Arundo donax
Distribution and Impact Report

March 2011

Agreement No. 06-374-559-0
State Water Resources Control Board

Prepared by: **California Invasive Plant Council**

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This report and spatial data set (GIS geo-database) are available for download at:
http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

The spatial data set is also viewable at the DFG BIOS web site:
http://bios.dfg.ca.gov/

BIOS project data sets are named:
Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

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EXECUTIVE SUMMARY

Arundo donax (giant reed, giant cane) is a large non-native grass found in many coastal watersheds in central and southern California. It is an extremely problematic invasive plant characterized by extensive infestations and a range of severe impacts to both ecosystem and human infrastructure. Even with a significant increase in research and studies on *Arundo* over the past ten years, no large-scale mapping efforts have been completed and no comprehensive analysis of impacts has occurred. This report set out to accomplish these goals within the study area (Monterey to San Diego), as well as to examine watershed-based capacity to implement control programs. Over $70 million dollars have been spent to date controlling *Arundo* within the study area. It is important to document where this work has occurred and assess the resulting reduction in impacts.

Arundo was mapped at a fine scale using high-resolution aerial imagery and field verification across the study area. *Arundo* acreage prior to the initiation of control programs was 8,907 acres (gross). This is a significant area, but is much less than had been speculated by many in the field. Over 34% of this acreage (>3,000 acres) has been treated to date, with two highly invaded watersheds achieving over 90% control. Many other watersheds have more than 50% control. This indicates that watershed-based control is a realistic objective.

Mapping data show that *Arundo* is most abundant in large low-gradient river areas, where it averages 13% cover. Within specific reaches, there are sections greater than a half-mile in length that have over 40% *Arundo* cover.

This study carried out additional field work to characterize *Arundo* stands and infestations. This work verifies relationships explored by other studies, as well as generating new findings. *Arundo* within the study area was taller (average 6.5 m, maximum 9.9 m) than many previous studies reported. Biomass was confirmed as being extremely high per meter (15.5 kg/m^2). Leaf area was extremely high at 15.8 m^2/m^2 (LAI), which is consistent with other studies in California, but higher than reported in Texas where stands are shorter. Mature stands comprise most of the *Arundo* mapped in the study area. The leaf area of secondary branches is the majority of the leaf area in mature *Arundo* stands, based on leaf area and cane density of new and old canes.

This abundance of growth and cover generates many abiotic and biotic impacts. Mapping *Arundo* at high resolution allows examination and quantification of a number of these specific impacts, including water use, fluvial processes, fire, and listed species.

Spatial data, used in conjunction with stand leaf area measurements and published leaf transpiration rates, generated an *Arundo* stand-based water use value that was extremely high (40 mm/day) compared to most other plants. There are very few studies that have measured *Arundo* water use. Our results agree with one paper (from a study in California, 41.1 mm/day) and are higher than a study in Texas on the Rio Grande (9.1 mm/day). When translated into potential water savings per year from restoration, net savings of 20 ac-ft/yr was estimated. This estimate includes adjustments for replacement vegetation, as well as a reduction of *Arundo* water use to bring it into alignment with other forms of vegetation that consume large amounts of water. This is a large potential water use reduction that could have significant implications for both the ecosystem and human water use.

This study expended significant effort in broadening the understanding of how *Arundo* is impacting geomorphic and fluvial processes. These abiotic processes are particularly significant because they regulate the entire riparian ecosystem. Any changes to fluvial processes have the potential for system-wide ramifications. Large stands of *Arundo* were found to functionally increase bed elevations by five feet (based on field investigation and model re-calibrations following flood events in 1998). In addition to this *Arundo* stand-based modification of elevation, a high roughness coefficient for flows higher than five feet was supported. This results in a significant reduction in flow capacity and represents an alteration of how *Arundo* stand function is characterized during flow events. New modeling was carried out for this study under four scenarios. Results indicated that *Arundo* stands constrain flows to the low-flow and bar-channel portions of the river profile. Over time this results in a deepening of the channel and a transformation of the system from a braided unstable channel form to a laterally stable single-thread channel form. Mapping of geomorphic forms on the larger systems documented that *Arundo* stands occur predominantly in the floodplain and terrace forms, and are nearly absent from the low-flow and active channel forms. Additional modeling using stream power indicated that over-vegetated floodplains and narrow, stable deep channels result in modifications of sediment transport during flow events. Sediment appears to be lost (removed) in channel areas and gained (aggregated) on floodplains/terraces with *Arundo* stands on them. These impacts to riverine fluvial processes change vegetation succession following flow events, sediment transport budgets, and the geomorphic structure of the habitat, all of which alter the ecosystem in a un-natural way. Such alterations are usually negative for native species that are adapted to pre-invaded ecosystem function. One system has had extensive *Arundo* control since the late 1990's, allowing examination of post-control system response. Active channel areas widened and portions of the floodplain with active flows increased. These are important post-control responses to flood events, indicating a 'normalization' of fluvial processing is occurring.

A historic review of large riparian systems using spatial mapping indicated that floodplain and low terrace forms have become much more vegetated on most systems over the last eighty years. This transformation has been observed in other systems, such as the Rio Grande, and is a result of water importation and a 'compression' of riverine systems. This dense vegetation is both native woody vegetation and *Arundo*. Mature *Arundo* stands, however, have much higher stem density and biomass per unit area, generating the observed flow reduction effects noted above. The historic analysis also showed a significant decline in acreage over time, on most systems, of the active channel area (low-flow and bar-channel areas with little vegetation). Most riverine systems have also become significantly compressed (narrower) over time as terrace and floodplain forms have been permanently separated from the river system by levees that protect both urbanization and agricultural land use. *Arundo* impacts to bridges, levees, and beaches were also described and documented. These impacts are from *Arundo* biomass and reduced flow capacity (*Arundo* stands and sediment trapping).

Impacts associated with fire were thoroughly explored with significant new findings. *Arundo*'s high biomass and stored energy were established based on field and published data. In addition to a high fuel load, *Arundo* stands have a tall, well ventilated fuel structure containing dry fuels throughout the year. This study specifically documented that transient encampments and highway overpasses are key ignition sources for fires that start in *Arundo*. This is a new class of fire events that are fully ascribed to *Arundo*. This study documented that fires are now starting in riparian areas, which did not occurred historically. Fire events were mapped over an eight year period on the San Luis Rey watershed. It was also demonstrated that *Arundo*-initiated fires are occurring on other watersheds. *Arundo*-initiated fires also burn un-invaded riparian habitat and fire suppression impacts were spatially quantified. Over a ten year period *Arundo*-initiated fires were estimated to impact 557 acres of *Arundo* and 732 acres of riparian habitat. Wildfires also burn *Arundo* stands. These fire events burned 544 acres of *Arundo* over a ten year period for the study area. *Arundo* stands that burn during wildfires burn hotter than native vegetation due to the high fuel load, and are very likely conveying fires through riparian corridors. The Simi fire in the Santa Clara watershed was one of the clearest examples of an upland wildfire spreading across a riparian zone dominated by *Arundo,* and then igniting fuels on a separate mountain range. *Arundo*-initiated fires and wildfires together burned 12% of *Arundo* acreage in a ten year period within the study area. The high acreage of burned *Arundo* and native vegetation, as well as suppression impacts, has significant impacts on the ecosystem and listed species.

Impacts to plants and animals were explored by examining 22 federally listed species from five taxonomic groups. Detailed biological assessments examining habitat, life history, distribution and abundance were carried out for these species. Listing documents and spatial occurrence data were used to evaluate *Arundo* impacts on each species. An *Arundo* impact score was calculated for each listed species. An additional metric examining the specific co-occurrence of *Arundo* and each species was derived for each watershed. The impact rank and the co-occurrence rank were then multiplied to generate an overall cumulative impact score. From this analysis, the taxonomic group, individual species, and watersheds were ranked based on scores. Avian and fish species were found to be the most impacted by *Arundo*, with amphibians also ranking high. Plants and mammals ranked very low in cumulative scoring. The two most severely impacted species were least Bell's vireo and the arroyo toad, followed by the southwestern willow flycatcher, southern steelhead, and tidewater goby. Several species that occur in estuary and beach habitat near river mouths also had impacts from *Arundo* identified. The watersheds with highest impacts to federally listed species were the Santa Margarita, Santa Ana, San Luis Rey, and Santa Clara watersheds. Three of the four watersheds have the oldest and most complete *Arundo* control programs in the study area.

A rudimentary cost-to-benefit analysis was also completed using *Arundo* spatial data. Cost of *Arundo* control was determined based on completed control work on numerous watersheds over the past 15 year. The $71 million expended to control 2,862 acres generates a per acre control cost of $25,000. Benefits derived from controlling *Arundo* are based on each impact (water use, sediment trapping, flood damage, fire, habitat, and beach debris). Valuations were conservative and a rationale was given for each impact class. Impacts that were difficult to quantify or value were not included. The benefit to cost ratio for *Arundo* at its pre-control distribution level was 1.94 to 1 ($380,767,747 to $196,481,844). Current *Arundo* distribution (reflecting 3,000 acres of control to date) generates a similar benefit to cost ratio of 1.91 to 1 ($239,461,270 to $124,934,194). A roughly 2:1 return ratio on funds invested is a significant benefit, particularly considering the additional impacts that were not assessed (due to complex valuation), as well as the conservative valuation of factors that were included.

The report concludes with a discussion of treatment priorities that include: continuing treatments of areas that have already been treated (protecting initial investment), controlling *Arundo* on watersheds where it is not abundant but could spread (early control is more cost effective), and prioritization of watersheds with large *Arundo* infestations. Programs are encouraged to use a top-down watershed implementation approach (starting in the upper reaches of the watershed), particularly if the watershed is heavily invaded. The watershed priority rankings are based on four impact classes (water use, geomorphology, fire, and listed species) and two classes of program capacity (experience and regulatory permits). Watershed-based control is most effective when there is a lead organization that can implement comprehensive control, acquire permits, obtain right of entry agreements, and secure funding.

1.0 INTRODUCTION

Arundo donax (giant reed, giant cane) is one of the largest grass species. A clonal plant that grows in dense stands, it is found in many subtropical and warm-temperate areas of the world. It is thought to be native to eastern Asia (Polunin & Huxley 1987), but the precise extent of its native distribution is unknown. *Arundo* has been introduced around the world as an ornamental/crop species, for erosion control, and for the production of reeds (musical instruments, construction, paper and pulp). It has become invasive in many places throughout the world, primarily in riparian habitat. Where *Arundo* invades, it often forms dense stands, resulting in a wide range of impacts to natural ecological systems (biotic and abiotic) as well as human created infrastructure. The Invasive Species Group of the World Conservation Union includes giant reed in its top 100 Worst Invaders of the World (Lowe et al. 2000).

Arundo was first introduced to California by Spanish colonists in the 1700s (Newhouser et al. 1999), and in the early 1800s for erosion control in drainage canals (Bell 1998). It is now a major threat to riparian areas in California, as well as other southwestern states. Two portions of the United States have particularly significant *Arundo* infestations (characterized as >40% of riverine habitat over areas longer than a river mile): coastal California (Monterey to San Diego) and the Rio Grande (Texas).

This study is the first research to take a broad range of impacts caused by the invasive non-native plant *Arundo*, and apply them to a significant portion of the plant's distribution in California. This was not previously possible because detailed *Arundo* spatial distribution data did not exist prior to this study. Mapping *Arundo* in high resolution from Salinas, California to the Mexican border in all coastal watersheds was the initial task. This captures *Arundo*'s primary distribution in coastal California.

There has been a significant increase over the past ten years in studies examining *Arundo*'s impacts and quantifying aspects of its productivity, structure, physiology, genetics and reproduction. We compiled information, and completed additional research and data collection to fill gaps in understanding or documentation. New research was primarily related to fluvial/geomorphic impacts, leaf area, biomass water use and fire impacts. Data collected also allowed verification that relationships described in the literature, such as biomass and structure data, applied to the study region. Many studies and reports have alluded to impacts related to fire, but this study explicitly quantifies fires that started in *Arundo*, as well as wildfires that burned *Arundo*, over the entire study area. Impacts to 22 federally-listed sensitive species were examined using spatial data for the species, spatial data for *Arundo*, and current understanding of the biology of the species. From this the magnitude of impact on listed species from *Arundo* is described and scored. Scores of cumulative impact are examined by species, taxa group, and watershed. To date, this is the largest suite of species over the broadest area to examine *Arundo* impacts.

This report presents the entire range of impacts over the entire study area, as well as each watershed. A coarse Cost Benefit Analysis is presented and made possible due to the explicit quantification based on acreage for each watershed, and the range of impacts that were quantified (with a cost assigned to them based on previous studies).

Finally this report provides a review of each watershed's *Arundo* control program, including: completed work to date, status of permits allowing work, and the identification of the lead entities carrying out the work. The spatial data set and impact quantification is used to highlight priority watersheds and actions. This is also examined in the context of current capacity to implement *Arundo* control projects. The need to implement sustainable watershed control programs with eradication as an obtainable goal is explored, as well as an evaluation of the challenges in completing programs, which is a process that can take over 20 years.

2.0 *ARUNDO* BIOLOGY

2.1 Physiology

Arundo is generally a hydrophyte, achieving its greatest growth near water. However, it adapts to many different habitat conditions and soil types, and once established is drought tolerant and able to grow in fairly dry conditions (Lewandowski et al. 2003). It can also tolerate saline conditions (Perdue 1958, Peck 1998), and in California it is found growing along the edges of beaches and estuaries (Else 1996). *Arundo* is a C_3 plant, but it shows the unsaturated photosynthetic potential of C4 plants, and is capable of very high photosynthetic rates (Papazoglou et al. 2005, Rossa et al. 1998).

Arundo's stems and leaves contain a variety of noxious chemicals, including triterpenes and sterols (Chandhuri & Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal et al. 1972), and hydrozamic acid (Zuñiga et al. 1983), as well as silica (Jackson and Nunez 1964). These likely reduce herbivory by most native insects and grazers where *Arundo* has been introduced (Miles et al. 1993, Zuñiga et al. 1983).

Arundo responds strongly to excess nitrogen from anthropogenic and fire sources (Ambrose & Rundel 2007). Most studies on growth and transpiration indicate that water availability is the primary factor affecting metabolic rates and productivity (Abichandani 2007, Perdue 1958, Watts 2009). *Arundo* generally has a shorter stature and is less productive when there is limited water availability, such as on higher elevation riparian terraces or drier portions of the watershed. This observation is based on the distribution of these less productive stands on many watersheds within the study area.

2.2 Genetic variation

Isozyme and RAPD analyses of *Arundo* on the Santa Ana River in California indicated genetic diversity comparable with those in the literature for clonal species, supporting asexual reproduction as the primary means of *Arundo* spread (Khudamrongsawat et al. 2004). Samples were also taken from one out-group on a separate watershed (Aliso Creek, Orange County). Several phenotypes were dominant and were found spread along the Santa Ana River. These dominant phenotypes were also found in the out-group population, possibly due to spread by humans. The moderate levels of genetic diversity in *Arundo* are likely explained by multiple introductions over time, with early introductions as a building material, and more recent use for erosion control and as a landscape ornamental (Bell 1997; Frandsen 1997). The moderate level of genetic diversity and the asexual mode of reproduction increases the potential for application of biological agents for control of *Arundo* (Tracy and DeLoach 1999).

2.3 Physical Structure

For this study, data were collected from fourteen *Arundo* plots on five watersheds (Figure 2-1). A variety of measurements were taken, and canes were collected from these plots. These data are presented in this section, section 2.4, and Chapter 4.

Figure 2-1. *Arundo* sampling locations in southern California.

Arundo is a clonal organism, so the plant will be examined at both the individual level (ramet) and at the stand scale (colony).

<u>The individual plant or ramet:</u>

Arundo is one of the largest herbaceous grasses, and is often mistaken for a bamboo (Figures 2-2 to 2-6). It is a tall, erect, perennial grass, 2 to 8 m high (Perdue 1958). Canes frequently attain lengths of 8 to 9 m in coastal California, as this study shows (Table 2-1). The main stems, or culms, are hollow with walls 2 to 7 mm thick and are divided by partitions at the nodes. In this study the culms were on average 23.8 mm wide (measured between nodes one and two). First year canes are un-branched, and in the second year single or multiple lateral secondary branches may form from the nodes (Figures 2-2 to 2-3) (Decruyenaere & Holt 2005). The secondary branches are a much smaller diameter than the main canes (typically <10mm versus >20 mm). In canes that are two years and older, the secondary branches bear a significant proportion of the leaves (this study). These secondary branches can themselves give rise to third degree and even fourth degree branches, but this is uncommon (Decruyenaere & Holt 2005, this study). Once a cane generates secondary branches these become the primary area of new growth, and continued growth of the main cane (leader) is slow to non-existent (Decruyenaere & Holt 2005).

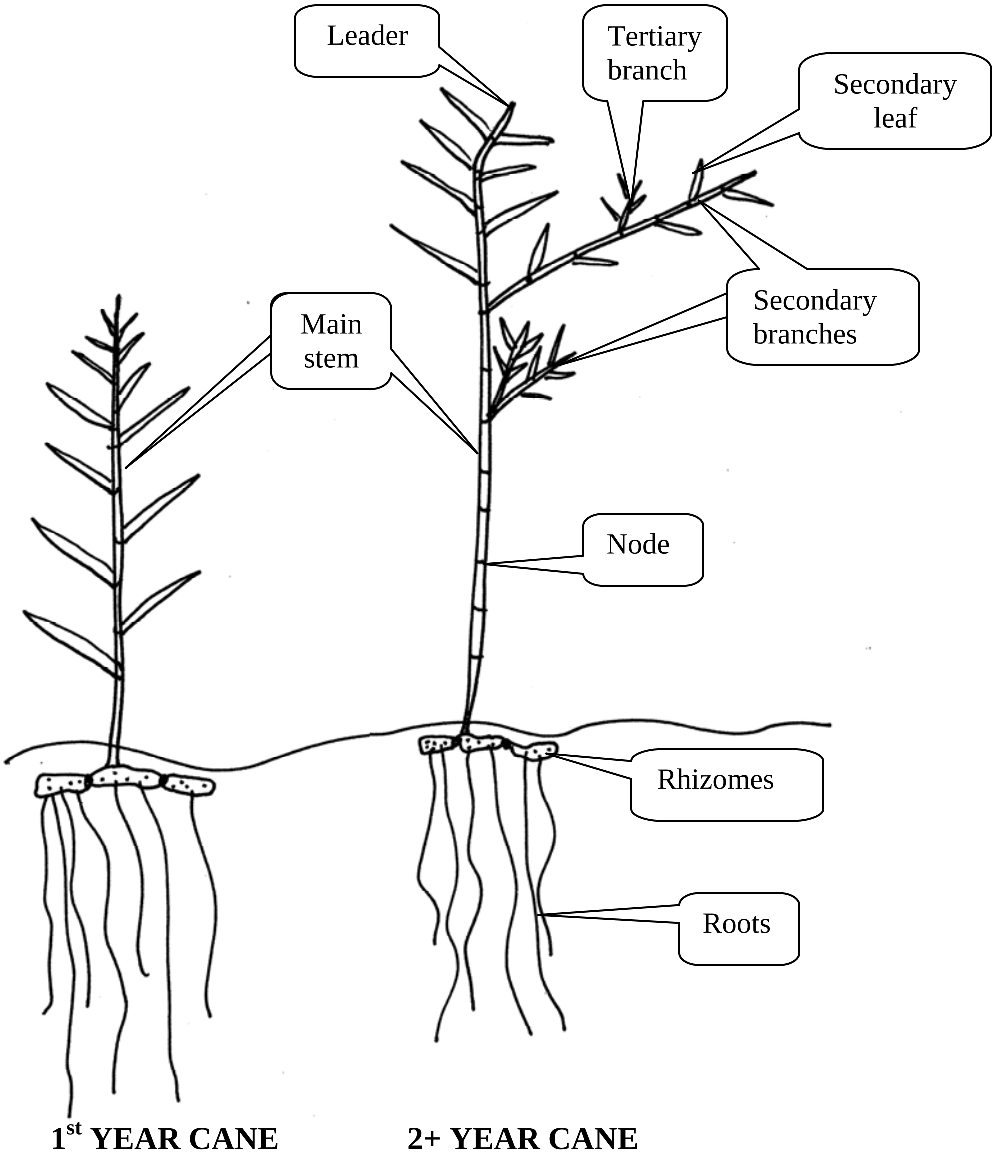

Figure 2-2. Illustration of *Arundo* structure for first year and 2+ year old stems. Older canes would have many secondary braches. Drawing by J. Giessow.

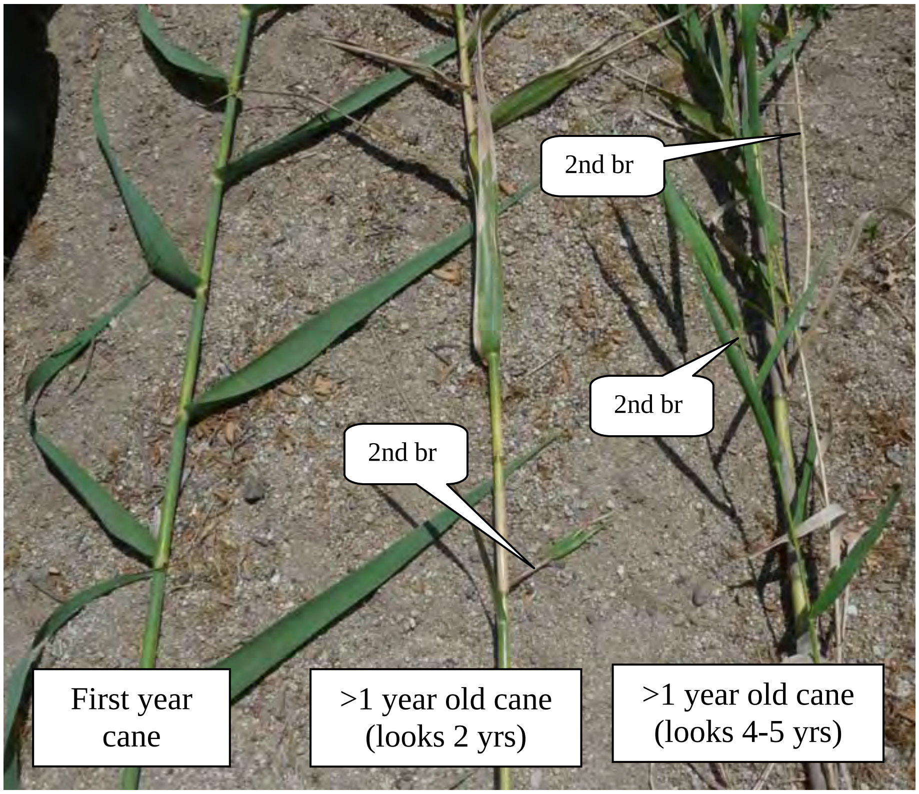

Figure 2-3. First year and >1yr year old *Arundo* canes, showing leaf and branching structure. First year canes have only cauline leaves. Older canes have an increasing number of secondary branches with leaves on them, and leaves on the old leader are often damaged and dying.

Figure 2-4. A single older cane with all secondary branches (25), leader, and main stem. This was cane SD#1b from the San Diego River with a height of 8.1m.

Figure 2-5. New first year canes often protrude from the *Arundo* canopy.
Older canes with extensive secondary branching cannot support the weight of the branches and leaves, and usually flop over and do not stand upright, especially in the upper portions of the stand's canopy.

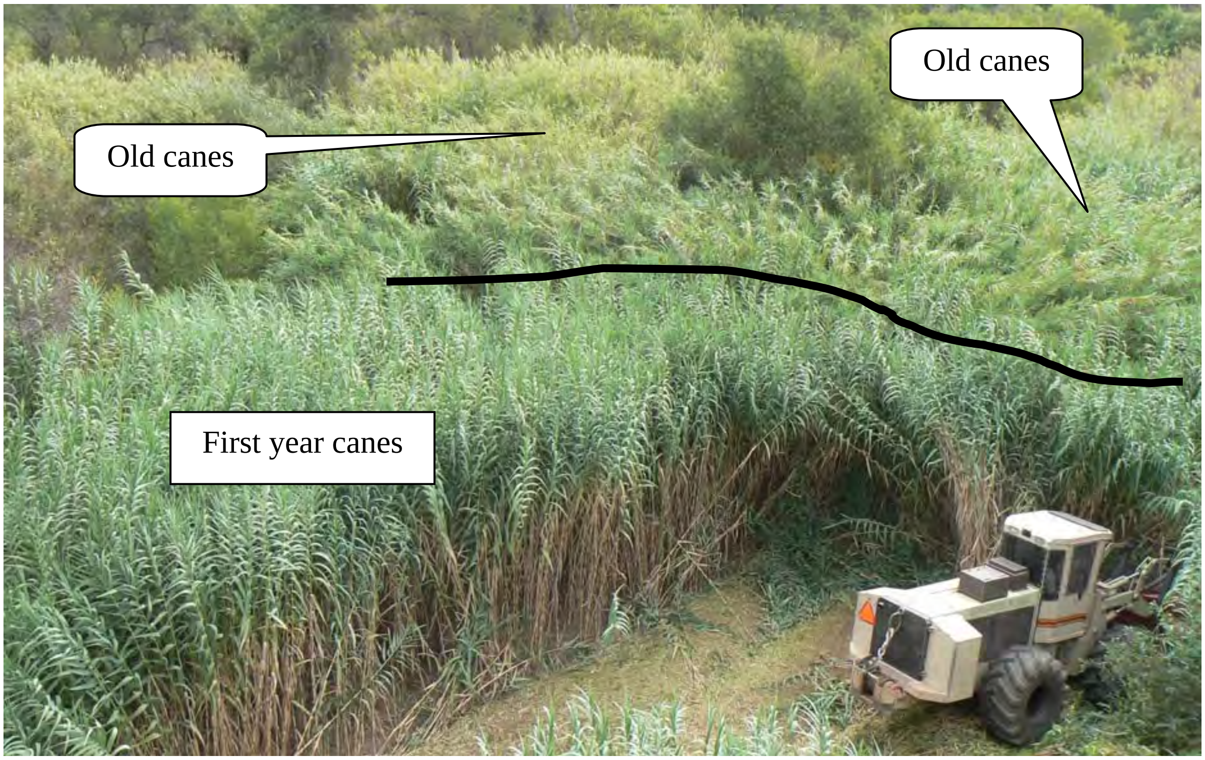

Figure 2-6. First year *Arundo* canes at full height (6+ m).
The tractor is 10' high. This area had been cut as a fuel break the year before and is being cut again. Energy stored in rhizomes underground allow this rapid regrowth after cutting or fire events. Note simple unbranched vertical structure, very high cane density, and deep green color of the new, resprouted canes. Older canes in the background are less vertical and are a more yellowish color.

Table 2-1. Summary of *Arundo* cane data from the fourteen locations sampled for this study. Locations of sampling plots are shown in Figure 2-1.

Plot	Cane height (m)	Cane diameter (mm)	Leader length (cm)	Leader # leaves	Mean leader single leaf area (cm^2)	# secondary branches	Mean branch length (cm)	Mean branch # leaves	Mean branch single leaf area (cm^2)	New cane # leaves	Mean new cane single leaf area (cm^2)
CC1	5.1	20	19	10	-	15	47.7	-	-	21	168.7
CC2 #1	9.7	28	90	23	83.7	57	11.7	4.5	10.5	-	-
CC2 #2	8.5	27	82	23	117.3	9	70.9	13.0	63.2	-	-
SA1	6.1	25	45	17	-	34	21.4	-	-	-	-
SA2	6.1	25	32	15	58.5	31	36.2	23.0	44.4	-	-
SA3	7.7	27	74	28	-	33	10.7	-	-	-	-
SA4	7.4	26	33	12	-	48	20.0	13.5	29.5	-	-
SC1	9.9	25	23	12	-	31	46.0	11.0	34.8	-	-
SC4	4.2	22	0	0	-	34	41.3	14.0	19.2	-	-
V1	8.4	26	0	0	-	28	43.4	-	-	21	216.2
V2	6.2	24	76	20	-	14	41.8	-	-	-	-
SD#1a	8.1	26	65	16	-	29	56.1	10.9	34.9	-	-
SD#1b	8.1	24	66	13	-	25	60.0	-	-	-	-
SC2	4.3	22	11	7	-	11	37.0	-	-	-	-
SC3	4.2	18	19	7	-	7	37.1	-	-	27	227.9
SC5 Lg	3.8	25	13	8	-	10	26.2	-	-	-	-
SC5 Sm	2.6	15	12	7	-	5	22.8	-	-	-	-
Mean	**6.5**	**23.8**	**38.8**	**12.8**	**86.5**	**24.8**	**37.1**	**12.8**	**33.8**	**23.0**	**204.3**
StdDev	**2.2**	**3.5**	**30.5**	**7.8**	**29.5**	**14.8**	**16.8**	**5.5**	**17.1**	**3.5**	**31.4**

CC = Calleguas Creek, SA = Santa Ana River, SC = Santa Clara River, V = Ventura River, SD = San Diego River.

Leaves are borne at nodes along the main stem and on the secondary branches. In this study, leaves found on the main stem were 5-6 cm (up to 8cm) broad toward the base, up to 61 cm long, and tapered to a fine point. Leaves on first year canes had an average width of 5.0 cm and length of 54.4 cm (n = 69) (Table 2-2). The main stem of older canes (>1 year) had much smaller leaves, average of 2.8 cm wide and 41.5 cm long (n = 60). As expected, secondary branch leaves were the smallest, average length of 27.9 cm and width of 1.7 cm (n = 200).

Table 2-2. Length and width of leaves of *Arundo* sampled in this study, by age and location.

