capture pollutants, delivering more water with more contaminants into stream channels with no opportunity for retention, settling, or filtration. The resulting increase in peak flows not only exacerbates floods and degrades water quality, but also exposes channels to increased erosive forces, altering habitat in ways that disturb the lifecycle of native salmon and favor invasive species (Shuster et al., 2005).

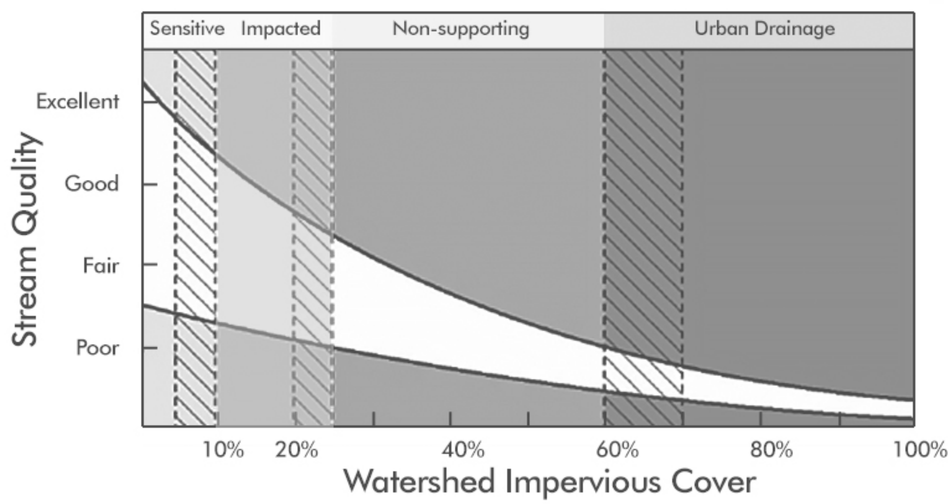

Figure 2-12. Stream Quality Degradation with Impervious Surface Cover. In this conceptual model, stream habitat quality degrades with increasing impervious cover in the contributing drainage area (or watershed), not linearly, but with threshold effects that push aquatic ecosystems into distinct states of degradation. Generally, at 10% impervious surface cover, channels demonstrate instability and adjustment, and pollutants begin to impact sensitive species. Beyond around 25% impervious cover, stream habitat quality is considered "poor" or "non-supporting" such that native biodiversity decreases unless intensive mitigation efforts employed. Different subwatersheds and aquatic communities respond differently to increasing impervious cover, so thresholds between ecosystem states may also differ. In the figure, this variability is represented as hashed vertical thresholds and a white cone. As impervious surface cover increases, the cone narrows, such that beyond 60% cover, poor quality dominates, no matter the mitigation measure (Schueler, 2000; Schueler et al., 2009).

The increase in peak flows due to urbanization may have less impact on severe storms, when soil conditions reach saturation over larger areas, and generate overland flow across the watershed. When urbanization increases peak flows for common storms, channels experience deeper flows more often. Deeper flows generate greater shear stress, the erosive force on channel beds and banks, influencing the geometry and bed characteristics of unrevetted channel boundaries and possibly introducing more opportunities for flanking or scouring engineered structures. Over time, higher peak flows alter in-stream habitat and can lead to the self-reinforcing process of channel incision, a characteristic of degraded urban streams. Even if urban hydromodification does not increase flood risk for severe storms today, as sea levels rise, nuisance flooding for frequent storms may be exacerbated by the unmitigated effects of increased peak flows.

2.4.2.4 **Flood infrastructure blocks fish migration.**

By disrupting longitudinal connectivity (along the channel network) between habitats (see *Opportunity Atlas Map W-3*), flood infrastructure limits wildlife migration. Kozlowski (2006, 2005) discusses impacts of infrastructure, especially drop structures, on salmonid migration in the watershed.

2.4.2.5 **Lack of riparian vegetation** and its influence on both in-stream and floodplain habitat formation, flow characteristics, and biogeochemical processes.

In altered channel reaches that lack shade, water temperatures in streams rise above threshold for salmon survival. The deep shade of riparian trees helps to keep water temperatures cool. Reduced light input reduces potential for growth of toxic algae, a nuisance and potential danger to people and their pets.

2.4.2.6 **Alteration of the sediment regime**.

By limiting interaction of flows with free channel boundaries, hardened flood infrastructure likely limits gravel supply (for benthic life and salmon spawning). Extreme flow volumes and velocities likely alter gravel transport. Impervious surfaces and runoff from roads likely increase fine sediment loads, especially at lower flows (due to human disturbances), which can result in burying any remnant gravel bars or smothering of organisms in the bed.

2.4.3 RESTORING CONNECTIVITY

Lateral connectivity between stream channels and terrestrial uplands occurs across the riparian zone, a periodically flooded region (Naiman et al., 2010). The shifting patches of wetland habitat in riparian zones maintains a disproportionate share of a region's biodiversity. With an undisturbed flow and sediment regime, the timing, intensity, frequency and duration of flooding, scouring and sediment deposition favors regeneration of native species and limits invasion by exotic species (Naiman et al., 2010, 1993; Steiger J. et al., 2005).

Where flooding is blocked by flood control structures, riparian zones are much reduced or no longer exist. Along Walnut Creek and many other streams, the former riparian zone has been converted to urbanized land use, a pattern that has led to a regional collapse of native species dependent on processes, connectivity, and disturbance of flooding in riparian zones. The disconnection of floods from floodplains and conversion of habitat area are mutually reinforcing phenomena, the other as the local and short-term value of developed floodplains promotes flood control and flood control leads to loss of biodiversity and connections to freshwater ecosystems.

Along altered channels, lateral connectivity of channel-to-floodplain habitat is blocked by culverts, levees, steep (if not vertical) and armored bank walls, and miles of industrial-strength chain-link fencing. This dis-connectivity isolates populations of amphibians and reptiles from water sources and other populations, reducing available habitat and genetic diversity of populations. Social connectivity to channels is also blocked, not only by the danger of flood infrastructure, but also by private parcels along the channel.

Restoring lateral connectivity between a channel, its banks, and floodplain would require:

- ***Allowing periodic overflow of channels*** (e.g. once every few years) onto a broader area that can tolerate inundation without posing danger to people or harm to built structures;
- ***Reconfiguring channel cross section dimensions and roughness*** to reduce extreme in-channel flow volumes and velocities that create excessive erosive forces on bed and banks;
- ***Making room for wider channel cross-sections*** to accommodate increased resistance to flows (e.g. along the channel's bed and banks)
- ***Removing bank revetments*** that prevent interaction of flows with erodible banks;
- ***Allowing vegetation growth*** along channel banks to interact with both erosive forces and sediment deposition of flows in ways that influence cohesive strength of bank material and provide protective cover and habitat;
- ***Educational programs*** to help people understand the opportunities and risks of lateral connectivity.

Longitudinal connectivity along the channels network is disrupted by three upstream tributary dams (which disconnect headwater sources of flow and sediment supply), a series of over 20 drop structures on mainstem reaches of Walnut Creek and its major tributaries, high flow velocities designed to convey high flows through narrow channels, channel reaches that dry out in summer because they lack pools to maintain perennial water, and backwater conditions at undersized bridge crossings.

High velocity flows through hardened channels and hydraulic control structures influence longitudinal connectivity by limiting species movement and sediment transport through the channel network. Flood control structures impede migration of salmon, such that migratory populations are now limited to the lower six miles of Walnut Creek with occasional observations in Pine and Grayson Creeks (Kozlowski, 2006; Walkling, 2013). Restoring longitudinal connectivity for salmon migration will require modification of drop structures (*Figure 2-13)* and reconfiguring channels to eliminate or reduce constricted, high-velocity, low-light reaches that fish cannot endure.

Historically, the lower Walnut Creek channel network may have experienced disconnection of flows resulting from active tectonics. As headwaters to San Ramon Creek cross the Calavaras Fault, they traverse alluvial fans whose high infiltration rates and sediment deposition may have cut off continuous surface flow. At the downstream end of Walnut Creek, historical maps, observational accounts and soil studies indicate an alkali meadow once covered a broad area as multiple tributaries met the head of tide (Dusterhoff et al., 2016). This region coincides with tidal base level control, but also an area of active creep on the Concord Fault, where right-lateral surface movement (horizontal, not vertical) recorded at rates of 2.9 to 3.9 mm/yr over the past 30 years (Galehouse, 2009) (*Opportunity Atlas Map W-1*). The alkaline soils indicate an area of evaporation in the low-gradient reach where Walnut Creek reaches sea level, suggesting the creek's outlet to Suisun Bay may have closed in some dry years. Tidal influence, upwelling of groundwater along the fault, or even incoming waves may contribute to sediment deposition, inlet closure, and backwater conditions – both historically and today. The area of former alkaline wetland and channel disconnectivity coincides with current, problematic sedimentation of the engineered channel (Copeland, 2012). As the District considers restoration approaches in lower Walnut Creek, flow discontinuity and backwater conditions deserve further study to understand potential processes to restore and risks to address, especially in the face of future sea level rise.

Figure 2-13. **Confluence Park on South Platte River** in Denver, CO receives accolades as a "top 10" destination in the city for its water-based recreation and connectivity to trails, restaurants, shops, and services. The grouted rock construction of five Class III whitewater features also serve to dissipate an eight-foot hydraulic drop over a 400-foot river reach. Constructed in 1995, the park has served visitors for over thirty years "without serious injury" or "significant bed degradation" and "virtually no maintenance cost (Merrick, 2019)." As infrastructure ages, transformations of channels and drop structures in Walnut Creek's watershed become opportunities to support multiple ecosystem services within engineered channel infrastructure through urban areas. Services of creeks can include play and communal celebration of creek corridors as public aquatic parks while also allowing fish passage and promoting flood safety. Precedents for multi-functional planning of urban river corridors, such as the greenways being integrated with development along Denver's South Platte River, deserve further consideration (*Appendix E*).

Along the former riparian corridor, once lined with walnut and oak trees, isolated patches of riparian trees remain and may not be able to regenerate or spread due to lack of flooding. These patches may serve as potential expansion points for restoration, and thus merit conservation and further study. Without a connected corridor, riparian birds lack sufficient habitat, reducing their abundance and species richness (Hilty et al., 2006). Fragmented habitat results in isolation of species and leads to declining populations. While islands of core protected areas can support a few species, connectivity is critical to supporting lifecycle requirements via movement, genetic dispersal, and avoiding extinction (Hilty et al., 2006).

In conserved uplands beyond the urban limit line, connectivity along riparian corridors still exists, though interrupted by culverts, road crossings and likely affected by 200 years of cattle grazing that continues today. In these isolated upland corridors, hillslopes supply sediment via landslides, an important, though intermittent, source of stream gravels that also poses threats to people (Graymer and Godt, 1999). Land conservation addresses both concerns and should be continued, if not expanded, in areas surrounding hollows and canyons prone to debris flows and slope failure.

At the watershed scale, the increase in connectivity and drainage density by urban impervious surfaces and piped stormwater systems affects flow regimes, especially for frequent storms, with implications for geomorphic stability of restored channels.

Vertical connectivity between channels and groundwater is blocked in reaches with concrete beds, where the high velocity and throughput of flood flows minimizes retention time, eliminating opportunities for groundwater recharge in losing stream reaches. For salmon, groundwater upwelling of cool water into deep pools provides critical habitat during hot summer months. Prior to colonial settlement and channel alteration, summer baseflows in lower Walnut Creek became discontinuous, with small isolated pools providing refugia for aquatic life, as the creek became naturally disconnected from Suisun Bay (Dusterhoff et al., 2016). In addition to vertical *hydrologic* connectivity, light and nutrient availability (i.e. inputs from the airspace above the channel) govern primary productivity and ecosystem function. Urbanization and channel alteration have affected distribution of sunlight and shade, and inputs of organic matter as well as pollutants.

At the watershed scale, vertical connectivity is reduced by impervious surface cover, which blocks infiltration and increases runoff. Replacing impervious surfaces with vegetated surfaces can increase retention, infiltration, evapotranspiration, nutrient cycling, and groundwater recharge.

2.4.4 SOCIAL LIMITS ON RESTORATION POTENTIAL

Today, as the County faces the problem of aging infrastructure and its unanticipated cascade of environmental and monetary costs, local decision-making should be informed by a full accounting of diverse perspectives on the scope and context of the problem and alternative solutions, with public input and facilitated dialogue to assess social factors that limit the restoration potential (see Section 4, *How?*). The following observations serve as a starting point for deliberation by the District and future conversations with communities and focus groups.

2.4.4.1 **Creek channels can no longer sustain themselves**.

Engineered channels require periodic, costly reconstruction but only provide a single benefit: flood protection that primarily serve the interests of parcel owners in the floodplain. The limited lifespan and costs for periodic reconstruction have not been addressed until the Fifty-Year Plan.

2.4.4.2 **The built environment relies on current flood protection infrastructure**.

Within the floodplain, development has not been designed or constructed to tolerate flooding, erosion or deposition. Landowners with parcels within the historically active floodplain depend on flood protection to retain property values. Investments outside of the FEMA-designated 100-year floodplain are assumed to be safe, and no flood insurance or flood risk disclosures are required for landowners. Within the 100-year floodplain, FEMA's National Flood Insurance Program (NFIP) offers guaranteed, subsidized flood insurance with discount rates varying by levels of community participation in the NFIP Community Rating System (CRS).[6]

The current value of durable private investments (structures but not contents) on property within the FEMA-designated 100-year floodplain of the five municipalities wholly contained within Walnut Creek Watershed (including Concord, Danville, Lafayette, Pleasant Hill, and Walnut Creek) totals $1.17 billion. For the 500-year floodplain within these municipalities, the estimated value of structures reaches $2.8 billion (Tetra Tech, 2018, Table 9-10 + 9-11). This does not account for the value of the undeveloped property.

Transportation infrastructure within floodplains serve the entire watershed community. Disruptions affect safety, disaster response and the local economy. In a model of a 1-0.5% chance annual flood over the San Francisco Bay Area with a maximum observed tide, I-680 was among the top-three most affected interstate highways in the region (Randolf et al., 2015, p. 35). The critical public service of sewage and wastewater treatment occur in zones susceptible to coastal and riverine flooding in lower Walnut Creek.

Over the history of flood infrastructure design and construction in Walnut Creek's watershed, federal flood infrastructure programs have provided funding, standard practices, cost-benefit analysis, engineering expertise, and insurance with a mission to keep local communities safe from floods. With the promise of protection from natural hazards, these federal programs encouraged development of floodplains. We now understand that increased development in floodprone areas increases exposure to floods in local communities, and thereby increasing flood risks (Birkholz et al., 2014; Birkland et al., 2003; Ciullo et al., 2017; Hanak et al., 2010). Federal support subsidized floodplain development, a boost for local economies in the decades following construction of flood infrastructure, but disregarded long-term consequences of increased flood risk and a cascade of environmental impacts (Rosenbaum, 2005).

[6] For instance, landowners within the designated "1% chance annual flood" area in unincorporated Contra Costa County receive a 25% reduction in premiums program (out of possible 45% discount) due to the County's "Class 5" rating in FEMA's CRS program (FEMA, 2018)

Today, regional planning efforts push to increase density of development on the floodplain (coinciding with the location of major transportation corridors and hubs) as revealed by the location of "priority development areas" within the current and historical floodplain (*Opportunity Atlas Map W-3*). Without attention to adaptation to future risks, increased investment to develop structures on floodplains leads to increased reliance on aging infrastructure that requires costly reconstruction, introduces residual risk, destroys habitat, and threatens regional biodiversity. In our analysis (see Section 3 *Where?*), we considered the projected increase in density of development and people in priority development areas as an opportunity for increased social and ecosystem connectivity of restored creek corridors. This assumption rests on the question: with regulated planning and design, could these areas of floodplain redevelopment support more people (and thus exposure to floods) with a balance of public access to "nearby nature" via expanded and restored riparian corridors that make room for safe, and even beneficial, conveyance of floods?

2.4.4.3 **Enduring investments on private parcels along altered channels and within the floodplain are not easily changed**.

Landowners seek stability or growth in the dollar value of private parcels and on-site investments. They expect property boundaries and neighborhood character to remain fixed (Plate, 2002). Municipal budgets rely on property tax and retail sales tax supplied from parcels on floodplains. These losses may be offset by benefits from increased use of restored creek corridors, increased sales tax revenue from new businesses, and increased diversification of economic activity with a more robust outdoor recreation industry that leverages public investment in riparian corridors (see *Appendix D3*).

2.4.4.4 **An over-simplified framing of flood risk**, promoted by policies and programs from the federal to local level, creates a false sense of security and thus increases community exposure and vulnerability to unanticipated, unmitigated hazards.

Since the 1950s, federal engineering programs design structural flood control projects to convey a maximum flood probability in simplified terms (i.e. up to a 100-year flood, but not beyond). For cost-benefit analysis, exposure is estimated as the total dollar value assigned to expected property damage, loss of life, and economic disruption. Current flood infrastructure standards and insurance programs often fail to consider:

- Residual risk of damage from flood greater than the design standard (usually 100 years), which is unmitigated;
- The broad range and unequally distributed consequences of unmitigated flood hazards;
- Compound hazard or infrastructure failure scenarios;
- The perception of reduced risk supports floodplain development and increased exposure to unmitigated risk ;
- The maintenance and repair needs and costs to ensure infrastructure performs to standard;
- Environmental (and subsequent social) consequences of flood infrastructure (ASFPM Foundation, 2004; Ciullo et al., 2017; Green, 2004; Hanak et al., 2010).

As floods have affected U.S. cities in unexpected and inequitable ways, flood policies and standards have not sufficiently evolved in light of unconsidered, but realized risks (Galloway, 2008; Green, 2004; Hanak et al., 2010). Many consider oversimplified "100-year flood protection" standards insufficient for urban communities (ASFPM Foundation, 2004; Galloway, 2008). In 2007, California enacted state law to increase flood frequency standards to the 200-year flood for cities in the Central Valley (SB5, 'The Central Valley Flood Protection Act'). Local and regional policies continue to allow, promote and subsidize investment in and construction of new and infill development within floodplains despite rising risks.

2.4.4.5 **The community does not understand the benefits versus costs of current flood infrastructure across its entire lifecycle**

Today, community discussion and decisions that guide replacement of this aging infrastructure must reckon with the simplified assumptions and unanticipated local changes that cascaded from this massive investment and its physical imprint within the watershed, largely funded by federal dollars and supported by federal programs.

A community-based assessment (i.e. that accounts for diverse perspectives, not only technical expertise) could support efforts to weigh alternative restoration approaches against the status quo. Without a full and fair assessment, based on available data, the community lacks a basis for decision-making.

The life, biodiversity, and services that creeks and riparian ecosystems offered to the local community (such as salmon runs or groundwater recharge) were not considered as a sacrificed benefit opportunity cost) when flood infrastructure was built. Even today, federal policies, programs, standards, funding, and expertise still fail to consider this full and cascading range of costs and benefits over the lifetime of a project. The impacts of floods versus the impacts of flood infrastructure from the 1950s through today can be chronicled as a social and ecological history with costs and benefits weighed or even calculated to project the benefits versus costs of flood infrastructure over its life cycle. The community holds many forms of data to analyze: precipitation and hydrologic data, property sale values and permit histories, disaster response accounting and investments (both official and private), the District's archives, aerial and remote sensing data, local newspaper accounts, oral and photographic histories, regional fisheries and aquatic ecology studies, anecdotal observational and experiences. This data records the repercussions of flood infrastructure, the community's response to floods and how flood infrastructure influences everyday life in floodplain neighborhoods or even regionally in terms of people's livelihoods (e.g. fisheries). The data may record gaps and disparities in level of protection or access to resources. Our spatial analysis (Section 3 *Where?*) begins to consider available data.

An accounting should consider that one value or cost does not fit all. Different stakeholders may have different values and thus different valuations of worth or cost for different forms of infrastructure and management regimes for local creeks and the watershed. Eliciting these differences can form the basis for community dialogue on the future of their creeks, riparian zones and watersheds.

2.4.4.6 **Local citizens remain unaware of risks, issues and opportunities** surrounding former creek channels, the need for infrastructure replacement, and potential for restoration of ecosystem services.

Surveys of local residents reveal that flooding does not rank as a broad or strong concern (see Section 1.2.1.2) (Metz, 2015), which can be attributed to the success of the existing flood control structures in preventing flooding in recent decades. Current programs have not communicated rising risks and uncertainties as floodplain investments increase, infrastructure ages and our climate changes (Hanak et al., 2010; Randolf et al., 2015). Globally, recent disasters have reduced confidence in structural approaches to flood infrastructure and oversimplified risk framing, leading to a call for improved communication of risk and uncertainty by moving away from the paradigm of ensured safety to more transparent, precautionary "risk culture" that embraces land-use planning for living with floods (Garrelts and Lange, 2011).

2.4.4.7 **Few regulated incentives or drivers** to support the scale and scope of transformation needed for process-based restoration and land use change.

Few to no institutions, regulatory drivers, programs, or funding sources currently exist to promote process-based restoration. Current flood infrastructure design, local policies, and the national flood insurance program continue to encourage enduring investment and development in exposed properties despite increasing risks, and loss of other values of natural creeks.

Environmental regulations often fail to address legacy impacts of infrastructure constructed prior to enactment of protective legislation. Current planning, funding and regulatory structures do not support watershed-scale planning.

Outside of the Municipal Regional Stormwater Permits and the County's Clean Water Program, few to no regulatory drivers, funding sources, or programs exist to retrofit existing development patterns throughout the watershed (e.g. buildings, pavement, and highways) and address urban hydromodification that increases the erosive power and pollutant load of streamflow. Stormwater programs and facilities have been underfunded for decades (Avalon 2014).

Policy now requires mitigation of urban hydromodification for new development, but not existing development. Green infrastructure planning requirements, set by the SF Regional Board as part of municipal regional stormwater permits (provision C.3.j of MRP 2.0) have a narrow and prescriptive scope, focused on reducing concentrations of mercury and PCBs in urban runoff (MRP 2.0 Table 11.1, 12.2). Over the long term, the provisions, tools, and timelines offered by the SF Regional Board aim to promote treatment of stormwater through infiltration, evaporation, and transpiration of water of appropriately sited and selected stormwater treatment measures. In theory, these plans and practices can support stream restoration, but funding to support planning and implementation is left to "alternative compliance funds, grant funding…new taxes or levies (California State Water Resources Control Board, San Francisco Bay Region, 2015, p. C.3.j.iii.(1))", which remain elusive without costly analyses and planning to identify the most cost-effective, locally -appropriate measures.

2.4.4.8 **The division of institutional missions** across different sectors, regulations, and funding allocations do not support multi-functional approaches to infrastructure, management or restoration.

Distinct agencies and funding streams are responsible for water supply, wastewater, stormwater, fisheries, environmental protection, transportation, and recreational facilities. Silos of expertise is recognized as a key barrier to multifunctional restoration.

Integrated Regional Water Management Plans (IRWMP), a regionally based program established in 2002 at the state level to incentivize and secure funding for integrated water resources management, has focused on prioritization, funding, and implementation of coordinated projects in the nine-county SF Bay area. The sequencing, requirements, and political aspects of the review and funding process, however, have limited funding for watershed-scale planning. Water districts have the highest participation and funding rates (Lubell and Lippert, 2011).

2.4.4.9 **Private property rights may assert privilege** in hierarchy of rights, such as the right to beneficial uses of water.

Floodplain landowners face few restrictions regarding flood-appropriate uses or building codes or regulation to limit encroachment or expansion of structures. Previously developed parcels within the watershed are not subject to stormwater regulation.

2.4.4.10 **The community has lost connections with creeks,** concern for flood risks, and awareness of potential ecosystem services from their watershed.

People have lost connections to creeks, their seasonality, resources, sensory experiences, and the health benefits of nearby access to nature. The local economy can directly benefit from ecosystem services provided by the watershed as outdoor recreation drives retail sales and businesses ventures via unique, local experiences that cannot be ordered online. In the Bay Area, outdoor recreation generates over $4.85 billion in expenditures (BBC Research & Consulting, 2011).

