

The background of the entire page is a close-up photograph of sycamore leaves. The leaves are large, green, and have a deeply lobed shape with prominent veins. Some leaves show signs of insect damage with small holes. A fuzzy, light-colored catkin is visible in the lower-left quadrant. The image is partially covered by a semi-transparent green rectangular box that serves as a backdrop for the title and subtitle.

# **SYCAMORE ALLUVIAL WOODLAND**

**Restoration and Enhancement Suitability Study**

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Photos were taken by SFEI in Livermore Valley while doing the field work for this study (unless otherwise noted).

# SYCAMORE ALLUVIAL WOODLAND

## Restoration and Enhancement Suitability Study

JULY 2023



PREPARED BY  
San Francisco Estuary Institute, and H. T. Harvey & Associates



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IN PARTNERSHIP WITH  
Alameda County Flood Control and  
Water Conservation District, Zone 7



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A PRODUCT OF **PREPARING FOR THE STORM**

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# INTRODUCTION

Sycamore alluvial woodland (SAW) is a unique and relatively rare native vegetation community in California that is inextricably linked to dynamic stream processes. SAW supports high levels of biodiversity, and channel reaches with self-supporting areas of SAW typically provide some ecological resilience. These reaches also typically support ecosystem services such as flood risk reduction, sediment management, and water quality improvement, particularly when coupled with process-based restoration such as floodplain reconnection projects. Like many riparian communities, land use change, stream alteration, and water management has degraded habitat and reduced the extent of SAW over the last century. To counteract these declines, efforts to protect and restore this vegetation community are slowly gaining traction. Further, restored channel systems that can support SAW are expected to be more resilient and able to adapt to a climate change regime bringing more variable and intense precipitation.

As urbanization and climate change continue to intensify, modify, and affect the magnitudes and rates of geomorphic processes in local watersheds, it is clear that these changes must be met with the identification and implementation of a diverse array of multi-benefit solutions. Motivated by this need, the “Preparing for the Storm” project, led by Zone 7 Water Agency (hereafter, “Zone 7”) and funded by the US Environmental Protection Agency (EPA) Water Quality Improvement Fund, aims to develop science-based plans and tools, implement comprehensive and coordinated actions at the site- and landscape scale, and strengthen existing and new partnerships. The streams and flood control channels managed by Zone 7 exist in the downstream-most portions of the watershed, and transport the water and sediment delivered from the upstream watershed. These channels experienced

## WHAT IS SAW?

Sycamore alluvial woodland is a sycamore-dominated (more than 50% of relative cover in tree layer of *Platanus racemosa*) riparian woodland type that grows along the alluvial benches of braided streams (Keeler-Wolf et al., 1996).

extensive storm damage in Water Years 2017 and 2023 because of upstream hydrologic conditions and the generation of water and sediment from publicly and privately held lands. This damage exemplifies the need for establishing greater resilience to hydrologic change with actions that require multi-jurisdictional and public-private landowner coordination and collaboration. The project effort focuses on systematically improving water quality and aquatic and riparian habitat while building resilience to withstand greater hydrologic variability and extremes in the future. This project is centered in the Livermore-Amador Valley (hereafter “Valley”), with opportunities varying along upstream to downstream and rural to urban gradients.

As part of the overall EPA-funded project, this study addresses distribution and regeneration patterns and restoration strategies of SAW, focused on upstream and rural valley reaches of Arroyo Mocho and Arroyo del Valle in Zone 7. This document describes the current distribution and health of sycamores along Arroyo Mocho and Arroyo del Valle, using field-based surveys at several locations, and explores the relationship of SAW to physical processes. As a suitability analysis, it explores potential restoration strategies along a process-based to planting-based restoration spectrum.



# BACKGROUND

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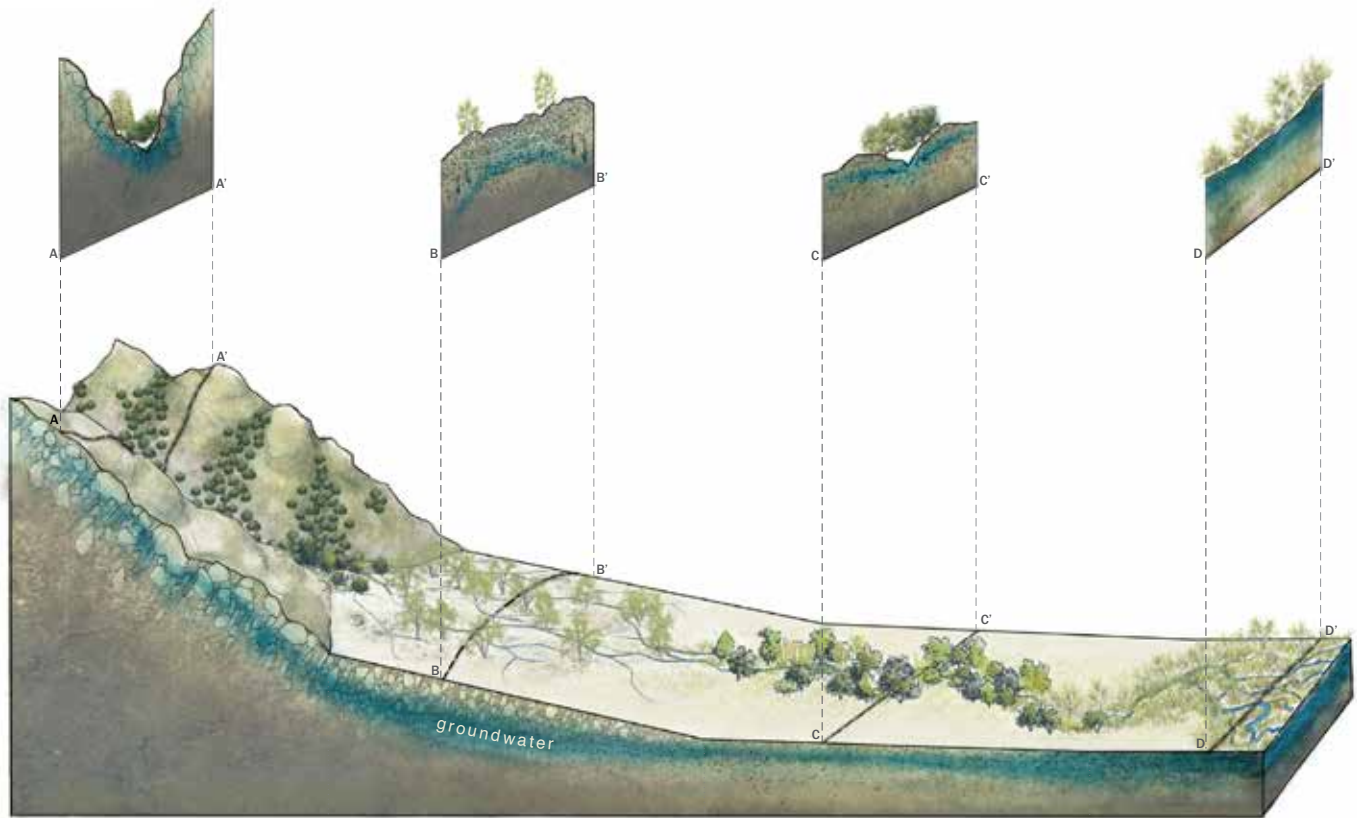
## Overview of SAW and threats

California (Western) sycamore (*Platanus racemosa*) is a distinctive riparian tree species native to California and northern Baja California. It is adapted to periodic flooding in high-disturbance coarse-grained stream channels and adjacent floodplains and side channels. These channels are typically multi-thread, consisting of a main channel and multiple connected smaller secondary channels and side channels, usually found in the lower reaches of canyons, along alluvial fans, and at the upstream edges of valleys. The species is equally likely to occur in wetlands and non-wetlands (i.e., facultative) (Lichvar et al., 2012). California sycamore can live up to 400 years and can reach approximately 23–30 meters (75–100 feet) in height at maturity. They can grow as both single- and multi-stemmed trees, and can utilize sexual reproduction via seed production or clonal reproduction via basal resprouting (stump sprouting) or sprouting from downed limbs as reproduction strategies.

SAW is defined as a moderately closed, winter-deciduous broadleaf woodland dominated by widely-spaced California sycamore trees along coarse-grained streams, with sparse understory of grasses and native shrubs (Holland, 1986; Sawyer et al., 2009). Associate species include California buckeye (*Aesculus californica*), coast live oak (*Quercus agrifolia*), blue elderberry (*Sambucus nigra* ssp. *caerulea*), and mule fat (*Baccharis salicifolia*). SAW is typically found on braided and topographically complex ephemeral and intermittent streams, usually with coarse-grained cobbly or bouldery substrates, that tend to occur along alluvial fans as streams exit upstream canyons and enter valley floors (Figure 1; Holland, 1986; Keeler-Wolf et al., 1996). Historically, SAW existed along such stream systems across California. SAW is adapted to

conditions in these dynamic streams, with recruitment closely linked to flooding and related geomorphic processes, including disturbance of the channel bed substrate, deposition of coarse sediment, and periodic inundation of floodplain areas. California sycamores help create and maintain suitable conditions for recruitment of other sycamores via a feedback loop with the channel; that is, the established California sycamores that are growing along the channel and side channels help to direct water flows to create channel complexity and provide roughness elements that affect the scour and depositional patterns during high flow events. The presence of scour and depositional processes drive the dynamism of the channel and floodplain, maintaining conditions that are supportive of SAW. Finally, SAW requires predictable groundwater levels that are close to the surface during the period of establishment, followed by a gradual decline through the dry season, which encourages deep root growth.

Sycamores are found both in and along current active channels as well as on floodplains and along side channels. Older, larger, and more well-established trees are typically found farther from the active channel, because they were either established at a time when the active channel was at that location, or they were established at a time when a large flood created disturbance across the entire floodplain. The localized conditions suitable for sycamore recruitment shift spatially through time, as the channel network migrates and evolves. Individual sycamores within SAW are typically part of a recruitment cohort; that is, a group of individuals that establish at the same time when conditions are favorable for seedlings.



**Figure 1.** Conceptual illustration of longitudinal profile and physical characteristics of streams supportive of SAW, along multi-thread channels along alluvial reaches at the base of canyons (reproduced from Stanford et al., 2013). SAW is best supported in the multi-thread alluvial fan reach (cross-section B), but individual sycamores are also found in the canyon reach (cross-section A) and the single-thread reach (cross-section C).

Though relatively rare across California due to the spatially limited extent of physical conditions to which it is adapted, SAW is important ecologically. As a riparian community, SAW provides unique habitat features and characteristics that other adjacent habitats do not. Vulnerable wildlife species are associated with SAW, including western pond turtle (*Actinemys marmorata*) and steelhead trout (*Oncorhynchus mykiss*; Belli, 2015; Casagrande, 2010). Given their large size, ability to accumulate significant amounts of dead wood and branches, and to produce cavities, sycamores provide substantial shaded riverine aquatic habitat for fish, nesting and roosting habitat for a variety of bird species (e.g., acorn

woodpecker), as well as seed and insect food sources (Bock and Bock, 1984; Rottenborn, 2000; Smith and Finch, 2013).

California sycamore serves important traditional Native American cultural uses. Certain documented uses include using boiled sycamore roots medicinally as an antiseptic wash (Ibrahim, 2022) and using the leaves and wood for rituals and traditional objects (Hajarashali, 2023). Though not explored in this study, uses likely vary across Tribes in California.

California sycamore and SAW are still present throughout their historical native range from Northern California to Baja California. However, the total area of SAW is now reduced compared



## WHAT IS SPROUTING and WHY DOES IT HELP?

Sprouting is a method that sycamores utilize in reproduction. Sprouting can include basal resprouting and resprouting from downed and partially buried trunks or large branches.

H. T. Harvey et al. (2020) states that:

Asexual reproduction in the form of basal sprouting and to a lesser degree sprouting from downed trees or branches are both important reproductive strategies. Basal resprouting is observed as new suckers growing off of the rootcrown of a mother tree, which is typically well past the peak of maturity and in general decline. However, having the mother tree's root network in place does provide basal sprouts a competitive edge over other establishing vegetation, and provides a greater ability to withstand high energy flows or sub-optimal soil moisture and groundwater table levels.

Sycamores also have the ability to regenerate from completely downed trees or large, somewhat intact trunks or branches. This type of regeneration is often seen when a large tree or trunk is downed during a flood or other disturbance and subsequently partially buried in a location where hydrologic conditions remain in place. This type of reproduction is often associated with main trunks or large branches that are still completely or somewhat connected to the rootball, providing access to essential belowground resources through the intact root network.

Many instances of basal sprouting are observed in this and previous sycamore studies. Observations of spouting from downed branches occurred after the large floods of 2017 in the Pacheco Creek and Coyote Creek watersheds (SFEI-ASC, 2018).





to historical totals, and thus the remaining area is of increasing ecological importance, and has been targeted for study and restoration. In the Bay Area and in the nearby Coast Ranges of Northern California, remnant areas of SAW can be found in multiple watersheds, including: the Livermore-Amador Valley and Sunol within the Alameda Creek watershed (Alameda County), the Pajaro River watershed (including Pacheco Creek) (Santa Clara and San Benito Counties), the Coyote Creek watershed (Santa Clara County), the Guadalupe River watershed (Santa Clara County), Los Banos Creek (Merced County) and in various small watersheds across Monterey County. Many of these locations have been the focus of one or more studies or data collection efforts to support restoration.

Over the last several hundred years, changes in land use and water management have caused substantial losses and degradation of SAW. Many of the stream systems that historically supported SAW have been altered, disrupting the regeneration process necessary to maintain SAW. Alterations can be described in four main categories. First, many streams across California have been altered hydrologically, including reduction in wintertime flooding, increase in dry season baseflows, and/or altered groundwater levels and seasonal variability. The primary cause of this is through dams, which reduce the magnitude, frequency, and duration of floods, often reducing or eliminating flood events that historically generated dynamic geomorphic conditions that create beneficial scour and deposition of coarse sediment in channels and inundation and disturbance of floodplains. The flow regulation that occurs in many streams downstream of dams also produces seasonally unnatural groundwater and soil moisture levels (Keeler-Wolf et al., 1996). For example, dry-season flow releases from dams can cause channels that were once intermittent to become perennial, which can artificially raise groundwater levels and encourage competition from native and non-native vegetation adapted

to perennial flow (Grossinger et al., 2006; White and Greer, 2006). Gravel mining can also substantially reduce water available to SAW by causing groundwater levels to drop.

Second, channel alteration has caused changes in the physical structure and function of streams that historically or currently support SAW. Historically, SAW reaches were typically wide, braided, and dynamic, with regular switching of primary channels and overbank flooding. Urban and agricultural development constrained the channels, as a result of stream crossings, narrowing and straightening channels, and reducing/removing overbank flooding through actions such as cutting off side channels and levee construction. Also, increased runoff due to altered land use (notably increased impervious surfaces due to development), construction of flood control channels that connect historical distributaries to the main channel network, as well as construction of sediment basins have disrupted the natural transport and storage of water and sediment and led to altered stream channel geometry. Dams also trap coarse sediment from upstream watersheds, reducing the sediment available for downstream SAW reaches, and even causing channel incision downstream of the dam. Channel incision, or lowering of the channel bed, is common in anthropogenically modified systems across California. It is detrimental to the stream because flows are confined within the banks which increases flow velocity and sediment transport, the frequency of floodplain inundation is reduced, and the groundwater table elevation is depressed. These hydrologic and geomorphic changes have fundamentally altered the physical processes that are needed for sycamores to recruit, establish, and survive.

Third, land use change since the 1800s has negatively affected areas of SAW in multiple ways. In many locations, sycamores have been cleared to make space for agriculture or

urban development. Also, areas of SAW may have been or are currently heavily grazed, making it difficult for young trees to establish. Other more indirect impacts of land use change have also had negative effects. For instance, increased urban and agricultural development fragments and degrades native ecosystems such as SAW, both longitudinally and laterally along stream channels. It also disconnects SAW from other habitats that may be important for those species that also use SAW. Other land uses, such as gravel mining, can alter channel form and stability and availability of coarse sediment, and can also reduce groundwater levels that are necessary to support sycamores.

Finally, a number of ecological changes have also disrupted SAW. The hybridization of California sycamore with the non-native London plane tree (*Platanus × hispanica*; Whitlock, 2003; Johnson et al., 2016) has caused genetic erosion of the species, making it more difficult to maintain and propagate genetically pure populations. Additionally, increased stream perennialization has made it easier for some riparian species, particularly willow (*Salix spp.*) and cottonwood (*Populus spp.*), to compete with sycamores. Further, introduced non-native species may also increase competition, such as through reducing overall soil moisture and reducing the amount of bare substrate present, which are needed for sycamore seeds to recruit.

## Sycamore regeneration conceptual model

SAW has recently been targeted for conservation and restoration due to its ecological importance and the past and present degradation and losses it has experienced. However, as a unique riparian vegetation community, opportunities to conserve and restore SAW are limited. Understanding the fairly specific physical and ecological conditions required for sycamore recruitment and establishment is key for making decisions about appropriate actions to take, whether it be identifying suitable locations for restoration, developing management actions, or determining how to enhance existing areas of SAW. Conceptual models are useful tools for restoration and enhancement, illustrating hypotheses concerning connections between physical and ecological processes and how these processes drive system responses (e.g., sycamore recruitment and establishment). The following text summarizes a sycamore regeneration conceptual model (conceptual model) established for a restoration planning effort along Pacheco Creek near Morgan Hill, California, led by H. T. Harvey, which describes the four stages of sycamore regeneration that must align spatially and temporally for natural

regeneration to occur (Figure 2; H. T. Harvey et al., 2020).

The first stage of the conceptual model is **setting the physical template**. California sycamore recruitment from seed requires suitable substrate and hydrologic conditions, and appears to be associated with relatively large winter flood events (e.g., with recurrence intervals of approximately 10 to 50 years) occurring within broad, multi-thread stream systems. The high fluvial energy during floods reworks the streambed and floodplain area, setting the template for sycamore regeneration. This energy scours, transports, and deposits sediment and generates fresh coarse alluvial sediment that is necessary for sycamore colonization. Additionally, seeds require adequate soil moisture when they are establishing their root network. Finer-grained soils are likely to better retain adequate soil moisture through the growing season, particularly important with faster-receding groundwater tables.

The second stage of the conceptual model is **seed source, development, and dispersal**.

## DEFINING RESTORATION and ENHANCEMENT

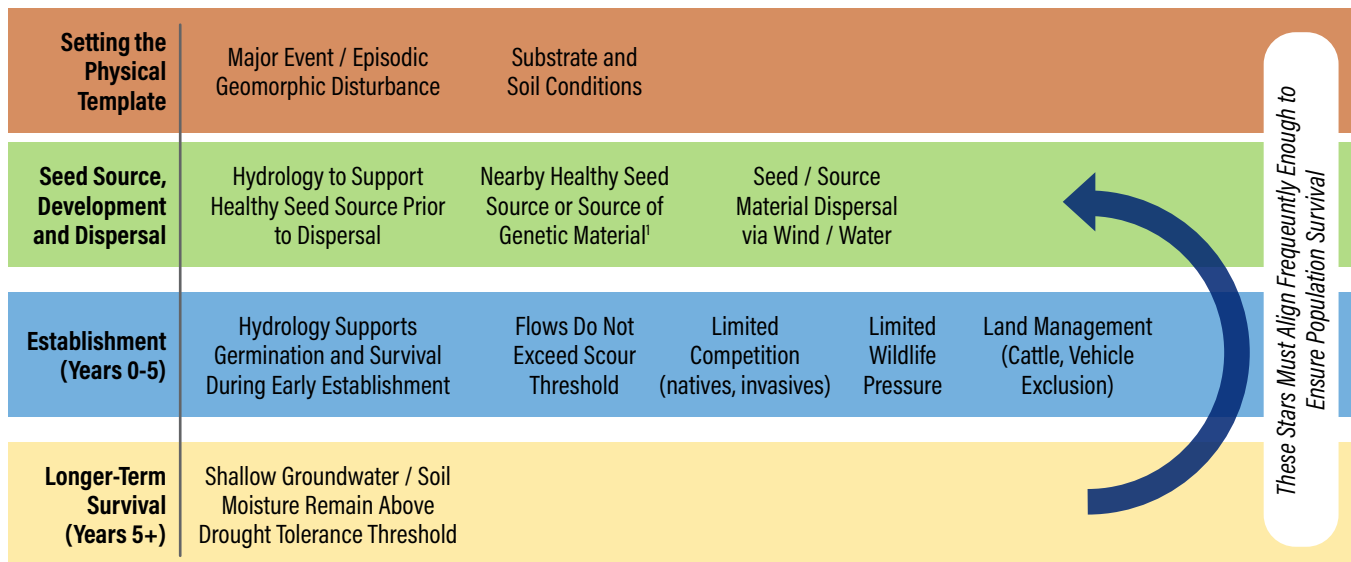
Ecological (or habitat) restoration is the process of assisting the recovery of an ecosystem (or habitat) that has been degraded, damaged, or destroyed (SER, 2004). Over the past 50 years, habitat restoration has become common, with many agencies, consultants, academics and organizations conducting work on aquatic and upland habitats with the goal of improving the overall condition of that habitat. But the word “restoration” has a wide variety of meanings amongst restoration practitioners. The type of restoration actions and the scale of those actions is quite broad; restoration can be wholesale creation (or re-creation) of entire habitats and cost hundreds of millions of dollars, or can also be the addition of a few native plants into an existing area costing only hundreds of dollars. This document acknowledges the variety of meanings for the word “restoration”, and consciously chooses two phrases to describe and differentiate two very specific types/styles/scales of restoration that will be discussed.

In the context of this report, **restoration** describes actions that restore large-scale geomorphic processes that build and maintain a stream corridor with dynamic and complex channel morphology, functioning and overall condition similar to historical conditions. Many channel systems have experienced previous land use changes, vegetation removal and community changes, channel modification, and/or channel incision that have disrupted these processes, thereby negatively affecting the system’s resilience, overall channel condition, and ability to support healthy areas of SAW. Successful restoration often requires a landscape-scale approach, and can be expensive, as it addresses the channel and floodplain shape, dimensions and elevation, as well as the delivery and transport of water and sediment through the channel system. In this document, we consider these restoration actions as “**process-based restoration**”.

Alternatively, **enhancement** describes smaller actions to improve the value, quality or condition of the SAW. While enhancement addresses changes that have occurred to the channel system, it does not focus on re-establishing fundamental physical processes. Instead, enhancement typically focuses upon improving the vegetation community within the area of SAW, including planting sycamore nursery stock grown from seeds or cuttings. Enhancement typically occurs on a smaller scale and is not as expensive as process-based restoration. In this document, we consider these restoration actions as “**planting-based enhancement**”.







**Figure 2.** The “Constellation of Drivers” conceptual model describes the four stages of sycamore regeneration where physical and ecological processes must align spatially and temporally for natural regeneration to occur (reproduced from H. T. Harvey et al., 2020).

Successful recruitment requires viable seeds from California sycamores to disperse during the period of winter storms (typically between January and March) by wind or water to the fresh coarse alluvial surfaces. Potential biological limitations of successful viable seed development and dispersal include plant disease and hybridization. Anthracnose (*Apiognomonia veneta*) is a fungal disease that infects stem tissue and can limit the transport of water and nutrients, causing leaf drop, twig dieback, death of new shoots, and may reduce seed production. Hybridization between California sycamore and London plane tree produces non-native offspring instead of pure native California sycamores, which may have long-term genetic impacts on sycamore plant communities.

The third stage of the conceptual model is **establishment**. This stage covers germination and the first five years of a tree’s development. The appropriate groundwater and/or soil moisture must be present to support germination and survival during root development. Root development will ideally keep pace with receding groundwater. If groundwater levels are too low or drop

too quickly, desiccation and drought stress thresholds may be exceeded, potentially causing mortality. In addition, only intermediate flooding is desirable during this stage, as large floods could cause scour of the seedlings or saplings. Low magnitude inundation of floodplains and direct precipitation early in the growing season provide needed moisture for an establishing tree. Over time, a young tree’s capacity to withstand drought and scouring floods increases. Seedlings and saplings are also susceptible to competition from other riparian plant species (e.g., willows or cottonwoods) and non-native plant species, which reduces the availability of needed resources (e.g., water and light). Additionally, intensive land uses or browsing stress, including off-road vehicles, livestock such as cattle, deer, or feral pigs, can jeopardize the survival of a young tree.

The final stage of the conceptual model is **long-term survival**. Mature sycamore trees, though more drought-tolerant than young trees and many other riparian plants, need continued water availability, with seasonal groundwater near the surface that slowly draws down from the late spring into the fall. California sycamore

trees typically root into perennial groundwater present at depth. However, groundwater levels and soil moisture need to remain above desiccation and drought stress thresholds to avoid declining health and potential mortality,

such as during a prolonged drought. Flooding is less likely to cause mortality of mature California sycamores; as the trees grow, they are less likely to be scoured and removed by large flood events.

## Previous studies

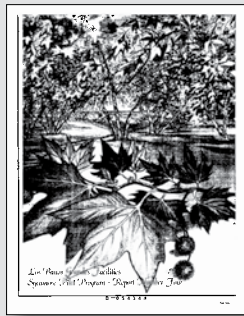
SAW was only formally recognized and valued as an important ecological habitat in California in the 1980s and 1990s (Holstein, 1981; Holland, 1986; Finn, 1991; Keeler-Wolf et al., 1996). Some of the earliest study and restoration of SAW occurred in the Central Valley and southern California (e.g., Holland, 1986; Finn, 1991; DWR, 1994; Keeler-Wolf, 1996; Gillies, 1998). But more recently, the San Francisco Bay Area and surrounding Northern California areas have been the focus of more intensive study of SAW, its current condition, and its requirements for resiliency. A number of studies over the past decade (e.g., Beagle et al., 2014; H. T. Harvey, 2014; SFEI-ASC and H. T. Harvey, 2017; SFEI-ASC and H. T. Harvey, 2018; SFEI-ASC, 2018; and H. T. Harvey et al., 2020) have synthesized and expanded the current state of knowledge on SAW and have provided recommendations for the specific streams that were studied. To date many of these broader sycamore and SAW studies have been concentrated in the Coyote Creek and Pajaro River watersheds in Santa Clara County, although there have also been site-specific studies focused solely

upon Sycamore Grove Park, in the Arroyo del Valle watershed (Sycamore Associates, 2002; Sycamore Associates, 2004; Kamman, 2009). H. T. Harvey continues to work in the Pajaro River watersheds, focusing on restoring hydrologic and geomorphic conditions suitable for SAW as well as planting and enhancing SAW habitat. Additionally, the University of California at Davis plant pathology lab conducted an assessment of California sycamore health at San Antonio Reservoir in Alameda County where the San Francisco Public Utilities Commission is attempting to restore sycamore alluvial woodland and other habitat types as part of its Bioregional Habitat Restoration and Water System Improvements Program (SFPUC, 2023).

Some of the key findings from these studies have built the foundation for the current understanding of SAW, have encouraged continued study through proposing testable hypotheses, and have assisted in the implementation of effective restoration strategies through the delivery of data and conceptual models.



Below are some examples of the foundational studies.



**DWR (1994 and 1995)** highlighted the importance of providing a water source for establishing sycamores, whether it be groundwater or regular irrigation, to encourage deep root growth. They tested sycamore regeneration techniques and had better success germinating sycamores from seed rather than from cuttings, but note that this work was carried out before genetic testing was available.



**Kamman Hydrology and Engineering (2009)** completed Phase 2 of the Sycamore Grove Recovery Program. This report includes site specific information on the hydrology downstream of Del Valle dam, and the impacts that flow regulation have had on groundwater levels and sycamore health, growth rates, regeneration, and mortality. They include suggested thresholds for surface water and groundwater levels to maintain existing sycamores.



**H. T. Harvey (2014)** completed the Upper Llagas Creek Flood Protection Project report, highlighting the effects of hydrologic modifications to creeks on sycamore restoration.



**SFEI-ASC and H. T. Harvey (2017)** found relationships between individual tree characteristics and their distribution and abiotic factors, such as the geomorphic/hydrologic zone the tree is located in, as well as the distance from the channel (as a proxy for geomorphic disturbance). They hypothesize that younger sycamores will be concentrated along the primary channel, while older sycamores will be concentrated in the outer floodplain. Additionally, healthier sycamores will be located in natural systems, while less-healthy sycamores will be located in managed systems.



