Afton Canyon River Restoration Post-Project Appraisal

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Abstract

Vegetation restoration projects throughout the American Southwest have yielded positive outcomes for degraded desert streams, including the Mojave River restoration at Afton Canyon in the Eastern Mojave Desert (Egan, 1999; 2016; Bunn et al., 2003). Although rare, beaver translocation has demonstrated success as a passive desert river restoration strategy at the Price and San Rafael Rivers in eastern Utah and the San Pedro River in Arizona (Soykan et al., 2009; Doden, 2021; Sandbach, 2023). The success of translocated beaver populations is determined by mortality rate and site fidelity, as dictated by habitat quality (Colleen & Gibson, 2000; McKinstry & Anderson, 2002; Petro et al., 2015; Morris et al., 2021; Bilby & Moseby, 2023). In deserts, beaver habitat is restricted to riparian forests (Rutherford, 1964; Bee et al., 1981; Welch et al., 1993). The restoration project at Afton Canyon has facilitated the return of native willow and cottonwood populations and beaver sightings have increased (Egan, 1999; 2016; MDRCD, 2022). It is likely that a combination of natural beaver recolonization and translocation would facilitate further habitat restoration.

Fremont cottonwood (*Populus fremontii*) along the southern bank of the Mojave River, Afton Canyon

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1. Introduction

Rivers are critical to the otherwise water-starved landscape of California's arid regions, shaping desert ecology (Kingsford, 2006). These rivers are highly productive and metabolically active systems providing critical habitat for a variety of native species (Fisher, 1995; Lamberti & Steinmann, 1997; Bunn et al., 2006; Brand et al., 2008). High temperatures, intense light, and low-current velocity create the ideal conditions for aquatic primary productivity (Busch & Fisher, 1981; Velasco et al., 2003; Bunn et al., 2003; 2006).

1.1 Hydrology

Afton Canyon was cut rapidly from the overflow and drainage of Lake Manix during the end of the last Quaternary ice age (see Map 1. Meek, 1989; Reheis & Redwine, 2008). The Mojave River runs underground for most of its 110-mi. length. Afton Canyon is one of just two locations where the underlying bedrock pushes water to the surface, along with the upper narrows (see Map 2. Egan, 1999; 2016). Upon exiting the canyon, the river continues eastward to its terminus at Soda Lake Basin (Meek, 1989). The health of the canyon ecosystem began deteriorating after the installation of the Mojave Forks Dam in 1967. The percentage of the basin behind the dam is quite small- just 215 sq. mi. The dam is immediately downstream of the confluence of the Mojave's two perennial tributaries: West Fork and Deep Creek. The decision to dam the naturally flashy river had considerable downstream consequences, preventing the seasonal flooding necessary for native species to propagate and presenting the perfect opportunity for the uncontrolled spread of the invasive phreatophyte saltcedar (*Tamarix ramoissima*). This species of tamarisk quickly dominated the riparian corridor, forming dense thickets (BRA, 1989; Egan, 1999; 2016; Doden, 2021; 2022).

1.2 Ecology

Tamarisk was introduced to Afton Canyon in the early 1990s in a misguided attempt to control embankment erosion and stabilize riverbank sands. Since that time, unchecked growth has altered the hydrology significantly, narrowing the active channel and increasing the incidence of overbank flooding (Graf, 1978; Bunn et al., 2003). Additionally, the tamarisk has been gradually reducing biodiversity throughout the region. Old growth stands crowd out native plant species and inhibit the ability of wildlife to access the riverbanks. The combination of this invasive growth and the historic impacts of cattle ranching throughout the 1900s further worsened the damage to the canyon’s natural resources, particularly as the livestock tended to prefer grazing on the already scarce native vegetation over the tamarisk (DeLoach et al., 2000; Egan, 2016).

Tamarisk is an aggressive invasive, adapted to take over its environment at the detriment of the existing native plant communities. Tamarisk is highly drought and fire tolerant, capable of propagation vegetatively or by wind and water, and is highly resistant to traditional control methods such as herbicides and bulldozing (Hefley, 1937; Everitt, 1980; Shmida, 1991; DeLoach, 1991; 1996; 2000). Once well-established, it prevents the re-establishment of native species (Smith & Devitt, 1996; Cleverly et al., 1997; Smith et al., 1998; DeLoach et al., 2000). This initiates a cascade of species loss as native birds avoid the monocultural tamarisk stands (Engle-Wilson & Ohmart, 1978; Hildebrandt & Ohmart, 1982; DeLoach et al., 2000).

Tamarisk also alters the morphology and hydrology of the stream channel, using huge amounts of groundwater (DeLoach et al., 2000). Dense tamarisk stands along the riverbank accelerates bank aggradation, disrupts riffle structures, fills backwaters, and causes excessive deposition into sand and gravel bars. The channel narrows and deepens, and is blocked with debris. These obstructions pose an outsize risk when overbank flooding occurs (Busby & Schuster, 1971; Burkham, 1972; 1976; Graf, 1978; DeLoach et al., 2000). The spread of tamarisk directly alters the flood regime, extracting water and depositing large quantities of salt, increasing both water and soil salinity. It is also extremely flammable, thereby altering the fire regime, a pressing concern given the already elevated fire risk in arid regions (Gibson, 2023).

1.3 Restoration

Desert rivers pose unique restoration challenges through their varied hydrology and geomorphology (Kingsford et al., 2006). These systems are in a constant state of flux driven by floods and drought and thus demonstrate highly variable ecology and behaviour, characterized by often unpredictable flows (see Figure 1). Permanent water is highly limited and flash flooding plays a vital role in the natural flood regime (Courtois, 1984; Laub et al., 2015). This variability also plays a significant role in determining aquatic primary productivity (Junk et al., 1989; Walker et al., 1995; Puckridge et al., 1998; Kingsford et al., 1999; Bunn et al., 2003; Young & Kingsford, 2006; Free et al., 2013; Laub et al., 2015).

At Afton Canyon, the Bureau of Land Management (BLM) has undertaken a series of riparian restoration projects, starting with a 12-year reforestation effort initiated in 1992 (Lovich et al., 1994). The project was a joint effort between the BLM and the LA Conservation Corps, leveraging the influence of American Forests, a prominent non-profit conservation organization. With the momentum provided by a reforestation grant, the collaboration successfully implemented a vegetation management strategy prioritizing invasive removal and native species conservation guided by the 1989 Afton Canyon Management Plan. The project utilized an integrated approach of prescribed burning, mechanical cutting, cattle exclusion, vehicle use limitation, and the targeted application of herbicides. The project effectively controlled saltcedar spread by 1996 (Egan, 2016).

Additionally, 700 acres of tamarisk was removed and over 10,000 poles of cottonwoods and willows were planted, enhancing riparian functionality sufficiently to restore perennial flow and facilitate the restoration of ponding behaviour. The ecological benefits were significant, facilitating population growth of native saltgrass (*Distichlis spicata*), Desert bighorn sheep (*Ovis canadensis nelson*), and Western Pond turtles (*Emys marmorata*). Additionally, use of the river corridor by resident and neotropical migratory birds markedly increased. Increased sightings in recent years indicate that the native beaver population has increased also- a fact attributed to the restored perennial flow (Lovich & Meyer, 2002; Egan, 2016; MDRCD, 2022).

