Working with Beavers
on Sonoma Water Channels

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Executive Summary

After historic extirpation from the region, North American beavers (*Castor canadensis*) have recently been re-establishing populations in Sonoma County streams. Sonoma Water is responsible for management of miles of waterways within the county. To support their multiple goals of flood protection and natural resource protection, Sonoma Water contracted with Prunuske Chatham, Inc. (PCI), Occidental Arts and Ecology Center (OAEC), and Swift Water Design to review the potential effects and considerations stemming from beaver activity in urban waterways, and to identify management approaches to address them. Beavers and their dams can benefit human communities in many ways, and they can also pose a concern for protection of infrastructure and flooding. Likewise, human activity in and around streams can support or strain beaver populations.

This report is intended as a guide for Sonoma Water staff as they work in waterways where beavers live, or where they could occur. It describes how to determine when beaver activity may pose a management concern, including qualitative and quantitative analysis of flood risk, and provides tools for staff to use when there is a significant risk to address. Primary tools for managing beaver impacts include:

- Regular monitoring of channels to identify new areas of beaver activity
- Installing protective fencing to prevent beaver damage to trees that have important landscape or ecological values
- Installing flexible pond levelers where needed to maintain beaver pond levels at elevations that protect infrastructure from flooding
- Installing exclusion devices to prevent beaver establishment in problematic locations such as culvert and weir inlets
- Monitoring channel conditions to ensure protective devices are functioning and woody material does not pose a blockage concern

The report also provides guidance for how Sonoma Water staff can carry out regular channel maintenance activities, including vegetation clearance and sediment removal, while protecting beaver populations. Measures to protect beavers during channel maintenance include:

- Retaining as much riparian/wetland vegetation for beaver forage as possible
- Using wildlife cameras to understand beaver activity, locations and patterns
- Identifying beaver lodges and avoiding work near them
- Avoiding work in beaver-occupied areas during kit season in spring and early summer
- Using hand tools rather than heavy equipment when feasible
- Considering alternatives to dewatering during sediment and aquatic vegetation removal work.

Sonoma Water can draw from these suites of tools based on specific site needs and beaver conditions. In most cases, Sonoma Water staff will have multiple options for working near beavers in ways that support beaver populations and the ecological benefits they provide, while meeting agency objectives for maintaining safe and functional waterways.

1 Introduction

In 2019, beavers began constructing dams in the town of Sonoma, California, along a channel maintained for flood control by Sonoma Water. Like many of Sonoma Water's channels, Fryer Creek has been channelized for flood control and is within a highly developed area. Beavers are native to the region, but were nearly eradicated here and throughout much of their North American range by the late 1800s due to unregulated trapping and loss of habitat (Lundquist and Dolman, 2018). A gradual return of beavers to the Sonoma Creek watershed had been observed starting in the mid-1990s (Knight 2013), but until the establishment of a breeding pair on Fryer Creek, beaver activity had been only occasionally observed in waterways managed by Sonoma Water.

In recent decades, recognition of the value of beavers for biodiversity and riparian system function has increased, and many California land managers have been working to support the reestablishment of beaver populations (Lundquist and Dolman, 2018). One of Sonoma Water's objectives for stream maintenance is "to balance the goals of flood protection, permit compliance, and protecting and enhancing natural resources" (Sonoma Water, 2020). Since beavers have moved in to Fryer Creek, Sonoma Water has turned their attention to understanding how beavers use and affect stream channels under their management, and how to maintain flood protection services where needed while protecting beaver populations.

Figure 1. Beaver dam in East Fork Fryer Creek.

To those ends, Sonoma Water has been working with local experts in beaver ecology and management, Occidental Arts and Ecology Center (OAEC) and Swift Water Design. Since 2019, this team has installed pond leveler devices on Fryer Creek to manage water levels behind the beaver dams. Subsequently, Sonoma Water engaged Prunuske Chatham, Inc. (PCI) to assist with a two-part study, with support from OAEC and Swift Water Design. First, the team was asked to determine whether the beaver activities in Fryer Creek pose a flood risk in this urban setting, and to develop recommendations for integrating beaver protection and flood protection at that site. That site-specific analysis would then inform the development of this generalized guidance document, for Sonoma Water staff to use if and when beavers establish elsewhere within Sonoma Water's purview.

PCI's 2021 study of Fryer Creek found that the current beaver dams in that location, with pond leveler devices installed, have a minimal effect on flooding impacts to nearby homes and other infrastructure. The devices can serve to keep an adjacent access road dry, and even the potential addition of further dam building on the reach (with pond leveler devices installed) is unlikely to cause significant changes to flood conveyance. The team recommended that Sonoma Water continue to maintain the pond leveler devices and monitor beaver activity, culverts, sediment accumulation, vegetation establishment, and felled trees to quickly address maintenance and ecological needs at the site. The Fryer Creek report provides protective practices to follow when performing channel maintenance activities, such as vegetation and sediment management, near the known beaver lodge and dams at that site. Measures to protect riparian habitat and encourage the development of mature riparian canopy there were also recommended.

This report is intended as a general guide for Sonoma Water staff as they work in waterways where beavers live, or where they could occur. It provides general background on beaver ecology, ecosystem and flooding effects, and discusses potential for beavers to establish elsewhere on Sonoma Water channels. Next, it draws from the Fryer Creek study to provide the general steps to take to determine whether beaver dams pose a concern for flooding, and management options to undertake if needed. Finally, protective measures are identified for when Sonoma Water staff work near beavers, and a seasonal calendar with typical timing is provided.

2 Beaver Ecology and Effects in Urban Settings

The North American beaver is a highly adaptable species with a range from northern Canada to northern Mexico, including California (Lundquist and Dolman, 2018). Recent research has found verifiable records that the American beaver is historically native to the watersheds of coastal California and the San Francisco Bay Area (Lanman, et al., 2013).

Beavers can establish anywhere there is water and food (Lundquist and Dolman, 2018). Beavers rely on deep water to protect themselves from predators, such as mountain lion, coyote, bobcat, and even bear and river otters. However, they are not limited to existing deep-water settings (ponds, lakes, large streams, and rivers); even small ephemeral streams can be dammed to create perennial ponds. Beavers create dwellings, where they eat, sleep, and raise kits (beaver young), by burrowing into banks and/or by building lodges made of mud and wood, with entrances that are underwater and protected from predators. Beavers typically feed on the bark of deciduous trees, including willow, poplar, cottonwood, and aspen, and on herbaceous matter, such as grasses, leaves, bulbs, and rhizomes. In Sonoma County, beavers favor willows, cottonwood, cattail, grasses, and blackberry leaves, but they can use many different species.

Beavers build dams to create deeper pools that provide shelter from predators, and will often build multiple dams in a row along a waterway to extend sheltered access to food. Beaver dams can range from 8 inches to 6 feet in height, 3 to 6 feet in width, and from 2 feet to much greater in length (one example in Canada was 930 yards long; Pollock et al. 2018). Pools typically need to be at least 3 feet deep to provide adequate cover. Dam building or repair behavior is triggered by the sound of running water.

As described in Pollock et al. (2018), beavers begin dam construction by pushing sediment and woody material into place, or by taking advantage of existing materials; then they anchor branches to the stream bottom or other substrate. They intertwine branches both perpendicular and parallel to the stream, and often place additional branches on the downstream side of the dam, parallel to the stream, with the cut end in the substrate and the branched end pointing upstream to add structural support. In addition to branches and mud, beavers incorporate a variety of other materials into their dams. These range from tree trunks, leaves and aquatic plants to plastic, metal or other debris. After the woody material is in place, beavers add mud and herbaceous material to protect the dam, especially on the upstream face (Pollock et al. 2018). The mud is typically collected from the stream bottom upstream of the dam. Beavers maintain their dams, repairing and adding or removing material to adjust water levels. In warm climates like Sonoma County's, dam construction can occur year-round, but tends to be less active in summer. See Section 5.3 for discussion of flow control (pond leveler) devices, which are often installed to manage beaver dam-caused flooding in urban settings.

Figure 2. Beaver lodge in bank of East Fork Fryer Creek.

Generally, beaver dams need to last for two years to provide sufficient time before kits typically disperse and leave the care of their parents (Pollock et al., 2018). However, beavers can abandon dams and find new territories after resources (food and construction materials) have been depleted. Dams also can fail due to high flows during large storm events. The strength of dams can vary depending on size, material, and age (Neumayer et al., 2020). New dams typically consist of recently chewed branches and an impermeable layer of mud on the upstream face. Mature dams will have both old and fresh branches, and may further stabilize over time as the willow and other riparian vegetation included in the dam sprouts and roots into the streambed. For abandoned dams the layer of mud is not maintained, which can lead to permeability and dam failure if the vegetation is not yet fully established.

Beavers can colonize urban waterways, including creeks, ponds, and ditches, as long as the necessary resources are present (Pollock at al., 2018). However, beavers have historically been viewed as a nuisance in urban areas and are often perceived as posing a threat to infrastructure and private property through vegetation impacts and increased flood risk. As a result, the default land management response in the past has been to remove beavers from urban settings (Pollock at al., 2018). However, typically the removal of beavers is temporary, as they will return to areas that have the desired resources (Boyles and Savitzky, 2008). This has led to alternative methods for managing beavers, such as pond leveler devices, that have been found to successfully mitigate the flood risk of beaver habitation (Boyles and Savitzky, 2008).

There are a number of examples of northern California communities where urban land managers are working to allow the persistence of beavers while protecting infrastructure and public safety. In Martinez (Contra Costa County), beaver activity on Alhambra Creek was determined to pose a flood concern in 2007 and pond levelers were installed in response, functioning successfully throughout the decade that beavers were present (Martinez City Council 2008, Perryman 2022, City of Martinez and LSA 2022). In El Dorado Hills, outside of Sacramento, beaver activity was causing flooding of a walking path, and a pond leveler device was successfully installed with the support of US Fish and Wildlife Service, the local Community Services District, and the American Rivers Conservancy (OAEC 2022). In Fairfield (Solano County), annual removal of the largest dams is reportedly practiced to prevent urban flooding and damage from dislodged dam materials, but beavers themselves are not removed (Hansen 2021), and neighborhood residents have created a walking tour map to educate visitors. Napa Flood Control District is implementing co-existence strategies in both Tulocay and Napa Creeks, in downtown Napa, with success. In the Pacific northwest, where beavers are more abundant, beaver colonization in Seattle city parks initially caused flooding and loss of some mature trees; the city is implementing pond levelers and installing protective fencing around trees, as well as adapting park landscape designs, to address these issues (Bailey et al. 2018).

2.1 Ecosystem Effects

Largely because of their dam-building habits, beavers can have a wide array of cascading effects on the places they live. Beavers increase wetland extent, restoring many of the ecosystem functions that wetlands provide, but in highly altered or constrained urban settings, these changes sometimes pose challenges for human management objectives.

2.1.1 Aquatic Habitat and Water Storage

Beaver dams increase overall aquatic habitat extent and complexity. These qualities are typically very limited in engineered urban channels, often by design, to facilitate rapid transmittal of water and ease of channel maintenance. Beavers change lotic (flowing) aquatic habitat to a mixture of lotic and lentic (stillwater) habitats, which in turn alters fish and wildlife resources (Figure 3). Ponding from beaver dams can deepen existing pools or create pools on streams that would typically go dry (Pollock, et al., 2003). This can be particularly beneficial to fish and wildlife in the summer, especially during prolonged droughts that are increasingly common as California's climate changes (Lundquist and Dolman, 2018). Ponding allows for greater infiltration of water into soil, groundwater recharge, and regulation of flows (Larsen et al. 2021). In engineered urban systems, longer inundation or saturation can also pose a challenge for maintenance access into riparian areas. Beaver dams form a "step-pool" water surface profile, where flow pools behind beaver dams and steps down at each dam, which can increase hydraulic diversity and habitat complexity in otherwise uniform urban channels (Pollock et al., 2018; Lundquist and Dolman, 2018).