**SFEI-ASC and H. T. Harvey (2018)** utilized previously collected data from Pacheco Creek and Upper Coyote Creek (Santa Clara County) to develop a detailed planting plan, maintenance plan, and monitoring plan applicable to these two sites, but also applicable to other sycamore restoration sites. They also highlighted important areas of future study, including: the role of groundwater on regeneration on channel bars, the effect of grazing on sycamore establishment, the effect of prolonged drought on seedling survival, the patterns of competition with other riparian species, and investigating episodic regeneration patterns.





**SFEI-ASC (2018)** further investigated the relationship between sycamore establishment and geomorphic zones through additional tree core data, and also collected new data on regeneration that occurred due to the large 2017 flood events. They proposed natural and anthropogenic drivers of sycamore regeneration, including the concept that sycamores tend to establish in “cohorts”, based upon larger flood events. Evidence from this study shows that the distance to groundwater matters for sycamore establishment and survival, grazing pressures negatively affect survival of seedlings, and that seed production from sycamores may be supported by released flows.



**H. T. Harvey et. al (2019)** conducted a study on hybridization of sycamores with London Plane trees to satisfy out of kind mitigation requirements associated with the Upper Llagas Creek Flood Protection Project. Experiments focused on plant propagation resulted in a series of new specific recommendations for increasing survival of cuttings and thus increasing cost effectiveness.



**H. T. Harvey et al. (2020)** described the relationship between the effects of management (e.g., flow, groundwater levels, grazing) and sycamore establishment and survival. They show that summer flow releases favor densely vegetated riparian corridors rather than more sparsely vegetated areas of SAW. They developed a conceptual model named the “Constellation of Drivers” that describes the sycamore regeneration process, along with a companion figure, the “Sycamore Hydrologic Establishment Zone” that describes appropriate hydrologic conditions for establishment.



**H. T. Harvey and Genomeadvisors (2020)** conducted a follow-up study on sycamore hybridization. They developed an efficient and replicable method for identifying sycamore, London Plane, and hybrid trees. Confirmed hybrid seed was collected from known native sycamore trees, suggesting that there may not be a safe distance far enough away from urban areas to collect pure seed. And hybrid seed appears to be successfully establishing in natural areas.

These studies have provided the basic technical knowledge that begins to support effective preservation, enhancement and restoration of SAW. However, some key additional identified knowledge gaps exist. For instance, more specific information about the role that groundwater plays in the establishment and survival of sycamore seedlings and saplings is needed, especially information and data on the depth to

groundwater and the timing of seasonal variation. Additionally, not much is known about when and why cohorts of sycamores become established. Further studies that aim to definitively link cohorts of sycamores with specific historic flow events, channel locations, site hydrology and sediment transport could provide the next level of information for future successful restoration and enhancement.







# GOALS AND OBJECTIVES

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Maintaining, enhancing, and restoring SAW relies upon a solid understanding of existing conditions and the factors influencing sycamore distribution, health and regeneration. A primary goal of this effort is to contribute to the regional knowledge about the characteristics and environmental drivers of healthy and self-sustaining SAW. Secondly, this effort seeks to provide guidance for identifying suitable locations for SAW enhancement or restoration. Guidance, including discussion of specific appropriate actions to take, focuses upon the gradient from process-based to more managed planting-based approaches, and is based upon the unique physical characteristics and any potential physical or hydrologic limitations of each individual site. These goals are framed as two primary questions:

- What conditions and processes are necessary for California sycamores to recruit and establish as part of a sustaining area of SAW?
- What planting-based and/or process-based restoration and management actions are appropriate to enhance and restore SAW?

There is increasing interest in the SAW regionally due to recent studies, restoration projects, and habitat enhancement planning processes (H. T. Harvey, 2014; SFEI-ASC and H. T. Harvey, 2017; SFEI-ASC, 2018; SFEI-ASC and H. T. Harvey, 2018). Ongoing urban and agricultural development coupled with climate

change has brought focus to stream systems and possible opportunities to better support natural processes and habitats to increase resilience to change. Within the context of growing knowledge provided by previous reports, other current efforts, and the interest in SAW in the Livermore–Amador Valley, this effort aims to provide specific, practical, and actionable information for the enhancement and restoration of SAW. This document is intended to inform actions by Zone 7 and other agencies and landowners in the region to support SAW. The Arroyo Mocho and Arroyo del Valle stream systems are understood to be the few channel systems that historically and currently support SAW in the Valley.

Specifically, this SAW study has three primary objectives:

**Objective 1:** Describe the current distribution, abundance, size, geomorphic position, and health of existing individual sycamore trees at each of the study sites;

**Objective 2:** Identify possible linkages between sycamore regeneration and sycamore distribution, health, geomorphic position and hydrologic conditions at the study sites; and

**Objective 3:** Develop a conceptual understanding of suitability at degraded sites and appropriateness of process-based and/or planting-based approaches.

Each objective is further discussed in the Results and in the Restoration and Enhancement Strategies sections below.



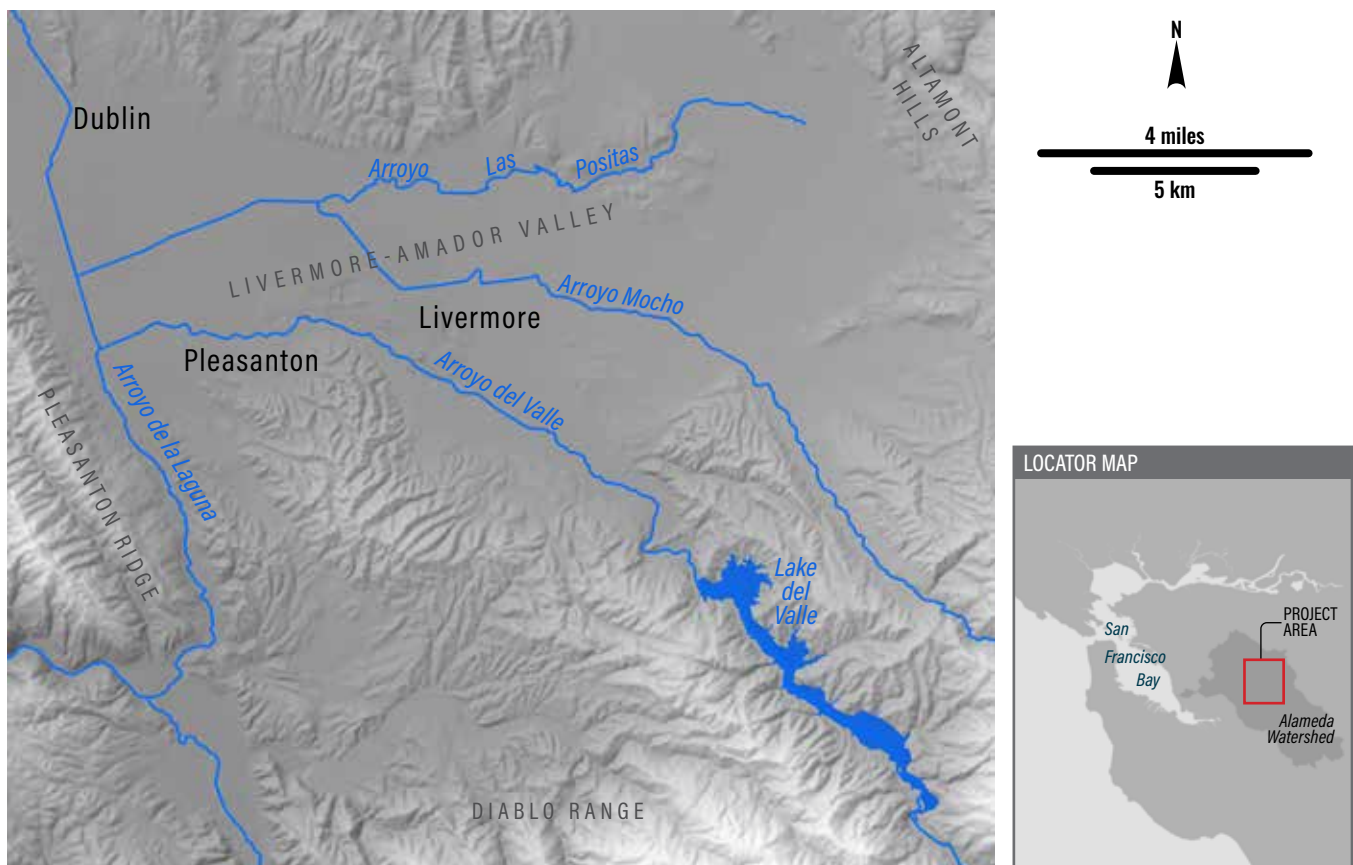


# STUDY LOCATION

The Livermore-Amador Valley is located within the southeastern San Francisco Bay Area, within Alameda County, and is a part of the Alameda Creek watershed (Figure 3). The eastern portion of the Valley is the Livermore Valley, while the western portion is the Amador Valley, and together they include the present-day cities of Livermore, Pleasanton, and Dublin. The Valley is part of the 1,100 square kilometer service area of Zone 7.

The Livermore-Amador Valley is a geologically down-dropped fault bounded valley, formed by the uplift of adjacent hills (Stanford et al., 2013). To the west is Pleasanton Ridge, bounded by the Hayward and Calaveras Faults. To the east is the Greenville Fault and the Altamont Hills. The north and south sides of the Valley are adjacent to portions of the Diablo Range. The underlying geologic units of these hills have significant control on the streams and wetland features of

the Valley. The northern and eastern hills are underlain by the Great Valley Sequence, which is a series of fine-grained sedimentary rocks, including marine deposits with high salinity content. As these areas erode, they form fine-grained silty and saline soils on the northern side of the Valley floor. The southern portion of the Diablo Range is underlain by the Franciscan Formation, which is highly erosive and forms cobbles, gravels and sands which, beginning in the Pliocene, formed well-drained coarse alluvial fans along the southern portion of the Valley. On the south side of the Valley, two main broad braided creeks, Arroyo Mocho and Arroyo del Valle (both tributaries to Arroyo de la Laguna, within the Alameda Creek watershed) drain the southern Diablo Range, transporting cobbles and gravels from the upper watershed and forming the alluvial fans along the southern portion of the Valley.



**Figure 3.** Study location map.



# Historical Setting

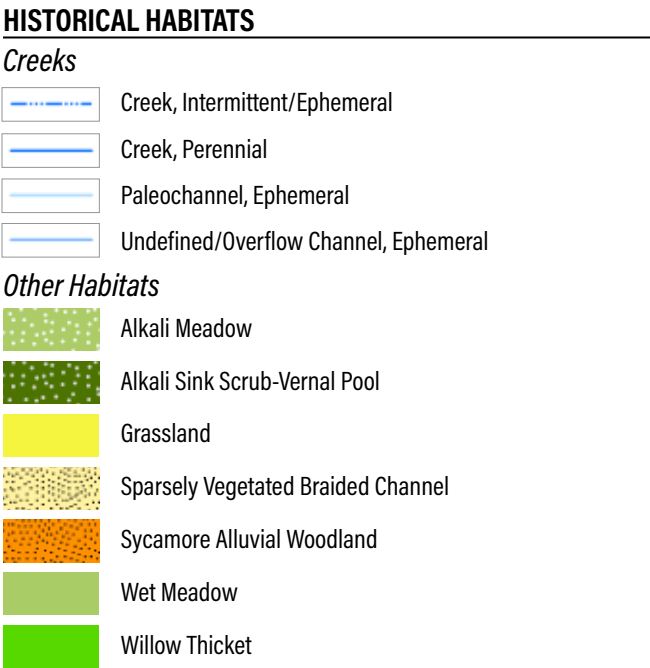
Arroyo del Valle and Arroyo Mocho historically supported extensive SAW along their coarse-grained, dynamic corridors with seasonally high groundwater levels (Figure 4a; Stanford et al., 2013). These Arroyos drained into the Pleasanton Marsh Complex, formed at the lowest point in the Valley. SAW was not found along other systems entering the Valley, likely due to the finer-grained sediments and overall smaller systems. Riparian habitat along other stream reaches in the Valley typically supported scattered oaks, sycamores, and willows and herbaceous vegetation in the wetter locations (Stanford et al., 2013).

The historical Arroyo del Valle was characterized by two segments within the Valley floor, the upper and lower. The upper segment was a coarse-grained perennial braided channel that supported SAW within a riparian corridor that was greater than 400 m (1,300 ft) wide. This channel had a high sediment load, and together with the highly variable flow regime, supported a dynamic braided reach, with its water infiltrating into the coarse gravels to the regional groundwater aquifer as it flowed downstream. Under these geographic and hydrologic conditions, local

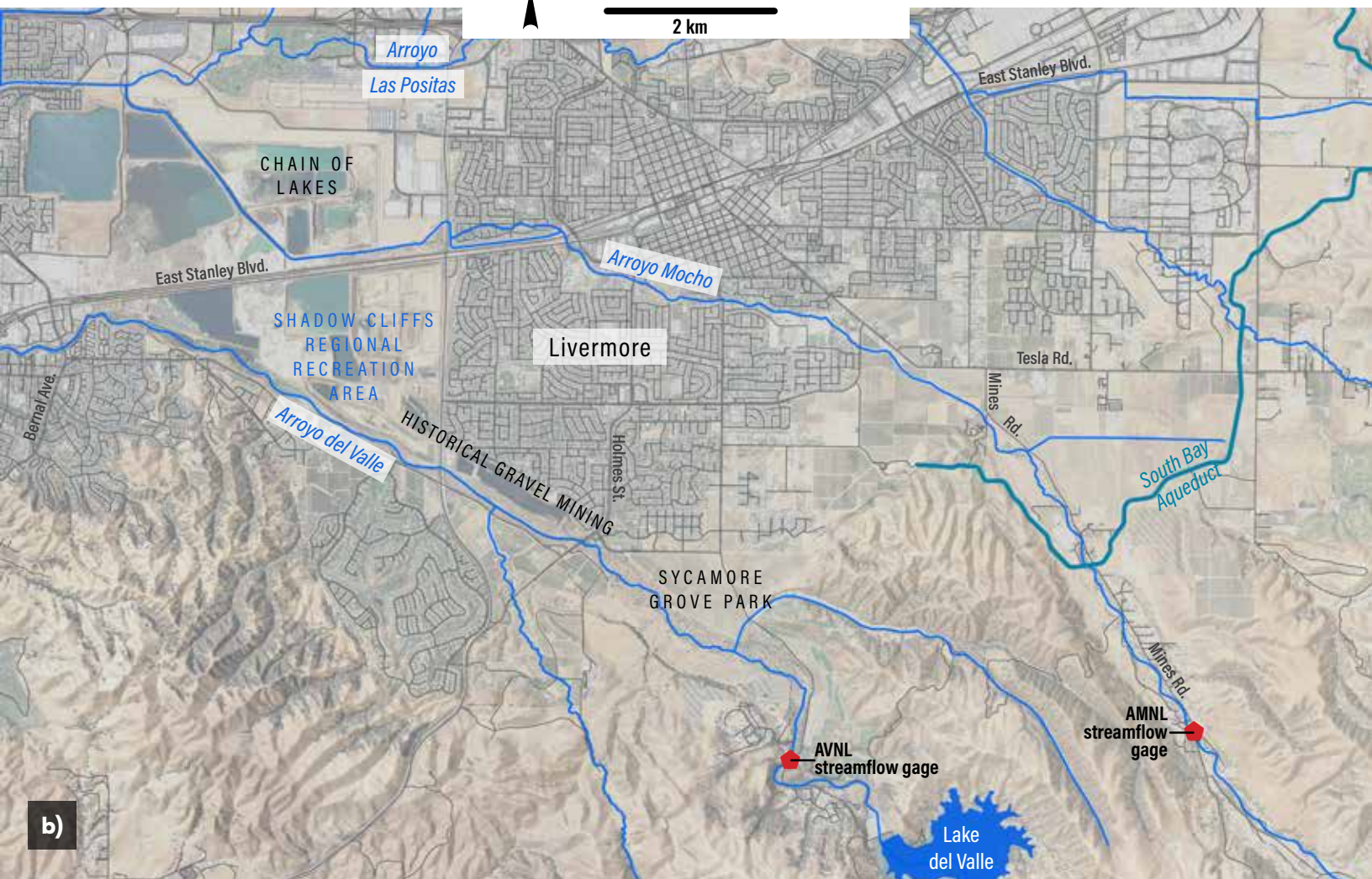
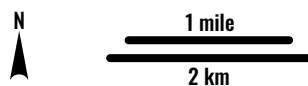
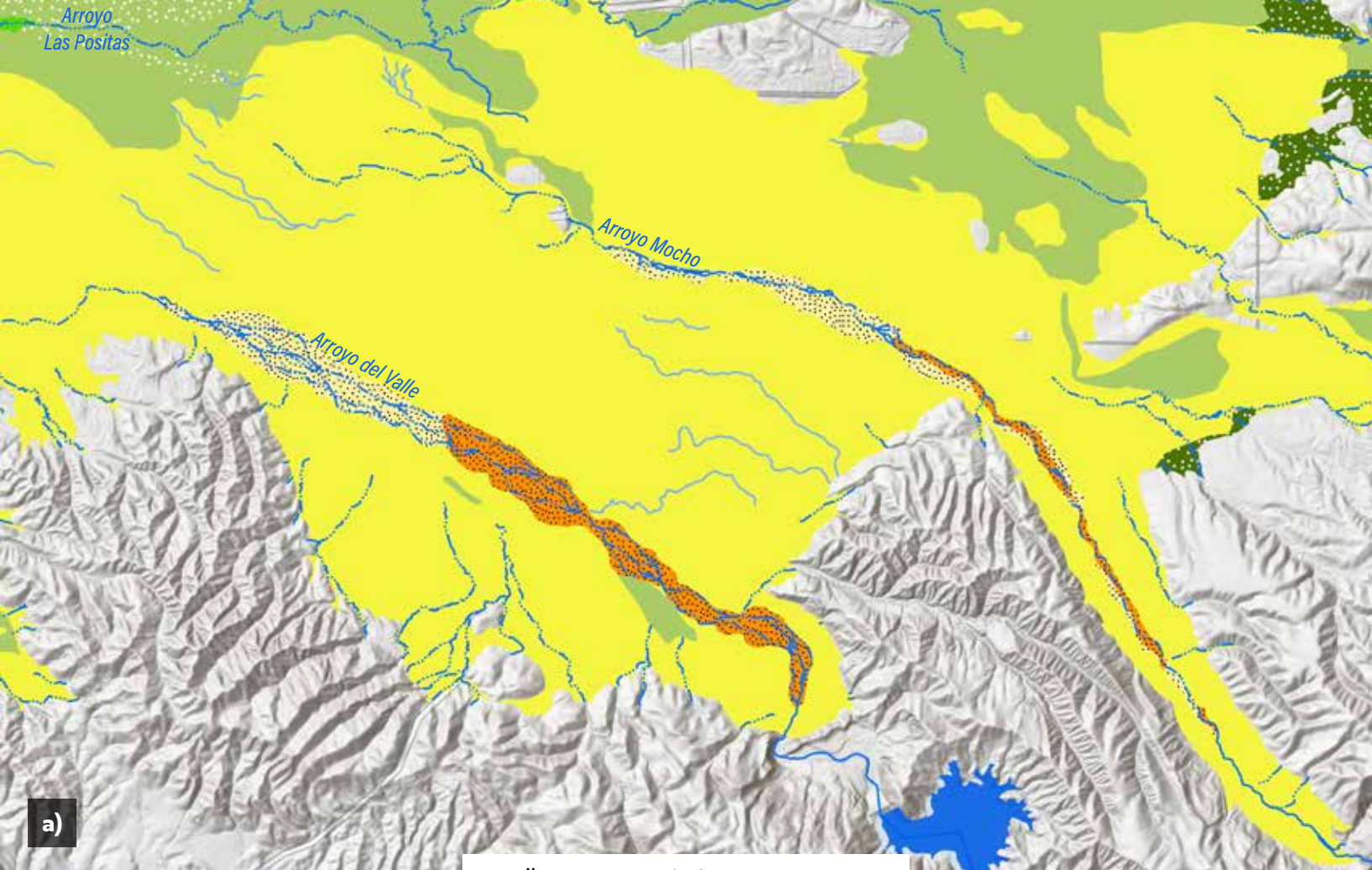
groundwater levels would have been near the surface during the winter and early spring months and then gradually receding during the dry season. Stands of sycamores were clearly visible along the channel corridor in early landscape paintings as well as photographs from the 1930s (Stanford et al., 2013). The lower segment (generally beginning in present-day Shadow Cliffs Regional Recreation Area, just upstream of Bernal Avenue) was a finer-grained intermittent distributary channel that supported sycamore and sparse oak in a riparian corridor that was 60 to 600 m (200 to 1,970 ft) in width. At the point where the channel reached the edges of the Pleasanton Marsh Complex, the upstream contributing watershed area was approximately 435 km<sup>2</sup> (168 mi<sup>2</sup>) (Stanford et al., 2013).

In comparison, the historical Arroyo Mocho was characterized by three primary segments within the Valley floor, the upper, middle and lower (Stanford et al., 2013). The upper segment was a meandering single-stem coarse-grained perennial channel that supported SAW in a riparian corridor that was between 60 and 200 m (200 to 650 ft) in width. The middle segment,

**Figure 4 (right).** In a), historical habitat types of the Livermore-Amador Valley ca. 1850 (Stanford et al. 2013). Sycamore alluvial woodland was present along Arroyo Mocho and Arroyo del Valle as they exited upland canyons and entered valley alluvium (dark orange). Scattered sycamores were also present further downstream along the alluvial and braided portions (tan). In b), current aerial imagery of the Livermore-Amador Valley (2018, courtesy NAIP). Stream gage locations Arroyo Mocho near Livermore (AMNL) and Arroyo del Valle near Livermore (AVNL) are shown as red dots.









beginning at about present-day Tesla Road, was a braided coarse-grained intermittent channel that supported SAW in a riparian corridor that was between 200 and 400 m (650 to 1,300 ft) in width. Within the shifting main channel, scour and deposition of sediment maintained the dynamic channel, providing the necessary physical template to support SAW along this segment. Continuing downstream, as the channel slope and stream power (the amount of energy exerted on the bed and banks by the flowing water) decreased, the lower segment, beginning generally around Oak Knoll (present-day East Stanley Blvd), transitioned into a finer-grained intermittent distributary channel system. Due to the decreasing water supply as flows infiltrated into the coarse gravels, this segment supported larger areas of grassland with fewer sycamores and sparse oak trees (Beagle et al., 2014). At the point where the channel lost definition in these distributaries, the upstream contributing watershed area was approximately 155 km<sup>2</sup> (60 mi<sup>2</sup>), a much smaller watershed area than the Arroyo del Valle. Overall, the Arroyo Mocho channel and riparian corridor was described as more narrow and dynamic than the Arroyo del Valle (Stanford et al., 2013). It was flanked by abandoned floodplain terrace surfaces. As an aggrading channel, it flooded frequently. Flows infiltrated into the coarse gravels continuing downstream, so that the channel was often dry by the time it entered the distributary channel system (about 2 mi east of the Pleasanton Marsh Complex; Stanford et. al., 2013). As with Arroyo del Valle, local groundwater levels along the SAW reaches were near the surface during winter and early spring, and receded into the dry season.

These historical segments supported SAW because of the intersection of landscape position, longitudinal gradients, and geologic and hydrologic processes that provided the appropriate disturbance regime, channel pattern and gradient, sediment size, floodplain

inundation, and shallow groundwater (Figure 5). Specifically, these segments existed on low gradient alluvial fans, where the channel had a dynamic and braided pattern. The channels were shallow and laterally unconfined, allowing surface flow to access the multiple braids of the active channel (mainstem and secondary channels) and smaller side channels outside of the active channel, locally scouring and depositing sediment. Flood waters easily spilled out of the main channel, accessing adjacent floodplain surfaces and allowing the flood waters to slow, deposit sediment, and infiltrate. Sediment in the channel bed was relatively coarse (cobble and gravel), facilitating infiltration of surface water into the sediment. During the winter and spring months, the shallow groundwater table was relatively close to the surface, slowly receding through the summer and fall months. Sycamore seedlings and saplings were supported within this environment, while other riparian species more dependent upon consistent water availability and associated with perennial streams were generally precluded.

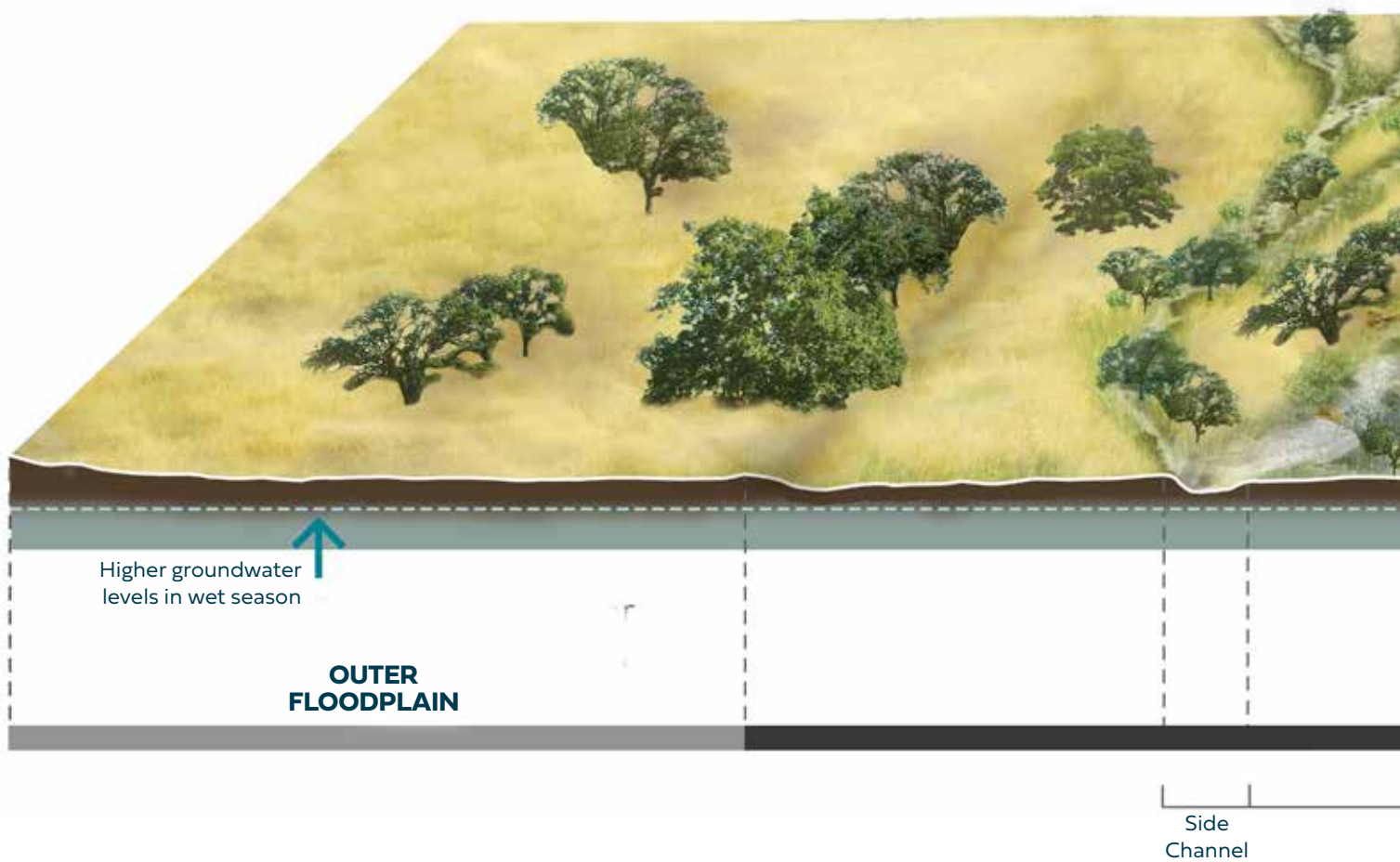
Longitudinally, the segments supportive of SAW were situated between upstream and downstream segments that were less appropriate for SAW, although sycamores would have still been present as part of the vegetation community (similar to the description in Figure 1). Upstream, a single-stem channel flowed through a narrow canyon, associated with a steeper gradient and greater stream power and where the channel was laterally confined and sediment and water transport was more efficient. Downstream, the channel was composed of finer-grained sediment and didn't have enough stream power to regularly scour the channel bed, transport the scoured coarse sediment, and deposit that sediment in pockets adequate for sycamore establishment.