Cane age and leaf location	**# leaves sampled**	**Max (cm)**	**Min (cm)**	**Ave (cm)**	**SD**
1st year cane: Leaves on stem					
Leaf length	69	74	15	54.4	14.5
Leaf width	69	6.8	2	5.0	1.2
>1yr cane: Leaves on main stem					
Leaf length	60	57	24	41.5	10.3
Leaf width	60	3.8	1.3	2.8	0.6
>1yr cane: Leaves on secondary branches					
Leaf length	200	52	4	27.9	10.8
Leaf width	200	2.8	0.1	1.7	0.5

This reduction in leaf size as canes mature is more than made up for by the much higher number of leaves found on secondary branches. Leaf density on the main cane decreased from an average of 23 for first year canes to 12.6 for older canes (Table 2-3), and leaf size also decreased. However, an entire new secondary branch class of leaves is present on canes >1 year. Leaf density on secondary branches was >270 on canes >1 year (Figure 2-4, Table 2-3). Canes older than one year had a leaf area that is greater than that of first year canes, and was predominantly made up of the secondary leaf area.

As canes mature, the leaves on the main cane become less important to photosynthetic production. The contribution of secondary branches to cane leaf area is an important observation that is not well documented in the literature. Decruyenaere and Holt (2005) note that the main canes have little growth once they generate secondary branches, and that the secondary branches become the primary areas of new growth. Leaf area is used to estimate water use and photosynthetic activity. This study will examine transpiration levels using leaf area data (Section 4.1). The field samples for this study were composed primarily of old canes. The large contribution of old canes with their secondary branches to stand leaf area can be seen in Figure 2-5, where the bulk of the leaves are secondary, and only a few new canes emerge out the top of the stand. First year and >1 year old canes can also be seen in Figure 2-6. The first year canes have a simpler structure with no branching, while the older canes in the background are more complex.

The underground structure of *Arundo* is composed of fleshy rhizomes from which arise roots that penetrate deeper into the soil (Figures 2-2 & 2-7 to 11). Rhizomes are generally shallowly buried, spreading out horizontally from the plant and forming a dense underground mat. Rhizomes are generally found 5-15 cm below the soil surface, with a maximum depth of 50 cm, while roots can be more than 100 cm deep (Sharma et al. 1998, this study).

Table 2-3. Density of leaves on *Arundo* stems sampled for this study, by class.

Cane Age and Leaf Location	# Sampled	Max	Min	Mean	StdDev
1st year cane: Leaves on					
Leaf density per cane (count)	3	27	21	23	3.5
Leaf area per leaf (cm^2)	69	352	29.6	206.3	
Leaf area per cane (cm^2)	3	6,153	3,542	4,740	
>1 year old cane: Leaves on culm					
Leaf density per cane (count)	3	23	15	12.6	8.3
Leaf area per leaf (cm^2)	60	141	30	86.5	
Leaf area per cane (cm^2)	3	2,580	877	1,000	
>1 year old cane: Leaves on secondary branches					
Leaf density per branch (count)	19	15	3	11.1	3.3
Leaf area per leaf (cm^2)	200	102	1.8	33.9	
Leaf area per branch (cm^2)	18	837	12	406	240
Leaf area per cane (cm^2) calculated	14	8,904	906	4,699	2,628

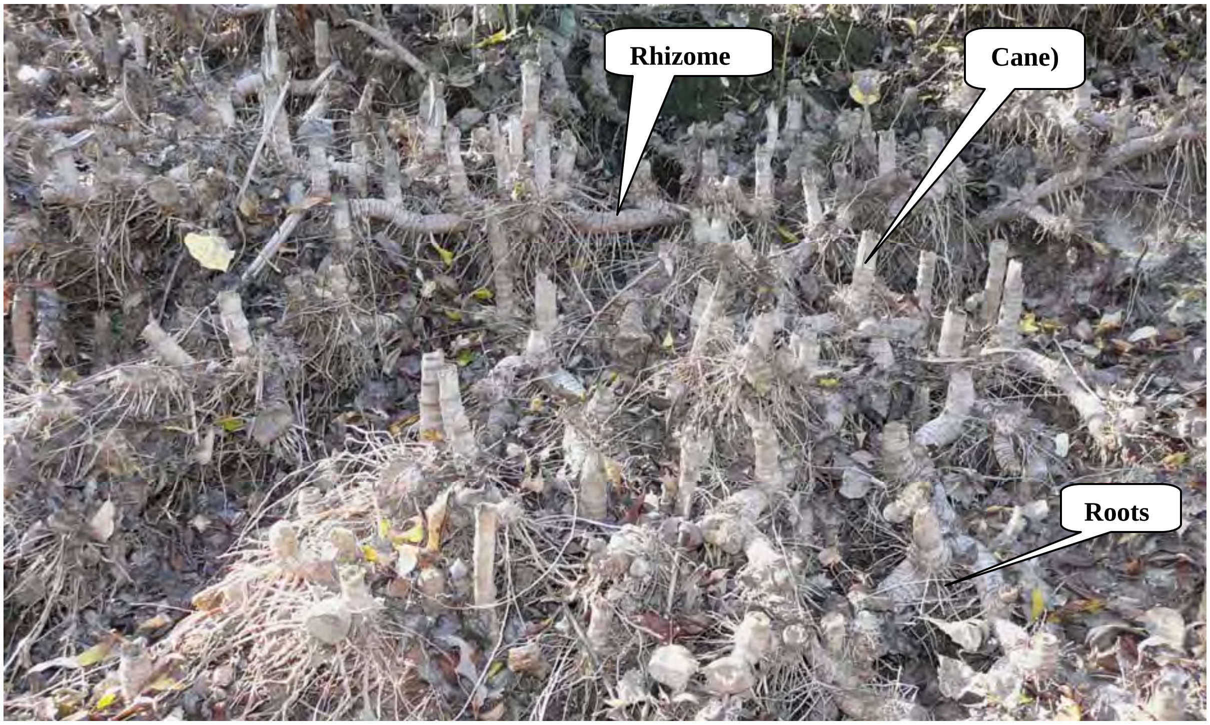

Figure 2-7. Dense rhizome and root network of an *Arundo* clump that was scoured during a flow event, removing the upper soil matrix and canes.

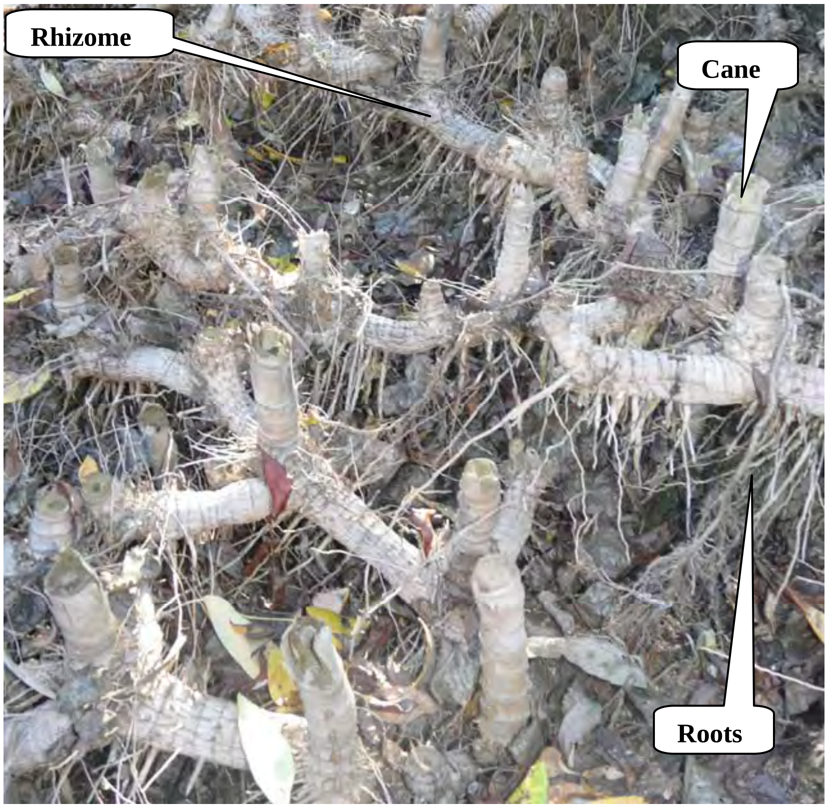

Figure 2-8. Close up of rhizomes showing emerging canes and roots.

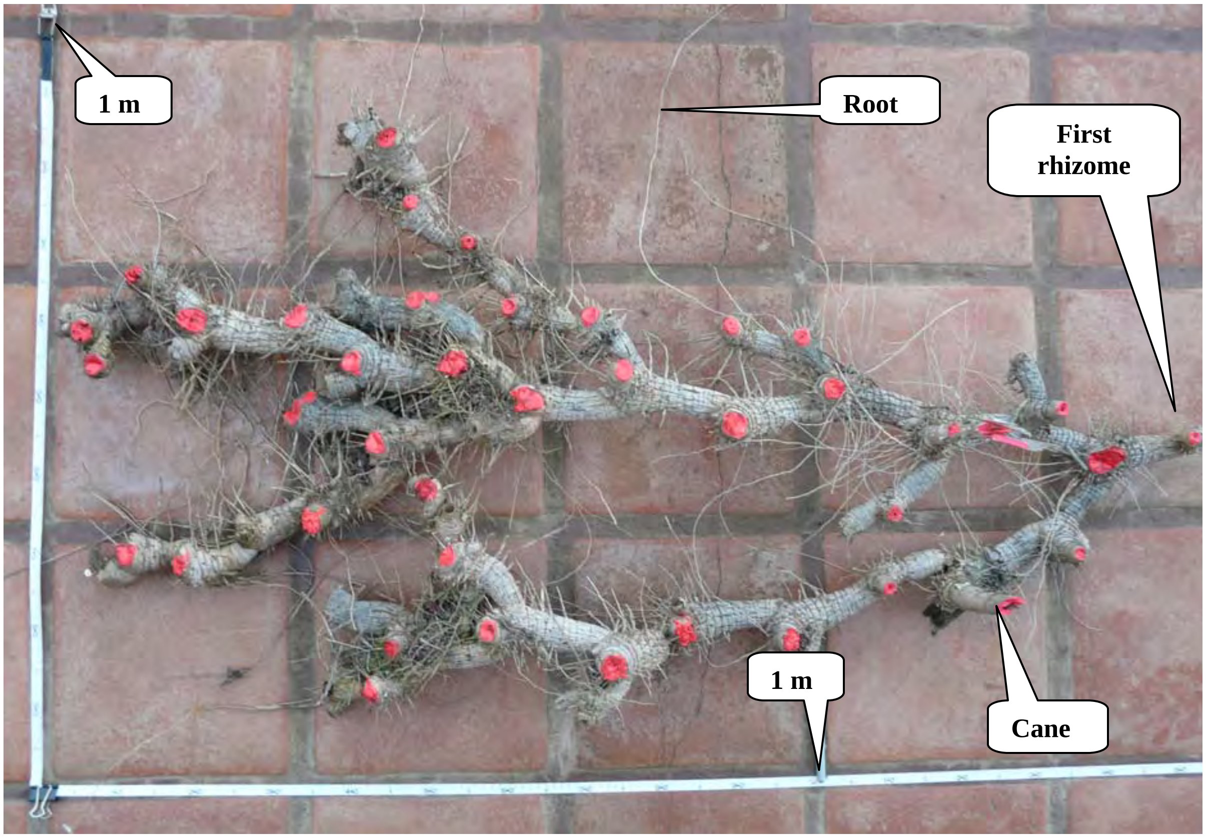

Figure 2-9. Rhizome network arising from a single growth point.
33 canes emerged from the marked 1 x 1m area (painted red).

Figure 2-10. Close-up of slightly desiccated *Arundo* rhizome.
The cane emergence points at the nodes are painted red, and long thin roots are visible.

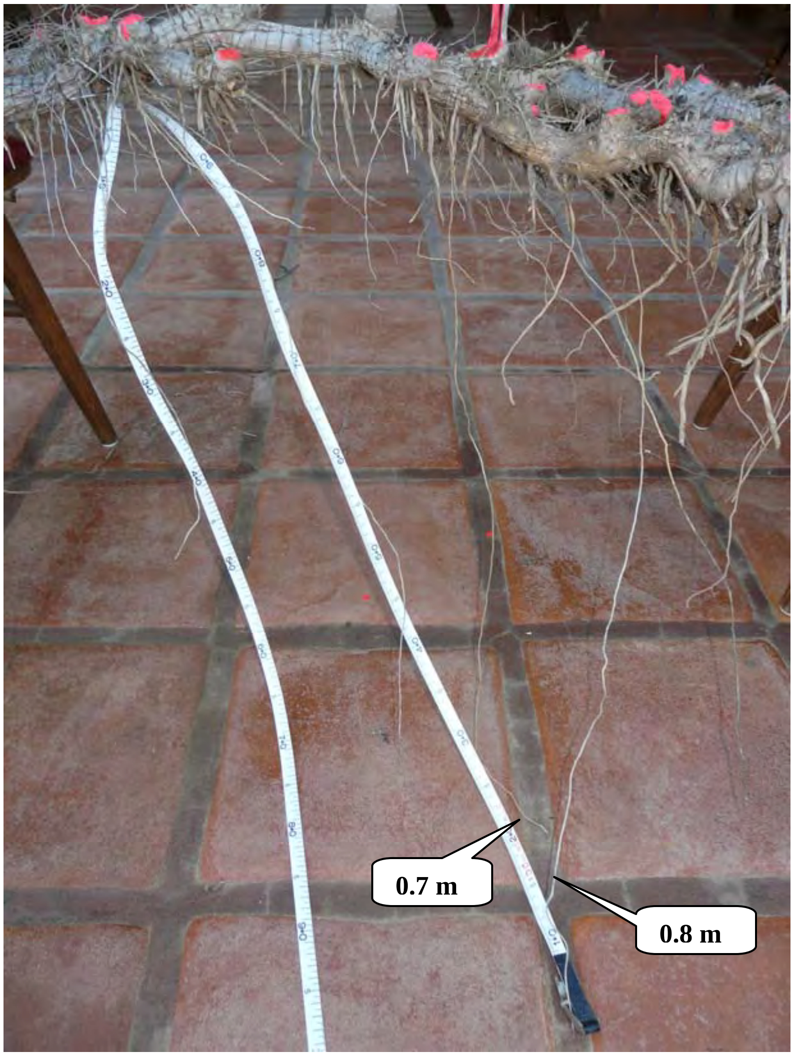

Figure 2-11. Rhizome network showing root length of up to 80 cm.
This was a dislodged rhizome network scoured out by flood action, so many of the roots have already been broken off, but it gives an idea of root density (near the rhizome) and length.

Arundo flowers are borne in large (3 to 6 dm long) plume-like terminal panicles, generally between March and September. However, many plants do not seem to ever flower, or at least not every year (Else 1996). The spikelets are several-flowered, approximately 12 mm long with florets becoming successively smaller.

Plants generally become dormant during the colder months, signified by the leaves turning brown/yellow, and the stems fading from their green color. These leaves and stems then turn green again in spring as temperatures rise and daylight lengthens. In areas with hard freezes during winter months, *Arundo* generally dies back to the ground and then re-sprouts in the spring. Deep freezes can kill the plant, probably by destroying the rhizome network.

<u>The stand or clonal mass:</u>

Few studies have specifically examined stand structure. Quantification of stand structure is critical in the scaling up of information derived from specific canes, leaves, or rhizomes to the stand scale. Specific information on biomass, leaf area, transpiration, and other data derived on a per cane basis cannot be converted into per unit land area without an understanding of stand structure. Some recent studies have specifically accounted for stand structure in scaling up cane-specific data (Abichandani 2007, Watts 2009, Spencer et al. 2006) although it was not always clear how they defined the stand area.

Scaling up from cane to stand (land area) based data is very sensitive to the measured cane density per land area. Determining cane density for a stand is not as straightforward as one might expect. Overestimations of cane density may be generated if one only samples in areas where canes emerge. Extrapolating specific data on a given parameter to spatial data, such as the GIS data set produced in this study, requires that the same definition of "stand area" be used when measuring cane density, or that adjustments be made to account for the sampling of canes from only the portion of the stand that has cane emerging.

In this study the *Arundo* stand is defined as its aerial extent as viewed from above, and all areas that have *Arundo* cover are classified as part of the stand footprint (Figure 2-12). This is the spatial extent of the stand as recorded in the GIS spatial data that was mapped for this project (more details can be found in Chaper 4). However, data on *Arundo* is typically collected on a per cane basis. To use cane data to represent an entire stand, we must understand cane distribution within the spatial area of the stand and if there is variation by stand size and/or age.

Arundo canes are not uniformly distributed within the aerial extent of the stand. There are two portions of the stand footprint that have no or very few canes. The first area we will examine is the edge of the stand. This area, when viewed from above, has *Arundo* canopy cover, but the canes are not rooted within the edge area, rather they are draping over into this space (Figures 2-12 & 13).

When individual ramet (cane) based data is scaled up to represent stand or clonal mass, adjustments need to be made to account for the areas that have no canes within the stand (if these areas were not sampled). This adjustment can occur as a reduction in cane density for the stand, or as an adjustment applied to account for the percentage of the stand that has no cane emergence. Most studies do not specify what was done with edge areas and gaps within the *Arundo* canopy. If these areas were sampled they would have cane density accounts of zero. Most studies seem to sample within the cane emergence zone only. The importance of the edge areas depends on stand size, which is usually a function of age. A small stand has significant edge (areas with aerial vegetation cover but no canes emerging from the zone, Figure 2-14). Over 70% of the stand area may have no canes emerging from it. Large stands, as long as they are not linear, have much less edge area as a proportion of the total stand area. Only 5% of the stand area might not have canes emerging from it.

The second area that has no canes in the aerial canopy of a stand occurs as alleys or gaps and is less predictable to specific locations of the stand (Figures 2-12 & 14). These areas are important in mid to large-sized stands that often form as multiple clumps grow into each other. As the stands grow older, these 'alleys' or gaps fill in. *Arundo* stands older than 10 to 15 years have fewer and fewer areas within the stand that have no canes. *Arundo* stands older than 20 years are difficult to sample internally, as these areas are not accessible from the ground. Old *Arundo* stands are more easily traversed across the top of the canopy than on the ground, where cane density precludes movement (Figures 2-15 & 16). Vegetation sampling crews on the Santa Margarita River could walk across the *Arundo* canopy for hundreds of meters in 1996 (Cummins pers. comm. 1998).

Gaps within *Arundo* stands also occur where there are low-flow channels (primary and sometimes secondary. These would technically be defined as separate stands as they have different rhizome systems, but they may appear as one stand when mapping. The 10 meter wide low flow channel of the San Diego River was crossed within *Arundo* canopy, attesting to the strength and density of the aerial cane network (Giessow pers. comm. 2009).

Cane density also varies within the portion of the stand where canes emerge. This makes sense since a stand starts as an individual (single fragment) or group of individuals (larger rhizome fragment with many nodes), and continually expands outward. Lateral growth creates a pattern of greater density within the older portions of the stand and lower density toward the edges (Figure 2-17). However, this variation is fairly minimal compared to the variation in cane density between different stands (field observation J. Giessow, this study). Data from this study recorded an average cane density of 6.5 m (maximum 9.9 m, minimum 2.6 m, Table 2-1). *Arundo* cane density is significantly higher than that of native vegetation (Ambrose 2006, NHC 1997a,b & 2001), and this has multiple effects such as restricting wildlife movement and blocking water flow. Sampling bias may also be occurring in many studies where cane density is not sampled from the interior of older stands which are hard to access. This study was able to sample deep interior portions of stands that were accessible during biomass reduction with heavy equipment. However, cane density does not increase indefinitely; eventually new canes that emerge do not reach light and they senesce each year (Decruyenaere1 & Holt 2005). Cane data collected in this study indicates that each square meter within the rhizome/cane emergence zone generates 3.4 (n=14, ± 2.7) canes per year. Dead canes were not common, with a density <1/m^2 on the study plots (Table 2-4). This study will adjust stand based calculations by multiplying the cane per me^2 by 70% to account for areas with no canes emerging from them (adjusting for edge drape and areas with no cane emergence within the aerial footprint of the stand).

Some areas are near a typical mature density (center), while edges and runners are expanding outward, creating lower density. Also see Figure 2-9 to look at rhizome growth pattern. This is a small 3 x 3 m clump, but similar patterns occur in larger stands. The canes drape and extend well outside of the central cane emergence footprint indicated in red.

This study will make scaling up adjustments of 70% to account for cane density measurements from sampling only carried out within the cane emergence zone. This will occur for stand-based biomass and water use calculations.

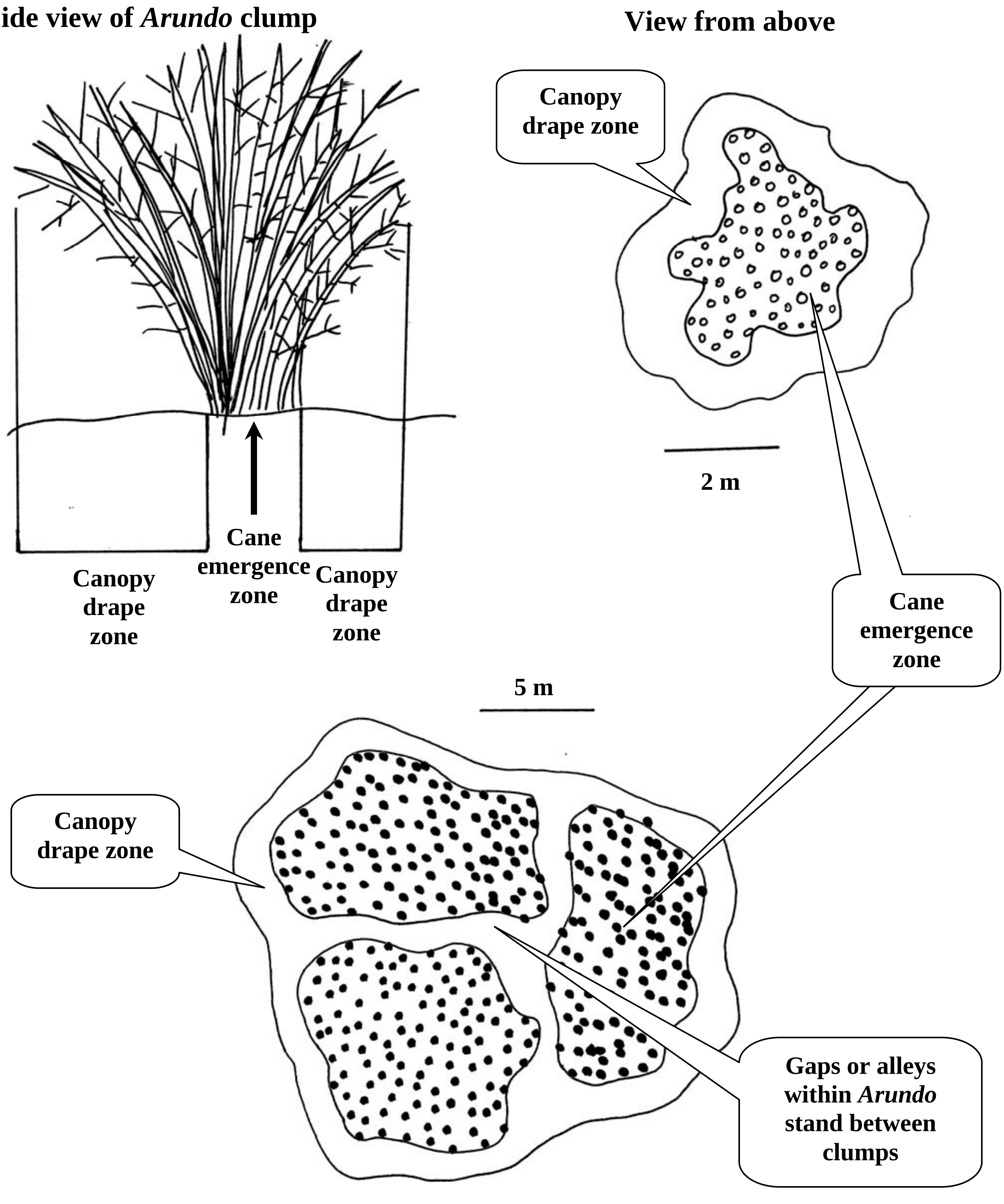

Figure 2-12. Draping effect of *Arundo* on the edge of the stand and gaps between clumps within a stand.
Drawing by J. Giessow.

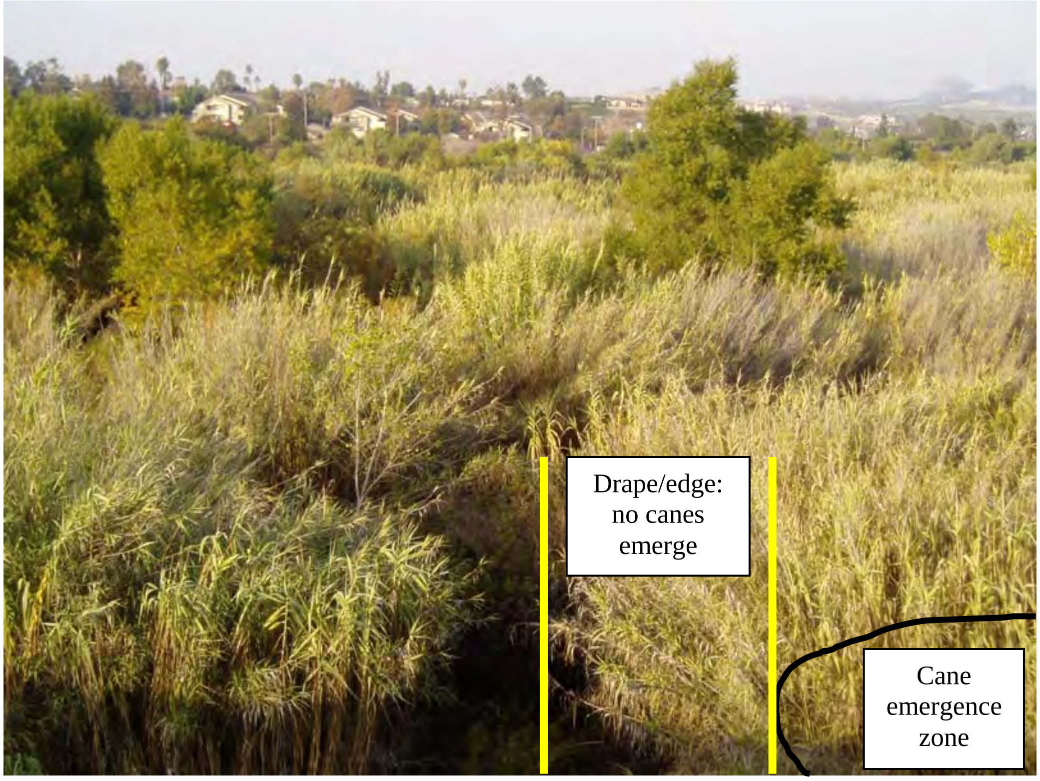

Figure 2-13. A mature *Arundo* stand showing draping of *Arundo* canes along an edge.

Figure 2-14. Oblique aerial photo showing patchiness of *Arundo* stands, particularly farther from the low-flow channel.
Greater patchiness means greater edge area composed of *Arundo* cover without actual canes emerging. The left side of image is unmowed/reduced *Arundo* and the right is immediately after reduction/mowing (San Luis Rey River 2007, J. Giessow).

Figure 2-15. View from bridge over San Luis Rey River showing the top of a mature *Arundo* stand. This stand is >10 years old, > 9 m height, and 100% cover. Note the high amount of leaf surface area and non-vertical (nearly horizontal) position of the upper portion of the canes with secondary branches.

Figure 2-16. *Arundo* stand being prepared for foliar herbicide treatment.
The crew is pushing the stand away from the native trees. *Arundo* canes are supporting the worker on the left. Canes are 8-9 m long and density is typical of a mature stand (about 40 canes/m^2). San Diego River, Giessow 2010.

Figure 2-17. A cut *Arundo* clump showing uneven cane density.

Table 2-4. Summary of *Arundo* cane density measurements from this study and others. This study and others typically sample cane density from the cane emergence zone.

Source	Location	New	Old	Dead	Total
Giessow et al.(2010)	S. California, coastal	3.4	38.1	<1	41.5
Spencer eta al. (2006)	Across U.S.				74.5
Ambrose & Rundel (2007)	S. California: Santa Clara River (post fire)				31.6
Abichandani (2007)	S. California: Santa Clara River				34.9

Figure 2-18. Cane density and dead leaf litter within a dense *Arundo* stand.

2.4 Biomass and Cane Density

Biomass (above and below ground) generated from *Arundo* is important as it sheds light on several factors related to impacts caused by the plant. It provides information on productivity, resource consumption (nutrients, light, and water), physical presence in the system (with impacts to flows, sediment, wildlife, light, wind, and other physical parameters), as well as indicating issues with the fate of the biomass material itself (both in aquatic and terrestrial portions of the watershed system).

Arundo has very high amounts of biomass per unit of land area as documented in many studies looking at standing biomass of wild infestations and annual productivity of cultivated stands (Table 2-5). This study found an adjusted *Arundo* stand biomass of 15.5 kg/m2, which is corroborated by the most comprehensive study evaluating *Arundo* biomass (Spencer 2006). The large amount of biomass is related to high productivity of the plant, high density of individuals (high cane density), and tall growth form of the plant (average 6.5 m in southern California). In addition to the high amount of biomass per unit of land area, *Arundo* has a large amount of energy per unit of dry weight (17 MJ/kg to 19.8 MJ/kg, see chapter 6). These values compare favorably with other fuel crops (*Arundo* is one of the highest) and are higher than most native tree, scrub, and herbaceous assemblages in the riparian zone. This is why fuel crop producers consider *Arundo* one of the top potential biofuel crops.

Belowground biomass estimates have been less studied, but appear to be in the range of 22.5% of the total plant/stand biomass (Sharma et al. 1998). Applying this proportion of above and below ground biomass generates overall estimates of 20.0 kg/m^2 or 89 t/acre (Table 2-6). These biomass levels are at the upper end of any vegetation class (Table 2-7), and are well above typical riparian vegetation values.

Table 2-5. *Arundo* aboveground biomass from various studies (wild and cultivated).