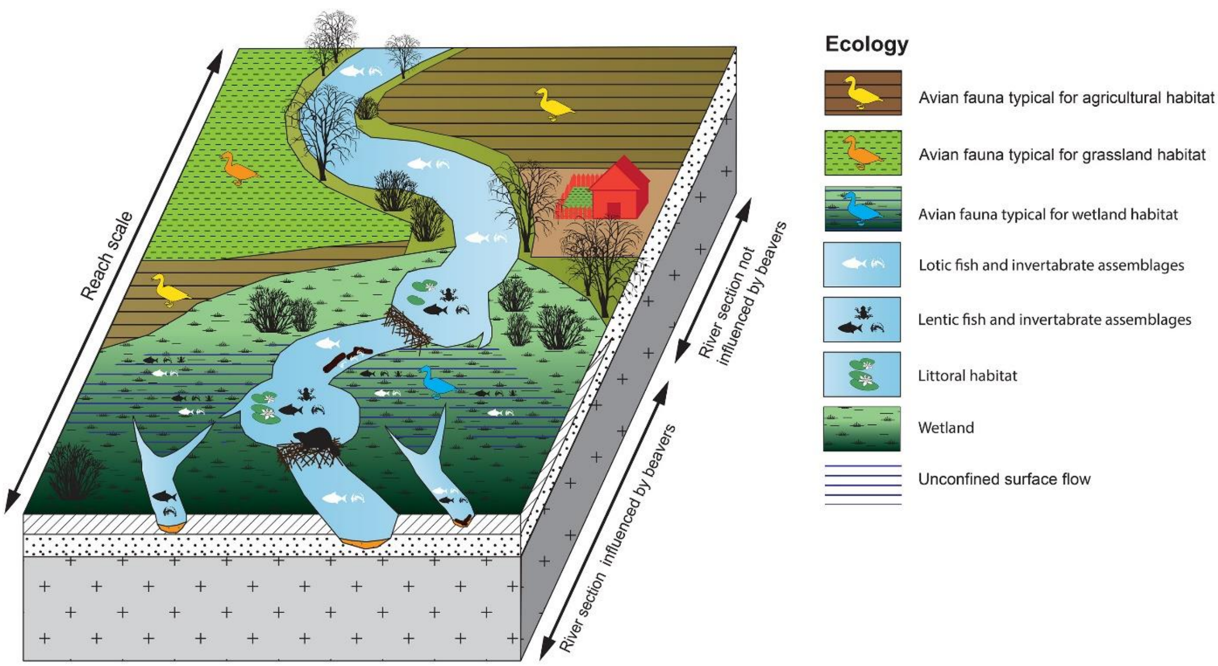


Figure 3. From Larsen et al. 2021. Conceptual illustration of how beaver dams affect aquatic and riparian habitat.

2.1.2 Water Quality

Ponding of water by beaver dams can result in a range of effects on water quality in urban streams. Fine sediment is captured behind beaver dams, improving downstream water quality but also increasing maintenance (sediment removal) needs on flood control channels. Nutrient cycling is also affected, with research indicating that beaver ponds typically reduce downstream nitrate-nitrogen and potentially phosphorous while increasing ammonium (Larsen et al. 2021, Muskopf 2007). See Figure 4 for a conceptual summary of the multiple biogeochemical changes related to beaver dams.

Effects of beaver dams on water temperature are complex, with slower flow velocities and potential loss of riparian cover contributing to increased temperature, but increased water storage volumes potentially counteracting those effects, and results varying over time and spatial scales (Larsen et al. 2021). Recent research from semi-arid central Oregon found that beaver dams in that location beneficially moderate water temperatures for steelhead, buffering temperature extremes and creating cool-water refugia through increased groundwater connectivity (Weber et al. 2017).

In the still and potentially warmer waters of beaver ponds, dissolved oxygen levels are often reduced, especially in deep pools with limited mixing. Low dissolved oxygen levels can potentially reduce habitat quality for fish and aquatic wildlife. However, the effect is typically reversed a short distance below a beaver dam.

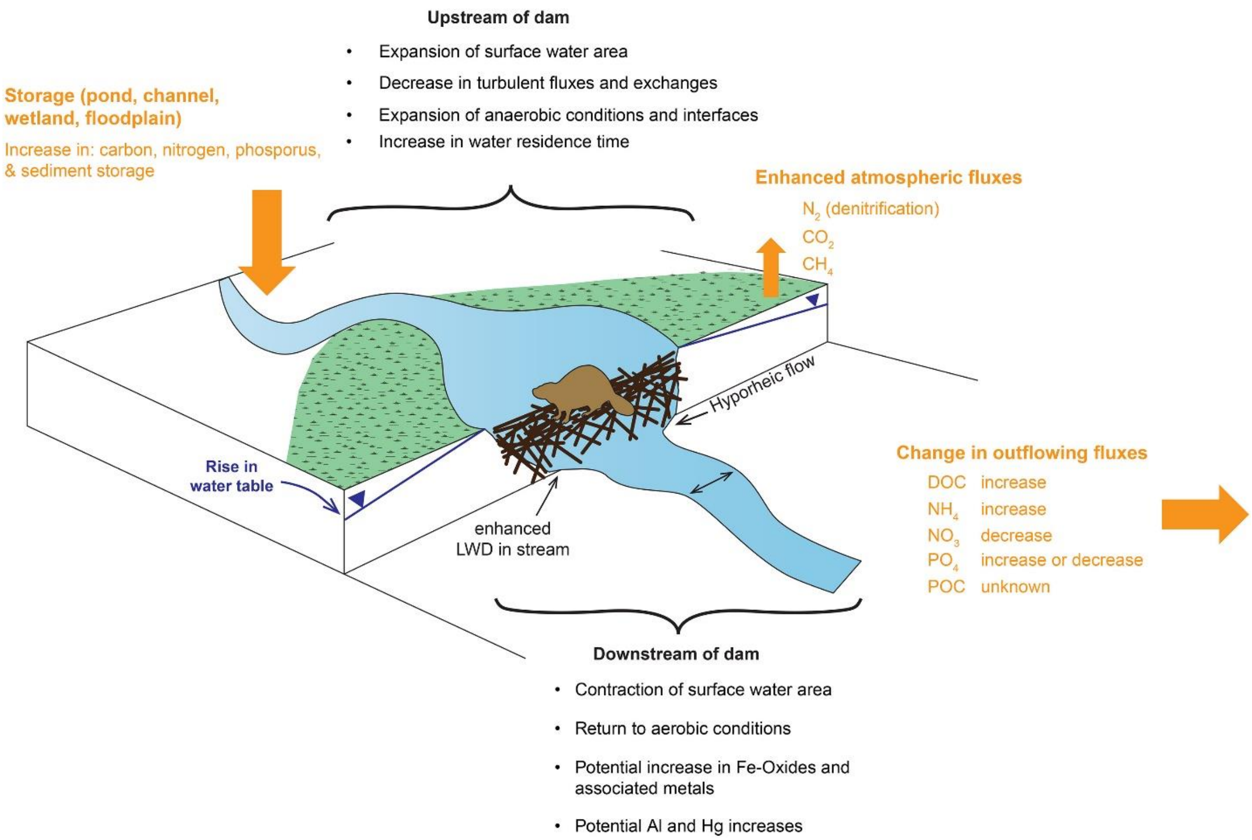


Figure 4. From Larsen et al. (2021). Conceptual model of changing biogeochemical conditions, pathways and fluxes potentially induced by beaver dams, from upstream to downstream.

2.1.3 Riparian Tree Cover

In general, beaver dam-building leads to the expansion of riparian habitat and the woody species that occupy it (Kay 1994). However, in urban settings where natural vegetation and tree regeneration may be very limited, beavers could cause the loss of significant tree canopy through direct cutting or by inundation of flood-intolerant tree species. If native riparian species (which are typically flood-tolerant) are not present, and trees are not protected with caging, this could contribute to an increase in stream temperatures; see Water Quality for further discussion.

2.1.4 Biodiversity

By increasing the extent and structural diversity of wetland and riparian habitat, beaver dams support increased biodiversity (Lundquist and Dolman, 2018). Beaver dams create conditions capable of supporting a greater number of herbaceous plant species in the riparian zone (Wright et al., 2002). The microhabitats created by beaver dams and digging also significantly increase the diversity and abundance of aquatic invertebrate species (Rolauffs et al., 2001; Hood & Larson, 2014). This greater diversity in plant and invertebrate species in turn supports a greater abundance and diversity of animals that live in, or migrate through, the riparian corridor (Pollock at al., 2018; Lundquist and Dolman, 2018). The constant source of water, especially during dry summers and prolonged droughts, along with abundant food and shelter from prey, results in an increased occupancy of fish and amphibian species (Pollock et al., 2003; Hossack et al., 2015; Pollock, 2018). Special-status species occurring in Sonoma County that may benefit from beaver activity include steelhead, salmon, California red-legged frog, and western pond turtle. The Marin Municipal Water District is seeking CDFW's support in reintroducing beavers into Lagunitas Creek to help endangered coho salmon (Houston 2022). In general, beaver dams are not thought to be a problematic barrier to steelhead and coho movement; adults are moving upstream during high flows and can pass or jump over typical beaver dams, while juveniles may be able to jump over dams or move through small gaps in the dams (Pollock et al. 2018, Bouwes et al. 2016, Kemp et al. 2012). Beavers and salmon have coexisted for millennia, but how they relate in constrained, developed settings is not fully understood.

Ponded water and wetland habitat from beaver dams also attracts a wide diversity of waterfowl and migratory songbird species (Cooke and Zach 2008; Lundquist and Dolman, 2018). Trees felled by beaver or killed by beaver dam ponding provide foraging, refuge, and nesting habitat for various birds and mammals (Pollock, 2018; Lundquist and Dolman, 2018).

Figure 5. The ponded area created by beaver activity on East Fork Fryer Creek supports mallards and other waterfowl.

2.1.5 Invasive Species

Beavers are likely to have varied impacts on the abundance of invasive plant and wildlife species in riparian corridors, depending on the particular invasive species of concern and how the effects of flooding, wetland habitat expansion, and herbivory interact. Limited research is available on the topic, but one study of two wetlands in the eastern U.S. found that beaver herbivory reduced abundance of invasive aquatic parrot feather (*Myriophyllum aquaticum*; also highly invasive in California) by nearly 90%, while also reducing cover of a native perennial forb (Parker et al. 2007). On the other hand, studies of beaver populations in Arizona and Montana found that they are associated with higher abundance of invasive tamarisk *(Tamarix* spp.) and Russian olive, possibly due to preferential herbivory on native willows and cottonwoods (which have lower tannins and salt content), as well as by creating more open, sunny corridors in which the non-natives can thrive (Mortenson et al. 2008, Lesica and Miles 2004).

In Sonoma County, Sonoma Water staff have noted an increase in invasive water primrose (*Ludwigia* sp.) establishment at the Fryer Creek site. Sonoma Water is also concerned that this may lead to an increase in mosquito activity in this area; water primrose cover can make insecticide treatment for mosquito control less effective. Water primrose is a highly invasive species throughout the region's waterways, but has not to date been prevalent on Sonoma Water channels in Sonoma Valley, according to staff. Relatively shallow water, which may be exacerbated by current drought conditions, high nutrient loads from urban and agricultural runoff, and warming climate are also likely to facilitate water primrose establishment. Control of this species is challenging. Sonoma Water's main approaches to date have been using manual or mechanical removal methods, and attempting to gradually shade the species out by increasing tree canopy cover. Beaver are known to feed on water primrose, but not to an extent that suppresses it.

Figure 6. Establishment of invasive Ludwigia and native tules in East Fork Fryer Creek channel above beaver dams.

Other species found in Sonoma County that could increase with expansion of wetland and ponded habitat include mosquitofish (introduced for mosquito control but frequently escaping from intended pond locations) and introduced food or sport fishing species (centrarchids such as bluegill and largemouth bass). Also, bullfrogs and red swamp crayfish can proliferate in warm water pond habitats. These introduced species can in turn pose a significant threat to native fish and amphibians.

Finally, although they are native plant species, cattails (*Typha* spp.) and aquatic fern (*Azolla filiculoides*) are of management concern to Sonoma Water and also spread rapidly in warm, shallowly ponded waters. Both species can form dense coverings and reduce biodiversity. Cattails can rapidly fill Sonoma Water channels, reducing capacity for high flows to pass through, but also slowing down high flows and providing habitat benefits to a variety of fish, birds, and other wildlife. Azolla, when at low to moderate cover, can provide habitat benefits; it is a food source for waterfowl, it can provide a basking surface for frogs, its presence can limit algal growth, and it can reduce mosquito breeding. However, stands can grow very rapidly to cover pond surfaces, and dense growth of it can pose a concern for water quality. At high cover, azolla limits light penetration and gas exchange, leading to reduced dissolved oxygen in the water column.

2.1.6 Climate Resiliency and Fire Resistance

Beavers can contribute to climate change resiliency (Pollock et al., 2018; Lundquist and Dolman, 2018). Elevated water levels from beaver dam ponding can help prevent drying of wetland sediment and soils and the associated releases of sequestered carbon into the atmosphere (Wohl, 2013; Lundquist and Dolman, 2018). Maintaining greater hydration of the soils and vegetation also helps reduce vegetation flammability, which can be a benefit especially where natural habitat abuts human infrastructure and wildfire is a concern, as it is on most Sonoma Water channels. The ponding from beaver dams also slows runoff and increases groundwater recharge (Pollock et al., 2018; Lundquist and Dolman, 2018), an important function in places that experience more extreme variability in rainfall timing and quantity due to climate change such as California. Riparian zones inhabited by beavers have also been found to be resistant to fire and provide wildlife refuge during fires (Fairfax and Whittle, 2020), which are much needed benefits as places like California continue to experience increased wildfire activity from climate change.