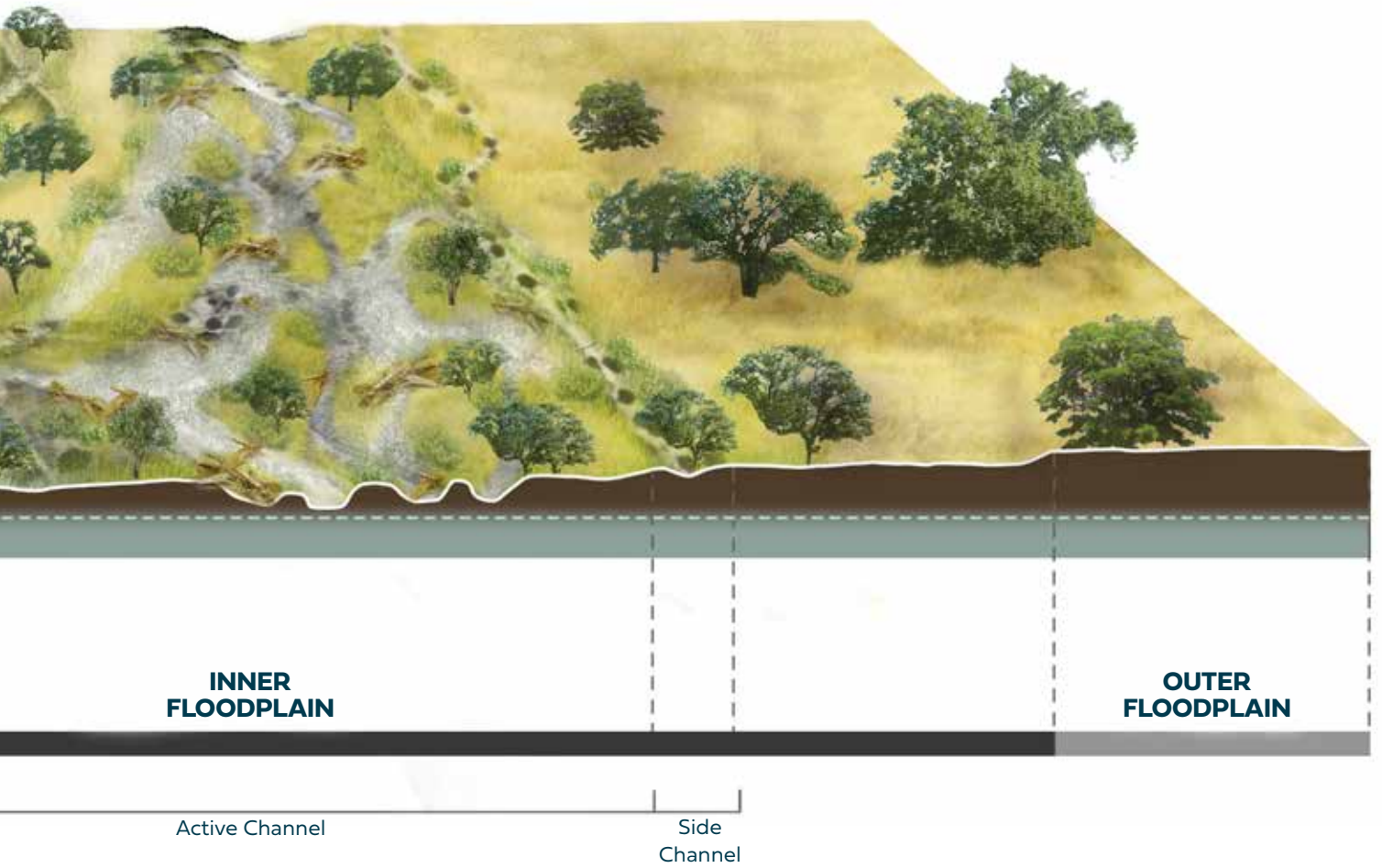




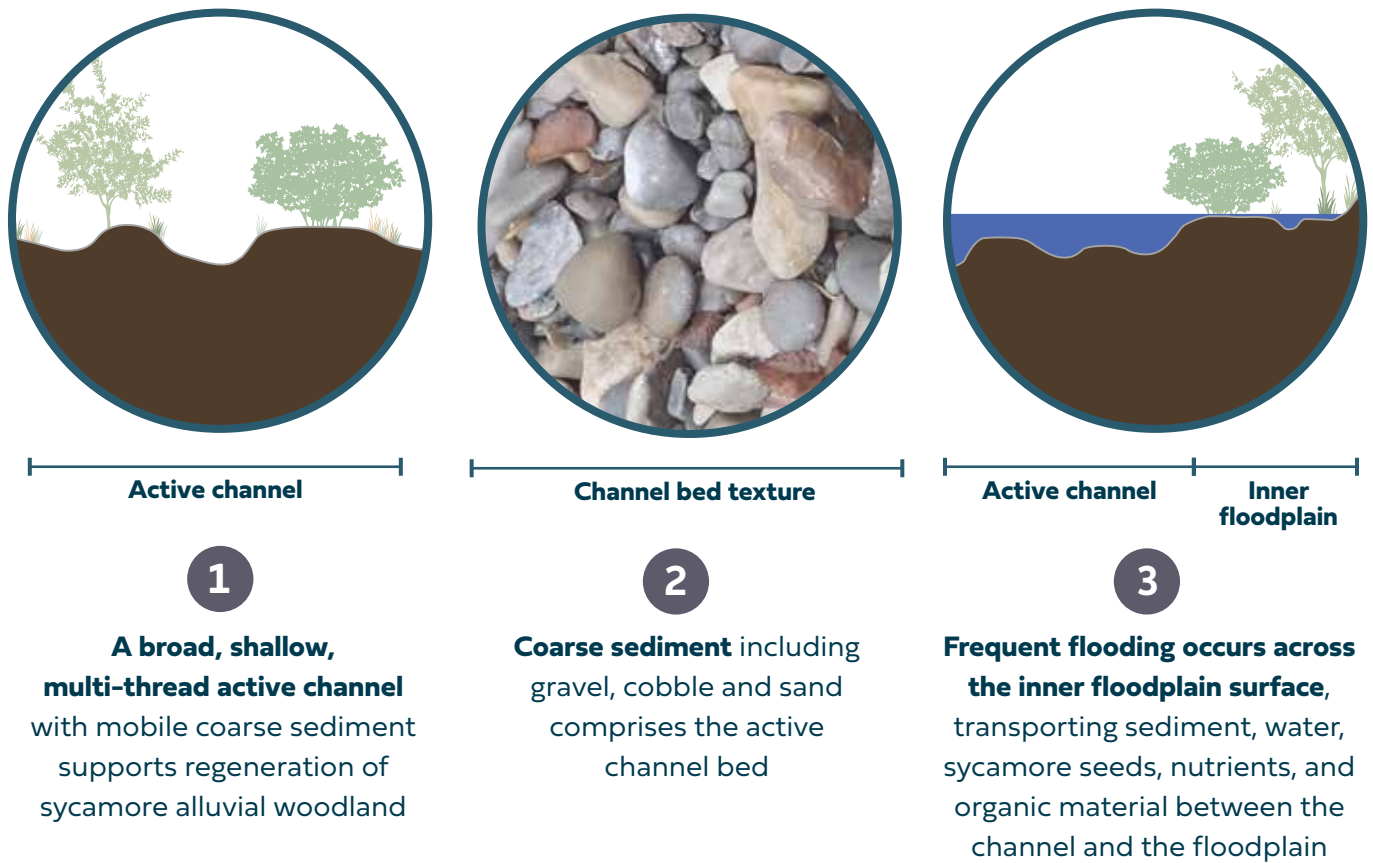
# Historical Conditions of Sycamore Alluvial Woodlands

**Figure 5.** Conceptual historical channel cross section illustrating common features of stream segments that supported actively regenerating SAW.



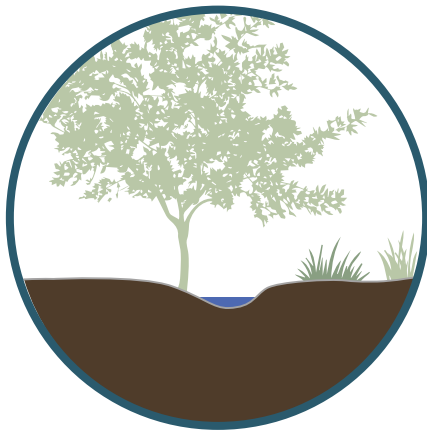


# Historical Conditions of Sycamore Alluvial Woodlands



**Figure 5 (continued).** Conceptual historical channel cross section illustrating common features of stream segments that supported actively regenerating SAW.

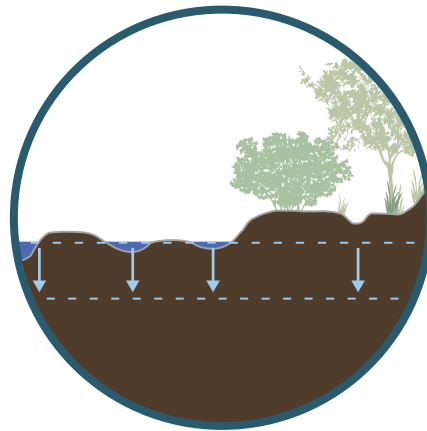




Inner floodplain   Side channel   Inner floodplain

4

**Side channels are conducive to sycamore establishment** because they have fresh coarse sediment deposits delivered during large floods and frequent inundation of low-velocity surface flows, both necessary for seedling establishment



Active channel   Inner floodplain

5

**Groundwater levels are high** (though not high enough to support willows and cottonwoods), connected to the channel bed **during the winter and spring**, and gradually decline in the late spring through fall



# Transformation

Prior to rapid transformation with Euro-American settlement in the early 1800s, the Valley was home to and managed traditionally by the Chochenyo Ohlone people (Stanford et al., 2013). After grazing in the Mission era (early 1800s), much of the Valley was converted to grain crops during the mid-1800s. Although the Valley was largely unwooded, during this time and through to the early 1900s, local residents likely cleared land of the small number of trees and used some of the sycamore and oak trees for timber and firewood. After World War II, the Valley began to rapidly urbanize, with construction of houses, offices, and other commercial properties. Today the Valley is densely urbanized with a population of more than 200,000 people. While much of the Valley is now developed, with over 40% of the Valley covered in impervious surfaces (i.e., pavement and buildings), some areas of agriculture remain, primarily in eastern portions of the Livermore-Amador Valley. In fact, the City of Livermore is actively managing its jurisdiction to retain the agricultural heritage and character of the city. Today, vineyards are the dominant crop.

The history of land use and management transformed the stream channels and habitat types within the Valley both directly and

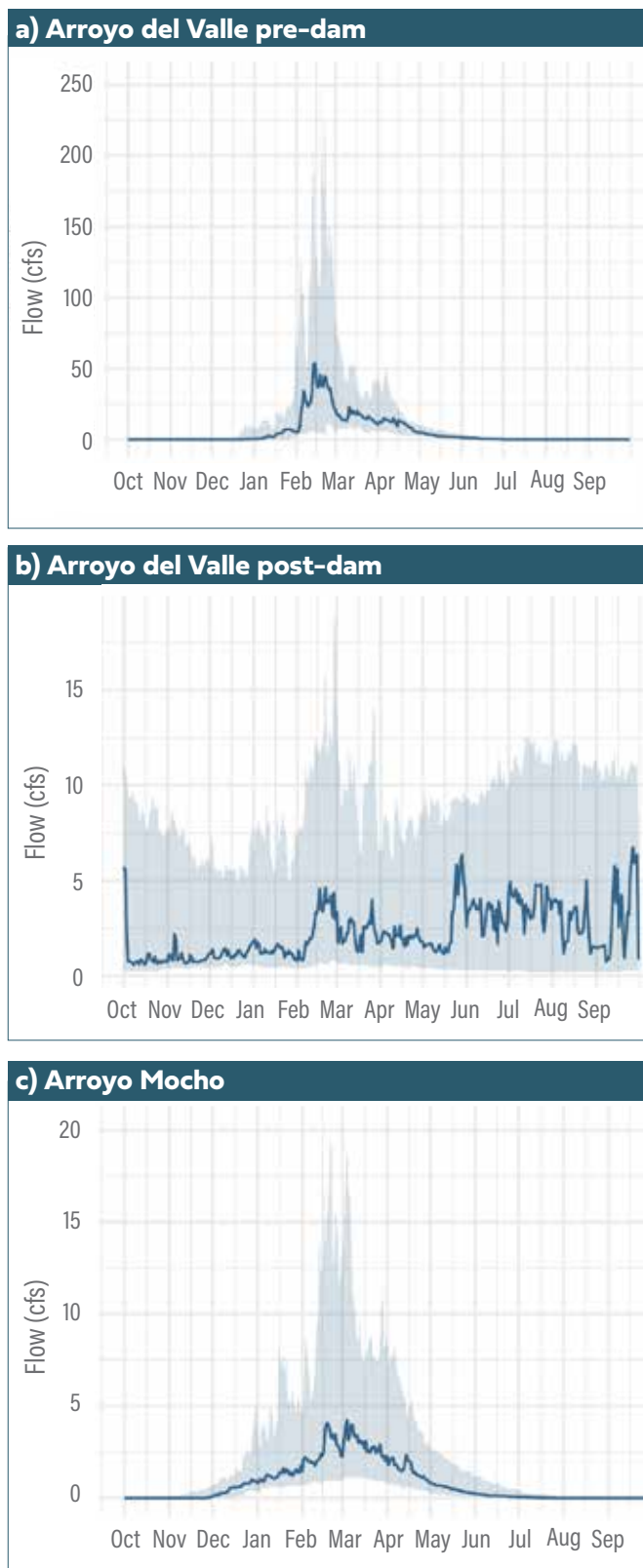
indirectly. For example, localized tree clearing for agriculture, gravel mining, and development directly reduced the extent of SAW. Indirect impacts included the connection via ditches of many of the discontinuous small drainages, as well as large channels like the Arroyo Mocho and Arroyo del Valle, to increase drainage across the Valley in the late 1800s. Arroyo Mocho was connected from its point of distribution (the point on the longitudinal profile where the channel lost definition, spreading across the alluvial fan surface), so that it joined the Arroyo Las Positas (occurring sometime between 1878 and 1889), while the Arroyo del Valle was connected to the Arroyo de la Laguna through the ditching and draining of the Pleasanton Marsh Complex. These actions significantly altered the flow of water and sediment through the Valley, affecting the presence and persistence of many habitat elements. Though these drainage network changes largely occurred downstream of primary SAW habitat, the physical processes and conditions conducive to sustaining SAW were altered via incision as a result of the increased connectivity of the stream network, which reduced channel dynamics (including sediment deposition and erosion, area of active floodplain, and groundwater levels).

## Present Setting

Arroyo Mocho and Arroyo del Valle, two of the primary drainages in the Valley, are now heavily modified and managed (see Figure 4b). While Arroyo del Valle can still be defined by two primary geomorphic segments, the hydrology and channel form within each segment is different than it was historically. The Del Valle dam was constructed on Arroyo del Valle in 1968 for flood control and water storage, significantly modifying flows and cutting off supply of coarse sediment to the downstream segments. As illustrated in Figure 6a and b,

flows are now managed such that winter peak flood events are largely eliminated, and summer low flows are augmented with releases of water either from the dam or from the South Bay Aqueduct turnout that is located at the base of the dam. Based on the 1913 to 1930 water years, the flow regime prior to the dam was characterized by mean daily flows of  $0.8 \text{ m}^3/\text{s}$  (30 cfs), a median annual maximum flow of  $322.1 \text{ m}^3/\text{s}$  (11,375 cfs), and a mean of 190 zero-flow days during the dry season (note median daily flows are shown in Figure 6). Post-dam (1964-





**Figure 6.** Annual hydrographs for Arroyo del Valle and Arroyo Mocho, where the solid line shows median daily flow and the light blue shading represents the 25th to 75th quantiles. In a), the pre-dam hydrology for Arroyo del Valle is shown, compared to the post-dam (after 1968) hydrology in b). The annual hydrograph for Arroyo Mocho is shown in c).

2019 water years), mean daily flows are similar at  $0.6 \text{ m}^3/\text{s}$  (23 cfs), but the median annual maximum flows and mean zero-flow days are only  $3.4 \text{ m}^3/\text{s}$  (120 cfs) and 11, respectively (Mills and Blodgett, 2017).

The upper segment of Arroyo del Valle, from below the dam to Shadow Cliffs Regional Recreation Area, is still occupied by SAW in much of its former extent. Sycamore Grove Park is home to the largest present-day area of SAW in the Valley, including many sycamores that are 100+ years old, with the oldest nearly 275 (pith date of 1750) years old (Kamman, 2009). A braided channel pattern and large portions of its historically wide riparian corridor is still present in this segment. However, flow regulation has limited channel dynamics, reducing active channel braiding, deposition, and reworking processes. A single, well-defined mainstem channel now exists within the broader channel corridor. In addition to regulated flow, the dam traps sediment and thus limits coarse sediment deposition. The reduced sediment supply and geomorphic disturbance has resulted in diminished opportunities for sycamore recruitment and establishment, such that existing SAW could be considered remnant stands that are not actively regenerating. In most years, releases from the dam maintain perennial flow, which also keeps the shallow groundwater levels higher than historical levels. This is potentially impacting the capacity of sycamores to establish and outcompete other native and non-native vegetation. The lower segment has been profoundly modified. The segment that flows adjacent to Shadow Cliffs is laterally confined by levees/berms on either side of the channel and has two on-channel, flow-through ponds from historical gravel mining. Following the historical pattern, the stream corridor downstream of Shadow Cliffs is narrower than upstream, but is now tightly confined by adjacent development, is incised, has a dense woody riparian corridor, and has a direct channel connection to Arroyo de la Laguna.

As a smaller watershed than that of Arroyo del Valle, flows are generally lower for Arroyo Mocho, but the hydrograph is similar to that of Arroyo del Valle prior to the dam given their similar watershed positions, characteristics, and proximity (Figure 6c). The absence of a dam, however, means that Arroyo Mocho retains the flashy hydrology of large winter peak flows and a long dry season. Based on 73 years of record (1913-1930 and 1965-2019 water years), the flow regime is characterized by a mean daily flow of  $0.1 \text{ m}^3/\text{s}$  (4.9 cfs), a median annual maximum flow of  $16.0 \text{ m}^3/\text{s}$  (563 cfs), and a mean of 117 zero-flow days (Mills and Blodgett, 2017).

While Arroyo Mocho does not have a dam, the valley floor channel morphology has been substantially altered and flow is augmented in downstream reaches. The valley reaches can

still be described in terms of three primary segments, similar to historical conditions. The upper segment has remained fairly rural and relatively unmodified, however some rural residential housing and vineyards are present and Mines Road parallels the creek. SAW remains along much of this segment. While this segment was and continues to be a single-thread channel, this reach is slightly incised (likely due to increased stream power caused by additional runoff from the landscape) and therefore reduced the frequency at which it is able to fully interact with the adjacent floodplain surface. The middle segment, with areas of SAW and individual stands of sycamores persisting, retains aspects of its previous braided pattern, but is incised now as well, reducing its ability to aggrade and braid across the valley floor. It has lost its wide corridor due to encroaching development. The

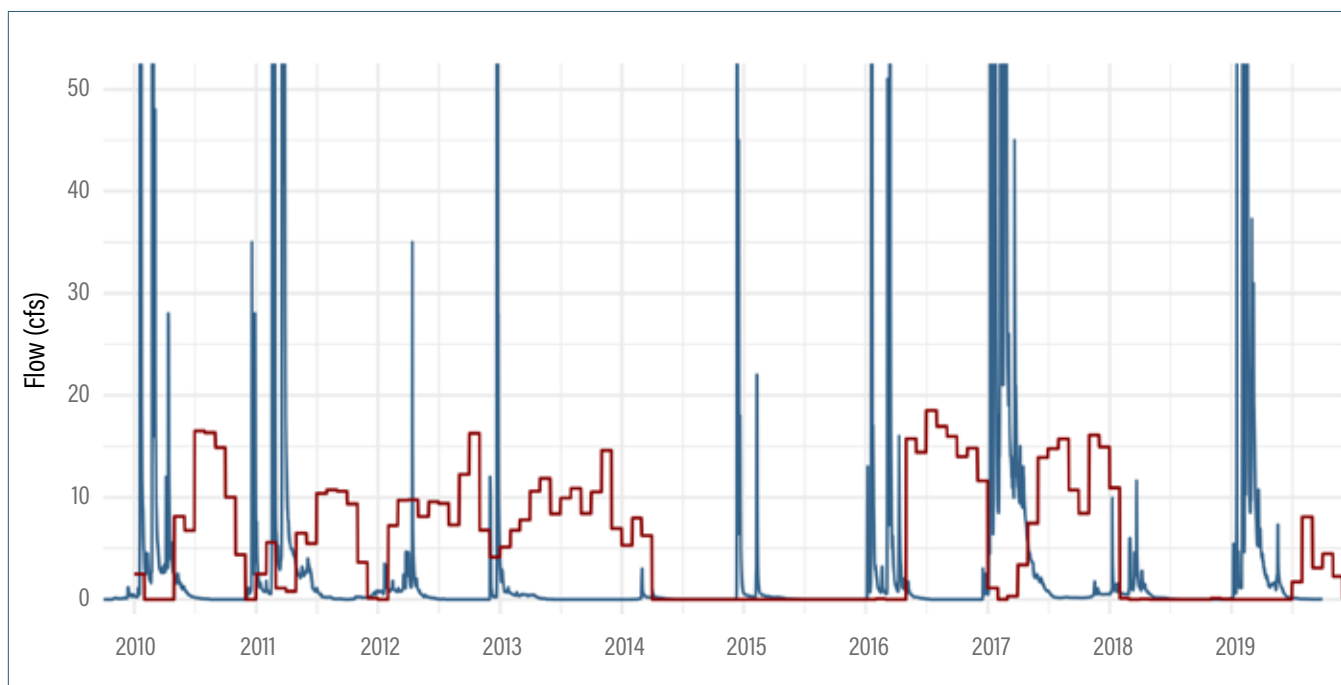




historical channel incision limits the frequency and extent of floodplain inundation such that there are only narrow surfaces available for sycamore recruitment and establishment. This segment still deposits coarse sediment, however the majority is transported to the downstream extent and deposited, including at the Holmes Street Bridge, where sediment is removed periodically by maintenance operations. For example, Arroyo Mocho at Holmes Street bridge has had 12 sediment removals during a period of 15 years (2005 to 2019), removing a total of nearly 15,300 cubic meters (20,000 CY) of sediment (Pearce et al., 2021). Also, flow is augmented in the dry season when water is available from the State Water Project (via the South Bay Aqueduct) to increase in-channel flows for groundwater recharge (Figure 7). This has altered the seasonal surface and groundwater hydrology to which sycamores are adapted. Downstream, the lower channel segment has been straightened and leveed as it flows through the quarry reach

(aka future “Chain of Lakes”) to its confluence with Arroyo Las Positas. This segment is straightened, confined, has multiple artificial dog-leg bends, and has a sediment basin where sediment is periodically removed. Infiltration of surface water is significantly reduced in this reach due to the change in channel pattern from a broad distributary channel to a narrow and confined channel.

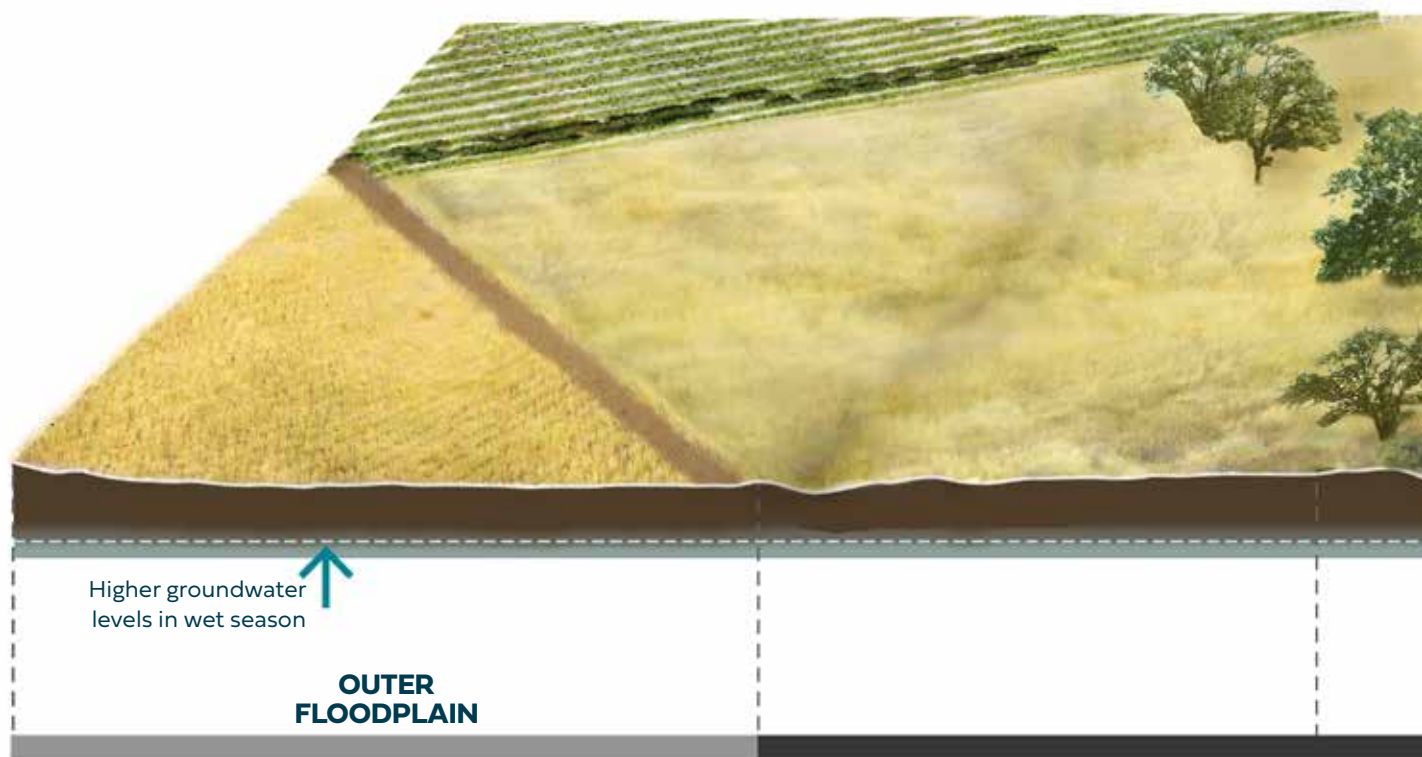
The characteristics and physical processes currently present and those potentially possible along these stream segments are essential factors in considering the appropriateness for supporting the recruitment and establishment of sycamores and the maintenance and resilience of SAW under current and future conditions. The current segments that still support SAW are reliant upon many of the physical characteristics of the channel that existed historically, but, as described above, have typically experienced significant land use, channel, and watershed-scale change (Figure 8).



**Figure 7.** Arroyo Mocho daily flow (blue) with monthly mean daily flow augmentation (red) via the South Bay Aqueduct, based on information provided by Zone 7. Note that flows above 50 cfs are not shown.