Location	Description	Above ground dry mass	Source
U.S. - 13 sites across US	Biomass of stands in field: wild	$17.1\ kg/m^2$ 171 t/ha 76 US t/ac	Spencer 2006
U.S. - 14 sites, 6 coastal watersheds in southern California	Biomass of stands in field: wild	$15.5\ kg/m^2$ 155 t/ha 69 US t/ac	This study
India	Biomass of stands in field: wild	3.6 to $16.7\ kg/m^2$ 36 to 167 t/ha 16 to 74.3 US t/ac	Sharma et al. 1998
Southern CA (Santa Clara)	Annual yield (post fire): wild	49 t/ha 21.8 US t/ac	Ambrose & Rundel 2007
India – wild stands	Annual yield: wild	72 t/ha 32 US t/ac	Raitt 1913
Australia	Annual yield: crop	101 t/ha 45 US t/ac	Williams et al. 2008
Europe	Annual speculated max yield: crop	100 t/ha 45 US t/ac	Shatalov & Pereira 2000
Italy	Annual yield: crop	30 t/ha 13.4 US t/ac	Angelini et al. 2005
Italy – cultivated stands	Annual yield: crop	39.3 t/ha 17.5 US t/ac	Marinotti 1941
Greece	Annual yield: crop	120-230 t/ha 53.4-102.4 US t/ac	Mavrogiapolus et al. 2001
Greece	Annual yield (Yr 1, new crop): crop	15 t/ha 6.7 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 2): crop	20 t/ha 8.9 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 3): crop	30 t/ha 13.4 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 4, mature): crop	39 t/ha 17.4 US t/ac	Hidalgo & Fernandez 2000
Spain	Annual yield: crop	45.9 t/ha (ave) 29.6-63.1 t/ha (range) 13.2-28.1 US t/ac	Hidalgo & Fernandez 2000

Table 2-6. Above and below ground biomass values for *Arundo*, using relationship from Sharma 1998 (22.5% of biomass is below ground).

Study	Above ground biomass	Below ground biomass	Total biomass
This study	15.5 kg/m^2 155 t/ha 69 US t/ac	4.5 kg/m^2 45 t/ha 20 US t/ac	20.0 kg/m^2 200 t/ha 89 US t/ac
Spencer 2006	17.1 kg/m^2 171 t/ha 76 US t/ac	5 kg/m^2 50 t/ha 22 US t/ac	22.1 kg/m^2 221 t/ha 98 US t/ac

Table 2-7. Typical biomass values for different vegetation types.

Study	Above ground biomass	Study
Willow forest (as crop)	4-8 t/ac (annual) 15 t/ac (4 year growth)	Turhollow 1999
Switch grass	5 t/ac	Turhollow 1999

2.5 Growth Rate

Individual Ramet or Cane Growth:

When conditions are favorable, *Arundo* canes can grow 0.3-0.7 m per week over a period of several months (Perdue 1958). Young stems rapidly achieve the diameter of mature canes, with subsequent growth involving thickening of the walls (Perdue 1958). Annual yield studies demonstrate the productivity of *Arundo* stands (Table 2-5). Old canes typically have little new growth on the main leader (Decruyenaere & Holt 2005), but have extensive growth on secondary branches, as well as growing new secondary branches. In colder regions of the world *Arundo* dies back and then resprouts, although frost can damage the plant if it occurs after initiation of new growth (Sharma et al. 1998, Perdue 1958). In southern California dormancy is limited to total to partial browning of the canes and leaves during the winter.

Rhizome Growth:

In mature stands, most new shoots develop from large apical buds at rhizome termini, resulting in relatively evenly spaced, vertically oriented shoots 2 cm or more in diameter (Decruyenaere & Holt 2005). Rhizome growth extends laterally along an axis, but will branch (Figure 2-8). Rhizomes appear to ‘self-discriminate’, growing into areas with no rhizomes present (Decruyenaere & Holt 2005). Stands expand 7-26 cm/year (Decruyenaere & Holt 2005), as well as generating higher density. Comparisons of imagery over a 10 year period for sites in San Diego showed minor (none visible) to moderate

(0.5m/yr) expansion of established stands. Generally expansion was surprisingly slow, but highly variable. A few studies have examined expansion and lateral spread of rhizomes and canes, but these data are presented as increasing cane density within quadrats. Future studies should more explicitly describe length (m) or area (m^2) of spread.

Stand Growth:

Three general factors seem to affect growth rates of both canes and rhizomes: 1) availability of water, 2) availability of nutrients and 3) temperature regimes (affected by shade). Water availability seems to be the primary factor restricting the growth of *Arundo* stands in coastal California. This is based on field observations across the study area and our review of transpiration and nutrient studies. Generally watersheds in coastal California have favorable temperature ranges and are not nutrient limited. Areas with water available throughout the year develop into dense, tall *Arundo* stands. Areas with low water availability, such as upper terraces that are far from the water table, frequently have *Arundo* stands with lower cane density, shorter stature, and large amounts of dead material in the canopy (an indicator of stress).

Riparian systems are typically not nutrient limited in coastal California (Peterson et al. 2001, Suffet & Sheehan 2000). Artificially high nutrient levels increase growth rates of all riparian vegetation, but *Arundo* with its higher productivity potential (compared to native vegetation) is able to capitalize on this, turning it into a competitive advantage (Ambrose and Rundel 2007).

Nutrient use/nutrient loaded systems:

In the last century, nutrient inputs to river systems have increased dramatically due mainly to agriculture and municipal sewage. These same nutrient inputs are present in high quantities in the rivers of Southern California's watersheds (Pederson 2001, Suffet and Sheehan 2000). Nationwide, the use of fertilizer in agricultural areas has increased from 20 to 40 million tons annually. The average percent of nitrogen, the main constituent in commercial fertilizers, has risen from 6.1 to 20.4 % (Texas Water Resources Institute 1986). This increase in use and composition of fertilizer alone has led to a loading of river systems with nutrients, mainly nitrogen and phosphorus. Nitrogen, found in the form of nitrate in fertilizer, poses unique risks to river systems; it is soluble and moves quickly through soils in the shallow groundwater between agricultural practices and rivers. Phosphorus, on the other hand, is not very soluble and typically adheres to soil particles. Other anthropogenic and natural sources are thought to have also contributed to nutrient loading in river systems, including: nitrogen enriched rainfall and air; manure from animal feedlots and corrals; fertilizer applied to lawns; leaky septic tanks; oxidation of organic materials; and the symbiotic nitrogen fixation by plants.

2.6 Reproduction and Spread

This discussion is separated into spread within a site, spread within a watershed, and spread between watersheds.

2.6.1 Within Stand Spread

Once *Arundo* is present at a given location it grows and spreads laterally. Lateral spread occurs mainly through lateral rhizome growth and budding (forming new ramets or individuals in the asexual colonial

Arundo stand) (Decruyenaere & Holt 2005). In addition, *Arundo* canes can drape/bend over and touch the soil surface, and if conditions are favorable (wet and/or sediment covering a node) a new bud may form (developing into a new ramet or individual) (Boland 2006).

2.6.2 Spread Within A Watershed

Arundo is dependent on asexual reproduction. *Arundo* plants in North America do not appear to produce viable seed. Multiple studies in California have determined that seedlings are not present in the wild (Else 1996, Witje et al. 2005) and that plants that flower do not produce viable seed (Khudamrongsawat et al. 2004). Studies in India indicate that the apparent sterility of *Arundo* seed is caused by the failure of the megaspore mother cell to divide (Bhanwra et al. 1982).

New individuals within a watershed and the colonies they grow into are created through vegetative propagation. This occurs when plant fragments, usually rhizomes, become rooted at new locations and form into separate plants. Dispersal generally occurs during flood events, when floodwaters break off pieces of *Arundo* plants and transport them downstream (Else 1996, Decruyenaere & Holt 2005). Establishment of new *Arundo* stands within a watershed is, therefore, generally limited by the extent of river flow and floodplain inundation. However, *Arundo* fragments can also be moved to new locations within a watershed via human disturbance.

Several studies have shown that almost any segment of stem or rhizome can sprout if it possesses an axillary bud (Boose and Holt 1999, Wijte et al. 2005, Else 1996). Buds occur at the stem nodes and approximately 5-10 cm apart on the rhizomes (Wijte et al. 2005). Both rhizomes and stems can withstand a certain amount of drying out and still sprout. Drying rhizomes to 58.8% moisture loss and stems to 36.5% moisture loss did not affect their ability to sprout (Else 1996). Rhizomes were able to sprout when buried up to one meter deep (Else 1996), but stems have shown reduced sprouting at depths as low as 10 cm due to limited energy reserves in the stem (Boose and Holt 1999).

Else (1996) reported that of *Arundo* vegetative reproduction observed following dispersal by flooding on the Santa Margarita River in San Diego County, 57% was from rhizomes, 33% was from stem fragments, and for the remaining 7% the plant part that gave rise to the new plant could not be identified. Rhizomes are frequently broken off at bank edges when they are undercut (Brinke 2010) or scoured out (Figure 2-7). Any disturbance (natural or human caused) that mobilizes live rhizome material during conditions that are favorable for establishment will likely result in spread of *Arundo*. Flow events will break off rhizome fragments along stand edges and disperse them within flow areas (Brinke 2010). For this reason significant spread of *Arundo* within a watershed is episodic. Flows reach higher geomorphic forms (floodplain and terraces) only during large events. These large hydrologic events mobilize *Arundo* material for potential asexual propagation. Low flow events are confined to channel areas. New *Arundo* establishment in this area is often removed during later flood events. Little propagule material is typically mobilized during these low flow events in comparison to larger events, but undercutting of *Arundo* stand edges does generate a steady amount of propagules downstream.

The combination of within watershed dispersal events and stand growth rates generates a pattern of expansion that increases episodically to the system's maximum carrying capacity for *Arundo*. Larger watersheds with favorably wide floodplains have about 13% *Arundo* cover, but portions of these systems can have cover >44%.

2.6.3 Historic Air photo Analysis: Stand Growth Rates and Spread Within Watershed

Review of historic aerial photography on watersheds in the study area indicated some interesting patterns of spread and growth. The basic pattern that repeated on most watersheds was that there was little *Arundo* present on most systems from the 1930's to the 1960's. It looks as though *Arundo* was present as scattered clumps and small stands. Aerial photography during this time was of low resolution and black and white, limiting our ability to detect and map *Arundo*. Large stands of *Arundo* would have been detectable, but they were not present. The overall historic extent of *Arundo* on most systems was scattered with low total acreage. As will be seen later in this report (Chapter 5), this makes sense, since historically riparian systems were broad and dry.

In the 1960's riverine systems became much narrower (levees and land use change) and water was imported. This resulted in perennial flows on many systems or at minimum, significantly raised water tables. *Arundo* responded to these changes by aggressively spreading and growing into dense stands. This transformation occurred during the 1970's and 1980's on most systems. By the 1990's *Arundo* had achieved an extensive distribution that appears to be at or near the current distribution of the plant.

Lateral expansion of established stands appeared to be fairly slow, on the order of 1 to 2 feet a year. Disturbance events (fire, grading, clearing, flood action) and the subsequent growth seem to be more important to rapid expansion of *Arundo* than the slow lateral growth of established stands. The concurrent use of both growth strategies allows *Arundo* to become abundant on southern California watersheds that are characterized by episodic flow events. Review of historic aerial photos indicated that significant spread of *Arundo* within a watershed appears to be very episodic. Large magnitude flow events (25 to 100 year) are necessary for the plant to actively invade significant new areas in a riparian system, particularly higher floodplains and terraces.

2.6.4 Spread Between Watersheds

The spread of *Arundo* between watersheds is primarily due to humans moving *Arundo* plants (planting or dumping biomass) or soil/fill material contaminated with *Arundo* fragments. *Arundo* fragments can wash up into estuaries, but generally cannot get very far up into the riparian system as river flows push material out of the system.

2.7 Ecological Function: Abiotic and Biotic

2.7.1 Abiotic

Invasive species that modify abiotic ecosystem processes have significantly greater impacts than those that affect only biota (flora and fauna) because abiotic processes shape and control the entire ecosystem. *Arundo* strongly affects riparian abiotic processes, including: hydrology/geomorphology (including flooding - Chapter 5, water use/transpiration - Chapter 4) and fire (Chapter 6). *Arundo*'s strong influence on these ecosystem properties has two main consequences: 1) it modifies the habitat in ways that impact native flora and fauna, and 2) it modifies habitat in ways that benefit its own growth and continued spread. The modification of flows, geomorphology and sediment transport strongly affects successional patterns of vegetation. *Arundo*’s proliferation indicates that it benefits from this alteration of river processes. The significant increase in fire events (area and frequency, as documented in Chapter 6) and intensity also favors *Arundo*, as it is more productive than native vegetation after fire events (Ambrose & Rundel 2007).

2.7.2 Biotic

2.7.2.1 Vegetation

Arundo tends to form dense, monotypic stands that replace native riparian vegetation and naturally occurring open areas between vegetation groups. The displacement of native vegetation results in changes to vegetation composition, vegetation structure, and food resources. These changes have impacts on the native flora and fauna.

When *Arundo* forms dense stands, there is generally less plant diversity in comparison to un-invaded areas. A study in the Russian River in northern California showed that *Arundo* invasion was associated with significantly lower richness of native perennial plant species on stream banks, but not on gravel bars (Cushman and Gaffney 2010). Plots invaded by *Arundo* exhibited significantly lower native and exotic species richness and abundance of both established plants and seedlings than un-invaded plots. In coastal southern California watersheds, *Arundo* often displaces nearly all vegetation, leaving only mature gallery trees, which have a canopy layer higher than the *Arundo* stand (Figures 2-15 & 16). Native vegetation displacement is particularly pronounced in the shrub, perennial herb and annual herb growth form classes. Within dense *Arundo* stands there is generally little or no understory vegetation (Figure 2-19). In addition to displacing native vegetation, *Arundo* also alters the habitat by filling in areas that would naturally be open and unvegetated. Open portions of riparian habitat can be critical for fauna that use these areas for movement (both within and through the habitat). Unvegetated soil substrate can also be a place of refuge (both sand and litter covered).

A system that has dense stands of *Arundo* affects abiotic processes, tending to have a higher fire frequency and intensity, as well as altered flooding patterns. Removal of riparian vegetation by *Arundo* exacerbated flood and fire events alters the natural riparian successional patterns, and generally leads to more dominance of *Arundo*. This is an important positive feedback loop that leads to type conversion (Ambrose & Rundel 2007).

Arundo's impacts on vegetation and federally listed plants will be discussed further in Chapter 7.

2.7.2.2 Arthropods

Several studies have examined the impacts of *Arundo* on arthropods. All have indicated reduced diversity, density and/or productivity of arthropods within *Arundo* stands compared to native riparian vegetation. Native riparian vegetation in Sonoma County in spring contained twice the abundance, biomass, and species richness of aerial insects compared to *Arundo* (Herrera & Dudley 2003). Furthermore, insects recorded in *Arundo* were rarely observed feeding there, indicating that *Arundo* is used for its structure more than as a food source. Ground dwelling insects showed the same responses to *Arundo*, but to a lesser degree than aerial insects. Habitat that contained a mixture of *Arundo* and native riparian habitat showed an intermediate response. The *Arundo* infestation within the study area was at a much lower level than some southern California systems. High cover stands would likely show even less use.

Studies on arthropod use of *Arundo* leaf material indicate it is of low quality for native arthropods. Aquatic caddisfly larva survival was much lower for individuals fed *Arundo* (20%) compared to Alnus, Salicaceae, or Tamarix litter (85%) (Going & Dudley 2008). The high concentration of secondary compounds (tannins, alkaloids) and silica in *Arundo*, and the low nitrogen levels are likely to be poor food resources (Khuzhaev & Aripova 1994, Wynd et al. 1948).

Invertebrate species assemblages within soil and leaf litter in *Arundo* stands tend to be opportunistic forms that generally do not utilize the plant tissue directly and tend to be non-native. Invertebrates associated with *Arundo* rhizomes in southern California followed this pattern (43% non-native), and non-native detritivorous isopods were the most abundant in the Sonoma County study (Lovich et al. 2009, Herrera & Dudley 2003).

The preference of arthropods for native riparian vegetation over *Arundo* stands is likely due to the greater habitat structure, the more complex and massive litter layer, and the higher quality food resources. Despite its large biomass per square meter, *Arundo* appears not to provide much to the food web. This has significant impacts on wildlife. A large reduction in aerial insects, in particular, could have serious negative impacts for insectivorous birds such as the endangered least Bell's vireo (*Vireo bellii pusillus*) and southwestern willow flycatcher (*Empidonax traillii extimus*).

2.7.2.3 Wildlife

Dense *Arundo* stands can negatively impact fauna through a reduction in food resources, alteration in structure for nesting/denning, and creation of a physical barrier to movement within and through riparian habitat to upland areas (wildlife corridor). While there have not been many studies that document all of these impacts, they do seem probable based on the limited research that does exist, coupled with personal field observations and wildlife specialists' assessments as reported in management plans and regulatory documents. *Arundo* biomass has the potential to contaminate pools and areas used by native fish and amphibians for breeding and feeding, and can impact wildlife on beaches and estuaries where it collects after flood events. *Arundo* biomass piles and live plants may also create structure in areas where none naturally occurs, which may impact predation.

Studies on the use of *Arundo*-invaded habitat by wildlife are often compromised by native riparian habitat adjacent to and/or dispersed within the *Arundo* stands. Large continuous stands of *Arundo* do exist, but they are difficult to monitor as the density of canes restricts access to interior portions of the stand. Species frequently have territories/ranges that include *Arundo*-invaded and un-invaded habitat. Even with this caveat, patterns are still apparent.

Many reports and surveys have identified *Arundo* as a factor in reduced habitat fitness for reptiles and amphibians, although there are no specific research studies. Since reptiles and amphibians are highly dependent on specific hydrological/geomorphological processes occurring, they may be severely impacted due to *Arundo*'s complicated, long-term impacts on hydrology, geomorphology, and water use. This report explores these impacts in depth, and the impacts appear to be significant. *Arundo* stands can impact reptiles and amphibians by creating physical barriers to their movement within the riparian habitat, and to adjacent upland areas. Arroyo toads appear to avoid *Arundo* stands on MCB Camp Pendleton (Camp Pendleton Land Management Branch Reports and pers. comm. with land managers), but are dependent on migrating from breeding pools to upland habitat. Specific impacts will be explored for four endangered reptiles and amphibians in Chapter 7.

Arundo impacts on geomorphology/hydrology, especially channel and pool formation, are likely to be significant factors affecting fish species. There may also be impacts associated with contamination by large amounts of *Arundo* biomass within pools and other areas used for breeding and juveniles. It is generally thought that *Arundo* does not shade the waterway in the same way as native vegetation, resulting in increased water temperatures that would negatively affect fish and amphibian species. However, there is no published data on temperature in *Arundo* dominated streams as compared to native vegetation. Of greater consequence would be *Arundo*'s impact on channel depth, width, and number of channels/braiding (Chapter 5). Deeper, narrower channels may be cooler, but they also have reduced feeding opportunities and appropriate substrate may be lacking. Wrong depth and aspect, and higher water velocity may also impede movement and/or cause reproduction to fail. Four endangered fish are examined in Chapter 7, with a more detailed discussion of *Arundo* impacts on habitat, movement/migration and reproduction.

Arundo impacts bird species due to its physical structure and its apparent reduction in abundance and diversity of insects (available data primarily relate to insectivorous species). In three drainages in southern California, *Arundo* stands contained reduced abundance and species richness of birds compared to native stands (Kisner 2004). The number of non-listed avian species declined by 32-41% as *Arundo* cover increased from 0 to 50%. Species richness of both ground and foliage gleaning birds declined in areas with increased *Arundo* cover. Preliminary results of a study on the lower Santa Clara River in southern California show diminished avian species diversity and fewer total individuals in *Arundo* stands relative to native stands, with intermediate diversity in mixed patches (Orr 2010). *Arundo* may also affect bird abundance as avian species rarely use it for nesting. The branching structure of *Arundo* is very different from native shrubs and trees, and it is presumed that it does not provide the architecture or support required for nesting. In the Prado Basin on the Santa River in southern California, from 1987 to 2006, only 0.8% percent of least Bell's vireo nests were in *Arundo*, compared to 76% in willow and mulefat (Pike et al. 2007). *Arundo* biomass washes downstream during flood events and can collect within estuaries and beaches. On the Santa Margarita River watershed, large piles of dead and sprouting *Arundo* eliminate nesting sites for Western snowy plovers and increase the presence of predators, which use it as perches and prey on rodents in the piles of vegetation (USFWS 2001). Eight endangered bird species will be reviewed in Chapter 7.

Arundo has complicated effects on mammal species. *Arundo* stands may provide areas for dens, but food resources are lower in comparison to native plants due to lack of seed and low quality forage. The dense cover and growth reduces mobility of mammals, which could reduce the use of riparian habitat as corridors for movements. This would be a significant impact and it remains undocumented. One endangered mammal, the San Joaquin kit fox, will be examined in Chapter 7.

2.8 *Arundo* Biology: Conclusions

Several observations were made in field studies, including:

- Mature stands are taller than has been typically reported in the literature: 6.5 m mean and a range of 2.6 – 9.9 m. (Section 2.3)
- Adjustments need to be made when scaling up from cane specific data to stand data due to canes not actually emerging within all areas of the *Arundo* canopy. Areas along edges and gaps within stands few to no canes. (Section 2.3)
- Biomass per unit area measured in this study is very high for mature *Arundo* stands: 15.5 kg/m^2. This is in general agreement with the literature. (Section 2.4)
- Reviewed literature demonstrates that *Arundo* spreads through asexual propagation (fragments of rhizomes and, infrequently, canes). Seeds are not viable. This makes *Arundo* spread dependent on flood action or anthropogenic disturbance. (Section 2.5)
- Review of historic aerial photography indicates that spread of *Arundo* within a watershed is very episodic. Large magnitude (50 to 100 year) events are necessary for the plant to actively invade significant new areas in a riparian system, particularly floodplains and terraces. (Section 2.6.4)

3.0 SPATIAL DATA SET: The Distribution and Abundance of *Arundo* from Monterey to Mexico

3.1 Methodology

Arundo was mapped for all coastal watersheds from the Salinas River in Monterey County in the north to the Tijuana River in the south (Figure 3-1). Four additional large-form riparian invasive plant species (*Washingtonia robusta, Phoenix canariensis, Cortaderia selloana, and Cortaderia jubata*) were also extensively mapped due to their presence and high abundance within a majority of the riparian corridors that were surveyed. Due to limited high-resolution aerial photo coverage, only partial mapping of all five species occurred in the Bolsa Nueva, Pajaro River, and Big Basin watersheds just north of the Salinas River Watershed. In addition, mapping of both *Cortaderia* species was limited to the immediate coastline above Santa Barbara County. For *Cortaderia* species, central coast populations north of Santa Barbara were mapped as jubata grass (*C. jubata*), and populations south of Santa Barbara were listed as pampas grass (*C. selloana*). The photo resolution that was available for most of this region (Central Coast) was too coarse to differentiate *Cortaderia* populations to species.

The mapping methodology utilized for this project borrows techniques from previous large-scale, watershed-based weed mapping efforts that have taken place in San Diego and Los Angeles Counties. Each plant population was captured using one of the following digital mapping approaches: (a) in-house surveys compiled by heads-up digitizing on high resolution aerial photography within a GIS; (b) field surveys using high resolution aerial photography on an integrated Tablet PC/GPS or; (c) a combination of option a. and b. (in-house surveys followed up by field checking).

3.1.1. Step-by-Step Process

1) In-office Surveys

Initial mapping efforts took place in the office. The database was generated within ESRI's desktop GIS application (ArcGIS 9.3) using a geodatabase (GDB) as the chosen file format. Domains (i.e. a data dictionary) were setup before mapping commenced to help ensure data integrity by limiting the choice of values within each field. Target species were then digitized within the GIS implementing a dual-monitor workstation setup. A primary tablet monitor (Figure 3-2) hosts the GIS application where plant populations are delineated as defined areas (i.e. polygons). High-resolution (1 ft or better) vertical aerial photos[1] were the primary base layer used for delineating plant population boundaries in the GIS. After a population was digitized, key attributes were noted (Table 3-1). Relevant supporting data was also captured during this phase that included "area mapped" to discern presence/absence and homeless encampment locations within the riparian zone. A secondary reference monitor was used as an additional aid to help distinguish smaller clumps as well as those populations partially covered by thicker tree canopy cover. High-resolution oblique imagery from four directions served as the reference. These images were freely available for all urban and wildland-urban interface (WUI) areas across the project extent courtesy of Microsoft's Bing maps "bird's eye view" function (*www.bing.com/maps*). The California Coastal Records oblique imagery database *(www.californiacoastline.org)* also served as a reference source for the immediate coastline (particularly for the central coastline *Cortaderia* species mapping).

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[1] Two to four time periods (2004, 2005, 2006, and/or 2008) were available depending on the given area.

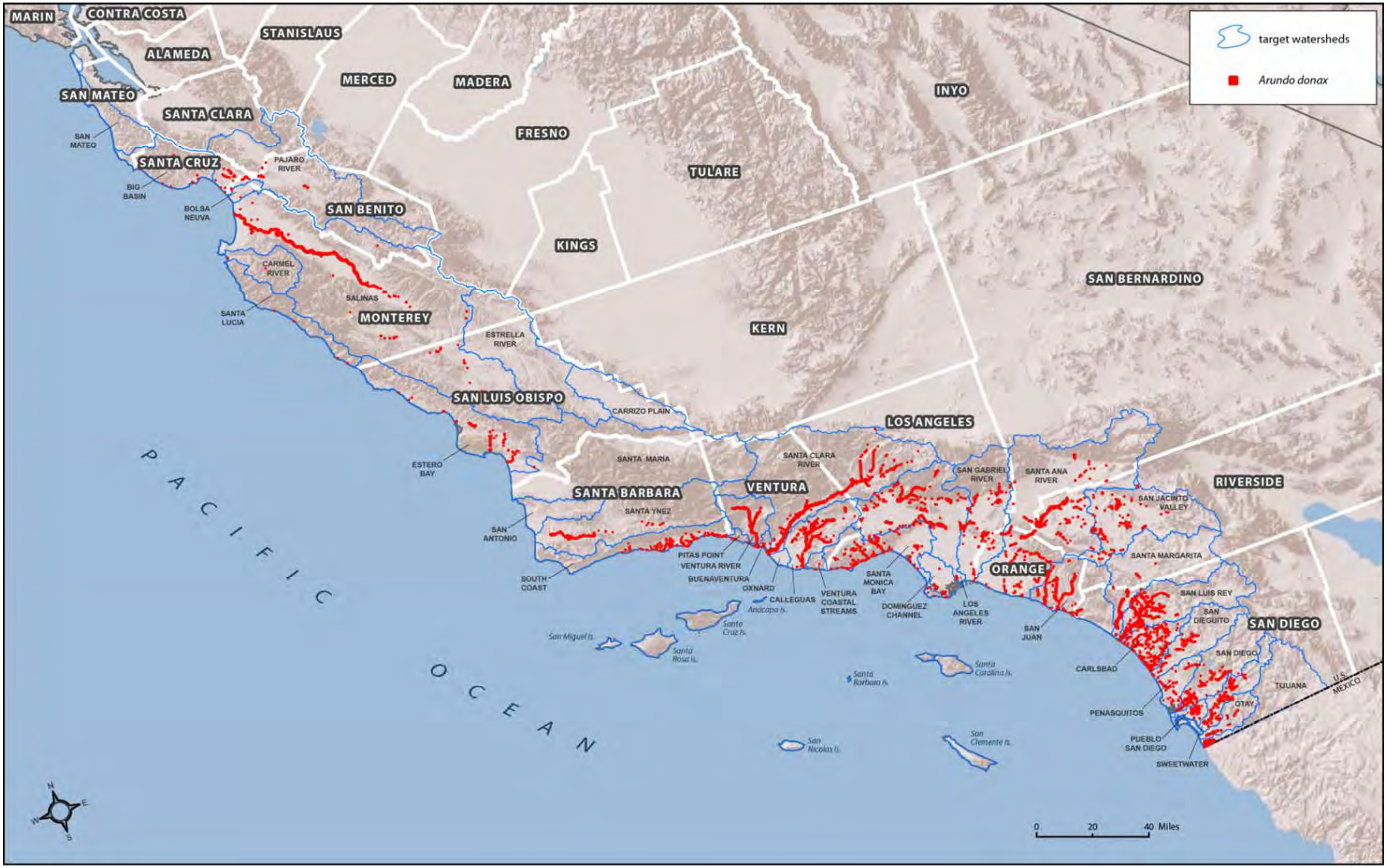


Figure 3-1. Distribution of *Arundo* mapped within the study area from Monterey to San Diego, CA.

Figure 3-2. In-office surveys using a dual-monitor workstation.

Table 3-1. Data dictionary used for plant mapping.

Attribute	Notes
Plant Species	Common and scientific names are noted.
Percent Cover	70-100%= 100%; 50-69%= 50%; 15-49%=20%; 2-14%=5%
Plant Count	Estimated number of trees within a polygon
Average Height	Estimated tree height
Treatment Status	Status was marked as: treated, untreated, funded for treatment, or status unknown
Comments	Supplementary information
Observer	Person responsible for the last edit of a particular record
Mapping Methodology	Method was noted as: in-office survey, field survey, or combination
Date Mapped	Records that were only collected in-office took the date of the base photography as the map date; all other records used their observed field date
Data Source	Organization that collected the record
Watershed Name	HUC unit name
Gross Area (Acreage)	Total overall area in acres
Net Area (Acreage)	Total net area (factoring in percent cover) in acres

2) Data Transfer to Tablet

After the initial survey of a watershed was completed, the data was “checked out” of the GIS database and transferred to a ruggedized tablet PC. The field tablets used for this project (Xplore’s iX104c3) were outfitted with GPS receivers (mounted or bluetooth) with an accuracy of 2-5 m (with real-time corrections) (Figure 3-3). The most current vertical aerial photography from the GIS database was also transferred onto the tablet as a base layer for the field mapping software. ESRI’s ArcPad 8.0 was chosen as the mapping application because of its seamless integration between the field computers and central database back in the office. Toolbars in ArcPad were customized to optimize the time spent collecting data in the field.

Figure 3-3. Field surveys with ruggedized tablet PCs and integrated GPS.