Overall, beaver dam complexes provide ecosystem benefits for a wide array of species (Lundquist and Dolman, 2018), and interested stewards such as Sonoma Water are focusing on what they can do to support the existence of dams in systems that are managed for flood control. However, in order to realize these benefits and accommodate beaver occupancy of flood control systems, it is important to understand the impacts that beavers can have on flood conveyance and how those impacts can be managed.

2.2 Flood Impacts

In urban settings, areas of development and infrastructure may be at increased risk of flooding when beavers colonize channels engineered for flood conveyance (Pollock et al., 2018; Lundquist and Dolman, 2018). Dams created by beavers that partially or fully span artificially narrowed urban channels can force flows out of the channel and onto adjacent areas constrained by development (Pollock et al., 2018; Lundquist and Dolman, 2018). Beaver dams can also block culverts at roadways, railways, and other infrastructure, which can lead to flooding or washouts (Pollock et al., 2018; Lundquist and Dolman, 2018). Another potential flooding concern is that dam materials could pose a blockage risk to downstream culverts.

However, site-specific conditions need review to determine whether flood risk is elevated or not. In the case of Fryer Creek, based on hydraulic modeling, PCI found that the four beaver dams present have a minimal effect on flooding when pond leveler devices were installed (see Management Options section for detail). PCI's findings also illustrate that other structures, such as undersized downstream culverts, may act as more significant controls on peak flow water surface elevation upstream compared to beaver dams. The material in the beaver dams observed on Fryer Creek was relatively small, and would likely pass through the crossings or create a small partial blockage that would then be forced through during a high flow event. Regular monitoring for larger debris, and removal prior to fall rains can prevent blockage.

2.2.1 Predicting Beaver Dam Flood Impacts with Hydraulic Modeling

Hydraulic models can be used to predict the flood impacts of beaver dams and help identify management needs. For example, Stout (2017) developed a one-dimension (1-D) hydraulic model of a beaver-impacted reach that includes eight dams and a reach without dams to compare hydraulic response. The study found that a relatively low number of beaver dams resulted in significant increases in water depths and widths, as well as a decrease in flow velocities (Stout, 2017). Neumayer et al. (2020) developed 2-D hydraulic models of 12 cascade scenarios in total in two catchments during eight different flood events to test flood retention benefits. In the study's modeled scenarios, beaver dams did not affect flood retention times for flood events with return intervals of more than 2 years, but beaver dams did result in larger (over 300%) inundation areas (Neumayer et al., 2020). This modeling study did not address the likelihood of property damage from flooding.

More locally, PCI conducted 2-D hydraulic modelling for the Fryer Creek study (PCI, 2021). In this study, a 2-D hydraulic model was used to model a channel with recently established beaver dams to compare the relative effects that the dams had on flooding. Additional models were analyzed to determine the impact that various potential beaver dam build-up scenarios would have on flooding, including: the addition of more beaver dams; the existing dams being built up an additional 1.5 feet and 3.0 feet; and cattails becoming established upstream of the beaver dams to the same elevation as the dam crests. Hydraulic findings of this study included:

- A road culvert downstream of the beaver dams creates a significant hydraulic constriction that controls water surface elevations upstream through the location of the beaver dams. This reduces velocities through the reach and causes a backwater that significantly minimizes the impact that the beaver dams would otherwise have on flood depths.
- The effect of potential future beaver dams on flood depths was much more significant at lower flows than at higher flows.
- Even when modelled beaver dam height is increased, the hydraulic effect on water depth is dampened during high flow events. Ultimately, it's only at the maximum expected beaver dam height that there appears to be a significant increase in water depths.
- If cattails become established in the pools upstream of a beaver dam, and do not lay over during a high flow event, water depths during the 25-year peak flow event would increase by approximately 20% throughout the reach (from 5' without the beaver dams to 6.6' with a beaver dam and cattails).

2.2.2 Dam Failure Potential and Resilience

Though beaver dam failures may be common during flood events (Butler and Malanson, 2005), beaver dams have also been shown to remain intact after even the largest flood events. Westbrook et al.'s (2020) study of dam failures across Kananaskis Country, Alberta, found only about a third of dams were breached during the largest flood on record. Typically, it was just the most upstream dam that failed in reaches where some dams failed and some remained intact (Westbrook et al., 2020).

For those dams that have failed, there is limited detailed information on failure thresholds (G. Müller and Watling, 2016; Neumayer, et al. 2020). Klimenko and Eponchintseva (2015) estimated that natural dam failure occurred during a 10-year peak flow event for active dams about 3-9 feet in height. However, the twig and mud construction of the dams prevented widening of breaches within the failed dams (Klimenko and Eponchintseva, 2015). Westbrook et al. (2006) report the failure of a 3-foot-tall dam spanning 26 feet during a flow of 282 cubic feet per second (cfs). Levine and Meyers (2014) report a failure of a 32-foot-wide dam due to bank erosion during a flow of 247 cfs. These reported values indicate a unit discharge failure threshold of 8 to 11 square feet per second (sf/s) per foot width of the dam (Müller and Watling, 2016). Physical modeling (flume studies) by Müller and Watling (2016) found unit discharge failures of 9 to 17 sf/s. It should be noted this is very preliminary research. The models created in the experiments were much simpler than natural dams. The extreme variability in natural materials used and sites chosen by beavers, and streambed and bank composition, among other potential factors, all preclude a definitive understanding of beaver dam stability thresholds. In reality dams may be much more resilient to failure than expected.

2.3 Erosion

In general, channel-spanning beaver dams act similarly to engineered check dams; ponding upstream of the dam typically acts to reduce reach-wide velocities. This velocity reduction dissipates stream energy, which often causes sediment deposition and aggradation upstream of the dams (Green and Westbrook, 2009). In certain cases, colonization by beaver can focus flow into the channel and cause deposition along the channel banks. A study by Curran and Cannatelli (2014) for a channel on the Atlantic Coastal Plain found that beaver dams caused bank deposition between sequential dams, which ultimately caused a narrowing of the channel width and incision between dams. The study indicated that introduction of beavers can be a useful restoration tool where channels are unstable laterally and bank erosion is a concern (Curran and Cannatelli, 2014).

Under some conditions, however, beaver dams may contribute to bank erosion or undercutting of banks. PCI's study of Fryer Creek indicated that there can be localized increases in velocity across dams due to the reduced cross sectional flow area at a beaver dam. If dams persist during high flow events, it may be possible that the increase in velocity may cause local bank erosion, or cause water to end-run around the dam and scour the adjacent bank. In unconstrained systems, this contributes to meanders. Actively used dams where an end-cut occurs will typically be promptly repaired by beavers, but abandoned dams can continue to drive the meander process over time. Additionally, reach-scale aggradation as a result of beaver dams can reduce overall stream slope, which in turn can induce higher shear stress along channel margins and result in the tendency for meander formation. For this reason, the use of check dams as channel stability features has recently declined significantly, with their applicability being mostly limited to very select channel conditions.

Beaver burrows have the potential to impact infrastructure. Beavers typically create their burrows under trees to take advantage of the structure provided by roots, but sometimes burrow into non-reinforced embankments including levees, dams. If extensive, a burrow system in these locations could pose a stability concern, as the void created has the potential to collapse. Beavers can also burrow far from a stream channel and cause stability concerns for roads, especially those that carry heavy vehicles.

Monitoring for beaver activity, including detecting their burrow locations, is important in urban and managed settings in order to identify such concerns early.

3 Potential for Additional Beaver Establishment in Sonoma Water Channels

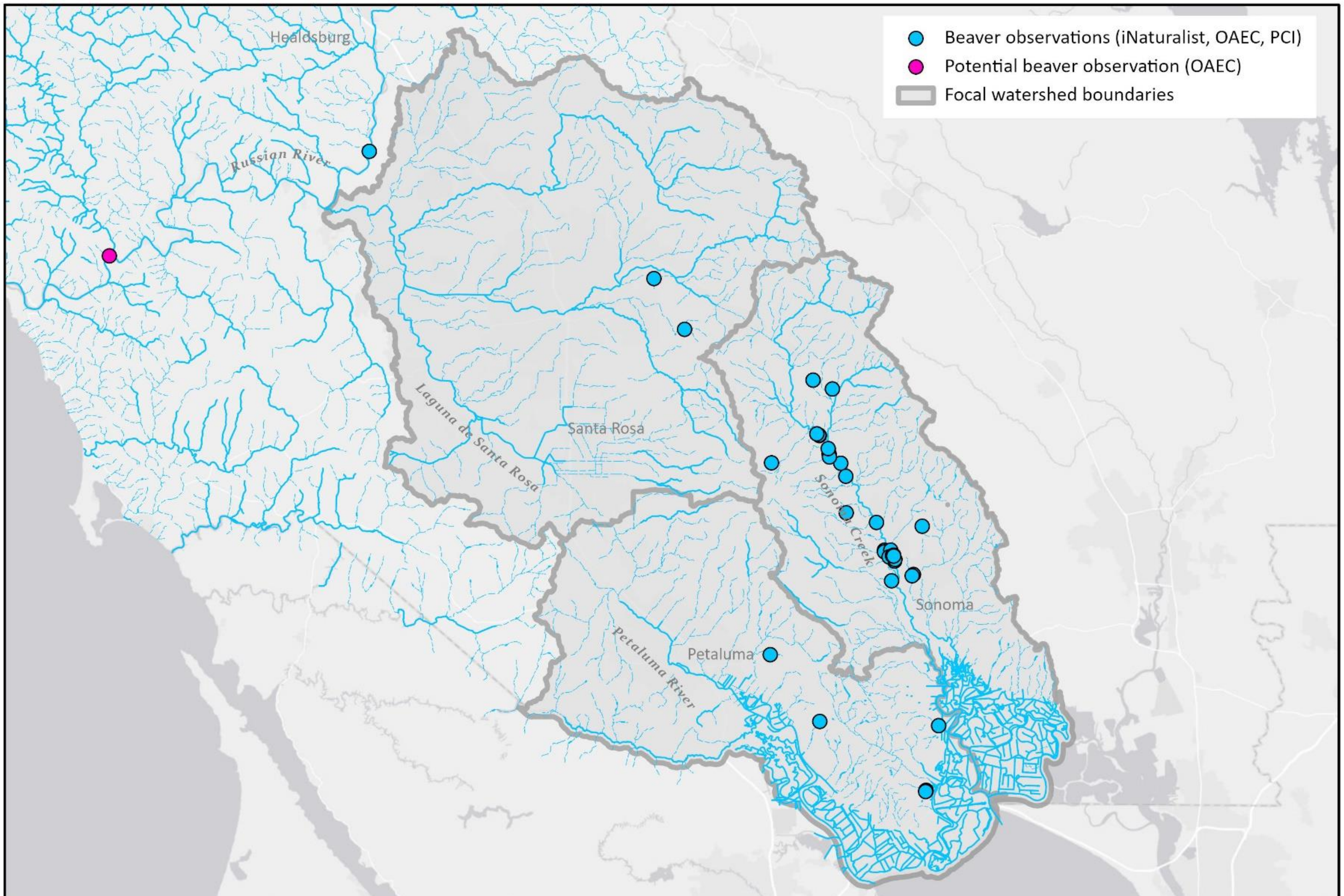
Many waterways in Sonoma County have the potential for future beaver establishment, or are already colonized. Many of the region's riparian areas have the resources and habitat beavers need, and especially in the Sonoma Creek watershed, also have potential movement routes for beavers to arrive from known occurrences. Beavers disperse as juveniles to find new habitat and establish new colonies, traveling up to 30 miles by water or 12 miles overland (Lundquist and Dolman 2018).

Sonoma Water's Stream Maintenance Program (SMP) activities occur in a subset of the county's waterways. Most of these activities occur in engineered flood control channels (referred to as "SMP reaches" in this document), primarily in the Laguna de Santa Rosa, Petaluma River, and Sonoma Creek watersheds (SCWA 2020). SW conducts limited additional channel maintenance activity in other watersheds and in modified and natural channels (SCWA 2020; see that document for detailed maps).