2 Methods

Archival research, field observations, satellite imagery analysis, and a flow frequency analysis were used to evaluate the success of the river restoration project.

2.1 Vegetation Diversity Survey

On November 11th and 12th, I conducted the field portion of this analysis by cataloguing notable observations. In particular, I followed the river course for approximately four miles recording the vegetation species I observed along both riverbanks. I repeated this process twice: at the Railway Trestle and at Deep Crossing.

2.2 Remote Sensing

The use of remote sensing in canopy cover characterization through the use of the Normalized Difference Vegetation Index (NDVI) is well-established (Jasinski, 1990; Hatfield et al., 2008; Plant, 2001; Trout et al., 2008). NDVI is the preferred tool for vegetation monitoring due to its ability to compensate for changing conditions- especially surface slope, aspect, illumination, and others. It is calculated according to the following equation:

$$NDVI = ((IR-R)/ (IR+R))$$

where:

IR=pixel values from the infrared line, R=pixel values from the red band (Lillesand, 2004).

The multiband datasets presented in this study were generated using the NDVI Colorized Raster Function in ArcGIS. The process was conducted on two NAIP imagery mosaics, each comprised of 3 tiles, visualizing the full extent of the river corridor through Afton Canyon. This imagery provides a visualization of vegetation health and density through the difference between the red and near-infrared bands, and the resulting NDVI3 colormaps are below in Figures 17 and 18.

2.3 Flow Frequency Analysis

Flow frequency analysis is a technique used to predict flow according to different return periods. This term refers to the estimate of likelihood that a given event will occur in any one year. This helps predict the magnitude of flow that we can expect from the river in question. In this case, I used the Hydrologic Engineering Centre's Statistical Software Package, or HEC-SSP to determine the percent chance exceedance values for certain flow rates.

3 Results

3.1 Vegetation Management

Archival research indicates the efficacy of the vegetation management strategy implemented by the BLM. This finding is supported by canopy cover density indicating an increase in healthy vegetation.

3.1.1. Site Vegetation Survey

By 2016, native riparian species including Gooding's black willow (*Salix nigra gooddingii*), Fremont cottonwood (*Populus fremontii*), and honey mesquite (*Prosopis glandulosa*) had successfully re-established in the riparian corridor and saltgrass meadows began to form (Egan, 1999; 2016). Today, this trend continues.

The river corridor is highly vegetated and heterogeneous, supporting cottonwoods, sycamores, ash, and various species of willows and mesquites (see Table 1). Unfortunately, recent inconsistency in tamarisk management has allowed for saltcedar re-establishment in some previously restored areas. As such, this exercise corroborated all evidence presented in Egan's project evaluation (Egan, 1999; 2016).

3.1.2 Aerial Imagery

The vegetation restoration project at Afton Canyon had a notable successes, one of which was the restoration of perennial flow. The prior Post-Project Appraisal, conducted in 2016, concluded that the project improved the functionality of the canyon river system significantly, noting ponding and expansive heterogeneous vegetation (Egan, 2016). The imagery analysed in this study aligns with this conclusion regarding both flow regime as well as species variety. The satellite imagery in Figures 5-16 display the entire extent of Afton Canyon, the Union Pacific Railway Bridge, and Mojave River Deep Crossing over a time span from 2010 to 2020. The most notable increases in vegetation density appear to occur between 2016 and 2020.

3.2 Flow Frequency Analysis

I conducted a flow frequency analysis using the Bulletin 17B Log-Pearson III method, using annual peak flow data to provide percent chance exceedance values for various flow rates. In this case, the FFA indicated that a 100-year flood event for this system has an expected discharge of 35,616 cubic feet per second.

4 Discussion

Although site-specific objectives vary between restoration projects, two main motivations are reducing the loss of native desert species from ecosystem degradation and restoring flow patterns and natural river behaviour. Accomplishing these objectives given the constraints of arid conditions and the growing risk of desertification requires careful consideration when formulating a restoration strategy. At Afton Canyon, the explicit stated intent was most closely aligned with the first objective. However, the evidence indicates that the BLM have successfully achieved both. The river corridor has expanded and become more lush and vegetated, this vegetation is highly diverse and heterogeneous, the river has consistently perennial flow, and sightings of native species have increased-including of the native beavers.

4.1 Beaver Translocation

The translocation of beavers (*Castor canadensis*) has become a common river restoration technique (McKinstry & Anderson, 2002; Butler & Malanson, 2005; Pollock et al., 2007; Woodruff, 2016; Charnley, 2019; Nash et al., 2021). However, the method is both understudied and underutilized in desert streams despite its potential to greatly improve ecosystem resilience by enhancing riparian habitat (Apple et al., 1984; 1985; Andersen et al., 2010). Beavers reduce channel incision and reintroduce ecosystem heterogeneity by accumulating large woody debris and constructing natural dams within the channel (Naiman et al., 1988; Pilliod et al., 2018; Baker & Hill, 2003; Wright et al., 2022; Pollock et al., 2014; Hood & Bayley, 2008; Fairfax & Small, 2018; Fairfax & Whittle, 2020). Though research is limited, beaver dam-building activity appears to benefit desert stream ecosystems through the same modes as Mediterranean rivers once the translocated population is successfully established (Meentemeyer and Butler 1999; Margolis et al. 2001; Snyder et al. 2006).

Beavers are highly adaptable and occupy a wide variety of habitats throughout their North American range (Gurnell, 1998). According to Lanman et al., the historic range of the beaver in California includes nearly the entire state (see Map 1). Multiple papers analysing these records have indicated that the only regions with conditions unfavourable enough to be considered prohibitive are the streamless reaches of the southern deserts (Grinnell et al., 1937; Tappe, 1942; James & Lanman, 2012; Lanman et al., 2012; CDFG, 2005; Asarian, 2013; Lanman et al., 2013). In fact, the near extirpation of the species from Southern California's rivers in the 1800s is largely associated with increased fur trapping—not the unsuitability of the habitat conditions (Tellman et al., 1997; Hastings, 2002; Lanman et al., 2013). In fact, many of the American Southwest's desert streams have historically supported beavers (Hoffmeister, 1986). Although the unpredictability of the flow regimes in these rivers generally limits beaver habitat extent, a subset of desert streams with perennial and relatively well-regulated flow and sufficient riparian vegetation are the notable exception (Allen & Price, 1895; Lovich, 2012).

The suitability of an ecosystem to support beavers is primarily reliant on a stable water body providing adequate and reliably accessible food resources and shelter for protection (Allen, 1983; Novak, 1987; Gurnell, 1998). Other key factors include: (1) a sufficient distribution and variety of suitable woody plant species at approximately 40-60% canopy cover, (2) a low-gradient high-sinuosity channel, and (3) favourable topography including broad valleys and wide floodplains (Allen, 1983; Easter-Pilcher, 1987; Gurnell, 1998; Baker & Hill, 2003). As such, the conditions that most often render a stream channel unsuitable for beaver translocation include an excessively high flow rate and volume, erosion rate, or gradient (Retzer et al., 1956; Yeager & Rutherford, 1957; Allen, 1983; Olson & Hubert, 1994). Additionally, high fluctuation in flow can render a stream too unstable to support a beaver population (Martin, 1977; Gurnell, 1998).