3) Field Verification

After data was transferred to the field tablets, crews were sent out to verify the accuracy of the in-office surveys if locations were accessible and a line-of-sight could be established. Records were checked for spatial accuracy, percent cover estimation, and current treatment status. New populations and edits to existing populations were also collected by sketching directly on the tablet with a digital pen (Figure 3-4). The GPS functionality was only used only as a reference to orient the mapper’s position on the basemap (i.e. high-resolution aerial photograph). Tracklogs in ArcPad (digital “breadcrumbs”) were used to document surveyed areas and track progress/time spent mapping in the field.

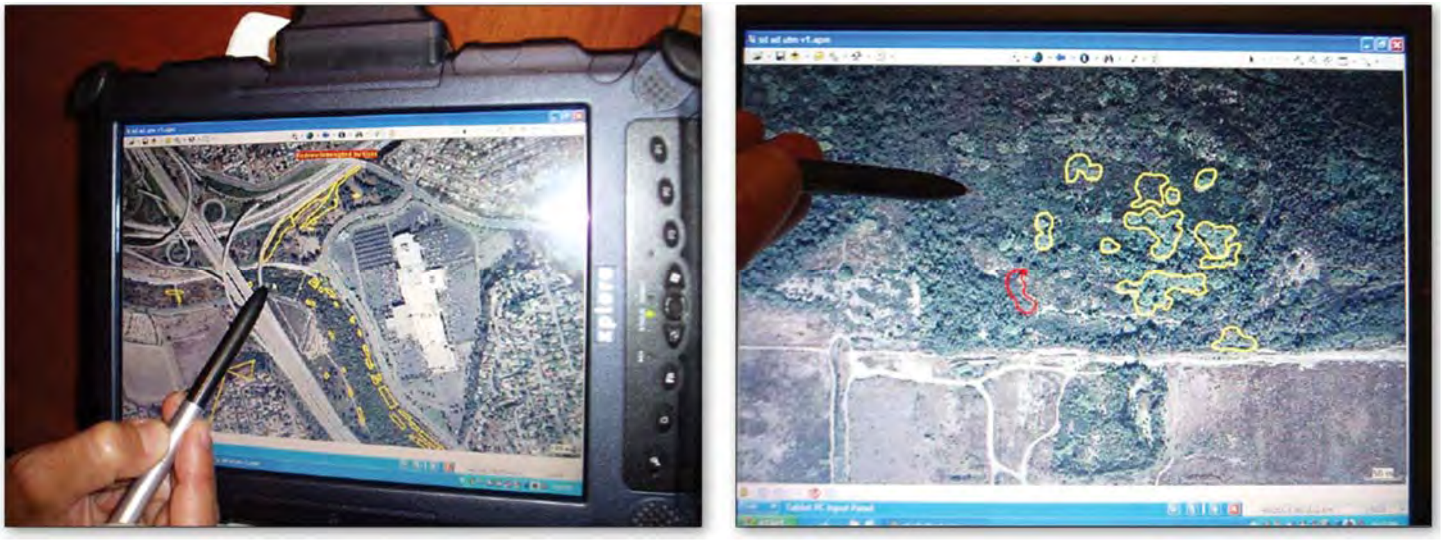


Figure 3-4. Digital sketch mapping.

4) Data Transfer To GIS

After field verification was completed for a given watershed, data is “checked” back into the GIS database at the office. Additional data attributes (watershed name, mapping status, acreage) were added through an automated process and existing attributes were re-checked for consistency.

3.1.2. Data Quality

The combination of methodologies mentioned above is the obvious choice for capturing the highest possible accuracy, but there were instances where either the in-house or field surveys were not feasible. In-house surveys were not completed when high-resolution imagery (6 in-1 ft vertical or 1 m plus oblique photography) was not readily available for a particular region. As field checking commenced, it became apparent that smaller clumps were often misidentified or omitted when high-resolution imagery was unavailable.

There were instances when field surveys were not achievable due to access (i.e. private property, difficult terrain, etc.) and/or general project time constraints. For instance, the Salinas River has thousands of smaller disconnected clumps of *Arundo* that were widely dispersed across several miles. Field checking all of these populations was not practical, nor was it achievable within the given timeline and budget. Preselected locations along the Salinas River were visited and field checked where it was inherently difficult to distinguish *Arundo* populations in-office. *Cortaderia* populations along the Central Coast also were not field verified. There are hundreds of miles of coastline covered by steep bluffs in this region that have a significant amount of *Cortaderia* present throughout the landscape. Given the time constraints, the area that needed to be covered, and the fact that this was species was a lower priority in terms of project goals, ground-truthing this extent was not achievable for the project.

It should also be noted that all species mapped were defined by their full footprint extent as interpreted from a vertical perspective. For *Arundo* in particular, this means capturing both the cane emergence zone and cane drape zone (as shown in Fig 2-13). Mapping populations in this manner can have an effect on acreage estimates, depending on the photo resolution used to delineate the footprint extent. Because individual canes are much more identifiable on the 6in. and 1ft. aerial imagery, the delineated footprint of a population can be wider than a delineation of that same population using 1m imagery. Higher resolution, in turn, will boost acreage estimates, especially in areas where individual clumps are widely dispersed and cane drape zones are more extensive.

Attribute Accuracy

"Percent cover" was determined based on a rough visual interpretation from the ground. In some cases, values may be moderately under or overestimated because of issues with access to property and/or line-of-sight due to other vegetation cover, structures, etc. This holds true for *Arundo* and *Cortaderia* in particular. Based on local field comparisons of previous surveys that used a similar methodology, overall acreage totals tend to be underestimated by approximately 15-20% (Giessow pers. comm. 2010). Because the resolution of the base photography has significantly improved over time (1 m in 2001 compared to the present standard of 1 ft/6 in), it is expected that the acreage calculations now have a higher degree of accuracy.

"Treatment status" may not represent current ground conditions due to ongoing treatment programs that are currently unknown or not being tracked by the project team. Because this is intended to be a living database, the plan is to update treatment information periodically as the data becomes available.

There may be misclassifications of species because of the inability to ground truth a particular population, or because the field mapper misidentified the species. This holds true for the *Washingtonia robusta* and two *Cortaderia* species in particular. It is currently not possible to accurately distinguish between *W. robusta* and *Washingtonia filifera* when conducting in-office surveys alone.

Positional Accuracy

Positional accuracy may vary across the project extent due to fluctuating base imagery resolutions that were available when the in-house mapping took place. Data collected during the project is no better than that of the base photography's accuracy used to delineate a population's extent.

Cartographic offsets may be present in the data due to several conditions including (a) GPS accuracy affected by quality of unit, and/or poor signal due to canopy cover, terrain, cloud cover, time of day, etc; (b) scale and legibility constraints due to the basemap aerial photography's resolution and quality, and/or; (c) field mapper interpretational errors due to line-of-sight issues caused by dense vegetation, terrain, structures, etc.

Completeness

In order to accurately quantify impacts within each system, one goal for the project was to map the full baseline extent of all *Arundo* populations present within any given system over time. While the mapping team used 2006 imagery as the starting point for developing this baseline extent, some watersheds previously had large watershed-scale eradication programs in place. These include the Santa Ana, Santa Margarita, San Luis Rey, and Carlsbad watersheds. Subsequently, earlier datasets provided by local program managers as well as historic aerial photographs were used to fill in gaps for areas that were treated and re-vegetated prior to 2006. Therefore, it should be noted that the final data output is not a single snapshot for one specific year. There may be several time periods represented for a given area, particularly in San Diego County. Santa Ana Watershed *Arundo* acreage was also adjusted higher to reflect *Arundo* control (in the mid 1990's) that could not be documented in aerial photography. The acreage adjustment estimation was based on existing program management documentation and annual reports available through the Santa Ana Watershed Authority (SAWA).

It should be noted that *Arundo* stands were certainly missed within the study area, particularly small clumps and stands that were obscured by native tree canopy or scattered stands in areas with little *Arundo*. The mapping data set captures a majority of the population that occurs in the project area, but it does not capture all *Arundo*. For instance, a majority of neighborhoods outside of the immediate urban-wildland interface were not extensively surveyed for *Arundo*. Because these areas may be connected to streams and rivers, projects should re-evaluate this data set prior to utilizing it for a specific project or use.

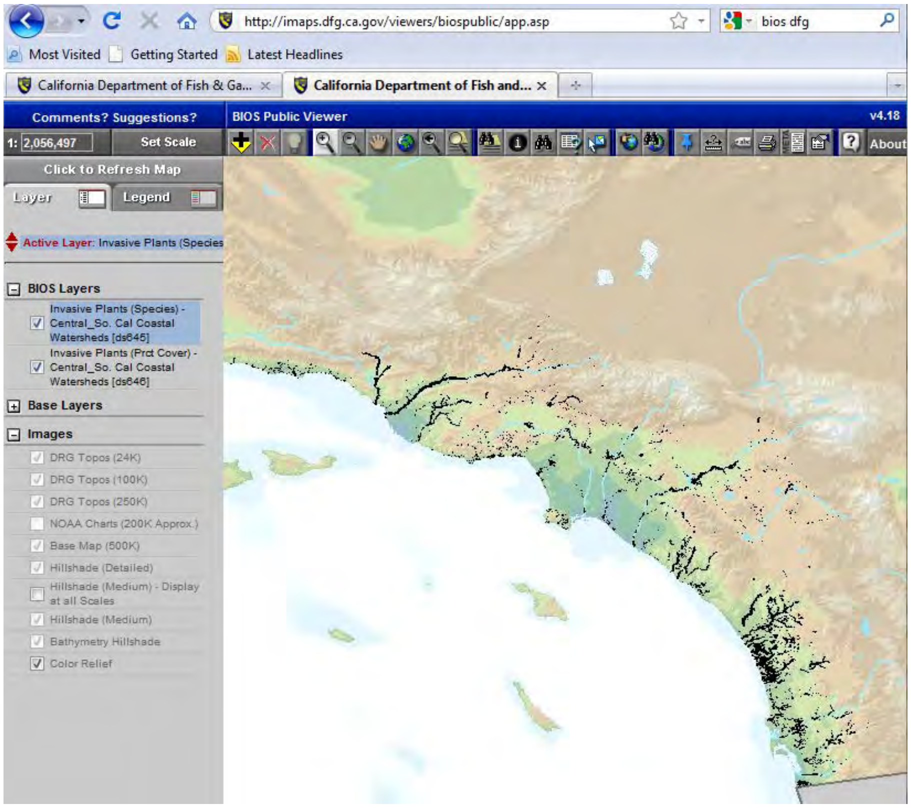
Data set availability at BIOS and Cal-IPC

The GIS database (ESRI geodatabase) is currently hosted on the Department of Fish and Game BIOS (Biogeographic Information & Observation System) web-based mapping application. (http://bios.dfg.ca.gov/). The data sets are named:

Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]

It can be viewed and printed from this platform along with a multitude of other spatial data. The geodatabase is also available for download at Cal-IPC (http://www.cal-ipc.org/ip/mapping/arundo/index.php). This website also hosts a PDF version of this report and associated map books tied to the distribution and listed species co-occurrence with *Arundo*). There is currently no funding to maintain or update the invasives GIS data set. If future revisions do occur, updates will be indicated on the Cal-IPC website.



1: 2,056,497

Active Layer: Invasive Plants (Species

BIOS Layers
- ☑ Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
- ☑ Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

Base Layers

Images
- ☑ DRG Topos (24K)
- ☑ DRG Topos (100K)
- ☑ DRG Topos (250K)
- ☐ NOAA Charts (200K Approx.)
- ☑ Base Map (500K)
- ☑ Hillshade (Detailed)
- ☐ Hillshade (Medium) - Display at all Scales
- ☑ Hillshade (Medium)
- ☑ Bathymetry Hillshade
- ☑ Color Relief

Figure 3-5. DFG BIOS data viewer with invasive plant data set active.

Cal-IPC > Invasive Plants > Mapping > arundo > **Arundo Mapping**

Arundo Mapping

In 2010, Cal-IPC completed mapping *Arundo donax* (giant reed) in southern California coastal watersheds. Mapping was based on high-resolution aerial imagery, GIS digitizing, and field work. Click below for detailed maps of each section of the coast. Note that pampas grass and Mexican fan palm were also mapped.

Download the GIS geodatabase (ZIP 72MB).

Map of the entire region mapped. (PDF 13MB)

Figure 3-6. Cal-IPC web site project page for *Arundo* mapping downloads.

3.2 Results: Acreage by Watershed and Region

Arundo acreage for coastal watersheds from Monterey to San Diego was estimated to be 8,907 acres at its peak distribution (Table 3-2). This captures the 'full maximum extent' of *Arundo* on all watersheds within the study area prior to the initiation of control programs (Figure 3-1). This data will be used to examine and quantify impacts in the chapters that follow. In most areas mapped, dense stands (>80% cover) were the 'typical' stand structure. This is not surprising given the clonal nature of the plant. The largest exception to this observation was the Salinas River, which had many expansive areas with low *Arundo* cover. This is unusual for *Arundo* and may reflect water management practices on the river that have made flows seasonal over the last 20 years. For this reason, 'net' acreage is also given (gross acreage multiplied by the noted stand-specific *Arundo* cover). Examination of Table 3-2 shows that most *Arundo* stands on watersheds were mapped as having high cover, such that gross and net acreage values are similar. Later sections of the report use acreage values that are most relevant to the particular effect being looked at. The fire chapter uses gross acreage, while biomass and water use (which are sensitive to cane density) use net figures.

This study's mapped value of 8,907 acres, although high, is far lower than some estimates of *Arundo* acreage, even for individual watersheds. Santa Ana River has been reported as having over 10,000 acres of *Arundo* (Iverson 1993). This highlights the need for a more standardized and consistent approach to mapping *Arundo*. Many programs continue to map *Arundo* in mixed vegetation classes. This can lead to drastic overestimation of *Arundo* biomass and distribution. Vegetation mapping is very different then species-specific mapping and they should not be used interchangeably. Newer programs, such as on the Ventura and Salinas Rivers and in the San Diego region, use *Arundo*-specific mapping. This data set will aid all programs in using a standardized approach to gauging *Arundo* distribution and abundance.

The *Arundo* mapping also tracked treatment status. Impressively 36% of *Arundo* distribution is already under management/control (Table 3-2). This reflects a substantial investment of federal, state, and local resources. It is encouraging to see significant acreage has been controlled. Several watersheds have achieved particularly high rates of initiated control including: Santa Margarita (99%), San Luis Rey (90%), Carlsbad HU (67%), San Dieguito (51%), Ventura (47%), and Santa Ana (40%). Several watersheds that are heavily invaded have had little or no work occur in them, such as Salinas, Santa Clara, and Calleguas. A later section of this report will examine watershed-based programs and their status.

The *Arundo* mapping acreage is an important tool for not only quantifying impacts but also planning and implementing control efforts. These accurate estimates of *Arundo* acreage allow for better project descriptions, budgets and rationalization of project needs. High quality spatial mapping also assists with environmental planning and permitting. Agencies can more precisely see where *Arundo* occurs, and sensitive species and other concerns can be addressed more specifically. State level funding and project prioritization decisions may also be made in a broader context. Multiple factors still need to be weighed, but this high-resolution mapping gives land managers a stronger quantification of both benefit and cost, much more than was possible prior to the project.

As noted under the discussion of accuracy, this data set under-represents the acreage of *Arundo*. The *Arundo* mapped only accounts for stands that were visible in imagery and field reconnaissance. While there are very few instances of misclassification, there are *Arundo* clumps and portions of stands that are missed due to obstructed views and/or it was too small to see. Previous work by the authors has indicated that detailed re-mapping of areas during control has typically indicated a 15-20% underestimation of *Arundo*. This data set may be slightly more accurate (10-15% underestimate) in many areas as aerial imagery has improved in quality and resolution within the last several years. It is highly unlikely that *Arundo* acreage has been over estimated by this study.

3.3 Conclusions: Distribution and Abundance

- *Arundo* mapping documented a total (gross) of 8,907 acres of *Arundo* within the study area. Net acreage, adjusted for *Arundo* cover, was 7,864 acres. This represents the peak distribution of *Arundo* in the study area prior to control activities. (Section 3.2)
- Over 3,000 gross acres of *Arundo* have been treated to date within the study area. This is 34% of the peak *Arundo* acreage occurring within the study area. (Section 3.2)
- Three large, contiguous watershed units have the highest levels of *Arundo* control observed in the study area: Santa Margarita at 99%, San Luis Rey at 90% and Carlsbad HU at 70 %. (Section 3.2)
- Most other invaded watersheds in the study area with more than 100 acres of *Arundo* have had at least 30% of their *Arundo* treated. Noted exceptions to this are Calleguas, Salinas and Santa Clara watersheds, which have less than 10% of their *Arundo* acreage under treatment. (Section 3.2)

Distribution and abundance data is extremely valuable because it quantifies past and current levels of invasion on watersheds, allows detailed examination and quantification of impacts, and facilitates watershed based control. Programs can use the spatial data to implement watershed based control, develop proposals and budgets, and manage control programs.

Table 3-2. *Arundo* acreage in central and southern California by hydrologic unit.

Hydrological Unit	Total Area (Acres)	Treated *Arundo*		Untreated *Arundo*		Total *Arundo*		Percent treated
		Gross Acres	Net Acres	Gross Acres	Net Acres	Gross Acres	Net Acres	
Big Basin[3]	235,181			0.3	0.3	0.3	0.3	0%
Bolsa Nueva	32,649			0.2	0.2	0.2	0.2	0%
Buena Ventura	13,226			0.5	0.5	0.5	0.5	0%
Calleguas	220,527	1.4	1.4	230.0	227.7	231.5	229.1	1%
Carlsbad[3]	135,753	103.7	103.7	44.0	44.0	147.7	147.7	70%
Carmel River	163,643			0.0	0.0	0.0	0.0	0%
Carrizo Plain	278,848							
Domigz Channel	81,760			2.6	2.6	2.6	2.6	0%
Estero Bay[3]	480,544	1.2	1.2	15.0	8.6	16.1	9.8	12%
Estrella River	610,278							
Los Angeles	533,834	16.3	16.3	116.5	115.1	132.8	131.4	12%
Otay	98,380			18.6	18.6	18.6	18.6	0%
Oxnard	18,721							
Pajaro River	838,942			8.1	8.1	8.1	8.1	0%
Penasquitos	103,790	2.2	2.2	21.4	21.4	23.6	23.5	9%
Pita’s Point	14,051			0.5	0.5	0.5	0.5	0%
Pueblo S. Diego	37,546	0.0	0.0	15.4	15.0	15.4	15.0	0%
Salinas	2,272,492	137.4	106.4	1,868.7	1,225.3	2,006.1	1,331.7	8%
San Antonio	135,624							
San Diego	278,977	56.2	56.2	94.0	93.3	150.2	149.5	38%
San Diego Bay	10,931							
San Dieguito	221,555	89.8	89.8	85.2	85.2	175.0	175.0	51%
San Gabriel	456,886	3.5	3.5	41.0	40.8	44.6	44.3	8%
San Juan[3]	317,261	13.2	13.1	161.9	160.3	175.2	173.4	8%
San Luis Rey	358,662	612.4	612.4	71.4	71.4	683.9	83.9	90%
San Mateo[3]	164,484							
Santa Maria	1,188,373			0.1	0.1	0.1	0.1	0%
Santa Ana[1]	1,752,490	1,083.1	1,006.9	1,640.7	1,526.8	2,723.9	2,533.8	40%
Santa Clara	1,037,141	0.3	0.3	1,081.0	1,018.5	1,081.3	1,018.8	0%
Santa Lucia[3]	193,641			0.1	0.1	0.1	0.1	0%
Santa Margarita	475,449	684.7	684.7	4.2	4.2	688.9	688.9	99%
Santa Monica[3]	267,152	0.4	0.3	18.3	18.2	18.6	18.5	2%
Santa Ynez	576,066			21.4	6.0	21.4	6.0	0%
South Coast[3]	240,092	7.8	7.8	22.0	22.0	29.8	29.8	26%
Sweetwater	146,781	5.7	5.7	36.7	36.1	42.3	41.8	14%
Tijuana[2]	299,181	41.1	41.1	94.5	89.5	135.6	130.6	31%
Ventura[3]	22,475			0.1	0.1	0.1	0.1	0%
Ventura River	144,669	143.6	117.4	188.4	132.5	332.0	249.9	47%
Totals:	**14,458,055**	**2,995.5**	**2,861.9**	**5,911.7**	**5,001.8**	**8,907.2**	**7,863.7**	

[1] Adjusted- added 400 ac treated for older treatments that were not detectable; [2] Adjusted- added 40 ac treated for older treatments that were not detectable; [3] Hydrologic Unit composed of many smaller coastal streams/watersheds.

4.0 IMPACTS OF *ARUNDO*: *Arundo* Water Use and Stand Transpiration

4.1 Determining *Arundo* Water Use (Stand transpiration)

Water loss from watershed systems resulting from *Arundo donax* invasion is a topic of serious concern, but realistic or direct estimates of such losses are scarce. This chapter attempts to estimate water loss (in mm per day per m^2 of ground area) from *Arundo* stands in southern California as a function of *Arundo* leaf transpiration. Study estimates utilize reported transpiration rates for *Arundo* from a variety of areas coupled with leaf area indices and cane densities measured in the study area. Comparisons are also made between this study's estimates of stand-level water loss to those reported by others.

4.1.1 Background:

Vegetation in a system contributes to water loss primarily as function of *transpiration* through the leaves (E), but *evaporation* of water from exposed soil (i.e., not covered by plant canopy or litter) is also a contributing factor. Combined water loss via plant transpiration and surface evaporation is termed *evapotranspiration* (ET). Measuring ET is often a complicated process (Allen et al. 1998), but plant physiology studies often directly measure E using individual plant leaves and gas analyzers. The leaf-based measurements (E_l) can then be scaled up, based on leaf area per unit area of ground ("leaf area index" or LAI), to yield estimates of water loss at the stand scale via plant transpiration (E_{stand}, or water lost per unit area of ground). In a mature vegetation stand, where much of the ground is shaded, E_{stand} will account for the majority of total water loss via ET (Allen et al. 1998).

4.1.2 Methods

In an effort to estimate water loss from *Arundo* stands in the study area, published scientific and unpublished gray literature was searched for direct estimates of *Arundo* transpiration (E) or evapotranspiration (ET) from *Arundo* stands. The search yielded three Master's thesis studies that measured *Arundo* E_l (Abichandani 2007, Watts 2009, Zimmerman *unpublished data*), two of which then scaled up to E_{stand}. One direct measurement of ET was also found from a Mediterranean region study reported in a conference proceedings (Christou et al. 2003) and one additional internet report in which stand-scale *Arundo* water loss was estimated using data from Zimmerman's thesis work (Hendrickson & McGaugh 2005). LAI values are a very important factor in calculating stand transpiration rates. Additional data on *Arundo* stand LAI is also reported for papers that examined stand structure (Sharma et al. 1998, Spencer 2006).

The *Arundo* leaf-scale transpiration rates (E_l) reported in the three Master's theses were fairly similar. To be conservative, the lower measured value from the Abichandani study was used to estimate stand-scale water loss via transpiration (E_{stand}) for this study. In order to scale up from the average reported E_l to E_{stand} for the study area LAI for the study area was calculated based on filed sampling of *Arundo* stand structure. *Arundo* cane density and a number of structural traits on canes taken from 14 sites in the southern California study area were measured (Figure 2-1). Sites were selected in the field to represent mature *Arundo* stands, not areas that had been previously controlled, burned or otherwise disturbed. Mature *Arundo* stands are the majority of the acreage in the study area. The goal of this study is to measure water use of mature *Arundo* stands. Mature *Arundo* stands do vary significantly in cane density and robustness of growth- predominantly as a function of water availability. For this reason samples were taken from 11 'wet' sites (73%) and 3 'dry' sites (27%). This is approximately the proportion of wet and dry stands observed in field mapping within the study area.

One or two representative "old" (>1yr) *Arundo* canes were collected from each of the 14 sites (17 canes total) and one "new" (1st year) cane from three of the sites (Table 4-1). Leaf area was calculated as length*width*0.74 based on an examination and measurement of leaf shape. Structural traits measured on old canes included (a) length of and number of leaves on the leader portion (i.e. the portion of the central branch with green leaves) and (b) number and length of secondary branches. Individual leaf area for all leaves was then measured on a subset of leader canes (3 canes, 60 leaves) and secondary branches (18 branches, 200 leaves). Only the green photosynthetic area was measured on leaves. Cane (stem) surface and leaf sheaths were not included in calculations of photosynthetic area. The sum of measured leaf areas for each leader or branch was used to determine the average total leaf area per unit length of leader cane or secondary branch (26.8cm^2 leaf area/cm leader and 5.7cm^2 leaf area/cm secondary branch). Total expected leaf area was then calculated for all 17 old canes collected as a function of their leader and total secondary branch lengths multiplied by the appropriate leaf area/cm branch value.

Structural traits measured on new canes included the length of the cane, number of leaves and total leaf area, calculated as the sum of areas measured for each individual leaf (3 canes measured, 69 leaves). An average leaf area for a new cane was then calculated. To determine site-specific LAI, the total expected leaf area of each collected old cane was multiplied by the number of old canes counted in a representative square meter within the site and added to the average total leaf area of a new cane multiplied by the density of new canes in that same square meter (Table 4-2). Stand adjusted LAI is also given, representing for true stand-based leaf area (adjusts for area with no canes emerging, see Section 2.3). As there are significantly more old canes per unit area in a mature *Arundo* stand, greater effort was expended in calculating old cane leaf area.

Secondary branch leaf area relationships were explored using three different formulas: a linear regression, a quadratic regression and the branch length to leaf area relationship that was used. All three relationships were fairly consistent, generating final secondary branch LAI values ranging from 15.0 (linear), 19.0 (quadratic), and 17.0 (average leaf area per cm) (Figure 4-1, Table 4-2).

While leaf-based transpiration (E_l) is often reported in mmol $m^{-2}_{\text{leaf area}}\ s^{-1}$, different studies utilize discrete (and sometimes unspecified) methods for scaling up to the level of the stand. Consequently, there appears to be no clear convention in units used to report such water loss (e.g., kg $m^{-2}\ hr^{-1}$ or mm/day, etc.). For ET water loss is often reported in mm/time (Allen et al. 1998), which is roughly equivalent to a water loss of 1 liter/m^2/unit time. Following the assumption that the bulk of evapotranspirative loss in a mature stand is accounted for by transpiration, mm/day was used to report this study's calculated E_{stand} for *Arundo*. To scale from E_l to E_{stand} in mm/day: (1) average E_l was multiplied by the molar mass of water, giving grams $H_2O\ m^{-2}_{\text{leaf area}}\ s^{-1}$; (2) divided by the density of water at 25C, giving $m^3\ H_2O\ m^{-2}_{\text{leaf area}}\ s^{-1}$; (3) multiplied by the LAI (in m^2 leaf area per m^2 ground area), giving $m^3\ H_2O\ m^2_{\text{ground area}}\ s^{-1}$; (4) divided $m^3\ H_2O$ by 0.001 to yield mm $H_2O\ m^{-2}_{\text{ground area}}\ s^{-1}$; and (5) multiplied by 34,679 s/day of daylight (9.6 hrs or 3,516 hrs/yr - this value is based on average sunlight per day for the study area with 932 hours subtracted for winter dormancy. To compare this study's E_{stand} estimate with those reported in the other papers, reported E_{stand} values were sometimes converted from other units. Thus, some conversion error should be expected. However, when possible and for the greatest consistency in comparisons, E_{stand} was recalculated using average E_l and LAI values from the paper and following the general method above. These recalculated values are reported along with those given directly in the paper (Table 4-3). This re-calculation of values for other studies validates the process being used in this study to scale up from leaf-based transpiration to stand-based transpiration.

Table 4-1. Structural characteristics measured on *Arundo* canes collected from 14 sites in southern California study area.

Plot	Cane height (m)	Cane diam (mm)	Leader Length (cm)	Leader # leaves	Ave leader single leaf area (cm^2)	# secondary branches	Ave branch length (cm)	Ave branch # leaves	Ave branch leaf area	New cane # leaves	Ave new cane single leaf area
CC1	5.1	20	19	10	-	15	47.7	-	-	21	168.7
CC2 #1	9.71	28	90	23	83.7	57	11.7	4.5	10.5	-	-
CC2 #2	8.45	27	82	23	117.3	9	70.9	13.0	63.2	-	-
SA1	6.11	25	45	17	-	34	21.4	-	-	-	-
SA2	6.06	25	32	15	58.5	31	36.2	23.0	44.4	-	-
SA3	7.74	27	74	28	-	33	10.7	-	-	-	-
SA4	7.42	26	33	12	-	48	20.0	13.5	29.5	-	-
SC1	9.9	25	23	12	-	31	46.0	11.0	34.8	-	-
SC4	4.16	22	0	0	-	34	41.3	14.0	19.2	-	-
V1	8.41	26	0	0	-	28	43.4	-	-	21	216.2
V2	6.21	24	76	20	-	14	41.8	-	-	-	-
SD#1a	8.08	26	65	16	-	29	56.1	10.9	34.9	-	-
SD#1b	8.1	24	66	13	-	25	60.0	-	-	-	-
SC2	4.33	22	11	7	-	11	37.0	-	-	-	-
SC3	4.22	18	19	7	-	7	37.1	-	-	27	227.9
SC5 Lg	3.77	25	13	8	-	10	26.2	-	-	-	-
SC5 Sm	2.61	15	12	7	-	5	22.8	-	-	-	-

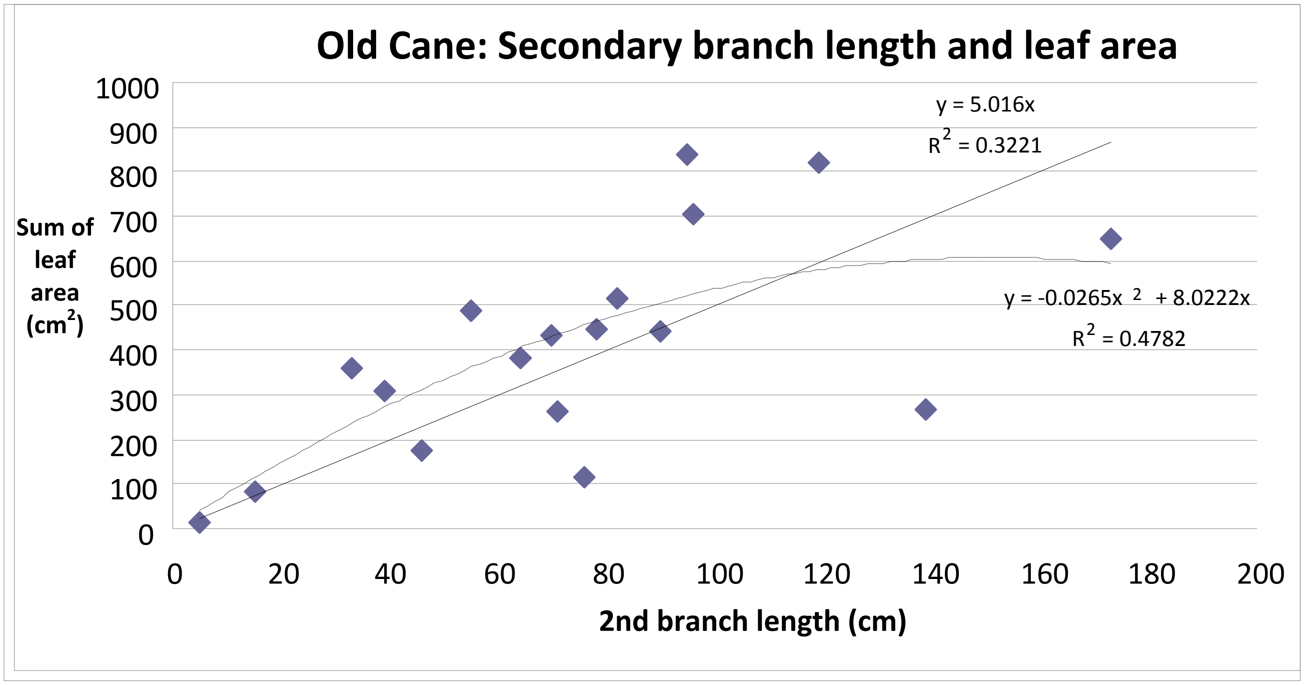


Figure 4-1. Secondary branch leaf area to length relationship.