The following sections describe existing conditions and possible future expansion areas for beavers in Sonoma County, and in Sonoma Water SMP reaches. Additional beaver establishment may require additional management and monitoring by Sonoma Water and other land managers. This discussion of future potential for expansion is meant only as a general assessment; Sonoma Water staff's routine monitoring of channels will continue to be the most important tool in identifying specific dam locations in a timely way.

3.1 Current Beaver Establishment in the Region

In the mid-1990s, beavers established in Sonoma Creek near the community of Glen Ellen (Knight 2013). This was the first time beavers were documented in the watershed since they were extirpated decades earlier. Since then, though there has not been a concerted effort to monitor beaver population dynamics in this area, observations indicate that beavers have expanded their range in the Sonoma Creek watershed and continued their range expansion along Santa Rosa Creek and into the Russian River. From October 2016 to October 2017, 25 iNaturalist observations of beavers were recorded along Sonoma Creek, ranging north from Glen Ellen to south near Sonoma Raceway. Beavers, from spring 2019 to the present, have also constructed four dams on a Sonoma Water-managed reach of Fryer Creek, a tributary to Sonoma Creek. Beaver activity has also been noted in the Petaluma River watershed, at Lake Ilsanjo in Annadel State Park, and along side channels in the Russian River (iNaturalist 2021; Figure 7). OAEC also reports occurrences at Spring Lake, along Santa Rosa Creek, and possibly in the Russian River near Duncans Mills. No Sonoma County observations have been reported north of the Russian River.



PRUNUSKE CHATHAM, INC.

Figure 7. Beaver Observations, Sonoma County (iNaturalist, OAEC, PCI)

March 2022
Basemap: ESRI
Streams: USGS
Beaver data: iNaturalist,OAEC,PCI

3.2 Modeling Potential Beaver Dam Establishment

Given the increasing interest in beaver re-establishment, its ecological benefits and the need to coordinate with land managers to manage flood considerations in urban settings, researchers have developed tools to assess where potential beaver habitat occurs, occurred historically, and/or could be restored. One such tool is the Beaver Restoration Assessment Tool (BRAT), developed by Utah State University researchers (Utah State University 2022). It is a spatial modeling tool designed to assess whether the upper limits of stream networks have potential to support beaver dam building, quantified in estimates of dam density (i.e., number of dams per mile). Both existing and historic capacity estimates are made based on a variety of factors that reflect access to a reliable water source, access to woody building materials, ability to construct dams at base flows, and the likelihood that a dam could withstand typical floods. The BRAT model produces several management layers including: potential risk areas (i.e. proximity to floodable infrastructure and/or proximity to high intensity land use areas), areas of unsuitable/limited dam building opportunities, and conservation/restoration opportunities. This tool was primarily designed to help identify where to focus beaver restoration activities, but it is also intended to help identify general regions of potential beaver establishment. It relies on coarse-scale inputs such as generalized vegetation data, and is not highly accurate at a local scale. It should be considered only a supplement to use in conjunction with local knowledge of beaver populations and site-scale conditions.

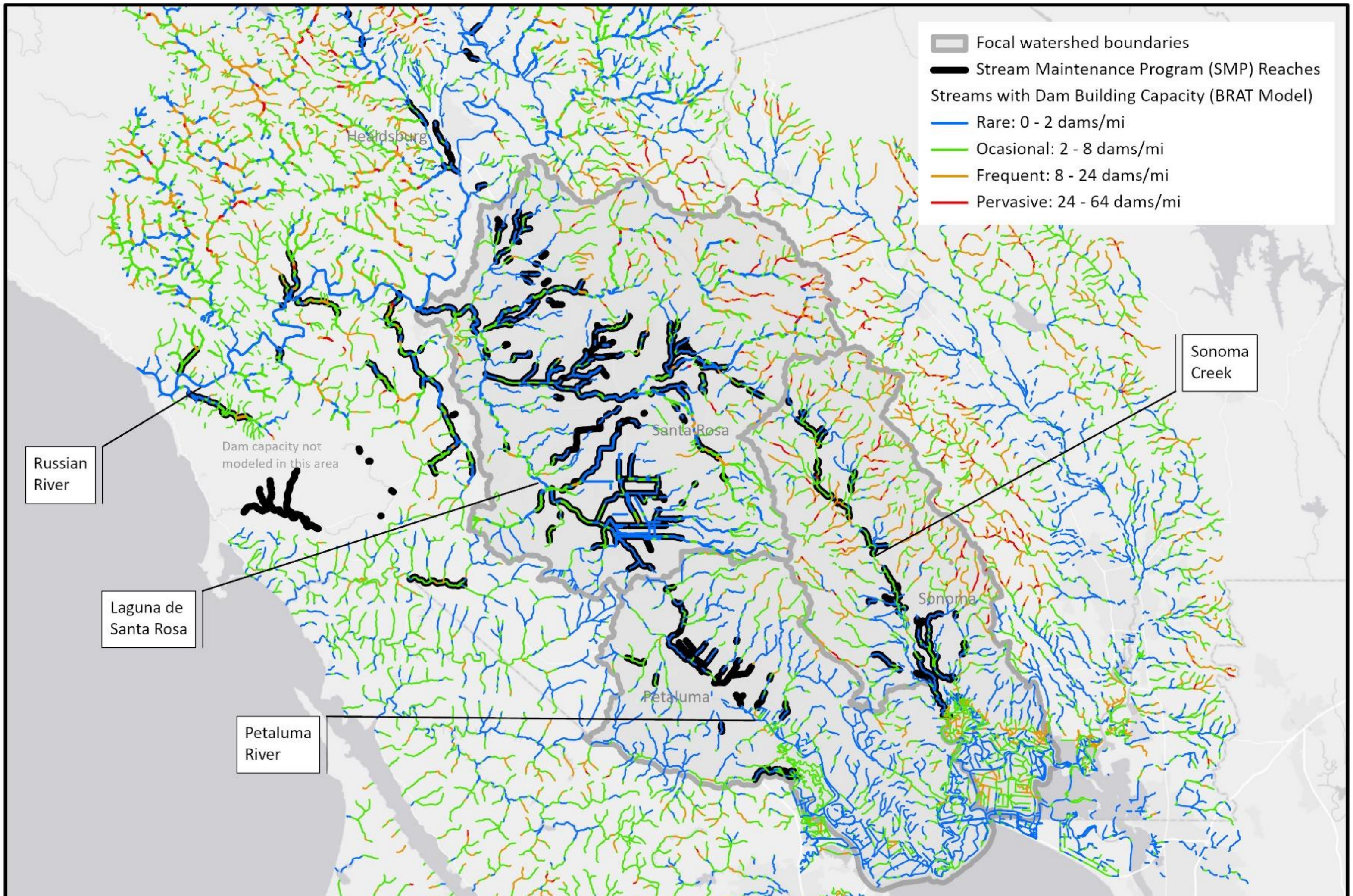
In 2018 the Nature Conservancy contracted Utah State University to apply BRAT in California to facilitate planning of beaver conservation and restoration projects (Macfarlane et al. 2019). The model output classifies each stream reach as having no potential for dam building, or having rare (0-2 dams/mile), occasional (2-8 dams per mile), frequent (8-24 dams/mile), or pervasive (24-64 dams/mile) dam-building capacity. The resulting model-wide estimate of current dam building capacity is 715,548 dams or 6 dams per kilometer of stream channel, while historic dam building capacity is estimated at 11 dams per kilometer. Current capacity in California, therefore, represents an approximately 50% loss in dam building capacity. This significant loss is mostly due to loss of riparian vegetation, conversion of land to agriculture, overgrazing in riparian and upland areas, and conifer encroachment into wet meadow areas.

PCI reviewed Utah State's California BRAT model output for Sonoma County streams, and compared them to known occurrences and site conditions. See Figures 8a (overview), 8b (Santa Rosa area), and 8c (Sonoma and Petaluma areas). The BRAT results for Sonoma County, relative to local known occurrences, are as follows:

- Sonoma Creek and tributaries are modeled as ranging from rare to frequent dam-building capacities. Sonoma Creek is known to support an established beaver population.
- Side channels and streams of the Russian River are also modeled as having rare to frequent dam-building capacities. A recent iNaturalist observation noted beaver activity within a side channel of the Russian River.
- The Laguna de Santa Rosa and tributaries are modeled as having mostly rare dam-building capacities. No confirmed observations are known from this area, but dense vegetation obscures visibility in many places and may be limiting detections.

Most of the Sonoma Water SMP reaches are modeled as having rare – but not zero -- dam-building capacity. Fryer Creek is modeled as no capacity to occasional capacity by BRAT, and is known to support beavers.

In conclusion, the BRAT model is of limited value for site-scale predictions, and ongoing monitoring by Sonoma Water staff in the course of regular maintenance activities, coupled with discussion with local beaver experts, will be the most important tools in identifying beaver establishment and potential future dispersal. However, the model output supports the general conclusion that there is widespread potential for beavers to colonize throughout Sonoma County waterways, including numerous Sonoma Water SMP reaches, over time.

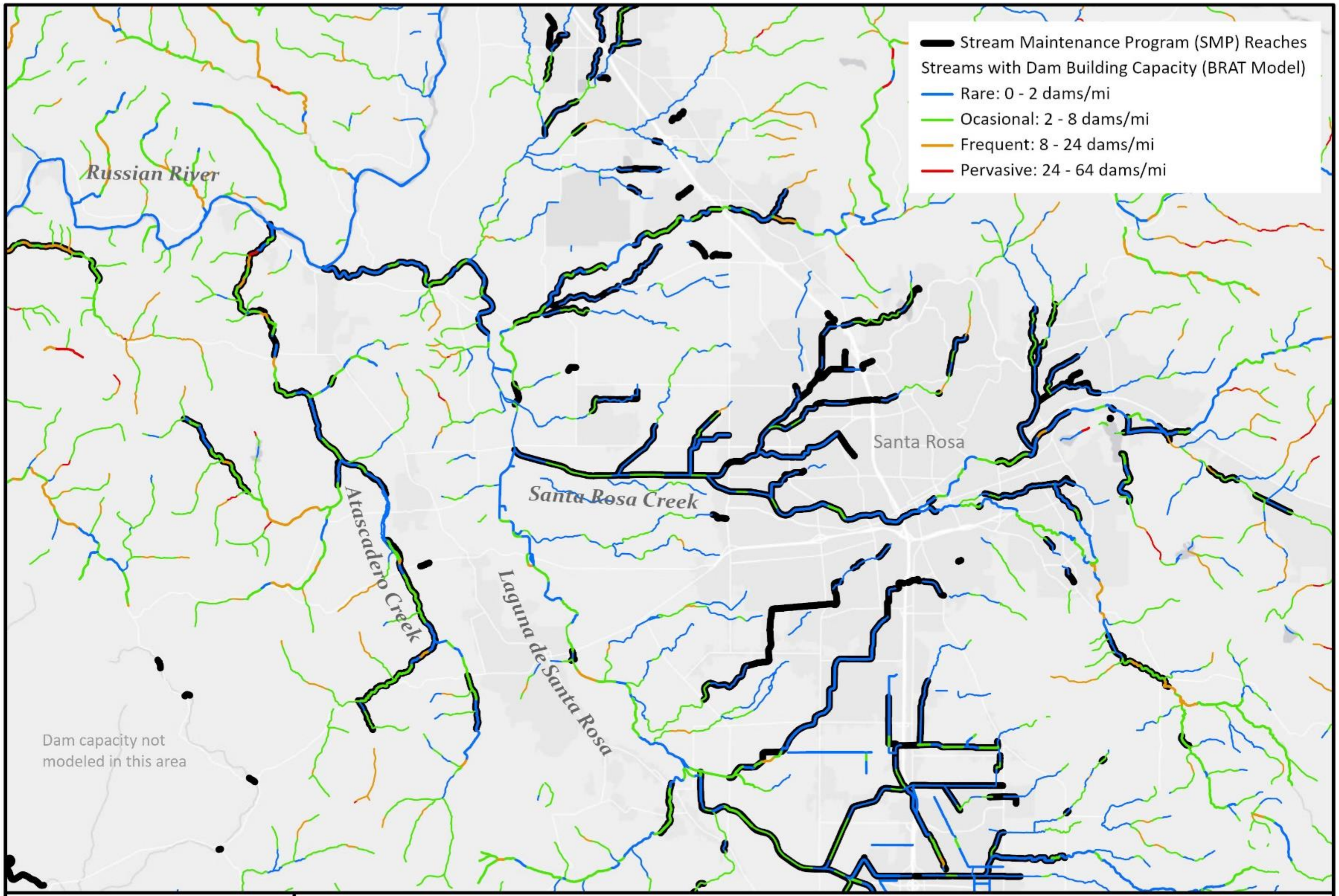


PRUNUSKE CHATHAM, INC.