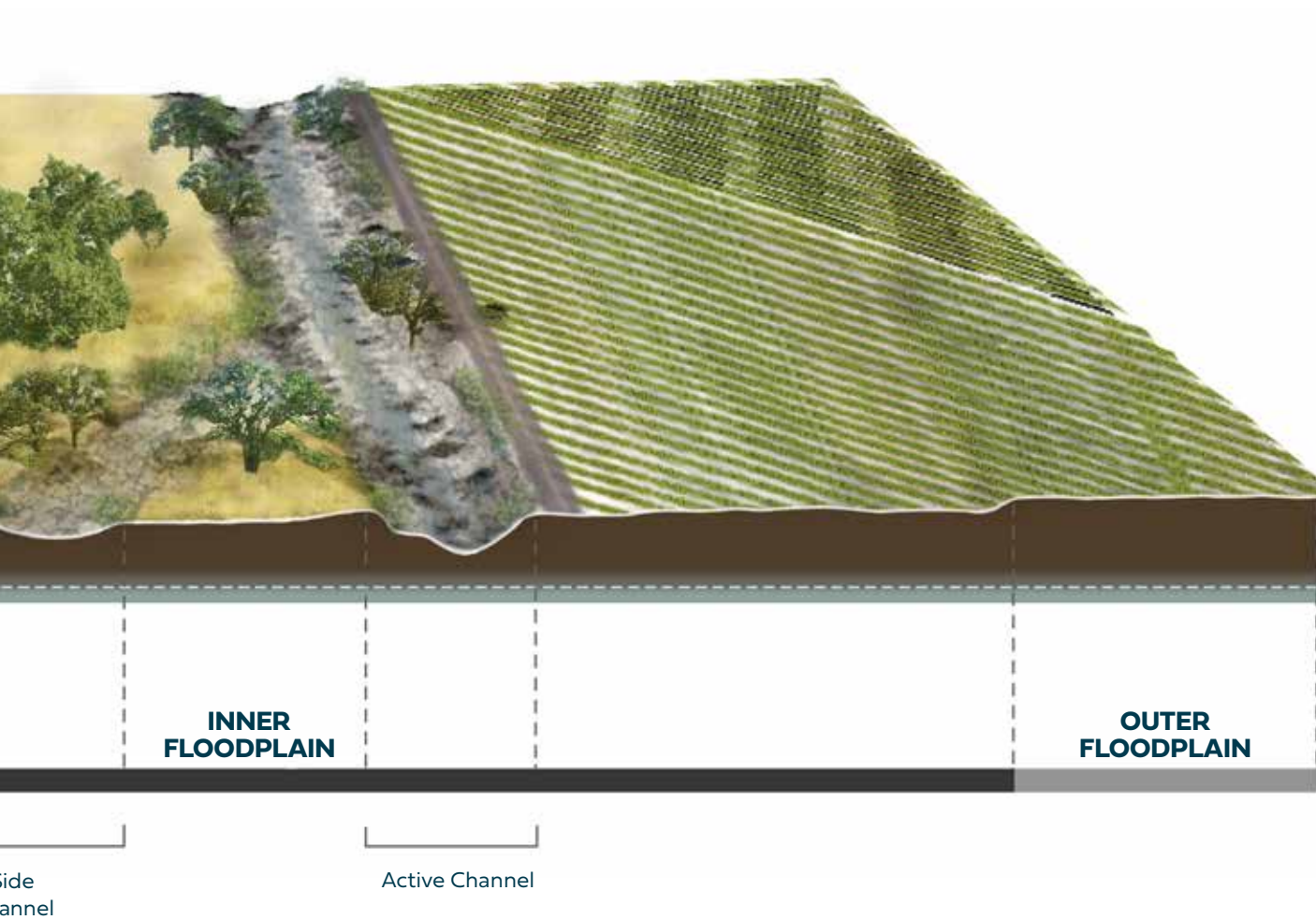
# Current Conditions of Sycamore Alluvial Woodlands

**Figure 8.** Conceptual current conditions channel cross section illustrating common features of stream reaches with remnant SAW.

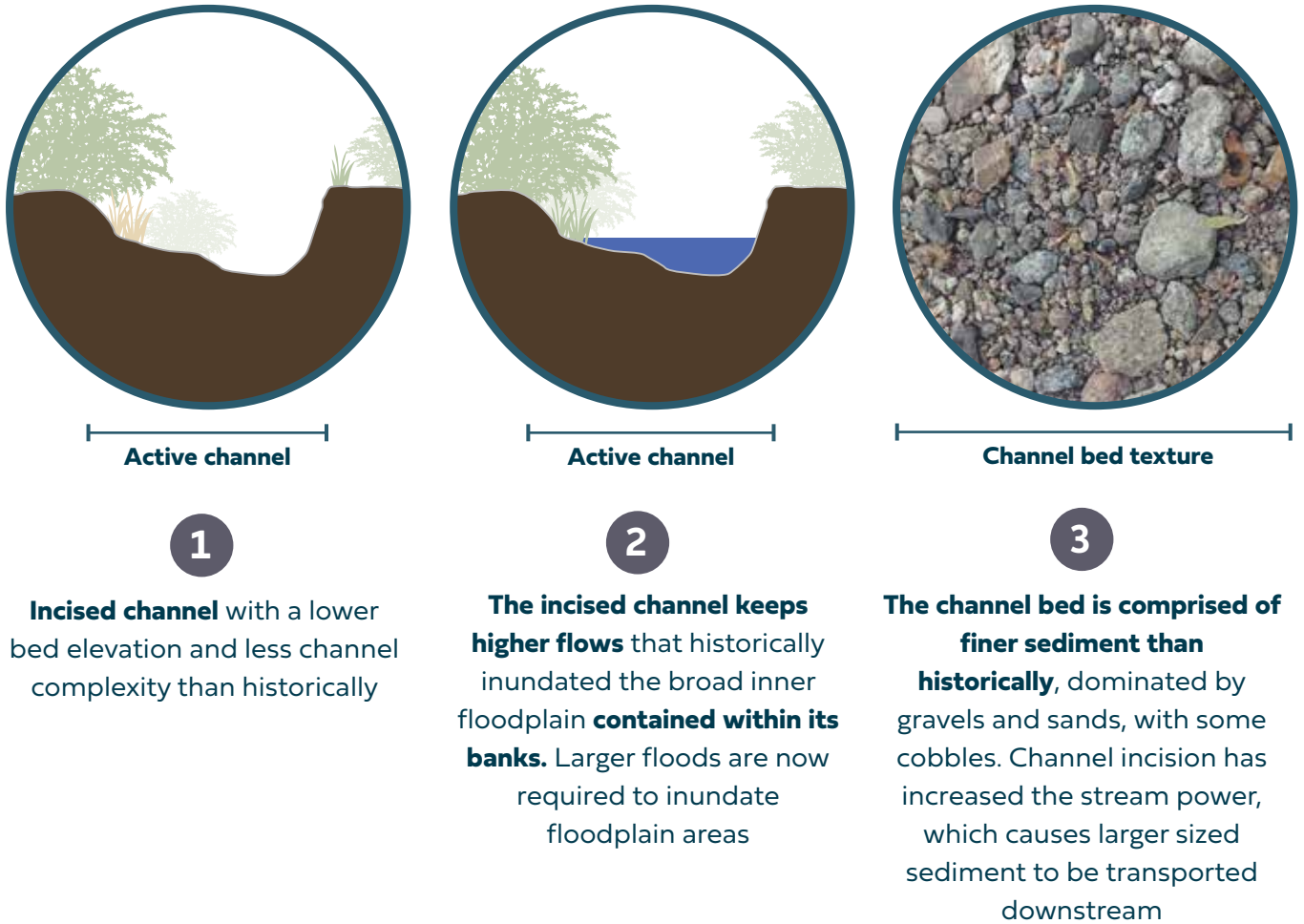


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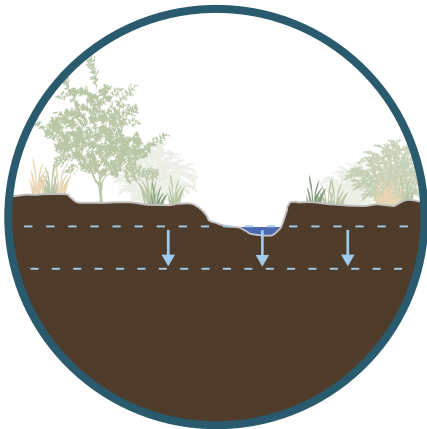


## Current Conditions of Sycamore Alluvial Woodlands



**Figure 8 (continued).** Conceptual current conditions channel cross section illustrating common features of stream reaches with remnant SAW.





Inner floodplain   Active channel   Inner floodplain

4

**Seasonal groundwater level fluctuations are similar to historical conditions.**

However, because of regional groundwater pumping and channel incision, the **elevation difference between floodplain surfaces and the groundwater table is now likely greater**



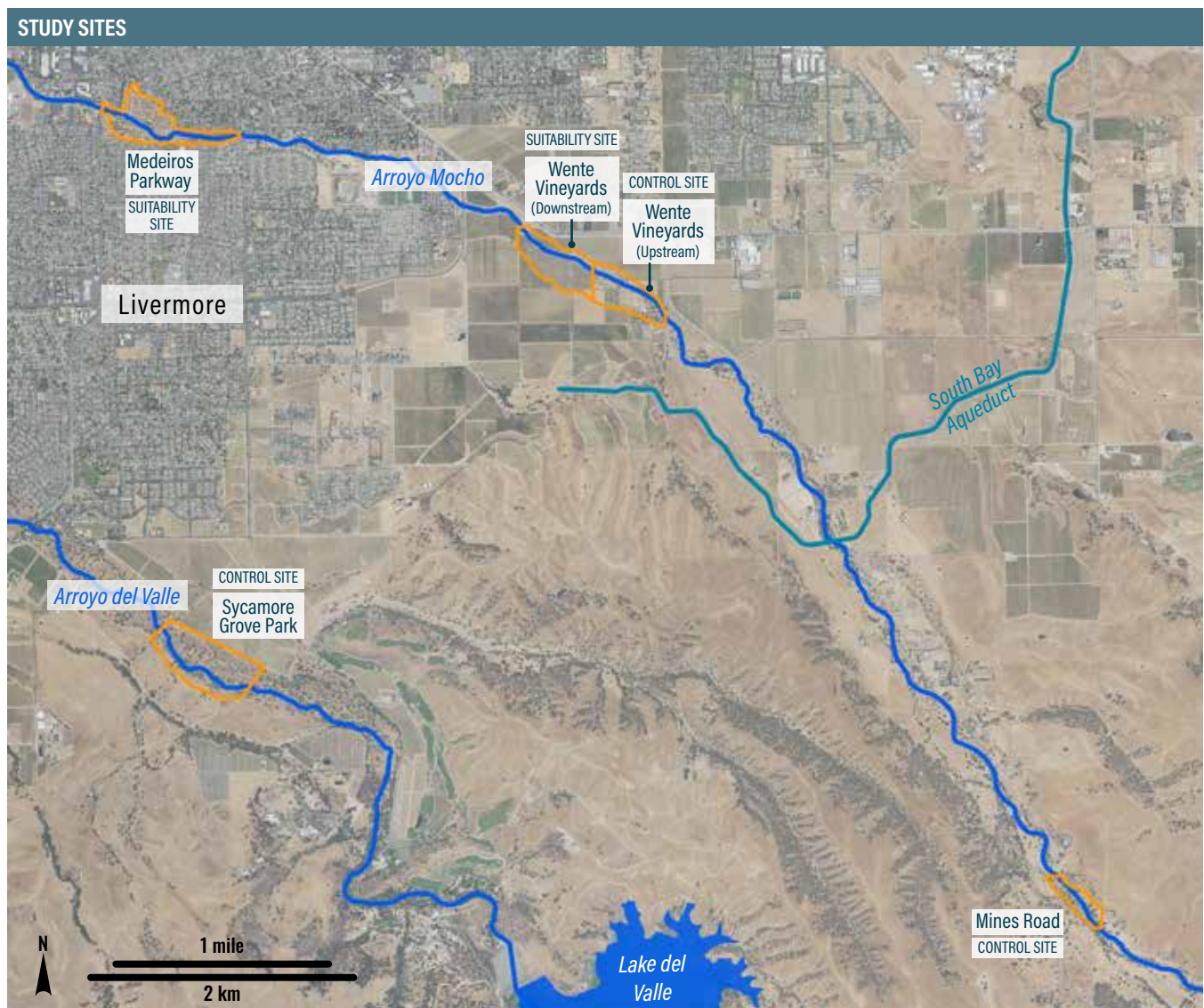


# Study sites

A range of characteristics were sought in selecting study sites. The five study sites are divided into three “control” sites where SAW is present and sycamores are fairly abundant, and two “suitability” sites where sycamores were historically more abundant than today (Figure 9). Control sites are intended to represent locations where SAW is currently in its best condition, acknowledging that these sites and the sycamore trees within have likely

been subject to modification. Suitability sites are locations where it is clearly evident that SAW has been negatively impacted, and would benefit from a greater understanding of how SAW may be better supported. Sites were located on both Arroyo Mocho, an unregulated system, and Arroyo del Valle, a regulated stream. The single site on Arroyo del Valle, Sycamore Grove Park (owned by Livermore Area Recreation and Park District, LARPD), is

**Figure 9.** (left) Map of the five Study Sites on the Arroyo del Valle and the Arroyo Mocho within the Livermore-Amador Valley. (right, detailed views of each site) Sycamore Grove Park (a, control site) is located on Arroyo del Valle, while Mines Road (b, control site), Wentle Vineyards Upstream (c, control site), Wentle Vineyards Downstream (c, suitability site), and Medeiros Parkway (d, suitability site) are located on Arroyo Mocho.

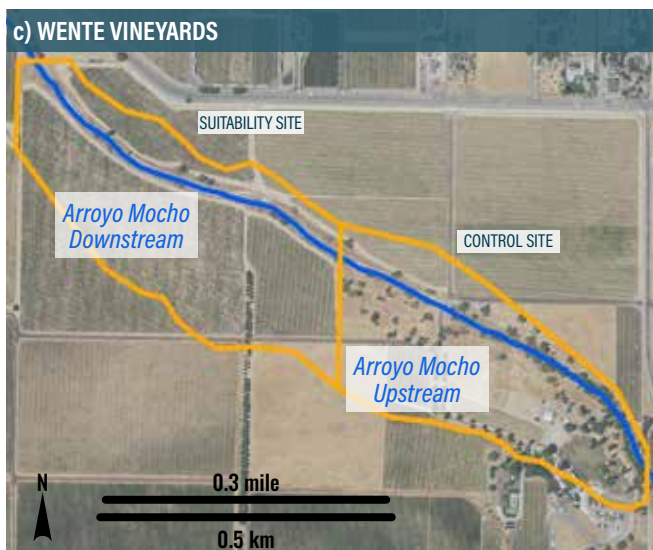
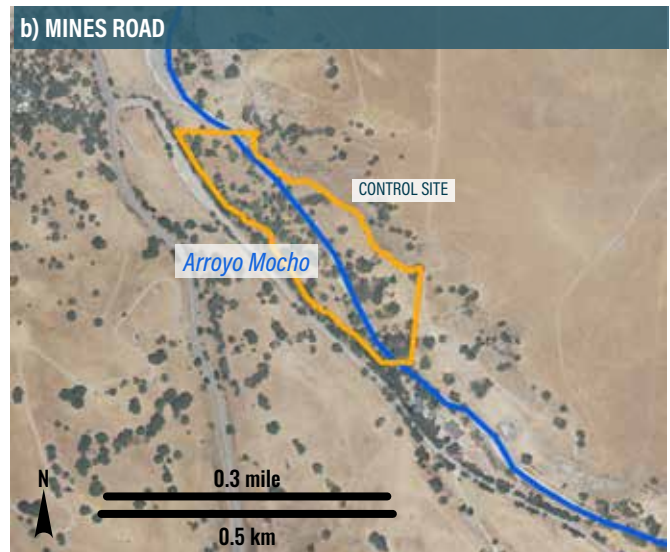




included as a control site, as it is well-known for its extensive stand of sycamores, despite its hydrologic modification since 1968. On Arroyo Mocho, the farthest upstream site is the Mines Road site (owned by Zone 7), which is a control site. Moving downstream, the next two sites are on the privately-held Wente Vineyards property. The upstream site is a control site, and shares a boundary with the downstream site, which is a suitability site given that sycamores were historically removed for agricultural land uses. And finally, the farthest downstream site is the Medeiros Parkway (previously owned by LARPD, but now owned by Zone 7), a suitability site impacted by historical agricultural uses, a former gravel

mine, as well as urban development. No sites are known to be grazed regularly.

Conducting the field surveys necessary for this effort relied upon existing and furthered relationships between Zone 7 and local agencies and landowners, which are relationships based on a long history of Zone 7 working successfully with local partners on various projects across the Valley. This is an example of the value in working with individual landowners or partners in order to develop a regional understanding and address watershed-scale challenges. Specifically, this effort involved the permission of Wente Vineyards and LARPD to conduct the sycamore field surveys in the fall of 2019.







SYCAMORE GROVE PARK

MINES ROAD



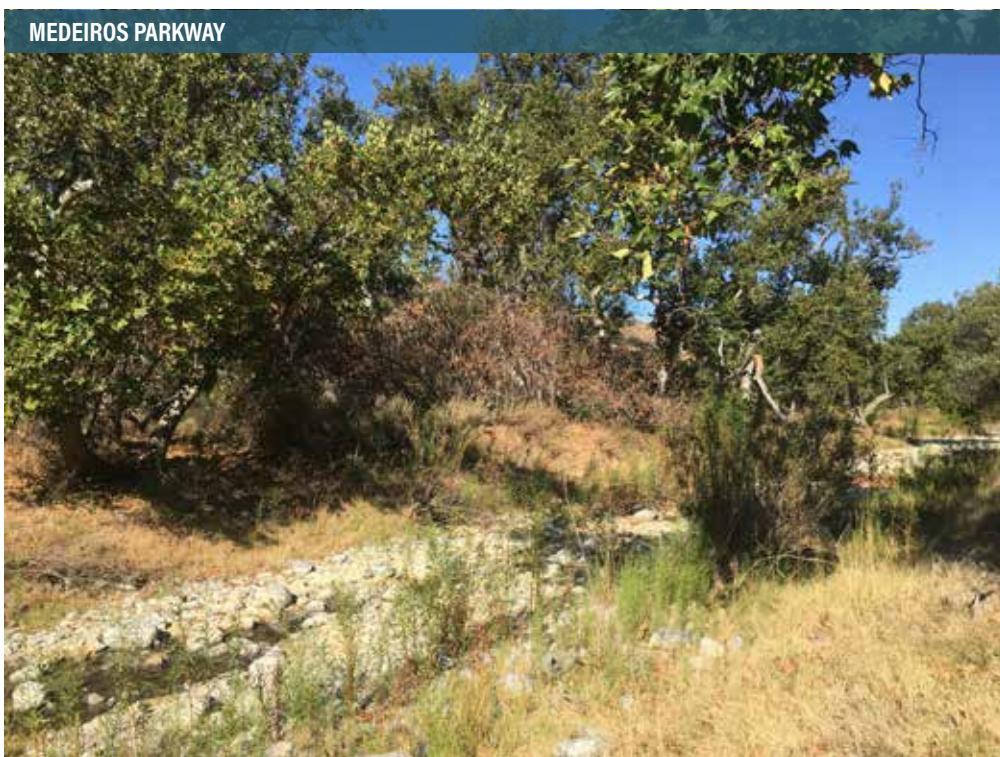




WENTE VINEYARDS (UPSTREAM)



WENTE VINEYARDS (DOWNSTREAM)



MEDEIROS PARKWAY







# METHODS

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## Geomorphic Zone Mapping

To delineate initial geomorphic zones for each site prior to fieldwork, the project team gathered digital elevation data (a RAS terrain developed from 2014 LiDAR data) and recent aerial photographs (2016 NAIP and other recent years via Google Earth). The team mapped geomorphic zone boundaries, delineating the active channel, side channel, inner floodplain, and outer floodplain. Delineations were based upon surface elevation changes, vegetation/lack of vegetation based upon the aerial photographs, distinguishable topographic/geomorphic features, consistency of patterns over time, and best professional judgment. These polygon types and boundaries were used and adjusted during field data collection, and subsequently updated as needed to create final geomorphic zone polygons.

## Field Data Collection

The field data collection component was designed building upon previous experience and studies of SAW. Data collection was completed at each of the five study sites during September, 2019 (field crews included SFEI staff Julie Beagle, Amy Richey, and Alison Whipple; H. T. Harvey staff Matt Quinn, Will Spangler, Ryan Hegstad, and Charles McClain; and Zone 7 staff Tami Church, with assistance from Living Arroyos intern staff). At each field site, staff systematically collected data on the location of each sycamore tree, sapling or seedling, using a GPS unit (Trimble TDC100, 1 m accuracy). Once a tree was identified and mapped, a number of characteristics of that tree were recorded directly into a spreadsheet on the field tablet. If a tree had multiple stems, the tree was recorded with a single tree number, but noted that it was multi-stemmed. These characteristics included:

- Size: diameter at breast height of the largest stem, measured in inches (and later classified into size classes: seedling (up to 2.5 cm, 1”), sapling (5-10 cm, 2-4 in), medium (13-99 cm, 5-39 in), and large (100-254 cm, 40-100 in))
- If multiple stems were present (with diameters of each stem measured and recorded)
- Geomorphic zone: active channel, side channel, inner floodplain, or outer floodplain
- Detailed geomorphic zone: active side channel, in-channel gravel bar, inset floodplain, mound, on bank, swale, top of bank, or none
- If scour or wrack was present
- Overall health: good, fair, poor, dead. Good condition was defined as having 66-100% healthy foliage, a large and dense canopy, many live branches, and minimal branch or twig die-back. Fair condition was defined as having 33-66% healthy foliage, moderately large and dense canopy, and moderate branch or twig die-back. And poor condition was defined as having 0-33% healthy foliage, a thin canopy, substantial branch or twig die-back, and presence of epicormic branches.
- Wildlife observations: cavity, nest, granary, or droppings





- If basal sprouting was present
- If seeds were being produced: none, some, or many

A subset of trees were selected by Julie Beagle for tree cores to be taken, to help produce an age estimate, based upon counting annual tree rings. A total of four trees were cored using a Haglof increment borer. Every effort was made to take a core that was oriented perpendicular to the growth rings. Cores were carefully stored in appropriate protective tubing, and taken back to the laboratory where individual rings were counted using a microscope. A total number of rings present was assigned to each core, allowing for an age estimate and assignment to a size class category for each tree.

## Hydrologic Data

As a primary physical driver of SAW, hydrology was assessed using data from the two streamflow gages on Arroyo Mocho (AMNL, maintained by Zone 7) and Arroyo del Valle (#11176500, labeled AVNL, USGS 2020b). The Arroyo Mocho gage is located approximately 0.7 km (0.5 mi) downstream of the Mines Rd site, and the Arroyo del Valle gage is located approximately 2.0 km (1.2 mi) upstream of the Sycamore Grove Park site. The period of record begins in 1912 for both gages, with missing years for Arroyo Mocho between 1931-1964 and for Arroyo del Valle between 1931-1958. Missing years were filled in via regression analysis using a non-linear model based on streamflow data from the Alameda Creek at Niles gage (#11179000, USGS 2020a), which has a continuous period of record dating back to the 1892 water year. The data were examined via summary plots, and flood frequency curves and intervals were calculated.







# RESULTS

## Sycamore characteristics at the study sites

**Objective 1:** Describe the current distribution, abundance, size, geomorphic position, and health of existing individual sycamore trees at each of the study sites



### *What is the distribution and abundance of sycamore trees?*

Individual sycamore trees were identified, counted, measured and mapped at each of the five study locations. A total of 309 individual trees (including 4 that were dead) were counted within the five sites combined, while the total number of trees at each site varied between a low of 10 (Wente Vineyard Downstream-Suitability) and a high of 118 (Wente Vineyard Upstream- Control) (Table 1). Approximately 70% of the total number of individual trees are located in just two of the five sites. The two suitability sites, Wente Vineyards Downstream and Medeiros Parkway, have the two lowest total number of trees present. Comparing both total number of trees and density of trees illustrates the variability between each project site, including variability between control sites, as well as variability between control and suitability sites.

Evaluating sycamore distribution by geomorphic zone can indicate variation driven by physical position or processes and suggest potential opportunities for regeneration. Sycamore density within each geomorphic zone for the five sites combined illustrates that the inner floodplain and the active channel have the highest density of trees present (Figure 10, left). This corroborates findings from other studies suggesting that the highest sycamore densities are typically found closer to the current active channel and in side

channels (SFEI-ASC and H. T. Harvey, 2017). Breaking down the patterns by each individual site shows that the three control sites have higher densities than the two suitability sites, with the Wente Upstream site having the highest densities overall. In fact, the density of sycamores in the Wente Upstream side channel zone is twice as much as the next highest density. These relationships suggest that the existing sycamore trees present were established in areas supported by dynamic flood flows, having the highest density in the active floodplain, active channel, and side channels.

Sycamore trees are currently predominantly located on broad inner floodplain zones. The high density within this zone likely reflects the combination of an appropriate environment for establishment during large floods (which might occur more frequently than on the outer floodplain), an elevation that is closer to the groundwater table, more-regular inundation of surface waters during flood to provide additional water support and maintain established trees, and lower rates of removal (as compared to the outer floodplain) due to land use pressures.

In contrast, the outer floodplain has a lower number and density of sycamores, with the lowest overall density of the four geomorphic zones in all five sites combined. For example,

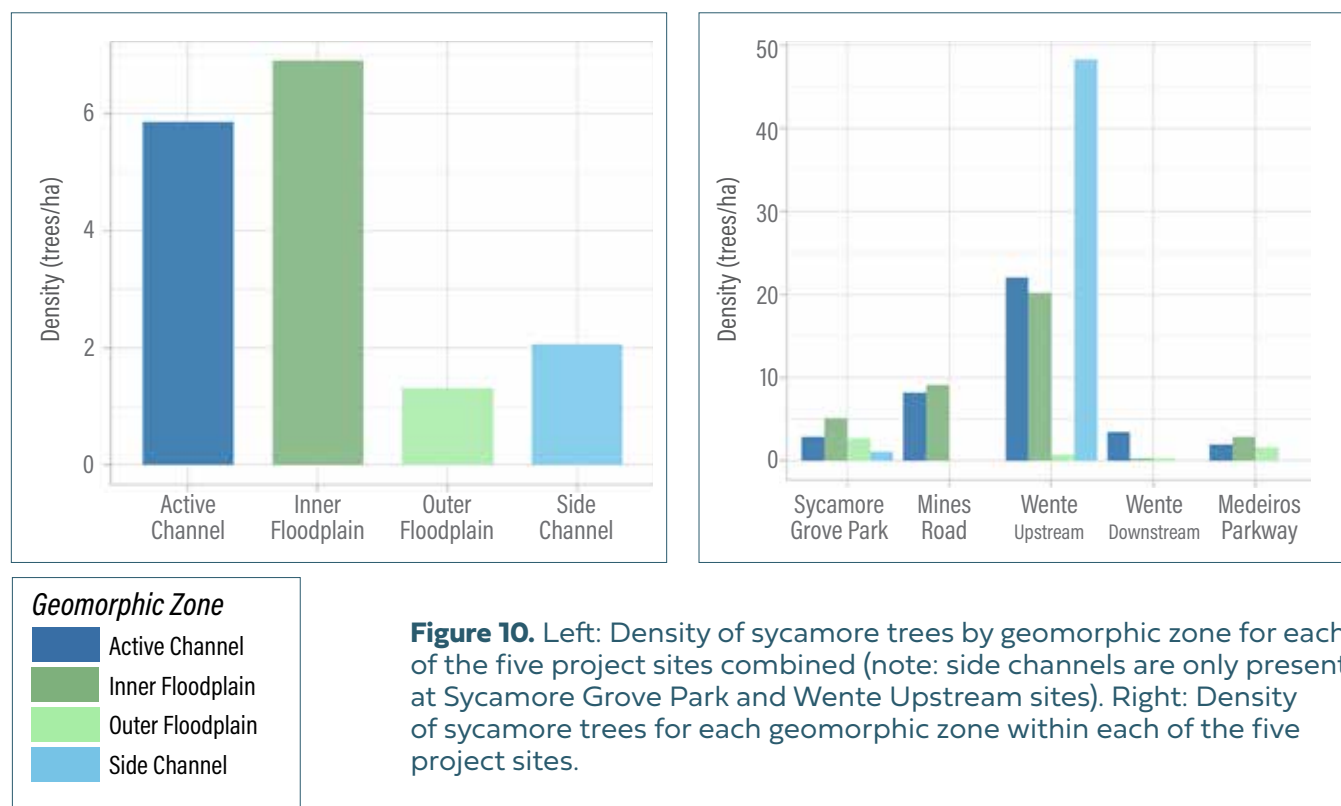
both Wente Vineyards sites only have a few trees on the outer floodplain, and the Mines Road site has none. The low density of sycamores in this zone is likely related to the lower inundation frequency of the higher-elevation outer floodplain, but it is also likely due to historical clearing of trees. Sites with higher densities of sycamores in the outer floodplain are associated with sites that likely have the greatest amount of groundwater support in the outer floodplain, given the

management of flows through the Del Valle dam (Sycamore Grove Park) and relative lack of channel incision and supplemental flows from the South Bay Aqueduct (Medeiros Parkway).

The side channel geomorphic zone at the Upper Wente Vineyards site supports the highest total density of sycamores of any geomorphic zone. This side channel connects hydrologically to the main channel more frequently than the surrounding inner or

**Table 1.** Location, type, site area, total number of sycamores, percentage of the total number of sycamore trees, and tree density for the five project sites.