2.4.4.11 **Unexplored conflicting interests exist**.

Land-use interests in the floodplain versus uplands, and regulatory agencies and municipalities likely hold diverse perspectives on the appropriate form and function of future flood protection (see *Appendix C2* for an initial stakeholder analysis).

2.4.4.12 **Human tendency to prefer order and stability**. Change may be viewed as a risk in itself.

2.4.4.13 **No funding** set aside for restoration or reconstruction of flood infrastructure or watershed-scale green infrastructure for mitigating urban hydromodification at this time.

In 2012, Contra Costa Clean Water Program initiated a ballot measure to assess a $12 to $22 per residential parcel fee to fund stormwater management across the County. The measure failed with only 40% voter support, leaving the program underfunded. California's Proposition 218, which limits property-related utility service fees to water, sewer or trash collection, had strained

County resources for meeting stormwater discharge permit obligations since it passed in 1996 (CASQA, 2020a).

In October 2017, California Senate Bill 231 passed into law, opening potential for local funding of green infrastructure planning and projects to manage floods, runoff, and restoration of riparian ecosystem, by allowing municipalities in California to establish a stormwater utility fee, on par with water and sewer utilities which require public hearings and governing board approval (e.g. city council, county supervisors) to set property-based fee assessments to fund stormwater management. The establishment of a stormwater utility is no longer limited to a voter-approved ballot measure (CASQA, 2020b). The failure of the 2012 ballot measure and results of recent surveys (discussed Section 1.2.1.2) indicate that public outreach, education, and grassroots coalition-building may be needed before a self-imposed property-based fee for green infrastructure is politically viable. Section 4 *How?* describes a community-based planning process for the Fifty-Year Plan. More specifically, the California Stormwater Quality Association provides guidance on creating a stormwater utility (CASQA, 2020c) and precedents for funding stormwater management initiatives (CASQA, 2020a).

The economics of keeping up with the costs of regional stormwater management requirements versus funding the next generation of a multi-billion-dollar flood infrastructure, however, are not nearly equivalent. Understanding and communicating the multiple public benefits of restored riparian corridors through a community-based planning process represents a first step in this much broader, more intensive – but currently unfunded – investment.

2.4.5 ECOLOGICAL OPPORTUNITIES VERSUS SOCIAL CONSTRAINTS

2.4.5.1 Riparian Restoration with Flood Management

Flood control channels in Walnut Creek's watershed, whether they be constrained by concrete (*Figure 2-14A*) or earthen levees, have been narrowed and straightened from their historically dynamic, irregular forms. With development of the floodplain, private parcels house buildings and developed structures that abut the the top of channel banks. To convey extreme flows and prevent flooding of adjacent properties, engineers designed smooth straightaways so can flows run fast and furious, contained within channels without disruption. Between levees, earthen channels must be managed to keep channels open with maximal cross-sectional area and limited roughness. Periodic maintenance such as dredging of sediment and vegetation removal ensures channels can convey their expected flow volume capacity.

Roughness along the channel bed and banks slows flow velocities by generating friction and turbulence. In contrast to engineered flood infrastructure, unaltered channels feature mobile bedforms and banks, channel sinuosity, vegetation or downed wood. These elements disrupt the momentum of the streamflow. Because rougher channels slow flows, they require increased channel cross sectional area to convey the same flow volume conveyed by a smoother channel. The continuity equation, $Q = VA$, explains that the flow volume in a channel, Q *[volume per time],* is a product of its velocity, V *[length per time],* and the channel cross sectional area, A (Chow, 1959).

Figure 2-14. **Comparison of idealized pre- and post-restoration cross sections for Grayson Creek**. In A, the current concrete flood control channels have smooth, reinforced beds (to resist erosive flows) and vertical banks. Because flows are fast and dangerous, razor wire fences line the top of bank. Beyond this lie private properties and structures that require protection from floods. In B, an idealized restored cross section has free channel boundaries, vegetation, irregular form, gravel bars and pools, overhanging trees with potential to drop large branches, and more hospitable habitat for fish and wildlife. The increased roughness in B will slow in-stream flows and expand flow volumes. To prevent flooding of structures (i.e. on the right bank), the floodable area will need to widen considerably compared to A. The rougher the elements of the restored stream channel, the wider the floodable area will need to be.

Restoration of the free-boundaries, sinuosity, bars and dunes, and riparian vegetation of self-sustaining streams will increase channel roughness, slow flows and expand flow volumes compared to current flood control channels (*Figure 2-14*). To convey the same flood volume as current channels (e.g. a 100-year flood), restored and roughened channels must have a greater cross-sectional area which can be expanded by channel deepening or widening. Channels with greater depths have an increased force of water flowing over the channel bed, which increases the erosive potential of flow on channel boundaries. Highly erosive flows can reduce habitat quality, cause incision and bank failures, and often lead to engineered hardening of channel boundaries to prevent propagation of instabilities through the channel network. For instance, narrowed flood control channels often concentrate flows in a deeper channel with concrete or hardened boundaries to not only smooth flows for faster velocities, but also to prevent erosion. Restored channels that are widened and rougher, however, will spread and slow flows. As a restoration measure, widened rather than deepened channels could forego the engineering of armored channel boundaries that negatively affect habitat quality and require maintenance over limited lifespans.

2.4.5.2 Restoration requires widening channels and floodable areas

To restore streams, the floodable area will need to widen beyond the narrow confines of current concrete channels. Widened channels can accommodate expanded flow volumes over roughened channel surfaces and support lateral connectivity of flows. Private property and built structures along existing narrowed channels, however, would be in the way. To support widened and restored creeks, structures built along stream channels must either be removed or designed to accommodate flooding (e.g. elevated so that they do not block flows). Because climate change is expected to increase peak flows, restored streams must not only accommodate rougher channels and slowed flow velocities, but also be designed to accommodate larger, future storms.

To get an idea of how wide a restored, hydraulically rough channel will need to be, we can refer to the Manning equation[7], an empirical formula for uniform open-channel flow that relates roughness and flow velocity for a concrete versus restored channels. *Q* is discharge (or flow) in cubic feet per second, *V* is velocity in feet per second, *A* is channel cross sectional area in square feet, *R* is hydraulic radius (the cross sectional area divided by the wetted perimeter) in feet, and *S* is channel slope (feet/feet). Channel roughness is represented by a coefficient, Manning's *n*. Values of Manning's n cannot be directly measured, but must be back-calculated from measurements of all the other variables. From multiple empirically determined values of Manning's *n* for a range of channels, the hydrologist can estimate the Manning's n for a given channel by comparing the channel under study with photographs of channels whose *n* value has been empirically determined (Barnes 1967). For a smooth concrete channel, the *n* can be as low as 0.01, whereas complex channels with vegetated banks and gravel bars can exceed 0.05.

Using Manning's equation and simplifying assumptions (methods explained in *Appendix A2*), we estimated the change in channel width required for roughened channels compared to concrete counterparts in a small versus large tributary (e.g. East Fork Grayson versus Pine Creek) and mainstem Walnut Creek (*Figure 2-15* and *Appendix A2, Table 2*). For small tributaries with a channel capacity of 2100 cfs, the restored channel width could be 5 to 21 times the width of a concrete channel with the same capacity, depending on roughness characteristics (n=0.035 to 0.1). Similarly, a restored large tributary channel (5,100 cfs) could be 8 to 23 times wider and restored mainstem Walnut Creek (18,100 cfs) could be 7 to 26 times wider than a concrete channel. As channel width and roughness increase, flow velocities reduce by 73-93% (across all estimated scenarios). Restored channels with a wider floodable area and slower flows should require less rigid channel geometry and materials than current flood control channels. Current land use along concrete channels, however, constrains this possibility.

Modeling of flows under conditions of higher roughness values with scenarios that include compound channels (with low-flow channels flanked by low floodplains to accommodate high flows) or even flood bypass areas can provide more accurate estimates of the footprint required for wider, natural channels. In the meantime, county and municipal policies should be updated to define appropriate "no further development" setbacks for restored creek channels (discussed in Section 4, *How?*) based on the estimate that floodable areas will need to widen by 130-2050 ft, depending on channel type, if concrete channels are restored.

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7 $$Q = VA = \left(\frac{1.49}{n}\right) A R^{\frac{2}{3}} \sqrt{S} \quad \text{[U.S.]}$$

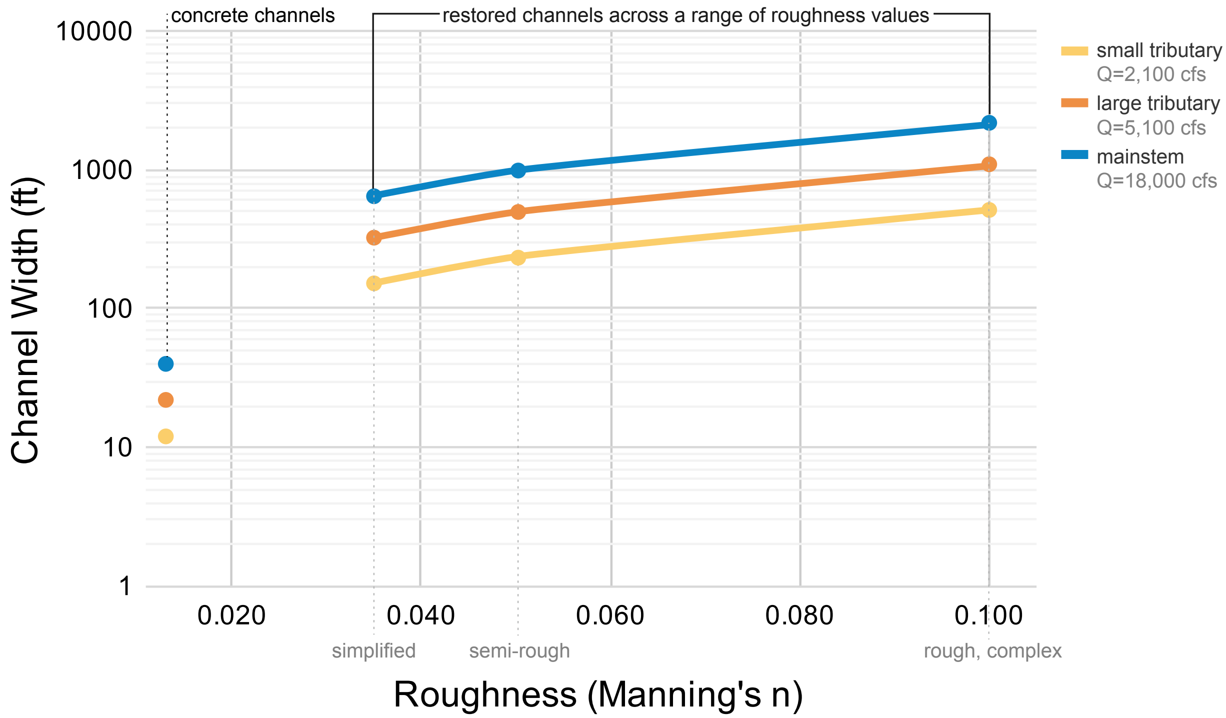

Figure 2-15. **Channel width for increasing channel roughness of concrete versus restored channels**. Across three different channel types (small tributary, large tributary and mainstem Walnut Creek), as channel roughness increases, so does the required channel width to convey the same flow volumes as a concrete channel. For a straightened concrete channel, Manning's n was estimated at 0.013. For a trapezoidal earthen channel with low sinuosity, no pools, little vegetation or irregularities, n might be 0.035. For the channel depicted in *Figure 2-14B* with an imagined sinuous channel forms, pools and gravel bars, willows and occasional large trees, n might reach 0.05 (or more) in low flows, but be reduced during moderate in-channel floods. If floodplain conditions are rough and complex, overbank flows could again increase roughness (Chow, 1959). Typically, n=0.1 or greater where channels have step-pool or cascading forms, which tend to occur upstream in steep reaches above the lowland flood control channels.

2.5 WHAT RESTORATION STRATEGIES TO PURSUE?

At this early stage in the planning process, when confounding constraints exist but the opportunity for changing flood infrastructure remains open, we encourage the District and community to explore a range of restoration approaches. To achieve the greatest social and ecological potential, several approaches deserve consideration as ideal long-term strategies, which may only be possible with strong stakeholder partnerships and grassroots community participation to consider, debate, and negotiate if and how land use change can best accommodate local needs and values.

2.5.1 STRATEGIES ACROSS SCALES

Our recommended strategies are based on the dilemma of flood risk and land use constraints, but also the opportunities to restore keystone processes that could support native salmon as "umbrella species" (i.e. restoring processes for salmon supports habitat needs for other native species) for the watershed. In theory, restoring processes required to sustain salmon populations should also sustain the diversity of native species, up and down the food chain, that evolved with the variability, disturbances, and dynamics that also keep invasive species at bay. As a communication tool, restoring for salmon as a "charismatic" or "flagship species" (i.e. a compelling and inspiring social target), may help the District communicate trade-offs across a range of restoration strategies, from aesthetic or social enhancements to more ambitious restoration of connectivity and processes required to support salmon (*Figure 2-7*). The six strategies defined in this section informed our analysis of restoration opportunities in Section 3 *Where?,* resulting maps in the *Walnut Creek Watershed Opportunity Atlas,* and discussion of next steps in Section 4 *How?*.

2.5.1.1 **Develop and communicate a watershed plan** of restoration objectives, strategies, and tools in partnership with community stakeholders.

Based on the value of floods and connectivity as keystone processes to restoring ecosystems, and the need to protect people from hazards of floods, we recommend the development of a watershed plan that explores, negotiates and reflects community values, objectives, and priorities for restoration.

2.5.1.2 **Conserve uplands and undeveloped lands** through permanent legal protection

Conservation of uplands through state and regional parks, land trusts, water districts, and the county's urban limit line have protected the flow and sediment regime for headwater streams, conserved riparian forests, and prevented impacts of urbanization on San Ramon and Las Trampas Creeks (*Opportunity Atlas Map W-4*), where impervious surfaces remain relatively low. Across the watershed, the comparison of impervious surface cover and the urban limit line demonstrates further opportunities for land conservation to support stream restoration, groundwater recharge, and carbon sequestration. Despite the value of conserved uplands and regional initiatives for increasing density of housing and services near existing transit corridors, development pressures on lands beyond the urban limit line continue, threatening the restoration potential of Walnut Creek.

2.5.1.3 **Mitigate urban hydromodification at sub-watershed scales** to address the impacts of urbanization on geomorphic processes influenced by runoff volumes and sensitive native species influenced by impacted water quality.

In urbanized areas, the interception, capture, and infiltration of precipitation can reduce runoff generation from impervious surfaces. Promoting the detention, evapotranspiration, and infiltration of stormwater runoff can mitigate the hyper-connectivity of urban drainage systems (Bonneau et al., 2017; Davis et al., 2012; Liu et al., 2014; Loperfido et al., 2014; U.S. Environmental Protection Agency, 2015, 2015; Woznicki et al., 2018). Together the increase in the volume and connectivity of runoff in urbanized areas vastly inflates stream discharge during frequent storms, increasing erosive effects of flows over time and threatening the stability of unarmored, restored stream channels (Dunne and Leopold, 1978; Walsh et al., 2012, 2005).

Green infrastructure is a multi-functional approach to mitigating impacts of urban development on ecosystem services of a watershed through distributed facilities that integrate with neighborhood features such as parcels, streets, sidewalks, trails, parking lots, parks, or schools (Benedict and McMahon, 2002; Gartner et al., 2013; Lovell and Taylor, 2013). At its best, the planning and design of this “natural” infrastructure forms an integrated network that regulates flows of water, sediment, nutrients and pollutants in ways that leverage, engage and mimic natural processes from hillslopes to riparian corridors and downstream into SF Bay. Measures to harvest rainfall, disconnect urban drainage pathways, and promote infiltration are all best management practices of green infrastructure with potential co-benefits of water quality improvement (LeFevre et al., 2012; Stagge et al., 2012), groundwater recharge (Beganskas and Fisher, 2017; Edwards et al., 2016; Masetti et al., 2016; Newcomer et al., 2014), improved habitat connectivity (Connop et al., 2016), promotion of leisure and recreation, cooling of summer temperatures (Giannakis et al., 2016), or water supply provision to offset intensive summer irrigation needs (American Rivers et al., 2012; American Rivers and CNT, 2010; Walsh et al., 2014). Capturing benefits depends on appropriate scale, distribution, siting, design, maintenance, and monitoring of green infrastructure technology and facilities (Bonneau et al., 2018; Connop et al., 2016; Fanelli et al., 2017; Golden and Hoghooghi, 2018; Green Nylen and Kiparsky, 2015; Hale et al., 2015; Jefferson et al., 2017; Radavich, 2015).

Flood control districts, planning authorities, and water resources managers are increasingly turning toward integrated green infrastructure as cost-effective watershed-scale management of ecosystem services (Gartner, Mulligan, Schmidt, & Gunn, 2013). Precedent studies, quantification of benefits, planning and engineering guidance and tools, and improved scientific understanding and science-policy-practice collaborations are critical to adoption, and also becoming more widespread (Connop et al., 2016). To be cost-effective, green infrastructure plans, as now required by the SF Regional Board’s MRP 2.0, should prioritize infiltration of precipitation and runoff into permeable soils with potential to reach subsurface aquifers (Green Nylen and Kiparsky, 2015). Infiltration is a service of soils that has been bypassed by impervious surface cover and storwmater drainage systems. Water flow through soils and the subsurface promotes water quality treatment (e.g. filtration through porous media, microbial breakdown, nutrient cycling, vegetative uptake), decreases runoff interaction with polluted road surfaces, and begins to restore a natural flow regime in creeks (i.e. reduced peak flows and flooding in typical winter storms but increased groundwater volumes and cool base flows in summer).

Rainwater harvesting (such as collecting rain from rooftops into large barrels along the side of the house) can provide complementary benefits of reducing precipitation and providing water for later reuse in landscape irrigation, which in term can increase infiltration in lieu of rapid runoff to storm drains. The benefits of rainwater harvesting are generally greater in climates whose rainfall is more evenly distributed around the year. In the Mediterranean climate of California, the benefits are limited in that rainfall is concentrated in a few months of the year, so the storage capacity of the tanks has usually been met before the largest rainstorms occur, and the volume of water stored is relatively small compared to the irrigation demands of a garden or landscaping of the typical single-family home. Nonetheless, such rain harvesting approaches can still provide some benefits to controlling runoff, infiltrating rain, and providing alternate water sources in between rainstorms. In addition they can help to foster a water awareness and water conservation culture in the community.

Cities are increasingly employing deep infiltration facilities for groundwater recharge and reduction of storm-sewer overflows where impermeable near-surface soils resist infiltration, but permeable subsurface layers exist (e.g. Los Angeles, Seattle, and Portland). Although the MRP 2.0 does not require green infrastructure to promote groundwater recharge, it would be forward-thinking for municipalities to identify opportunities, study impacts, and incorporate the best opportunities for shallow and deep infiltration into Green Infrastructure plans (*Figure 2-15*). *Appendix A2* reports details of an infiltration suitability analysis for Walnut Creek Watershed, which is summarized in the *Opportunity Atlas Map W-5*.

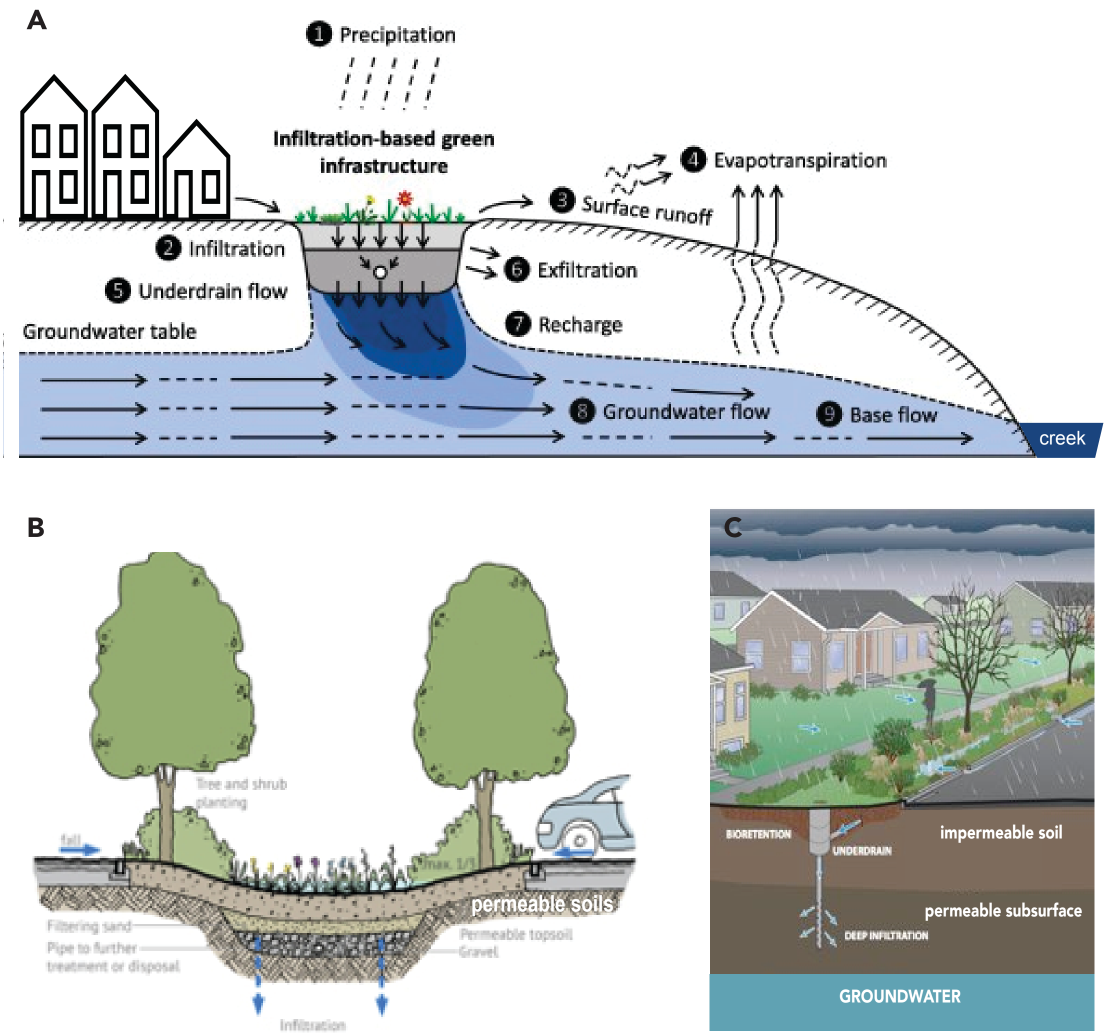

Figure 2-15. (A) Infiltration facilities to restore an urbanized watershed's hydrologic cycle re-integrate plants and open soils in ways that capture precipitation and runoff, filter water through porous media and allow retention and slow drainage into the subsurface, eventually either evapotranspiring out to the atmosphere or reaching creeks as clean, cool baseflow (figure adapted from Zhang and Chui, 2019). Shallow infiltration facilities (B) take advantage of permeable soils to collect and infiltrate water into the subsurface (figure of bioretention facility from Susdrain (2021)). Deep infiltration facilities (C) bypass impermeable soils into deeper, highly-pervious subsurface layers, allowing recharge of groundwater aquifers despite near-surface conditions (figure of infiltration well adapted from SvR Design Company (2021)).