As a result, the hydrologic conditions of many desert river ecosystems limit the potential suitability of beaver translocation as a river restoration strategy. However, the expansion of anthropogenically-driven flow regulation in desert riparian forests has increased the potential suitability of beaver translocation. In particular, the reintroduction of beaver into Southwestern desert streams where they were extirpated in the 1800s is a growing practice in the broader field of river restoration. The practice continues to evolve as the secondary impacts of desert vegetation restoration and management activities aiming to sustain regional biodiversity have additional benefits on stream form and functionality. Perhaps the most notable example is the restoration of perennial streamflow to degraded desert rivers with inhibited intermittent flow through their dam-building activities (Shafroth et al., 2002; 2010; Pollock et al., 2007; Taylor et al., 2008; Soykan et al., 2009; Andersen & Shafroth, 2010). The successful ongoing maintenance and restoration of the Mojave River corridor in Afton Canyon is reliant on the premise of consistent management, and the passive benefits of beaver translocation can facilitate this continued success.

5 Conclusion

The inherent fragility of arid landscapes to land-use changes is well-established (Favretto et al., 2016; Quintas-Soriano et al., 2016; Liu et al., 2020; Ge et al., 2022). Urbanization, agriculture, intensive military uses, mineral extraction activities, and large-scale energy production are the land uses that most often encroach into the bounds of natural desert landscapes. These uses exert further pressure on already overstressed water bodies and bring with them secondary impacts including a higher incidence of invasive species spread (Wallace & Thomas, 2008; Gober, 2010; Gibson, 2023). This was the case at Afton Canyon, where the construction of the Mojave Forks Dam and the invasive spread of tamarisk severely degraded the river ecosystem (Egan, 1999; 2016).

Though research is limited, the translocation of beaver to facilitate desert river restoration has the potential to become a powerful and consistently viable tool for improving habitat without the often-damaging impacts of active river restoration strategies (Chazdon et al., 2021; Holthuijzen et al., 2021). At present, beaver translocation outcomes in desert rivers remain suboptimal. High mortality driven by predation and stress and the propensity of translocated beavers to disperse beyond the targeted restoration site are arguably the two greatest obstacles preventing this approach from achieving its full restoration potential (Doden et al., 2022a; 2022b). However, the adaptability of the species cannot be underestimated. The success of translocated beaver populations is determined by mortality rate and site fidelity, as dictated by habitat quality (Colleen & Gibson, 2000; McKinstry & Anderson, 2002; Petro et al., 2015; Morris et al., 2021; Bilby & Moseby, 2023).

Given the right conditions, beavers have successfully established in desert streams throughout the American Southwest and Afton Canyon is particularly well-suited to the approach. Restoration activities throughout the region have greatly improved the diversity and density of native vegetation, secured a consistent and perennial river flow, and fostered more supportive conditions for the small existing native beaver population, as illustrated by the subsequent uptick in sightings (Egan, 1999; 2016; MDRCD, 2022). As a result, translocation is highly viable and cannot be discounted as a mechanism of further improving channel conditions as restoration efforts continue.