Location	Type	Site Area (hectares)	Number of Sycamores	Percent of Total Sycamores	Sycamore density (trees/ha)
Sycamore Grove Park	Control	31.7	98 (+ 4 dead)	32.1%	3.09
Mines Road	Control	5.0	45	14.8%	8.97
Wente Vineyards (Upstream)	Control	12.3	118	38.7%	9.59
Wente Vineyards (Downstream)	Suitability	15.7	10	3.3%	0.64
Medeiros Parkway	Suitability	18.1	34	11.2%	1.87



**Figure 10.** Left: Density of sycamore trees by geomorphic zone for each of the five project sites combined (note: side channels are only present at Sycamore Grove Park and Wente Upstream sites). Right: Density of sycamore trees for each geomorphic zone within each of the five project sites.



outer floodplain surfaces, and was likely more frequently connected historically during

the time when the existing mature trees established.

## ***What is the distribution and abundance of sycamores by size?***

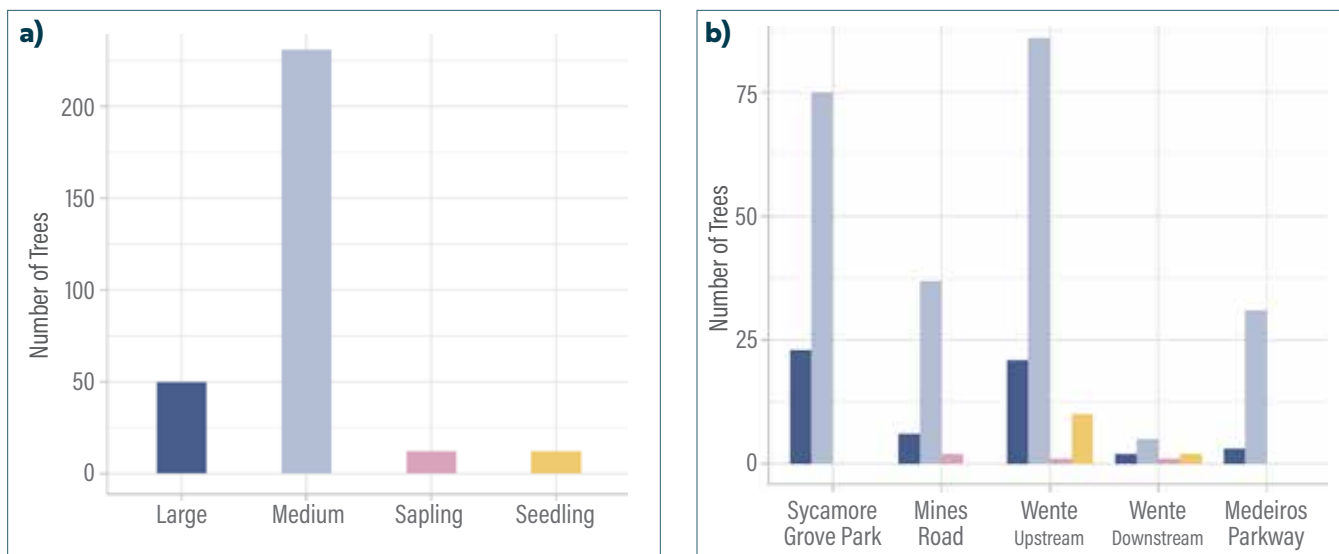
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The size of individual sycamore trees present at each site, which is representative of their age, provides information about the timing of regeneration and establishment, as well as the success of trees at each site and within each geomorphic zone. Across all five sites combined, the medium sized trees dominate ( $n = 231$ ), followed by large trees ( $n = 50$ ; Figure 11a). Overall there are very few seedlings ( $n = 12$ ) and saplings ( $n = 12$ ), indicating that sycamores have not had much success regenerating in these locations in the recent past. The total number of sycamores within each size class for each site shows a similar pattern; medium sized trees dominate, especially within the control sites, followed by large sized trees (Figure 11b). The two Wentz Vineyard sites both have seedlings and saplings present, although in low numbers, while the Mines Road site has saplings present, but no seedlings. Notably, Sycamore Grove Park and Medeiros Parkway both lack seedlings and saplings. In other words, three of the four sites on Arroyo Mocho have seedlings and/or saplings, while the furthest downstream site (with the shortest duration of annual surface water and the greatest human disturbance) on Arroyo Mocho, and the single site on Arroyo del Valle (downstream of regulated releases from a dam) did not have seedlings or saplings. In other words, three of the four sites on Arroyo Mocho have seedlings and/or saplings, while the furthest downstream site (with the shortest duration of annual surface water and the greatest human disturbance) on Arroyo Mocho, and the single site on Arroyo del Valle (downstream of regulated releases from a dam) did not have seedlings or saplings.

It is possible, and perhaps probable, that the lack of observed seedlings and saplings across the five sites is a direct result of the overall drought pattern that has dominated the Bay Area for the

past 25 years. During this time period there have only been a handful of Water Years that had high season-long precipitation totals, or individual large flood events (e.g., 2006, 2011, 2017, 2023). Successful establishment requires both the appropriate abiotic conditions as well as the appropriate (wet) establishment conditions. Both conditions generally have not been present over the recent past.

As with the total number of sycamores, due to the differences in spatial area of each site and geomorphic zone, the density provides more comparable information. Figure 12 shows the density of trees in each size class for each of the four geomorphic zones. Size classes are designated by the trunk diameter at breast height (DBH), and grouped into seedlings (up to 2.5 cm, 1 in), saplings (5-10 cm, 2-4 in), medium (13-99 cm, 5-39 in) and large (100-254 cm, 40-100 in). The density of medium sized trees in the side channel in the Wentz Vineyards Upstream control site stands out, as density is approaching 50 trees/hectare. This high density is attributable to the fact that a number of trees were closely aligned along a relatively narrow side channel. It is likely that these trees were established at a time when the side channel was flooded. Determining actual tree ages could point to a flood or sequence of wet years that may have established suitable conditions for sycamore recruitment. The density of trees in the active channel and the inner floodplain of the Wentz Upstream site is the next highest, varying between 2 and 17 trees/hectare for all size classes. The most noticeable aspect is that the tree density for the other sites are all fairly consistent, typically less than 5 trees/hectare. This low density overall, and especially the low densities found in the active channel zone, supports the finding that regeneration and establishment of sycamores at these sites is low (Figure 13).

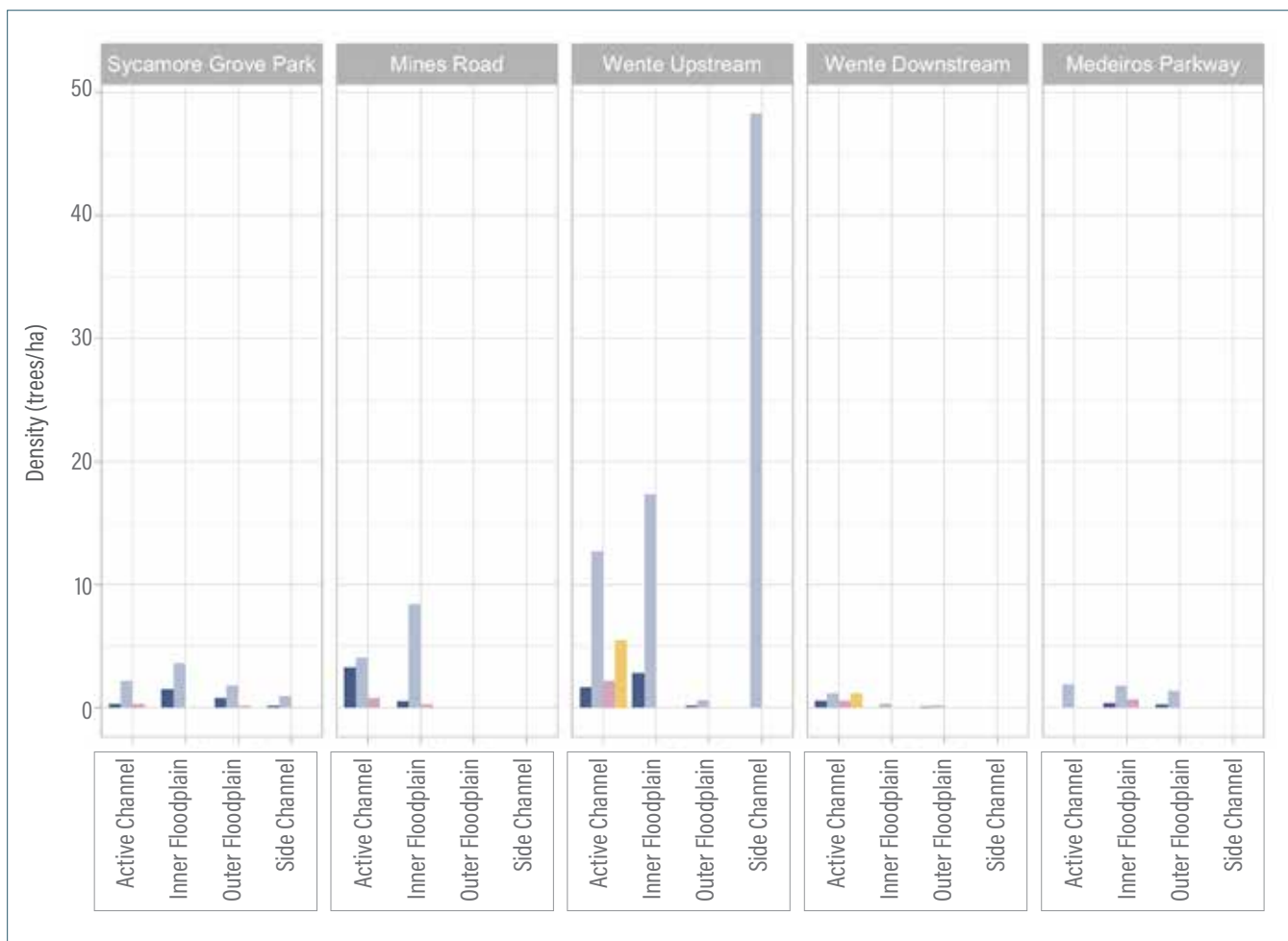


#### Size Class

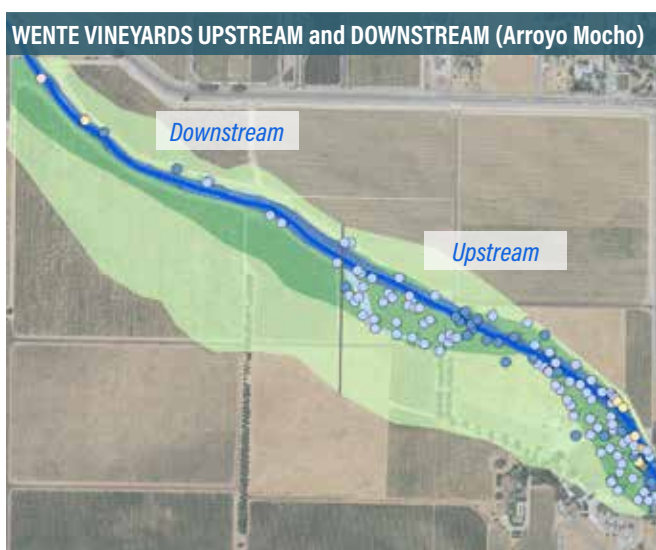
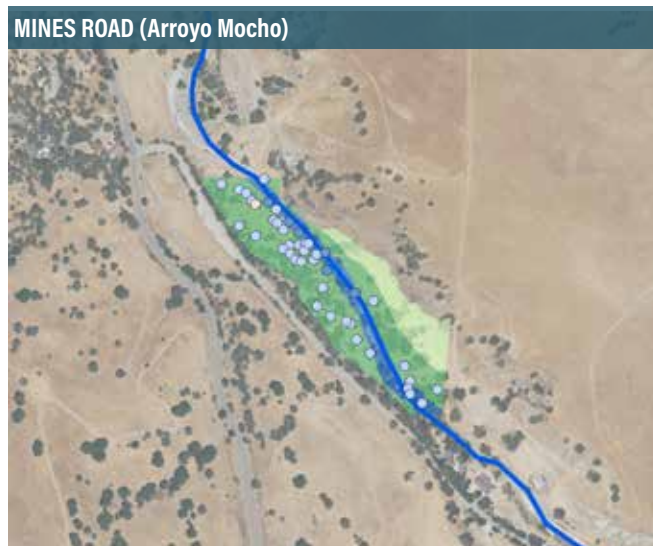


**Figure 11.** Top Left: a) Total number of sycamore trees by size class for the five sites combined. Top Right: b) Total number of sycamores by size class for each study site.

**Figure 12.** Below: Density of sycamore trees by size class and geomorphic zone for the five study sites.







## STUDY SITES

### Geomorphic Zone

<span style="display:inline-block; width:15px; height:15px; background-color:blue; border:1px solid black;"></span>	Active Channel
<span style="display:inline-block; width:15px; height:15px; background-color:green; border:1px solid black;"></span>	Inner Floodplain
<span style="display:inline-block; width:15px; height:15px; background-color:lightgreen; border:1px solid black;"></span>	Outer Floodplain
<span style="display:inline-block; width:15px; height:15px; background-color:lightblue; border:1px solid black;"></span>	Side Channel

### Size Class

<span style="display:inline-block; width:10px; height:10px; background-color:darkblue; border:1px solid black;"></span>	Large
<span style="display:inline-block; width:10px; height:10px; background-color:lightblue; border:1px solid black;"></span>	Medium
<span style="display:inline-block; width:10px; height:10px; background-color:orange; border:1px solid black;"></span>	Sapling
<span style="display:inline-block; width:10px; height:10px; background-color:yellow; border:1px solid black;"></span>	Seedling



0.3 mile  
0.5 km

## STUDY SITE LOCATIONS

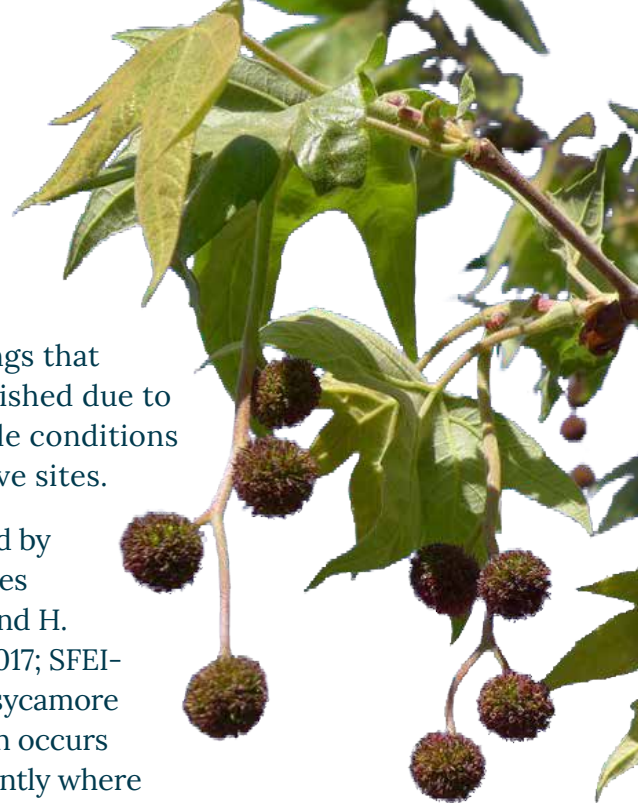


**Figure 13.** Maps of the five sites showing the geomorphic zones and size classes for each individual sycamore tree.

The relatively high density of medium sized sycamores across the different geomorphic zones indicates that this age class a) had appropriate conditions for regeneration and establishment a number of years ago (in a single year or in a series of years), and b) these trees have had appropriate conditions to survive/thrive during their lifetime. And conversely, the absence of seedlings and saplings at two of the five sites, and the relative low density of seedlings and saplings at the other three sites indicates that conditions have not been favorable for large-scale successful regeneration and establishment recently (approximately in the past 20 years). However, it is interesting to note that both Wenté Vineyard sites are the only sites that have both seedlings and saplings present, and the Mines Road site has a small number of saplings present. This possibly indicates that conditions are more favorable presently in the middle and upper reaches of Arroyo Mocho. It is possible that further detailed investigation of the channel could reveal that of all of the study sites, these sites currently have the most mobile and dynamic sediment scour, transport, and deposition processes, likely creating more favorable conditions for seedlings and saplings to establish. However, investigation of sites

after the flooding during the 2023 Water Year could also reveal new seedlings that were established due to the favorable conditions across all five sites.

As suggested by earlier studies (SFEI-ASC and H. T. Harvey, 2017; SFEI-ASC, 2018), sycamore regeneration occurs most frequently where surface water and shallow groundwater are readily available. Three sites support saplings, but only the Wenté Vineyards site supports seedlings, with most located at the upstream end of the Upper site (Figure 10). Most of the seedlings and saplings are located in, or along the edges of the active channel or side channels. The active channel and the inner floodplain area closest to the active channel appear to be the most hydrologically connected areas, providing the greatest amount of water to seedlings and saplings, supporting the seedlings and saplings observed.



## ***What is the health status of individual sycamores?***

A health condition was assigned for each of the 309 individual sycamore trees based upon field indicators. For all sites combined, 48.8% of the total number of sycamores are in good condition, 46.3% are in fair condition, 3.6% are in poor condition, and 1.3% are dead. Overall, the proportion of good condition to fair condition is roughly the same for each of the five sites, ranging from a low of 40% in good condition at the Wenté Vineyard Downstream site, to 65% in good condition at the Sycamore Grove Park site (Figure 14a). All of the sites,

except the Wenté Vineyard downstream site, have a small proportion of trees in the poor health class, ranging from 1% at the Wenté Vineyard Upstream site to 12% at the Medeiros Parkway site. Only Sycamore Grove Park has trees that are dead; the cause of death is unknown, but could possibly be related to the extended drought.

Health by size class shows that all of the seedlings and saplings are in good condition, and approximately half of the medium and large size classes are in fair or worse condition (Figure 14b).

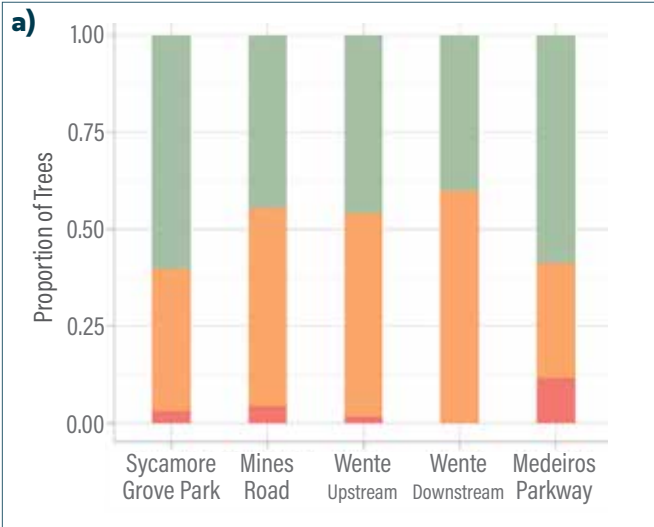


This suggests that while only a limited number of sycamores are able to successfully recruit, the current seedlings and saplings are in good condition. Additionally, the current conditions are causing stress to approximately half of the established trees, causing them to be in the fair or poor health class.

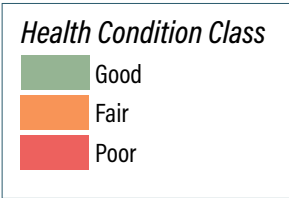
These same general proportions hold when looking at proportions of individual trees in each health class for each geomorphic zone (Figure 15). The active channel, inner floodplain, and side channel geomorphic zones have just less than 50% of sycamores in the good health class. However, the outer floodplain has 60% of sycamores in good condition, suggesting that conditions in this zone provide better support,

or, more likely, that these older, larger trees have a better capacity to withstand the current conditions. In addition, three of the four dead trees within the dataset are located in the active channel, and one on the inner floodplain at Sycamore Grove Park, although it is unclear what specific conditions at this site may have caused the observed mortality.

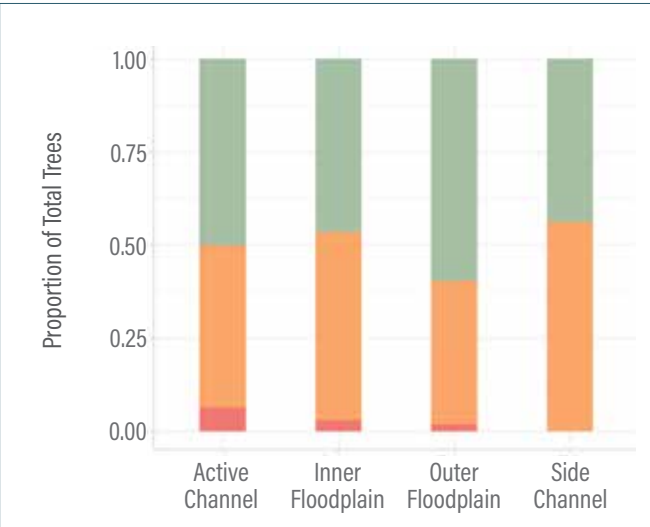
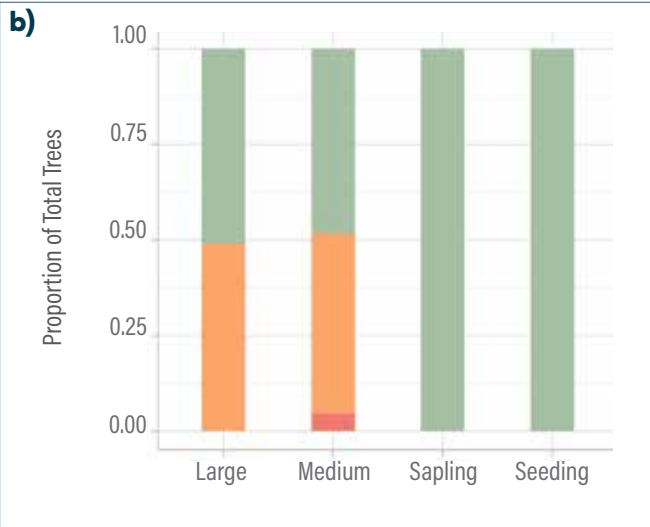
The patterns described above can also be observed in the map showing the distribution of trees in each health class and geomorphic zones, helping to visualize patterns between sites and between zones (Figure 16). Each site visually has a mix of good and fair condition trees, with only a small number of poor condition trees, as shown in Figures 14 and 15

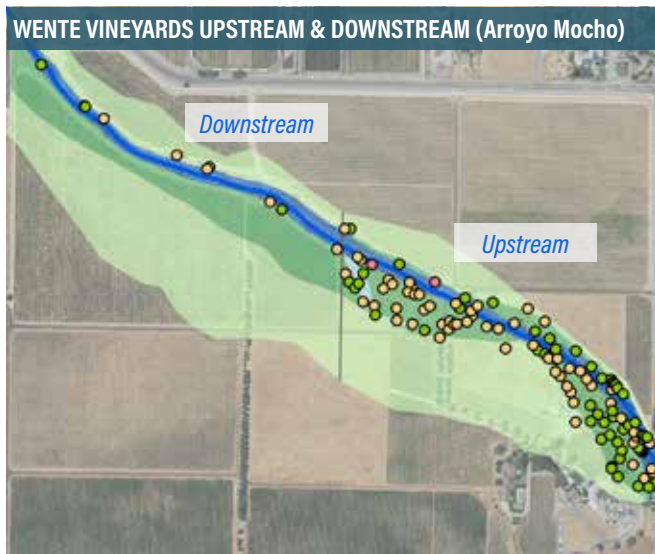
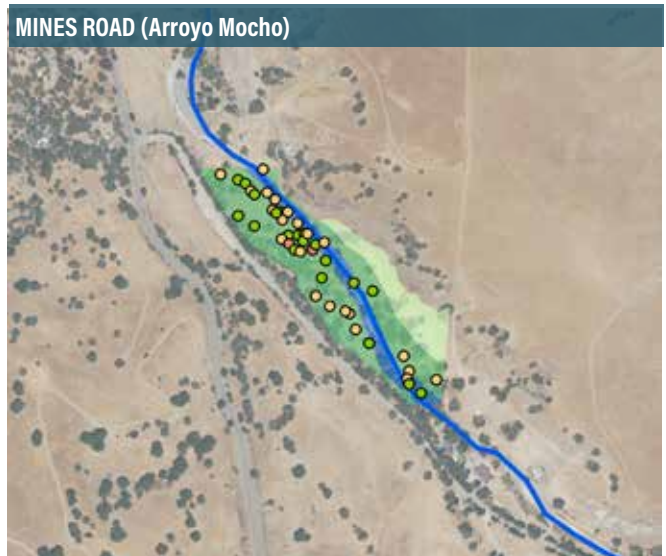
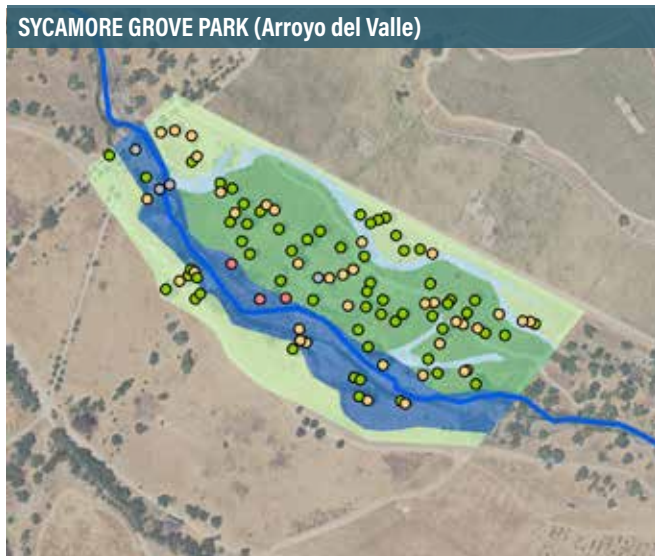


**Figure 14.** Top Left: a) Proportion of total trees in each health condition class for each site. Top Right: b) Percentage of sycamore trees by size class for each of the health condition categories, across all five sites combined.



**Figure 15.** Right: Proportion of sycamore trees in each health condition class for each geomorphic zone.





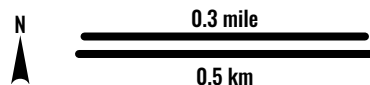
## STUDY SITES

### Geomorphic Zone

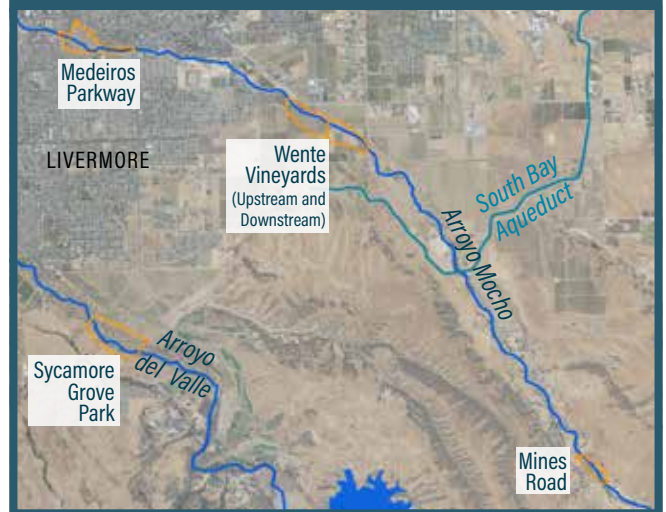
<span style="display:inline-block; width:15px; height:15px; background-color:blue; border:1px solid black;"></span>	Active Channel
<span style="display:inline-block; width:15px; height:15px; background-color:green; border:1px solid black;"></span>	Inner Floodplain
<span style="display:inline-block; width:15px; height:15px; background-color:lightgreen; border:1px solid black;"></span>	Outer Floodplain
<span style="display:inline-block; width:15px; height:15px; background-color:lightblue; border:1px solid black;"></span>	Side Channel

### Health Class

<span style="display:inline-block; width:10px; height:10px; background-color:yellow; border:1px solid black;"></span>	Good
<span style="display:inline-block; width:10px; height:10px; background-color:orange; border:1px solid black;"></span>	Fair
<span style="display:inline-block; width:10px; height:10px; background-color:red; border:1px solid black;"></span>	Poor



## STUDY SITE LOCATIONS



**Figure 16.** Maps of the five sites showing the geomorphic zones and health classes for each individual sycamore tree.





below. While the pattern may seem to be random upon first inspection, there are some subtle patterns that relate the health condition of the trees to the size class and to the geomorphic zone. With regard to size class, all of the seedlings and all of the saplings are in good condition, and are located within the active channel or on the edge of the inner floodplain.