- ***Shallow Infiltration*** relies on vertical infiltration of precipitation and runoff into surface soils where moderate slopes and permeable soils permit slow percolation into deeper soils and groundwater reservoirs, often accessible to trees and plants, but setback from seismically-active or environmentally-sensitive areas. In addition to vegetated, non-compacted soils of open space, facilities for shallow infiltration include bioretention, permeable pavement, and open-bottom planter boxes.
- ***Deep Infiltration*** collects and conveys runoff past impermeable surface soils into deep, unsaturated subsurface layers with more significant pore space and permeability, often draining into seasonal or perennial aquifers. To mitigate pollutants as well as runoff volume, deep infiltration practices are often combined. For example, pretreatment in biofiltration facilities may overflow into a deep drain that directly infiltrates into a deep permeable layer. The depth to deeper permeable layers can vary significantly, therefore facility types (e.g. trenches versus wells) and costs vary, so geotechnical study of soil types and depths supports best practices.

Changes to the built environment occur intermittently and incrementally in patches within single parcels or short stretches of road or highway. For green infrastructure facilities to be integrated into suitable areas as they are redeveloped, plans, policies and guidance must be in place in the near-term to support watershed-scale transformation on a fifty-year timescale. For example, if specific opportunities for cost-effective green infrastructure exist in Priority Development Areas (i.e. not only infiltration facilities, but also riparian corridor widening or rainfall capture for irrigation or non-potable uses), those should be identified before detailed planning begins.

2.5.1.4 **Widen the riparian corridor** to restore multiple dimensions of stream corridor connectivity and take advantage of Walnut Creek's unique variable flow regime to support self-sustaining channels and native aquatic species.

Connecting and widening the riparian corridor helps to restore free boundaries of channels, allowing the flow regime to rework habitat through geomorphic processes and restore connectivity with the groundwater. Making room for floods can support social connectivity through public access and trails. These dynamic processes create and sustain in-stream ecosystems, floodplain wetlands and riparian forests.

2.5.1.5 **Connect habitat along creek corridors** to support mobility and migration needs of wildlife across their life stages with specific attention to supporting viable runs of migratory salmon.

2.5.1.6 **Encourage social connectivity** to a public creek corridor that supports ecosystem services for the watershed and a range of direct human uses: passive to active, programmed to spontaneous, water contact and terrestrial.

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3 WHERE? Mapping Opportunities for Restoration

3.1 MAPPING RESTORATION OPPORTUNITIES

In this section, we present analysis and maps of opportunities to restore biophysical processes in Walnut Creek's watershed and support a wide range of public benefits through a socially and physically connected riparian corridor.

3.1.1 PROCESS-BASED GOALS FOR AN URBANIZED WATERSHED

Based on the opportunities and constraints for process-based restoration discussed in Section 2.5, our geospatial analysis focused on three primary restoration goals for Walnut Creek's watershed:

- **Mitigate the effects of urbanization throughout the watershed** to restore the flow regime and water quality within creek channels, as discussed in Section 2.5.1.3.
- **Restore the processes, free boundaries and connectivity of creek channels** that maintain dynamic riparian habitats for native freshwater and riparian communities, especially the two to three salmonids species who are regionally threatened umbrella species that have potential to repopulate historical spawing grounds if connectivity is restored, as discussed in Section 2.5.1.4 and 2.5.1.5. We specifically target reaches constrained by engineered flood infrastructure of limited service life.
- **Encourage community use, enjoyment, and stewardship of creek corridors and aquatic ecosystems** to support the public benefits of a shared community resource, as discussed in Section 2.5.1.6.

3.1.2 RESTORATION CONSTRAINTS

Keystone processes of riparian corridors have been disrupted by land use across the watershed and by flood infrastructure that has protected property and investments on developed floodplains for the past sixty years. Given the discussion of Walnut Creek's watershed from Section 2.4, our analysis considered specific constraints to restoration as:

- **Flood control channels require periodic re-construction**, every 50-100 years, at great expense to many but limited benefits.
- **Flood control structures limit longitudinal connectivity along the channel network,** creating a population sink for native salmon by blocking migration to and from upstream reaches suitable for spawning and rearing; also disrupting flows of sediment and nutrients.
- **No lateral connectivity of flood flows.** Flood control channels are designed to convey large floods, and thus disconnect the natural patterns flood disturbance and exchange within minimized riparian zones; this reduces vegetation cover and aquatic-terrestrial connectivity important for riparian birds and amphibians, nutrient cycling, light and termperature regulation.
- **Confined and hardened channel boundaries** disrupt exchange of sediment, nutrients and subsurface flow, eliminate complex features needed for habitat.
- **Urban hydromodification** throughout the watershed alters the flow and sediment regime by intensifying overland flow and flood peaks (especially for frequent floods), and reducing retention,

storage, infiltration and groundwater recharge with negative effects on summer baseflow for native fish (e.g. magnitude, temperature); this limits the potential to restore flood control channels into self-sustaining creeks.
- **The community has lost connections with creeks,** concern for flood risk, awareness of potential ecosystem services from their watershed, and public benefits derived from nearby nature provided by accessible streams and longitudinally connected riparian corridors.

3.1.3 RESTORATION STRATEGIES

Given the above goals and constraints, we sought to map on-the-ground opportunities and constraints for restoring keystone processes of Walnut Creek's riparian corridors on a reach-by-reach basis (for riparian corridor connectivity) and across the watershed (for mitigation of urbanized hydroregime). Our analysis identifies suitability criteria for two primary strategies for meeting restoration goals. Based on existing public data and accessible geospatial tools, we characterize and rank stream reaches according to the opportunities and constraints to:

- **Widen the riparian corridor** to make room for flood flows, riparian forests, dynamic processes that create and sustain aquatic ecosystems, and a range of recreational uses;

At the watershed scale, our analysis applies suitability criteria to identify areas to:

- **Promote cost-effective infiltration of rainfall, runoff and flood flows across the watershed** to restore more natural flows and promote groundwater recharge to support local water storage and cool summer baseflows.

In the following analysis, we identify appropriate project sites to apply these strategies. We assessed site suitability with consideration of the multiple potential social and ecological functions of a publicly-accessible riparian creek corridor.

We assume that once we understand which reaches can be widened and how urban hydromodification can be addressed, strategies to ensure longitudinal connectivity of riparian corridors can be better considered. For instance, restoration design for individual reaches can and should consider the influence of drop structures on fish migration and longitudinal connectivity along riparian corridors. As restoration of individual reaches begin, planning and design strategies must consider connecting restored reaches to each other.

3.1.4 WALNUT CREEK WATERSHED OPPORTUNITY ATLAS

The resulting *Walnut Creek Watershed Opportunity Atlas* (Atlas) presents the mapped opportunities for restoring expanded and connected riparian corridors and mitigation of urbanization on water quality and the flow regime. As a communication tool, the *Atlas* allows the local community to begin considering of restoration opportunities from a common set of suitability maps, based on an initial set of simple assumptions. We hope the *Atlas* serves as a conversation starter: base maps that can support the questioning, re-interpretation, and negotiation of the potential for change within the watershed.

3.2 GEOSPATIAL ANALYSIS FRAMEWORK

To understand the relative suitability of creek reaches for riparian expansion and land areas for infiltration-based green infrastructure, we used publicly available geospatial data, defined suitability criteria, applied spatial analysis tools, and ranked areas based on well-defined criteria.

We first analyzed opportunities and constraints for restoration of creek corridors in Grayson Creek, a sub-watershed within Walnut Creek's larger drainage area. In 2015-16, we presented results to the District and local watershed groups as part of a UC Berkeley graduate-level studio in Environmental Planning (see *Appendices B1-B5*). With feedback from these presentations, we expanded data sources and refined logic for identifying opportunities and constraints to restoration for the entire Walnut Creek Watershed. The resulting spatial analysis defines suitability criteria to assess the potential for restoration to provide four types of public benefits on a reach-by-reach basis, then assesses opportunities to partner with landowners to overcome the physical and social constraint of private parcels encroaching on existing channels. Similarly, we defined suitability criteria for siting three types of infiltration-based green infrastructure, then mapped infiltration opportunity areas across the watershed.

3.2.1 DATA INVENTORY

We collected geospatial data from state, regional, County and local agencies to support analyses of watershed, floodplain and channel conditions and the social context of land use, parcellation, right of ways, circulation plans, jurisdictional boundaries, and demographics. We leveraged existing, publicly available data to understand physical properties of geology, soils, slopes and natural hazards within Walnut Creek's watershed. See *Appendix A1, Restoration Suitability Ranking Methods and Data Soures* for a list of data sources and citations. The resulting merged datasets, ranking schemes and calculated values have been compiled into a geodatabase with documented metadata, available via request.

3.2.2 PRINCIPLES AND ASSUMPTIONS OF ANALYSIS

3.2.2.1 Avoid prioritization to encourage community dialogue

To invite community dialogue, we sought to explore opportunities and constraints for restoration of creek corridors in holistic but simple terms. We avoided complex weighting factors, prioritization schemes or ranking among individual projects. By keeping it simple, we hope our results can be shared with stakeholders in ways that encourage open dialogue about how to proceed with a community-based, participatory planning process, as discussed in *Section 4 How?*.

3.2.2.2 Acknowledge the scales of physical, biological and social processes

Biophysical processes that shape and maintain creeks operate across multiple spatial and temporal scales. The processes that shape channel form are driven by regional geology and climate, flow patterns of water and transport of sediment through a watershed. Channels in Walnut Creek today reveal another dominant driver of their form – people. Social processes shape creeks: population booms, economic pressures, local land use policy. These forces also fragment the landscape into hundreds of thousands of privately-owned parcels which require road access and networks of infrastructure. Within urbanized valley corridors, former creek paths have been simplified into neat, straight, narrow lines between thousands of parceled investments.

To consider the influence of physical and social processes on the potential for restoration, we analyzed planning reports and geospatial data across a hierarchy of spatial scales: regional and County, municipal, neighborhoods, reaches, parcels. We consulted geologic maps to understand tectonics, the evolution of drainage networks, erosion patterns and Quaternary deposits and their influence on soils, infiltration, groundwater recharge and natural hazards.

Restoring riparian corridors will require land use change, shared decision-making across multiple jurisdictions, the purchase of properties from willing owners. These social processes will take time and negotiation. To consider social processes, we analyzed parcel land use, ownership and configuration, barriers within and along riparian corridors, and the influence of zoning, municipal general plans and regional policies. By analyzing parcel land uses and ownership, we tried to understand which land uses might be more amenable to change over short time scales – versus those which may take decades. For example, a reach flanked by large public parcels such as schools, parks, and corporation yards, appear more readily amenable to accommodating a wider riparian corridor than a reach flanked entirely by small, private residential parcels.

3.2.2.3 Limits of data availability and tools

We consider our results to be an initial step to define and map opportunities with the caveat that the available geospatial data drove our approach. Our methods and results remain limited by the type and quality of available data. Our analysis only *suggests* the potential benefits of each reach based on a set of well-defined, but limited suitability criteria as supported by available data. Results must be vetted within the community to understand how each potential restoration reach functions physically, ecologically and socially across multiple spatial and temporal scales of concern and communities of interest. See an example of a functional assessment that integrates non-spatial data for lower Grayson Creek in *Appendix B3*.

For widening riparian corridors, we assume a 300-foot wide expansion from the current creek centerline will achieve the same or greater flood conveyance capacity as now provided by existing engineered flood control infrastructure. This applies to all channel reaches. As discussed in Section 2.4.5, the required width depends on the expected flow capacity and the degree of flow resistance introduced by restored stream corridors. For mainstem reaches of Walnut Creek and lower reaches of its larger tributaries, this will likely exceed 300 feet, especially if communities seek to expand the designed flood capacity beyond current levels.

We did not consider land value, the District's on-going facility assessment, the relative cost of the construction, or the lifecycle of restoration approaches (i.e. their maintenance or replacement over long time scales). For infiltration suitability analysis, we did not consider land use or ownership, which would be a reasonable next step, as assessed in other communities (see

Appendix B5, Table 2 for a precedent review). In terms of biophysical processes, we can anticipate that climate change and sea level rise will change flooding and sedimentation patterns, but we did not address this anticipated change directly in our analysis. Instead, as argued in previous sections, we assume that restored, widened creek corridors can add flexibility to flood protection approaches, helping local communities adapt to change over generations (Jones et al., 2012).

To overcome data limitations, we suggest a community-based analysis and interpretation of resulting maps within a broadened framework that considers trends, risk, criticality, dependencies, complexity and other metrics. With community feedback, investment in more refined hydraulic models can help reduce gross assumptions, expand scenarios, and bound a range of restoration options with uncertainty analysis.

3.2.2.4 How long do we have? Timeframes for replacement and restoration

Our geospatial analysis considers current flood infrastructure in terms of channel type, a creek centerline location, adjacent land uses and parcel ownership. We assumed that all altered channels and in-channel flood protection facilities (as identified in publicly-available County GIS data) will need replacement in the next fifty years. The District's facility assessments are on-going (Table 1-1). We did not rank or rate specific facilities or reaches according to their projected service life or rank their functional role or ecological impacts. For example, we considered restoration of concrete and constrained earthen channels as equally worthwhile. We did not consider the influence of bridge crossings (or other non-flood-protection infrastructure) on flood risk, replacement need, or complicating constraint. Once the District completes field-based facility assessments of remaining service life, these data should be incorporated into opportunities analyses, prioritization and strategy development. Some facilities may require more urgent attention than others, but we did not account for this likely possibility in our analysis.

3.3 RIPARIAN CORRIDOR ANALYSIS

By ranking reaches according to opportunities to widen corridors and work with partners to overcome constraints, the prioritization and scope of individual projects can emerge. With a phased approach to restoration projects over decades, initial projects focused on reaches with greatest potential benefits and partnership opportunities can inform an adaptive learning and management framework to demonstrate strategies, test assumptions, build knowledge, develop trust and collaborative relationships, then improve approaches in subsequent phases.

Given this basis, our analysis used a three-step approach for defining and ranking opportunities across all altered channels within Walnut Creek's watershed (*Figure 3-1*). First, we defined and applied *criteria* to rank "reach benefits" based on the potential to support ecosystem services and contribute to community benefits. Then, we considered the opportunity to expand the width of the channel corridor along the channel and its adjacent floodplain by considering parcel land use and ownership within the floodplain. We developed simple critera to rank these intersecting parcels according to potential "partnerhips" with landowners to achieve restoration goals. Third,

1 REACH BENEFITS	For altered channels, seek baseline benefit of expanding riparian corridors. Then identify potential benefits along channel reaches.
2 PARCEL PARTNERSHIPS	Along altered channels and adjacent floodplains, identify parcel land use and ownership. Categorize opportunities for partnership.
3 RANKED OPPORTUNITIES BENEFITS x PARTNERS	Define opportunities for expanded riparian corridors according to a matrix of reach benefits and parcel partnership opportunities.

Figure 3-1. The opportunity analysis for riparian corridor connectivity followed three steps: we first identified a range of potential benefits along altered channel reaches, then opportunities to partner with property owners of channel and floodplain parcels. We assessed the opportunities for realizing community benefits and parcel partnerships together in the third step.

we considered the combined opportunities for *realizing reach-based benefits through parcel-based partnering opportunities* with a scoring matrix. The resulting maps, illustrated in the *Atlas*, highlight reaches with opportunities to realize community benefits and overcome limitations to channel widening.

As a first step, we distinguished five categories of potential benefits that emerge from the restoration of the processes, functions and services of connected riparian corridors (*Figure 3-2*). With this categorization, we sought to identify restoration opportunities across a range of benefits and stakeholder interests. For simplicity, each benefit was weighted equally in our analysis. This multi-functional, community-serving approach aligns with the Fifty-Year Plan vision to reduce flood risk while supporting the biophysical processes that sustain riparian ecosystems and their ecosystem services. For each benefit category, we assessed available geospatial data and developed suitability criteria to determine how the watershed's context informs the potential for realizing a given benefit. Once we determined which reaches most reflect a strong likelihood for realizing each benefit category, we counted the number of overlapping benefits per reach. To determine the number of overlapping benefits, we used a filtered approach (*Figure 3-3*). As a result, each reach of altered channel was assessed: how many overlapping benefits might be realized in a range of one (i.e. the minimum benefit of infrastructure replacement) to five (i.e. high potential for all benefits to emerge from the riparian corridor expansion strategy).

Figure 3-2. Targeted benefits that emerge from strategies to widen and expand riparian corridors, restore ecosystem process and function, and connect communities to ecosystem services of their watershed.

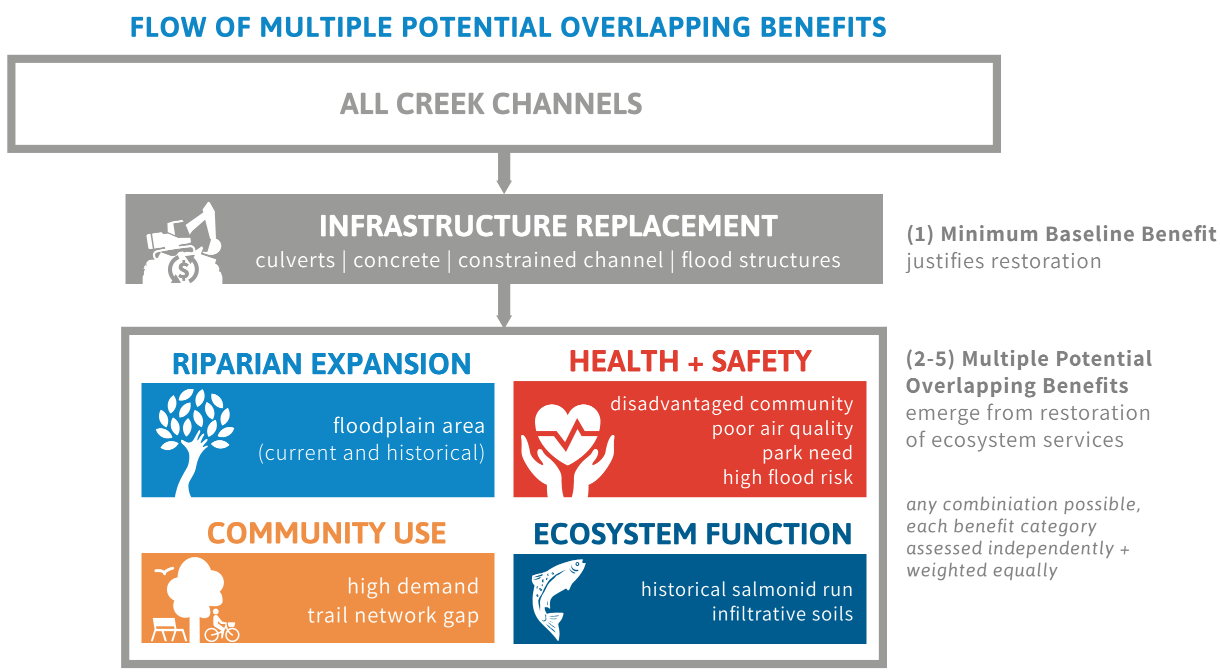


Figure 3-3. Process for identifying and ranking multiple potential benefits of restoration along the channel network

As a second step, we explored how to overcome the constraint of private parcel encroachment on channels and their adjacent floodplains. Widening the riparian corridor and connecting it longitudinally requires land along current channel boundaries, but most adjacent land is currently held as privately-owned parcels. Owners expect these investments to be safeguarded from floods, in direct conflict with the restoration strategy of expanding the floodable area. We identified potential partners who might be willing to expose land to occasional flooding. We based this potential on land owners with a public-serving interest or underserved land use.

The final phase of the process identified restoration opportunities based on both reach benefits and parcel partners. The resulting ranking of opportunities suggest a phased approach to restoration planning, expanding from District-owned parcels to other parcels as the District develops partnerships where multiple benefits align with a broad set of stakeholder interests. See *Appendix A1* for details of data used, their sources, and logic of analysis.

3.3.1 METHODS: ASSESSING BENEFITS OF RIPARIAN CORRIDOR RECONNECTION

3.3.1.1 Restoring Keystone Processes to Capture Multiple Benefits

The goal of this step was to identify stream reaches that capture a diverse range of social benefits associated with expanding the riparian corridor along altered channels. Using available geospatial data and knowledge of the historical watershed conditions, we defined criteria for identifying reaches that best capture the following benefits (*Figure 3-2*) and then a filtering approach to assess potential benefits for each reach (*Figure 3-3*). We first assumed that only reaches with altered channels, and thus a need for infrastructure replacement, could justify the restoration intervention. This is our baseline benefit.

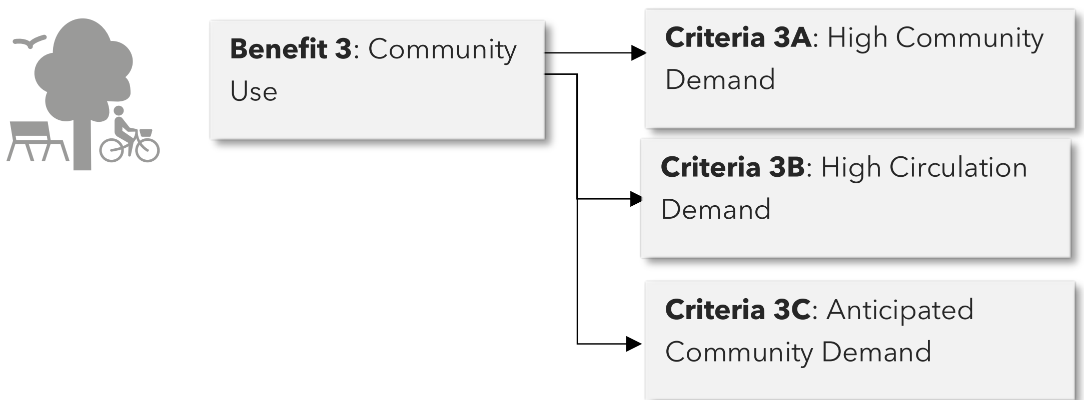
We describe each benefit below. Find details on data processing and geospatial tools used to define and map individual criteria in *Appendix A1*.

Benefit 1: Baseline → **Criteria**: Concrete, Riprap, Earthen (constructed) Channel

BENEFIT 1: Baseline Infrastructure Replacement. We first considered the benefit of converting an existing altered (concrete or otherwise channelized) channel to a natural channel. This criteria identifies channels that could be restored from a channelized state and allows us to map reaches with justified, baseline restoration need.

Benefit 2: Riparian Corridor Expansion → **Criteria**: Within FEMA 100-Year + 500-Year Floodplain

BENEFIT 2: Riparian Corridor Expansion. Restoration that expands the width of riparian corridors makes room for floods, a keystone process that sustains dynamic habitat, and opens opportunities for slower flows, recharge, biofiltration and nutrient cycling (as discussed in Section 2). We used the FEMA-delineated floodplain to represent areas where current topography could support the expansion of flood flows across a greater surface area. The FEMA delineation assumes floodplains are protected by current the incarnation of flood protection infrastructure, however. Future iterations could consider the historical floodplain[1].



BENEFIT 3: Community Use Benefit. We next identified reaches where an expanded, connected riparian corridor can act as a community resource by opening access to nearby nature. We defined criteria to assess current high-use areas where access to creeks and trail networks present an opportunity to connect high-use destinations and hubs of activity. Reaches with this benefit represent restoration areas that could double as a linear greenway park with safe and inviting "Class 1" multi-modal paths that expand the County's "active transport" network and connect to vital services such as transit stations, schools, commercial areas, workplaces, and higher density housing. To this end, we analyzed three separate criteria: areas with high community demand, areas with high circulation demand, and areas of anticipated community demand.

Areas of High Community Demand (3A)

We assume that areas with a high density of people will create a strong demand for linear park corridors and high opportunity for human use of creek corridors. With attention to public amenities that support a broad range of users and diverse opportunities for recreation with a welcoming sense of safety, restoration in these reaches have high potential to increase creek access and community use.

To map areas of high community demand from public data, we identified community destinations such as schools, hospitals, churches, civic and cultural uses (e.g. libraries, museums), office buildings, multi-family very high density, multi-family high density, BART,

[1] Available as a GIS shapefile for the watershed (and shared with the District in 2021) based on georeferenced soil surveys and landform delineations in the USDA NRCS SSURGO database at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

park and ride locations, and bus transit hubs. From these points, we identified channel reaches within a two-minute walk (528 feet) to determine which reaches best connect to high use areas.