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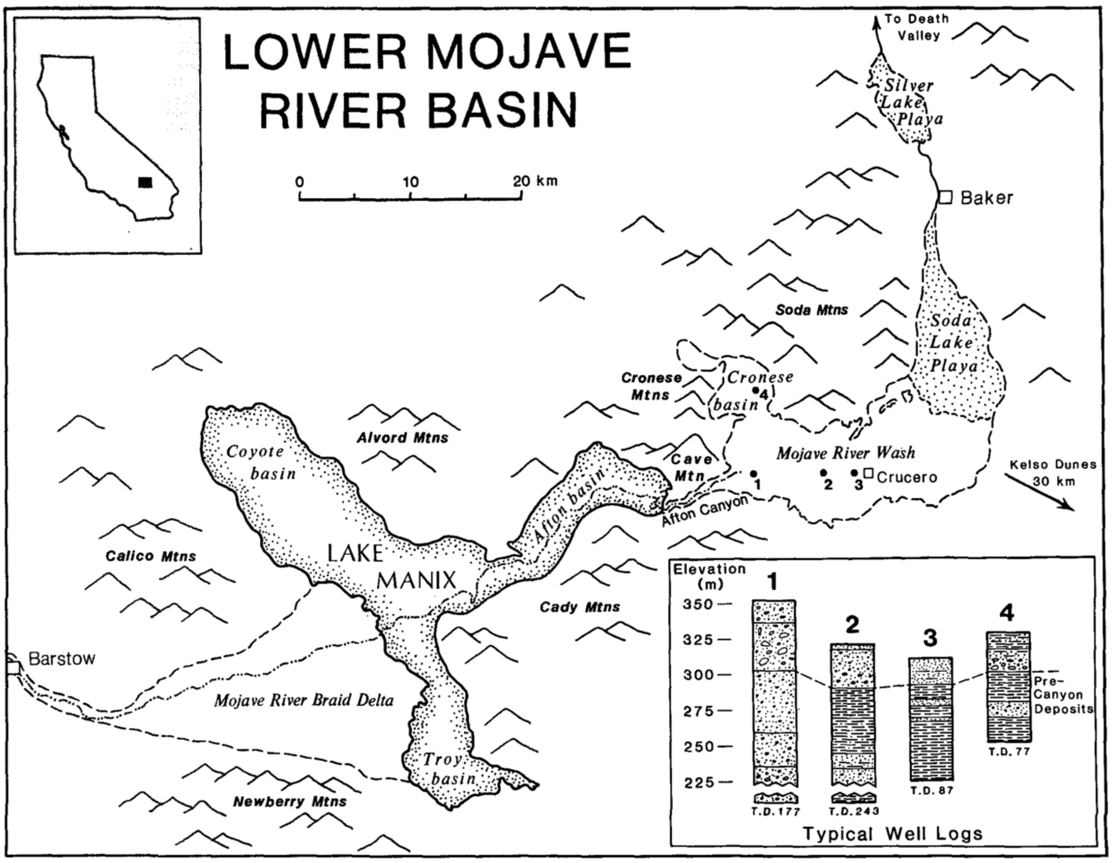
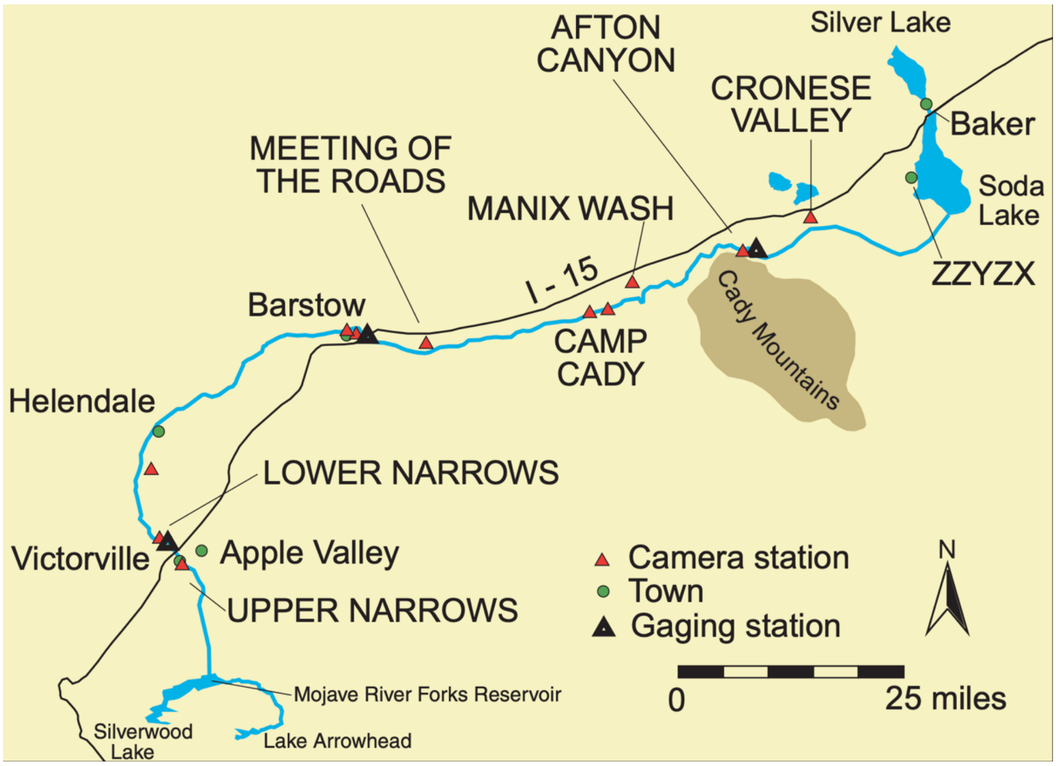
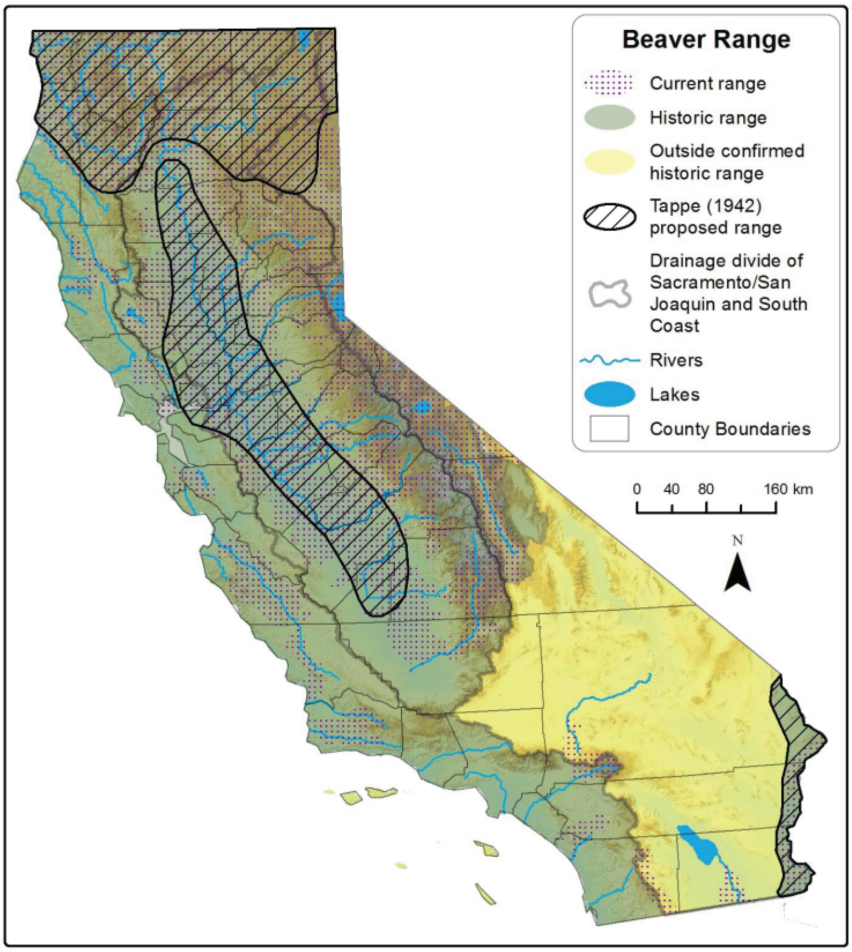
Maps



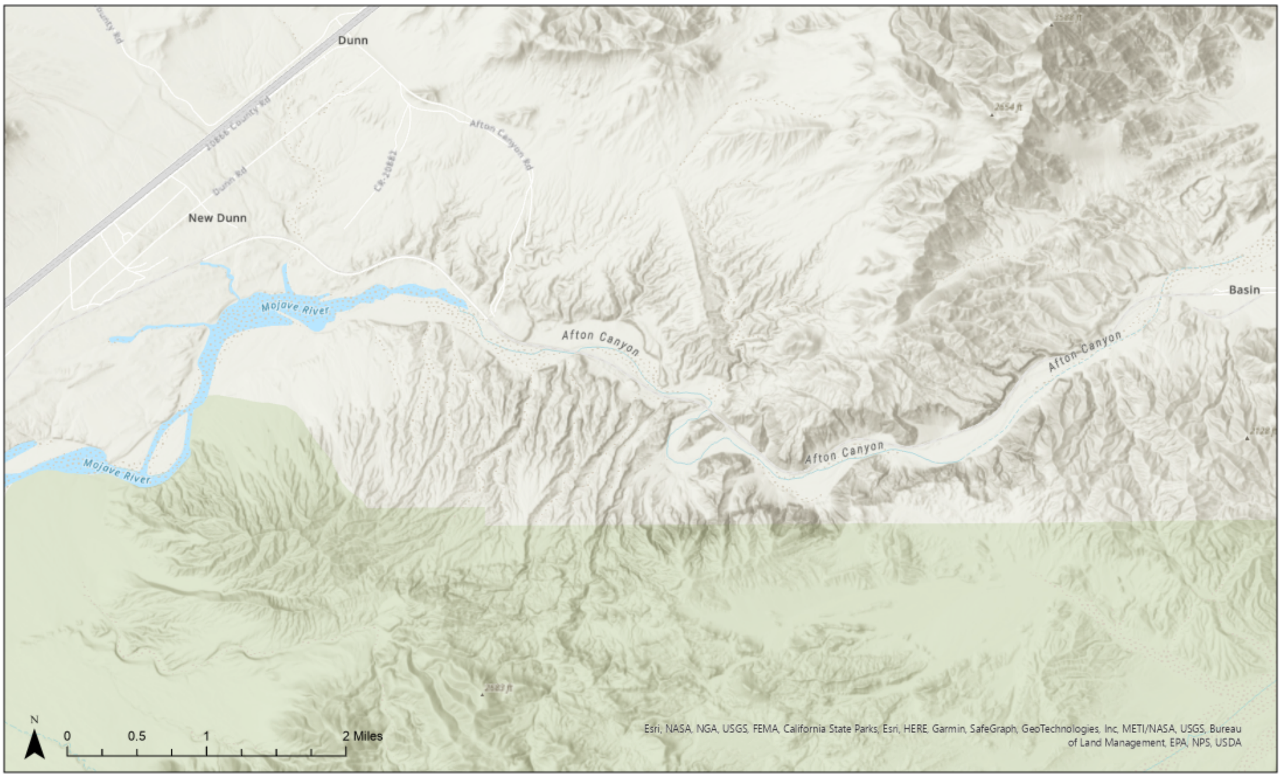
Map 1. The ~215km^2 ancient pluvial Lake Manix, located in the central Mojave Desert, west of the Cady Mountains (Meek, 1989).