Figure 8a - Sonoma Water Channels and Potential for Beaver Activity (BRAT Model, Utah State University)

0 2.5 5 10 Miles

March 2022
Imagery: ESRI
BRAT Model: Utah State University
Data: Sonoma Water



PRUNUSKE CHATHAM, INC.

Figure 8b - Santa Rosa Area - Sonoma Water Channels and Potential for Beaver Activity
(BRAT Model, Utah State University)

March 2022
Imagery: ESRI
BRAT Model: Utah State University
Data: Sonoma Water

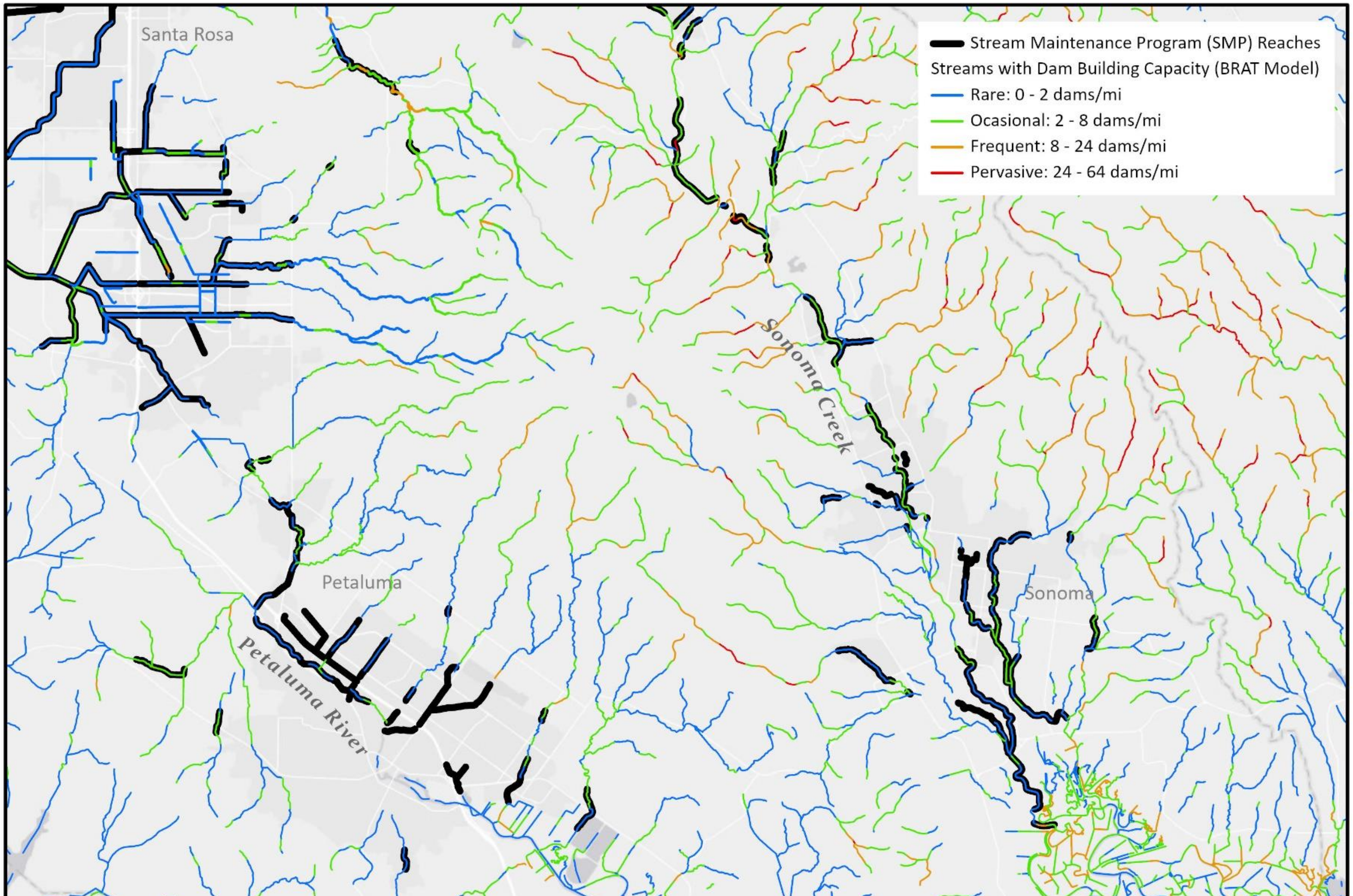


Figure 8c - Sonoma and Petaluma Areas - Sonoma Water Channels and Potential for Beaver Activity
(BRAT Model, Utah State University)

March 2022
Imagery: ESRI
BRAT Model: Utah State University
Data: Sonoma Water

4 Assessing Impacts of Beaver Activity on Sonoma Water Channels

When beaver activity is noted along Sonoma Water channels, a number of factors will be important to review as staff determine whether management actions are needed, and which are appropriate. These include ecological, physical, and community considerations.

4.1 Ecological Considerations

There are significant ecological considerations to keep in mind when managing for both flood risk and natural resource protection. Taking the following into account will help Sonoma Water staff understand and weigh the suite of positive and negative effects beaver may have in an urban setting as they determine what management actions are appropriate.

Potential beneficial effects

- Is beaver activity facilitating the development of valuable habitat for wildlife?
- Is habitat created by beavers being used by special-status species? Beaver ponds can provide valuable food and shelter resources for salmonids, western pond turtle, California red-legged frog, and other species. Potential use by these imperiled species would increase the need for careful review and potential regulatory agency consultation prior to alterations to the habitat.
- Is increased groundwater recharge and storage of high flows from beaver dams an important value in this location?
- Is increased hydration of vegetation, and reduction in wildfire fuel flammability, an important value here?
- How does beaver establishment at this location relate to the larger regional population? Is this a new area of establishment? Could it represent a stepping stone for future dispersal into more natural waterways where beaver activity may be especially valuable?

Potential negative effects

- Are beavers harming trees or other vegetation of special value? These could include ornamental plantings, restoration plantings, trees providing shade and other riparian benefits, especially where tree cover is limited, as it is in many flood control channel settings.
- Is beaver activity facilitating undesirable vegetation, such as invasive *Ludwigia*, and/or invasive fish and wildlife, such as bullfrog, warm water fish, or crayfish?
- Are beaver ponds causing eutrophication or poor water quality that may affect native fish and aquatic wildlife?

4.2 Flood Risk Analysis

As beavers become colonized in a region, nearby residents, businesses, or owners of infrastructure may rightfully be concerned about the potential impact that the dams may have on flooding. Depending on site characteristics, an initial simplified analysis may be adequate to assess flood risk; in others, a more detailed hydrologic analysis may be useful.

4.2.1 Initial Site Assessment

To determine whether a simplified, or more comprehensive analysis is appropriate for a particular site, individual characteristics of the site should first be considered. These considerations include:

- **Is there any critical infrastructure nearby that would be impacted by an increase in flooding**? Typical infrastructure includes: nearby buildings, streets, culverts or bridges, storm drains. If yes, additional analysis may be warranted.
- **Is there a history of flooding under pre-beaver dam conditions?** If the site has a low potential to cause flooding, a simplified analysis may be warranted. If alternate historical flood data is not available, FEMA flood maps may be useful to determine whether the site is within the 1% annual chance flood area (100-yr storm event inundation area). Depending on the location, base flood elevations (100-yr water surface elevations) may also be available. FEMA flood insurance rate maps are available online: https://msc.fema.gov/portal/search. However, note that due to climate change, historic information and models are imperfect indicators of likely future conditions. Assessments of the potential for a particular site to experience flooding should consider that climate change will result in a higher likelihood of more extreme flood events in the future.
- **Consider the entire pathway of elevated floodwaters.** Even if flooding of adjacent infrastructure is not a concern, elevated floodwaters could cause damage further downstream along the re-routed course.
- **Is the beaver dam occupying a significant portion of the cross sectional flow area?** Beaver dams will have a greater effect on flood depths in smaller channels than larger channels.
- **Are there nearby stream crossings or downstream channel constrictions that could create a backwater that would reduce a beaver dam's effect on flood depths?**

4.2.2 Hydraulic Modeling – Simplified Approach

If a simplified approach is desired after taking into account the various site considerations, determining hydraulics based on a single cross section (Single Section Method) may be used to provide an initial estimate of flood depths with a relatively low effort. Single section hydraulics assume steady, uniform flow and predict hydraulics based on cross-sectional geometry, hydraulic roughness, and the slope of the energy grade line. There are many free programs that utilize the Single Section Method, including FHWA Hydraulic Toolbox (FHWA, 2018) and USFS WinXSPRO (Hardy et. al, 2005). The goal of this analysis would be to determine whether a specific beaver dam is significantly threatening nearby infrastructure, and if so, whether a more comprehensive hydraulic study should be undertaken.

As with any model, the accuracy of the results will be dependent on assumptions made for the input parameters and the applicability of the flow characteristics at the cross section used in the analysis. Because the Single Section Method assumes uniform flow, it is best suited for straight channels with a constant slope and cross sectional area, and where mean channel velocities and flow depths remain constant throughout the reach. The Single Section Method is a 1-dimensional hydraulic model, which means that flow only travels directly perpendicular to the cross section being used.

More in-depth hydraulic models are needed for flood risk analysis when the channel geometry has significant variability (step-backwater method), or when flow does not only travel in one direction (2-dimensional models). These models typically require iterative calculations over multiple cross sections or a 3-D surface. These more comprehensive models would be warranted if results from the Single Section Method show significant flooding potential, or impacts to critical infrastructure.

For sites without previously established hydrology, the USGS application Streamstats can be used to develop peak flows. StreamStats provides basin characteristics and statistics including peak flow estimates using regional regression equations for six regions in California (USGS, 2020).

Typically, the section used for the Single Section Method would be taken at a riffle crest, as the hydraulic slope most closely approximates the average channel slope in these locations (normal depth). The cross sectional geometry should be estimated using existing surveys or LiDAR data where available, typical survey methods (Total Station or RTK GPS), or approximated using a rod and level or sag-tape procedure. Bank pins should be established at cross sections surveyed in order to re-locate the same section for potential future surveys. The site survey should include an estimate of channel slope by collecting ground data from the upstream riffle crest to the downstream riffle crest, at minimum. The slope of the energy grade line can generally be assumed to be the same as the riffle crest-to-riffle crest slope.

If used in the correct circumstances, the Single Section Method can predict similar water depths as a more extensive hydraulic model. To test this, the Single Section Method was used to predict water depths over a beaver dam that was modelled using 2D HEC-RAS for the Fryer Creek beaver impact analysis (PCI, 2021). In order to compare the differences in predicted flood depths between the two models, the same Manning's roughness was used for both models and the slope from the beaver dam to the next downstream riffle crest was used for the Single Section Method. A dam was selected from a reach with a relatively constant channel cross section and that did not have a backwater from a downstream constriction. A comparison of the results show that the two models predicted a difference in water depths at two different flow rates (100-cfs and 400-cfs) of less than 6 inches (Figure 9).

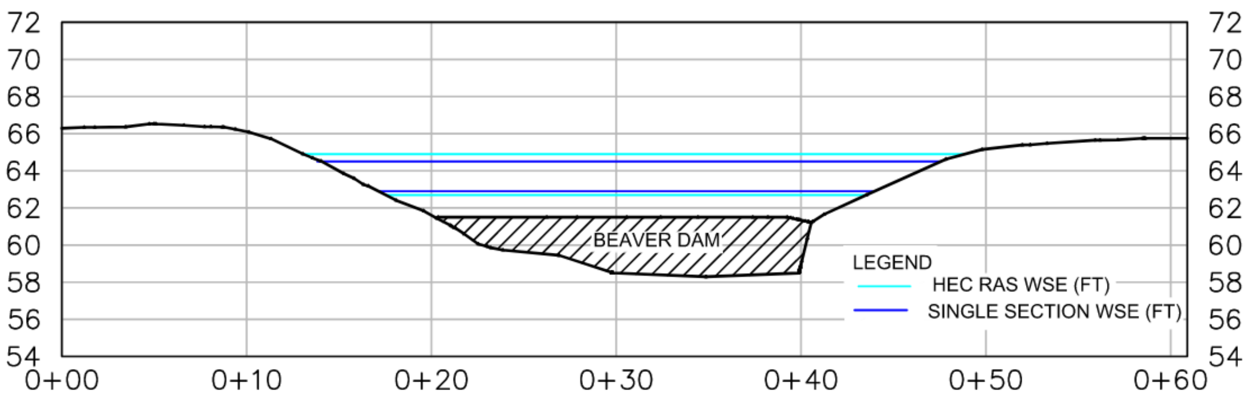


Figure 9. Comparison of predicted water depths using the Single Section Method and 2-dimensional HEC-RAS.