Table 4-2. *Arundo* cane densities and leaf area indices (LAI) for 13 of the 14 study sites. The contribution of leader canes, secondary branches, and new canes toward the total LAI for the site is shown. Cane densities were not measured on the San Diego site, thus LAI could not be computed.

Plot	Hydrology	Leaf area (m^2) per cane				Cane density/m^2		Leaf area/m^2 ground (LAI)				
		Leader: old cane	2ndry branch	Total old cane	New cane (<1yr)	Old cane	New cane (<1yr)	Leader old cane	2ndry branch	New cane	Total: old+new	Stand adjusted (70%)
CC-1	Wet	0.05	0.41	0.46	0.47	53	4	2.7	21.6	1.9	26.2	18.3
CC-2	Wet	0.23	0.37	0.6	0.47	29	4	6.7	10.8	1.9	19.4	13.6
SA-1	Wet	0.12	0.41	0.53	0.47	66	2	7.9	27.4	0.9	36.2	25.4
SA-2	Wet	0.09	0.64	0.73	0.47	30	2	2.6	19.2	0.9	22.7	15.9
SA-3	Wet	0.20	0.20	0.4	0.47	84	11	16.6	16.9	5.2	38.8	27.1
SA-4	Wet	0.09	0.55	0.64	0.47	19	4	1.7	10.4	1.9	14.0	9.8
SC-1	Wet	0.06	0.81	0.87	0.47	25	2	1.5	20.3	0.9	22.8	15.9
SC-4	Wet	0.00	0.80	0.8	0.47	36	4	0.0	28.8	1.9	30.7	21.5
V-1	Wet	0.00	0.69	0.69	0.47	28	5	0.0	19.4	2.4	21.8	15.2
V-2	Wet	0.20	0.33	0.53	0.47	30	5	6.1	10.0	2.4	18.5	12.9
SD1	Wet	0.18	0.89	1.07	0	44	0	7.7	39.2	0.0	46.9	32.8
SC-2	Dry	0.03	0.23	0.26	0.47	24	2	0.7	5.6	0.9	7.2	5.1
SC-3	Dry	0.05	0.15	0.2	0	40	0	2.0	5.9	0.0	8.0	5.6
SC-5	Dry	0.03	0.09	0.12	0.47	26	2	0.7	2.4	0.9	4.0	2.8
	Mean:	**0.09**	**0.47**	**0.56**	**0.41**	**38.1**	**3.4**	**4.1**	**17.0**	**1.6**	**22.6**	**15.8**
	StdDev:	**0.08**	**0.26**	**0.27**	**0.17**	**18.3**	**2.7**	**4.6**	**10.3**	**1.3**	**12.4**	**8.7**

Table 4-3. Summary of *Arundo* transpiration (E) and evapotranspiration (ET) reported in literature or calculated as described in the text.

Study	Location	Stand biomass (t/ha)	Average single leaf area (cm^2)	Average # leaves per cane	Leaf area per cane (m2)	Average # canes per m^2	LAI (m^2 leaf/m^2 ground)	Peak (mid-day) E_l ($mmol/m^2/s$)	E_{stand} (mm/day)
Direct Measurements of transpiration (E)									
Abichandani 2007	Santa Clara River, CA		163.3 (132.5-215.9)[1]	25.0 (21.5-28.4-27.9)	Newer (1 to 3 yr): 0.4082	Ave 34.9 (riverbed 29.2, n= 43; terrace 40.6, n=26)	14.25	4.03 (1.89-5.80)[a]	41.1 (36.4)[a]
Watts 2009	Rio Grande River, TX						4.1 (3.4-6.1) and 4.5	4.3 (1.6-8.4)[b]	9.1 (11.0)[b]
Zimmerman (unpublished)	Napa River, CA							6.3 (2.5-11) Summer only	
Indirect calculation of stand-level transpiration									
Cal-IPC (this study)	Southern California	155	1st yr: 206.3 > 1 yr: leader 86.5, 2ndry branch 33.9	1st yr: 23 (SD3.5) >1 yr old: leader 12.6 (SD8.3) + 2ndry branch lvs 271.6 (SD 174.9) = 284.2	1st yr: 0.474 >1yr: 0.556 (leader 0.100, 2ndry branch: 0.457)	41.5 (SD 19.7)	15.8	Used 4.03 in calcs	40.0
Iverson 1998	Based on rice								4.7[d]
Hendrickson & McGaugh 2005	Cuatro Cienegas, Mexico								17.3[d]
Other structural data									
Spencer 2006	16 sites across US (leaf area is north CA)	171	1st year: 520.7	1st yr:10.3(SD 6.1) >1 yr old: 100.6	1st yr: 0.5362 > 1yr old: 0.1162	74.5	11.22	Used 4.03	28.3[c]
Sharma et al. 1998	India	36-167				53 to 82	12.6 to 28.7		
Direct Measurements of Evapotranspiration									
FAIR 2000-EU study	Europe								3.22
Christou et al. 2003	Greece & Italy	21.1							1.6 (ET)

[a] Average across season, and wet and dry sites; [b] E_{stand} as calculated using formulas applied to this study; [c] E_{stand} calculated using formulas from this study using LAI from the that paper; [d] E_{stand} reported in paper, but insufficient additional data to use formulas in this study.

4.1.3 Results and Discussion

Examination of calculated water loss values for *Arundo* (both reported and results from this study) reveals a substantial amount of variation in E_{stand} (Table 4-3). While some of this variation may be an artifact of differences in scaling procedures and conversion factors, variation should be expected. Both *Arundo* transpiration (E) and evapotranspiration (ET) are affected by prevailing ambient conditions (temperature, humidity, wind, and available soil water) as well as characteristics of the vegetation. For example, both Abichandani (2007) and Watts (2009) found higher leaf-based transpiration (E_l) rates for *Arundo* in areas with higher available soil moisture. Zimmerman's unpublished *Arundo* transpiration data showed E_l also increases with temperature, while Abichandani and Watts found higher E_l rates in summer and spring when temperatures are higher. Thus, variation should be expected among regions where such conditions are likely to vary both within a season and on average across a year. Nonetheless, the average E_l rates (accounting for seasonal and hydrological variation) reported by Abichandani and Watts are quite similar despite the different study regions (Table 4-3). Zimmerman's average E_l is higher, but those measurements were only taken during the summer while the others studies included cooler seasons.

Given the similarities in E_l, variation in E_{stand} across studies must be primarily driven by factors other than leaf-scale transpiration rates. Watts (2009) showed much lower E_{stand} than either Abichandani (2007) or this study, and it should be noted that Watts' estimate includes refinements that would lead to a lower average. Specifically, prior to scaling-up transpiration rates, Watts divided the *Arundo* canopy into vertical layers and adjusted E_l rates downward for shaded leaves. In addition, Watts accounted for diurnal fluctuations in E_l in his scaling operations. It is unclear whether Abichandani's tabled E_{stand} values include such refinements, but this study's calculations are based on average peak E_l rates for sunlit leaves without any adjustment downward for shading or diurnal drops in leaf transpiration. As a result, the E_{stand} estimate for this study is probably more representative of an average maximum water loss, rather than an overall average. Yet, these adjustments are still unlikely to be the primary cause of the large differences seen in E_{stand} among studies. It is reported LAI that appears to be driving different stand based transpiration estimates. The average LAI reported by Watts (4.1) is much lower than that reported by Abichandani (14.25), which is slightly lower than results found on this study's sites (15.8) (Table 4-3). Consequently, differences in *Arundo* stand structure are likely the primary factor driving variations in E_{stand} across all studies reviewed.

Structural differences probably explain the lower estimate of E_{stand} reported by Hendrickson & McGaugh (2005) despite their likely use of a higher E_l rate than used in this study (i.e., Zimmerman's summer measures). However, it is not clear exactly what E_l rate they used or exactly how their scaling-up from leaf to stand was performed, though some adjustments for lower daily and seasonal E_l rates were incorporated. Variation in *Arundo* stand structure could also partly explain the lower daily ET rate derived by Christou et al. (2003) in the Mediterranean (Table 4-3). For example, the studies by both Abichandani (2007) and Christou et al. were performed on relatively young, artificially created *Arundo* stands, which may have shorter canes or less leaf area overall than naturally-occurring, mature stands. In Abichandani, the stand was 3-4 years old. Average cane densities were similar to those found in this study (Table 4-3), but the average area of a single leaf was larger and more comparable to leaves on new canes from this study (Table 4-1, average = 206.3cm^2). In addition, the average number of leaves per cane reported by Abichandani (Table 4-3) is comparable to the average number of leaves counted on just the leader portion of a cane plus only one secondary branch in this study (Table 4-1). Thus, it seems likely Abichandani's planted stand had bigger but far fewer leaves overall, as reflected in the lower LAI compared to this study. This may also be true of the Mediterranean stands reported in Christou et al., which were 1-3 years old during the study. Christou et al. did not report any leaf area data, but their reported average *Arundo* biomass (21.1 tons/ha) is roughly 7 times lower than the average biomass estimate generated for this study's stands (156.8 tons/ha). Given such large differences in stand structure among the study regions, it is likely that even a more refined measurement for this region would still be much higher than those in the other regions reviewed.

However, the large disparity between the daily ET rate derived from Christou et al. and the E_{stand} rates reviewed here becomes more pronounced when one considers that water lost via transpiration and evaporation combined should be higher, even if only slightly, than transpiration alone. It is unlikely that structural differences, differences in regional climate, and errors in converting data from one unit convention to another can fully explain the large differences seen here in E_{stand} versus ET. Instead, the comparison demonstrates the difficulty of generating realistic estimates of water loss from *Arundo* stands. Utilizing locally measured rates of leaf transpiration and stand structure is a good start, but complex scaling procedures will likely yield better estimates of stand-scale transpiration losses. Ultimately, though, actual locally measured ET may be more reliable, though perhaps more costly. Future studies need to focus on determining ET of mature *Arundo* stands that are comparable to *Arundo* stands in the field that have high leaf area and high biomass per unit area.

4.2 *Arundo* Water Use Across Study Area

This study found an average leaf area (LAI) for *Arundo* stands of 15.8 m^2/m^2. This value was within the range of LAI values reported by other studies (4.1 - 28.7; Table 4-3). The study area LAI value was then used with published leaf transpiration values to generate a stand-based transpiration value of 40 mm/day (Table 4-3). There are only two published studies for *Arundo* stand based transpiration. One study found a similar stand transpiration value of 41.1mm/day (Abichandani 2007). It was conducted on the Santa Clara Watershed which is one of the watersheds within this studies project area. Stand structure, density and leaf area were all comparable to data collected for this study. The other published paper found a much lower stand based transpiration value of 9.1 mm/day (Watts 2009). This study was on the Rio Grande River in Texas. Stands there were shorter and had significantly lower leaf area (Table 4-3).

The current study and the two other published studies would be classified as 'leaf area transpiration measurements scaled up using LAI'. Additional studies looking into stand based water use are definitely needed and would preferably utilize a range of methods used to measure stand based transpiration/water use. Other methods include: lysimeters (tank with soil and plants with controlled water supply), base flow separation studies (stream inflow and outflow studies), analysis of diel groundwater fluctuations, semiemperiacal models, micrometeorological approaches (Brown Ration Energy Balance) and eddy covariance (as outlined in Shafroth 2005).

Using the stand-based transpiration values from this study to calculate water use per acre generates water use estimates that are very high (Table 4-4). Water consumption per acre of *Arundo* is 48 ac ft/yr, and this is far above published values for most vegetation (Johns 1989). Even with the high LAI values measured in this and other studies, an average annual stand-based transpiration is likely to be closer to 20 mm/day, which equals 24 ac ft/yr/ac of water use. The value of 20 mm/day is still at the high end of values published for other 'water hungry' vegetation types such as *Phragmites* (Moro et al. 2004), which is similar in structure and habit to *Arundo*, albeit smaller (less biomass and lower LAI values reported).

Water loss via ET in an *Arundo* stand would not equal the water gained or 'saved' through *Arundo* control. Removal of *Arundo* from riparian systems would likely increase water lost to evaporation, runoff, and any water use of re-colonizing vegetation (see Watts 2009 and/or Shafroth 2005 for additional discussion and references).

A replacement vegetation water use value of 3.3 mm/day or 4 ac-ft/yr/ac was used in our analysis (Table 4-4). This was based on a 'typical' vegetation mix that replaces *Arundo*, which is composed of: 25% trees, 25% shrubs, 25% herbs, and 25% open/un-vegetated. Water use was estimated based on data collected in a major water use review paper that compiled data from hundreds of studies using a wide range of water use measuring methods (Johns 1989). This data, along with a review by Shafroth et al. (2005), were used to approximate replacement vegetation water use. Compared to the estimates shown here for *Arundo*, the lower and more restricted range of replacement vegetation water use estimates suggests that most types of replacement vegetation will potentially use significantly less water.

As within *Arundo* stands, water loss under alternative states is probably best determined through direct measurement or complex models, and very few reports of such exist for riparian vegetation within the study area. Reported estimates of ET or E_{stand} for native riparian vegetation in other areas may be a good starting point for comparison, but many of these studies were conducted in the more arid southwestern portion of the U.S. where water availability may be significantly less than the coastal watersheds of southern California (especially considering the artificial water augmentation from urban and agricultural runoff that has transformed most systems into perennially flowing rivers and streams).

Willow water use from eight studies ranged from 0.9 to 3.3 mm/day (Johns 1989). Mixed riparian vegetation water use from three studies ranged from 0.9 to 1.6 mm/day (Johns 1989). Cottonwood water use from three studies ranged from 2.8 to 6.5 mm/day (Johns 1989). *Typha* (cattail) water use from six studies ranged from 2.4 to 13.8 mm/day (Johns 1989). Mulefat water use from two studies ranged from 2.2 to 3.9 mm/day (Johns 1989). Other riparian/wetland studies looking at other non-native plants found widely ranging water use. E_{stand} based on eddy-covariance from a site dominated by *Tamarix ramosissima* (salt cedar) reached up to 7 mm/day (Cleverly et al. 2002). In a similar study, E_{stand} from sites dominated by mixtures of native and invasive woody species reached peak values of approximately 9 mm/day (Dahm et al. 2002). E_{stand} in a pond lined by *Phragmites australis* in Nebraska was estimated at 4 mm/day in a stand that had a maximum LAI of 2.6 (Burba et al. 1999). E_{stand} in *P. australi*s in Germany was estimated at 10 to 16 mm/day in stands with summertime LAI of about 5 (Herbst and Kappen 1999). *P. australis* in semi-arid Spain has been shown to have average midsummer E_{stand} values of about 23 mm/day in a stand with LAI values of 8.9 (Moro et al. 2004).

The final estimated net water savings from removing an acre of *Arundo* was 16.7 mm/day or 20 ac ft/yr/ac (Table 4-4). This represents a very large potential water savings, even if it represents a peak or maximum savings yield. If future studies are able to corroborate water savings of similar magnitude, *Arundo* control could represent an important water conservation action that will benefit multiple uses including habitat, urban and agricultural water use.

Arundo Impacts: Transpiration and Water use

- Due to high leaf area of mature stands, stand-based transpiration is very high (E_{stand} 40 mm/day). There are two other studies evaluating stand-based *Arundo* transpiration. One study on the Santa Clara watershed (within this project's study area) is in agreement (41.1 mm/day). The other study on the Rio Grande River is lower (9.1 mm/day). (Section 4.1).
- Stand-based transpiration rates of *Arundo*, when used to calculate total water over larger areas, indicate very high levels of water use: 48 ac-ft/ac per year. (Section 4.2)
- Net water savings for areas after *Arundo* removal are high (16.7 ac-ft/yr), even when *Arundo* water use is lowered to 20 mm or 24 ac-ft/ac per year to reflect levels that may be closer to physiological water transpiration limits. (Section 4.2)
- New studies using different approaches to measure stand-based water use of *Arundo* are needed to corroborate and refine stand-based water use found in this and other studies. New studies

need to be on mature stands of *Arundo*. Stands under treatment or in post-fire or flood recovery should be excluded, as these are not representative of the majority of *Arundo* stands within the study area. (Section 4.2)

Water use by *Arundo* appears to be a significant impact on invaded systems. Water use by vegetation is difficult to measure. Additional baseline and comparative studies are needed.

Table 4-4. Estimated water use by *Arundo*, replacement vegetation and net water savings from *Arundo* control.

Hydrologic Unit	**Net *Arundo* Acreage**	**ESTIMATED WATER USE (Ac-ft/yr/ac)**			
		***Arundo*: This study** (using 40mm)	***Arundo*: likely maximum** (using 20mm)	**Native vegetation** (using 3.3mm)	**Net gain from *Arundo* control** (using 16.7mm)
One acre of Arundo	*1*	*48*	*24*	*4*	*20*
Calleguas	229	10,983	5,487	905	4,582
Carlsbad	148	7,088	3,542	584	2,957
Los Angeles River	131	6,297	3,146	519	2,627
Otay	19	891	445	73	372
Penasquitos	24	1,129	564	93	471
Pueblo San Diego	15	719	359	59	300
Salinas	1,332	63,828	31,890	5,262	26,628
San Diego	149	7,164	3,579	591	2,989
San Dieguito	175	8,387	4,190	691	3,499
San Gabriel	44	2,124	1,061	175	886
San Juan	173	8,312	4,153	685	3,468
San Luis Rey	684	32,778	16,377	2,702	13,674
Santa Ana	2,534	121,442	60,675	10,011	50,664
Santa Clara	1,019	48,829	24,396	4,025	20,371
Santa Margarita	689	33,018	16,497	2,722	13,775
Santa Monica Bay	18	886	443	73	370
Southcoast	30	1,429	714	118	596
Sweetwater	42	2,002	1,000	165	835
Tijuana	131	6,261	3,128	516	2,612
Ventura	250	11,977	5,984	987	4,997
Other watersheds	28	1,359	679	112	567
TOTAL:	**7,864**	**376,948**	**188,333**	**31,075**	**157,258**

5.0 IMPACTS OF *ARUNDO*: Hydrology, Geomorphology and Flooding

5.1 Hydraulics, Sediment Transport, Geomorphology

5.1.1. Introduction

Arundo is a highly aggressive, non-native plant species that has invaded riparian areas and floodplains, displacing native plants, degrading habitats, and altering channel characteristics. The biology and ecology of *Arundo* have been fairly well studied and reported, but comparatively few studies have examined the effects of *Arundo* on river form and process. The changes in river geomorphology, flood risk, and sediment erosion, storage, and delivery that follow *Arundo* invasion are not well understood.

The overall goal of this study is to describe the potential effects of *Arundo* invasion on river processes in selected of Southern California watersheds. The specific objectives are to:

- Develop an understanding of the typical response of river forms and processes to invasion by *Arundo*, or other non-native plants (tamarisk), from review of published literature and reports
- Summarize the geomorphic environments and extent of *Arundo* infestation for three of the Southern California study streams – the Santa Margarita, San Luis Rey, and Santa Ana Rivers – from GIS
- Prepare a case study of the effects of the *Arundo* invasion on the hydraulic characteristics, geomorphology, sediment budgets and sediment transport capacity of the Santa Margarita River
- Based on the GIS analyses and the case study results, develop a simplified scoring system to evaluate the potential response of the San Luis Rey and Santa Ana Rivers to their *Arundo* infestations.

This section relies on existing information from previous reports and studies, as well as information collected for this study. This information included review of the existing literature on the effects of *Arundo* on geomorphology. Data generated for this study included: GIS databases and maps of river environments and *Arundo* distributions (mapped for this project: Section 3), a HEC-RAS model of the Santa Margarita River initially developed by NHC (1997a), and other reports on the Santa Margarita River. The documents reviewed for this study are listed in the References Section.

Work completed specifically for this project included: additional HEC-RAS runs for different vegetation scenarios and analysis of RAS model output to assess hydraulic and sediment transport capacity characteristics. The Santa Margarita River was inspected on October 1st, 2010. Study methods and their limitations are described further in the text.

To the extent practical, the analyses and results for this study were prepared in a GIS environment. We relied on GIS support from other team members for the analysis and mapping of *Arundo* and fluvial landforms on the three Southern California Rivers included in this study. Further details on their methods and procedures are described in Sections 3 and 5.2.

Section 5.1.2 summarizes the effects of *Arundo* infestation on river form and process from a review of published and unpublished literature and develops a general understanding of riverine response to infestation. Section 5.1.3 summarizes the riverine and riparian or floodplain vegetation characteristics of three of the Southern California study streams. Section 5.1.4 provides a case study of the Santa Margarita River, briefly describing its watershed and historical geomorphology before analyzing the potential effects of *Arundo* infestation on hydraulic conditions, sediment transport capacity and long-term sediment budgets. The relationship between changes in hydraulics and sediment transport and river form and process are summarized at the end of this chapter.

Section 5.1.5 then combines the geomorphic analyses of the three rivers studied herein with the trends and observations on hydraulics and sediment transport along the Santa Margarita River to predict likely impacts of *Arundo* on the San Luis Rey and Santa Ana Rivers. Section 5.1.6 provides conclusions and recommendations.

Elevations are reported in feet and refer to the North American Vertical Datum of 1988 (NAVD 88). Elevations originally reported in the National Geodetic Vertical Datum of 1929 (NGVD 29) were approximately converted to NAVD 88 by adding 2.74 feet, a value obtained for the Santa Margarita study area using the datum and coordinate system conversion software program Corpscon (USACE 2004). All GIS data for this project are in the UTM Zone 11N NAD 83 (m) coordinate system.

The Marine Corps Base, Camp Pendleton and U.S. Naval Facilities Engineering Command are gratefully acknowledged for their support of this study which included the use of hydraulic and sediment transport models previously developed by NHC. In addition, Base Command and the Navy granted access to Camp Pendleton and permitted discussions with base personnel involved with *Arundo* control and management on the Santa Margarita River.

5.1.2 Arundo and River Morphology

This chapter briefly summarizes the establishment, spread, and distribution of *Arundo* in the river environment and the observed effects of the spread of *Arundo* on the morphology and characteristics of rivers and streams from existing literature. The riverine response to *Arundo* infestation focuses on large, low-gradient, braided rivers in the American Southwest that are similar to selected coastal rivers being studied in Southern California.

The general purpose of this chapter is to develop a qualitative understanding of river morphology evolution under *Arundo* infestation and identify gaps in our understanding. This conceptual model will be used to help extend and interpret specific hydraulic and sediment studies on the Santa Margarita River, which are discussed in Section 5.1.4.

5.1.2.1 *Arundo* in the River Environment

General Characteristics

Arundo donax (Giant Reed) is a member of the grass family (Poaceae) and is native to tropical and subtropical areas of Asia and Europe. *Arundo* was introduced to America in the 1800s for use as construction material and for erosion control along streams and ditches. Tamarisk (*Tamarix* spp.), or salt cedar, is another invasive, non-native species with a similar distribution to *Arundo*. The two species are often found together and studies of *Arundo* in the river environment often also include this species. Tamarisk includes several shrub and tree species native to drier areas of Eurasia and Africa that were introduced to North America in the 1800s as an ornamental shrub, windbreak, and for shade.

Arundo tends to be found on bare, moist substrate where water is plentiful, including the bed, banks, unvegetated bars and islands, and the floodplain of rivers (Else 1996; Stillwater Sciences 2007). *Arundo* requires significantly more water than native plants to support its very fast growth rate (Iverson 1994, Watts 2009, Abichandani 2007). Once established, *Arundo* plants grow very quickly, as much as 10 cm per day in its early growth stages (Quinn and Holt 2004), and mature stands reach heights of 6 m to 10 m (Rieger and Kreager 1998, Lawson et al. 2005, this study-Chapter 2). *Arundo* stands spread laterally via rhizomes (Rieger and Kreager 1998), often resulting in extremely dense, monotypic stands. Growth rates are so high that it often out-competes other species, particularly when colonizing sites that have been disturbed by erosion or wildfire.

Tamarisk grows in similar environments to *Arundo* and appears as shrubby trees growing as high as 35 ft tall along rivers in the American Southwest (Graf 1978). Tamarisk spreads by both adventitious roots and by seeds that are dispersed by wind or flowing water. Tamarisk is salt tolerant and survives in dry conditions by growing roots that extend up to 100 feet deep, as they follow a slowly receding ground water table (Graf 1982).

Dispersal & Establishment

Arundo relies on downstream dispersal of stem or rhizome fragments for vegetative propagation, which primarily occurs during seasonal floods. *Arundo* seeds are thought to be infertile (Khudamrongsawat and Holt 2004, Bhanwra et al. 1982). Thus, new *Arundo* stands are limited to the lateral extent of river flows and floodplain inundation. *Arundo* can be widely dispersed into disturbed soils when large floods occur, such as those in Southern California in 1969 (Ambrose and Rundel 2007).

The dynamics of *Arundo* establishment in the river environment have been examined on the Santa Margarita and Santa Clara Rivers in Southern California. Else (1996) examined *Arundo* establishment after a large flood on the Santa Margarita River. She found the density of establishment was greatest on depositional bars, followed by channel banks, and floodplain areas nearest to the river. Establishment was least common on the channel bed. *Arundo* dispersal was directly correlated with flood magnitude and it was most widely distributed in broad, unconfined reaches of the Santa Margarita River with low stream gradients. Steeper confined reaches showed less *Arundo* establishment, presumably as a result of greater flow velocities that provided fewer areas for *Arundo* propagules to deposit and grow.

Rates of Spread

Over a period of decades, *Arundo* stands can laterally propagate throughout the floodplain from points where it was deposited during flood events. Large floods can cause much more extensive lateral spreading of *Arundo* in a single season but these events are infrequent. Based on mapping of *Arundo* extents on the Santa Margarita, Santa Ana, and San Luis Rey Rivers by Cal-IPC (2010b), the maximum coverage of the floodplain by mature *Arundo* along a river reach may be from 40% to 55% of the total area occupied by the floodplain and active channel.

Erosion of *Arundo* Stands by Floods

During floods, large rafts of *Arundo* are observed to float downriver and deposit on the inundated floodplain. It is also common for tidal currents and wave action to cover beaches with *Arundo* that was transported downstream during a large flood (Else 1996; Cal-IPC 2010a). While *Arundo* stands are eroded during large, infrequent floods, it is not known what velocities or shear stresses can be resisted by the *Arundo* stands. It appears floods remove the plants and roots, and in some situations only the above-ground vegetation is mobilized.

5.1.2.2 Observed Effects on Rivers

Introduction and Context

Arundo (and to some extent, Tamarisk) is typically found in rivers and streams in Southern California to elevations of 1,000 feet. This elevation range, and geographic area, includes a broad range of river types and environments. However, the focus of this study is on large, low-gradient coastal rivers where *Arundo* was found to be most abundant (Chapter 3). As described in the next section, the riparian systems of the Southern California coastal study streams are dominated by *Arundo*, which often occupies most of the surrounding low floodplain (Jackson et al 1994). Effects may be very different in other river types and environments where the dispersal and establishment of *Arundo* is limited by channel or flood characteristics.

Most of our understanding of the effects of *Arundo* on river morphology is based on historical case studies, generally from analysis of maps or air photographs. These studies have two weaknesses. One is that the study period is relatively short, generally less than 70 years, so the role of large floods in eroding existing stands or distributing propagules is not well understood.

The second complicating factor is that the study period also includes human impacts on watersheds and flows that may reinforce the observed riverine response to *Arundo*. The effect of *Arundo* on river morphology in these human-modified streams would be correctly interpreted as the difference between the channel evolution that would have occurred without *Arundo* and that which occurred with *Arundo* present. We found no studies that had adequate control or had completed sufficient analyses to resolve this issue.

Long-term Historical Studies

The effects of *Arundo* and Tamarisk infestation on long-term geomorphic change have been studied on several large rivers in the American southwest, including the Rio Grande in Texas (Dean and Schmidt 2010), the Green River in Utah (Graf 1978; Allred and Schmidt 1999; Birken and Cooper 2006) and the Rio Puerco in Arizona (Friedman et al. 2005). These studies relied on interpretation of historical aerial and ground photographs to assess and measure changes in the river planform. Information on channel profiles, invert elevations and cross-section areas was often not available.