Map 2. Modern map of Afton Basin, one of the Mojave River watershed's five sub-basins (Webb et al., 2001; USGS Report 95-4189)



Map 3. Historic Range of Beaver (*Castor canadensis*) throughout California (Lanman et al., 2013)



Map 4. Afton Canyon Extent

Tables

Table 1. Afton Canyon Observed Vegetation, Site Visit 11-12 November 2023

Common Name	Scientific Name	Invasive Non-native (Y/N)
Amargosa Nitrophila	*Nitrophila mohavensis*	N
American Bulrush	*Schoenoplectus*	N
American Coot	*Fulica americana*	N
Beavertail Pricklypear	*Opuntia basilaris*	N
Big sagebrush	*Artemisia tridentata*	N
Bulrush	*Scirpus* sp.	N
Cactus Apple	*Opuntia engelmannii*	N
California Bulrush	*Schoenoplectus californicus*	N
Cattail	*Typha latifolia*	N
Coyote Willow	*Salix exigua*	N
Creosote Bush	*Larea tridentata*	N
Desert Sunflower	*Geraea canescens*	N
Desert Willow	*Chilopsis linearis*	N
Fremont Cottonwood	*Populus fremontii*	N
Gooding's Black Willow	*Salix nigra gooddingii*	N
Hairy Desert Sunflower	*Geraea canescens*	N
Honey Mesquite	*Prosopis glandulosa*	N
Lizard Tail	*Anemopsis californica*	N
Mojave Desertstar	*Monoptilon bellioides*	N
Mojave Poppy	*Eschscholzia glyptosperma*	N
Saltcedar	*Tamarix ramoissima*	Y
Saltgrass	*Distichlis spicata*	N
Sandbar Willow	*Salix exigua*	N
Screwbean Mesquite	*Prosopis pubescens*	N
Seep Willow	*Baccharis glutinosa*	N
Sycamore	*Platanus racemosa*	N
Three-square Bulrush	*Schoenoplectus pungens*	N
Torrey's Rush	*Juncus torreyi*	N
Velvet Ash	*Fraxinus velutina*	N
Western Honey Mesquite	*Prosopis Glandulosa var. toreyana*	N
Zebra Tail	*Callisaurus draconoides*	N

Table 2. Table of Flow Frequency Analysis Results for USGS Water Gage #10263000 Mojave River at Afton Canyon

Percent Chance Exceedance	Curve Based on Sample Statistics		
	Computed Curve FLOW in CFS	Confidence Limits FLOW in CFS	
		0.05	0.95
0.2	99976.5	317381.4	40370.3
0.5	57326.5	168276.2	24499.2
1.0	35616.7	97905.5	15956.4
2.0	20798.6	53182.3	9809.8
5.0	8956.1	20551.8	4555.5
10.0	4084.5	8537.6	2212.3
20.0	1505.9	2838.2	870.2
50.0	192.7	319.9	116.7
80.0	20.2	34.8	10.8
90.0	5.7	10.7	2.7
95.0	1.9	4.0	0.8
99.0	0.2	0.6	0.1

Figures

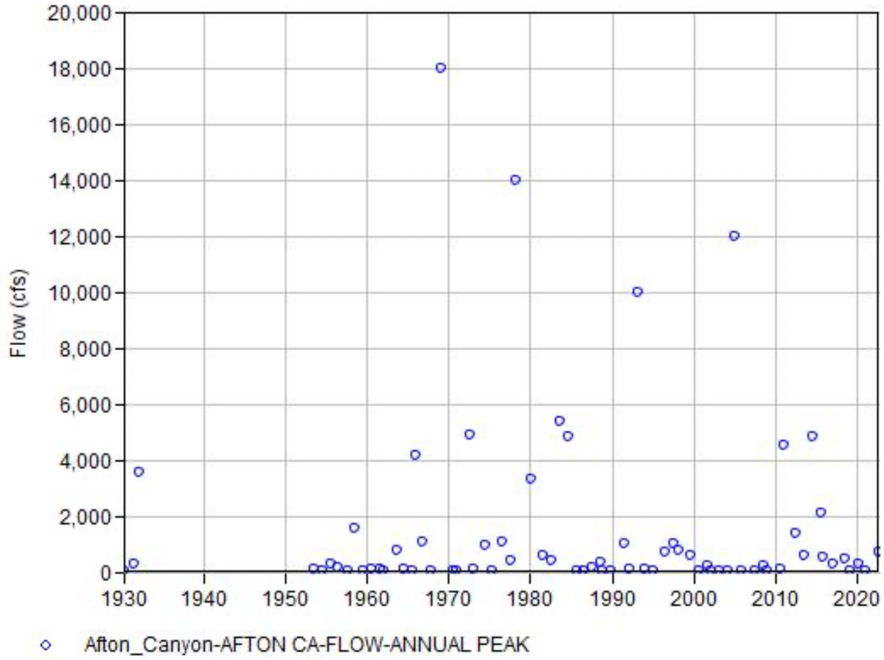


Figure 1. Scatterplot of Annual Peak Surface Flow for USGS Water Gage #10263000 Mojave River at Afton Canyon