4.2.3 Hydraulic Modeling – Comprehensive Analysis

In the event that beavers colonize a site where their presence could potentially increase flood depths and significantly impact nearby infrastructure, a comprehensive hydraulic modelling effort could be conducted. The goal of the analysis would be to determine whether the beaver dams are detrimentally impacting flood depths, and if they are, whether the dams should be removed or limited in height by installing flow management devices. The analysis should:

- Analyze site conditions and collect topographic data of the stream channel and nearby surroundings. Data should be collected with enough accuracy/precision to effectively model flood peaks with an appropriate modelling platform for site conditions and available data.
- Determine site hydrology based on appropriate methods as outlined in the current version of Sonoma Water's Flood Management Design Manual (SCWA, 2020)
- Conduct hydraulic modelling of site conditions with and without beaver dams. The hydraulic model should include the entire area of interest and extend upstream and downstream far enough to allow for stabilization of model results from instabilities caused by boundary

conditions. If necessary, this analysis should inform on the height to install any flow management devices.

- Conduct hydraulic modelling of a range of alternatives that represent possible future beaver dam build-out scenarios. The alternatives analysis should include consultation with experts familiar with beaver behavior to help inform the possible build-out scenarios. These scenarios may include: additional beaver dams becoming established in locations nearby, existing beaver dams being raised from their current height, hydraulic roughness increasing as a result of vegetation becoming established, or sediment being captured upstream of beaver dams.

4.3 Other Community/Stakeholder Considerations

In addition to considering ecological effects and potential flooding impacts of new beaver dams on Sonoma Water channels, it will also be important to consider local community and other stakeholder interests as Sonoma Water decides how to address a new beaver settlement. On Fryer Creek, for instance, many local residents see the beaver dams on a daily basis, from their homes or from the public pathways. Many feel strongly about beaver protection, or simply enjoy watching the bird and wildlife activity that beaver dams facilitate. Others may be concerned about potential flooding, odor, or mosquito populations. Listening to community input, and communicating Sonoma Water's beaver-related plans and protection measures, will continue to be an important aspect of Sonoma Water's work, educating the public and building community trust. Providing basic information on beaver biology and ecology may also be valuable.

Community input can be gathered through informal interactions in the field or meetings with neighborhood members where needed. Locals can be informed of Sonoma Water's practices through neighborhood meetings, explanatory signage, or guided walks. Educational signage could be installed in key locations to help passers-by understand and appreciate how Sonoma Water is working with beavers on these channels. Residents could also be invited to serve as observers of beaver activity and report new findings such as new dam locations.

5 Management Methods

If the assessment of potential impacts of beaver to a SMP reach determines that problematic effects are likely, there are multiple tools available to help manage beaver activity. The purpose of this plan is to provide an array of management strategies that apply to the most likely concerns, while leaving flexibility for Sonoma Water staff to adjust their approach based on particular site conditions. These strategies can be refined over time, as methods are tested in a variety of settings, and outcomes observed. The table below provides a brief summary of beaver dam settings, and potential management actions. Following sections describe each action in detail. See the Stream Maintenance Program Manual (SCWA 2020) for guidance on types of actions which may require permitting by or consultation with regulatory agencies.

Table 1. Summary of Potential Beaver Dam Settings and Management Strategies

Potential settings for beaver activity along SW channels	*Management options*
Away from homes or other infrastructure	No intervention is likely to be needed. Monitor for possible beaver dispersal toward more developed areas.
Where vegetation clearing is needed	Follow Beaver Protective Measures during maintenance activities. See Section 6.
Near homes or other infrastructure vulnerable to flooding, and beavers are currently present/active	Make initial simplified assessment of flood potential; see Section 4.2.1. If none, no further measures needed. If potential for flooding: - Implement measures to manage height of dams, such as pond leveler device installation. See Section 5.3. - Conduct comprehensive flood risk analysis, if needed, to refine understanding of site and management options. See Section 4.2.3.
Near homes or other infrastructure vulnerable to flooding, but beavers are no longer present	If absence is confirmed by a wildlife biologist, modify (notch) the dam with hand tools, or remove if necessary. See Sections 5.5 and 6.
In or near a culvert	Install trapezoidal fencing to prevent blockage of culvert. See Section 5.4.1.
In or near a concrete water conveyance structure	Install a steel weir inlet protector device ("Beaver Back Saver"). See Section 5.4.2.
In a location resulting in undesirable damage to living trees	Install protective fencing around trees to prevent beaver damage. See Section 5.2.
In a location determined to pose a threat to safety or infrastructure that cannot be addressed by measures above	As a last resort, consider exploring whether live trapping of beavers and relocation may be possible, or whether frequent dam removal to encourage abandonment is appropriate. See 5.6 and 6.

5.1 Monitor for Beaver Activity

Staying apprised of beaver activity, especially in new locations on SMP reaches, will be a crucial step in working with beavers. Sonoma Water staff already inspect channels on a frequent basis. If field staff are trained to recognize signs of beaver activity, they can incorporate that element into existing routine site inspections. Identifying activity early will allow for more time and more options for managing beaver activity where needed.

Since beavers themselves are often most active at night, and may be hard to detect during the day, looking for signs of their activity is the easiest way to determine if they are present. Typical signs include chew marks on trees; cut lengths of plant debris in waterways; lodges of branches and mud or excavated into banks; worn pathways into the water; tracks in muddy areas; and scat. Note whether or not activity appears recent, indicating current or past beaver activity. See Figure 10, below, for reference photos.

Another animal species in the region is sometimes mistaken for beaver, the muskrat. Muskrats have been seen in multiple waterways throughout central and southern Sonoma County, based on PCI observations and iNaturalist (2022) reports. Beavers and muskrats are both brown, semi-aquatic rodents and occupy similar habitats. They can be distinguished based on the basis of the beaver's larger size, its broad, flat tail, and other traits. Beavers' tails do not visibly break the surface of the water while swimming; the muskrat uses its tail as a rudder and it can be seen moving back and forth on the water surface. See Figure 11 for details.

Once beavers are known to be active on a channel, more detailed observations may be useful to help guide protective measures. Identifying burrow locations will help spot any resulting concerns with bank stability promptly. Wildlife cameras can be installed to help confirm den location(s), kit season, and activity patterns to support avoidance. See Section 6.

BECOME BEAVER AWARE

Beaver are often nocturnal and can be difficult to observe in the daytime. Learn to recognize and age the following signs to determine if beaver are currently present on the landscape:

Beaver dams – see pp. 1, 9, 10, 11, 16, 18, 26 for more examples. (Brock Dolman/OAEC)

Bank lodge on a river. (Michael van Hatten/CDFW)

Bank lodge on a lake. (Kate Lundquist/OAEC)

Bank burrow with channel leading to entrance. (Kate Lundquist/OAEC)

Bank burrow entrance. (Brock Dolman/OAEC)

Beaver-dug channel provides safe access to forage and a means to drag food back to lodge. (Kate Lundquist/OAEC)

Beaver slides in and out of water. (Kate Lundquist/OAEC)

Figure 10. From Lundquist and Dolman (2018). Reference images of beaver sign, for supporting staff in monitoring for beaver activity.

MORE BEAVER SIGN

Beaver trail. (Brock Dolman/OAEC)

Beaver track front foot.
(Mary O'Brien/Grand Canyon Trust)

Beaver track rear foot.
(Mary O'Brien/Grand Canyon Trust)

Felled trees (Aspen) with tooth marks and wood shavings. (Photo: Brock Dolman / OAEC)

Chewed sapling. (Brock Dolman/OAEC)

Chewed sapling. (Kate Lundquist/OAEC)

Beaver building scent mound.
(Sherry Guzzi/Sierra Wildlife Coalition)

Beaver scat.
(Jim Coleman/OAEC)

Scat on pond bottom. (Kate Lundquist/OAEC)

Figure 10, cont'd. From Lundquist and Dolman (2018). Reference images of beaver sign.

Beaver

Native

Photos courtesy of Alaska DFG and Cheryl Reynolds

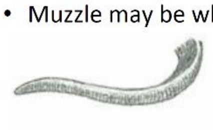
Muskrat

Native

Photos courtesy of N. Carolina State Parks and Merle Ann Loman

- **Black whiskers**

- Fine, **black whiskers**
- Muzzle may be white



Drawings courtesy of Danielle M. Crosier

- Tail **broad and flat**.
- Tail flattened top-to-bottom
- Slap water with tail when disturbed

- Tail **flattened side-to-side**
- Tail used for swimming with rapid side-to-side serpentine motion

Silhouettes courtesy of USFWS

- Adult size averages 40 pounds
- Length to over 3 feet, including tail

- Adult size: 2-5 pounds; body length up to 1 foot

Photo courtesy of Anh Vinh Nguyen

- Fully webbed

Photo courtesy of USFWS

- No webbing

Photo courtesy of Ohio DNR Division of Wildlife

- 5 visible toes on front track
- Rear track to 6 inches in length
- Tracks may be accompanied by a broad tail drag

Photo courtesy of WDFW

- Rear track is 2-3 inches in length

Figure 11. Comparison of beaver and muskrat. Excerpted from CDFW's Nutria Identification Guide (2022).

5.2 Install Fencing Around Trees to Protect from Beaver Damage

In some situations, loss of some trees to beaver harvest will not conflict with Sonoma Water's other resource goals. However, if damage is occurring to landscape plantings, important mature trees, or restoration plantings, or is extensive enough to reduce shading and other riparian habitat values, trees can be effectively protected by installing protective fencing (tree cages). Installing tree cages may also be appropriate for protecting trees that are large enough to potentially block a downstream culvert, if they were felled.

Trees can be protected either individually or in groups with 3-foot-high galvanized welded wire (Lundquist and Dolman, 2018). Chicken wire is not strong enough to withstand beaver chewing. The wire should completely surround the tree, while leaving a 12-inch space to allow for growth. Caging should be checked every three to five years to ensure it is in place and not restricting tree growth.

An alternative to caging is to paint the base of trees with a mixture of oil or latex paint (matched to tree color) and fine sand (Pollock et al. 2018, Lundquist and Dolman 2018). This requires repeated application over time. Mix 20 ounces of masonry sand with 1 gallon of exterior grade latex paint. Remove any debris from the tree bark before applying, and avoid applying too thickly so the mixture does not roll off. Paint the base of the trunk from ground level up three feet.

In addition to protecting existing trees, in some cases active replanting of riparian trees and shrubs may be warranted along channels. Among the many benefits native riparian vegetation provides, it can shade stream channels, which can in turn reduce cover of invasive plants, like water primrose (*Ludwigia* spp.), that inhabit slow-moving, shallow, warm water.

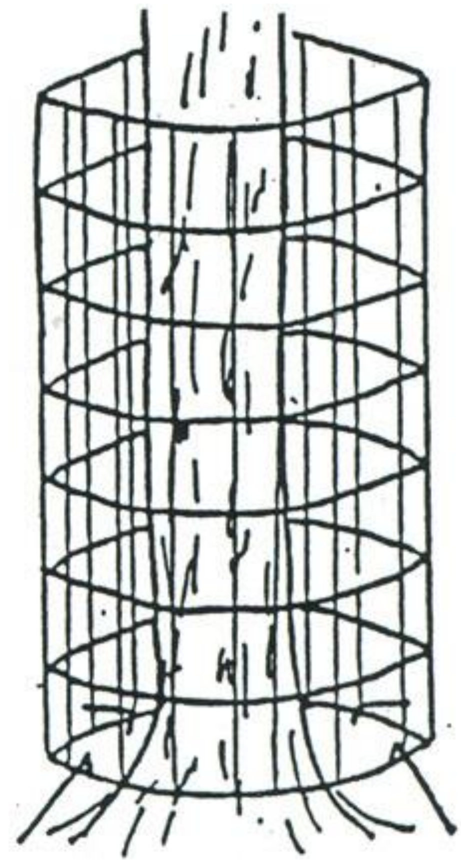


Figure 12. Protective fencing (tree cage) to protect tree from beaver damage. Image: Beavers.org

Another approach to large-scale tree protection mentioned in the literature is installation of long fences along stream edges. This would force beaver to travel longer distances in the upland, more exposed side of the fence to access trees, potentially discouraging them. The effectiveness of this method is not clear. The use of chemical or physical (e.g., noise or lights) beaver deterrents is not considered effective because any deterrence is short-lived (Pollock et al. 2018).