Patterns for the distribution of fair and poor condition class trees in the medium and large size classes are not as clear. At Sycamore Grove Park, there are fair and poor condition trees in the active channel, but also a number of fair condition trees on the inner and outer floodplains. The other sites have fair condition trees scattered throughout the site and across geomorphic zones. However, the Upper Wente Vineyards site seems to have a high proportion of trees in the inner floodplain that are in fair condition. This could be related to the incision of the mainstem channel at this site, leaving the sycamores on the inner floodplain at an elevation that is too high above the groundwater table.

### ***Degradation within suitability sites***

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The descriptions of Arroyo Mocho and Arroyo del Valle illustrate that both channels have undergone a number of land use, hydrologic, and geomorphic changes as the Valley developed. These changes have altered the in-channel characteristics and processes, and thus has negatively affected SAW along the entire reach where it was historically supported. However some sites along this reach have been affected more significantly than others. This is evident in the differences between the control sites and the suitability sites described in the results above. For example, the two suitability sites have the fewest number of trees (10 and 34), the lowest overall density (0.64 and 1.87 trees/acre), low densities of sycamores within the inner and outer floodplain geomorphic zones, and no sycamores in side channels because side channels do not exist at these two sites. The data presented above illustrates the relative level of decline and provides the rationale for future actions to improve the extent and condition of SAW at the suitability sites.

# Sycamore regeneration at the study sites

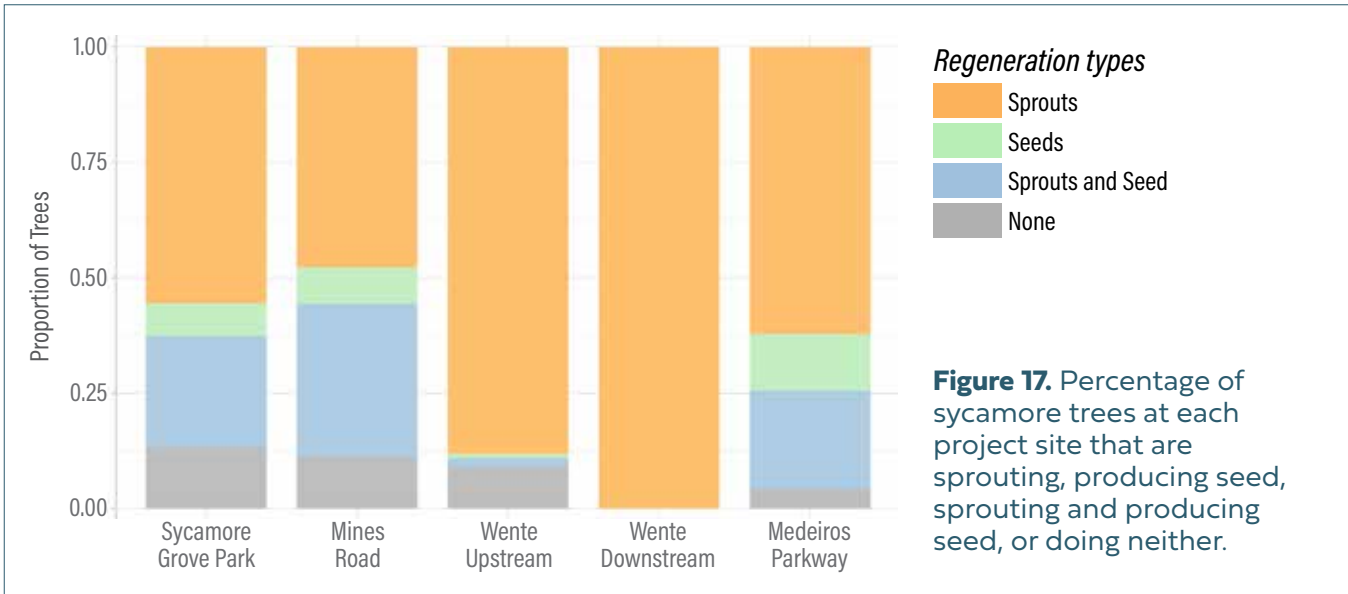
**Objective 2:** Identify possible linkages between sycamore regeneration and sycamore distribution, health, geomorphic position and hydrologic conditions at the study sites



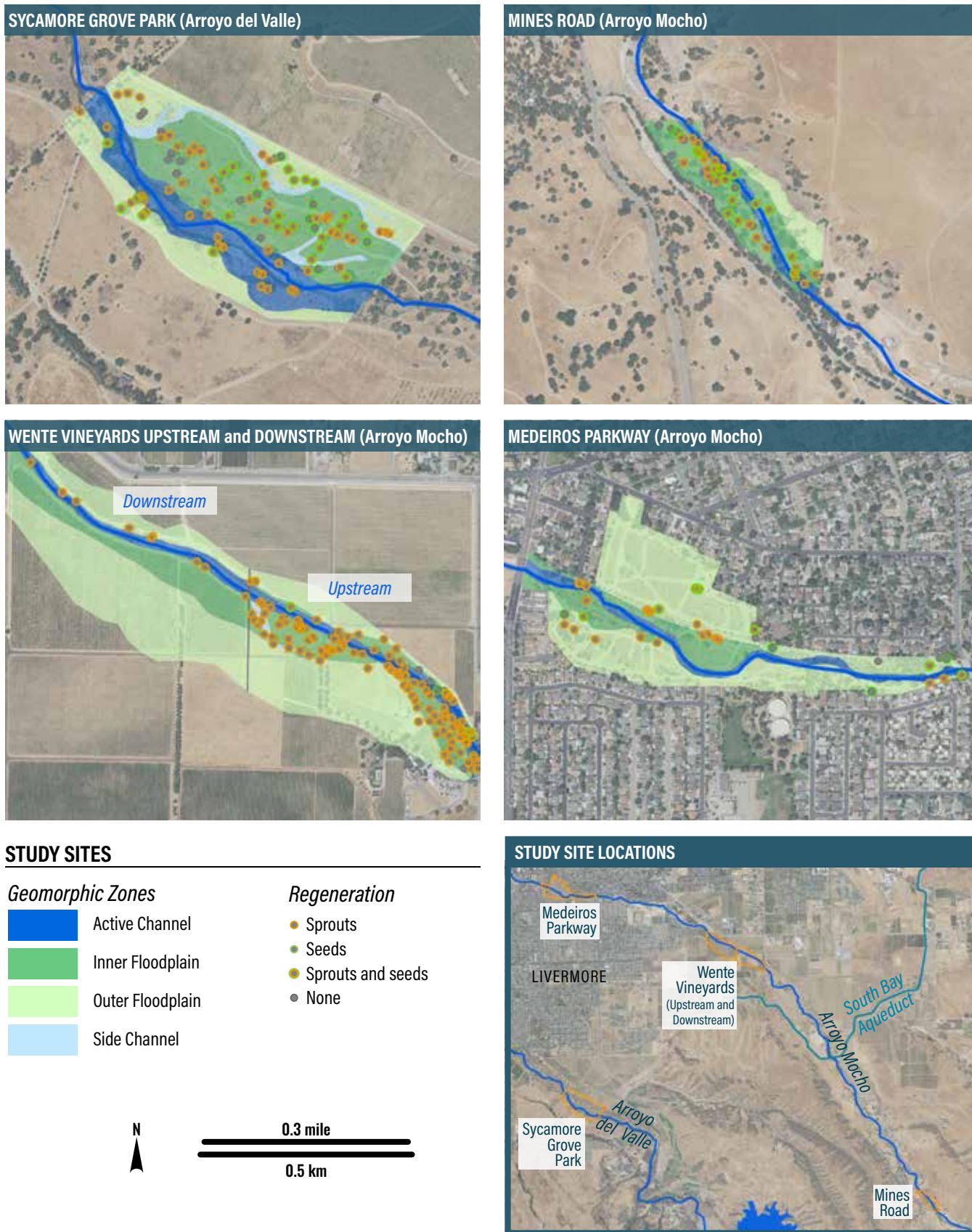
## How are individual sycamores regenerating?

For all 305 sycamore trees combined (excluding four that are dead), 254 trees (83% of the total) are basally sprouting (at the time of the survey), 61 trees (20% of the total) are producing seed, and 46 trees (15% of the total) are both sprouting and producing seed. However, 36 trees (12% of the total) are not sprouting or producing any seed (Figures 17 and 18). Regeneration details by site illustrates a more complex pattern regarding the production of seed. The patterns of basal sprouting, seed production and sprouting/producing seed at three of the study sites (Sycamore Grove Park- control, Mines Road- control, and Medeiros Parkway- suitability) are similar to the patterns observed for the full set of 305 sycamores described above. For these sites

45-65% of trees are basally sprouting, 10% are producing seed, and 25% are both sprouting and producing seed. However, the two Wentle Vineyards sites (Wentle Vineyard Upstream-control, and Wentle Vineyard Downstream-suitability) do not follow this same pattern. At the Wentle sites, the dominant pattern of regeneration is sprouting. In fact, 100% of the sycamores at the Wentle Vineyards Downstream site are observed to be sprouting, making it the only site of the five where seed is not being produced, but also making it the only site where every tree is trying to regenerate. It is not clear why very few sycamores at the Wentle Vineyards sites are producing seed. Most of these trees are located on the inner floodplain surface, which might not have as consistent







**Figure 18.** Maps of the five sites showing the number of trees that are currently sprouting and/or producing seed.

access to groundwater due to the incision of the stream. Alternatively, the tree health and age could be contributing to the lack of seed production; more than half are in fair or poor condition, and the majority of trees are in the medium size class.

While these data were collected in the fall, which could have slightly underestimated the amount of trees producing seed due to the timing of data collection (sycamores typically drop their seeds in winter), the data suggests

that at three sites only about 30–40% of the trees are producing seed, and at the Wente Vineyards sites only about 5% of the trees are producing seed. This limited seed production provides less opportunity for seeds to be transported downstream and be recruited although seed production can be variable by year. Sprouting will help the population of existing sycamores persist, but will not contribute to new or genetically distinct populations.

## ***How is regeneration linked to sycamore size, health and geomorphic position?***

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Size class, tree health, and geomorphic location may help predict which trees are reproducing and how those trees are reproducing. Where sycamores are producing seed, a larger proportion of the large size class is producing seed, as compared to the medium size class (Table 2). However, since the medium size class has a much larger total number of sycamores, the medium size class has a higher total number of trees that are currently producing seed. In contrast, a higher proportion of all sycamores are sprouting as compared to producing seed, including more than two-thirds of the medium and large size class sycamores, with proportions at each site nearly equal between the medium and large size classes.

Besides size, tree health is also likely impacting the production of seed. At the sites where seed is being produced, in general a larger percentage of trees that are in the good health class are producing seed, as compared to those in the fair or poor classes. This suggests that the health of a sycamore affects its ability to produce seed. Of note, in addition it is unknown how the stress from anthracnose infection might affect seed production. The only exception is at the Mines Road site, where 50% of the

sycamores in poor condition are currently producing seed. But the regeneration mode of sprouting illustrates the opposite relationship. As sycamores decrease in health, the proportion of trees that are sprouting increases. This suggests that trees that are in fair or poor condition may utilize sprouting as a mechanism of regeneration, when they are unable to produce seed. Returning back to the Mines Road site, 100% of the poor condition trees are found to be sprouting, suggesting that they are actually under some stress.

The relationship between geomorphic zones and regeneration appears to be more complex. Across the five sites, trees that were producing seed were observed in each geomorphic zone. There is no clear pattern evident, and is likely affected by the specific environmental characteristics of each site more so than by the geomorphic zone. However, the highest proportion of trees that are producing seed are located on the outer floodplain, either suggesting that this location successfully supports seed production, or that the large, old, and good condition trees in this location are successful in producing seed. Additionally, there is no clear pattern evident in the relationship between geomorphic zone and sprouting.



**Table 2.** Percentage of sycamores that are producing seed or sprouting by size class, by health class, and by geomorphic zone for each of the five study sites.

Site	Sycamore Grove Park		Mines Road		Wente Upstream		Wente Downstream		Medeiros Parkway	
	Producing Seed	Sprouting	Producing Seed	Sprouting	Producing Seed	Sprouting	Producing Seed	Sprouting	Producing Seed	Sprouting
By Size Class										
Large	46%	81%	50%	66%	0%	83%	0%	100%	40%	80%
Medium	29%	78%	35%	76%	3%	91%	0%	100%	33%	74%
Sapling	none	66%	none	50%	none	100%	none	100%	none	100%
Seedling	none	none	none	none	none	91%	none	100%	none	none
By Health Class										
Good	42%	77%	45%	65%	6%	85%	0%	100%	45%	60%
Fair	19%	83%	26%	78%	0%	97%	0%	100%	20%	100%
Poor	0%	100%	50%	100%	0%	100%	none	none	0%	100%
By Geomorphic Zone										
Active channel	0%	79%	30%	80%	8%	83%	0%	100%	25%	100%
Inner floodplain	33%	70%	37%	71%	0%	93%	0%	100%	25%	100%
Outer floodplain	50%	91%	none	none	0%	100%	none	none	35%	69%
Side channel	40%	90%	none	none	0%	100%	none	none	none	none



## ***How is regeneration affected by hydrologic conditions?***

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Floods drive processes – including seed dispersal, sediment deposition, and inundation of floodplain surfaces – that affect different life stages of sycamores and the regeneration of SAW. Large events reshape channel and floodplain geometry, and likely help set the stage for potentially substantial sycamore recruitment events, due to newly deposited sediment and large floodplain areas accessed by floodwater. In contrast, smaller flood events are likely important for maintaining growth for younger trees, with a smaller potential for new sycamore recruitment on more limited areas of newly deposited sediment. Under a relatively natural flow regime and channel geometry, side channels and lower portions of the inner floodplain inundate in higher frequency flood events (e.g., 2-yr recurrence interval), whereas the full extent of the floodplain would be activated only during large infrequent events (e.g., 25-yr recurrence interval). Flood processes have been altered primarily as a result of flow and sediment regime changes from dams and the disconnection of floodplains from streams and rivers (e.g., via levees or channel incision). The flood regimes experienced at the study sites are likely different today from when the majority of the sycamores were established. Flood regime characterization provides insights into the conditions to which SAW is adapted, and helps to identify what may be some of the more significant changes affecting SAW over the last two centuries of landscape and hydrologic modifications.

Both Arroyo del Valle and Arroyo Mocho hydrology exemplifies the flashy intermittent streams of California's mediterranean-type climate, with high inter- and intra-annual variability. Flood frequency analysis shows the smaller magnitude of winter peak flows that occur often, as compared to infrequent flood events that are much larger (Tables 3 and 4).

The annual maximum daily flow time series shows the interannual variability (Figure 19 and 20). For Arroyo del Valle hydrology, pre- and post-dam hydrology is shown. Del Valle Dam has substantially reduced peak flood flows, with most peaks captured by the dam and larger floods occurring during managed releases from the reservoir, which appear to be approximately the 10-yr return period flow, or ~55 m<sup>3</sup>/s (~2,000 cfs). However, peak flows up until the 2022 water year have not been above 67 m<sup>3</sup>/s (2,400 cfs) since the construction of the dam (based on the mean daily flow record). Only the recent New Year's Eve 2022 and subsequent storms prompted higher releases at 84 m<sup>3</sup>/s (~3,000 cfs) for a day. This means that historically intermediate floods (e.g., pre-dam 5-yr recurrence interval) have not been experienced by the stream and floodplain since the construction of the dam, illustrated conceptually in Figure 21a and b. Thus, flows that regularly inundated, eroded and deposited sediment at the Sycamore Grove Park site now only occur rarely. This difference is likely reflected in the absence of the braided channel planform and large areas of bare sediment that can be seen in the early (1939-1940) aerial photography in comparison to more recent imagery (Figure 22). This change may be a factor contributing to the general absence of young sycamores at this site.

Channel incision and other altered channel geometry also changes the flood regime experienced by SAW along these systems. While no dam is present on Arroyo Mocho, channel incision has occurred along much of the channel (though likely minimal at the Mines Road site). This means that floodplain activation occurs only with larger flood events (that is, peak flows that used to spill out of channel banks now remain within the deeper channel, see Figure 21a and c). The



**Table 3.** Flood frequency analysis for Arroyo del Valle pre- and post-dam, using the 1913-2019 water years, with the 1931-1958 missing years reconstructed via regression using the Alameda Creek at Niles gage (#11179000, USGS 2020a).

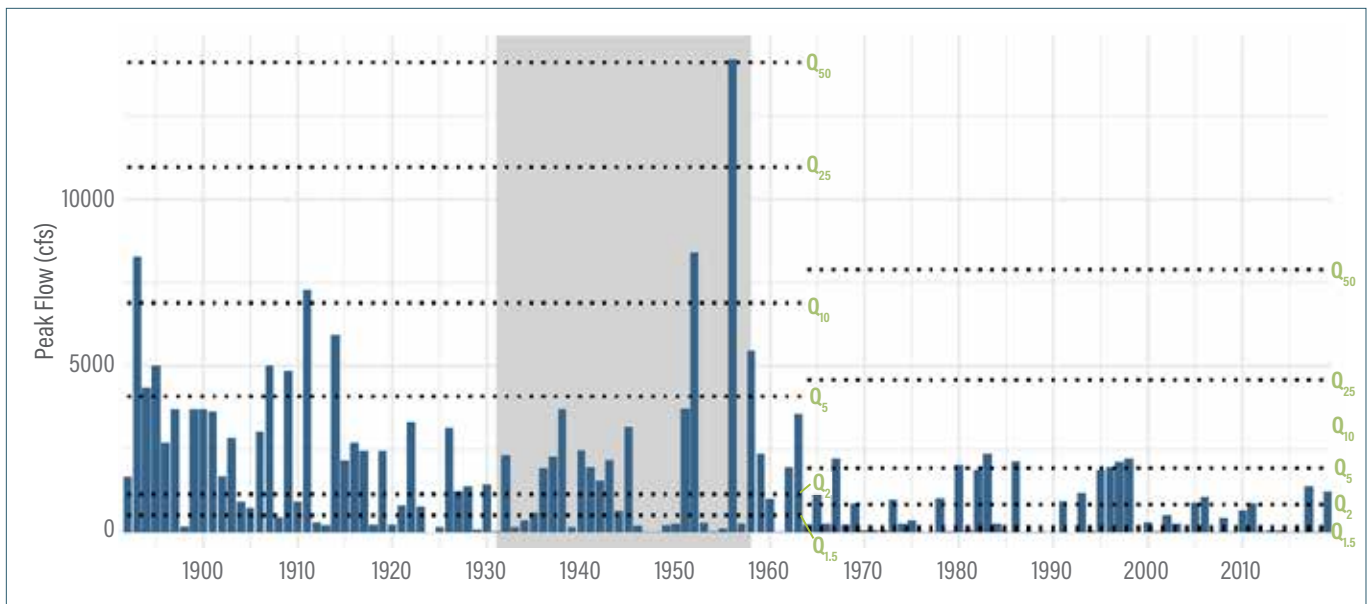
Return period (year)	Pre-dam estimated flow (m <sup>3</sup> /s, cfs)	Post-dam estimated flow (m <sup>3</sup> /s, cfs)
1.5	14.4 (510)	1.8 (65)
2	32.4 (1,144)	4.5 (159)
5	115.5 (4,079)	23.7 (838)
10	195.2 (6,894)	54.7 (1,930)
25	319.6 (10,969)	129.6 (4,575)
50	399.6 (14,112)	223.2 (7,881)
100	486.7 (17,188)	360.3 (12,725)

**Table 4.** Flood frequency analysis for Arroyo Mocho, using the mean daily flow time series for the 1913-2019 water years, with the 1931-1964 missing years reconstructed via regression using the Alameda Creek at Niles gage (#11179000, USGS 2020a).

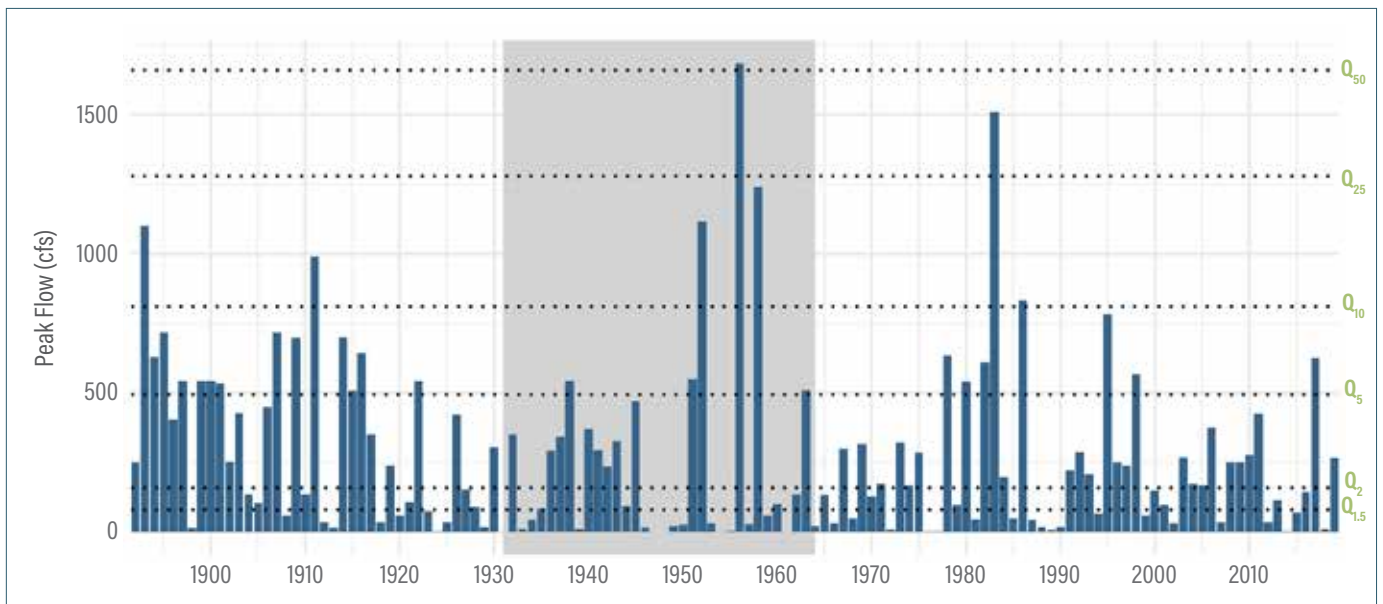
Return period (year)	Estimated flow (m <sup>3</sup> /s, cfs)
1.5	2.3 (80)
2	4.5 (159)
5	14.0 (494)
10	22.9 (810)
25	36.2 (1280)
50	47.0 (1660)
100	58.0 (2050)



Photograph by Elke Rank, Zone 7 Water Agency. Photo taken January 9, 2023, just below 23 m<sup>3</sup>/s (1000 cfs) of flow.



**Figure 19.** Arroyo del Valle annual maximum daily mean flow for the 1913-2019 water years with dashed horizontal lines representing return interval flows (#11176500, USGS 2020b), labeled in green. The gray shading represents years of reconstructed flows using the Alameda Creek at Niles gage (#11179000, USGS 2020a). The break at 1964 represents altered hydrology due to the construction of Del Valle Dam.

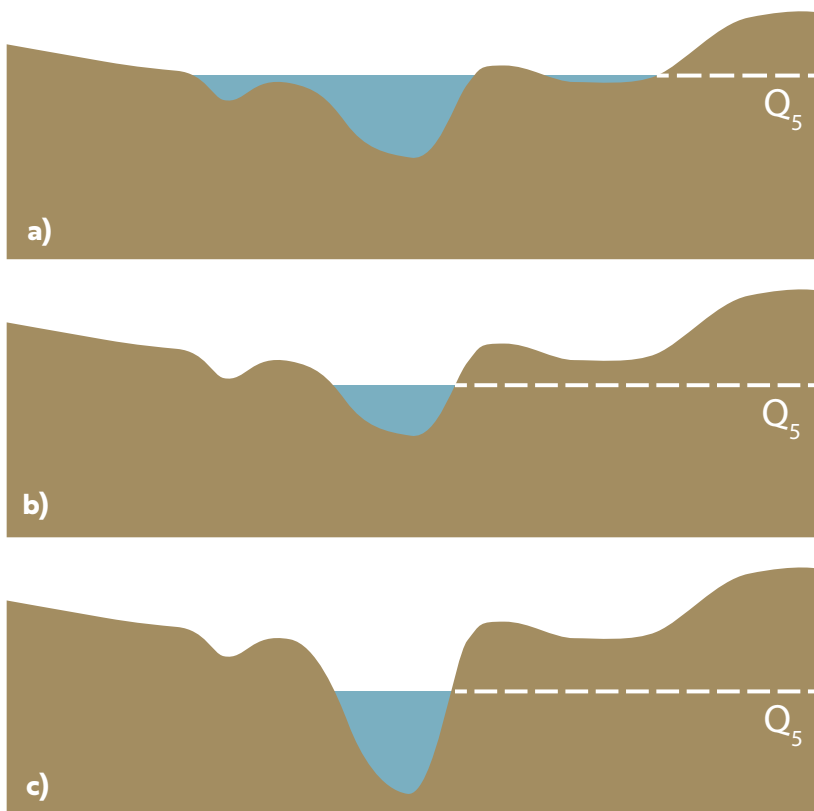


**Figure 20.** Arroyo Mocho annual maximum daily mean flow for the 1913-2019 water years with dashed lines representing horizontal lines representing return interval flows (AMNL, maintained by Zone 7), labeled in green. The gray shading represents years of reconstructed flows using the Alameda Creek at Niles gage (#11179000, USGS 2020a).



area for potential sycamore recruitment is thus diminished along the lower Arroyo Mocho reaches. For example, even the recent 2022-2023 floods, which may have been approximating a 20-yr flood recurrence interval flow, do not appear to have fully activated the inner floodplain along the reach near the Wente sites (based on preliminary examination of satellite imagery). It is unclear how much of the Mines Road site was activated, and whether its less-incised channel translated to greater disturbed area and areas for sycamore recruitment. Also, active channels in today's farmed and developed valley floors are less likely to be allowed to meander, which is apparent in the aerial comparison shown in Figure 23. While historically the active channels and side channels shifted in space over time,

providing new opportunities for sycamore establishment, these opportunities are rare today. It can be concluded that sycamores in the majority of the remnant SAW along Arroyo Mocho and Arroyo del Valle established during very different flood regimes than the SAW now experiences. However, questions remain as to whether they established during very large (and infrequent) flood events that inundated and re-worked the channel and floodplain, and/or whether they established during smaller flood events over time as the active main and side channels shifted in space across the floodplain. Re-establishing flood processes, dynamic and variable hydrology, and space for that hydrology to play out within the landscape are likely important elements for process-based regeneration support of SAW.



**Figure 21.** Conceptual illustrations depicting differences between typical “natural” conditions as shown in a), and an altered flood regime as a result of altered hydrology that reduces the magnitude and/or frequency of high flow events (e.g., via a dam) as shown in b), or altered channel geometry, such as channel incision, that limits the ability of high flows to access floodplain areas, as shown in c).



**Figure 22.** Aerial imagery comparison for the area that is now Sycamore Grove Park along Arroyo del Valle. In a), the 1939-1940 imagery shows a braided channel pattern with large areas of bare sediment (light signature), indicating regular disturbance by high flows. These signatures are largely absent in the post-dam imagery (2018, courtesy NAIP).



**Figure 23.** Aerial imagery comparison for the reach where the Wentz Vineyard sites are located along Arroyo Mocho. In a), the 1939-1940 imagery shows the wider active channel, evidence of meandering, and side channels in comparison to a narrower stream corridor in the contemporary imagery (2018, courtesy NAIP).





# DISCUSSION

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## Future actions at study sites

The detailed data collected in this study provides insight into the current characteristics of sycamores and SAW at five locations within the Livermore-Amador Valley, and illustrates the variability in the distribution and abundance of sycamores, size, health, and reproduction across the study sites. This data allows for comparison between the less impacted sites (control sites) and the more impacted sites (suitability sites), and determination of processes and characteristics that are still present and intact to support sycamores, as well as determining the likely cause(s) of decline that are observed at the suitability sites. Understanding these processes and causes is the first step towards knowing what future restoration actions are appropriate. The discussion below aims to provide additional site-specific details and considerations for future actions.