Areas of Circulation Demand (3B)

Creekside multi-use trails can connect, expand, and improve local bike and pedestrian networks. Easy access, shorter and safer routes, connectivity to destinations, and shaded environs along an ever-changing creek can encourage diverse types of recreation and “active transport” alternatives to driving. People on foot, bikes, scooters or wheelchairs can begin to reduce Vehicle Miles Traveled (VMT), relieve traffic pressure on roadways and reduce the community’s greenhouse gas emissions. Community benefits of creekside multi-use bike paths and greenways include:

- Reduces route lengths and increases multi-modal trips
- Increases perceived safety of biking
- Increases cyclists willingness to travel
- Increases bicycle commuting, offseting car commuting
- Elevates trips to an aesthetic, community-building experience

To understand the potential benefits of a creekside “Class 1” multi-use, off-street path, we identified stream reaches in source areas (high-density residential parcels) and high demand areas (major commercial, transit and institutional parcels that are considered destinations) that lack convenient access to “Class 1 or 2” routes. Additional details and supporting evidence for these methods can be found in *Appendix A1*.

Areas of Anticipated Demand (3C)

Areas of Anticipated Demand represent currently under-utilized areas where land use is likely to intensify due infill pressure. To offset the increased building mass and street infrastructure while reducing flood risk, higher density neighborhoods can strategically integrate multi-functional green infrastructure with social benefits. We first identified vacant land and parking lots to represent currently under-utilized land. These open parcels may be ripe for redevelopment, but may not represent all under-utilized parcel types.[2] Next, we identified Priority Development Areas (PDAs) delineated by the Association of Bay Area Governments (ABAG) to represent areas with high potential infill development (Mackenzie et al., 2017). PDAs are typically transit-accessible areas approved for future growth (MTC, 2020). We assume that increased density of people and built structures will increase demand for “nearby nature” within the next fifty years.

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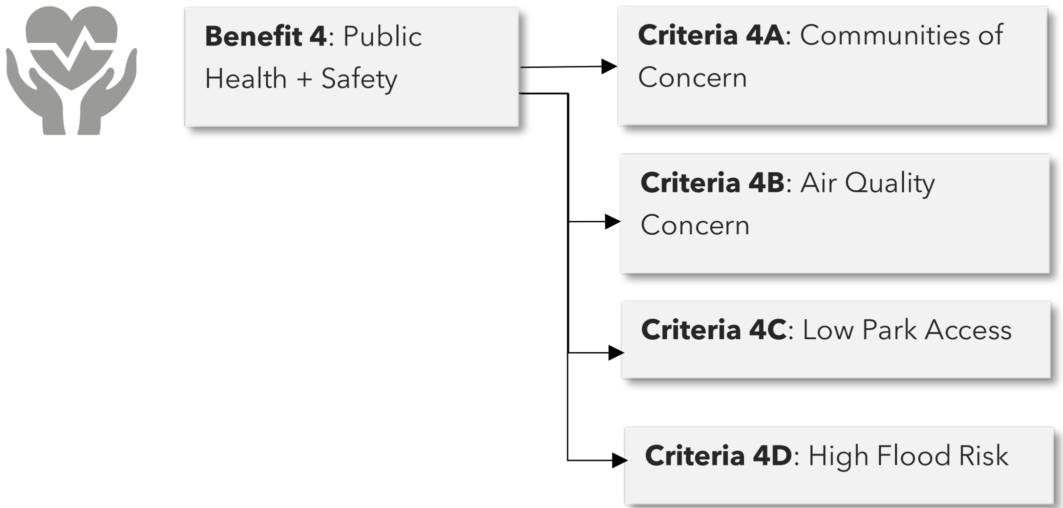
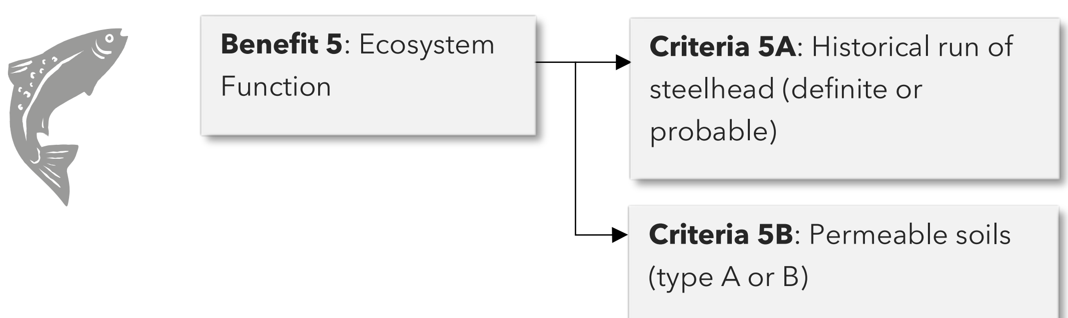
[2] For example, in our initial Grayson Creek, the District and city planners helped us identify closed shopping centers as areas of anticipated demand. At the scale of Walnut Creek watershed, we did not have a readily-available source for similar data. Developing under-utilized parcel data could improve this analysis.



***BENEFIT 4: Public Health and Safety Benefit*.** Vulnerable populations, such as disadvantaged communities and neighborhoods, disproportionately suffer from poor air quality, high flood risk, and lack of parks. We defined criteria to determine areas of higher need for accessible trails, recreational amenities, and the ecosystem services of nearby riparian greenways. Our criteria aim to capture areas with limited access to resources, where flood exposure poses more risks and lack of resources present a barrier to post-flood recovery. We analyzed four criteria that contribute to this benefit: communities of concern, areas with air quality concern, areas with low park accessibility, and areas with high flood risk (see *Appendix A1* for criteria details).

- Communities of Concern (4A)
- Air Quality Concern (4B)
- Low Park Accessibility (4C)
- High Flood Risk (4D)



***BENEFIT 5: Ecosystem Function*.** In addition to restoring riparian connectivity by expanding channel connections with floodplains, the opportunity to restore salmon runs in the watershed shows great promise. Steelhead and Chinook salmon have been recently observed in the lower watershed, but they cannot migrate through the system to fully support their anadromous lifecycle. Removing barriers to migration and restoring more natural flow and sediment regimes can allow reestablishment of anadromous salmon, whose presence will affect food webs and

biodiversity across multiple ecosystems: local streams, their adjacent riparian and terrestrial zones, the San Francisco Bay and the Pacific Ocean. Expanding viable runs for these threatened species into Walnut Creek's watershed supports ecosystem function for the Central Coast of California.

Historical Runs (5A)

To assess reaches with potential to restore salmon runs, we mapped historical runs of steelhead (Map W-2) (Leidy et al., 2005). Re-establishing populations of native salmonids depends first on removal of migration barriers to suitable spawning grounds. Water quality (high dissolved oxygen, low suspended sediment), temperature, resource availability, and vegetative cover are essential for juvenile rearing. Data to better predict sufficient flow of cool water, spawning gravels, and riparian vegetation (e.g. recently available in Bay Area Open Space Council, 2019) can be incorporated into future iterations of this analysis.

Permeable Soils (5B)

Restoration that targets processes required to sustain habitat across the lifecycle of umbrella species, such as salmonids, can support restoration of native freshwater ecological communities throughout the watershed and beyond. Removal of in-channel migration barriers to fish passage, however, is not enough to address impacts of urbanization on the flow and sediment regime. A broad range of restoration strategies, including infiltrating runoff to reduce frequent peak flows and promote groundwater recharge through permeable soils, can restore the watershed-scale processes needed to maintain restored channels.

3.3.1.2 Overcoming Land Use Limitations, Identifying Potential Parcel Partners

In the second phase of our analysis, we analyzed parcel configurations, zoning and ownership to understand where land uses and landowners present opportunities for widening and connecting stream reaches to support the Fifty-Year Plan vision.

Scale of Parcel Partner Opportunities

To identify stakeholders and potential partners who own property along the creek corridor, we analyzed parcels at two scales with respect to the creek corridor (*Figure 3-4*):

Altered Channel Parcels: for parcels that intersect with an altered channel, potential partnership determined by ownership and zoning code of parcels that contain the current channel bed and banks.

Riparian Buffer Parcels: for parcels adjacent to the altered channel, potential partnership determined by ownership and zoning code of parcels within a combined area that comprises the 500-year floodplain (as designated by FEMA) and a 300-foot (100 m) riparian buffer on either side of the altered channel centerline.

These two scales of parcels are used to further characterize the opportunities, constraints and strategies for restoration of keystone processes. We distinguish parcel ownership by the District from partners to emphasize opportunities where the District has greater leverage to pursue restoration strategies in the near-term enabled by their parcel ownership, property rights, and access.

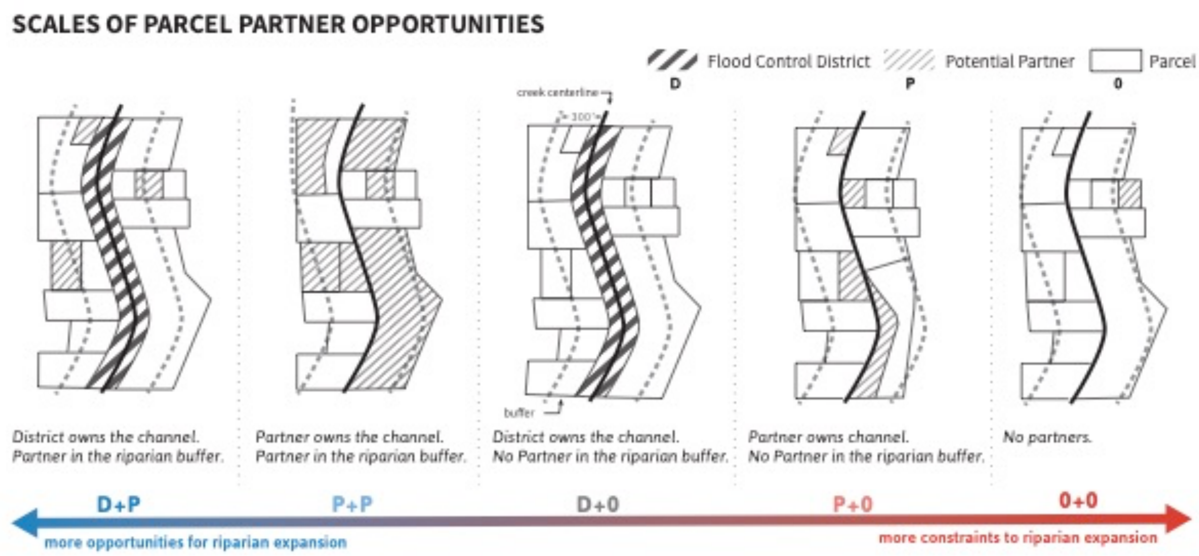


Figure 3-4. Spatial assessment of parcel configuration, ownership, and partnering opportunities for the altered channels and adjacent riparian buffer. The assessed buffer combines both the 500-year floodplain (per FEMA delineation) and a 300-foot wide buffer beyond the centerline of the existing channel. The gradient (blue-to-red arrows along the bottom of the figure) represents the range of opportunities to constraints for widening the creek corridor. D = District, P = potential partner identified, 0 = a privately-owned parcel with no potential partner identified.

Types of Potential Parcel Partners

Identify parcels owned by the Flood Control District

Parcels owned by the Flood Control District represent opportunities for the District to begin considering restoration strategies with reduced constraints of acquiring parcels, access routes or partnership agreements to alter channel conditions.

Identify parcels with potential partners

Using spatial parcel delineations with associated zoning codes and landowner data we identified potential partners at the channel and riparian buffer scale as:

- Educational Partners (school districts, public/private schools and colleges)
- Publicly-owned Parcels (county, government, or municipality)
- Underused parcels (vacant or parking lots)

We refer to these key stakeholders as “*potential parcel partners*”. They represent land owners within the riparian buffer who may be more willing, able, and incentivized to participate in restoration strategies, land use agreements, and projects that promote recovery of ecosystem services and community connectivity to a riparian greenway corridor.

Ranking of Potential Parcel Partners

Using the categorization of reaches according to potential parcel partners who own the channel or adjacent riparian buffer, we assumed that reaches with District-owned channels and potential partners in the riparian buffer represent a greater opportunity for riparian expansion than reaches where we identified no potential partners (see color bar on *Figure 3-4*).

<u>District-owned channel, potential partners in the buffer (D+P)</u> constitute reaches where the altered creek channel is currently owned by the Flood Control District, and at least some areas in the riparian buffer are owned by a potential partner. In these areas, the Flood Control District has jurisdiction within the channel, but potential for riparian corridor expansion would require partnerships and negotiation with other landowners. The identified potential partners represent an initial contact for exploring restoration strategies.

<u>Potential partners own the channel and the buffer (P+P)</u>: constitute reaches where the altered creek channel is owned a potential partner, as are some areas in the riparian buffer. Because the District does not currently own the channel, challenges for maintenance and replacement already exist. Partnerships will be required for any change to the channel, but potential partners in the riparian buffer suggest that opportunities for expansion could be explored.

<u>District-owned channel, no identified partners (D+0)</u> constitute reaches where the altered creek channel is currently owned by the Flood Control District, but no identified partners exist along the channel. The lack of vacant, underused or publicly-owned parcels along these reaches presents a greater constraint to riparian corridor expansion. While alteration to the channel seems possible due to District ownership, any changes to channel conditions will likely change flow characteristics (e.g. roughness), conveyance capacity, and flood risk for other parcels; so it is unlikely that the District can act alone. Discussions with identified partners can be a starting point for exploring a range of long-term strategies.

<u>Potential partners own the channel but not the buffer (P+0)</u>: constitute reaches where potential partners own parcels that contain an altered channel, but no identified partners exist in the adjacent riparian buffer. These represent areas that offer some potential for replacing the channel, but any changes to conditions will likely have cascading effects on other parcels. Because of this, major constraints to any change remain, but discussions with identified partners can be a starting point for exploring a range of long-term strategies.

<u>No identified partners (0+0)</u>: constitute reaches where private parcels that contain and line the channel are not owned by the District, have no potential partners identified. This suggests that investments and land uses on these parcels present the greatest constraint to any change to the channel (including maintenance, repair, or placement) or flood characteristics. As flood infrastructure approaches the end of its service life, parcel owners and local jurisdictions must be involved in exploring replacement and restoration options and phasing. Initial restoration efforts elsewhere in the watershed may help the larger community to understand the potential benefits of expanded and connected riparian corridors, opening dialogue and negotiation for long-term strategies.

3.3.1.3 Potential Benefits and Partners to Rank Opportunities

As a final step, we examine the number of benefit categories against potential for parcel partnerships along each reach of altered channel. Where a reach met criteria for a full range of potential benefits (all five benefit categories overlap) and had a parcel configuration where the District owned the channel and potential partners were identified in the riparian buffer, we assigned the highest opportunity rank for riparian corridor expansion. At the other extreme, where a reach only met the baseline benefit (infrastructure replacement need) and had no parcel partners identified, we defined it as a "most constrained reach." A range of other combinations represent an intermediate mix of opportunities and constraints, where a number of strategies could be explored with a broad range of stakeholders.

When assessed benefits and potential parcel partners are considered together, we used a restoration opportunity matrix (*Figure 3-5*) to assign a score to each reach. Along all reaches of altered channel, we multiplied the number of overlapping benefits (as assessed according to five categories, so within the range of one to five) by a ranking of parcel-based opportunities (a simple range of one to five from least to most opportunity). The range of scores for this combination, from one to 25, distinguishes extremes of the most opportune versus constrained reaches in terms of the potential benefits to derive from restoration and the potential to partner with landowners for room to restore. With an assigned score for every reach, we produced maps to highlight the most and least opportune reaches for riparian expansion, based on a simple framework that attempts to balance the opportunity for restoration and against the constraint of current land use.

As the community responds to and interprets the resulting maps, stakeholders may reveal other types of analyses that could help to further categorize and sort different types of benefits, criteria, partnerships and opportunities to inform the planning process. The score is not meant as a prioritized playbook for action, but a conversation starter to support participatory planning for a range of restoration strategies that respond to the local context and community.

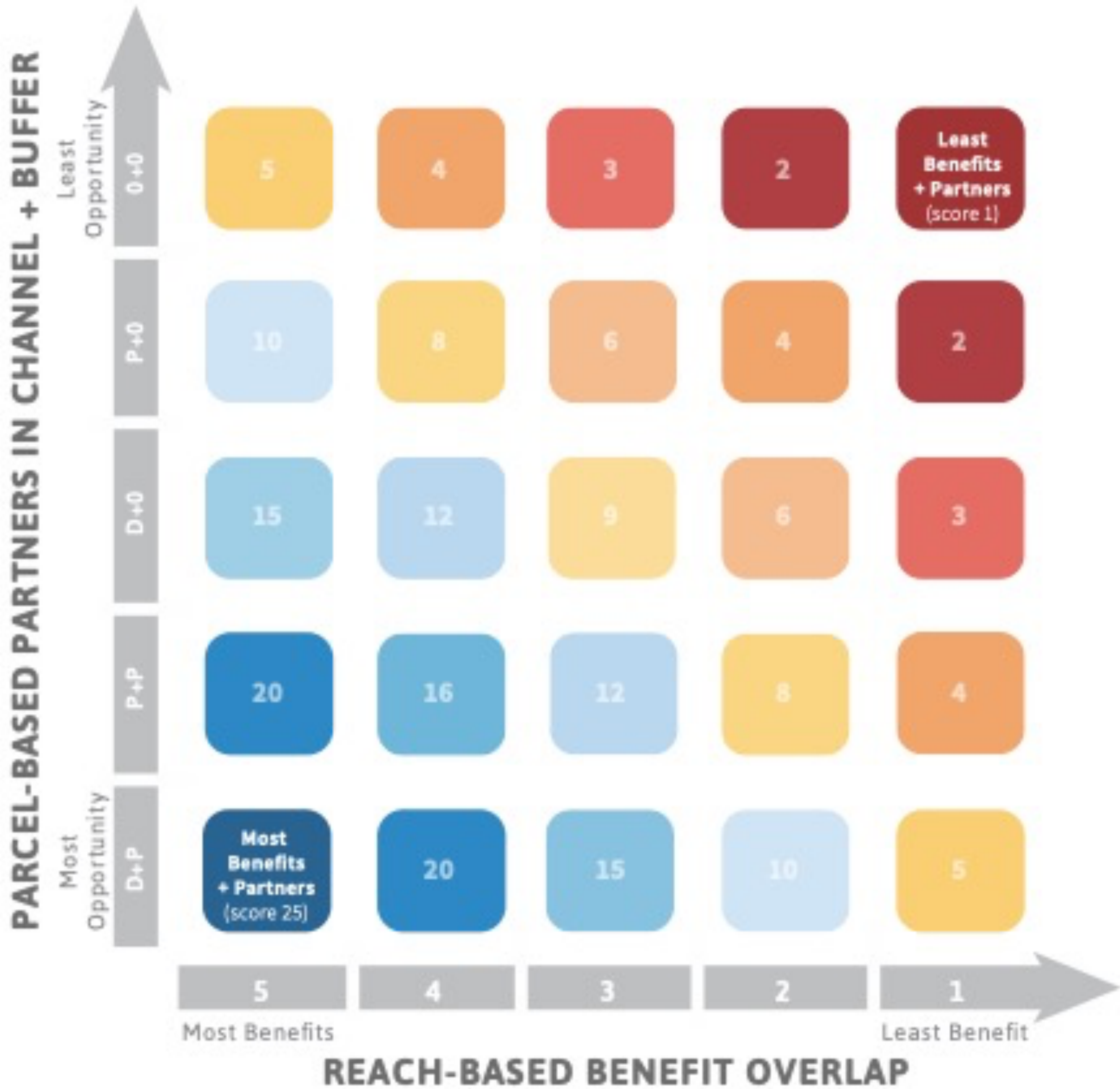


Figure 3-5. The Restoration Opportunity Matrix shows a range of opportunities versus constraingts for riparian corridor expansion by multiplying the number of benefits against constraints of privately owned parcels encroaching on channels and existing floodplain land use. A score of 25 represents the most opportunities and least constraints. A score of 1 represents fewest opportunites, most constraints.

3.4 WATERSHED INFILTRATION ANALYSIS

3.4.1 METHODS: INFILTRATION TYPE + SUITABILITY CRITERIA

Restoration of self-sustaining creeks depends on natural flow and sediment regimes. Widening and connecting the riparian corridor is not sufficient. Flows do the work to transport sediment, maintain channel form and rejuvenate habitat.

Previous research shows that promoting stormwater infiltration can improve water quality, increase groundwater recharge, and reduce peak flows (Jefferson et al., 2017). To understand where conditions support safe and cost-effective infiltration, we developed criteria to identify suitable locations throughout the watershed to promote infiltration and mitigate urban land use impacts on water quality and the flow regime. We developed our methods with initial analysis on Grayson Creek (*Appendix B3*), followed by a refined strategy for identifying infiltration opportunities in Walnut Creek's watershed.

Specifically, we assessed suitability of:

- **Shallow infiltration**, through measures such as bioretention, permeable pavement, infiltration trenches with minimal soil remediation;
- **Deep infiltration**, which use deep drains to convey stormwater past surface soil layers with lower infiltration rates into deep, unsaturated, permeable layers;
- **Limited infiltration**, in which infiltration is only limited by the presence of low permeability soils but poses no other hazards.

We identified and assessed seven biophysical criteria that either restrict or support shallow, limited, or deep infiltration opportunities (*Figure 3-6*). We first designated unsuitable areas of the watershed where steep slopes, high groundwater table, or natural hazards posed risks or limitations to infiltration. Opportunities for shallow infiltration are identified within hydrologic soil groups A and B (permeable soils) and limited infiltration areas within hydrologic soil group C (relatively impermeable soils, where elevated underdrains or oversized facilities are possible). In areas with low permeability soils (soil group C and D), we consider deep infiltration as an option if deeper permeable geology allows for infiltration to aquifers for longer-term storage.

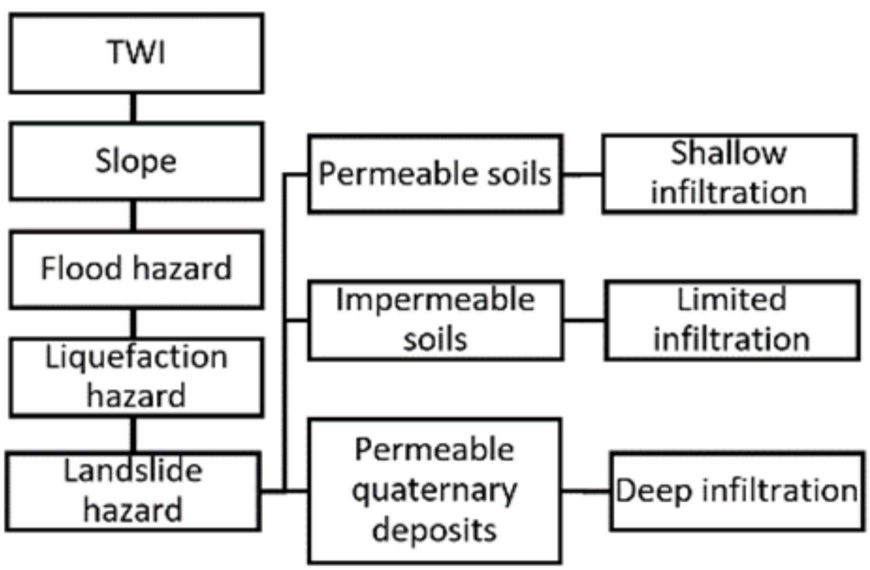


Figure 3-6. Flow chart of criteria used to determine suitable infiltration areas and types. Unsuitable areas are eliminated in the first step (or column) of the analysis. Topographic Wetness Index (TWI) is calculated from local slope and contributing area to predict areas with near-surface groundwater, which we considered a limit on infiltration

capacity. Then infiltration opportunities are categorized according to soil and subsurface permeability rankings to determine infiltration suitability. See *Appendix B3* for details on infiltration suitability criteria and data sources.