General Observations

Historically, rivers in the arid southwest were often dry during the summer and fall and they typically exhibited a wide, shallow, laterally unstable channel, with multiple flow paths around large, unvegetated sand and gravel bars. Studies on these rivers reported similar trends following *Arundo* and Tamarisk infestation, with the planform showing long-term channel narrowing coupled with a simplified channel form and increased lateral channel stability.

The braided channels transformed into a narrower, more laterally stable single thread channel with root-stabilized, steep banks supporting both native and non-native vegetation. Few unvegetated bars remained and secondary channels were eventually filled in with sediment, covered by vegetation, and attached to the adjacent floodplain. In some cases, bed scour and channel deepening occurred due to confinement of flows.

Channel narrowing primarily occurred through the development of floodplains from vertical accretion of bar surfaces along the river bank. Plant colonization, by *Arundo* and Tamarisk, stabilized the bar surface and increased floodplain and bar roughness and sediment trapping efficiency, creating a mechanism for further sediment capture, deposition and vertical accretion.

Trends in Width and Planform

Allred and Schmidt (1999) noted a long-term trend to narrowing and bed aggradation on the Green River, based on comparing re-surveys of cross-sections. Similarly, Friedman et al (2005) found long-term channel narrowing and bed aggradation along the Rio Puerco, which led to a 27% decline in cross-section area at their study site. In contrast, Pollen-Bankhead et al. (2009) reported channel narrowing and incision following non-native plant infestation in Canyon de Chelly, Arizona. At this site, channel incision may have resulted from flow confinement and erosion-resistant banks, the latter resulting from root reinforcement and vertical accretion of fine-grained, cohesive bank sediments.

The relationship of the channel width and area following *Arundo* infestation has not been related to the local flood regime and to typical dominant discharges and it is not clearly understood how the rivers have adjusted to narrowing, increased bank strength, and dense vegetation on the floodplain. It has been noted on the Green River, Rio Grande and Rio Puerco, that channel narrowing and floodplain accretion after infestation have resulted in a more frequent overbank flooding than occurred historically, suggesting that channel dimensions have not adjusted to the local flood regime. Further adjustments, likely to channel depth, might be expected.

On the Rio Grande, Dean and Schmidt (2010) reported that large floods acted as a negative feedback mechanism or ‘reset’ event, restoring the channel condition to a previous wider and more laterally unstable state but that channel narrowing resumed immediately thereafter. Since the last large flood in 1991, they found as much as 90% of unvegetated sand and gravel bars in the active channel bed had become part of the vegetated floodplain (which is dominated by *Arundo*). No such effect was observed following large floods in Tamarisk infested sections of the Green River (Birken and Cooper 2006). Whether this is a result of the differing resistance to erosion of the two species or to the differing hydraulic forces exerted on the floodplain vegetation is not known. It is also not known if floodplain and bed elevations are “re-set” by these large floods.

The above indicates that large floods do not always ‘reset’ channel and floodplain characteristics in river reaches altered by non-native plant infestation. Little is known of the hydraulic forces that can be resisted by these invasive plants so it is not possible to predict a particular flood frequency or magnitude that will lead to their erosion and partial removal. However, the Dean and Schmidt (2010) study suggests that the time to return to the channel form observed under *Arundo* infestation is much less than the typical period between large floods that disturb the channel and floodplain.

Vertical Adjustments of the Bed and Floodplain

Dean and Schmidt (2010) measured sediment accretion on the floodplain of the Rio Grande that occurred during a rapid invasion of *Arundo* and Tamarisk. Average rates of vertical floodplain accretion of 0.6 ft/yr to 0.77 ft/yr were estimated using anatomical changes to tree rings caused by burial. The accretion occurred over a 15 year period following a large flood ‘reset’ event. Friedman et al. (2005) measured rates of channel filling in response to hydrologic changes and Tamarisk infestation on the Rio Puerco, New Mexico. Channel filling occurred in two phases, a period of channel narrowing with little change in thalweg elevation followed by vertical accretion of the floodplain and channel bed at an average rate of 0.26 ft/yr from 1962 to 2000.

Lateral Migration and Bank Erosion

Gran and Paola (2001) conducted flume experiments that documented how vegetation affects channel form and process in braided stream environments. In general, they observed channel responses that were similar to those following *Arundo* and Tamarisk infestations discussed above. They found that vegetation reduced the number of channel braids because smaller channels were choked with sediment and could not reestablish themselves. Gran and Paola (2001) noted a direct relationship between channel stability and the density and extent of vegetation. Vegetation also created less variability in flow velocity through the channel cross-section and resulted in increased bank strength (associated with dense root mats that are characteristic of these species) and decreased bank shear stress due to added roughness effects. Consequently, lateral migration rates declined. Increased bank strength also increased channel relief through the formation of higher and steeper banks and promoted channel scour, increasing maximum channel depths.

Additional studies examining the effects of invasive plant colonization on bank stability were conducted by Pollen-Bankhead et al (2009) and Brinke (2010). Pollen-Bankhead et al (2009) documented the effects of invasive plants on bank stability and bank retreat rates in Canyon de Chelly National Monument, Arizona. They found that tamarisk and Russian Olive, another invasive plant species, significantly increased bank stability through root reinforcement of the sand banks in the study area. Bank retreat rates doubled from an approximate rate of 2.5 ft/yr to 5 ft/yr following vegetation removal.

Brinke (2010) measured the root density and tensile strength of *Arundo* on stream banks of the Santa Clara River, California. When compared with Red Willow, a common native species, *Arundo* had a denser root mass and provided 40% greater tensile strength in the upper 10 cm of the bank. The converse was true below 10 cm depth, where Red Willow showed higher root density and greater tensile strength. Brinke (2010) concluded that *Arundo* contributed to less bank cohesion on stream banks exceeding one vertical foot and speculated that undercutting and cantilever failure were a primary bank erosion mechanism for *Arundo*-topped stream banks.

5.1.2.3 Observed Effects on Hydraulics and Sediment Transport

We found very few studies that compared hydraulic and sediment transport characteristics of large, low-gradient rivers; either prior to or following *Arundo* infestation. NHC (1997a,b; 2001) did complete geomorphic, hydraulic, and sediment transport studies of the lower Santa Margarita River in support of bridge and levee improvement projects at the Marine Corps Base Camp Pendleton (MCBCP). Section 5.1.4 discusses these studies in detail.

Although they do not specifically address the effects of *Arundo* on hydraulic capacity, numerous HEC-RAS models that include estimates for the hydraulic roughness effects of non-native vegetation have been used to support flood control and river management applications (USACE 2009). Few studies have reliable flow and water level data available to accurately calibrate hydraulic models for the effects of *Arundo*. However, where adequate calibration data are available, analysis of the specific effects of *Arundo* infestation scenarios may be possible with these existing HEC-RAS models.

Spencer (2010) investigated the hydraulic effects of *Arundo* on Manning's *n*, flow velocity and flow direction at study sites on Cache Creek and Stony Creek, California. Flow velocity measurements were collected around five *Arundo* plants growing in Cache Creek and a set of artificial *Arundo* stalks placed in the river bed on Stony Creek. Measured Manning's *n* roughness coefficients were found to vary between 0.019 and 0.121 with an average roughness of 0.066. Channel roughness was higher when *Arundo* was present, resulting in higher water surface elevations for the 2-year and 100-year flood events when modeled using HEC-RAS, a software program that simulates one-dimensional, open channel flow (USACE 2010).

Response to *Arundo* Removal or Eradication

Despite a number of programs to eradicate *Arundo* on rivers throughout California, we did not find any reports in the literature that documented the geomorphic, hydraulic or sediment transport effects of widespread *Arundo* removal. In particular, the period between *Arundo* eradication and re-establishment of native vegetation presents significant opportunity for local and downstream channel adjustment and changes in sediment transport processes, particularly if large floods occur during this period.

5.1.2.4 Summary of Understanding

Since its introduction in the late 1800s, *Arundo* (and to some extent, Tamarisk) has flourished on rivers and streams in Southern California to elevations of about 1,000 feet. This elevation range, and geographic area, includes a broad range of river types; however, our focus has been on large, low-gradient, braided rivers similar to the Southern California study rivers. It is in this river type that *Arundo* is likely to best disperse and establish most rapidly.

These river types have also been altered by humans. For instance, water development projects that divert flows, reduce flood flows or capture coarse sediment from the upper watershed are expected to narrow channels and convert braided rivers to simpler forms, among other effects, even in the absence of *Arundo*. Channel confinement through levees and construction of bank protection or river training structures may also have similar effects on river morphology. Other factors, such as altered seasonal flow patterns, changes to groundwater elevations, or more frequent and greater low flows, may also affect riparian vegetation, *Arundo* establishment, and channel form. The effects of some these changes may be confounded with those that directly result from *Arundo* establishment and growth.

Based on the existing literature, the response of this river type to *Arundo* infestation consists of a simplification of channel form, increased lateral stability, floodplain accretion, and long-term channel narrowing. Bed aggradation and shallower channels have been observed in some studies; channel incision or deepening in others. The long-term expectation would be for a deeper channel following narrowing and confinement of flows. However, this may be obscured by changes in watershed hydrology, the time required to erode sufficient sediment to deepen the main channel, or by rapid floodplain accretion.

Historically, braided and laterally unstable channels prior to infestation transform to narrower, more laterally stable single thread channels with root-stabilized, steep banks following infestation. Plant colonization stabilizes bar and floodplain surfaces, increasing channel roughness and sediment trapping efficiency, thereby creating a mechanism for further sediment capture, deposition and vertical accretion. Observed long-term rates of vertical accretion vary widely in the reported literature and are as high as 0.8 ft/yr. Long term average annual accretion rates likely vary with the magnitude and frequency of flooding, volume of sediment in transport, as well as the specific river conditions.

The local depths of deposits following large floods can be much greater, NHC (1998, 2001) observed several feet of sediment deposition in many locations on the floodplain adjacent to the Santa Margarita River following the 1993 flood that flooded the Marine Corps Air Station (MCAS).

There may be an upper limit on vertical accretion, which would about correspond to the elevations of typical floods. This may be reached fairly soon if the channel bed incises or does not accrete as rapidly as the floodplain. If the channel bed fills as the floodplain accretes, this limit may not be reached for a long time.

Most research on the effects of *Arundo* and Tamarisk on river systems is limited by the duration of study (about the last 70 years) and the simultaneous occurrence of human-caused changes affecting basin hydrology and sediment load. These changes often produce river responses that are similar to those from *Arundo* infestation and may obscure identification of geomorphic change specifically due to *Arundo*.

5.1.3 Southern California Study Streams

5.1.3.1 Introduction

This chapter summarizes geomorphic and vegetation characteristics of the three Southern California study streams: the Santa Margarita, Santa Ana and San Luis Rey Rivers. These study streams were selected because they contain some of the greatest observed concentrations of *Arundo* found in Southern California coastal rivers (Chapter 4, Cal-IPC 2010b). The geomorphic and vegetation characteristics presented in this chapter form the basis for comparing results from the Santa Margarita River case study (Chapter 4) to other study streams (Section 5.1.5).

5.1.3.2 Study Streams

The Santa Margarita, Santa Ana and San Luis Rey are large, sand bed, Southern California Rivers that cross coastal lowlands before discharging into the Pacific Ocean. Cal-IPC has identified specific sections of the lowland portions of these rivers as areas of interest (AOI). These management sections ranged from 17 to 37 miles in length and either ended at the Pacific Ocean or, in the case of the Santa Ana River, at a reservoir.

The AOIs were divided into broad reaches based on changes in channel planform, the degree of confinement by hillslopes or levees, and the extent of *Arundo* infestation. Geomorphic and riparian vegetation characteristics from the GIS analysis are summarized by reach in Tables 5-1.1, 5-1.2 and 5-1.3. The management sections and stream reaches are shown in Figures 5-1.1, 5-1.2 and 5-1.3; yellow areas in each figure represent the extent of the floodplain mapped in the GIS for each reach.

5.1.3.3 CAL-IPC GIS Analysis

Cal-IPC (2010b) mapped geomorphic and vegetation characteristics of the study streams in a GIS (see Methods in Section 5.2). They divided channel and floodplain into the categories described below from 2009 aerial photos and digital elevation models (DEM) from the U.S. Geological Survey (USGS 2010). No field verification was completed.

Fluvial Landforms

- *Low Flow Channel* – The part of the main channel where water was flowing at the time of the aerial photos.
- *Bar / Channel / Floodplain - unvegetated* – Main channel or floodplain areas with less than 50% vegetation cover, usually consisting of bar surfaces, dry channel beds or recent flood deposits or erosion
- *Floodplain - vegetated* – Areas on the river floodplain with more than 50% vegetation cover.

- *Floodplain / Low Terrace – vegetated* – Areas on either the river floodplain or an adjacent low terrace with more than 50% vegetation cover.
- *Upper Terrace - vegetated* – Areas on higher ground adjacent to the low terraces with more than 50% vegetation cover.

The above mapped landforms were used to calculate river characteristics by reach. Channel width was defined as the area of the low flow channel divided by the reach length. This width may not be representative of the active or main channel width commonly adopted for river studies. This is discussed further throughout the text.

Floodplain area was defined as the sum of the "low water channel", "bar/channel/ floodplain unvegetated", "floodplain – vegetated" and "Floodplain/ low terrace" areas. The average floodplain width was defined as the above area divided by the reach length. A width ratio (expressed as a percentage) was then constructed for each reach by dividing the average channel width by the average floodplain width.

Anthropogenic Features

- *Line Features* – Levee crests, bridge berms, in-stream grade control weirs, and dams
- *Point Features* – bridge crossings, water infiltration ponds, stormwater and treatment pond inflow points

Longitudinal Profile – Longitudinal stream profiles of each study reach were generated from USGS 10 m grid DEM data (USGS 2010).

Arundo Coverage – The spatial extent of *Arundo*, as mapped by Cal-IPC (2010b) from 1996 to 2009. The quoted coverage in Tables 5-1.1 to 5-1.3 represents the maximum observed extent of *Arundo* infestation. *Arundo* coverage has changed on the study streams in recent years because of eradication programs.

5.1.3.4 Study Stream Characteristics

General Morphology

In the late 1990s, the study streams had single thread channels at low flows that were bordered by well-vegetated floodplains; only a few reaches had less than 50% vegetation cover. Except where the rivers were confined by natural topography or levees, the low flow channel width (See definition above) was generally less than 10% of the floodplain width (see Width Ratio; Tables 5-1.1 to 5-1.3); alternatively, the floodplain was at least 10 times as wide as the low flow channel.

The San Luis Rey and Santa Ana Rivers study streams are about twice as steep as the Santa Margarita River, on average. However, the three study streams have a common pattern of steeper slopes in their upstream reaches and shallower slopes near the mouth. Along the study stream, slopes near the mouth are about one-fourth to one-eighth of those in the most upstream reaches.

Floodplain widths averaged 1,100 feet in the Santa Margarita River, 800 feet in the San Luis Rey River and 1,300 feet in the Santa Ana River (removing the very wide Reach 1) and they varied considerably from one study reach to another, as a result of both human and topographic confinement. Width ratios and the portion of the floodplain that was not vegetated were greatest in the Santa Ana study reaches; the portion of the floodplain that was vegetated was greatest in the San Luis Rey study reaches, where less than 15% of the floodplain and channel area has less than 50% vegetation coverage.

Arundo Characteristics

Arundo coverage varied from 15 to 23% of the total floodplain and channel area in the three management sections. The percentage *Arundo* cover was not a consistent portion of the total vegetation cover and it covered from less than 1% to more than 50% of the total floodplain area when averaged over the study stream reaches. *Arundo* was uncommon within the low flow channel width (Section 5.2).

All three study streams show a marked decline in *Arundo* coverage in the upstream study reaches compared to the downstream ones. Such an observation may result from slow upstream propagation, flood history, or the role of steeper stream slopes in limiting the establishment and development of *Arundo*. The relative importance of these two factors cannot be resolved with the existing information, but Tables 5-1.1 to 5-1.3 suggest that *Arundo* is an insignificant portion (in terms of geomorphic processes) of total cover in those study reaches where slopes exceed 0.004, including those steep reaches on the San Luis Rey River that have much of their floodplain covered with other vegetation.

There also appears to be a pattern along the study streams, and particularly on the Santa Margarita River, where the reaches with the highest *Arundo* concentrations occur where slope declines or the floodplain widens considerably when compared to the reach upstream. The best example is on Reach 7 of the Santa Margarita River which has the highest percent *Arundo* coverage of the study reaches (Table 5-1.1). The slope in Reach 7 is about half of that in Reach 6 and the floodplain is about twice as wide. This pattern is thought to occur because the less steep, wider reach has much lower average velocities which promote deposition of *Arundo* propagules and increase the likelihood of *Arundo* establishment and propagation. Section5.1.5 discusses this observation in more detail.

Table 5-1.1. Santa Margarita River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	1.52	0.0008	1270	163	12.8%	59.7%	1.5%
2	1.47	0.0017	773	66	8.5%	91.0%	14.7%
3	1.70	0.0015	1444	58	4.0%	87.4%	21.5%
4	0.42	0.0015	2493	52	2.1%	91.5%	18.9%
5	0.90	0.0014	1929	72	3.8%	87.5%	44.3%
6	1.30	0.0024	2505	61	2.4%	92.2%	28.2%
7	0.42	0.0015	2213	87	3.9%	93.1%	54.8%
8	1.60	0.0023	1045	73	7.0%	71.7%	44.6%
9	0.77	0.0024	630	52	8.2%	66.9%	18.2%
10	1.21	0.0031	823	58	7.0%	73.9%	10.2%
11	1.89	0.0026	664	105	15.7%	68.7%	24.9%
12	4.11	0.0033	424	48	11.3%	69.7%	21.0%
Weighted Ave		**0.0023**	**1,078**	**73**	**8.7%**	**76.3%**	**23.1%**
Total	**17.32**						

[1] – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
[2] – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
[3] – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

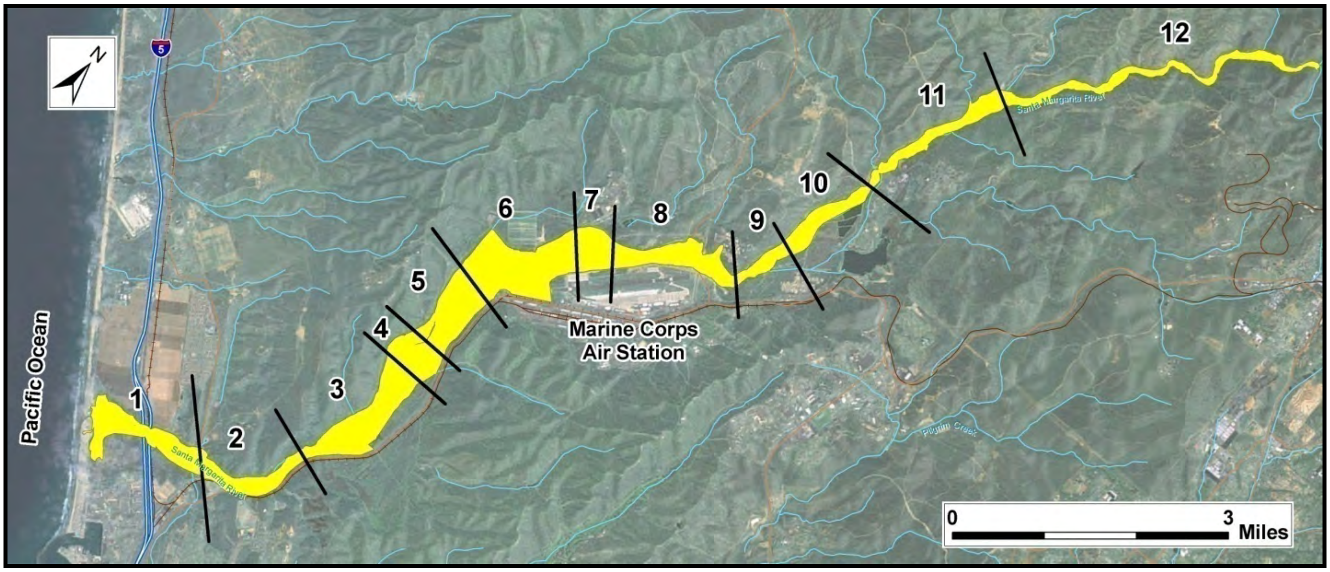


Figure 5-1.1. Santa Margarita River study reaches, with yellow denoting extent of mapped floodplain.

Table 5-1.2 Santa Ana River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	3.16	0.0012	9146	90	1.0%	98%	12.5%
2	12.17	0.0025	1758	136	7.7%	82%	41.2%
3	2.08	0.0030	733	207	28.3%	56%	10.5%
4	2.35	0.0047	2312	219	9.5%	76%	19.4%
5	9.67	0.0038	749	197	26.3%	30%	0.2%
6	3.98	0.0058	529	151	28.5%	36%	0.4%
7	3.44	0.0097	1441	133	9.3%	49%	0.0%
Weighted Average		**0.0039**	**1942**	**159**	**15.7%**	**59.8%**	**16.6%**
Total	**36.86**						

[1] – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
[2] – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
[3] – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

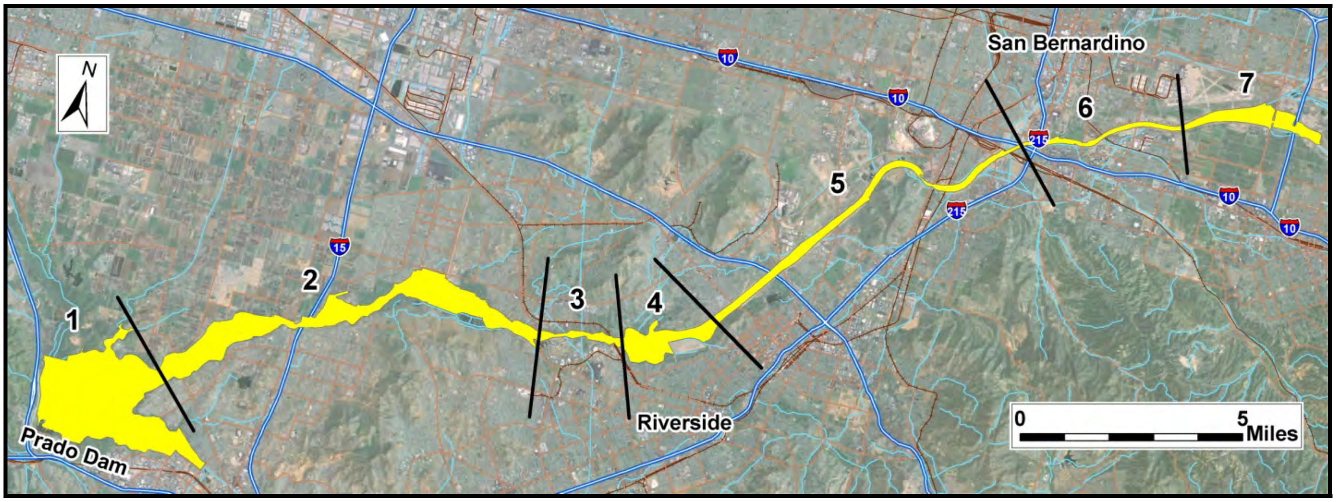


Figure 5-1.2. Santa Ana River study reaches with extent of mapped floodplain denoted in yellow.

Table 5-1.3 San Luis Rey River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	0.86	0.0007	506	178	35.2%	52.9%	11.4%
2	1.66	0.0015	582	52	9.0%	80.4%	47.1%
3	5.79	0.0023	509	44	8.7%	91.4%	20.4%
4	5.53	0.0021	834	48	5.7%	85.5%	29.9%
5	0.62	0.0030	544	38	7.0%	94.7%	22.3%
6	5.07	0.0029	1232	60	4.8%	92.4%	12.8%
7	3.73	0.0037	443	37	8.4%	89.6%	7.7%
8	3.73	0.0050	1186	29	2.4%	83.7%	0.1%
9	2.03	0.0110	797	24	3.0%	86.0%	0.2%
10	2.01	0.0148	424	31	7.3%	74.4%	0.3%
11	1.16	0.0048	1157	33	2.8%	68.1%	0.0%
Weighted Average		**0.0042**	**790**	**46**	**6.8%**	**85.7%**	**14.9%**
Total	**32.19**						

1 – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
2 – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
3 – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

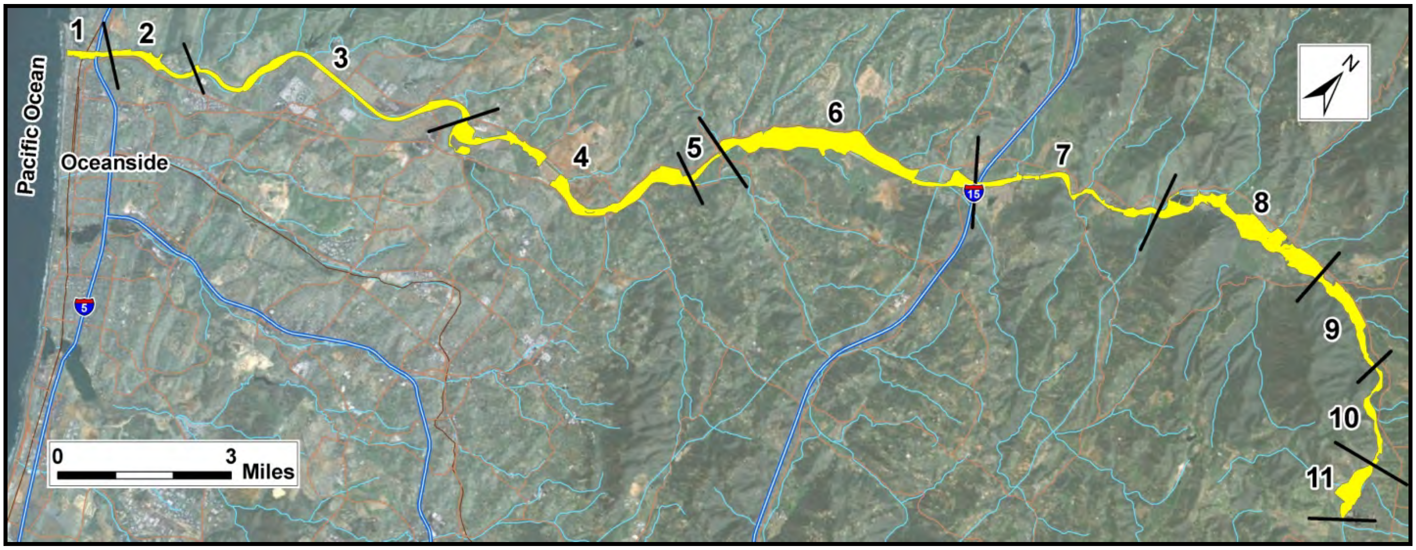


Figure 5-1.3 San Luis Rey River study reaches with extent of mapped floodplain denoted in yellow.

5.1.4. Santa Margarita River Case Study

5.1.4.1 Introduction

This chapter briefly describes the Santa Margarita River watershed, its climate and hydrology, and the morphology and historical behavior of the lower Santa Margarita River, before describing the effects of *Arundo* infestation on hydraulics, sedimentation and geomorphology. The effects of *Arundo* on these characteristics were determined from surveys, field observations, other consultant reports, and rerunning of hydraulic models developed in NHC (1997b) and NHC (2001). The NHC studies were completed during the period of maximum *Arundo* infestation, prior to the eradication programs that began in the late 1990s.

5.1.4.2 Santa Margarita Watershed

The Santa Margarita River watershed has an area of 740 square miles and drains into the Gulf of Santa Catalina (Pacific Ocean) near the city of Oceanside. Maximum elevations are about 6,825 ft at Thomas Mountain near the eastern end of the watershed. The upper watershed of the Santa Margarita River is mostly underlain by granitic rocks of pre-Cenozoic age; the central watershed, near Temecula and Murrieta, is mantled by Holocene and Pleistocene alluvial deposits (Jennings 1977). Occasional outcrops of Eocene and Jurassic marine rocks and metasedimentary and metavolcanic rocks are found in the central and lower watershed.

Three reservoirs regulate flows from the watershed. Vail Dam was completed in 1949 and regulates inflows from about 320 mi^2 of the upper Temecula watershed. Vail Lake storage capacity is about 40,000 acre-ft and it captures nearly all the winter runoff from its watershed, having overtopped only twice since the late 1940s (CDM 2003). Skinner Reservoir on Tucalota Creek, constructed in 1974 by the Metropolitan Water District (MWD), regulates a 51 mi^2 watershed and primarily stores imported water, releasing local inflows. Diamond Valley Lake Reservoir stores 800,000 acre-ft of imported water for the MWD; it reached full capacity in 2002. Skinner and Diamond Valley Lake Reservoirs have little effect on winter floods.

Lake O'Neill, operated by Camp Pendleton, provides off-stream storage for up to 1,200 acre-ft, which is diverted from the Santa Margarita River in spring and used for groundwater recharge in late fall. Releases for recharge are between 8 and 10 cfs (CDM 2003).

5.1.4.3 Climate and Hydrology

The Santa Margarita watershed has a Mediterranean climate, characterized by warm summers and cool, wet winters. Summers are dry and there are often several months without rain. About 90% of the annual precipitation falls as rain during large frontal storms that occur from November through April. Average annual precipitation is about 11 to 13 inches near the coast and over 25 inches at the highest watershed elevations, where it may include some snowfall.

The USGS has operated the Santa Margarita River at Ysidora (11046000) gage, near the mouth of the river, since 1923. Suspended sediment records were collected in the 1968-71, 1972-74 and 1977 water years. Inspection of the gage records shows an annual hydrograph where runoff primarily occurs during winter months, and is event-driven with most of the water discharge (and also most of the sediment discharge) occurring during a few, intense storms (Warrick and Rubin 2007). Annual maxima vary dramatically from year to year; annual instantaneous peaks at the Ysidora gage have ranged from zero to 44,000 cfs (Figure 5-1.4).