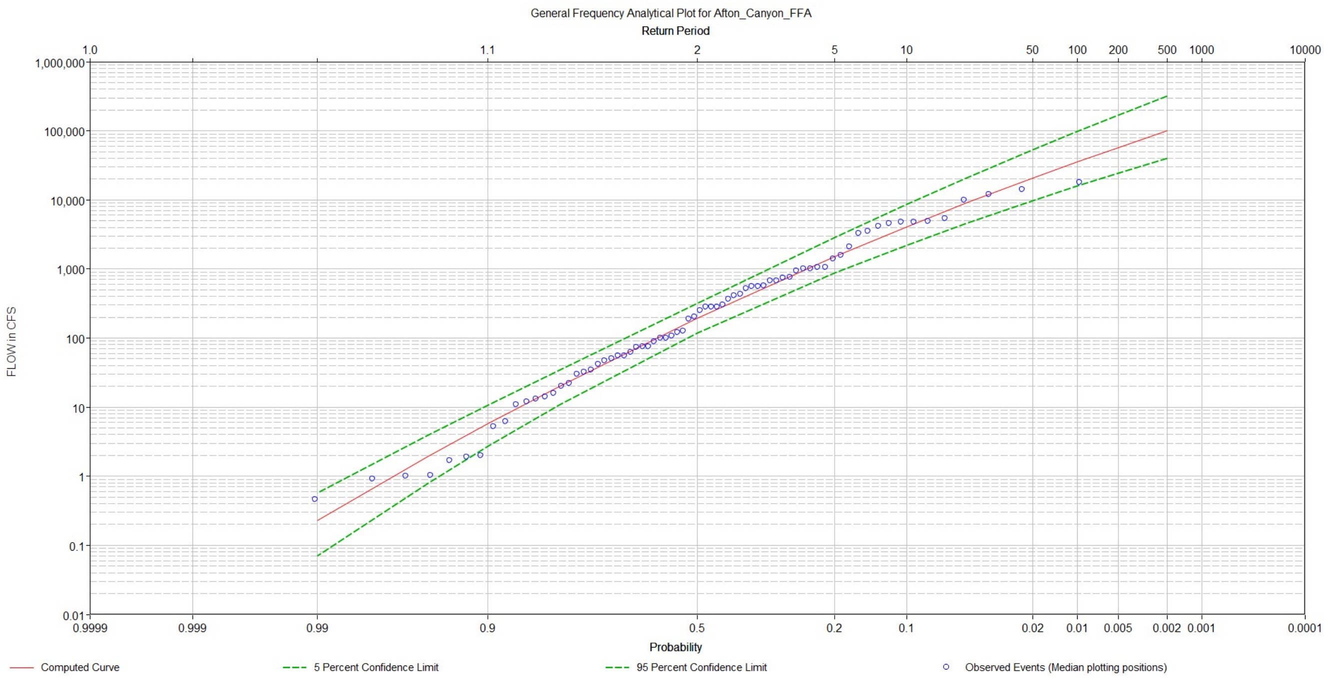
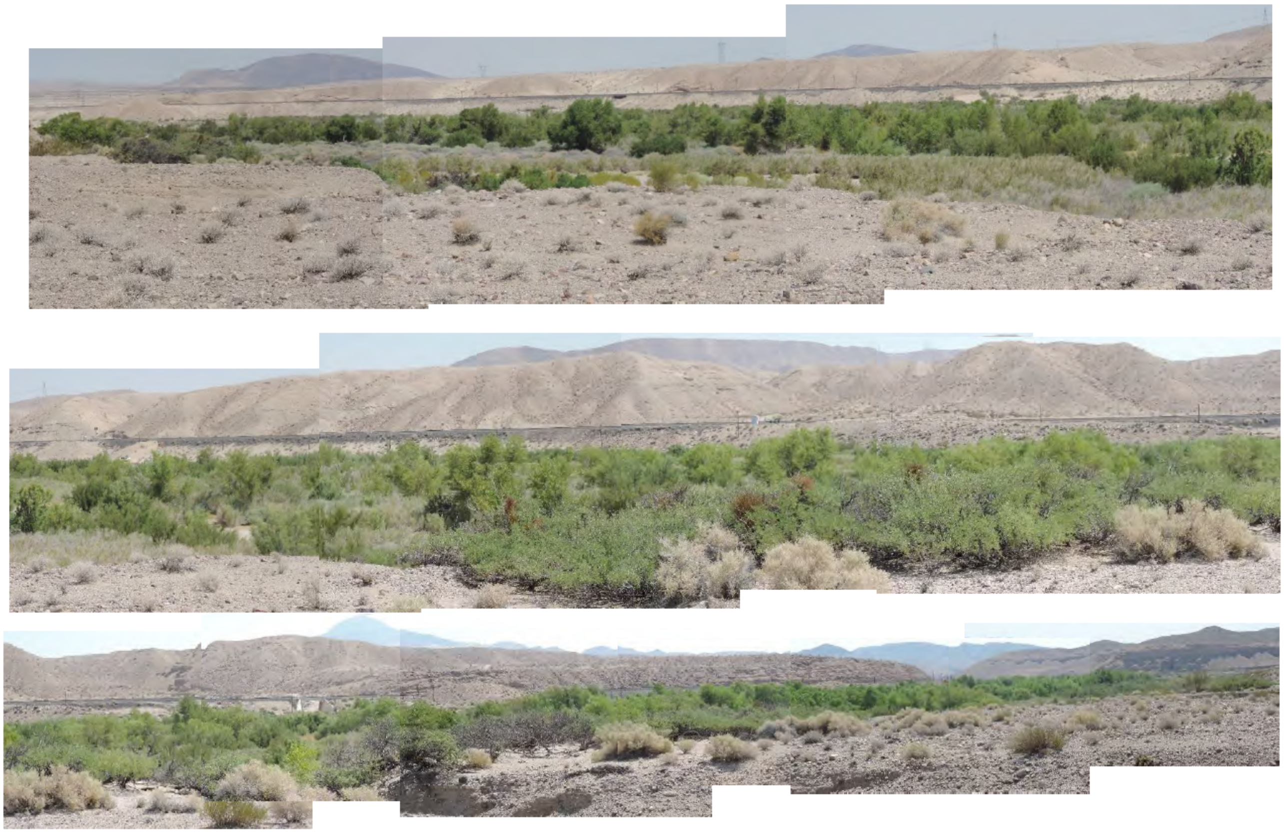


Figure 2. Graph of Flow Frequency Curve for USGS Water Gage #10263000 Mojave River at Afton Canyon



Figures 3a, 3b, 3c. Panoramic photo set of western Afton Canyon, with Mojave River upstream (upper left) to downstream (lower right). (Tom Egan). 24 July 2016.

Figures 4a, 4b, 4c. Panoramic photo set of western Afton Canyon, with Mojave River upstream (upper left) to downstream (lower right). 11 November 2023