Despite the decline in extent and condition of SAW, both Arroyos have not lost their ability to support SAW, primarily due to the continued presence of intrinsic geomorphic and hydrologic processes in both watersheds. However, the level of modification of those processes, the level of current geomorphic functioning, and the external stressors and constraints are different between the two Arroyos, causing different challenges within each watershed. For instance, the Arroyo Mocho is still characterized by a largely natural hydrograph (Table 4, Figure 20), which allows the channel to maintain its dynamism, including delivery of coarse sediment from upstream and unimpeded high flows to scour and deposit sediment and provide flood flows to adjacent floodplains. But the upper and middle reaches of the Arroyo are impacted by channel incision that has occurred. The slight channel incision at the Mines Road site has somewhat confined

the channel within its adjacent floodplains, increasing the stream power within the channel, and reducing the frequency of inundation on the inner floodplain surface, negatively affecting sycamore recruitment. Further downstream at the Wente Vineyards sites, there is no evidence of historic realignment or straightening, but instead just narrowing and simplification of the channel corridor. However, the substantial incision that has occurred in this reach has increased localized stream power and reduced floodplain inundation more so than further upstream. Interestingly, the Wente Vineyards site is the only location where seedlings were observed, indicating that the active channel margin locations are still able to support sycamore recruitment. It is possible that the seedlings were able to establish in this reach due to the increased hydrologic support from State Water Project surface water inputs. In addition to negative impacts due to incision, the Wente Vineyards downstream site has also been impacted by historical sycamore removal for agricultural land use, with the only remaining trees located immediately along the channel margins. And finally, at Medeiros Parkway, the most downstream site, SAW extent is limited by previous agricultural and current urban development, and sycamore recruitment may be limited by water availability (both surface water and groundwater) as well as seed source availability.

Along Arroyo del Valle, the factors that are affecting SAW at Sycamore Grove Park are different compared to Arroyo Mocho. The presence of Del Valle dam and the management of flows due to the dam are the most substantial factors affecting sycamore regeneration and health in Sycamore Grove Park. The presence of the dam has cut off coarse sediment delivery



to the downstream channel, affecting its ability to maintain its historically braided pattern. In addition, any new deposits of coarse sediment must be sourced from the reworking of existing channel bars and floodplains, which provides much smaller volumes of coarse sediment compared to historical delivery from the upstream watershed. The management of high flows through the dam has significantly reduced the amount of disturbance and reworking that can occur in the channel (post-dam flows are 5-8 times smaller for the 1.5 to 5 year return period as compared to pre-dam flows; post-dam flows are 2-4 times smaller for the 10 to 50 year return period as compared to pre-dam flows), and these flows, are likely too infrequent to meaningfully support sycamore recruitment. In addition, the management of

low flows through the dam may also affect sycamores. Releasing water throughout the summer and fall months creates perennial flow in a once-intermittent channel, which is also keeping groundwater levels higher and at a more consistent elevation than historically. Of note, Sycamore Grove Park is the only site that has dead sycamores, with three located in the active channel and one on the inner floodplain at the channel margin.

Given the differences between Arroyo Mocho and Arroyo del Valle, and the observed variability in SAW between the five sites, any future actions that are implemented should be tailored to each site. In the section below, considerations for each site in the context of appropriate future actions are discussed.



## **Sycamore Grove Park (control site)**

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Located on Arroyo del Valle, Sycamore Grove Park is the largest of the five study sites, but only had 98 total sycamores, for the third highest density. Sycamores are present in each of the four geomorphic zones, but this site has the lowest densities per zone of the three control sites. The medium size class dominates the total number of sycamores present, followed by the large size class, and with a small number of saplings. Of note, Sycamore Grove Park has the largest number (24) of large size class sycamores of the five sites. All but one of the large sycamores are located on the inner or outer floodplain, and of the relatively small number of sycamores that are located in the active channel, most are in the medium size class. Most sycamores are in good or fair condition, although there are three in poor condition (all located in the active channel), and four that are dead. It is unclear why the three sycamores are in poor condition, but perhaps could be related to previous years of drought conditions. Alternatively, Kamman (2009) hypothesized that regular releases from the dam was causing the summertime groundwater table to remain elevated, potentially stressing the existing sycamores.

## **Mines Road (control site)**

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This site is the smallest of the five study sites, yet has the second highest density of sycamores at 8.97 trees/hectare across the entire site, despite only having moderate density of sycamores in each geomorphic zone as compared to other sites. All of its sycamores are located in the active channel and on the inner floodplain. The majority of sycamores are in the medium size class, with a handful of large trees and a couple of saplings. Most medium sycamores are located along the inner floodplain suggesting that they may have all established during previous floods that occurred during a similar timeframe. The large sycamores are

Approximately one-third of the sycamores are producing seed, but Sycamore Grove Park also has the highest proportion of sycamores that are neither sprouting or producing seed. The large size class sycamores, the good health class sycamores, and those located on the outer floodplain and in side channels are producing the most seed, with none of the sycamores located in the active channel producing seed.

Sycamore Grove Park is the only study site on Arroyo del Valle, which has vastly different controlling processes and characteristics as compared to Arroyo Mocho. The Del Valle dam has significantly altered the annual hydrograph (Figure 6b) and the delivery of coarse sediment to the study site. It is unlikely that actions to address channel geomorphic processes would provide meaningful results, with possibly the exception of implementing pulsed flows from the dam or the addition of fresh coarse sediment downstream of the dam. Instead, actions could focus upon the fair and poor condition sycamores that are primarily located in the active channel, and increasing the overall total number of new seedlings and saplings through intensive revegetation efforts.

primarily located in and along the active channel. Almost all of the sycamores are in good or fair condition, and overall about one-third of the sycamores are producing seed, even some of the sycamores that are in poor condition. Although unknown, perhaps the rate or intensity of anthracnose infection is less at this site, allowing for better condition sycamores.

Mines Road is the most intact site of the five because it is located furthest upstream on Arroyo Mocho and has been subject to fewer development pressures. The Arroyo here has fairly good sediment scour, transport and deposition processes, and likely has a high



capacity to support new sycamore recruits. However, the Arroyo here is slightly incised, meaning that it has lost some of its ability to maintain multiple channels, regularly inundate the floodplain, change course, and maintain a high elevation groundwater table. Because of the intact upstream watershed processes (delivery of coarse sediment and a natural hydrograph), this site could be considered for

actions that help it return to a more dynamic channel pattern (e.g., laying banks back, creating new inset floodplain surfaces, grading new pilot side channels, adding embedded large woody debris), encourage regular flooding onto the adjacent floodplain surfaces, improve the health of the fair condition sycamores, and increase the total number of new sycamores in and along the active channel.

### ***Wente Vineyards Upstream (control site)***

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Wente Vineyards upstream site has the highest total number of sycamores (118, or 39% of all sycamores in the study), and has the highest density (9.59 trees/hectare). In addition, this site has the highest density of sycamores in the active channel, inner floodplain and side channel geomorphic zones. This site along with the Wente Vineyards downstream site, are the only two that have all four classes of sycamore size, including seedlings and saplings. Medium sized sycamores dominate the site and are located in each geomorphic zone, but notably, the seedlings and saplings observed at this site are all located in the active channel where there is the greatest amount of surface and groundwater support. This site has a similar distribution of condition as compared to the Mines Road site, with almost all sycamores in good or fair condition. The majority of the fair condition sycamores are located on the inner floodplain, suggesting

that conditions, possibly including groundwater support, could be deteriorating. Interestingly, the majority of sycamores are only sprouting, with a very tiny percentage observed to be producing seed.

Like the Mines Road site, Wente Vineyards is supported by intact upstream watershed processes. However this site is significantly more incised than upstream, which limits channel complexity and ability for flood waters to inundate the floodplains. The adjacent land use is largely agricultural, meaning that there are opportunities to address incision and encourage increased channel complexity. And despite the sycamores on site producing little seed, the site benefits from sycamores upstream that are producing seed; the presence of seedlings and saplings suggest that the current environment in the active channel is able to support new sycamore establishment.

### ***Wente Vineyards Downstream (suitability site)***

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Wente Vineyards downstream has the lowest total number of sycamores (10) and the lowest total overall density (0.64 trees/hectare) of all five sites. Of the 10 sycamores, seven are located in and along the active channel, one on the inner floodplain, and two on the edge of the outer floodplain. Like Wente Vineyards upstream, this site has sycamores in all size classes, including seedlings and saplings located in the active channel. All of the sycamores are

in good or fair condition, however none are producing seed.

The incision described at the Wente Vineyards upstream site continues here, creating a relatively deep and simple channel morphology with lengths of tall vertical banks. All of the adjacent inner and outer floodplain areas are currently in agriculture, suggesting that historic sycamores that existed were removed to make

way for agricultural uses (see Figure 23). But because the land use is agricultural, there is opportunity to adjust the channel morphology and planform and increase the frequency of floodplain inundation. Also of note, this site does not have any side channels present, which also offers an opportunity for future creation of side channels during restoration efforts because side channels are important locations for recruitment. Also, the presence of seedlings and saplings suggests that current conditions can support establishment, and efforts to increase the total number of sycamores within the active channel via active planting would likely be successful.

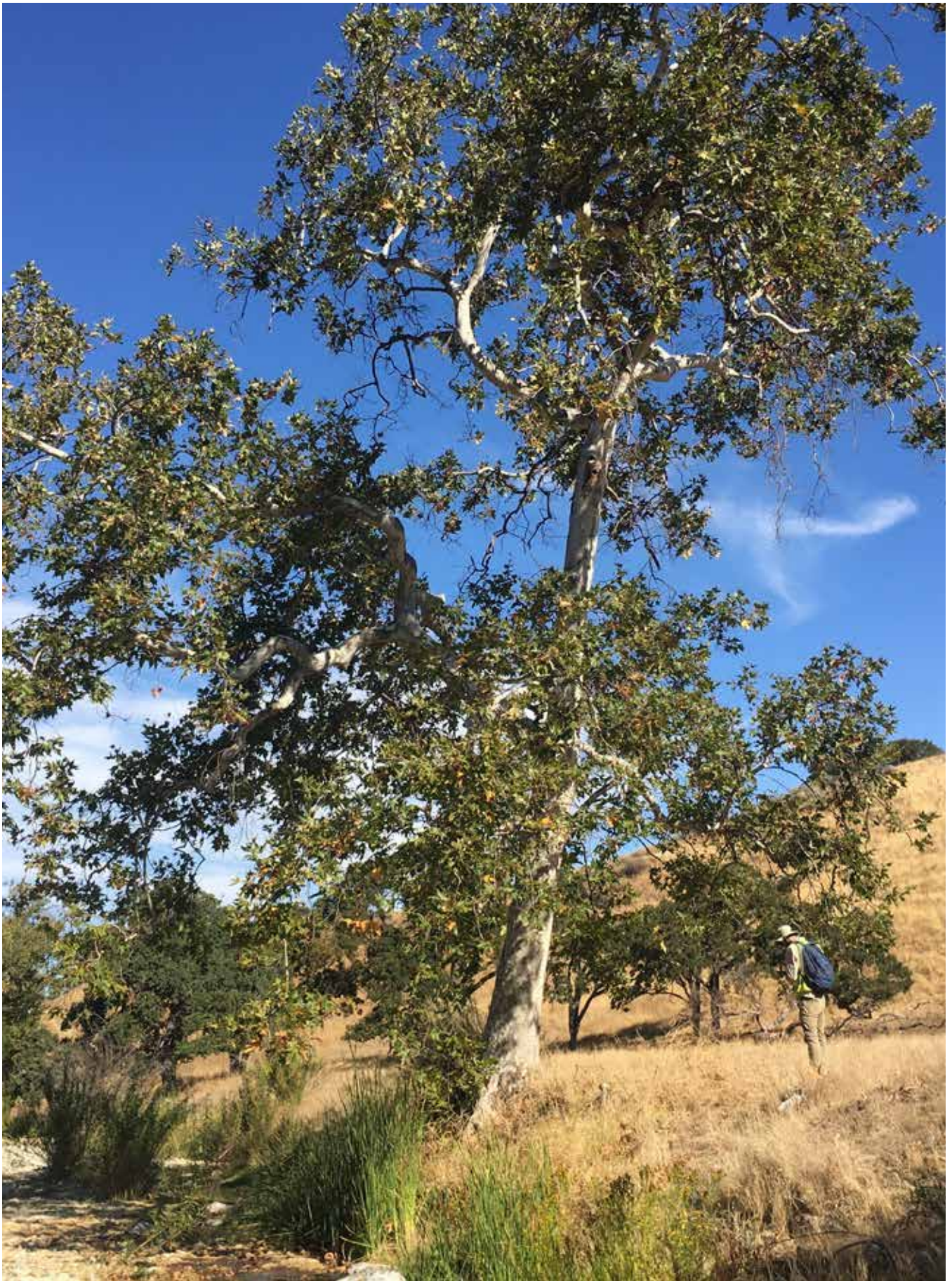
### **Medeiros Parkway (suitability site)**

Medeiros Parkway is the second largest site of the five, but has the second lowest number of sycamores (34) and the second overall lowest density (1.87 trees/hectare). Sycamores are present in the active channel, inner floodplain and outer floodplain, and consist primarily of medium sized trees, with a handful of large sycamores. Unlike other sites, only two individual sycamores are located within the active channel. While over half of the sycamores are in good condition, Medeiros Parkway has the highest percentage of sycamores in poor condition of the five sites. These consist of four medium-sized sycamores, all located on the inner or outer floodplain. Approximately one-third of the sycamores on site are producing seed, including all of the sycamores located in the active channel and on the inner floodplain.

This site is different from the other three sites on Arroyo Mocho because it is located further downstream along the longitudinal profile, in a zone of deposition very near the historic channel distributary. Despite the channel corridor running through open space parkland, dense suburban development borders the outer floodplain, and has likely reduced its extent. Medeiros Parkway is not incised like the Wente Vineyards sites, but instead has more frequent inundation of the floodplain and greater channel complexity (although likely reduced from historic conditions) including a number of









secondary and side channels. However, this site has a shorter duration of surface flow as compared to upstream sites, as surface flows infiltrate into the channel bed in the reaches upstream. It is possible that the reduced duration of surface flows has a negative impact upon the success of seedling establishment. This site could benefit from actions to create more significant and defined side channels, increase the total number of sycamores in

and along the active channel through planting (although irrigation would likely be necessary), as well as actions to improve the health of existing sycamores on the inner floodplain. Assessment of channel morphology and condition after the floods of the 2023 Water Year could provide important information on how the channel in this location responds to flood events.

## ***Other considerations for future actions***

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In addition to these site specific considerations, study-wide observations about regeneration should also be considered in terms of the natural regeneration that can be expected from the sites. For instance, the data illustrates that sycamores in the large size class have the highest proportion of trees that are producing seed. Sycamores in the good health class also have the highest proportion of seed production. This means that the older, large, good condition sycamores are responsible for producing the most seed. However, these old, large, good condition trees are primarily located on the outer floodplain; although seed can be wind transported, seeds that fall on the outer floodplain have a lower likelihood of being transported by flows to downstream locations because outer floodplains are naturally less likely than lower elevation geomorphic surfaces to have surface flows in any given year. In addition, less seed is being produced by trees that are located in geomorphic zones with better potential for downstream transport of seed. These two factors together may be reducing the chances of natural regeneration by seed.

The other mode of regeneration is sprouting; nearly all of the sycamores across all five sites, regardless of size class or geomorphic zone are observed to be sprouting. Interestingly, a greater proportion of sycamores in the fair

or poor health classes are observed to be sprouting, as compared to those in the good health class. This regeneration strategy does not increase the overall spatial coverage of sycamore trees, nor does it increase the genetic diversity within the population, but it may prolong the life of a sycamore tree so that it may be able to produce seed in other years.

The geomorphic zone data suggests that sycamores are the most numerous in locations that are frequently inundated, are dynamic with scour and deposition, and have the closest proximity to groundwater. Currently the largest number of sycamores are located in the active channel and inner floodplain. However, channel incision has reduced the frequency of floodplain inundation, and in combination with groundwater pumping, has likely lowered the elevation of local shallow groundwater tables. This is likely making conditions less suitable for new sycamore recruitment, especially on floodplains of incised reaches. The data show that there are overall very few seedlings and saplings across the study sites, indicating that conditions have not been favorable for large-scale successful regeneration and establishment recently. This suggests that restoration actions should be considered to help maintain and improve SAW at these sites and along the full SAW-supporting reaches of Arroyo Mocho and Arroyo del Valle.





# RESTORATION & ENHANCEMENT STRATEGIES

## Assessing Site Suitability

**Objective 3:** Develop a conceptual understanding of suitability at degraded sites and appropriateness of process-based and/or planting-based approaches



The growing body of California sycamore studies, including the current effort, has carefully characterized and described the hydrologic and abiotic factors affecting sycamore regeneration and resilience. Collectively, these studies show that a viable population of sycamores requires a suite of specific hydrogeomorphic characteristics and processes to ensure that sycamores are able to successfully regenerate and maintain healthy areas of SAW through time. Stream reaches that historically supported SAW clearly had these characteristics and processes present. However, as described above, many areas of SAW (inclusive of the study sites on Arroyo del Valle and Arroyo Mocho) have experienced decline due to a number of land use, hydrologic, and geomorphic changes through time. This decline is evident in the reduction of area of existing SAW, reduced overall health of sycamores that comprise areas of SAW, and the reduced success of sycamore regeneration. This observed decline has spurred the interest in restoring and enhancing areas of SAW so as to improve, grow, and make the remaining areas more resilient.

The concept of SAW restoration covers a wide continuum of actions, ranging from

reestablishing geomorphic process in rivers to allow for natural recruitment and regeneration of sycamores, to smaller enhancement actions, such as sowing sycamore seed or planting cuttings or saplings, or improving conditions for naturally recruited saplings. Regardless of where on the continuum the planned actions fall, the actions will have the greatest amount of success if undertaken in the appropriate location. In general, sites that historically supported SAW will likely have better outcomes and be more resilient into the future.

Selecting an appropriate site for restoration is crucial for success. But consideration of what actions are most appropriate and could be taken at any given site is likely more important in determining the success of a project. There are a number of questions that can help in appropriate site and action selection. For instance:

- Does the site currently, or did it historically support sycamores or SAW?
- Does the site have appropriate hydrology and sediment supply?
- Does the site experience a relatively natural flow regime, and does it have regular inundation by floods?



- Is the site supported by seasonally-variable shallow groundwater, that is typically less than 3 m (10 ft) below the ground surface?
- What is the current channel morphology, and is it complex and dynamic or is it static?
- Is the channel incised or incising?
- Is the site within a coarse-grained alluvial channel reach?
- What current limitations affect the site?
- What are the past and present land uses?
- What human activities will impact flows, groundwater elevation and/or floodplain inundation at the site?
- How will the site likely change in the future, given land use, development, and climate change?

Restoration actions can be broadly classified into two main types: process-based restoration and planting-based enhancement. Process-based restoration can occur in stream reaches where there is appropriate hydrology and sediment supply as well as space to restore stream processes. This type of restoration aims to create conditions under which sycamores can naturally recruit and regenerate, under current and future climatic regimes. In contrast, planting-based enhancement is reasonable along stream reaches where process-based restoration is infeasible, but where conditions are suitable for established trees. This type of enhancement utilizes planting and other relatively simple actions to enhance areas of SAW or provide managed regeneration support.

## Process-Based Restoration Actions

Process-based restoration focuses on restoring a complex and dynamic channel that is able to scour and deposit coarse sediment, regularly activate side channels, and include floodplains that are inundated by frequent overbank flooding. It also requires supportive groundwater. This type of restoration requires understanding of the channel morphology and processes, and the hydrology and sediment delivery of the watershed. While restoration actions can be challenging, and sometimes require actions be taken outside the boundaries of a given restoration site, the aim is to restore natural

processes so that the channel can function with minimal intervention. Such conditions are likely to provide the greatest support for long-term maintenance and resilience of SAW. Process-based enhancement strategies and actions are illustrated in Figure 24 and further discussed in the following text. Of note, this type of restoration can also include planting-based enhancement actions such as planting to increase sycamore density or planting to provide a future seed source for channel reaches with the appropriate characteristics for SAW, in addition to the more involved process-based actions.

### ***1: Provide a wide channel corridor***

The channel must have a wide enough corridor for geomorphic processes to occur, such as channel meandering and overbank flooding. Through time, as urbanization occurs, channels are often encroached upon by the construction

of roads and houses, or conversion of floodplain area to agriculture, in addition to the construction of levees or berms to confine channel meander and flooding. Currently, many channels that support SAW have a more

narrow corridor than they did historically. Actions to protect undeveloped land within the corridor, converting unused developed land back to channel corridor, or promoting low-intensity use that can be abandoned as the channel migrates will ensure that other

actions to restore geomorphic processes can be successful. In addition to providing space for geomorphic processes to occur, this action also provides habitat for a diverse riparian community within the corridor.

## ***2: Create a complex channel morphology***

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This action is about restoring and enhancing channel features and processes to support SAW. Stream channels that support SAW must be dynamic, generating a morphology that allows for sycamore recruitment and long-term support. Once established, sycamores will provide the feedback loop with the channel by providing roughness elements that will encourage scour and deposition of sediment during high flow events. Most channels supporting SAW likely will still retain aspects of historical channel morphology, despite anthropogenic modifications.

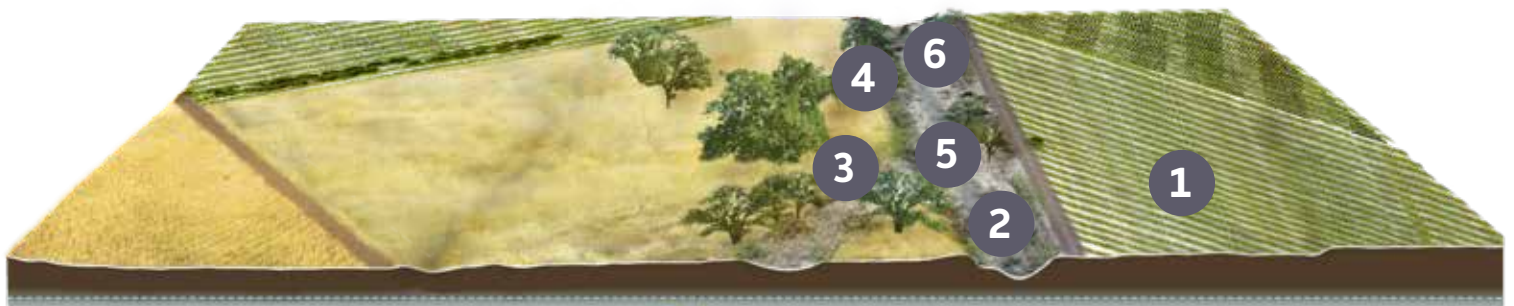
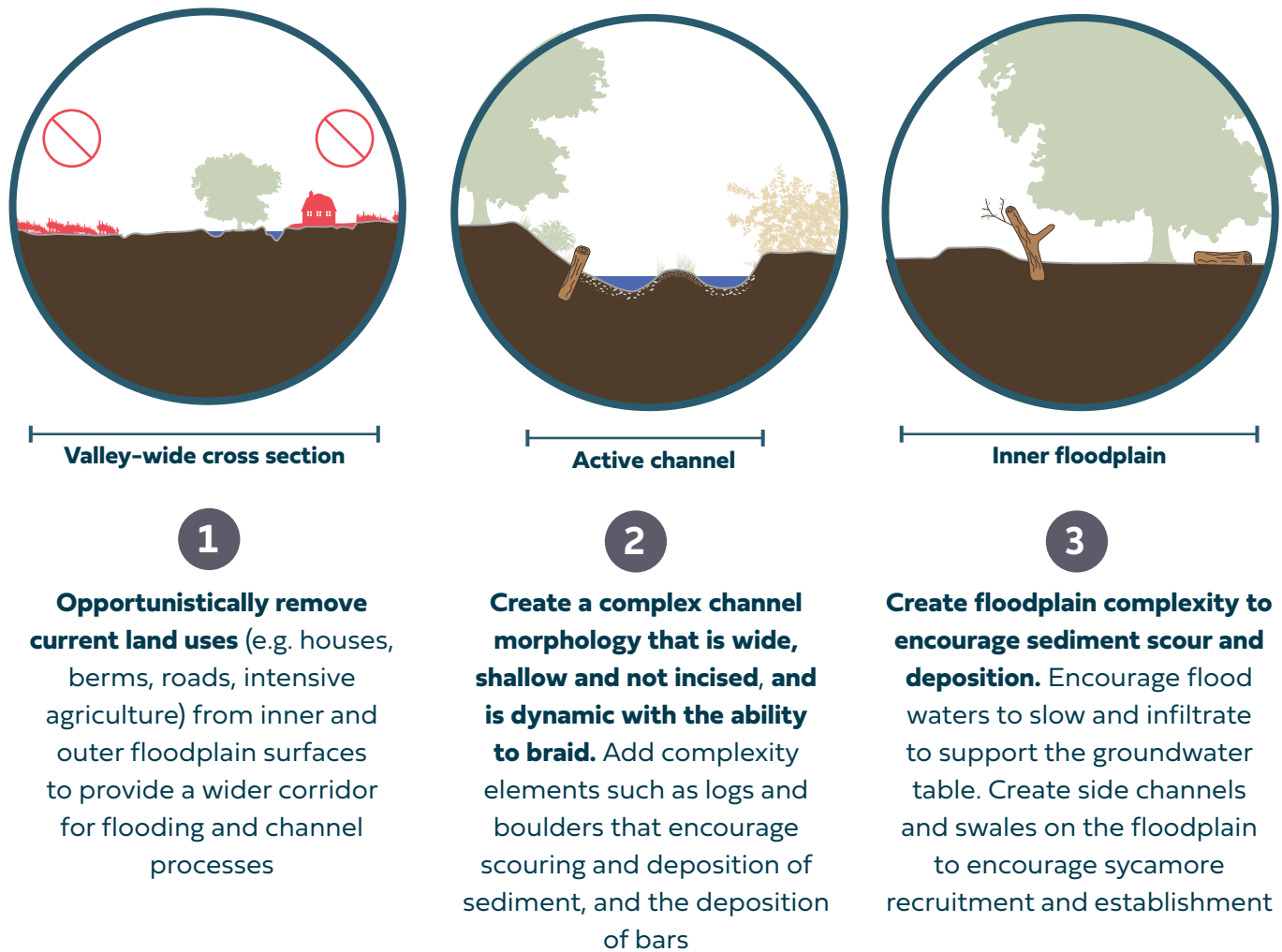
Ideally, channels should be created to be relatively wide and shallow, not incised, and contain a number of elements (e.g., large woody debris, boulders) to provide complexity. The channel should have the ability to meander and braid, depositing sediment to create low elevation and wide lateral, medial and point bars. Flows should be able to regularly access (e.g., every 2-3 years) the inner floodplain. Sediment should be encouraged to deposit both in the channel and on the floodplains. Side channels that carry flow from the channel, through the floodplain area, and then return the flow back to the main channel should be present to increase groundwater levels throughout the site, create additional areas for sycamore recruitment and establishment, and provide a pathway for surface water transport of sycamore seed to downstream locations. Channel processes and morphology will vary depending on channel slope or the position along the longitudinal profile, from higher gradient segments where the channel exits

the confined upland hills, to the low gradient segments that flow across the valley floor; created channel morphology should reflect the positioning within the broader stream reach.

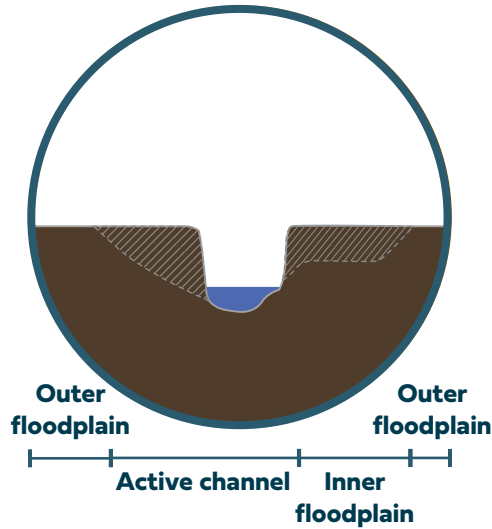
Actions should focus upon establishing a channel with this type of dynamic morphology and active geomorphic processes. For instance, side channels (with appropriate inlet and outlet elevations) could be reactivated or new channels created. Side channels provide areas for scour and deposition (essential for sycamore recruitment) within a smaller channel that typically has lower velocity flow, as compared to the main channel. Additionally, side channels also tend to retain surface water longer during the falling limb of the hydrograph, allowing for slow infiltration to support the groundwater table. This action might require lowering the elevation of existing side channels on floodplains within incised reaches. Complexity elements can be added into the channel to encourage scour and deposition. For example, Post Assisted Log Structures (PALS) or flow deflection jams installed on point bars can encourage continued channel migration and deposition on the inside bend of the meander. Boulders or log steps that are anchored and partially embedded into the bed and bank and installed perpendicular to flow can promote localized scour and channel complexity as well as slowing or halting channel incision. Sycamores that are downed (naturally) and sprouts can also provide roughness elements on the edges of channels and promote scour and deposition. Deposition of wide, low elevation



## Process-Based Restoration Actions



**Figure 24.** Example process-based restoration and enhancement actions.



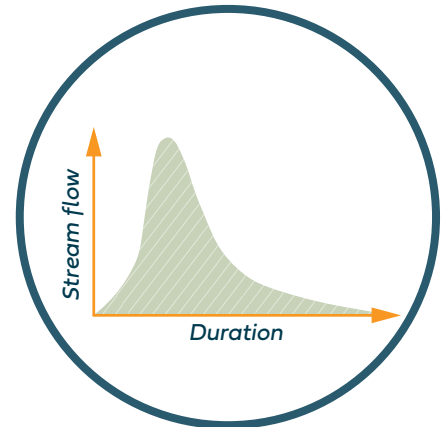
4

**Address channel incision** by setting back the channel banks to encourage lateral migration and sediment deposition. Lower floodplain elevations so they are activated more frequently. Consider if appropriate grade control features are necessary.