5.3 Install Flexible Pond Leveler Devices to Manage Pond Water Levels

Where beaver activity is ongoing and actively maintained dams have been determined to pose a flooding concern for nearby infrastructure, flexible pond leveler devices can be installed. Pond leveler devices allow for maintaining adequate pond habitat to sustain beavers while reducing the risk of flooding (Figure 13). These have been used successfully by Sonoma Water on Fryer Creek, and have proven to be a cost-effective measure in flood control channels in many other regions (Simon, 2006; Boyles and Savitzky, 2008; Pollock et al., 2018; Lundquist and Dolman, 2018).

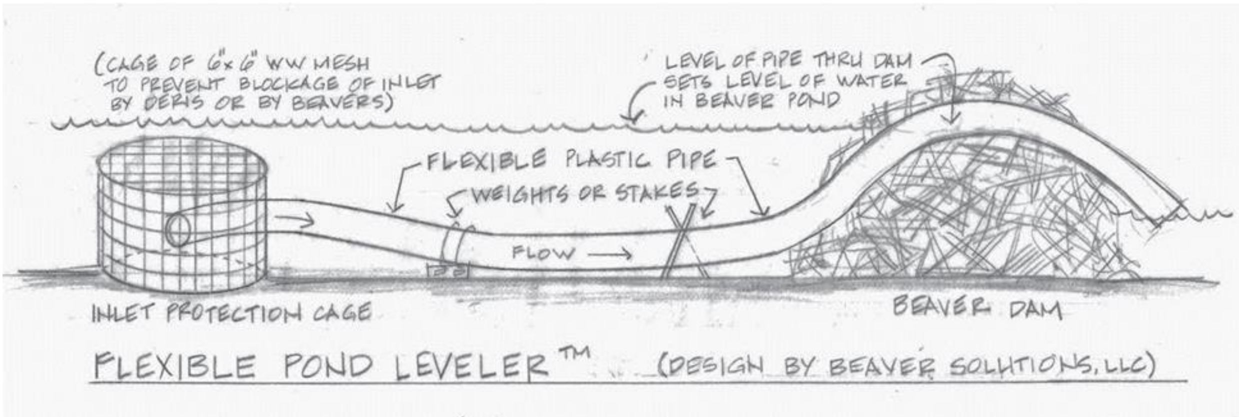


Figure 13. Beaver dam pond leveler device. Diagram by Sherry Guzzi, Sierra Wildlife Coalition (Source: Lundquist and Dolman, 2018)

Flexible pond levelers consist of a flexible PVC or HDPE pipe, sized to pass base flow, which is anchored in a notch in the dam. By diverting water through the dam with a flexible pipe, the water level upstream of the beaver dam is controlled by invert of the pipe through the beaver dam. The inlets of the flexible pipe are guarded by heavy gauge wire to prevent beavers from hearing or feeling the water flow, and blocking the inflow with dam building material. The device inlet must always be completely submerged, preferably with a minimum freeboard of 12” to prevent formation of an audible whirlpool at the inlet. If the beavers can find the inlet, they will block it immediately. The outlet is hidden at the downstream edge of the dam to mimic the natural leakiness of all beaver dams, and avoid triggering the beaver’s natural instinct to cover the outlet. The devices prevent the sound of flowing water over the dam, which is a key trigger for beavers’ dam-building or dam-repair behavior.

Flexible pond levelers limit how high the beavers can pond water upstream, thus reducing dam-building stimulus and related tree removal. These devices can easily be raised and lowered as needed to allow for adaptive management of water level heights during base flows and dam height impacts during flood flows. However, levels should be reduced incrementally, to ensure that beaver lodge submerged entrances are not exposed.

Installation of a flexible pond leveler typically requires about half a day of labor for 2-3 people; typical materials cost was reported to be approximately $600- $1000 by Wheaton (2013).

Ongoing monitoring and maintenance of these devices is important. Regular inspections are needed to ensure that all portions of the pond leveler devices are clear, working as intended, and maintaining water levels at the desired elevation. In particular, inspect inlet protection fencing for potential damage or plugging after larger storms where bedload or vegetative debris have been transported by the stream. Potential blockages may not be visible above the water surface, so staff may need to enter the water to conduct inspections.

Figure 14. Pond leveler device - caging around intake visible above a dam.

Figure 15. Pond leveler device - flexible pipe allowing water to flow through dam.

5.4 Protect Culverts and Weir Inlets from Blockage

Beaver activity has potential to obstruct flow through water conveyance infrastructure including culverts and concrete weirs. This can be prevented with installation of protective devices. These devices or protective fencing, like pond leveler devices and any other installation within a stream channel, will require monitoring and maintenance to ensure they are clear of debris and functioning as intended. To minimize maintenance needs, installation of these devices is recommended only when blockage is a clear concern.

5.4.1 Prevent Culvert Blockage with Trapezoidal Fencing

Beavers may attempt to build a dam in or adjacent to a culvert, where it could reduce or block the flow of water (Lundquist and Dolman, 2018). To prevent beavers from building there, a trapezoidal fence can be installed, with the narrowest end at the culvert and wider end upstream. The fence prevents the beaver from constructing at or near the culvert. If the dam-building continues, the beavers will be forced to build a longer dam along the fence, and the stimulus to build will diminish as the beavers get farther from the rushing flow of water at the culvert. Trapezoidal fencing is best suited to wider channels, where there is enough room to effectively widen the upstream fence end. In narrower channels, the fencing can be installed in conjunction with a pond leveler device; first, let the beavers build along the fence until water height is suitable for the device, and then install a pipe through the fence.

Figure 16. Trapezoidal fence to protect culvert in Massachusetts. Photo by Michael Callahan (www.beaversolutions.com).

5.4.2 Prevent Blockage of Concrete Weir Inlets by Installing a "Beaver Back Saver" Device

The Sutter National Wildlife Refuge has designed, fabricated and deployed a steel manifold with perforated poly pipe inlet attached to prevent twin track water conveyance structures from being blocked by beaver. These deterrence devices save time and money for those managing water control structures as they save a great deal on maintenance expenses. These can be manufactured in-house or purchased through Briggs Manufacturing Inc. in Willows, CA.

Figure 17a. Weir inlet protector device illustration. Courtesy of OAEC.

Figure 17b. Weir inlet protector device installation. Courtesy of OAEC.

5.5 Notch Abandoned Dams to Reduce Water Levels

If a dam is no longer in use by beavers, but still poses a flooding concern, partial breaching or notching can be undertaken. By notching the dam to lower the water level to a safe elevation (rather than removing the dam completely), other benefits of beaver dams, such as increased storage and infiltration of water, can still be retained for some time. The notch should be wide enough to let incoming debris flow through during storms. Consult with a wildlife biologist before work to confirm that there is no current beaver activity. Notching a dam that is in active use by beavers is not recommended as a flooding management strategy because beavers are likely to rapidly repair the notch.

5.6 Dam Removal, Live Trapping and Relocation

Dam removal, live trapping, and relocation are not likely to be appropriate measures on Sonoma Water channels, though they are used in other states. Attempting to remove dams from urban flood control channels can be laborious and costly when beavers immediately and continuously return (Boyles and Savitzky, 2008). Repeated dam removal to encourage beavers to abandon the site should only be considered as a last resort if dams pose a serious management concern and other measures have been unsuccessful, and should be done in consultation with a biologist.

Current California state policy does not allow for individuals or other agencies to relocate beavers. California Department of Fish and Wildlife (CDFW) provides permits for depredation of beavers when there is damage to land or property. In other parts of the western U. S., where relocation by other agencies is allowed, these efforts have often been unsuccessful, with beavers failing to establish at their new sites (Pilliod et al. 2018). It can also be challenging to trap all beavers in an area of concern, so re-establishment of remaining beavers – or rapid dispersal into the vacated area from nearby populations - is possible.

However, if beaver activity poses a serious management concern and all other methods have been exhausted, live trapping and relocation may merit consideration. With recent growing awareness of the ecological services beavers provide, CDFW's position on beavers is evolving and policy may change. Land managers in some regions where beaver have been extirpated are eager for the re-establishment of beaver, and may be interested in receiving relocated beaver. A beaver biologist and regional representatives of CDFW should be consulted if live trapping and relocation is being considered.

There is little literature on beaver relocation practices in California, but elsewhere in the West (where populations are more numerous and relocation is permitted), authors report that planning relocation to ensure that beavers can immediately avoid predators and access food supplies, and readily build dams, is crucial. Fresh willow cuttings can be provided at release sites to support beavers as they adjust to their new environment.

Lethal trapping is not recommended on Sonoma Water channels, as beaver populations are only gradually recovering from historic extirpation in this region, they play an important role in our region's ecological health and biodiversity, and are a native species.

5.7 Monitor Channel Conditions

Ongoing monitoring of channel conditions, which is already a part of regular Sonoma Water practice, is a crucial step in working with beavers. In addition to monitoring for new beaver activity, frequent on-the-ground review of channel conditions is needed to:

- **Monitor culverts regularly to ensure that they are clear of debris.**
- **Ensure pond leveler devices are functioning as intended and set at the appropriate level.**
- **Monitor for potential bank erosion adjacent to dams or above bank burrows.** Some bank erosion might be acceptable in many locations while in others it may pose a concern for infrastructure stability.
- **Assess channel reaches with beaver dams annually for sediment accumulation and vegetation establishment.** If seasonal flow does not control vegetation establishment in the low-flow channel, perform vegetation clearing as needed for public safety. Balance the vegetation's value for beaver and other habitat benefits with the need to reduce flood risk. Undertake the clearing with as light a touch as possible, minimizing the area of disturbance and retaining patches of each native vegetation type. See next section for additional beaver and habitat protection guidance.
- **Monitor for large trees felled by beavers, which may pose a concern for culvert blockage in a storm.** Monitor for these regularly throughout the year and remove them from the site. Perform a final clearance of downed material in late summer, prior to fall rains. However, recently downed trees provide essential resources for beaver, so if any trees can be safely left on site temporarily while they are still fresh (e.g., trees felled early in the dry season), these may be retained, at Sonoma Water's discretion. Note that, if all felled trees are immediately removed, beavers are likely to cut down additional trees, may cause damage to nearby residential infrastructure, or may leave the area. Consider anchoring selected fallen trees in place near the den to provide the beavers with woody vegetation without potentially causing culvert blockage.

The preferred time to remove a felled tree should be assessed by a wildlife biologist considering several factors. Beavers harvest trees for the leaves and bark and need to chew on trees for tooth sharpening. If there are fresh chew marks and bark attached to a tree, it is likely still in use. If a felled tree has the bark peeled off, beavers may be done with it or they may use it for building materials or tooth sharpening. Leaving felled tree material if it can remain without causing a flood risk is preferred.

Figure 18. Monitoring will be needed for locations like this one on East Fork Fryer Creek, where pond leveler devices have been installed to prevent flooding of adjacent access path and homes, to ensure that water levels are maintained at the desired elevation.