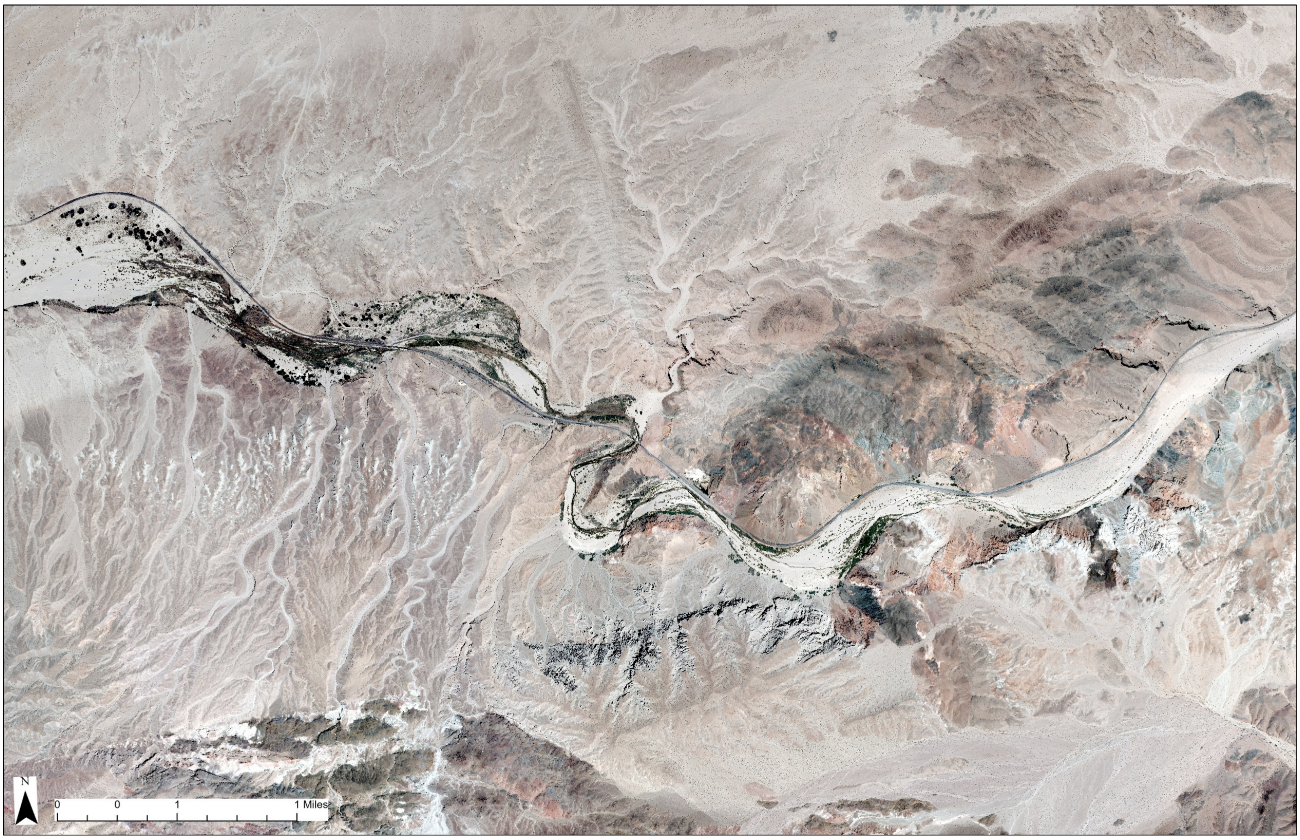


Figure 5. Aerial Satellite Imagery of Afton Canyon. 26 April 2010.

Figure 6. Aerial Satellite Imagery of Afton Canyon. 03 July 2014. Note the expansion of the 'green ribbon' of riparian wetlands.

Figure 7. Aerial Satellite Imagery of Afton Canyon. 30 May 2016. Egan's PPA is released later this year, in December 2016.

Figure 8. Aerial Satellite Imagery of Afton Canyon. 23 May 2020.

Figure 9. Aerial Satellite Imagery of Afton Canyon at Union Pacific Railway Bridge. 26 April 2010.

Figure 10. Aerial Satellite Imagery of Afton Canyon at Union Pacific Railway Bridge. 03 July 2014.

Figure 11. Aerial Satellite Imagery of Afton Canyon at Union Pacific Railway Bridge. 30 May 2016.

Figure 12. Aerial Satellite Imagery of Afton Canyon at Union Pacific Railway Bridge. 23 May 2020.

Figure 13. Aerial Satellite Imagery of Afton Canyon at Mojave River Deep Crossing. 26 April 2010.

Figure 14. Aerial Satellite Imagery of Afton Canyon at Mojave River Deep Crossing. 03 July 2014.

Figure 15. Aerial Satellite Imagery of Afton Canyon at Mojave River Deep Crossing. 30 May 2016.

Figure 16. Aerial Satellite Imagery of Afton Canyon at Mojave River Deep Crossing. 23 May 2020.

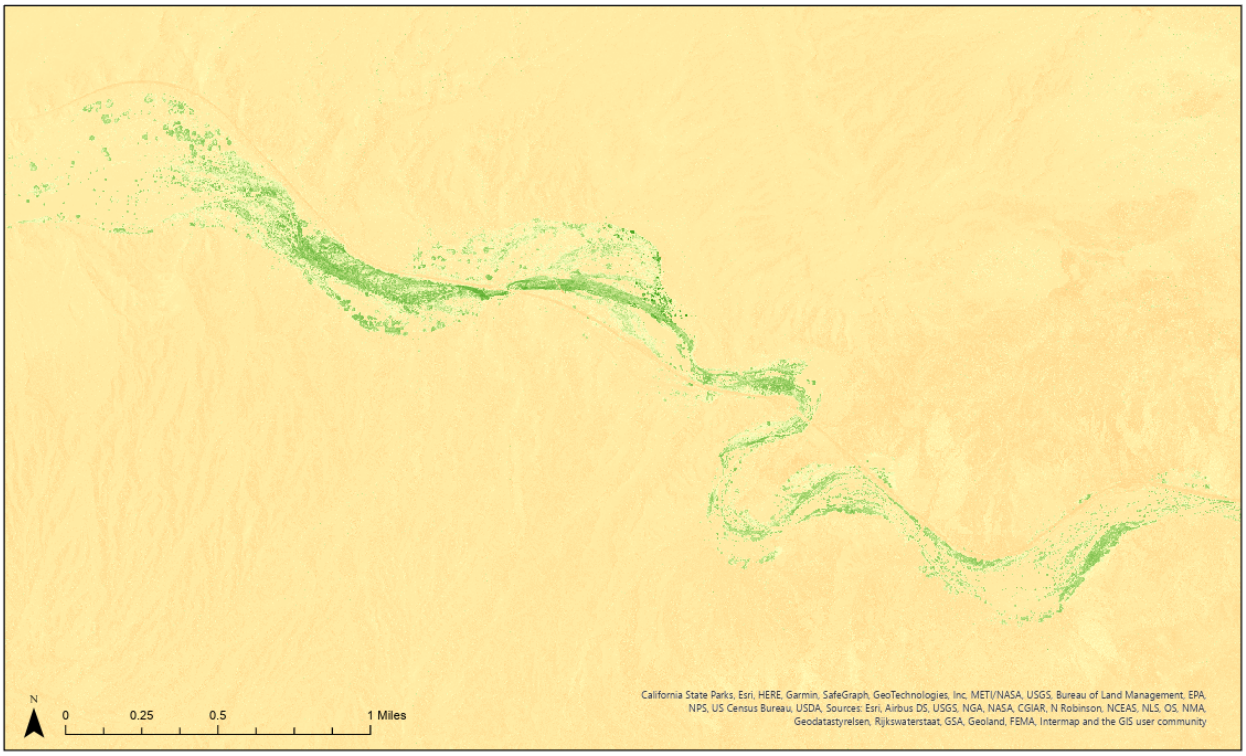


Figure 17. NDVI3 Colorized Imagery of Afton Canyon. 30 May 2016.