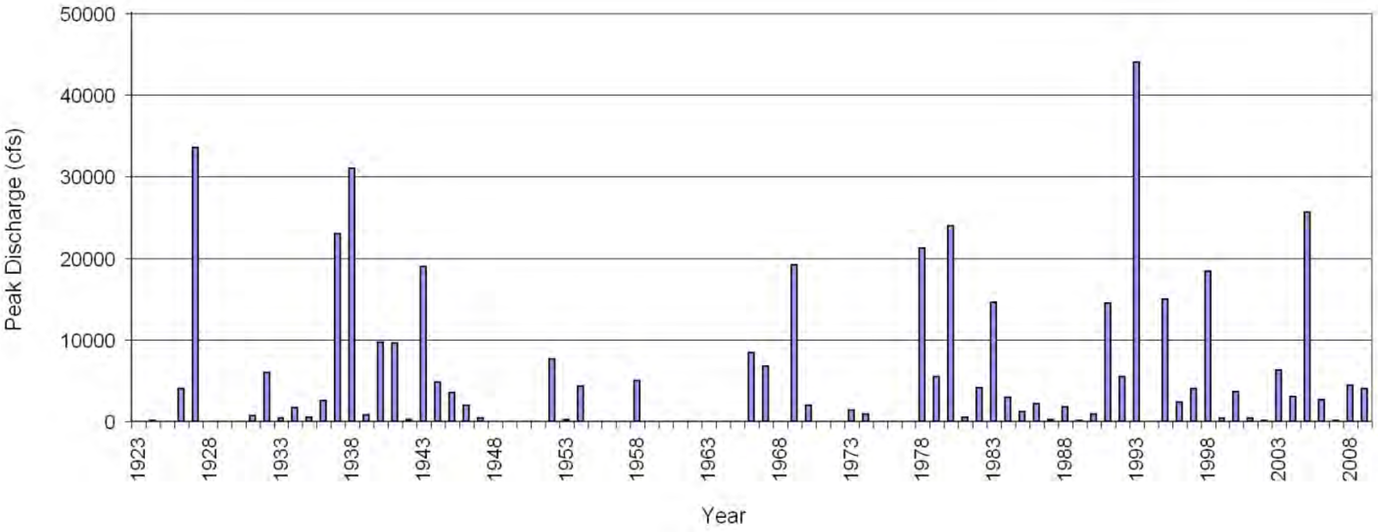


Figure 5-1.4. Annual peak discharges recorded at USGS stream gage 11046000 on Santa Margarita River near Ysidora.
Years with zero values or no data are shown as blank.

Large floods, those with return periods of more than 10 years and flows greater than 15 to 20,000 cfs, have been recorded at the gage in 1927, 1937, 1938, 1943, 1969, 1978, 1980, 1993, 1998, and 2005. Figure 5-1.4 shows a twenty-five year gap starting in the 1940s and lasting until 1969 that had no large floods. The 1993 flood was by far the largest on record; its peak discharge of 44,000 cfs is now about equivalent to the 50-year flood (USACE 1994a; Table 4.2=5-1.4). Before installation of the gage, large floods occurred in 1916 and 1884 (McGlashan and Ebert 1918). Stetson (2001) provides accounts of historical flooding and flood damages.

Most years include a long period of very low (<5 cfs) flows at the gage in the summer and fall, often extending for three or four months. Examination of decadal flow duration curves at the Ysidora gage shows a trend toward an increased duration of flows exceeding 10 cfs since the 1970s (Figure 5-1.5). This shift to a sustained, year-round, base flow is thought to be due to urbanization, water regulation since the construction of Vail Reservoir and groundwater recharge releases.

5.1.4.4 Lower Santa Margarita River

The Santa Margarita River begins at the confluence of Murrieta River and Temecula Creek near the City of Temecula. It is about 30 miles long; about 19 miles flow through Camp Pendleton near the mouth of the watershed. The lower Santa Margarita River begins at the mouth of DeLuz Canyon. Downstream, it flows through a 500 to 5,000 ft wide valley bordered by hilly terrain underlain by marine sedimentary rocks. The greatest widths are adjacent to the Marine Corps Air Station (MCAS) and at Ysidora Flats. The MCAS occupies a large part of the floodplain and is protected by a levee; otherwise the lower river valley is not developed, except for five bridges crossings and a few connecting roads.

The focus for this chapter is a 5.5 mile long project reach of the lower Santa Margarita River, which is adjacent to the MCAS and extends from De Luz Canyon to Ysidora Flats (Figure 5-1.6).

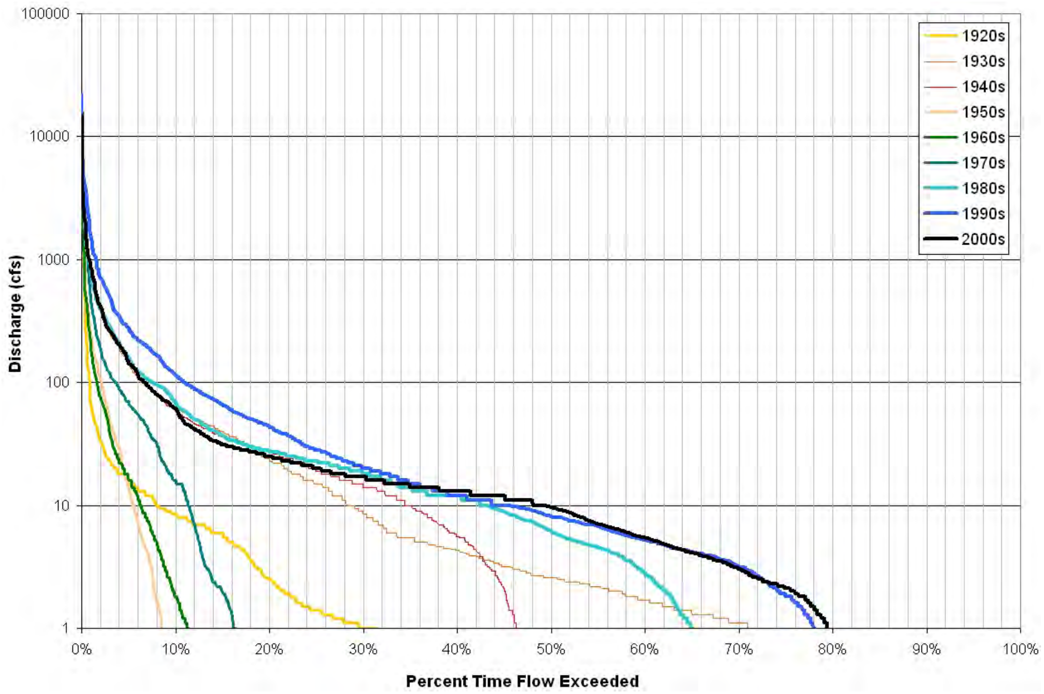


Figure 5-1.5. Flow duration curves plotted by decade at the Ysidora gage (11046000).

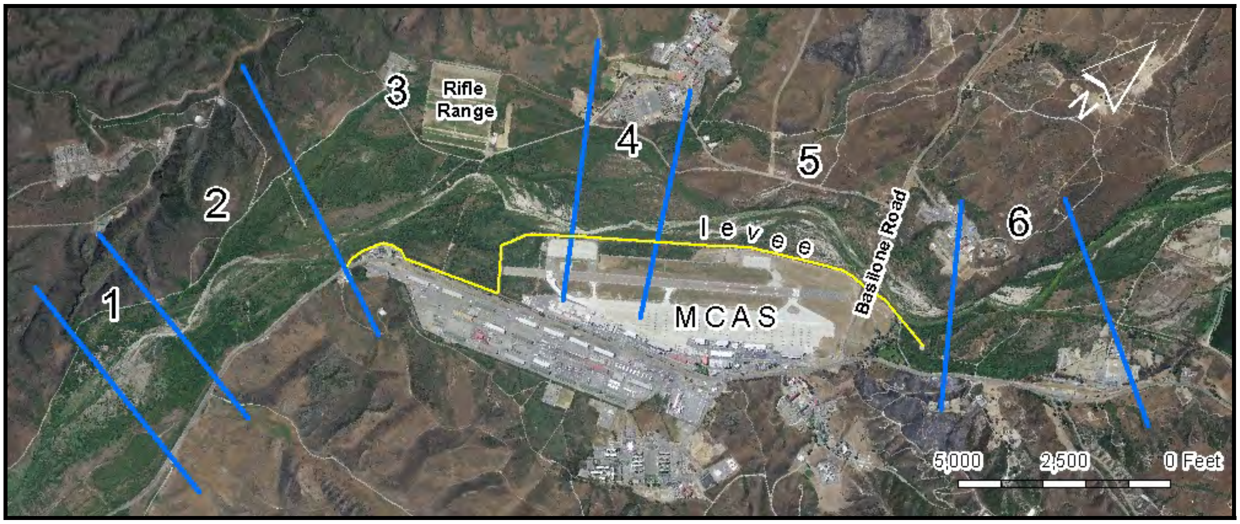


Figure 5-1.6. Sub-reaches (numbers 1 through 6) in the lower Santa Margarita River project reach.

This project reach is where NHC examined hydraulics and sediment transport capacity with mature stands of *Arundo* on the river bank and floodplain (NHC 1997a; 1997b; 2001) and covers about the same river mileage as Reaches 4 through 9 in Table 5-1.1 and Figure 5-1.1. The river floodplain is confined to varying degrees throughout the project reach, particularly upstream of the O'Neill Lake diversion and in the vicinity of Basilone Road Bridge (Table 5-1.4; Figure 5-1.6).

The sub-reach breaks on Figure 5-1.6 were set based on the degree of confinement, channel dimensions and longitudinal slope, using historical air photos, ground inspections and surveyed channel cross-sections. Channel confinement resulted from geologic and anthropogenic features, including high bluffs, bridges, in-channel road or pipeline crossings, and levees along the MCAS. The sub-reaches are described on Table 5-1.4.

In the late 1990s, the main channel, as defined by channel banks, was typically 200 ft to 400 ft wide and bordered by moderate to abundant vegetation where the floodplain had not been developed. The main channel was generally four to eight times wider than the low flow channel defined in Table 5-1.1. The floodplain surface was generally 4 to 6 feet higher than the low flow channel invert, as indicated by field inspection and channel surveys. Small, concentrated flow paths (distributary or chute channels) were common on the floodplain and on vegetated bar surfaces throughout the project reach (Figure 5-1.7).

River banks generally consisted of loose or partially consolidated sand and were between four and six feet high. Stream bed materials consisted of coarse and medium sands with some fine gravel. Sands and silts were the common deposits observed on overbank floodplain areas.

Figure 5-1.7. View of the Santa Margarita River in Sub-Reaches 2 & 3 (view is upstream) taken on May 16, 1995.

Table 5-1.4. Description of the lower Santa Margarita project sub-reaches.

Sub-Reach	Reach Length (ft)	Slope (ft/ft)	Average Floodplain Width (ft)	Ave Channel Width (ft)	General Observations
Sub-Reach 1 (sta. 0 to sta. 18+61) *Downstream sub-reach*	1,900 ft	0.0011	3,200 ft	205 ft	Narrow active channel bed flowing in an undeveloped and well vegetated floodplain.
Sub-Reach 2 (sta. 18+61 to sta. 71+07)	5,250 ft	0.0023	1,900 ft	350 ft	Valley narrows due to adjacent hillslopes through this undeveloped sub-reach located just downstream of the MCAS airfield.
Sub-Reach 3 (sta. 71+07 to sta. 143+98)	7,300 ft	0.0023	3,500 ft	405 ft	Wide valley section with broad floodplain partly confined by MCAS levee and the Rifle Range and Rifle Range Road crossing.
Sub-Reach 4 (sta. 143+98 to sta. 162+66)	1,900 ft	0.0025	2,300 ft	310 ft	Short reach of intermediate width connecting the very wide sub-reach 3 with narrow sub-reach 5
Sub-Reach 5 (sta. 162+66 to sta. 241+58)	7,900 ft	0.0022	1,100 ft	325 ft	Narrow floodplain sub-reach due to the Basilone Road crossing and MCAS levee along the right bank.
Sub-Reach 6 (sta. 241+58 to sta. 274+55) *Upstream sub-reach*	3,300 ft	0.0030	1,500 ft	345 ft	Narrow floodplain sub-reach due to flow confinement and infrastructure on the south side of the valley.

5.1.4.5 Historical Changes in the Project Reach

Planform

NHC (1997a) examined the position of the lower Santa Margarita River on historical air photos and maps and found that it maintained the same overall course since 1938. Its course had been more or less straight, except where it followed the natural curvature of valley walls or was guided by levees along the MCAS. The channel mostly lay on the northwestern portion of the valley bottom, due to encroachment by the MCAS facilities.

Within this general alignment, the main or active channel has shifted several hundred feet at some locations and exhibited a general decrease in width since 1938, interrupted by dramatic increases in channel width following large floods, such as in 1969 (NHC 1997a; see also Figure 5-1.8). Large floods also restored multiple flow channels and braid bars in the project reach. Vegetation encroached on recently deposited bar and overbank sediments and a single channel re-established over time.

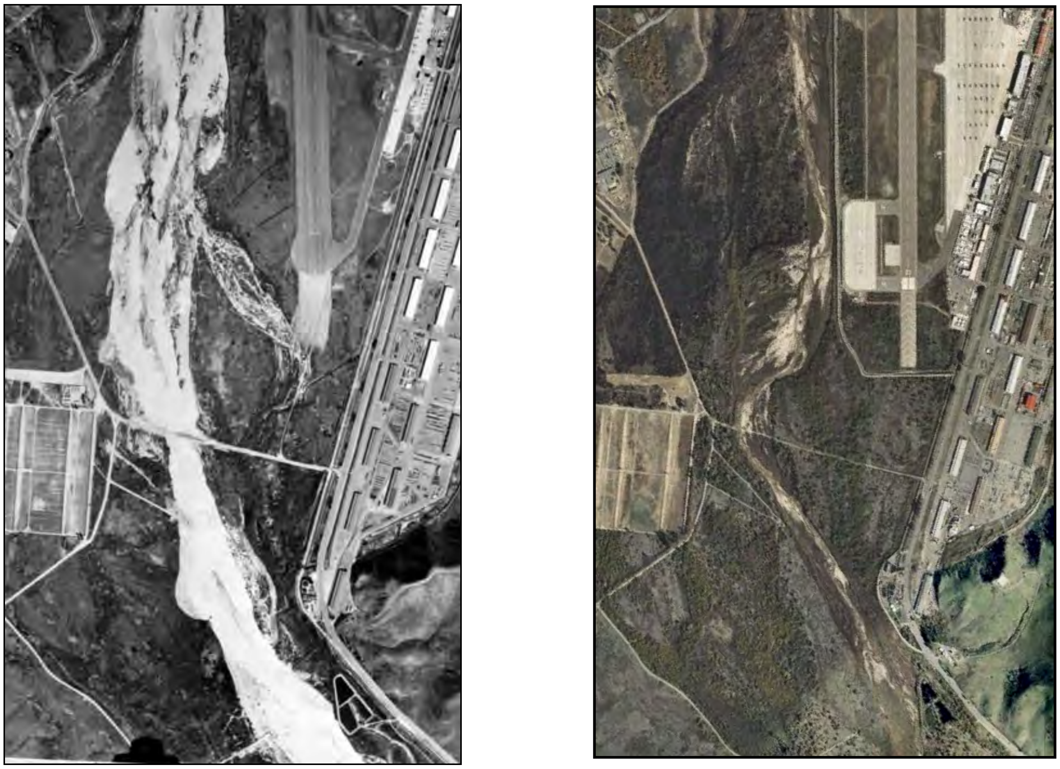


Figure 5-1.8. Comparison of 1970 (left) and 2008 (right) air photos of Sub-reach 3.

Bed Profiles

NHC (1997b) compared channel invert (thalweg) profiles from 1946 to 1994 and found no consistent trend in elevations. Rather, the sub-reaches showed bed elevations that varied around a mean value over time, suggesting a relatively stable profile that responded to large floods, bar development, scour and sediment deposition. No channel invert elevation surveys have been completed since 1994, and a profile that shows the potential effects of recent *Arundo* eradication on channel elevations has not been surveyed.

NHC (1997a) concluded that there was no clear evidence of recent aggradation or incision along the lower Santa Margarita River. However, numerical modeling of long-term sediment transport suggested aggradation rates of 1.5 ft per 100 years, as a result of the lower bed slopes in the downstream end of the project reach (Table 5-1.4).

Floodplain Vegetation

Figure 5-1.8 compares air photos of Sub-reach 3 from 1970 and 2008. The non-vegetated active channel bed is several times wider in 1970 than 2008, despite the recent *Arundo* eradication. Channel and floodplain conditions in the 1970 air photo resulted from the 1969 flood, which followed a twenty-five period with no significant floods. Stetson Engineers (2001) reported that large floods in 1927 and 1993 also scoured much of the valley bottom and dramatically enlarged the active channel in Deluz Canyon just upstream of the project reach.

Interestingly, the 2008 air photos were taken not long after the 2005 flood, whose peak was slightly greater than that in 1969. Despite this, the 2008 channel shows no evidence that it had recently enlarged to the width observed after the 1969 flood. This different behavior is assumed to result from changes in the riparian vegetation in the channel and on the floodplain, or changes in channel and floodplain geometry, that resulted in greater bank and floodplain resistance to erosion.

While intriguing, such behavior is not well documented or understood. However, it suggests that the large floods that once greatly altered the channel and floodplain vegetation on the lower Santa Margarita River conditions may not be as effective under current conditions.

Arundo Eradication Programs

Efforts to control *Arundo* in the Santa Margarita River watershed began in 1997 (Lawson et al. 2005), and eradication has proceeded upstream to downstream, beginning at Interstate 15 in the middle watershed. *Arundo* removal continued for over a decade until 2009 when the river mouth was reached. The distribution of *Arundo* along the lower Santa Margarita River and the years when stands were removed are documented in a GIS database prepared by the California Invasive Plant Council (Cal-IPC 2010b).

The total area of *Arundo* stands in the project reach near Camp Pendleton was estimated to be about 400 acres in 1997 (Cal-IPC 2010b). Cal-IPC (J. Giessow, pers. comm.) provided a comparison of the 1997 and 2010 geomorphology in the project reach (See section 5.2.4), noting that the area of low flow channel and unvegetated bar or floodplain had increased from 120 acres in 1997 to 360 acres in 2010. Bed level changes or adjustments associated with the increased width for the main channel have not been documented.

5.1.4.6 Project Reach Hydraulics

HEC-RAS Model

In the late 1990s, NHC developed a calibrated, steady, one-dimensional HEC-RAS model (USACE 2010) of the Santa Margarita River project reach, as part of studies for a new levee (NHC 2001). The model was based on 62 cross-sections in the project reach, an average of one every 470 ft, developed either from July 1998 LiDAR, September 1996 air photos or June and July 1998 cross section surveys (Figure 5-1.9).

Figure 5-1.9. Location of HEC-RAS model cross-sections (in yellow) (NHC 2001).

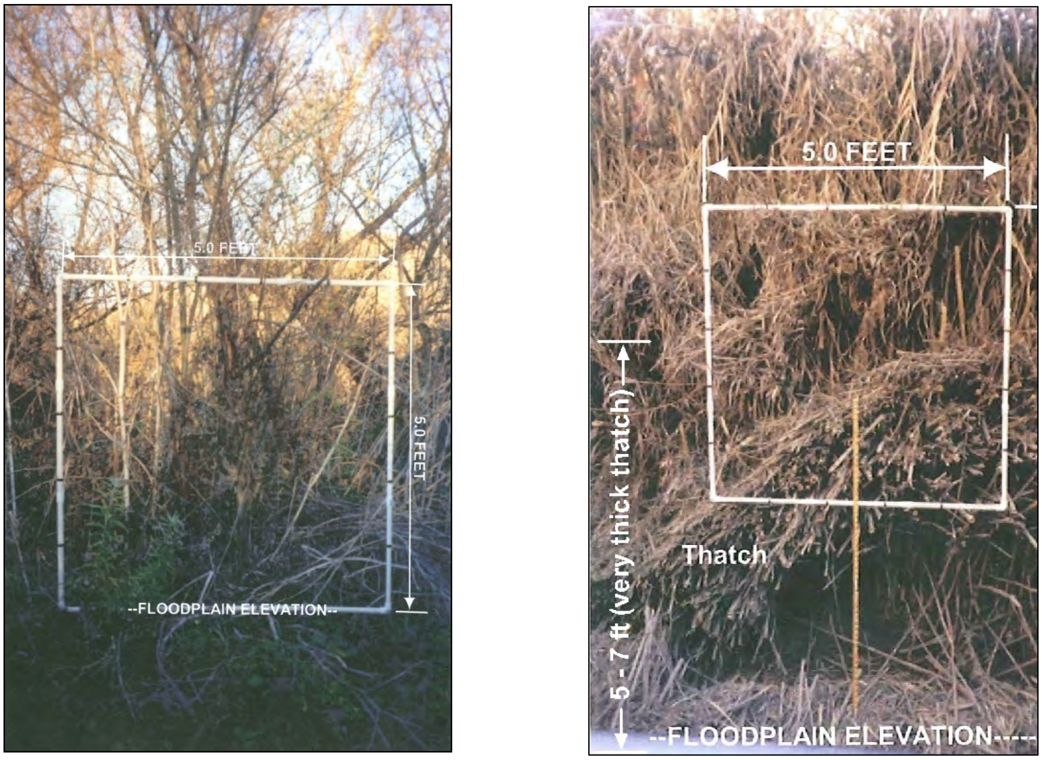
Model Calibration

The HEC-RAS model was calibrated to high water marks surveyed after the 1993 (44,000 cfs) and 1998 (18,400 cfs) floods. Calibration consisted of adjusting Manning's roughness and floodplain characteristics until calculated water surface profiles matched those observed during the floods. The initial calibration in *Arundo* infested areas resulted in Manning's n value on the floodplain that seemed unreasonably high, as much as 0.35 to 0.40, and were considerably higher than typical published values for roughness on vegetated floodplains.

Field observations of mature *Arundo* stands showed an extremely dense thatch of interlocking plant stems that extended 5 to 7 feet above the ground surface that effectively blocked conveyance on the floodplain (Figure 5-1.10). Above that elevation, the *Arundo* stems were not as interlocked or densely spaced and appeared to be able to bend in the flow, similar to native plant species such as willow. However, the *Arundo* exhibited a much higher density of stalks or stems than native willow species (Figure 5-1.10).

These observations led to a modified approach to hydraulic modeling in thick *Arundo* stands on the overbank or floodplain. The calibrated model eliminated flow conveyance in the first 5 feet in mature *Arundo* stands and used an average Manning's n value of 0.15 for water levels over 5 ft from the ground (NHC 2001). This range of roughness was in general agreement with the results of flume measurements of Manning's n for woody vegetation that included tamarisk (Freeman et al. 2000).

Additionally, a Manning's n of 0.10 was adopted for native vegetation on the floodplain and one of 0.05 for bare (un-vegetated) floodplain. A Manning's n of 0.04 to 0.06 was adopted for the low flow or main channel.



(a) Native Riparian Vegetation (b) Mature Stand of *Arundo*

Figure 5-1.10. Photographs of floodplain vegetation on the Santa Margarita River (1/4/1999).

Model Scenarios

The floodplain roughness in the calibrated HEC-RAS model described above was then adjusted to predict hydraulic characteristics over a range of flows for four different floodplain vegetation scenarios. These were:

- *Scenario 1 – Total Mature Arundo Infestation:* This scenario represents the ultimate extent of *Arundo* infestation, where the entire floodplain surface is covered by mature, monotypic stands.
- *Scenario 2 – Native Vegetation*: This scenario assumes that native vegetation covers the entire floodplain surface and that no *Arundo* is present.
- *Scenario 3 – Bare Floodplain:* This scenario assumes a floodplain surface where floodplain sediments are exposed as a result of fire, *Arundo* eradication, or a large flood event.
- *Scenario 4 – 1997 Floodplain:* This scenario represents the mix of *Arundo*, native vegetation, and bare surface on the floodplain observed in 1997, as interpreted from aerial photos onto the cross sections. Manning's n values vary across the floodplain in each cross section, based on the appropriate values adopted for the different vegetation types observed in the 1997 air photos.

In those scenarios where *Arundo* was present, floodplain elevations were raised 5 ft to simulate zero conveyance in mature *Arundo* stands (Scenarios 1 and 4). Otherwise, the low flow or main channel geometry and floodplain geometry were not altered and remain as described for the NHC (2001) model.

Peak Flows

Table 5-1.5 summarizes the peak flows adopted for the steady state HEC-RAS model runs that were performed as part this study.

Table 5-1.5. Peak flows adopted for the project reach (USACE 1994).

Return Period (years)	*Peak Discharge (cfs)*
2	3,000
5	9,400
10	17,000
25	31,500
50	46,000
100	64,000

Hydraulic Model Results for the 4 Scenarios

Table 5-1.6 provides a general summary of the variation in reach-averaged hydraulic variables for the various scenarios, compared to the native vegetation scenario (Scenario 2).

Table 5-1.6. Differences in hydraulic characteristics between scenarios.

Scenario	**Wetted Width**[1]	**Average Depth**	**Average Flow Velocity**	
			Channel	**Overbank**
1 – *Arundo* Infestation	Wider	Deeper	Faster	Slower
2 – Native Vegetation	*(baseline)*	*(baseline)*	*(baseline)*	*(baseline)*
3 – Bare Floodplain	Narrower	Shallower	Slower	Faster
4 – 1997 Floodplain	Variable	Variable	Variable	Variable

[1] Wetted Width – width of the wetted channel cross-section for a given flow discharge

The ratios of values for Scenarios 1 and 3 compared to Scenario 2 are generally consistent throughout the range of peak flows in Table 5-1.5. The ratios comparing Scenario 4 (1997 vegetation) to Scenario 2 vary. This occurs because the floodplain roughness varies from one cross section to another largely because the extent of the total floodplain area occupied by *Arundo* varies from one sub-reach to another (Table 5-1.7).

Table 5-1.7. Extent of *Arundo* by sub-reach as of 1997.

Sub-Reach [1]	***Floodplain Area (ac)***	***Arundo (ac)***	***Percentage***
1	128	24	19
2	210	93	44
3	396	112	28
4	113	62	55
5	203	90	45
6	59	11	18

[1] See Figure 5-1.6 for location of sub-reaches.

Design Water Surface Profiles

Figure 5-1.11 shows the project reach water surface profiles for the 100-year flood for each of the four scenarios. For the 1997 floodplain vegetation scenario (Scenario 4), 100-year water levels are typically close to that for native vegetation, but rise two to three feet in sub-reaches 4 and 5 where the infestation is dense (Table 5-1.7). Complete coverage by *Arundo* (Scenario 1) raises flood levels by 4 to 5 feet above those for native vegetation throughout the project reach; bare soil or no floodplain vegetation (Scenario 3) lowers them 2 to 3 feet throughout the project reach.

Water surface profiles for the 5-year flood show a similar pattern to that for the 100-year flood, but have smaller differences in stage. The full *Arundo* coverage scenario (Scenario 1) raises water levels up to 3 ft above those for native vegetation, whereas bare soil or no floodplain vegetation (Scenario 3) lowers them about 1 ft. The 5-year water levels for the 1997 vegetation scenario (Scenario 4) are close to those for complete native vegetation coverage, but rise one to two feet in sub-reaches where the infestation is particularly concentrated.

Comparison of results from Scenarios 1 and 4 to those from Scenario 2 suggests that there is a threshold for floodplain coverage by mature *Arundo*, below which impacts on average depths and water surface profiles are relatively insignificant. A rough idea of the threshold can be obtained by comparing *Arundo* densities in Sub-reaches 4 and 5 to those further downstream (Table 5-1.7). On this basis, percent *Arundo* coverage somewhere over 30% generally results in significant adjustments to the water surface profile.

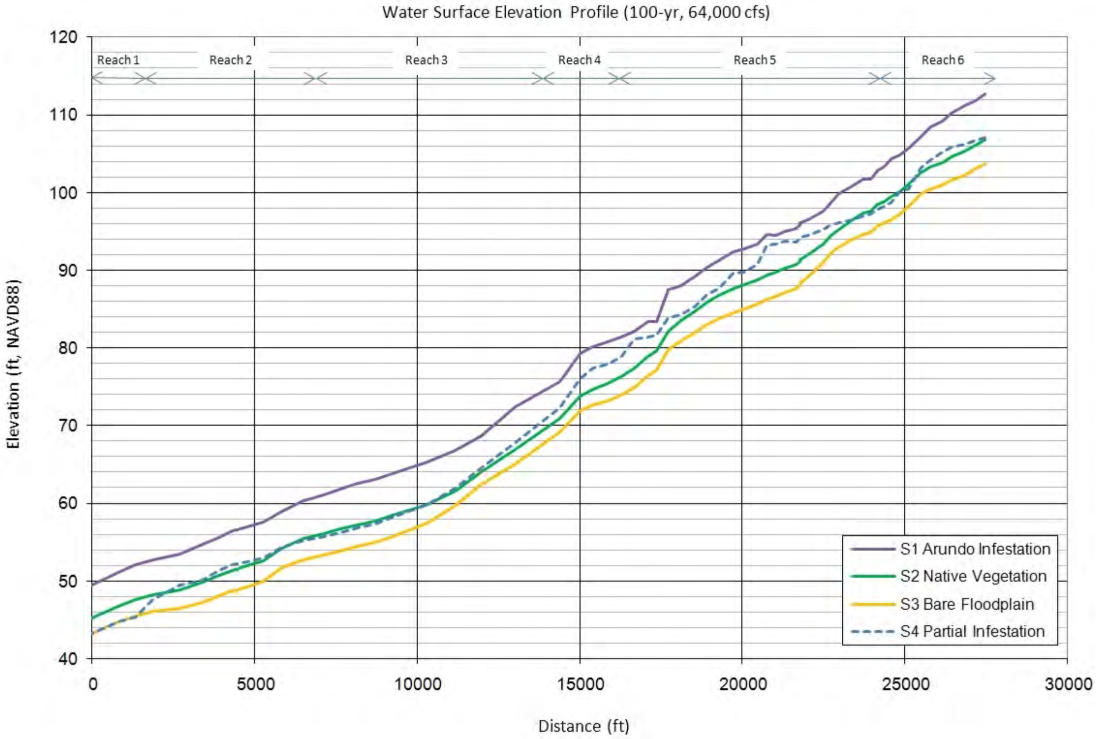


Figure 5-1.11. Project reach water surface profiles for scenarios 1 to 4: 100-year peak flow.