3.5 RESULTS

The *Watershed Opportunity Atlas* (Atlas) presents maps of resulting opportunity reaches, potential parcel partners and infiltration suitability areas. Throughout this report we reference maps in the Atlas as (Map ID) where the ID abbreviates watershed scale (W), municipal scale (M), or reach scale (R) followed by a uniquely identifying number.

3.5.1 OPPORTUNITIES FOR RIPARIAN CORRIDOR RECONNECTION

3.5.1.1 Capturing multiple benefits of expanding riparian corridors

In total, 23 percent of all altered channels have high potential to serve the full range of benefits we analyzed: riparian corridor reconnection, community use, public health and safety, and migration connectivity for salmonids. The mainstem channels of Walnut Creek and San Ramon Creek show the highest levels of overlapping benefits along much of their lengths (Map W-6).

In particular, the confluences of creeks with historical salmon runs present concentrations of highest-benefit opportunities for restored riparian corridors. These highest-ranking reaches include:

- Walnut Creek confluence with Pine Creek (Map M-4),
- the broad area where Las Trampas, Tice, Sans Crainte creeks join San Ramon Creek and flow into Walnut Creek (Map M-7),
- where Green Valley Creek joins San Ramon Creek (Map M-13).

In general, more upstream reaches showed fewer potential benefits. Our assessment method showed that restoration of upstream tributary reaches of altered channels had fewer benefits than mainstem reaches. Often, the FEMA-designated 500-year floodplain is most expansive in valley lowlands, so in upper tributary reaches, the benefit of reducing flood risk did not appear as extensively or frequently. For community use criteria, upstream reaches often have a lower density of people, so they showed less demand for access to open space and parks, though some show potential benefit of extending a bike path network to address gaps in the existing network. Likewise, changes to community use, as indicated by Priority Development Areas (PDAs), are expected along transportation corridors that line valley bottoms. According to our criteria and data, neighborhoods surrounding the uppermost reaches of altered channels have resources to serve public health and safety, so they often did not meet criteria for this benefit.

Other highest-benefit reaches that stray from these two major patterns include the upper reaches of altered channels in Pine Creek, a short culverted reach on Green Valley Creek, and the downstream reach of Bollinger Canyon Creek where it bends across the Calavaras Fault into San Ramon Creek. These reaches all historically supported salmon runs.

Because historical salmon runs did not likely occur on Grayson, Pacheco, Clayton Drain and Galindo Creek, their potential to achieve the fifth benefit of ecosystem restoration, to support salmon, was reduced. Although we did not discount the effects of urbanization in any benefit criteria, these drainage areas also have the highest percent impervious cover and lowest water quality indicators (Map W-2) suggesting that even with restoration, constraints of urbanized watersheds could present challenges to the most sensitive native species. Flows from these basins affect conditions in lower Walnut Creek, however. The analysis shows that mainstem reaches of Grayson and Pacheco Creek meet criteria for the four other potential benefits, so their restoration potential should not be ignored.

Las Trampas Creek's subwatershed historically supported salmon, but much of the mainstem does not meet criteria for all benefits. Upstream of Las Trampas Creek's confluence with Reliez Creek, including Lafayette Creek, the analysis did not show specific benefits for public health and safety. Neighborhoods in these reaches have indicators of good air quality, bike trail connectivity, access to parks, and flood protection. Our assessment did not identify vulnerable communities in areas surrounding altered channels, but our data was limited. Throughout areas of downtown Lafayette, we identified reaches with high potential for community use (given present or expected changes in land use with PDAs) in addition to ecological restoration benefits. Given this benefit and historical salmon runs, their restoration potential should not be ignored.

3.5.1.2 Parcels with potential partners for restoration of riparian corridors

Of all altered channels, 36% are owned by the District, a total of 35.6 miles. Wherever the District owns the channel's parcel, at least one potential partner exists in the adjacent floodplain (Map W-7). Along half of District-owned channel, the District also owns an adjacent parcel (17.7 miles). District-owned channels cover most mainstem, lowland portions of the five major creeks: Grayson, Pine, Walnut, San Ramon and Lafayette creeks. The lowest reaches of Galindo and Green Valley Creeks also fall under District ownership.

Of altered channels that are not owned by the District, 36% have no potential partners in the channel or the floodplain (55.2 miles). About 6 miles of channel have potential partners who own the channel and parcels in the floodplain.

In many cases, the reaches with in-channel and floodplain potential partners fall between District-owned channels or at least extend them.

3.5.1.3 Opportunities for expanding riparian corridors with a wide range of benefits

For creeks to offer more benefits to more people, restoration of ecosystem function requires expanded riparian corridors. Scores from the restoration opportunity matrix (*Figure 3-5*) show that 6.5% of altered channels with the highest potential benefits (all five) are owned by the District and have potential partners in the floodplain (list of locations and partners in *Table 3-1*). A nearly equal amount has only the baseline benefit and no potential partners, 6.1% or 6.11 miles. The vast majority of altered channels lie in between these two extremes (Map W-8).

The *Atlas* maps the opportunity matrix assessment, including both benefits and partner analyses, for the watershedand at three levels: the highest ranked and most promising opportunities, the lowest ranked and most challenging reaches, then the middle range as opportunities that are promising but may require more time for planning and negotation to overcome constraints. At the municipal scale (Maps M-1 to M-15), mapped opportunity assessments reveal detailed matrix scores (1-25), showing opportunities to expand restoration up or downstream from highest ranked reaches to create longer, laterally connected corridors of riparian habitat.

3.5.2 OPPORTUNITIES FOR INFILTRATION ACROSS THE WATERSHED

Low permeability soils dominate the watershed, a limitation on opportunities for infiltration at the surface. Given further restrictions due to steep slopes, liquefaction, or an estimate of high water table, only 2% of the watershed area appears suitable for shallow infiltration of stormwater. The most opportune areas to promote shallow infiltration exist in:

- ***Grayson Creek watershed***, the neighborhoods in Martinez (north of Route 4), the hills south of Cilpancingo Parkway, and Ellinwood Creek (Map M-3);
- ***Pine Creek watershed***, neighborhoods surrounding upper Ygnacio Valley Road, Treat Boulevard and Lime Ridge Regional Open Space in Concord (Map M-6); and also the northern slope of Shell Ridge Open Space in Walnut Creek (Map M-9);
- ***San Ramon watershed,*** along fans and former floodplains that drain into San Ramon Creek over the Calavaras Fault (Map M-15);
- ***Las Trampas watershed***, limited to upper Grizzly Creek and tributaries of Happy Valley Creek near Redwood Road and Rose Lane (Map M-12). The City of Lafayette has the fewest opportunities for shallow infiltration.

Permeable Quaternary deposits, gravels and sands beneath fans and lowland valleys, present opportunities for deep infiltration of stormwater via wells that bypass impermeable soil layers. Areas suited for deep infiltration constitute 21% of the watershed (Map W-5). The largest areas to promote deep infiltration exist in:

- ***Grayson Creek watershed***, the fans and former floodplain of Murderers Creek and upper Grayson Creek;
- ***Las Trampas watershed***, the fan of Reliez Creek and an expanded deltaic wedge of Quaternary deposits at the mouth of Las Trampas (near the junction of I-680 and Rt 24);
- ***Pine Creek watershed***, the foot of Shell Ridge's north-facing slopes and pockets between Pine and Galindo Creek;

Where soils have intermediate permeability, limited infiltration rates can be mitigated by underdrains or oversized facilities, such as rain gardens. Areas suitable for limited infiltration constitute 24% of the watershed.

Table 3-1 Catalog of opportune reaches for riparian corridor expansion with potential partners identified in geospatial analysis. The column labeled (L) represents an estimate of the reach length in miles. A map for each site is available in the Walnut Crerek Watershed Opportunity Atlas. Maps are identified by Site ID. We abbreviate Drop Structure as DS, School District as SD, Priority Development Area as PDA, Contra Costa County as CCC, East Bay Regional Park District at EBRPD.

SITE ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
G1	1.8	**GRAYSON CREEK** Pacheco Blvd to mouth at Walnut Creek.	*Contra Costa County*	Central CC Sanitary District CalTrans *Others: private landowners*
		Lower Grayson Creek shares a floodplain with Walnut Creek. Grayson Creek's restoration opportunities are more constrained due to lower ecological potential. The watershed is highly urbanized (>30% impervious). Water quality is poor. Historical steelhead runs were possible, but not probable or definite. Despite limits, a public riparian greenway promises social benefits and fish do persist in this perennial reach.Throughout Grayson Creek's shared floodplain with W1 and W2, consider multi-benefit opportunities to open and connnect public access while seeking creative solutions to reduce flood risk. See Appendix B for detailed studies.		
W1	0.7	**WALNUT CREEK** between confluence with Grayson Creek + Clayton Valley Drain.	*City of Concord* *Contra Costa County*	Caltrans Contra Costa Water District EBRPD CCC Board of Education *Others:* Southern Pacific Transport Co, among other smaller landholders
		Three road crossings (Imhoff Drive, State Route 4, and Marsh Drive) complicate the strong restoration opportunities on this short, tidal reach. Consider potential water access for kayak, canoe. Reaches W1, W2, G1, and G2 should be considered simultaneously in partnership with Contra Costa County, Caltrans, EBRPD due to their shared floodplains, the future influence of sea level rise, and the potential for restoration at the edges of the airport.		
W2	1.6	**WALNUT CREEK** along Buchanan Fields (see W1) to Pine Creek Confluence, upstream to Diamond Blvd Crossing.	*City of Concord* *Contra Costa County*	Mount Diablo Unified SD SF BART District EBMUD *Others:* Conco Storage, Concord Airport Plaza, CBC Properties, HD Development of MD, Montecito Properties, Pur Sterling LLC
		The confluence of Walnut and Pine creeks offers strong public benefits and adjacent parcels have potential partners (airport, theme park). Other adjacent parking lots and light industrial land uses have low-investment built structures. Consider job and manufacturing displacement in concert with nearby PDAs in Concord and Pleasant Hill. Site W1 and W2, along with Grayson Creek, should be considered simultaneously. An initial opening of public loop trails along these reaches (where currrently gated) could raise awareness of the Fifty-Year Plan. See Appendix B for detailed studies.		

Site ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
W3	**1.3**	**WALNUT CREEK + ELLINWOOD CREEK** at **DS W-1**. If include connectivity with Ellinwood Creek add 1.1 miles to project length.	*City of Concord* *City of Pleasant Hill* *Contra Costa County*	Caltrans EBRPD *Others*: private owners
		Consider restoring a robust connnection between Walnut Creek and Ellinwood Creek for aquatic off-channel habitat, fish passage around DS W-1, and allowing pedestrian and bike crossing beneath I-680; requires tight partnership with Caltrans. Closing of the adjacent JFK University campus in 2020 could open opportunities for restoration if the site is sold or redeveloped.		
W4	**0.6**	**WALNUT CREEK** at Monument Boulevard to Fair Oaks Elementary School. *Consider integrated planning with Pleasant Hill PDA*	*City of Concord* *City of Pleasant Hill* *Contra Costa County*	EBRPD Mount Diablo Unified SD CCC Redevelopment Agency *Others: Lisa Lane HOA, J Hanson (large parcel on right bank) + other private owners, especially in PDA*
		Potential partners at Fair Oaks Elementary School, EBRPD and Contra Costa County Redevelopment Agency open this opportuninty for restoration of a high-benefit reach that could possibly be extended up or downstream if partners or willing sellers emerge. Re-aligning the crossing of EBRPD Iron Horse Trail beneath Monument Blvd (with a widened bridge over a restored Walnut Creek) could improve the speed and safety of the bike commute to Pleasant Hill BART, only 1.3 miles (an 8 minute ride) from this reach.		
W5	**1.1**	**WALNUT CREEK** at **DS W-2**, upstream to Seven Hills School + Heather Farm Park.	*City of Concord* *City of Walnut Creek* *Contra Costa County*	Seven Hills School City of Walnut Creek SF BART District Contra Costa Water District EBRPD Caltrans *On right bank between BART and Treat Blvd: Countrywood Homeowners Assn, Rancho Dorado Homeowners Assn, + other private parcel owners, especially in PDA along Treat Blvd.*
		With proximity to Pleasant Hill BART and PDA plus Heather Farm Park, restoration of the 1.1 mile reach presents strong social benefits including ecological potetntial of longitudinal connectivity. Upstream of DS W-2, District and BART property (in green, Map R-W5) cover a 3-4 acre area between Bancroft Rd and the BART tracks. Seven Hills Ranch, on the upstream eastern bank, is a ~30-acre parcel of oak savannah habitat with a minor tributary, potential wetland habitat, and source of cool summer water. The ranch site offers valley vistas; public access to views can promote sense of safety along the creek. If the site is conserved and connected with restoration of Walnut Creek, the combined area has potential to anchor wildlife habitat. Creek restoration is constrained by private parcels on the left (west) bank.		

Site ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
W6	**0.4**	**WALNUT CREEK** from Walnut Creek Intermediate School to Ygnacio Valley Blvd. Possibly extend to Civic Center Park (+0.5 mi) *or* ***DS LT-1*** *(20-50 yr service life)* (+0.7 mi)	***City of Walnut Creek*** ***Contra Costa County***	Walnut Creek School District EBRPD + Iron Horse Regional Trail State of California Central CC Sanitary District Others: *private parcels.*
		The reach ranks as a strong opportunity because of potential partership with Walnut Creek School District and EBRPD. With Walnut Creek PDA throughout the western floodplain, more opportunities for integrated planning emerge. A long-term vision for transforming DS LT-1 into an urban confluence park could be integrated into PDA plans, perhaps in partnership with Kaiser Medical Center. For people and wildlife, consider restoration in current and historical floodplains at Indian Creek with connectivity to open space at Shell Ridge (e.g. via Howe Homestead Park, 0.6 miles from Walnut Creek downtown, and along Indian Creek to Joaquin and Shell Ridges). Off-street trail connection to Mt Diablo, a hiking and biking mecca, from downtown Walnut Creek could garner strong community and political support.		
SR1	**0.6**	**SAN RAMON CREEK** at confluence of San Ramon and Sans Crainte creeks. From I-680 crossing downstream to Murwood Elementary School. Possibly extend to Los Lomas High School (+0.7 miles)	***City of Walnut Creek*** ***Contra Costa County***	CalTrans Walnut Creek SD Las Lomas High School Acalanes Union High SD State of California Central CC Sanitary District *Others:* Kaiser Foundation Hospitals, Retreat Apartments, Ontario Mountain Associates, Creekside Terrace LLC, 14000 Creekside Apt Owners Assn, WCSI Properties LLC, Change Income Partnership,+ other private owners
		Murwood Elementary sits at the confluence of Sans Crainte and San Ramon creeks. FEMA-designated floodplain extends upstream. Flood risk may influence potential partnerships in this reach. Downstream of the confluence, Walnut Creek's PDA holds promise for integrated planning, partnerships, and public benefits to a growing community. Under-utilized Kaiser properties, Los Lomas High School, and Murwood School anchor partnership opportunities in the historical floodplain.		
SR2	**0.6**	**SAN RAMON CREEK** Downstream of Stone Valley Creek confluence to **DS SR-3** (40 yr service life). Possibly extend to **DS-2A** (+0.3 miles).	***Contra Costa County***	CalTrans State of California *Others:* G.F. Ludden (Stone Valley Ck), private landowners
		In unincorporated Contra Costa County, this reach has high potential benefits due to a historical steelhead run and current lack of parks and trails. Adjacent parcels are largely residential. I-680 currently constrains the right (east) bank and presents a barrier to bike and pedestrians. Caltrans is a needed partner. The District and the state of California own parcels along the channel in this reach.		

Site ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
SR3	**1.4**	**SAN RAMON CREEK** Green Valley Creek confluence upstream to Sycamore Creek confluence, including **DS SR-9 + DS SR-10** (30-60 yr service life) and **DS GV-1**. *Consider Danville PDA as an opportunity for partnership and collaboration.*	*Town of Danville*	CalTrans Contra Costa County Danville Development Agency Danville Community Development Agency *Others*: Diablo Park LLC, Catholic Diocese of Oakland, San Ramon Valley Christian Academy, Whispering Creek LLC
		In the reach between I-680 and Sycamore Creek (includes DS SR-10) the District owns or has easements for channel or adjacent parcels. Few parks exist nearby and I-680 presents a barrier to pedestrian or bike into downtown Danville; a riparian greenway would offer strong community benefits. Danville's PDA opens opportunities for integrated plannning downstream of the I-680 crossing. At DS SR-8, large schools on each bank offer potential for restoration partnerships. Between DS SR-8 and SR-10, residential parcels and I-680 crossing constrain the creek. The confluence at Green Valley Creek presents opportunities for an urban park within the PDA.		
SR4	**0.8**	**SAN RAMON CREEK** From I-680 crossing at Fosteria Way downstream to Camino Ramon Pl, including **DS SR-13** (65-100 yr service life). Possibly to **DS SR-12** (60 yr service life) and Iron Horse Trail (+0.22 mi)	*Town of Danville* *City of San Ramon*	EBRPD CalTrans *Others: M. Adam (~4 acre pacel downstream of DS SR-13) + private landowners*
		The Borel Homestead property, owned by EBRPD, and channel parcels owned by the District anchor opportunities at this multi-benefit reach and the surrounding historical floodplain. Here, San Ramon Creek forms broad alluvial fan downstream of the North Calavaras Fault. Tributaries from the east also cross the fault onto fans. All are potential sites for shallow or deep infiltration to offset increased stormwater runoff from urbanization. I-680 and residential parcels constrain the channel in this reach, which lies in Danville. Connecting a restored riparian greenway to the Iron Horse Regional Trail, downstream of DS SR-12 (60 yr service life), would greatly expand the off-street trail network for locals and connect regional cyclists to destinations in San Ramon.		
GV1	**1.0**	**GREEN VALLEY CREEK** I-680 crossing to Diablo Rd; *consider connectivity with Danville PDA*	*Town of Danville*	Caltrans Green Valley Shopping Center Danville Park RE LLC Danville Grange No 85 San Ramon Unified SD
		A historical steelhead run with some conserved uplands, Green Valley Creek's mouth lies in Danville's PDA and includes large, creekside parcels. Upstream, the creek flows beneath I-680 and rises through a residential neighborhood within a FEMA-designated floodplain. The Green Valley Shopping Center on the left (south) bank is in Danville's PDA. Integrated planning with the PDA in the confluence area could open opportunities for an actively-used urban park with connected riparian greenway to serve the growing downtown and into suburban communities along Green Valley Creek.		

Site ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
P1	**1.8**	**PINE CREEK** Mouth at Walnut Creek to Meadow Homes Park and Monument Blvd.	*City of Concord*	Cal Trans Mt. Diablo Unified SD EBMUD Concord Redevelopment Agency *Others:* CBC Properties, Wing Four-Corners LLC, PG&E, Uhaul Real Estate, and other private landowners
		The alignment of Lower Pine Creek with Concord's PDA opens an opportunity for land use change to support restoration, and for restoration to offer public benefits to a growing community. The city-owned land at Walnut Creek's confluence, the combined parcels of Meadow Homes Elementary School and Park, and the highway crossing at Route 242 anchor opportunities for partnership to widen the riparian corridor. The reach bisects a Community of Concern (MTC/ABAG 2017), a rare area of affordable housing in the watershed. Opportunities of 'underutilized land use' should be considered along with concerns of community displacement from jobs and affordable housing. Marginalized communities may disproportionately benefit from access to nearby riparian greenways, but only if paired with access to jobs, affordable housing, public transit and services. Integrated planning with Concord PDA should consider solutions with and for the existing local community.		
P2	**0.7**	**PINE CREEK** Monument Blvd to to Detroit Ave. Possibly extend restoration to the BART line (+0.6 mi), **DS P-1** (+0.3 mi) or San Miguel Rd (+0.4 mi).	*City of Concord*	Mt. Diablo Unified School District Oak Grove School District PG&E Public Storage Properties Wing Four Corners LLC SF BART District
		A former salmon run with conserved uplands and no downstream migratory barriers, reaches P1 + P2 have high ecological potential for restoration. A city-owned park, SF BART (maintenance yard), Flood Control District parcels and Ygnacio Elementary School anchor parternship opportunities. Big box stores, parking lots, low-rise commercial and light industrial uses line the reach from Monument Blvd to the BART tracks. The channel transitions from concrete to earthen upstream of BART where the District owns easements and parcels, but residential homes line the creek and gates block access to the creek. Connections from a restored riparian greenway to Lime Ridge trails could expand access to natural habitat for people and wildlife.		

Site ID	L (mi)	LOCATION	JURISDICTIONS	POTENTIAL PARTNERS
LT1	**0.2**	**LAS TRAMPAS CREEK** at **DS LT-2** at Bridge Rd, possibly connecting to Boulevard Way (upstream) or Newell St Class II Bike Lane (downstream)	*Contra Costa County*	*Caltrans* *private parcel owner* potential interest from **Olympic Boulevard Corridor Trail Project**[3] (led by Contra Costa Transportation Authority with EBRPD, Cities of Lafayette + Walnut Creek)
		Within a short bike ride of downtown Walnut Creek, a restored riparian greenway would offer multiple public benefits. Upstream of DS LT-2, the District owns parcels along the channel for ~530 feet. Otherwise, residential parcels within unincorporated Contra Costa County line the entire reach. Some (in green, Map R-LT1) have no built structures. Neighborhoods in this reach are isolated by I-680 except for busy Olympic Blvd, which had a recent trail study, but did not acknowledge opportunities of the Fifty-Year Plan. Integrated planning with Caltrans would support both efforts and perhaps open a safe, off-street I-680 crossing along Las Trampas Creek. Downstream of this site, DS LT-1 has a 25-50 year service life.		
LT2	**0.3**	**LAS TRAMPAS CREEK** at Lafayette Creek confluence, including **DS LT-3** (<25 year service life) , + full meander around 4th St; possibly to **Carol Lane DS** (5-25 year service life).	*City of Lafayette*	EBRPD Las Trampas School properties along Mt Diablo and Golden Gate in PDA
		EBRPD and the City of Lafayette own parcels (in green, Map R-LT2) along Las Trampas Creek's left (south) bank from Moraga Blvd to DS LT-3. The District owns parcels at the drop structure, accessed from 4th St. The Lafayette PDA includes Lafayette Creek and the meander loop portion of Las Trampas Creek. Consider expanding restoration upstream through Lafayette Creek with integrated PDA planning. The Carol Lane DS (0.54 miles downstream from DS LT-3) has more strategic importance than opportunity due to its limited service life and lack of potential for partnering landowners. Between the two drop structures, residential parcels cover the channel and both banks.		

[3] The Olympic Boulevard Corridor Trail Project's Preferred Alignment Report from 2015 considered a route along Las Trampas Creek. See *Appendix A1*, Figure 2 for a map of preferred alignments. As of September 2021, the full report by Alta Planning and Design was available at https://www.contracosta.ca.gov/DocumentCenter/View/44097/Olympic-Connector-Preferred-Alignment?bidId=

3.6 DISCUSSION

3.6.1.1 Phased Strategies

The resulting maps suggest the need for a range of phased strategies. In the near-term, District-initiated demonstration projects that widen riparian corridors can help the community learn and prepare for more complex initiatives that connect projects longitudinally, but require changes in land use. The pursuit of projects can be based on opportunities for public benefits and partnerships. Two sites of strategic importance, however, did not arise as opportune sites for restoration. Because we facility service life assessments are still underway (summarized in Table 1-1), our analysis did not consider where infrastructure has an especially short remaining service life. We know that Carol Lane Drop Structure (built in 1941) has an estimated life of 5-25 years. The East Fork of Grayson Ccreek (built in 1957) has an estimated life of 30-40 years. Neither arose as an opportunity site. They're constrained by private parcels and require a short-term strategic approach. These sites will likely be the first in a longer term experiment to understand best practices for restoration of highly constrained reaches.