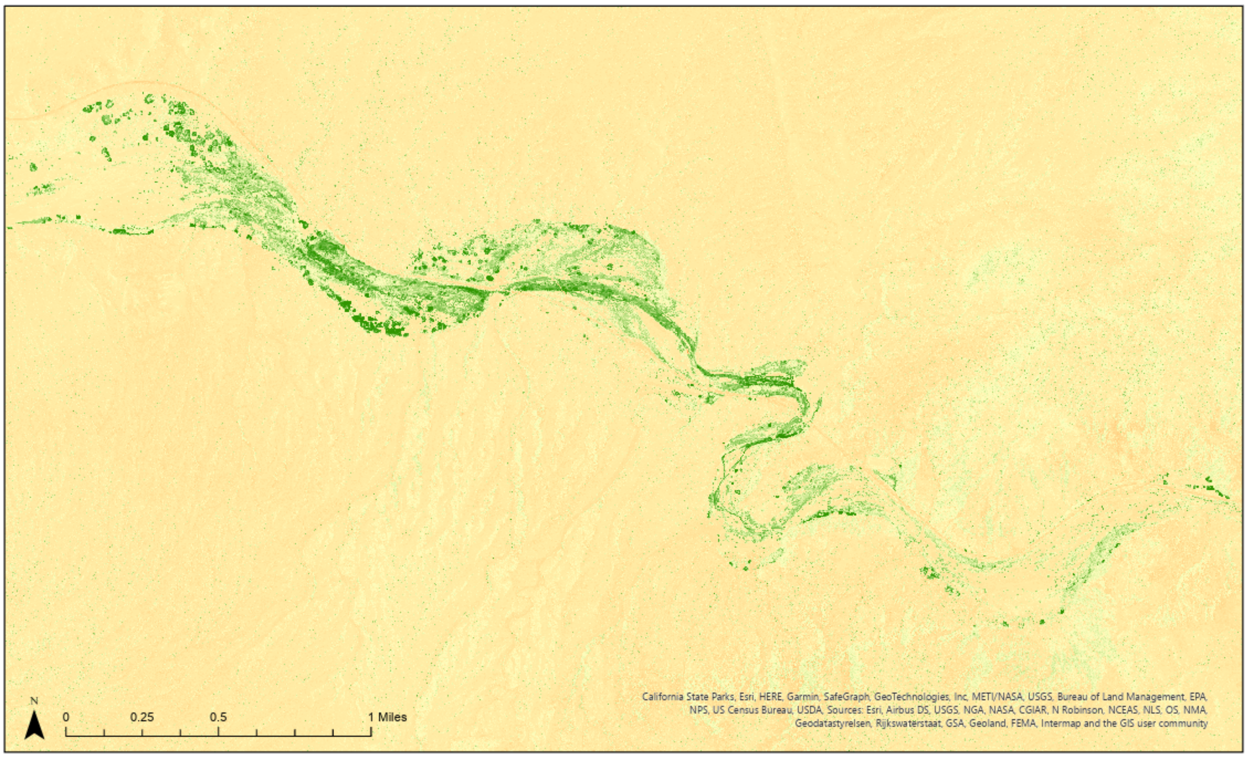
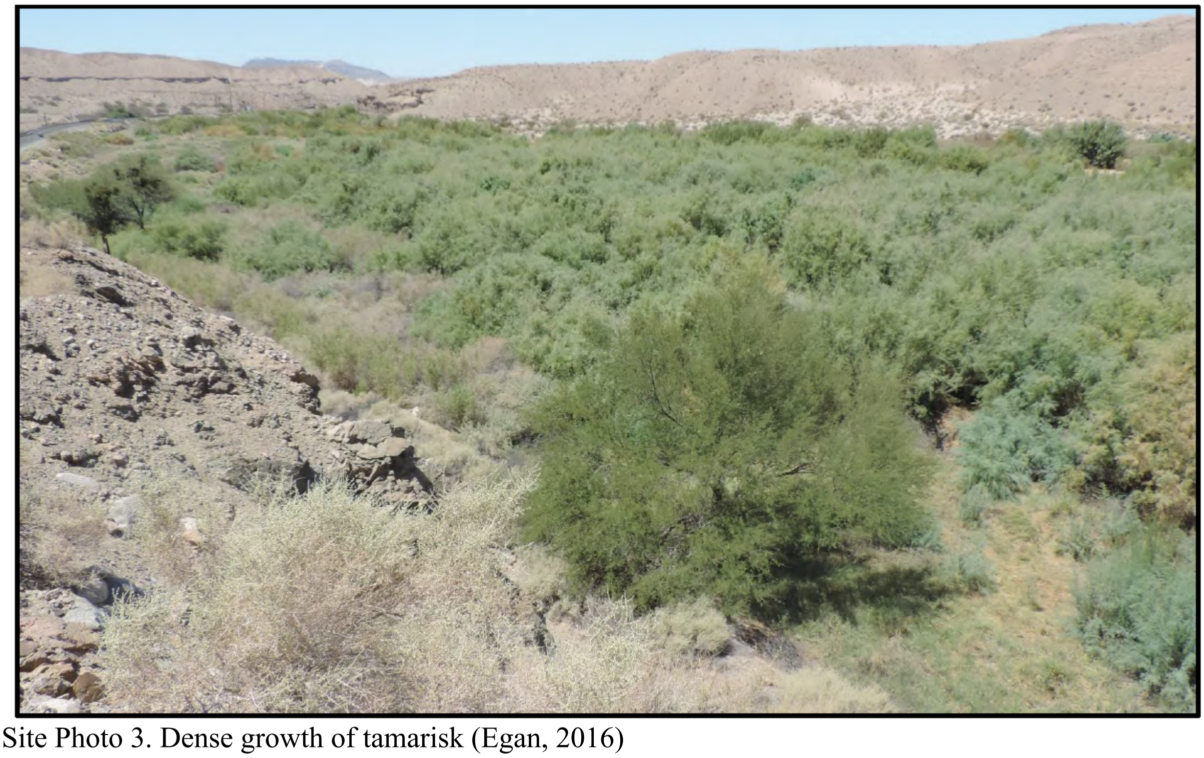


Figure 18. NDVI3 Colorized Imagery of Afton Canyon. 23 May 2020.

Appendix A.

Site Photo 1. View east, downstream, of western Afton Canyon, from the southern bank of the Mojave River 24 July 2016 (T. Egan); in an attempt to re-create a historic photo-point. Fremont cottonwood (*Populus fremontii*) and Gooding's black willow (*Salix nigra gooddingii*) are the dominant woodland vegetation, reaching upwards to 40 feet height; with saltcedar (*Tamarix ramosissima*) beginning to re-invade the riverine channel. The Union Pacific Railway's Afton West (No. 1) Trestle is situated in the topographic notch centre of the photo; with the entrance to West Pyramid Canyon of the Cady Mountains on the right.

Site Photo 2. View east, downstream, of western Afton Canyon from the railway ridge. 11 November 2023. The southern riverbank was obstructed by the Note the Union Pacific Railway's Afton West (No. 1) Trestle just right of centre, with the entrance to West Pyramid Canyon of the Cady Mountains on the right. The river corridor is clearly identified by the tall cottonwoods and denser and shorter willow stands.



Site Photo 3. Dense growth of tamarisk (Egan, 2016)

Site Photo 4. Black willow, Fremont cottonwood. 12 November 2023.

Site Photo 5. Afton Canyon. 11 November 2023.

Site Photo 6. California bulrush (*Schoenoplectus californicus*) and saltgrass (*Distichlis spicata*) growth along riverbank. 11 November 2023.