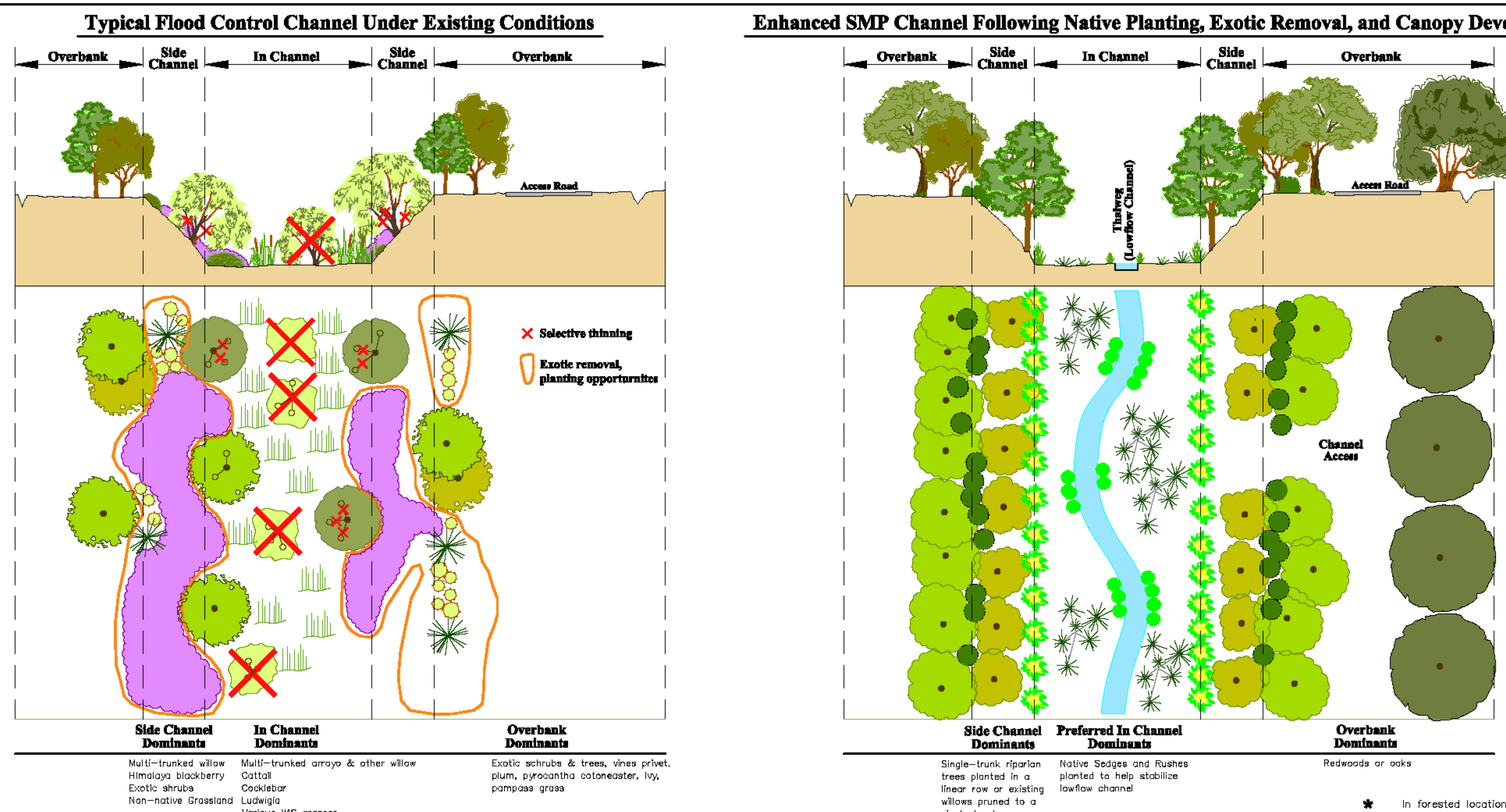
6 Protecting Beaver During Vegetation and Sediment Management

Beaver-occupied areas along Sonoma Water's SMP reaches will require ongoing maintenance. The vegetation in riparian areas will need to be managed annually for public safety and fire fuel reduction and will include such activities as mowing, downed tree removal, tree pruning, invasive plant removal and hazard tree removal. The sediment build-up in waterways will require periodic sediment removal in areas potentially occupied by beavers. This sediment removal could help the beaver persist by maintaining adequate water depths, as they need 3-foot pool depths to ensure escape cover from predators. These maintenance activities can be conducted in a way that minimizes negative impacts to beavers. These activities should be overseen by a qualified biologist who is familiar with beaver behavior, or beaver specialist.

- **Retain as much beaver forage as possible.** Throughout reaches where beavers occur, remove only as much vegetation as is necessary for flood protection and public safety. Riparian and wetland plants including willows, cattails, and green grasses are essential food sources for beaver. When favored beaver food sources are cut or pulled, consider leaving them on the bank near the lodge for beaver to utilize. Materials unused by beaver after 3 or more months can be removed. Sonoma Water also increases beaver forage by planting native trees, shrubs, and herbaceous plants in riparian areas. While most woody plantings will be protected from beaver use during their establishment, some, once well-established, can serve as food sources for beaver. See Figure 19 for a schematic representation of Sonoma Water's typical approach to selective thinning and invasive plant removal, and revegetation planting layout and species palette.
- **Designate the area within a 100-foot radius of a beaver lodge as "sensitive."** Use landscaping flags on the banks to help work crews identify where this area begins and ends.
- **Use wildlife cameras to monitor beaver presence before and after maintenance, especially when conducting larger projects such as sediment removal.** Use camera monitoring observations to confirm den location(s), kit season (typically mid-April to mid-June; generally prior to sediment removal work), and activity patterns to support avoidance. Also, use camera monitoring to compare beaver activity patterns before and after work on site, to determine whether work appears to affect beaver persistence or activity. If camera monitoring indicates disruption of beavers by maintenance activities, confer with biologist to identify any changes needed in management practices.
- **Avoid work in the sensitive area during kit season (generally mid-April to mid-June) to the extent possible.** Mowing or weed abatement to reduce fire hazard may need to be performed within a sensitive area in this time frame. If so, have a biologist conduct a sweep through the area immediately ahead of the work to ensure no beavers are present. If possible, leave some herbaceous plants near the bank burrow as the nursing female will rely on green vegetation for milk production.
- **Use hand tools to conduct work in the sensitive area. If heavy equipment use cannot be avoided within the 100-foot sensitive area:**
    - Keep heavy equipment at least 50 feet from a lodge entrance. Use the smallest equipment practical.
    - If possible, keep heavy equipment on the opposite bank from a lodge to minimize ground vibration, using the excavator's arm and bucket to reach towards a lodge entrance.
    - Minimize the length of time equipment is in use.

- **Within the sensitive area, minimize the removal of favored food species (willow, cattail, green grasses) to the extent possible.** Where Sonoma Water determines this is necessary for flood or fire protection, consult with a biologist familiar with beaver ecology to identify how much vegetation, which plant species, and which locations, can be cleared with the least impact on beavers. If possible, undertake an adaptive management process in which a minimal amount of vegetation is removed the first year; observe beaver responses; and slowly increase the amount removed annually (if needed) to determine what this site's minimum beaver food resource threshold is. Focusing vegetation removal work in the midday hours will reduce likelihood of direct interactions with beavers, who are most active from dusk to early morning.
- **Consider dewatering impacts and options.** Sonoma Water typically undertakes temporary dewatering to facilitate channel sediment removal. Dewatering in beaver-occupied waterways, especially around dens, could cause beavers to abandon the site. It may be possible to install a temporary dam that would keep a den area watered during this process, or to conduct sediment removal without dewatering. The latter would use the existing beaver dam to contain turbidity, although additional measures to curtail turbidity within the pond and downstream of the dam may be needed. Changes to sediment removal practices will require review of Sonoma Water's permits for instream work to ensure the new approaches are acceptable to regulatory agencies. If the process of sediment removal is done in a way that does not cause abandonment by beavers, the resulting increase in pond depth could ultimately be beneficial to beavers.

See the seasonal calendar in Section 7 for an overview of typical timing for key beaver protection and maintenance activities.



Stream Maintenance Program Plant Palette

Common Name	Scientific Name	Planting Area	Planting Source
Trees			
Big leaf maple	*Acer macrophyllum*	Mid to Upper Bank	Container
Box elder	*Acer negundo*	Mid to Upper Bank	Container
California buckeye	*Aesculus californica*	Upper Bank	Container
White alder	*Alnus rhombifolia*	Toe to Mid Bank	Container
Oregon ash	*Fraxinus latifolia*	Toe to Mid Bank	Container
N. California black walnut	*Juglans californica*	Mid to Upper Bank	Seed (fresh) or Container
Fremont cottonwood	*Populus fremontii fremontii*	Toe to Mid Bank	Cutting or Container
Coast live oak	*Quercus agrifolia*	Upper Bank	Container
Valley oak	*Quercus lobata*	Upper Bank	Container
Red willow	*Salix laevigata*	Toe to Mid Bank	Sprigs
Arroyo willow ***	*Salix lasiolepis*	Toe to Mid Bank	Cutting
Pacific willow	*Salix lucida lasiandra*	Toe to Mid Bank	Cutting
Coast redwood	*Sequoia sempervirens*	Mid to Upper Bank	Container
California bay laurel	*Umbellularia californica*	Upper Bank	Container
Vines			
California blackberry	*Rubus ursinus*	Toe to Mid Bank	Seed or Container

Common Name	Scientific Name	Planting Area	Planting Source
Herbs/Grasses			
Spike bent	*Agrostis exharta*	Toe to Mid Bank	Seed
Leafy bent grass	*Agrostis pallens*	Toe to Upper Bank	Seed or Container
Sloughgrass	*Beckmannia syzgachne*	Toe to Mid Bank	Seed
Santa Barbara sedge**	*Carex barbarae, C. obnupta, C. bolanderi*	Toe	Seed or Cutting
Torrent sedge	*Carex nudata*	Toe	Seed or Cutting
Pale spikerush	*Eleocharis macrostachya*	Toe	Seed or Cutting
Blue wild rye	*Elymus glaucus*	Mid to Upper Bank	Seed
California fescue	*Festuca californica*	Mid to Upper Bank	Seed
Red fescue	*Festuca rubra*	Toe	Seed
Meadow barley	*Hordeum brachyantherum*	Toe to Mid Bank	Seed or Container
Wire rush	*Juncus balticus*	Toe	Cutting or Container
Pacific rush	*Juncus effusus*	Toe	Cutting or Container
Common rush	*Juncus patens*	Toe	Seed or Container
Rice cut grass	*Leersia oryzoides*	In-Channel	Seed or Container
Creeping wild rye	*Leymus triticoides*	Toe	Seed
Bulrush, Tule	*Scirpus acutus occidentalis, S. californicus*	Toe to Mid Bank	Cutting or Container
Small fruited bulrush	*Scirpus microcarpus*	Toe to Mid Bank	Cutting or Container
Purple needle grass	*Stipa pulchra*	Mid to Upper Bank	Cutting or Container

Common Name	Scientific Name	Planting Area	Planting Source
Shrubs			
Western spicebush	*Calycanthus occidentalis*	Toe to Upper Bank	Seed
Stream dogwood	*Cornus sericea*	Toe to Mid Bank	Container
California hazelnut	*Corylus cornuta californica*	Mid to Upper Bank	Container
Toyon	*Heteromeles arbutifolia*	Upper Bank	Container
Ocean spray	*Holodiscus dicolor*	Mid to Upper Bank	Container
Twinberry	*Lonicera involucrata*	Toe to Upper Bank	Container
Coffeeberry	*Rhamnus californica*	Upper Bank	Container
California wild rose	*Rosa californica*	Toe to Upper Bank	Seed or Container
Blue elderberry	*Sambucus mexicana*	Upper Bank	Container
Snowberry	*Symphoricarpos albus laevigatus*	Mid to Upper Bank	Container
Ferns/Other			
Bracken fern	*Polystichum aquilinum*	Mid to Upper Bank	Cutting or Container
Sword fern	*Polystichum californicum*	Toe	Container
Western chain fern*	*Woodwardia fimbriata*	Toe	Container

* In forested locations.
** Or equivelent.
*** Not preferred but can be used on case by case basis.

Notes

1. Species for each project should be chosen based on native flora (current and historic) of project area.
2. Seeds, cuttings, seedlings and saplings used for revegetation should be obtained from local (Russian River Watershed or North Coast Floristic Province as defined in Jepson 1993) stock (local native plant nurseries should be used, or plants can be collected using appropriate collection techniques from adjacent sites – willow sprigs should be collected from adjacent sites and planted on the same day as collection).
3. Timing of planting should be appropriate for species and source (e.g. broadcast seeding of herbs and grasses in fall before first rains, cuttings planted when soil moist to at least 10 inches from rainfall, etc.).

FLOOD CONTROL\STREAM MAINT\CHANNEL MAINTENANCE PROGRAM\CONCEPTUAL PLANTING DIAGRAM.dwg APRIL 28, 2008

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Stream Maintenance Program
Conceptual Planting Diagram

Figure 11-6

Figure 19. Excerpt from SCWA (2020), Figure 11-6. Schematic diagrams of typical Sonoma Water vegetation thinning (red "X"s) and removal (orange outline) for flood control channel maintenance (left), and of native riparian planting (right).

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7 Seasonal Calendar of Beaver-related Activities

The calendar below shows typical timing for beaver activity, monitoring, and maintenance tasks.

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">Key beaver activity and monitoring</td><td></td><td></td><td></td><td colspan="3">Kit season</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="8">Camera monitoring to confirm den location(s), kit season, activity patterns</td><td></td><td></td></tr>
<tr><td rowspan="7">Key maintenance activities</td><td></td><td></td><td colspan="4">Flag sensitive area around lodge for avoidance. No work in sensitive zone, if possible.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Mowing/trimming for fuel reduction</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="5">Vegetation pruning or removal as needed - for public safety and invasive species management</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Sediment removal as needed</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Ongoing: Monitor for downed wood to remove or other debris that may cause flood damage</td><td></td><td></td><td colspan="2">Final check for downed wood prior to rains</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Ongoing: Maintain pond leveler devices and culvert fences. Monitor for new dams.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Ongoing: Protect selected living trees from beaver damage by installing protective fencing (tree cages). Monitor existing tree cages to ensure adequate space around trunk is maintained.</td><td></td><td></td><td></td><td></td><td colspan="2">Plant native trees for habitat and shading of Ludwigia</td></tr>
</table>

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