Ideally, restoration of the watershed's flow regime should precede restoration of free-boundary channels, but realistically this will not occur because impervious surfaces are already widespread (especially in Grayson Creek and the cities of Concord and Walnut Creek) and mitigation via green infrastructure retrofits will require a long-term effort to reverse the effects of hydromodification. Policy reviews should identify gaps to incentivize and enforce appropriate green infrastructure measures whenever parcels or public right-of-ways undergo construction. Incentives can be built around infiltration zones (Map W-5), land use types, and also hydrologic sensitivity of subwatersheds (see *Appendix G*).

To restore a more natural flow regime over time, policies can increasingly encourage appropriate siting, types, scales, and distribution of infiltration measures can be integrated into green infrastructure plans, municipal codes, and public projects (e.g. road and highway upgrades, parks and school grounds) across the watershed.

The use of distributed infiltration-based facilities for groundwater recharge has been suggested as an adaptive management strategy for future climate variability and change (Newcomer et al., 2014), and is gaining momentum in California as a viable groundwater recharge strategy in urban areas. The County of Los Angeles' "Stormwater Capture Master Plan" (2015) demonstrates a groundwater recharge benefit to distributed infiltration stormwater capture. The County could consider developing a plan to increase groundwater recharge via small-scale infiltration facilities, floodplain expansion, and deep infiltration techniques. Most commonly, even infiltrated stormwater can reach acceptable water quality levels simply by virtue of filtering through the soil horizon, such that shallow groundwater can be used for a wide range of applications.

3.6.1.2 Partnerships, Awareness and Cooperation

Over the long-term, expansion of riparian corridors will require partnerships. As we identified, public agencies and institutional landowners in the floodplain may be initial potential partners due to large parcel sizes, potential for remnant riparian features, the public-serving benefits, but also existing working relationships toward a shared community-serving mission. Despite this, if potential partners are unaware of the opporunities of the Fifty-Year Plan, coordinated collaborations that account for needed restoration setbacks and fund parcel buyouts for expanded riparian greenway corridors are much less likely. Pleasant Hill's recently constructed senior center along Grayson Creek's banks (completed in 2013 on city-owned land, *Figure 3-7*) and CCTA's 2015 Olympic Boulevard trail alignment study along Las Trampas Creek (*Appendix A1*, Figure 2) offer examples of how institutional awareness of the Fifty-Year Plan and cooperative planning could expand and improve multi-functional benefits achieved with changes in land use and community investment.

Over a third of altered channels had no identified partners, and even where partners were identified, reach length remains limited which may not coincide with the most cost-effective design and construction strategies. At confluences, we identified high community benefits (due to need and demand), but few partners. Only one or two parcels is likely insufficient to open former floodplains to overbank flows and dynamic fluvial processes. The confluence of Pine Creek and Walnut Creek, however, presents an exceptional opportunity because the City of Concord owns the wedge-shaped 31 acre parcel between the two creeks.

Each identified reach deserves a more detailed functional assessment of opportunities and constraints that expands beyond the limits of our GIS-based analysis. In our initial study of lower Grayson Creek restoration opportunities (2016-17), we presented a potential framework for a

Figure 3-7. Pleasant Hill Senior Center, which opened in 2013, directly abuts Grayson Creek's concrete channel on city-owned property. In our analysis, this reach was among higher-ranked restoration opportunity sites along Grayson Creek, but expansion of a restored channel and riparian corridor to the eastern right bank is unlikely due to the recent multi-million dollar 23,000 square foot community structure built within about 10 feet of the flood control channel's concrete wall. According to 1930s-era aerial imagery, the open creek once had a 220 ft meander amplitide (width between outer bends of meanders), whereas today the straightened and confined channel is about 20 feet wide.

more detailed functional analysis for lower Grayson (*Appendix B4*) and graduate students at UC Berkeley conducted site-scale assessments to inform conceptual restoration plans (*Appendix B5)*.

Overall, this analysis confirms that restoration of riparian corridors will require sustained, multi-decadal partnerships and collaboration to addresses incompatibilities between floodable riparian corridors and existing land uses. Communication of opportunities for restoration should emphasize the broad range of community benefits and ecosystem services that emerge as dynamic, free-boundary creeks sustain themselves, the region's ecosystems, and people within the watershed. Collaborative environmental planning strategies for long-term, large-scale restoration follows in *Section 4, How?*

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4 HOW? Principles, Strategies and Tools for the Fifty-Year Plan

4.1 PRINCIPLES OF COMMUNITY WATERSHED PLANNING

4.1.1 PARTNERSHIPS, COLLABORATION AND COOPERATION

Facing increasing flood risk and aging infrastructure, the Contra Costa County Flood Control and Water Conservation District (District) adopted the Fifty-Year Plan, but it cannot act alone. The District does not own the land needed to contain storm flows and restore connectivity (social or ecological). The District does not regulate land use, zoning, or building codes, nor can it restore a natural flow regime through stormwater management. The District does not have funds to replace or restore channels. The Fifty-Year Plan's vision for re-investment in flood management positions the District as a potential leader in innovative approaches to overcoming the challenges of restoring multi-functional riparian corridors in urbanized watersheds. However, our spatial analysis confirms that the District will need partners to widen riparian corridors, connect downstream-to-upstream habitat, and mitigate hydromodification in urbanized areas draining to Walnut Creek.

Even if citizens, city planners, and politicians are inspired by the vision of restored riparian corridors, the planning process will require negotiation of *how* plans are defined, *how* benefits versus costs are weighted, *how* alternatives lay out on the ground, and *how* the transformation is regulated, incentivized, funded, and then maintained. Social conflicts will arise. Answers to the questions of "how much" change is required to restore "how much" ecosystem function to meet "how many" community objectives are uncertain and may be impossible to predetermine. Adaptive approaches to planning, management, and even governance directly address this potential for social conflict and scientific uncertainty.

4.1.2 MULTIPLE SCALES OF PROCESS-BASED RESTORATION

4.1.2.1 Restoring Processes of Riparian Corridors Requires Land Use Change in the Floodplain

Over time, local land use decisions supported development of private parcels and public infrastructure throughout floodplains and right up to channel boundaries. To address the hazard posed by floods to these exposed investments, engineered channels were designed to convey flood flows through narrow right-of-ways. At the time of flood infrastructure construction, there was no legal mandate or local motivation to protect riparian corridors. In many cases, existing homes along the channel "severely limited channel width (Walkling, 2013, p. 20)." Concrete channels with armored, smooth boundaries and a deepened cross section allowed the District to minimize land acquisition costs and disturbance to newly-built communities.

As the District considers restoration measures, even modest approaches such habitat or aesthetic enhancements will likely increase flow resistance in concrete channels by introducing vegetation, freeing channel boundaries, or allowing salmon passage. Increased resistance, roughness, and irregularity of channel beds and banks will reduce mean flow velocities for a given discharge (see *Section 2.4.5 in What?).* As defined by the continuity equation, a "roughened" channel will require greater cross-sectional area to convey the extreme flow discharge supported by smooth, hardened concrete channels (Knighton, 1998).

To increase the channel cross-sectional area, further deepening of channels will increase forces acting on channel boundaries, creating conditions that promote channel instability, an unlikely restoration measure. Widening the channel cross section reduces flow depths and opens areas of the historical floodplain for inundation, increasing lateral connectivity, a process-based restoration strategy. Further alternatives to widening could include distribution of flows across multiple channels, effectively increasing channel cross-sectional area by splitting flood flows among multiple channels, a condition that occurred historically in secondary channels of lower Walnut Creek (Dusterhoff et al., 2016, pp. 15–16). Our spatial analysis explored parcel-based opportunities to widen riparian corridors, but did not consider how existing public right-of-ways might accommodate flows (e.g. via a seasonal channel, flood bypass, or pipe). Restoration strategies that leverage public right-of-ways to divert high flows and reduce the scale and intensity of required land use change would not restore lateral connectivity between channels and the floodplain, but could be an opportunity to maintain a natural-looking channel with enhanced habitat, managed riparian vegetation, and natural bed materials that support salmon migration through urbanized reaches.

4.1.2.2 Restoring Processes of Riparian Corridors Requires Mitigation of Urban Hydromodification at the Subwatershed Scale

Restoration of channels cannot occur without addressing the impacts of urbanization on water quality and the flow regime, as discussed throughout *Section 2, What?* On private parcels, rooftops and paved surfaces increase the water than runs off while decreasing the water retained and transpired by vegetation, and infiltrated into soils. Roadways are impervious and directly connected sources of polluted runoff to stream ecosystems (Shuster et al., 2005). Mitigating watershed-scale urban drainage patterns to restore the flow regime of local creeks will thus require cooperation and partnerships with regulatory agencies, parcel owners, neighborhood groups, engineers who design public infrastructure, planners and decision-makers who influence land use and public right-of-ways at state (e.g. Caltrans, State Parks, CA Fish and Wildlife), regional (SF Regional Water Quality Control Board, ABAG, MTC, East Bay Regional Parks), county, and municipal levels.

4.1.2.3 Restoring Processes of Riparian Corridors requires Partnerships and Collaboration Across Jurisdictions, Expertise, Interest Groups, Landowners, and Regional Agencies

Collaboration with land trusts can provide local knowledge and tap into existing networks to facilitate cooperative landowner agreements. Collaboration with watershed groups can help connect, expand, and manage a diverse and inclusive support network. Collaboration with scientists can structure systematic approaches to adaptive management and citizen participation in data collection and leveraging restoration interventions as low-cost experiments. *Appendix C2* outlines an initial stakeholder analysis with an emphasis on building coalitions across interest groups and collaboration among jurisdictions, institutions and agencies. A more in-depth analysis can help drive collaborative efforts to mitigate urban hydromodification throughout the watershed and consider appropriate land-use and policy change to restore riparian corridors.

4.1.3 NO SINGLE, OPTIMAL SOLUTION EXISTS

The outcome of the Fifty-Year Plan is not pre-determined; it will emerge from the planning process. A range of restoration approaches offer a varying array of benefits and costs as distributed across spatial arrangements, social groups, habitats, and periods of time (e.g. during summer drought, regular floods, extreme floods, as climate changes). Different approaches will align with values and preferences of some over others. Goals, values, trade-offs, perhaps even the scale, scope, and framing of the problem must be negotiated. Over decades of stream restoration planning and implementation across the United States, we have learned that failure of restoration initiatives most often stems from a lack of systematic planning (Roni and Beechie, 2012). The planning process, therefore, deserves careful consideration starting with agreement on:

- the appropriate **scale and scope of the problem**,
- **guiding principles** to ensure the planning process upholds community values,
- how to institute **effective adaptive management** to address uncertainty.

Both restoration planning and flood risk management are inherently social processes that require management and policies to govern use of land and water in a watershed. While the vision of the Fifty-Year Plan currently focuses on “restoration” of altered channels, recognizing broader social goals can inform the process and principles of restoration planning: to satisfy diverse community needs, to garner political and regulatory support to address impacts of land and water use on publicly-valued ecosystem services, and to engender trust in the District’s leadership. Achieving these goals depends on a planning process that allows communities to reimagine creek corridors and the potential for watersheds to serve the public through changes to land use, management, and policy. Collaborative dialogue and negotiation, if inclusive and facilitated with a focus on listening to and learning from voices that reflect a range of interests, experiences, perspectives and expertise, can influence outcomes by allowing creative solutions to emerge from diverse, and even conflicting, perspectives without deadlock or over-bargained, unsatisfying compromise (Innes and Booher, 2010). Outcomes of the planning process may be impossible to predefine, but a commitment to planning principles that promote shared understanding and trust among diverse stakeholders can lead to agreement on the progression of legitimate, just, and feasible resource use and management policies. The process can then deepen the social capacity for adaptation under uncertain future conditions (Innes and Booher, 2010). This may be an ultimate goal of the Fifty-Year Plan.

4.1.3.1 Defining an Unstructured Problem

The combined challenges of aging infrastructure, urban flooding, climate change adaptation, and ecosystem restoration in Walnut Creek’s watershed present the District with a complex social dilemma that has high uncertainty (Hurlbert and Gupta, 2016) (*Figure 4-1*). The District needs to replace flood infrastructure and protect constituents from flood hazards, but the problem remains relatively unexplored among diverse stakeholders. Which set of ecosystem services is most valued (e.g. continued flood protection for some property owners or land buyouts for public greenways that serve the entire county, restored salmon runs versus undisrupted land use)? Who will benefit and who will pay are not yet defined. At this early phase in planning, the problem has some structure, depending on the stakeholder perspective, but it operates at multiple scales with a range of potential impacts for current residents and business interests, those in the floodplain and beyond, with potentially dire or beneficial implications for future generations.

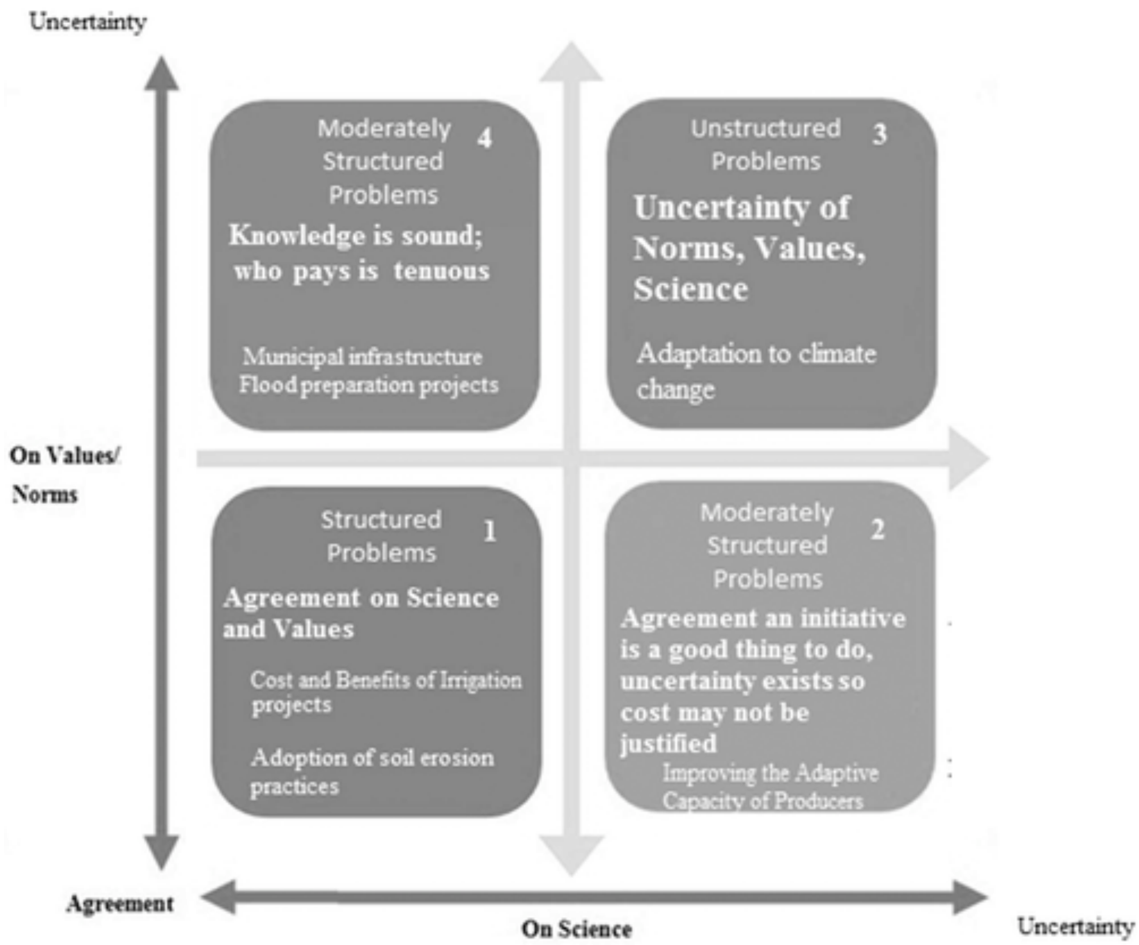

Figure 4-1. Policy dilemmas related to urban flood risk, ecosystem restoration, and climate change. Policy can be considered along a gradient that ranges from certain and well-established agreementand cooperation to uncertainty, disagreement and division. The *science* needed to address policy concerns (x-axis) may be well-founded and accepted (left boxes) or controversial, butting against the limits of current knowledge and predictive capacity (right boxes). *Stakeholders* affected by policy change (y-axis) may find easy agreement on values, norms and objectives (boxes 1 + 2 at bottom) or struggle to establish common ground among diverse interests (top). As problems become increasingly unstructured in terms of science and stakeholders(toward box 3 at top right), they require planning processes, strategies and solutions with increasing adaptive capacity. *Adaptive management* can address scientific uncertainty and *adaptive governance* can address uncertainties of deliberation through negotiation of needs, norms and values affecting shared community resources. Figure from Hurlbert and Gupta (2016).

The problem's structure involves the management of risk and shared resources, the appropriate use of engineering technology, and the evolution of society and ecosystems under urbanized watershed conditions in a globalized, carbon-fueled economy and an unstable climate. Science can help bound each aspect of the problem, but must transcend disciplines (e.g. climatology, ecology, hydrology, sociology, and economics) and stakeholder perspectives to support community decision-making. Interdisciplinary scientific methods and expert collaboration can integrate many sources of knowledge and explore the range of potential scenarios and strategies to inform decision-making. Ultimately, however, solutions and decisions boil down to the values, will, and negotiation among impacted communities.

4.1.3.2 Managing High Social Uncertainty

In urbanized watersheds with highly altered channels and extensive floodplain development, social conflicts limit, and possibly paralyze, opportunities to restore the biophysical processes that sustain riparian ecosystems. Recent surveys have established that local communities are concerned about climate change, environmental value and droughts, but awareness of flood risks and the Fifty-Year Plan is low (discussed in *Section 1.2*). Agreement is uncertain. Collaboration and partnerships are needed. Participatory, community-based approaches to watershed-scale land use and water-resource planning may be unfamiliar to the District, local communities, and individuals. Environmental regulations have yet to clearly and directly address the opportunities and conflicts of restoring riparian ecosystems in urbanized, flood-prone watersheds. Potential partners, such as school districts, may have inadequate resources and interest to expand responsibilities and commitments outside of focused mandates. Many community members likely lack the time, resources, and commitment to engage in volunteer efforts to restore creek corridors for future generations. What current residents and workers will be present to enjoy access to creeks and riparian corridors in the next twenty to fifty years? Mobility, perceived relevance, and commitment are common factors that constrain potential for participation and collaboration in long-term, sustained environmental problem-solving (Djalante et al., 2011).

Flexible arrangements, co-management agreements, and nested networks of "boundary" organizations (whose interests intersect at least one dimension of the problem) and "bridging" organizations (who connect with a subset of stakeholders) may be best able to address constraints to long-term, sustained community participation (e.g. the "multi-scaled, transitional learning networks" that emerged in solving other complex enviromental problems such as the San Diego Fire Recovery Network or CALFED (Booher and Innes, 2010; Butler and Goldstein, 2010; Djalante et al., 2011)). Overall, the social negotiation of restoration planning, especially when disaster response may be the strongest impetus, can be fraught with uncertainty (Berkes and Ross, 2013; Huntjens et al., 2012). Purely technocratic approaches, where expert scientistis, engineers and consultants attempt to ordain and promote solutions, will likely be insufficient to overcome challenges of needed land use change.

4.1.3.3 Potential for Social Conflict

Kondolf and Yang (2008) describe potential conflicts between professionals, advocates, agencies, scientists, and local stakeholders who view problems, possible solutions, pressures, and opportunities from different scales and perspectives. Through the planning process, expert professionals and scientists bring their own disciplinary tools (in restoration ecology, hydrology, geomorphology, landscape architecture, environmental regulation, or economic planning) with distinct themes, spatial scales, timeframes, and dynamics. Outside consultants often have less concern about the stability of current land use or economic flows than business interests, developers, and landowners (Kondolf and Yang, 2008).

Those who depend on floodplain property, investments, and infrastructure with potential exposure to damaging floods will hold different priorities than other stakeholders in the watershed. Changing land use in the floodplain can influence sales tax revenue that finance municipal budgets. The lives of individual families or small businesses faced with a parcel buyout proposition may be disrupted. Displacement pressures on low-income, marginalized floodplain communities may increase through increased property values and housing costs. For local stakeholders, these individual shorter-term concerns may outweigh enthusiasm for the long-term prospects of viable fish habitat, access to nearby trails and open space, mitigation of greenhouse gas emissions, or even preparation for a distant disaster. Concerns about property rights and values, housing affordability, and critical infrastructure strike at fundamental social needs for security and stability.

To address process-based restoration, land use change is needed to support the widening and connection of riparian corridors along with the mitigation of urban hydromodification across the watershed. This type of land change will require local and community concerns to be incorporated into planning processes for both creek restoration and the regional Water Quality Board's mandate for green infrastructure. Stakeholder dialogue can help untangle challenges, reveal common ground, and open opportunities for synergistic solutions (Huntjens et al., 2012; Innes and Booher, 2010). Individual stakeholders may hold different attachments, values, and timescales of concern that impact their relationship to the watershed, its ecosystem function and potential services. To reach a consensus of appropriate restoration and mitigation strategies, these values must be communicated, their basis understood through a collaborative process that creates a basis of shared knowledge, so solutions can be negotiated (Innes and Booher, 2010).

The results of this process remain unknowable, but leadership, recognition of stakeholder interdependence, dialogue, and a "robust and flexible" planning process can build trust, facilitate the emergence of consensus, and develop the social capacity to learn collectively and adapt (Huntjens et al., 2012).

4.1.3.4 Lack of Strong, Clear Regulatory Drivers

In 2017, the San Francisco Bay Conservation and Development Commission published an overview of how the regulatory process influences flood protection projects in our region (SF

BCDC, 2017), but does not directly address how to change floodplain land use or mitigate the urban hydroregime in order to restore riparian corridors. We summarize the regulatory drivers governing restoration of riparian corridors in *Figure 4-2*.

The San Francisco Regional Water Quality Control Board (SF Regional Board) protects beneficial uses of creeks in Walnut Creek's basin (*Table 2-1*) as discussed in *Section 2.2.1*. Its regulatory authority focuses on water quality through stormwater discharge permits and prescribed cleanup actions for significantly degraded water bodies. The Board's legislative mandates are driven by National Pollutant Discharge Elimination (NDPES) and Total Maximum Daily Load (TMDL) requirements of the U.S. Clean Water Act and Title 40, Code of Federal Regulations along with stormwater pollutant provisions of California's Porter-Cologne Act. Two departments within the County ensure compliance with stormwater discharge permits and TMDL requirements in Walnut Creek's basin:

1. **The County's "Clean Water Program"** ensures that discharge from the County and its municipalities into San Francisco Bay complies with a Municipal Regional Permit (MRP), as dictated by the SF Regional Board.
2. **The County's "Clean Watershed Program"** ensures that stormwater draining from unincorporated areas of the County comply with the MRP through the support of county ordinances. Constrained funding for these programs limits compliance with permit regulations (Contra Costa Clean Water Program, 2019).

Outside of limited regulation on certain types of development (through MRP C.3 provisions), the SF Regional Board lacks a mandate to control and manage floodplain land use or the impact of urbanization on the flow regime and riparian corridor connectivity.

Land use is regulated by the County and municipal jurisdictions, but socially-disruptive trends in housing affordability and climate change are increasing the attention and influence of regional and state legislators and policy-makers on local land use decisions. Once private parcels have been developed, landowners often seek to improve and grow investments; laws protect their rights to do so. The District and municipalities remain committed to protecting these investments from flooding. Regionally designated Priority Development Areas (PDAs) (zones to promote intensified development) overlap with floodplains, representing a policy gap and source of conflict in floodplain regulation and restoration.