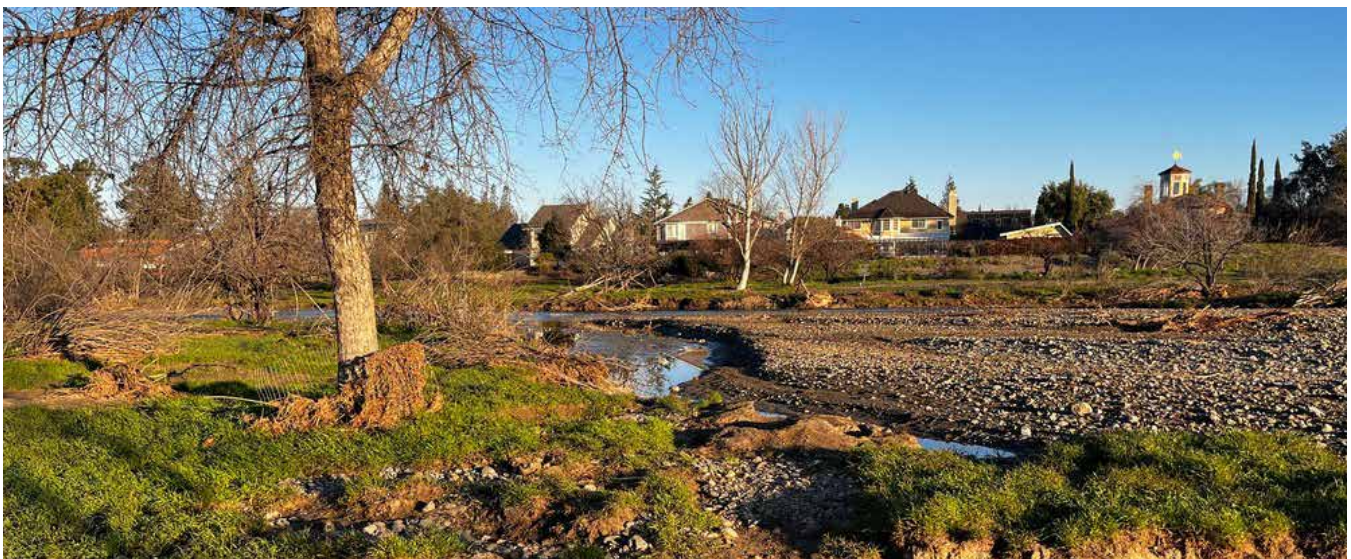
5

**Ensure the continued supply of coarse sediment** by working with upstream partners in the watershed



6

**Manage watershed flows to achieve a natural or naturalistic hydrograph**, with high flow events to scour and transport coarse sediment within the channel, and a dry season recession to lower the groundwater table



Photograph by H. T. Harvey.



bars should be encouraged, as these surfaces have a greater likelihood of supporting new sycamore seedlings and saplings due to appropriate surface and groundwater

conditions. Floodplains can have log steps or large wood complexes added, again to promote complexity, scour and deposition during higher flow events.

### **3: Create floodplain complexity**

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Alignment of appropriate conditions within the floodplain is an important component of SAW enhancement and recovery. As described above, floodplains that are frequently activated provide surfaces for high flows to spill across, slowing water velocity and depositing sediment. Surface water that remains on the floodplain during the falling stages of the hydrograph can provide longer-lasting pockets of surface water, and can slowly infiltrate, providing additional water for the roots of existing sycamores and raising the groundwater table. Floodplains that are topographically variable and otherwise complex can encourage scour and deposition and provide unique areas for sycamore establishment. Excavating long, linear depressions parallel to the channel on outer floodplains (this spatial arrangement is to prevent excess erosion during flood flows on the floodplain surface) and planting sycamores within the depression can help

those sycamores become established, as it reduces the depth to the local groundwater table. These depressions can be manually excavated, or can utilize future flows to deepen the depressions by simply creating pilot depressions with roughness elements that will encourage scour during future flows. In addition, side channels and swales on floodplain surfaces provide topographic complexity, hydrologic complexity, and variable moisture gradients increasing the chance that sycamore seeds will land in a location suitable for recruitment and establishment. For instance, trees surveyed in this study suggest that the large, mature, and good condition trees on the floodplain are currently producing the most seed. Because seed is primarily dispersed via flows, creating a network of swales on the floodplain surface could help transport seed closer to the main channel, where conditions for recruitment are more suitable, during large events.

### **4: Address channel incision**

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Channel incision, or lowering of the channel bed, is very common in anthropogenically modified systems across California. Incision of the channel causes flows to be confined within the channel banks, increasing flow velocity and sediment transport. With floods unable to regularly access adjacent floodplain surfaces, the floodplain becomes largely disconnected from the channel. Incision also typically depresses the groundwater table. While watershed-scale actions such as reducing peak streamflow through slowing, spreading, and sinking surface runoff can significantly reduce stream power (and thus incision), localized in-channel actions that address incision are typically large scale

and expensive, yet are necessary to allow for the return of appropriate geomorphic processes. In incised reaches, the elevation difference between the channel bed and floodplain surfaces must be reduced. This can be accomplished by either raising the channel bed elevation or lowering the floodplain elevation. Bed elevations can be raised by installing structures that cause deposition of sediment across the bed, but this strategy takes careful planning and study to ensure that the channel slope ties into upstream and downstream reaches, and will remain stable into the future. Alternatively, the elevation of adjacent floodplain surfaces can be lowered so as to be closer in elevation to the channel bed. In addition, this can

include excavating a wider channel and setting back banks to encourage channel braiding. Ideally, the created floodplain surface would be wide and regularly activated, however even more narrow and/or discontinuous floodplain surfaces along the channel length can still be effective at providing velocity refuge during floods, and locations for sediment deposition and recruitment of sycamores. With enough space, floodplain surfaces could be created at multiple elevations so that they are activated during different recurrence interval floods.

## **5: *Ensure continued sediment supply***

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The watershed upstream from a SAW-supporting stream reach provides both runoff and sediment, typically as pulses during high flow events. A consistent supply of coarse sediment is necessary for these reaches to continue to support SAW. Coarse sediment is needed for the deposition of bars and splays of sediment across floodplain surfaces. Regular supply of coarse sediment also reduces the likelihood of bed incision, which is important for seedlings that are just getting established on channel margins because coarse sediment deposition prevents or limits the scour and removal of those seedlings. Actions in the upstream watershed, such as the installation of dams, sediment basins, or the regular maintenance removal of sediment from the channel bed, reduce the amount of sediment that is available to maintain the geomorphic processes necessary for the support of SAW. Ensuring adequate sediment supply to SAW-supporting stream reaches likely requires working with upstream partners.

As an example from the Arroyo Mocho system, excess sediment currently deposits in the stream channel near the downstream portion of the reach that supports SAW, and at specific bridge crossings (e.g., at the Holmes Street bridge). This requires continued management and costly removal of this coarse sediment to





maintain conveyance capacity for flood control. Geomorphic-based restoration actions such as addressing channel incision and encouraging a broad, dynamic, and depositional channel in the upstream reaches will likely reduce the amount of sediment that must be removed from these

downstream locations annually. Alternatively, the removed sediment could be considered for reuse to support SAW in other channels where the coarse sediment delivery has been cut-off or modified.

## 6: Manage the hydrograph

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Hydrology is a primary driver of SAW. Natural flow regimes are marked by variable high flow events during the wet season that drive geomorphic processes and channel dynamics (e.g., transporting and depositing coarse sediment) and low or no flow during the summer and fall months. Many systems, including both Arroyo Mocho and Arroyo del Valle, now have modified hydrographs that are likely affecting the success of SAW. This action focuses upon addressing artificial flow augmentation, flow diversions, and/or retention/detention of flow that may be affecting hydrograph characteristics, including timing, magnitude, duration, rate of change, and frequency. Efforts to support a variety of flood types (large resetting events to maintain a dynamic channel-floodplain corridor and intermediate floods to sustain water availability) and a dry season recession that reflects natural patterns are expected to help support SAW.

If adjustments to flow management is an option, consider actions that mimic the historical hydrograph. For example, if peak flows have been attenuated due to an upstream dam, but that dam has the ability to control releases, consider releasing pulsed flows so as to encourage a dynamic stream morphology, including areas of scour and deposition within the channel and floodplain. Groundwater monitoring wells and piezometers are useful tools both for understanding current conditions and assessing the effectiveness of water management changes. If wells or piezometers are not present on site, they could be installed to understand groundwater depths and the

timing of groundwater elevation changes in relation to the management actions.

The Del Valle dam on Arroyo del Valle has significantly modified the hydrograph from pre-dam patterns (Kamman, 2009). Wet season high flow events are regulated by the dam, removing the frequent, geomorphically effective peaks from the hydrograph in the downstream reaches. However, the largest floods, such as those in 2017, are not fully retained by the dam, and typically cause substantial channel disturbance due to the magnitude of flow and stream power. In addition to high flows, the dam also regulates dry season flows downstream of the dam by consistently releasing low flows. The downstream reach is now perennial and keeps summertime groundwater elevations artificially high. While this additional groundwater is not consistent with historical patterns, these summertime releases have occurred for so long that the sycamores in Sycamore Grove Park now appear to be pre-conditioned and reliant upon these summertime flows (Kamman, 2009). Changes in water releases (including cessation of releases during drought) that rapidly affect the depth to groundwater (more so than under natural conditions) can cause water-related stress to sycamores, and can cause mortality (Kamman, 2009). The complex relationship between release amounts and timing and groundwater depth should be carefully considered with any management of the hydrograph.

In contrast to Arroyo del Valle, the Arroyo Mocho maintains many aspects of a natural hydrograph, in particular, unregulated wet-

season flood peaks that provide sediment transport and channel disturbance. Although limited by the channel incision that has occurred in valley floor reaches, the largest flood events (e.g., likely floods with recurrence intervals of 50 years or more) are still able to inundate adjacent floodplain surfaces, replenish coarse sediment, and provide a pulse of surface water to slowly infiltrate into the floodplain sediments. Seasonal recession of flows could support the growth of seedlings and encourage growth of healthy root systems. Actions to maintain these natural discharge peaks and seasonal hydrograph recessions will ensure that a primary driver of SAW success remains present.

Despite the unregulated wet season flood peaks, Arroyo Mocho has augmented dry-season flow from the South Bay Aqueduct that is maintaining non-natural surface water flow levels and is likely keeping shallow groundwater at a higher elevation and for a longer time period than it would be naturally. The higher groundwater elevations could provide additional support for other riparian species, such as willow or cottonwood, to

establish and persist as well as compete with California sycamores. These flows are supplied to Arroyo Mocho for groundwater recharge and storage, and are a key component of the local water supply. Flows are diverted into Arroyo Mocho only when the water is available from the State, and is carefully set at a specific flow that optimizes recharge with minimal loss. While it's not likely that these contributions will ever be modified or cease because they provide vital groundwater recharge to the Livermore-Amador Valley, it is intriguing to consider if the timing/volume of flows could be managed differently, so as to more closely mimic the natural hydrograph, without diminishing the groundwater recharge. For example, could flow contributions be largest in the early spring, and slowly diminish throughout the summer and fall, to mimic the natural seasonal recession of flows? On the flip side, augmented dry season flows also help mitigate against sycamore mortality during periods of drought. Actions that aim to better understand and/or monitor the shallow groundwater downstream of the South Bay Aqueduct will help to manage the dry season hydrograph in support of SAW.





# Planting-Based Enhancement Actions

Planting-based restoration focuses upon restoring sycamores in locations where they can thrive, even if alterations to the channel system and natural geomorphic processes make natural recruitment and regeneration improbable. In fact, planting-based enhancement is also equally appropriate at process-based restoration sites because active planting can increase the total area of this unique habitat type. This type of restoration requires understanding of the project site, and local limitations upon stream morphology, hydrology and sediment transport. These restoration actions tend to be less expensive,

but can require longer-term monitoring and maintenance. The following text describes enhancement strategies and actions to be considered for planting-based restoration projects (Figure 25).

Planting-based enhancement can increase the number and density of sycamores even if natural recruitment and regeneration are not occurring or are improbable. These examples illustrate specific enhancement actions that can be taken in areas where natural geomorphic processes are unable to support long-term resilience of Sycamore Alluvial Woodland.

## 1. *Select an appropriate site*

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A fundamental aspect of undertaking planting-based enhancement is site selection. Once established, trees planted in appropriate locations can thrive, whereas trees in inappropriate locations may struggle to survive and require frequent maintenance. Ideally, the site will be within a reach that historically supported SAW because these sites are likely to possess more of the geomorphic features and processes necessary to support SAW. Other sites may be able to support sycamores, but they may require additional/continual support and maintenance of the plantings.

The key component of site selection is an understanding of the surface water and groundwater hydrology at the site. Successful areas of SAW in the long-term need a relatively high groundwater table as well as a seasonal drawdown. Sites that currently support a healthy stand of willows, cottonwoods, or other riparian species might not be hydrologically appropriate or adequate for long-term support of sycamores given the consistent surface water flows or high/consistent groundwater table. In addition, the other riparian tree species will likely provide competition for resources

with California sycamores that are trying to establish.

If groundwater monitoring wells are not present on site, consider installing one or more wells to understand groundwater depths and seasonal variability. This information can help inform the amount and length of time that irrigation is needed.

Utilize any existing hydrodynamic modeling that may exist for the stream to better understand how often specific geomorphic surfaces are inundated during flood. This information will help during development of the planting plan. For example, on the Sacramento River system, sycamores are often naturally found on surfaces that are inundated every 3-5 years, as water is more accessible to seedlings/saplings on these lower surfaces (TNC, 1998).

In addition to hydrology, the substrate and soils are also important components. Investigation into the soil type, composition, and moisture-holding capacity should be completed, as sycamores typically have best success in sandy soils (e.g., sandy loams). Consideration of the

likelihood of excess sediment deposition, channel incision, or local scour should also

drive site selection, as these will likely have negative impacts upon newly planted trees.

## 2. Develop a planting plan

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After gaining an understanding of hydrologic and geomorphic processes present on site, the overall ecology of the site should be considered to maximize the potential benefit gained by conducting a restoration as well as maximize the success of the planted sycamores. Developing a planting plan will help translate the larger ecological thinking into specific on-the-ground implementation. The plan should incorporate multiple different strategies, such as:

- Planting in a variety of locations so as to increase the chances of success: along channel margins, at the top of channel banks, on mounds and bars within the channel, on the inner floodplain near the channel, and in side channels.
- Plant seedlings in clusters. Utilize existing sycamore locations and spacing to inform planting patterns and spacing. Use plantings as a way to increase the connectivity between existing stands of sycamores.
- Bury recently and naturally fallen branches to encourage sprouting from the branch, mimicking the process of natural disturbance. Include these locations within the irrigation plan.
- Consider planting in floodplain areas where sycamores have been historically lost due to direct removal. Although these plantings will require irrigation, once established they will have a lower likelihood of being scoured or disturbed by flood events.
- Consider complexity and roughness elements in the selection of planting locations. Locations that are downstream of a large boulder or log in the channel or on the floodplain are more protected and will have a lower likelihood of being scoured during flood. In-channel sediment mounds may cause continued localized deposition, which are potentially suitable locations.

## 3. Prepare planting locations

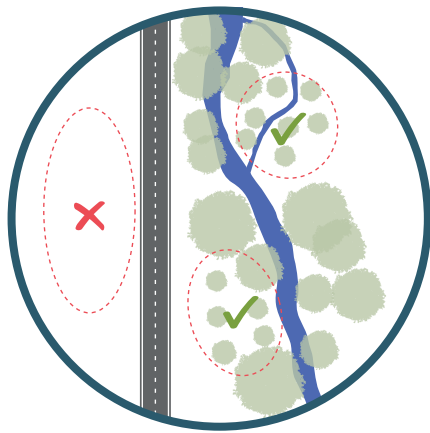
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Planting locations should be prepared in advance, to help ensure plantings become established. This preparation can take many different forms. For example, some sites may require very localized soil augmentation or treatments to adjust the grain size or texture and moisture-holding capacity of the soils. Other sites may require removal of non-native herbaceous or non-native woody vegetation that may shade out new plantings or compete for available water. But removal of existing non-native vegetation should be done carefully, in consideration of the existing habitat that it currently is providing. Choose planting locations that does not disturb existing native vegetation.

Recent practitioner observations suggest that adding mulefat to in-channel bars can help increase restoration success because the mulefat may act as a nursery for plantings, by providing a velocity refuge, stabilizing sediment and limiting scour, and helping to trap sediment. In systems that do not have areas of recent coarse sediment deposition (e.g., downstream of dams), but where coarse sediment is available, pockets of freshly deposited sediment could be placed along channel margins, on the edges of bars, or downstream of roughness elements, and sown with sycamore seed (see additional notes in section 4 below), so as to replicate the natural deposition processes.



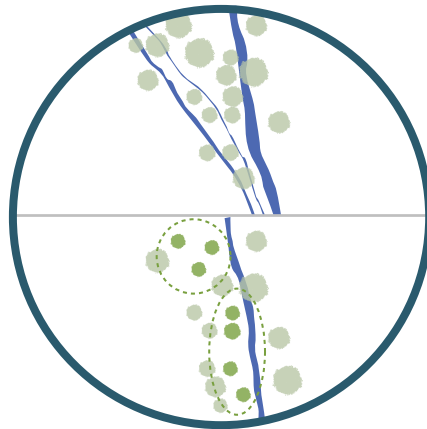
# Planting-Based Restoration Actions



Selected restoration sites

1

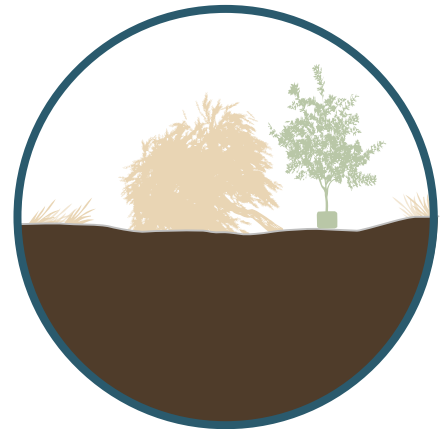
**Carefully select appropriate sites based upon existing conditions that will support SAW**, such as surface and groundwater hydrology



Selected restoration sites

2

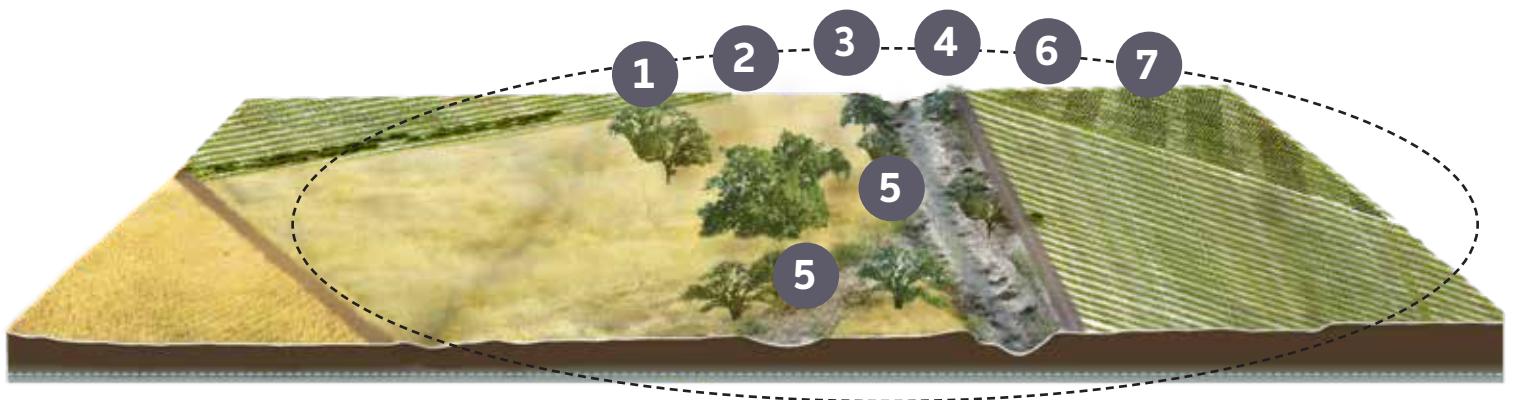
**A planting plan should be developed to identify appropriate locations for plantings** and clearly spell out planting protocols, maintenance, and monitoring actions



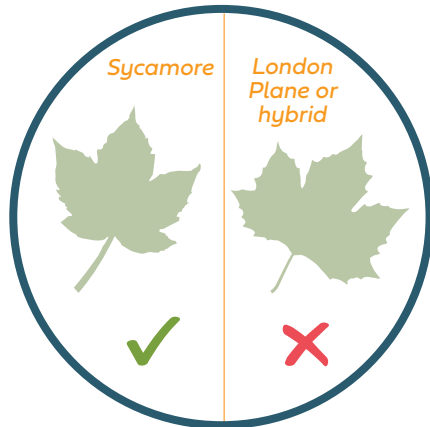
Selected restoration sites

3

**Planting locations should be prepared in advance.** Some sites may require removal of non-native herbaceous or woody vegetation that may shade out new plantings or use too much local groundwater

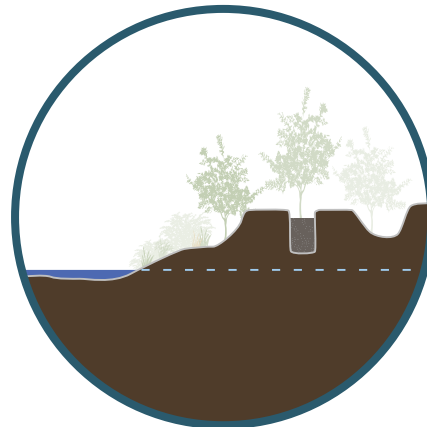


**Figure 25.** Example planting-based enhancement actions.



4

**Use local and pure seed or cuttings to prevent planting hybrid planting stock**



5

**Sycamore planting should be located where they can access surface water or groundwater, such as at the edges of active channels, within side channels, or on low-elevation floodplains**



6

**Most plantings will require irrigation for the first 3 to 5 years, until the root system has developed enough to reach deeper groundwater during the late summer/fall months**



7

**Areas with successful seedlings and saplings should be protected from grazing and browsing pressure, until the young trees are more mature**

**Selected restoration sites**



## 4. Use local and pure seed or cuttings

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Sycamore restoration must consider the potential for sourcing of stock that is hybridized with London plane trees. Because sycamore seed can be wind-pollinated by London plane trees, many hybrids currently exist, especially with the extensive use of London plane trees in urban landscaping. At least one restoration project has unknowingly planted hybridized seedlings within the project (Johnson, et al., 2016).

Methods for successfully propagating sycamore planting stock to be used in restoration projects continue to be developed. Currently,



local nurseries have about a 70% success rate of growing sycamores from seed, but only a 10-30% success rate from cuttings collected from genetically identified mature sycamore trees. Projects that choose to use seed should harvest and use seed from a local source. However, genetic testing of the seedling would be required to assure native rather than hybrid planting stock as seed from native trees can be pollinated by the London plane tree even at long distances (H. T. Harvey and Genomeadvisors Inc., 2020). If the project chooses to use cuttings, it is best to collect from genetically tested trees, but in the absence of that information, cuttings should be collected from very old sycamores that likely established before the introduction of London plane trees in the area.

It is generally preferred to utilize cuttings from a local and known genetically pure sycamore, rather than seed, given the expense in genetically testing individual seedlings. The tradeoff, however, is the low success rate of cutting propagation, requiring a very large number of cuttings to be harvested in order to achieve the desired number of plantings. Importantly, nurseries are continuing to experiment and work towards improved propagation success for cuttings (H. T. Harvey et al., 2019).

## 5. Plant near a water source

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Sycamores thrive when located near a water source, namely active channels with intermittent flow. Plantings should occur in hydrologically appropriate locations, such as at the edges of active channels, within side channels, or on low-elevation floodplains that are regularly inundated. Once a property is identified for restoration, specific locations for planting with suitable water availability should be established through on-site field observations.



Sycamore stakes at Medeiros Parkway. Photograph by H. T. Harvey.

Plantings on floodplain surfaces can also thrive, as long as they are irrigated so that they are able to develop a root system that can intercept the groundwater table. Floodplain locations chosen for planting should consider the depth to groundwater. For instance, what is the elevation difference between the floodplain surface and the channel bed? Has the channel incised within the reach, and has the local groundwater table been affected by this incision? In addition, any available data (e.g., from local groundwater monitoring wells) should be collected to verify the groundwater depth and its variability.

## ***6. Irrigate new plantings***

Most plantings will require irrigation for the first 3 to 5 years, until the root system has developed enough to reach deeper groundwater during the late summer/fall months. There are no set standards for amount and timing of irrigation, but previous

However, additional elements can be used to ensure that plantings on floodplains will have a sufficient water source. For example, the creation of a long, linear depression (parallel to the flow direction) on the floodplain surface can create appropriate locations for plantings. This depression would temporarily hold any surface water that is delivered (e.g., precipitation or surface flows), and also reduce the overall depth to groundwater, increasing the ability of new root systems to intercept the groundwater table earlier in their development.

experience suggests that watering 10 gallons per week for the first season is vital for establishment. After the first season, watering frequency can be reduced, but irrigation volume should remain relatively high, and should continue to saturate the rooting zone



and below to stimulate the roots to continue to grow deeply toward perennial groundwater. The health and vigor of the plantings should

be monitored regularly to adjust the irrigation frequency as needed.

## 7. Provide plant protection elements

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Seedlings and saplings should be protected from grazing and browsing pressure, until the saplings are more mature and can withstand these pressures. This could be accomplished by fencing animals out of the channel corridor, only allowing access to certain reaches of the creek, or installing protective fencing/cages around seedlings/saplings to prevent

browsing. Some locations that are appropriate for SAW use intermittent goat grazing to reduce fuels for wildfire. In those cases, temporary protection (e.g., robust fencing and cages such as welded wire with three T-posts per cage) should be used to protect seedlings and saplings during the grazing period, and even from feral pigs.

## 8. Reduce plant competition and threats from disease

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Sycamore seedlings and saplings must compete with adjacent herbaceous or woody plants for resources. Removal of the adjacent non-native plants can remove that competition, increasing the chances of survival. In some locations, invasive species such as *Arundo* (*Arundo donax*) (present at Sycamore Grove Park) or Tree of Heaven (*Ailanthus altissima*) (present at Medeiros Parkway) are present and represent significant threats to the success of seedlings and saplings. *Arundo* uses large amounts of water, and Tree of Heaven (along with other tree species) can provide too much

shade for new sycamores. Careful site selection and monitoring after planting can help assess these issues and address them as necessary to provide the best chance of success for plantings.

Although anthracnose (a fungal disease) was not found to be significant at the sites in this study, it likely affects sycamore health and regeneration. Anthracnose infection should be monitored within the planted areas, and if present, anthracnose infected leaf litter should be removed from the area.

## Future Considerations

The suite of conditions that support SAW should be considered in the context of present and future climate change. Changing rainfall patterns (amount, intensity, and timing) and flow regimes, more prolonged and acute droughts, as well as air temperature and humidity will likely affect the recruitment and establishment of new sycamores, as well as the health and longevity of existing sycamores. The potential for restoring and enhancing SAW may change in response to the future changing climatic conditions. Anticipating how restoration and enhancement

actions might need to change will be key to our success. For instance, future studies could focus on restoration experiments that test sycamore ecotypes from hotter or drier areas to compare their survival and success to local ecotypes. Increasing climatic extremes are likely, necessitating a greater understanding of how areas that are suitable for SAW may be spatially shifting, the new challenges that SAW is facing, and a new set of restoration or enhancement actions that may be needed to continue to support and enhance SAW.









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