Flood protection policies are mandated by the National Flood Insurance Act (1968) and its authorization of the National Flood Insurance Program (NFIP) as administered by U.S. Federal Emergency Management Agency (FEMA). To qualify for the program, communities must adopt land use controls that meet minimum criteria established by FEMA, which can be tailored to individual communities and environmental concerns. Once communities enroll in NFIP, government-backed financing becomes available for land purchase and development within delineated flood hazard zones and flood insurance is required for buildings within the delineated 100-year floodplain and made available through the NFIP.

Ironically, while one of the principal objectives of the NFIP was to prevent floodplain development, its subsidies and incentives have made the NFIP a major driver of floodplain development (Hausrath, 2007; Rosenbaum, 2005), resulting in loss and degradation of critical habitat for salmonids (NOAA, 2008, pp. 83–84). For each community enrolled in NFIP, rates adjust based on a Community Rating System (CRS) designed to incentivize flood risk reduction. For instance, areas permanently protected as open space (i.e. free from buildings, fill or encroachment to flood flow) receive credit for CRS Activity 420 as this measure reduces potential cost of damage by floods (Brody and Highfield, 2013). Other credits exist for buyouts, deed restrictions or restoration. In 2010, FEMA developed CRS credit for habitat protection in the Puget Sound (FEMA, 2010) in response to a National Marine Fisheries Service (NMFS) biological opinion pursuant to U.S. Endangered Species Act regulations protecting threatened salmon species (NOAA, 2008) that also requires adoption of riparian buffer zones (FEMA, 2012) and a percentage of floodplains to remain undeveloped (FEMA, 2013). In 2016, NMFS issued a biological opinion regarding impacts of NFIP on 16 ESA-listed anadromous fish species (e.g. Pacific salmon, green sturgeon) and Southern resident killer whales in Oregon with similar policy recommendations (NMFS, 2016).

By law, FEMA allows and encourages flood-prone communities to set more restrictive criteria to further reduce flood risk (Title 44 60.1 in Code of Federal Regulations). For instance, Contra Costa County, an exception among jurisdictions in Walnut Creek's watershed, earned a Class 5 community rating, leading to a 25% reduction on annual premiums in high risk areas of the unincorporated county (Balbas, 2018). However, despite potential for insurance discounts and decreased flood risk from adoption of higher standards, many communities in Walnut Creek's watershed maintain minimum-to-low flood protection standards (see FEMA, 2018 for ratings by enrolled community).

Given the threatened status of salmon and riparian-habitat-dependent species in the watershed and multiple policies that aim to support their recovery, projects that affect local creeks may be subject to further limits on floodplain development and flood infrastructure in the floodplain. Today, the net effects of various requirements and incentives of current policies on the potential to restore Walnut Creek remains unclear, contributing further uncertainty to the planning process.

The District and local communities face a relatively unstructured problem: where process-based restoration strategies are clear, but stakeholder values conflict, and the magnitude and distribution of costs and benefits remain unquantified (Allen et al., 2011; Hurlbert and Gupta, 2016). Lacking are strong regulatory drivers for restoration, funding to improve water quality, policies to mitigate urbanization effects on the flow regime, or incentives to widen riparian corridors, change land use and reduce flood exposure.

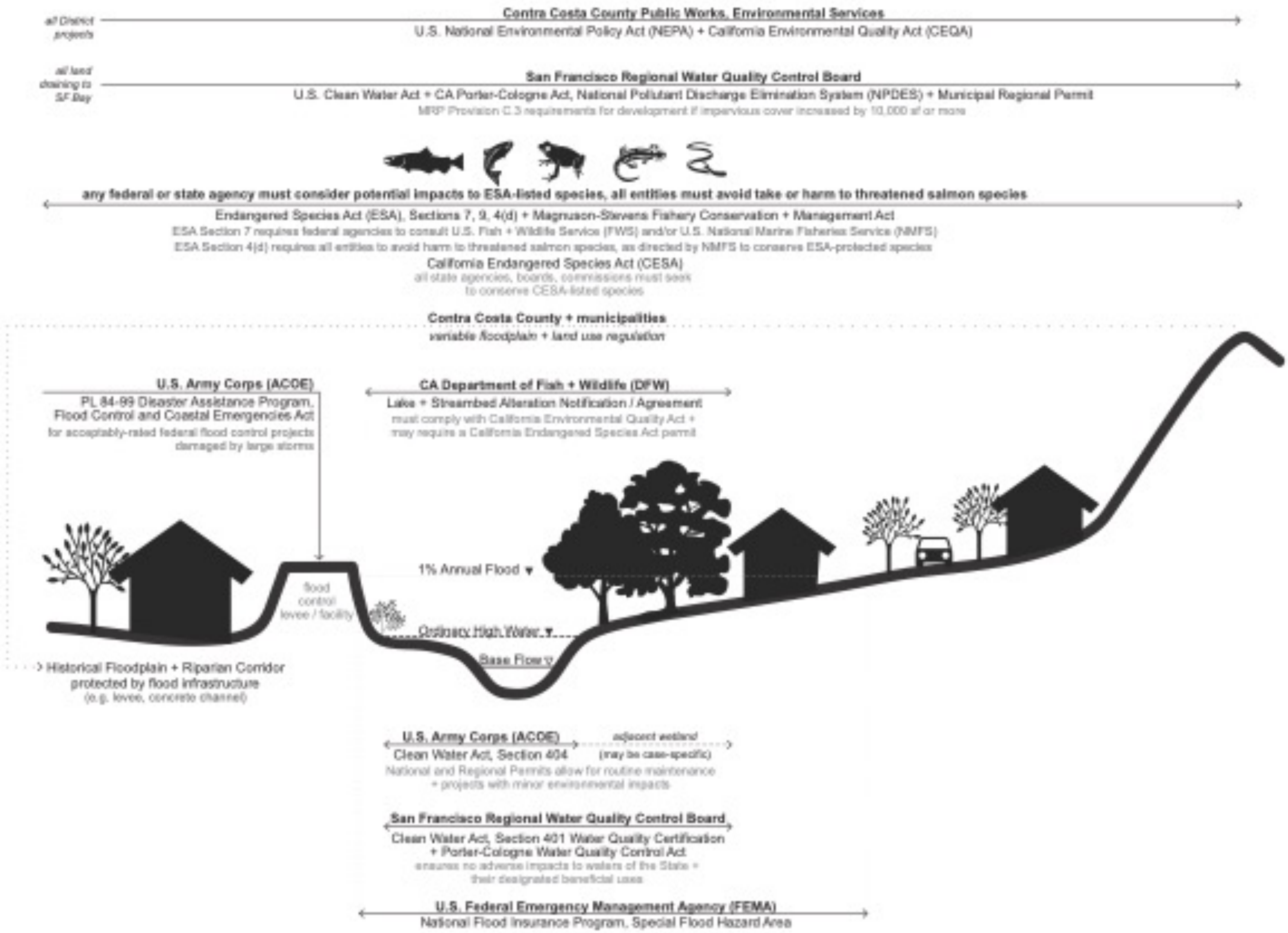

Figure 4-2. Regulatory mandates, jurisdictions, and influence on flood infrastructure and process-based restoration of riparian corridors

4.1.3.5 Communication and Awareness of Public Benefits and Ecosystem Service Values

Restoration of keystone processes through widening of riparian corridors and mitigation of urban hydromodification can be seen as a community investment in natural capital, as discussed in *Section 2.3.2*. This approach goes beyond "urban greening" enhancements of planting trees, opening a trail along a channel, or introducing static habitat features in channels. It is a contextual, locally-appropriate re-integration of biophysical watershed-scale processes as public-serving "natural infrastructure" that *accrues compounding social benefits over time* (Connop et al., 2016; Thorp et al., 2010; Turner and Daily, 2008; Tzoulas et al., 2007).

When framed in terms of ecosystem services, the concept of natural infrastructure of conserved floodable land can help to communicate the *social values* of process-based restoration. When ecosystem services of restored riparian corridors are clearly defined and measured, this data can offer the evidence needed to expand the network of partners and funders "beyond those within the traditional conservation community and can help make explicit the conflicts and synergies among stakeholders with different goals (Zavaleta and Mooney, 2016, p. 275) " (Goldman et al., 2008; Reyers et al., 2013, 2012). Quantifying benefits was mentioned in community watershed forums as a way to convince stakeholders to invest in restoration and mitigation (*Appendix B1*).

4.1.3.6 Addressing Uncertainties of Climate Change

Climate change increases the risks and uncertainty of local flood management and restoration potential, intensifying the urgency to address and overcome underlying social conflicts. Rather than a generalized, "feel good" habitat restoration goal, framing creek restoration as the re-integration of ecosystem services into an urbanized watershed focuses attention on cost-effective approaches to adapt to threats of climate change, such as extreme drought and floods (Jones et al., 2012).

A participatory process, dialogue among stakeholders, collaboration among institutions, modeling of scenarios, and evaluation of monitored criteria can inform solutions. Scientists can help constrain the range of possible technical solutions and potential ecological outcomes. Skilled communication of the science to the public — a distinct step from establishing scientific conclusions — allows opinions, consensus and decisions to emerge from negotations that have a basis in the 'best available science'. This strategy supported cost-effective decision-making in the City of Portland as they addressed regulatory requirements for combined sewer-stormwater discharges with multi-functional green infrastructure (discussed in *Appendix C4*). Development of the community and region's adaptive capacity through shared learning and democratic deliberation can be a critical and expected outcome of restoration planning for the Fifty-Year Plan. These forms of adaptive governance hold promise to address problems with global drivers, high uncertainty, and long-range consequences (Djalante et al., 2011).

4.1.3.7 Precedents for Multi-Functional Restoration of Watershed-Scale Ecosystem Services

Precedents for land use transformation along edges and patches of urban floodplains can be found in major metropolitan areas along the Pacific coast that still support Pacific salmon runs, and elsewhere across North America and Europe (see *Appendix E*). Tools, techniques and policy mechanisms to change land use and mitigate urban drainage as a means to restore keystone processes of riparian ecosystems are emerging and evolving. Across precedents of various scales and regions, the drive to reduce structural constraints on channels, acquire land, and restore widened riparian corridors originated with communities, agencies, and local leaders. Shared goals and values focused on the ecosystem services of public, open space. They recognized that open floodplain lands can accommodate the variability and dynamics of floods, allowing *more benefits to accrue for more people at less cost over time.* The proposed solutions won public support, regulatory approval, and local funding through collaborative planning processes. These precedents deserve further attention, study, and communication to share lessons and understand applicability to the Fifty-Year Plan.

4.1.3.8 Framing the Problem: A Long-Term Opportunity, Investment, and Learning Process

Given the complexity of the problem, the lack of control over resources needed to support restoration, the uncertainty of future conditions, and the need for collaboration and shared learning among diverse stakeholders, *leadership by the District may be less about proposing a vision and gaining buy-in, and more about encouraging and convincing potential partners to participate, share, engage in, and sustain a long-term planning process with a network of diverse, empowered stakeholders* (Innes and Booher, 2010).

The problem of aging infrastructure can be posed as an open-ended opportunity, a potential for the reconciliation of current values and emerging threats with the constraints and consequences of past decisions. The opportunity can become a collaborative pursuit of problem solving and shared knowledge focused on a community-determined scope and scale of concerns. A stakeholder-driven planning process can develop and justify solutions through dialogue and negotiation. Trust and project legitimancy can be earned by considering and questioning scientific evidence, local knowledge, and community values in dialogue and negotation with and among stakeholders. Doing so can build the social capacity needed to overcome complexity and multiple dimensions of uncertainty (Adger, 2006; Innes and Booher, 2010).

4.2 A WATERSHED RESTORATION PLANNING FRAMEWORK

4.2.1 AN ADAPTIVE, COLLABORATIVE PLANNING CYCLE

4.2.1.1 Adaptive Management and Social Learning

Adaptive management supports collective social learning through systematic, iterative management intervention to address problems of complex social-environmental systems with uncertain outcomes. Cycling through steps of planning, decision-making, implementation, monitoring, and evaluation provides a structure for framing problems, testing assumptions, and developing best management approaches (Allen et al., 2011). Integrating an adaptive management approach into long-term restoration and flood risk planning supports collaborative learning as an explicit goal. The watershed is not a flume in a lab where experimentation can be left to expert engineers and scientists. Learning in an urban watershed must acknowledge diverse sources of knowledge, experiences and consequences of incremental experimentation. A well-defined planning cycle can transparently structure negotiation, articulation, and agreement about values, objectives, performance criteria, and outcomes at each step.

To support social learning in ways that address uncertainty, the causal relationship between a restoration activity, expected outcomes, and monitored data must be purposeful with systematic data collection so that informative analysis can follow. Insufficient funding, lack of clarity and coordination, and inconsistent commitment often hamper efforts to address uncertainty of complex environmental problems through adaptive management (Doremus et al., 2011). Given these potential pitfalls of long-term adaptive management, we propose an adaptive, watershed-scale restoration planning model that cycles through four major phases. The phases are typical of adaptive management but with an emphasis on partnerships, negotiation, and transparent communication through a public, evolving watershed plan (*Figure 4-3*). To promote learning, the four basic phases can be defined as:

1. Define problems and goals
2. Plan and design
3. Decide, act, change, implement
4. Monitor and learn

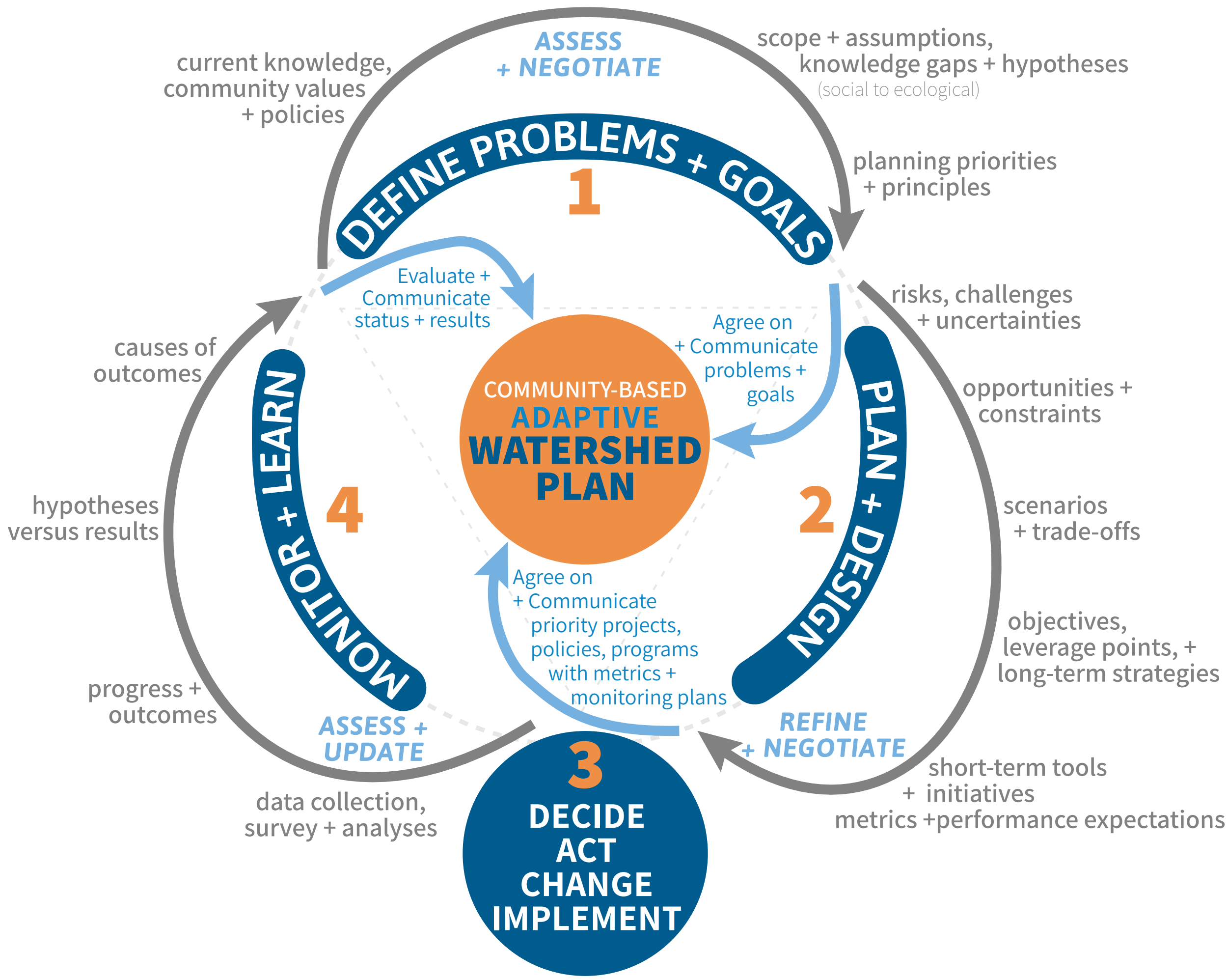

Figure 4-3 An Adaptive, Community-Based Planning Cycle for Collaborative Urban Watershed Restoration. The cycle loops through four essential phases: defining problems and goals, planning and design, implementation, followed by monitoring and learning. Each phase incorporates assessment, dialogue negotiation, and refinement toward agreements (in light blue) which are communicated in a community-based, working watershed plan (center in orange).

The proposed watershed plan becomes a living, working reference to communicate stakeholder understanding, goals of restoration, constraints, and commitments and the status of watershed metrics, their relationship to initiatives, objectives, and expected outcomes. The focus on stakeholder outreach, negotiation, agreement, and communication serves to inform and engage diverse stakeholders, invite them into the planning process with a commitment *to learn* through a cyclic but flexible and transparent framework.

4.2.1.2 Restoration Planning and Design

Beechie et al (2010) define four process-based principles of restoration planning and design:

- Address the root cause of ecosystem degradation over symptoms
- Customize strategies and approaches to local processes and conditions

- Pay attention to appropriate scaling (spatial and temporal)
- Define measurable expectations (e.g. extent, magnitude, recovery rate) for restoration actions.

In urbanized watersheds where the constraints of land use, urban drainage patterns, and both social and climatic uncertainty require long-term partnerships to address ecosystem degradation and emerging threats, planning principles must be customized to promote sustained collaborations and long-terrm social learning. To maintain momentum required for long-term change, decisions must be seen as legitimate and justified. To this end, we present a set of guiding, fundamental planning principles to consider throughout all phases of the adaptive cycle (*Table 4-1*).

Table 4-1. Planning Principles to Guide Urban Watershed Restoration

PLANNING PRINCIPLE	JUSTIFICATION
FREQUENT, TRANSPARENT COMMUNICATION	• Managing the complexity of stakeholder interests, negotiations and learning will require clear, frequent, transparent communication (Doremus, 2010). • Inviting, accessible communication facilitates engagement of diverse stakeholders, information-sharing, innovation and the development of durable, robust solutions. • Clear, open communication can help build a communal sense of coherence about problems and strategies. Allowing stakeholders to track progress toward goals helps demonstrate value of individual investments in the planning process and engender participation (Henfrey et al., 2017). • A Watershed Plan can be a well-known, easy-to-find, frequently-updated communication tool to record objectives, agreements, commitments, metrics, status and progress across multiple strategies and initiatives. As such, a Watershed Plan becomes a common point of engagement that supports initial, continued or intermittent involvement and participation. • Further discussion and exploration of a communication plan can be found in *Appendix C1*.
INCLUSIVE, COLLABORATIVE PARTICIPATION, DIALOGUE, AND LEARNING	• Inclusion of diverse stakeholders supports integration of relevant knowledge and concerns to reduce risk, weigh options, and generate more robust outcomes (Innes and Booher, 2010; Renn et al., 2011). • Partnership and formalized collaboration help to overcome the limitations of narrow and fragmented institutional mission, culture, and expertise of any individual agency when complex societal dilemmas involve shared risks and resources (Kiparsky et al., 2013). • Inclusion of diverse stakeholders supports open-ended, robust scope and definition of concerns that then influence the development of planning objectives and metrics. Because objectives and metrics drive the planning outcomes, their open-ended consideration is critical to overcoming limited purviews of select stakeholders, achieving efficiency, and avoiding the exacerbation of injustices (Henfrey et al., 2017; Huntjens et al., 2012). • Inclusion of diverse stakeholders in facilitated dialogue and debate throughout the planning process can de-escalate conflict and develop a shared narrative that helps build consensus and legitimize decisions (Dietz et al., 2008; Innes and Booher, 2010; Renn et al., 2011).

PLANNING PRINCIPLE	JUSTIFICATION
	• Innovation in public infrastructure is supported by information exchange, clarity of legislative mandates and reliability of funding, diverse social networks linked by boundary organizations, collaborative and incremental approaches that emphasize distributed experiments to limit cost of failure (Kiparsky et al., 2013; Roy et al., 2008). • Social networks that connect across individuals, agencies, organizations, and institutions at multiple levels can overcome weakness of top-down or bottom-up governance, allow independence and authority toward common, integrated goals with flexibility to adapt to changing conditions (Adger et al., 2005; Huntjens et al., 2012).
ATTENTION TO SCALE	• Patterns of in-stream flow variability that influence ecosystem function are driven by the exchange and flows of water across a watershed. Because of this, the combined management of flood risk and riparian corridor restoration must address the multi-scale social and biophysical factors influencing flow patterns, channel form, and ecosystem function within a given watershed or sub-watershed. • Multi-scaled cooperation beyond typical jurisdictional boundaries can address problems at appropriate scales, promote beneficial synergies, and avoid inefficient competition (Bedsworth and Hanak, 2010). • Restoration requires attention to mitigating impacts of urbanization on flow patterns and water quality across a watershed. Recognizing how flows of water connect parcel owners, public infrastructure engineering, land use planning from the watershed to channel helps justify broad community participation. Recognizing this cross-scale socio-ecological interdependence can foster interest and promote collaboration of individual residents, organizations, institutions, jurisdictions, agencies and experts (Falkenmark, 2004) in ways that amplify awareness, build trust, pool knowledge, address uncertainty and engender innovation (Djalante et al., 2011) • Supporting and increasing social capacity at the neighborhood scale where physical and land use change is required can promote more equitable solutions by incorporating local voices and concerns to prevent displacement and disempowerment of vulnerable populations that are typical during periods of dramatic change or disaster in urban areas (MacKinnon and Derickson, 2013).
INTEGRATIVE ACROSS RESOURCES, ISSUES AND RISKS	• Building partnerships across sectors and institutions can help address divisions and deadlock across water, land use, and risk management. • Addressing the complexity of how land use, flood risk, and watershed management link with climate change adaptation, greenhouse gas emissions, public health, biodiversity conservation, environmental quality and justice can broaden support, partnerships, and funding. • Current basin plans and designated beneficial uses (as regulated by the San Francisco Water Quality Control Board) should be integrated into a full range of local plans at appropriate scales to better serve flood management and restoration goals.
ADAPTIVE	• Address uncertainty about change over time, especially effects of climate change; • Address uncertainty regarding best practices and cost-effective strategies to overcome root causes of ecosystem degradation. If develop hypotheses regarding chain of causality, can propose best practices and test their efficacy.

PLANNING PRINCIPLE	JUSTIFICATION
	• Address uncertainty regarding social tolerance for changes in land use and need for economic stability.
ANTICIPATORY	• Prediction and foresight supports identification of early actions to reduce future risks and costs while increasing flexibility; supports contingency planning for worst case scenarios, but also identification of no-regrets strategies and robust actions (Quay, 2010). • Current flood maps, insurance programs, and community awareness do not reflect future risk. Flood frequency analyses based on historical data are no longer sufficient to predict or address flood risk; to anticipate risk hydrologic projections must integrate downscaled climate models (Bedsworth and Hanak, 2012). • Reach-scale projections of anticipated flooding in terms of depth and velocities given a range of storm scenarios and sea levels can help municipalities, floodplain communities and parcel owners better anticipate future likelihood of hazards and relative magnitude of consequences to inform strategies and decision-making (Quay, 2010). • Property values and land development pressures within the floodplain continue to rise. Restoration, acquisition, and land use plans can pro-actively anticipate long-term market trends, planning cycles, and regional pressures. At the same time, restoration and land use plans can prepare for unpredictable dips in the market or disaster recovery to buyout damaged properties, implement restoration measures, and avoid inefficient spending on emergency fixes and repairs that do not align with restoration strategies. • Ordinances, policies, and programs can anticipate opportunity and demand for change that may emerge from disaster and acute crises: drought, earthquake, or flood (Kiparsky et al., 2013). • Early and frequent cooperation with regulatory agencies and municipal jurisdictions can help anticipate requirements, criteria, plans, and support to support the potential for innovative process-based restoration that crosses scales beyond typical jurisdictions or projects. • As water suppliers anticipate threats of prolonged drought, opportunities for infiltrative green infrastructure, local groundwater recharge, conjunctive use, and large-scale distributed rainwater harvesting can be explored as mutually beneficial restoration strategies. • As public health agencies and municipalities anticipate threats of increased summer temperatures and heat waves, opportunities to increase access to cool, shaded, riparian corridors and trail systems can reveal co-benefits that garner increased public support and funding.

4.2.2 LONG-TERM STRATEGIES

Strategies seek to address underlying factors that threaten safety, well-being, and sustainability of life in the watershed and leverage opportunities for restoration of ecosystem services over the long-term. Strategy informs the developmet of short-term objectives, initiatives and tools toward meeeting broader goals. Although strategies focus on broad long-term goals, they can be flexible and responsive to shifts in power structures, threats, tensions and concerns as they emerge through the planning process.

At this early stage of the Fifty-Year Plan, we identify eight strategies to address the range of social and ecological constraints and challenges identified in previous sections of this report. Analyses and guidance to support many of these strategies are identified in the description of each strategy in *Table 4-2*.

1. **Make room for creeks and expand riparian corridors** to reduce flood risk and allow natural processes to do the work of restoring ecosystems, increasing local carbon storage and mitigating drought through groundwater recharge;
2. **Reconnect people with local creeks, nearby nature and ecosystem services** of their watershed by seeking more benefits for more people;
3. **Integrate water management** to encourage groundwater recharge, mitigate effects of urbanization on the flow regime, and reduce risks of drought and flood;
4. **Connect and expand habitat** strongholds;
5. **Remove barriers to salmon migration** especially where opportunities overlap with other strategic initiatives;
6. **Develop partnerships and collaborative initiatives** to raise awareness of the Fifty-Year Plan, streamline regulation, overcome limitations of local land use policy and fragmented parcels of riparian corridors;
7. **Commit to learning** through adaptive planning, management, and governance;
8. **Prepare to respond to crises**.

Table 4-2 Long-Term Restoration Strategies and Potential Initiatives.
Justification and recommendations about implementation include references to relevant appendices (App), figures (Fig) or tables from this report, and maps from the *Walnut Creek Watershed Opportunity Atlas*.

STRATEGY	WHY?	HOW?
Make room for creeks and expand riparian corridors. *Let nature do the work*.	• Open safe, inviting access to public waterways and riparian corridors as connected greenways that function as trail systems, water and air filters, and a refuge for people and wildlife. • Move exposed structures away from dangers of floods and invite the flood pulse to sustain ecosystems and provide more benefits to more people. • Store carbon in riparian forests and floodplain sediments to offset local greenhouse gas emissions • Reduce vehicle travel and reduce traffic by supporting increased use of inviting, off-street trails for commutes, safe routes to school and recreation by diverse users. • Provide cool and shaded refuge from extreme heat, filter pollutants from the air and water, and reap public health benefits of nearby nature	*App D2* ***Land Use Measures*** • Local land use and zoning ordinances • Land acquisition and easement programs • Landowner incentive programs • Planning and design initiatives • Funding and financing mechanisms *App C2* ***Stakeholder Strategies*** • Pursue a multi-scale, multi-jurisdiction review and analysis of current planning and policy (i.e. a code 'scrub') that influence restoration potential. • Publish a stakeholder guide for local policy change *App C1* ***Communication Strategies*** • Communicate the value of floods, the ecosystem services of a watershed, the costs of fighting natural processes and exposure to increasing flood hazard (see *Section 1* for discussion of rising flood risks)
Reconnect people with local creeks, nearby nature and ecosystem services of their watershed	• Offer walkable, inviting opportunities for recreation in nearby forests, creeks, and waterways. • Promote increased physical activity and supports mental health at low cost to individuals. • Increase awareness of the value of biophysical processes of a watershed and the conservation of regional biodiversity. • Support childhood development and learning through experiences in nature. • Activate edges of riparian corridors with dense, mixed-use destinations (e.g. housing, businesses, civic institutions) to promote access to nearby nature, use of the corridor and visibility into the corridor in	*App C2* ***Stakeholder Analysis*** • Empower citizens and residents in the planning process, including support for participation of marginalized communities, those with time scarcity and financial need. *App C3* ***Expert Interviews*** • Consider that the loudest or most powerful voices can drive local policy decisions rather than democratic process, a concern raised by concerned stakeholders. *App C1* ***Communication Strategies*** • Expand messages and experiences of educational outreach to include local historical ecology, risks of natural hazards, costs of environmental degradation and opportunities for restoration. *App B5* ***Graduate Studios*** • Institute on-the-ground programming and low-cost initiatives to open access to creeks and connect creekside trails.

<table>
<tr><th>STRATEGY</th><th>WHY?</th><th>HOW?</th></tr>
<tr><td></td><td>ways that build sense of place and safety.</td><td>Ideas offered by UC Berkeley graduate student Environmental Planning studios.
App F Benefits Review
+ App C2 Stakeholder Analysis
Develop a ‘benefits of restoration’ website, social media campaign, outreach events supported by evidence.
Rally focus groups and build collaborative coalitions to understand, capture and promote relevant, resonant benefits.</td></tr>
<tr><td>Integrate watershed planning with county and municipal planning</td><td>Current plans and standards assume continuity of current flood infrastructure operations, this assumption no longer stands.
Systemic social barriers to restoration need to be addressed.
Broader needs and compound risks (e.g. habitat, water and energy use, wildfire risk) need to be addressed in local land use decisions (Bedsworth and Hanak, 2012)
Municipal and county plans (e.g. General Plans, Green Infrastructure Plan, Climate Action Plans) are currently not required to reference stream restoration or watershed plans; need an external driver and oversight to integrate overlaps and meet shared goals.
Land (especially public lands and infrastructure) can accommodate multiple functions (e.g. reducing flood risk and offering public open space), but only if we develop integrative approaches to sustainability, recovery of ecosystem services, and climate change.</td><td>Plans and standards must be revised at the municipal and county levels to integrate the Fifty-Year Plan.
App C1 Communication Strategies
+ Fig 4-3 Adaptive Watershed Plan
Raise awareness of restoration potential in ways that support individual action and collective learning to address root sources of increasing risk of natural hazards, environmental degradation and climate change while avoiding traps of apathy, disempowerment when scope, scale, and framing of problems and solutions do not match community needs and concerns (Henfrey et al., 2017; Kenis and Mathijs, 2012; Renn et al., 2011).
Ensure skilled facilitation of dialogue and negotiation of conflicting interests
App D1 Regulatory and Planning Integration
Table 4-3 Intersecting Policy Review
Review considerations of critical policy, plans, and issues that intersect with the Fifty-Year Plan.
Table 4-3 Code Review
Review local ordinances to understand the impacts and limits current code, to highlight best practices, and define opportunities for policy change.
Table 4-4 Engineering Standards
Review and develop engineering standards and design guidelines to support the Fifty-Year Plan.</td></tr>
<tr><td>Integrate water management</td><td>Creek restoration requires offsetting impacts of urbanized impervious surfaces on runoff quality and quantity, especially</td><td>Map W-5 Infiltration Opportunities
Improve infiltration opportunity and constraints analysis through an infiltration feasibility study (preliminary methods and results in Section 3).</td></tr>
</table>

STRATEGY	WHY?	HOW?
	for frequent storms that do the most geomorphic work. • Recharging groundwater can help build reserve water supply for projected increase in drought intensity and frequency. • Groundwater supplies cool, clean water to local creeks; temperature and water quality are limiting factors to survival of salmonids across Pacific coast watersheds. • Riparian forests can store carbon and lower impact of the urban heat island and rising temperatures	• Pursue restoration of concrete channels and culverts where conditions promote infiltration. *App E* ***Precedent Studies*** • Understand precedents for policies and projects that promote groundwater recharge, conjunctive use and infiltrative green infrastructure. *App D* ***Land Use and Policy Strategies*** • Understand and influence regulatory and planning policy and incentive structures, and the gaps that fail to support local opportunities. • Integrate stormwater and green infrastructure planning in the watershed with regulatory agencies and wastewater districts to promote 'One Water' conservation and reuse approaches as part of watershed restoration. • Build upon menu of land use measures (D2) and precedents (E), consider impacts on sales tax revenue (D3), and publish guidance and model ordinances (D4) for use by local stakeholders.
Connect and expand habitat strongholds	• Conserve biodiversity of the Pacific Coast, SF Bay, Mount Diablo and California's freshwater ecosystems. • Overcome habitat constraints of conserved but fragmented uplands with potential connections across the valley and into SF Bay. Urbanized floodplains leave little to no habitat or connectivity through the core of the watershed.	*App D2* ***Land Use Measures*** • Understand policy and funding mechanisms to incentivize expansion and connectivity of viable, contiguous habitat especially for locally endemic species and those listed as threatened or endangered at the federal and state level. *App C1* ***Communication Strategies +*** *App C2* ***Stakeholder Analysis*** • Connect with interested stakeholders as advocates to build coalitions.
Remove barriers to salmon migration	• Restoring the riparian corridor to support the lifecycle of native salmonids will improve habitat for the entire food web. • Species protected by the U.S. Endangered Species Act are drivers for restoration. California Central Coast steelhead are listed as threatened. • Recovery of other listed species (e.g. southern resident killer whales) depend on substantial increases in salmon populations in our region.	*App A* ***Methods and Data Sources*** *+ Walnut Creek Watershed Opportunity Atlas* • Understand opportunities and prioritization to restore connectivity to conserved habitat for salmon. • Assess how drop structure replacement interacts with restoration strategies, phasing and salmon recovery. • Assess utility and integration of recently compiled vegetation data (Bay Area Open Space Council, 2019) to identify remnant riparian habitat

STRATEGY	WHY?	HOW?
	• Protection of endangered Coho salmon may depend on re-introduction into restored former habitats (e.g. former runs of the San Francisco Bay).	and inform conservation and restoration strategies *App D **Land Use and Policy Strategies*** • Consult with regulatory agencies regarding policies, permits, potential for streamlining and anticipating requirements for complying with CWA, ESA and FEMA requirements. • Consider salmon-specific restoration priorities, incentives, and policies with regulatory and scientific experts. *App C1 **Communication Strategies +*** *App C2 **Stakeholder Analysis*** • Connect with regulatory agencies, potential partners and interested stakeholders.
Prepare to respond to crises	• Public demand or social opportunity for change may arise from an acute crisis (e.g. flood, drought or earthquake, facility failure) • Advanced planning can promote transparency and inclusion, avoid disaster politics that promote the status quo. • Shovel-ready design plans and parcel buyout funding reserves can take advantage of emergency funds to promote restoration objectives rather than as-built repairs. • Crises may create willing sellers, but only if acquisition program is in place.	*App D1 **Regulatory and Planning Integration*** *Table 4-3 **Intersecting Policy Review*** • Incorporate Fifty-Year Plan opportunities and restoration strategies into hazard and disaster recovery planning at the municipal, county (Tetra Tech, 2018) and regional levels. • Develop a willing sellers program based on a more extensive precedent study (App F) and participatory planning methods (App C, D5). *App D **Land Use and Policy Strategies*** • Consider post-disaster policies to promote needed land use change through planning measures (D2) and new ordinances (D4).

4.2.3 TOOLS AND SHORT-TERM INITIATIVES

Tools outline currently-available mechanisms to address specific near-term initiatives in support of long-term goals and strategies. Tools address the incremental, iterative reality of democratic governance, social change and public infrastructure investments. Municipal and County zoning, codes and plans are the target, but regional plans increasingly influence local land use. Other Bay Area jurisdictions may have lessons learned to share. As the County seeks to set innovative precedents for restoring aging flood control channels, a logical first step includes reviews of existing policies (Table 4-3), codes (Table 4-4) and standards (Table 4-5) to identify barriers to restoration and opportunities for supportive change.

Initiatives are actions to set strategies in motion, put tools to use, and develop the capacity for increasingly sophisticated collective action. Initiatives aim progress toward quantified targets, build potential for feedbacks and innovation, and support a community's sense of accomplishment and adaptive capacity. They can be integrated into adaptive management cycles through a watershed planning framework (*Figure 4-3*). As an example of how to frame and link initiatives to strategies, Los Angeles' *Green New Deal* (2019, pp. 116–132) communicates the integration of strategies, tools, initiatives and metrics for restoration of the L.A. River as part of their *Sustainable City Plan*.

We pose potential near-term initiatives to support long-term strategies of the Fifty-Year Plan in the "How?" column of *Table 4-2* with future research initiatives detailed in *Appendix G*.

Table 4-3. Review of Intersecting Policies and Consideration of Critical Issues

PLANS	REVIEW CONSIDERATIONS
COMPREHENSIVE PLANS	• Goals, policies, and land use elements should support and promote green infrastructure (GI) and creek restoration. • Transportation element goals and policies should promote multi-modal creekside trails, connectivity with regional destinations, transit and on-street bicycle and pedestrian networks. • Public infrastructure goals and policies should promote riparian corridor restoration over channel replacement; green infrastructure over grey. • Conservation goals and policies should promote riparian area conservation and restoration; support historical fish corridors. • Open-space goals and policies should promote connection of parks and corridors to creek corridors. • The effectiveness of the County's urban limit line should be assessed in relation to restoration goals and strategies. Over time, development pressures may counter conservation and restoration needs.
PRIORITY DEVELOPMENT PLANS	• May not recognize flood risk and put more people in harm's way. • Should allow room, by way of setbacks, to restore riparian corridors. • Should integrate riparian corridors as public greenways to serve increased density of people (to serve a growing need) and human activity (to mitigate impacts on habitat).
TRANSPORTATION PLANS	• Goals and policies should promote multi-use trails and connectivity to major transportation hubs (e.g., BART). • Goals and policies should encourage innovate pathway and pedestrian walkway materials (e.g., permeable pavement, wood chips). • Goals and policies should promote inter-jurisdiction trail network along major stream corridors. • Complete Streets plans should include green infrastructure options that promote infiltration to mitigate urban hydromodification and amenities that connect and welcome people to riparian corridors.
CLIMATE ACTION PLANS	• Goals and measures to reduce greenhouse gas (GHG) emissions should consider and promote riparian forest restoration. • Goals and measures to reduce GHG emissions from vehicles should prioritize multi-use trails (specifically along riparian buffer areas). • Goals and measures to diversify water resources should encourage recharge through floodplain expansion, green infrastructure projects.
ASSET MANAGEMENT PLANS	• Asset management may be addressed in municipal stormwater comprehensive plans, and should include consideration of flood control channel age and condition.
CONSERVATION PLANS	• Prioritize habitat conservation and restoration in fish priority reaches • Goals and policies should promote removal of critical fish passage barriers, widened riparian corridors, and conservation of infiltration zones. • Regional conservation plans should incorporate opportunities afforded by need to replace aging flood infrastructure.
GREEN INFRASTRUCTURE PLANS	• Projects identified in the GI plans should include high priority channel rehabilitation areas, floodplains, riparian areas and infiltration zones. • Define riparian corridors based on required width for flows and habitat. • Define infiltration zones based on soils and hazards (Map W-5). • Should consider promoting green infrastructure in areas drainage to restored creek channels/ fish priority reaches.

Table 4-4. Municipal and County Code Review Considerations

CODE	REVIEW CONSIDERATIONS
ZONING, SUBDIVISION, BUILDING	• Conserve existing open space, creek corridors, riparian vegetation. • Define appropriate creek and floodplain corridor setbacks. • Incorporate land use mechanisms into plan revisions (e.g. special districts). • Limit new construction, renovation, or re-construction (i.e. damaged structures) within corridor setback. • Update building setbacks according to need for creek widening, floodplain expansion, public and maintenance access, trail networks. • Encourage high-use development and civic destinations (i.e. density bonus credits, affordability requirements) along edges of creek corridors to promote active use, pedestrian and bike connectivity, and public safety. • Encourage parcel buyouts in targeted creek corridor and infiltration zones. • Offer low-impact development offset credits for creek restoration, conservation and injection wells in appropriate infiltration zones. • Require flood-safe construction in an expanded floodplain (e.g. 500-year) • Encourage cluster development; reduce and disconnect impervious areas. • Integrate GI Plan into code updates: allow and encourage LID and GI; set impervious surface limits per land use; reduce soil compaction; limit loss of native vegetation; promote permeable pavement; reduce parking areas.
STREETS AND SIDEWALKS	• Reduce area and connectivity of impervious surfaces. • Treat and filter runoff at the source, prior to outflow into creek channels. • Identify public right-of-ways with potential to accommodate green infrastructure, restoration or bypass channels. • Encourage connectivity and public access to multi-use creek trails. • Create destinations and programming on adjacent right-of-ways (i.e. vendors, festivals, promenades, public amenities). • Design culverts and bridges (new, reconstruction, repair) that allow for widened channels, continuous creek trails, (i.e. no street crossings), public access and amenities, flood flows, passage of debris and wildlife migration. • Integrate GI Plan into code updates: allow and encourage LID and GI in public right-of-ways and landscaping; set impervious surface limits; reduce soil compaction; limit loss of native vegetation; promote permeable pavement; reduce street areas and parking dimensions and maximums.
ENVIRONMENT	• Consider incentives (e.g. allowing for expedited environmental review. process or supporting environmental permitting via technical assistance) for projects that propose creek front improvements or channel restoration. • Identify and reduce barriers to restoration (e.g. wetland standards). • Identify and add mitigation credit opportunities in specific channel reaches. • Consider exceptions to environmental requirements for projects that restore riparian areas, wetlands, critical habitat, lakes, and buffers. • Identify fish and wildlife habitat and connectivity zones and policy needs.
CREEK ORDINANCE	• Encourage restoration over replacement of concrete flood-control assets. • Prevent development in creek corridor or floodplain expansion zones. • Address development encroachment into floodplain. • Consider both public and maintenance access to the creek channel, floodplain, and trail network. • Understand and define types of development and land use activities that should be discouraged or incentivized in creek corridors and floodplains

Table 4-5. Engineering and Design Standards Review Considerations

STANDARD	REVIEW CONSIDERATIONS
ENGINEERING AND CONSTRUCTION	• Compile precedent studies, scientific research and best practices on urban river restoration and mitigation of urban hydromodification, especially in mediterranean climates. • Develop engineering guidelines, calculators, and templates for creek restoration, greenway trails and amenities, creek-front properties and infiltration zones. • Outline construction sequencing methods for in-channel, floodplain, and green infrastructure (GI) projects that minimize compaction and impact on existing ecological function. • Include maintenance responsibilities for proposed projects. • Consider permit streamlining for periodic maintenance activities.
STREETS AND RIGHT-OF-WAYS	• Integrate GI Plan into engineering and design standards. • Include standards for GI on small sites that do not require GI. • Eliminate conflicts with and update per Fire Code, Building Code, Zoning Codes. • Eliminate requirement for curb and gutter on all streets. • Eliminate requirement for approval of variance or deviations for GI in the right-of-way. • Include plans and details for curb cuts, curb extensions, and GI techniques (e.g., bioretention, swales, permeable pavement, etc.).
RESTORATION DESIGN DETAILS	• Develop landscape design templates for bioretention, vegetated swales, and riparian buffer zones with plant palettes, soil and drainage requirements, consideration of ecotones, and ecosystem services (i.e. carbon sequestration, air and water filtration). • Develop creek section typologies that show channel, floodplain, flood frequency, bed substrate, creek setback requirement to allow for natural channel dynamics of deposition and erosion, roughness, planting zones, trails, etc. Figures and calculations in Section 2 serve as a starting point. • Include typology of trail cross sections for multi-use or designated uses • Develop design standards for corridor and trail amenities (e.g. wayfinding and interpretive signage, seating, restrooms, public art) • Develop design standards and allowable uses for public access points (i.e. seating, garbage collection, vendors, programming) and recreational amenities (i.e. kayak launch, natural playgrounds, outdoor science labs) • Integrate GI Plan into engineering and design standards. • Consider stormwater treatment requirements prior to discharge into creek corridor or along corridor edges prior to discharge into creek channels.

4.3 CONCLUSIONS

The Fifty-Year Plan represents an unprecedented vision for the restoration of riparian corridors through urbanized floodplains. It reframes the problem of aging flood-protection infrastructure as an opportunity to address current community needs and values. The scale and scope of its vision stands beyond anything accomplished in the San Francisco Bay region. High profile, federally-supported projects on the Napa River (in Napa county) and Guadalupe River (through San Jose) can serve as informative local precedents through individual urban reaches (see *Appendix E*) but do not compare in terms of complexity of infrastructure replacement needs, the area of potential restored riparian corridor (in terms of channel length and corridor width), and the opportunity to open suitable habitat to anadromous salmon and connect people with the restored ecosystem services of creeks. Precedents can be used to consider applicability and lessons learned, but no single project can provide all the answers for any particular watershed, reach, or neighborhood.

Urban creek restoration often fails to link individual sites or reaches into connected habitat or restored riparian greenways. Most often, individual projects lack watershed-scale strategies and negotiated commitments. The enthusiasm for demonstrating restoration potential starts with the low-hanging fruit of one site or a few adjacent parcels. These small, discrete and opportunistic projects can introduce important educational and recreational benefits at one site, but cannot address ecological impacts of habitat fragmentation or urban hydromodification (Kondolf et al 2006). The momentum of demonstration projects often stalls because the larger problem of land use change never expands beyond the most opportune project reaches (e.g. involving a single landowner) to the most challenging (e.g. acquiring large swaths of land through costly and complex buyout programs). The failure to connect urban restoration sites reflects the stranglehold of economic and social constraints (i.e. floodplain encroachment, land use planning), timescales of interest, complexity of stakeholder negotiation, uncertainty of outcomes, and lack of sustained community commitment and focused leadership.

Incremental progress toward a watershed-scale vision of re-integrating ecosystem services into the urban fabric of developed floodplains requires broad and sustained stakeholder commitment to an evolving long-term strategy. This is a major benefit of the timescale of the *Fifty-Year* Plan. Beyond the time and effort, it takes leadership to build coalitions and integrate strategies across multi-scaled, multi-sector policies and plans.

In presenting opportunities, we encourage the District to think beyond any single reach, most ripe opportunity, or accessible initiative. The Fifty-Year Plan is much more than an infrastructure replacement project. It calls for a communal reconciliation of emerging threats and evolving values as people collectively adapt to not only aging infrastructure, but also climate change, development and affordability pressures, impaired air and water quality, public health concerns, and threats to biodiversity. By opening opportunities to integrate multi-functional riparian corridors through urbanized floodplain valleys, the Fifty-Year Plan can *build community capacity for change* at the watershed scale — an appropriate scale for managing climatic risks and habitat.

Nature can do its work if we stay out of harm's way. By restoring a creek's ability to sustain itself, entire communities can reap the benefits of nearby nature, re-engage the services of their watershed, grow an outdoor recreation economy that supports local jobs and a stable tax base, and better adapt to needs of future generations. In this way, the Fifty-Year Plan affects all community plans within a watershed. With wise and dedicated leadership promoting community focus on watershed scale strategies to restore the connectivity of local creeks, the Fifty-Year Plan promises to set a precedent for restoring and sustaining the productivity, biodiversity, and livability of an equitable and just San Francisco Bay.

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