Channel and Floodplain Velocities

Table 5-1.6 indicated that complete coverage by *Arundo* results in the deepest flows and greatest velocities in the main channel and the slowest velocities on the floodplain. This illustrates a key characteristic of dense vegetation, such as *Arundo*, in the hydraulic model: flows are concentrated in the main channel by dense stands along the stream banks, resulting in deeper and faster flow through the main channel for a given discharge.

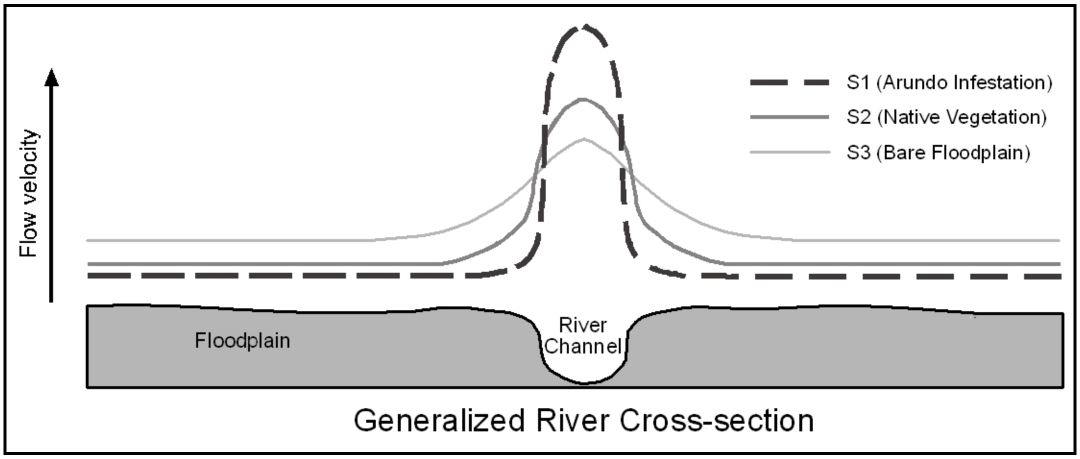


Figure 5-1.12. Generalized illustration of the effects of floodplain roughness (dense vegetation) on velocity across the section for Scenarios 1, 2, and 3.

In contrast, removal of floodplain vegetation results in the lowest average velocities in the main channel. Main channel velocities with floodplain vegetation removed would be lower still if channel widening due to the lower bank strength was incorporated in the RAS model. These observations are summarized in Figure 5-1.12.

Results by Sub-Reach

Table 5-1.8 compares hydraulic characteristics for the four scenarios for Sub-reaches 3 and 5. Sub-reach 5 has a 100-year floodplain width of about 1,100 feet; Sub-reach 3 is less confined and its floodplain width averages 3,500 feet (Table 5-1.4). As expected, the narrower Sub-reach 5 has greater average depths and velocities in the channel and on the floodplain than the wider Sub-reach 3 at the 100-year peak for all the scenarios. However, the percentage increases in average depths and velocities in Sub-reach 5, when comparing Scenario 1 to Scenario 2, are smaller than in Sub-reach 3. This is thought to occur because the main channel, whose roughness is not affected by differing vegetation types, occupies a larger portion of the total floodplain width and conveys a greater portion of the total flow. When Scenario 4 is compared to Scenario 2, the results are complicated by the different *Arundo* coverage percentages, but velocities increase in Sub-reach 3 and decrease in Sub-reach 5. In sub-reach 5, the increased floodplain roughness seems to be accommodated more by increased depths than velocities in the main channel, potentially as a result of backwater from Sub-reach 4.

Table 5-1.8. Depths and Velocities in Sub-reach 3 (wide floodplain) and Sub-reach 5 (narrow floodplain) for the 100-year peak flow.

Scenario	Sub-Reach 3 (wide floodplain)					Sub-Reach 5 (narrow floodplain)				
	Wetted Width (ft)[1]	Average Flow Depth (ft)		Average Flow Velocity (ft/s)		Wetted Width (ft)[1]	Average Flow Depth (ft)		Average Flow Velocity (ft/s)	
		CH	OB	CH	OB		CH	OB	CH	OB
1 – *Arundo* Infestation	3,530	17.5	7.5[2]	10.3	1.5	1,150	20.2	10.5[2]	13.4	2.3
2 – Native Vegetation	3,480	12.3	7.2	8.0	2.2	1,140	15.7	10.4	11.8	3.6
3 – Bare Floodplain	3,400	9.9	4.9	7.2	3.6	1,120	12.9	7.8	10.4	6.0
4 – 1997 Floodplain	3,280	12.2	6.6	8.4	2.5	1,140	17.5	10.0	10.9	3.7

[1] Wetted Width – width of the wetted channel cross-section for a given flow discharge

[2] Represents depth of active flow conveyance area only, and does not include 5 ft thickness of ineffective flow in *Arundo* areas.

Note: CH = Channel; OB = Overbank or floodplain

As noted earlier, the above results assume the same geometry for the main channel and floodplain for each scenario; only roughness changes from one scenario to another.

5.1.4.7 Project Reach Sediment Budget

Introduction and Context

Sediment transport in rivers is complex and this chapter considers only two of its components. This section discusses reach-based sediment budgets and addresses the question of whether *Arundo* infestation might reduce sediment delivery to downstream reaches and, ultimately, to the Pacific Ocean. This section also discusses the potential changes in sediment transport capacity that might result from the altered hydraulics discussed in the previous section and considers the likely channel response. The analyses are speculative for both of these components.

Sediment Budget Considerations

The sediment budget for a particular reach – such as the project reach on the Santa Margarita River – can be expressed as follows:

$$\text{Sediment}_{\text{Out}} = \text{Sediment}_{\text{In}} \pm \Delta\text{Storage} \qquad (1)$$

In (1), the change in sediment storage in the reach over time (ΔStorage) can be either negative (erosion from the reach) or positive (deposition in the reach), with erosion increasing the sediment output; deposition reducing it.

The budget can be constructed for various time periods or grain size classes. The analysis for the project reach focuses on long-term averages and the transport of sand. In the Santa Margarita River, sand makes up much of the bed material. It is transported both in suspension and as bed load (Slagel and Griggs 2006).

If we can assume that the sediment delivered to the project reach is reasonably constant over the long-term then the sediment that leaves the reach will differ from that arriving as a result of changes in sediment storage within the reach, including those that result from *Arundo* establishment. Changes in storage within the reach are best measured by comparing repeated surveys of channel and floodplain cross sections to define volumes and by sediment sampling to define the size distribution of the materials that have been eroded or deposited. Such information is not available on the Santa Margarita River and is seldom available for large rivers in Southern California. Instead, we rely on observations in other reports to roughly define the changes in sediment storage expected with *Arundo* infestation and sediment delivery studies to define the long-term sediment input to the stream reach.

Santa Margarita River Sediment Loads

Previous studies (Slagel and Griggs 2006, Inman and Jenkins 1999) have estimated annual sediment transport in the Santa Margarita River from sediment gaging at the Ysidora gage, which is downstream of the project reach. Average annual transport was between 50 and 70 acre-feet (65,000 and 80,000 m^3) in the two studies. Slagel and Griggs (2006) also concluded that average annual sand transport was about 20 acre-feet (25,000 m^3), or about 30 to 40% of the total transport.

Sediment Capture by *Arundo*

Previous studies (see Section 5.1.2) indicate that deposition occurs on the floodplain as *Arundo* stands establish and mature. Rates have not been measured on the Santa Margarita River but the average annual accretion rates discussed in Chapter 2 ranged from about 0.3 to 0.7 feet per year. Given these rates, the average annual storage in the *Arundo* stands on the floodplain might then be from 120 to 280 acre-feet over the 400 acres of *Arundo* growth that was present in 1997. Roughly one-third of the total is sand (see

Slagel and Griggs 2006), or about 40 to 90 acre-feet. This represents the average annual loss of sand in transport to storage in *Arundo* stands. Sediment deposition is also likely to occur on the remainder of the floodplain but this has been ignored in the simple budget constructed to evaluate *Arundo* impacts.

It is not known how long the above average rates of accretion or deposition might continue. Rates may be curtailed as the floodplain and braid channels fill with sediment, particularly because the channel thalweg does not seem to be aggrading on the Santa Margarita River.

Adding the above annual estimate of sand trapped on the floodplain to the transport observed at the Ysidora gage (the sediment leaving the reach) indicates that the annual sand inflow to the project reach might have been 60 to 110 acre-feet during the period of *Arundo* establishment and growth. On this basis, the sediment output from the reach was reduced to one-third or less of the sediment input by storage in the *Arundo* stands. This suggests that *Arundo* establishment and growth on the floodplain of the project reach has the potential to capture a substantial portion of the sediment delivery from the upper watershed. As discussed in the next section, losses to deposition on the floodplain may be partly compensated for by erosion from the channel bed.

Erosion in the Main Channel from *Arundo* Growth

Based on the literature review, at the same time as the *Arundo* stands on the floodplain are trapping sediment in transport, the main channel can be expected to narrow. We have no good measurements of the change in width that occurred as *Arundo* stands established and dominated the riparian and floodplain vegetation on the Santa Margarita River. However, measurements by Cal-IPC (Section 4.5) show that the main channel width about tripled in width following *Arundo* eradication. Assuming that the same results would occur in reverse during *Arundo* establishment and growth, the main channel with *Arundo* infestation might be about one-third to one-half as wide as it was prior to *Arundo* establishment.

As the channel narrows it would be expected to deepen to pass typical floods, as is commonly observed in regime studies. Such a response was not observed often in the literature review but that may be because the channel bed or thalweg rose as the floodplain filled but to a lesser extent, creating a deeper flow channel. It is not known how channel depths have changed on the Santa Margarita River following *Arundo* infestation.

A rough estimate of the increased depth required to pass typical floods as the channel narrows can be obtained by applying Blench’s (1969) regime equation. It suggests that the increase in channel depth for the above reductions in width might be about 50 to 100%. The typical channel depth before *Arundo* establishment is not known, but the observed channel bank height in the project reach as of 1997 or so, with *Arundo* in place, was about 4 to 6 feet, consistent with calculated average depths at the 2-year flood. Based on the ratio above, it appears that the channel may now be 2 to 3 feet deeper than it was prior to *Arundo* establishment. The greater channel depth might result from bed erosion, increased floodplain height adjacent to the channel, or a combination of the two processes.

The area of the main channel in 1997 was 118 acres and the bed material was sand. Assuming that 2 to 3 feet of erosion occurred over twenty years, the average annual net loss of bed material from the reach could be as much as 12 to 18 acre-feet over the project reach. As noted above, the net erosion might be zero if the channel deepens by filling on the floodplain rather than by eroding its bed.

Project Reach Sediment Budget Summary

The above suggests that annual trapping of sand on the floodplain during *Arundo* establishment and growth in the project reach was about 40 to 90 acre-feet; the erosion from the channel bed as it adjusted to narrower widths is expected to be less than 20 acre-feet. The above estimates are based on accretion and erosion rates from the literature rather than from measurements on the Santa Margarita River. However, they suggest that *Arundo* establishment and growth is likely to reduce the volume of sand transported through the project reach to the coast. As noted above, two-thirds of the sand transported from the upper Santa Margarita River watershed might be trapped in *Arundo* stands in the project reach during their establishment and growth.

After *Arundo* has established and reached its maximum coverage, we anticipate that accretion of sediment on the floodplain will slow, unless the channel fills rapidly so that flood waters continue to spill onto the higher floodplain. As the accretion on the floodplain slows or stops, the adjustment of channel depth to the narrower channel width will also slow or stop. At this point, sand transport out of the reach will be in equilibrium with sediment supply.

The observed difference between losses to sediment storage and gains from bed erosion in the Santa Margarita River may not be the same in other Southern California Rivers with different overall geomorphology. Where the floodplain is narrower than in the Santa Margarita River, bed erosion may be a large portion of storage and the reduction in sand transport towards the coast with *Arundo* establishment may be smaller. Where the floodplain is much wider, the opposite result may occur.

5.1.4.8 Project Reach Sediment Transport Capacity

Introduction and Context

Suspended sediment transport has been measured at the Ysidora gage on the Santa Margarita River; however, there are no measurements of bed load transport. Bed load and bed material load transport have been modeled by NHC (1997b) and West Consultants (2000) but only for the *Arundo* coverage that existed in the late 1990s. Consequently, an evaluation of the potential effects of varying *Arundo* coverage or *Arundo* eradication on sediment transport capacity must be calculated from the hydraulic output from the HEC-RAS model runs.

The RAS model runs have some limitations for calculating sediment transport capacity for different conditions. The actual channel and floodplain geometries under different vegetation scenarios are not known; nor do we know if the size of material on the channel bed differs for these scenarios. Instead, as described earlier, the RAS model adopted the channel and floodplain geometry from 1997 for all the scenarios, altering the floodplain roughness and conveyance to simulate different vegetation scenarios, and assumed the same bed material distribution.

Approach to Transport Capacity

We have adopted stream power as the best proxy for sediment transport capacity differences among the four floodplain vegetation scenarios (Bagnold 1966; Vanoni 1975). Stream power per unit length of channel, which is essentially a measure of the energy available to transport sediment once a critical threshold for mobility is passed, is defined as:

$$\Omega = \rho g Q S \qquad (2)$$

where Ω is stream power, ρ is the density of water, g is the acceleration due to gravity, Q is a discharge and S is energy slope, roughly parallel to the bed slope. For calculations from the model output, $Q = wdv$, where w is channel width, d is average channel depth and v is average sectional velocity, was substituted into Equation (2) and terms regrouped as:

$$\Omega = \tau v w \qquad (3)$$

In Equation (3), τ is the average bed shear stress. Stream power was calculated separately for the channel and floodplain for each of the four scenarios, for the 5-year through 100-year peak flows (see Table 4.2). Average annual stream powers were then calculated based on an expression reported in USACE (1995) that incorporates the stream power exerted by floods up to the 100-year return period and approximates the area under the annual probability-event yield curve.

Stream Power for Different Scenarios

Table 5-1.9 summarizes the stream power calculated for Scenarios 1, 3, and 4 as a ratio to that calculated for Scenario 2 (Native Vegetation), the adopted baseline or index condition. Numbers >1 indicate more power and greater sediment transport, and numbers <1 indicate less power and sediment transport. This table shows that the ratios of the stream power to that for Scenario 2 are not particularly sensitive to the magnitude of the flood, under the model assumption of fixed channel and floodplain geometry. In the Santa Margarita River we expect that the channel will respond rapidly to increased stream power, altering its depth, width (where geometry permits) or bed material size until thresholds for transport are increased or bed stresses are reduced. Thus, the observed differences may not persist for the frequent floods, but are likely to persist for the largest ones.

Table 5-1.9 is helpful when considering potential channel and floodplain responses to changes in floodplain vegetation. For example, it suggests that as vegetation changes from native to a mixture of *Arundo*, native vegetation and bare soil (Scenario 4) the stream power exerted in the main channel will increase and, hence, it will begin to deepen. Stream power exerted on the floodplain will decrease and filling of secondary channels and deposition on the floodplain might be anticipated. When floodplain changes from a vegetated state to bare soil (Scenario 3), as it would under the *Arundo* eradication program, the stream power exerted in the main channel reduces and deposition or channel filling might occur. On the floodplain, stream power is greatly increased and rapid development of channel braids would be expected, returning the channel form to a braided appearance, such as has been observed in the Santa Margarita River. This assumes that the *Arundo* root mass has been removed or that it does not affect stability of the sediments. Areas with rhizome mats still in place would be expected to be more erosion resistant than bare soil, and might reduce or prevent geomorphic change.

Table 5-1.9. Summary of relative differences in stream power by scenario for entire study area, (S2: native is baseline).
>1 = more power and sediment transport, <1 = less power and sediment transport

	Channel				**Floodplain**			
Flow Event	**S1 *Arundo***	**S2 Native**	**S3 Bare**	**S4 Mix-1997**	**S1 *Arundo***	**S2 Native**	**S3 Bare**	**S4 Mix-1997**
5-year	**1.41**	1.00	0.88	**1.02**	**0.23**	1.00	1.33	**0.95**
10-year	**1.59**	1.00	0.86	**1.06**	**0.38**	1.00	1.22	**0.92**
25-year	**1.51**	1.00	0.80	**1.10**	**0.50**	1.00	1.17	**0.89**
50-year	**1.50**	1.00	0.77	**1.13**	**0.59**	1.00	1.16	**0.92**
100-year	**1.50**	1.00	0.74	**1.14**	**0.66**	1.00	1.15	**0.95**
Average Annual	**1.50**	**1.00**	**0.83**	**1.07**	**0.49**	**1.00**	**1.20**	**0.93**

S1=all *Arundo*, S2=all native, S3=all bare, S4=1997 site conditions (mix of *Arundo*, native, bare).

Stream Power by Sub-Reach

In a similar fashion to the hydraulic characteristics, the relative changes in stream power also vary from sub-reach to sub-reach, depending on floodplain width. A narrow sub-reach (5) and a wider sub-reach (3) are presented in Table 5-1.10 to illustrate this.

Where the floodplain is wide relative to the channel there are potentially greater changes in stream power in the main channel with complete *Arundo* coverage (Scenario 1). Thus, a greater channel response (power and sediment transport) would be expected in wider floodplain reaches with complete *Arundo* coverage than in narrower ones, which is confirmed in Table 5-1.10. The lower power/sediment trapping effect on floodplains is more pronounced in narrower sub-reaches (S1 and S4 are lower). This may be off-set by the spatial extent of floodplains, however, as there is more invaded floodplain in sub-reach 3 to catch sediment, wider floodplain seems to balance in terms of sediment transport, narrower reaches may trap more.

Table 5-1.10. Differences in relative stream power for sub-reaches 3 and 5.

Sub-reach 3 (wider floodplain)

	Channel				**Floodplain (overbank)**				**Total**			
Flow Event	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97
10-year	**1.75**	1.00	0.82	**1.09**	**0.42**	1.00	1.18	**1.02**	**0.99**	1.00	1.02	**1.05**
10o-year	**1.78**	1.00	0.82	**1.20**	**0.72**	1.00	1.18	**1.09**	**0.99**	1.00	1.09	**1.12**

Sub-reach 5 (narrower floodplain)

	Channel				**Floodplain (overbank)**				**Total**			
Flow Event	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix‘97
10-year	**1.30**	1.00	0.86	**0.89**	0.28	1.00	1.28	**0.68**	**0.90**	1.00	1.02	**0.81**
10o-year	**1.33**	1.00	0.73	**0.83**	0.57	1.00	1.22	**0.69**	**0.91**	1.00	1.00	**0.76**

S1=all *Arundo*, S2=all native, S3=all bare, S4=1997 site conditions (mix of *Arundo*, native, bare).

5.1.4.9 Case Study Summary

This section summarizes our understanding of the effects of *Arundo* establishment on hydraulics, sediment transport and geomorphology, based on the case study in the lower Santa Margarita River project reach.

Similar to other rivers in Southern California and throughout the American Southwest, the establishment and spread of *Arundo* on the lower Santa Margarita River has narrowed the active river channel and simplified its river cross-section. This has resulted in a shift from a wide, braided river planform to a single channel with defined banks and few bare active geomorphic surfaces. The narrowing trend has been interrupted by occasional large floods which remove floodplain vegetation and widen the channel, such as occurred in 1969 and 1993. It is not understood or known what the minimum channel width might be in the absence of large floods.

Inspection of historical air photos suggest that there has been much less channel widening from recent large floods than occurred in 1969, presumably because of different erosion resistance of the floodplain since the *Arundo* stands have been established. Little is known of the hydraulic forces that can be withstood by the *Arundo* stands in various types of floodplain deposits (soils) so there is no good understanding of how large a flood would be required to remove stems, erode the root mass, and reset the floodplain vegetation. In any event, it appears that *Arundo* will out-compete native vegetation on the disturbed floodplains and re-establish mature stands on much of the floodplain in the time interval between very large floods.

The mature *Arundo* stands essentially eliminated flow conveyance during low and moderate floods on the portions of the floodplain that they occupy, increasing the portion of the flow passing through the low flow or active channel. During large peak flows, when water levels are more than 5 feet or so over the floodplain surface, flow is conveyed over the mature *Arundo* stands but considerable roughness is created by the stems and leaves. During very great flows, the *Arundo* stems may be broken off and carried downstream, substantially altering local resistance to flow.

Hydraulic modeling of four different floodplain vegetation scenarios (all *Arundo*, all native, all bare, 1997 field conditions) suggested that the conversion from native vegetation to complete coverage by mature *Arundo* stands would have three important implications. First, 100-year water levels are raised by 3 or 4 feet from the increased roughness. Second, the portion of the total discharge carried in the main channel increases and, thus, depths and velocities also increase for a particular return period flood. Third, the (modeled) conveyance on the floodplain is much less with *Arundo* infestation.

There are some interesting and significant subtleties suggested by the hydraulic modeling. First, there appears to be a threshold for *Arundo* coverage before there are significant effects on hydraulics. The exact portion of the floodplain that must be occupied for a significant effect is not fully understood. Second, the magnitude of the effect on hydraulics of *Arundo* infestation and the threshold for observing significant effects depends on the overall floodplain and channel width. Narrow total widths show less effect for a particular flood than wide ones, likely because there is less conveyance on the narrow floodplains for the native vegetation scenario, so there is a smaller increase in flows in the main channel when *Arundo* coverage is complete. Note that velocities are higher in the narrower reaches; the above differences refer only to the observed percentage increases with the *Arundo* scenario in the hydraulic model.

The results of the hydraulic model studies are limited because they do not account for channel adjustments that are expected to occur rapidly in response to the altered hydraulics on the floodplain and in the main channel. Stream power calculations, which were adopted as a proxy for sediment transport, show greatly increased stream power in the main channel and greatly reduced stream power exerted on the floodplain under complete *Arundo* coverage, when compared to native vegetation, and a smaller increase and smaller decrease for partial coverage (Scenario 4). The consequences of the changes in stream power (or any measure of forces exerted on the bed) when banks are less erodible because of *Arundo* establishment are expected to be increased depths of the main channel and sediment trapping and accretion on the floodplain and in overbank areas. Regime considerations suggest that average depths might increase by about 50% to 100% for frequent floods to compensate for the narrowed channel. However, this is only a rough estimate and has not been confirmed with field surveys or measurements.

Both of the channel responses described above change the sediment storage in the project reach on the Santa Margarita River and potentially affect the delivery of sediment from the upper watershed to downstream reaches and the Pacific Ocean. Considering only the sediment balance for sand, and relying on accretion rates observed in the literature, it appears that the annual loss of sand to trapping on the floodplain during *Arundo* establishment is much larger than the compensating erosion from the adjustments of the channel. In the Santa Margarita River project reach, the net deposition on the floodplain is a very large portion of the sand carried down from the upper watershed. As discussed, different conclusions might be drawn for rivers with much wider or much narrower floodplains.

Once *Arundo* reaches its maximum coverage, floodplain trapping and channel adjustments will eventually cease, and delivery from the upper watershed to the reach will equal that which passes through to downstream reaches and the Pacific Ocean.

5.1.5. Study Stream Arundo Responses

5.1.5.1 Introduction

This section applies the results of the literature review (section 5.1.3) and the case study analysis (section 5.1.4) to develop a method to qualitatively assess the potential impacts of *Arundo* infestation on river hydraulics, sediment transport capacity and geomorphology. Once developed, the method is applied to the Santa Margarita, Santa Ana and San Luis Rey Rivers, utilizing the river and riparian vegetation characteristics provided in Chapter 5.1.3. Stream responses to *Arundo* discussed in this chapter are based on the maximum extent of *Arundo* mapped in these study reaches by Cal-IPC, as presented in Chapter 5.1.3.

5.1.5.2 *Arundo* Impact Scoring System

The potential impacts of *Arundo* infestation on river characteristics and, to some extent, the potential impacts of reach characteristics on the maximum extent of *Arundo* coverage, were qualitatively assessed by totaling scores that were developed from the key findings and observations from the literature review, Santa Margarita River case study and GIS mapping effort (Chapter 5.1.3).

The Width Ratio and *Arundo* Coverage scores express the potential for modification of the river as a result of *Arundo* Infestation. The Changes in Floodplain Width and Bed Slope, and Other Features scores express the potential for *Arundo* to dominate the riparian vegetation on the floodplain in the reach. We have defined the *Arundo* Impact Score to be the sum of the individual scores, as defined below. As scores increase, significant changes in river characteristics become more likely and differences between the *Arundo* and native vegetation river characteristics become greater. The specific impacts of *Arundo* on river characteristics are likely to be different in each stream reach and river system; however, the general effects will be similar to those described in Sections 5.1.2.4 and 5.1.4.9.

Width Ratio Score

The Santa Margarita River case study demonstrated that wider floodplain reaches may have a greater hydraulic response to *Arundo* infestation than narrower ones. A score was developed based on this observation using the Width Ratio (see Chapter 5.1.3), which is the ratio of the low flow channel width to the floodplain width (Table 5-1.11).

Table 5-1.11. Width ratio score.

Width Ratio	Width Ratio Factor	Comment
Below 4%	2	Wide floodplain reach
4% - 8%	0	Average width floodplain reach
Above 8%	-1	Narrow floodplain reach, typically confined by either topography or levees

Width ratios of 4% and 8% were selected as the cut-offs between wide, average, and narrow floodplain categories, based on the differences observed between Sub-reach 3 (wide floodplain) and Sub-reach 5 (narrow floodplain) in the Santa Margarita case study. Note that Sub-reach 3 is Reach 6 (width ratio =

3.8%) and Sub-reach 5 is Reach 8 (width ratio = 7.0%) in Table 5-1.1. The scores assigned to the different width ratios is shown in Table 5-1.11.

Arundo Coverage Score

The Santa Margarita case study suggested that a threshold of floodplain coverage by mature *Arundo* exists, below which impacts on average depths and water surface profiles are relatively insignificant. This percent coverage seemed to be between 28% and 45% *Arundo* coverage for the case study river (see Section 5.1.4.6). Table 5-1.12 shows the scoring that was developed based on the percent *Arundo* Coverage mapped for each reach in section 5.1.3. Cut-off points of 25% and 40% were selected for scoring the impact of percent *Arundo* cover on river characteristics.

Table 5-1.12. *Arundo* coverage score.

% *Arundo* Coverage	***Arundo* Coverage Factor**	**Comment**
Below 25%	0	The effects of *Arundo* on hydraulics may not be significant in this reach
25% - 40%	1	This range of *Arundo* coverage represents a transition zone within which significant impacts to the water surface profile and consequently river hydraulics and sediment transport and geomorphology may occur
Above 40%	3	High percent *Arundo* coverage suggests this reach provides optimal conditions for *Arundo* establishment and changes in hydraulic, sediment transport and geomorphic effects are likely to be significant

Changes in Floodplain Width and Bed Slope Scores

The GIS analysis in Section 5.1.3 showed a relationship between the maximum percent *Arundo* coverage observed in a reach by Cal-IPC and changes in floodplain width and bed slope relative to the reach upstream. As previously discussed, large increases in floodplain width and declines in bed slope contribute to decreased flow velocities and sediment transport capacity. This promotes deposition and increases the likelihood of *Arundo* dispersal in that reach. Conversely, abrupt declines in floodplain width or increases in bed slope may promote the opposite effect and limit *Arundo* propagules from depositing.

Chapter 5.1.3 also noted there may be an upper slope limit for significant *Arundo* coverage in the floodplain vegetation that may be a proxy for a number of other factors. Also, the above discussion does not apply to river estuary reaches where salt water intrusion restricts *Arundo* growth and coverage. This is a narrow range, however, as *Arundo* tolerates up to 90% salt water.

Large increases (>100%) in floodplain width relative to the reach upstream are observed in Reach 7 of the Santa Margarita River, Reach 6 of the San Luis Rey, and Reaches 2 and 4 of the Santa Ana River. Each reach exhibits either a large (>50%) increase in *Arundo* cover from the reach upstream and more than 40% total *Arundo* cover. Conversely, Reach 3 of the Santa Ana River exhibits a 100% decline in floodplain width and nearly 50% decline in percent *Arundo* cover relative to the reach upstream. The scores associated with changes in floodplain width are summarized in Table 5-1.13.

Large decreases (>33%) in bed slope relative to the reach upstream are observed in Reach 7 of the Santa Margarita River, Reaches 2, 4 and 8 of the San Luis Rey, and Reach 3 of the Santa Ana River. Reach 7 exhibits greater than 45% *Arundo* cover and Reaches 2 and 4 exhibit large (>33%) increases in percent *Arundo* cover relative to the reach upstream. Reach 3 shows a decline in percent *Arundo* cover, possibly because of a large decline in floodplain width, and Reach 8 has negligible *Arundo* cover as does the reach upstream. The effect of changes in channel bed slope on the *Arundo* impact score are summarized in Table 5-1.14.

Table 5-1.13. Floodplain width score.

% Change in Floodplain Width	Floodplain Width Factor	Comment
>100% Decrease	-1	Flow confinement promotes higher average flow velocity, limiting the potential for deposition of *Arundo* propagules in this reach
Less than 100% Change	0	Changes in floodplain width may be significant in affecting the deposition of *Arundo* propagules but do not show a clear impact.
>100% Increase	1	Floodplain widening promotes a decline in average flow velocity and promotes deposition of *Arundo* propagules in this reach.

Table 5-1.14. Bed slope score.

% Change in Bed Slope	Bed Slope Factor	Comment
>33% Decrease	1	Decreases in bed slope promote lower average flow velocity which favors the deposition of *Arundo* propagules in this reach.
Less than 33% Change	0	Changes in bed slope may be significant in affecting the deposition of *Arundo* propagules but do not show a clear impact.
>33% Increase	-1	Increases in bed slope promote higher average flow velocity, limiting the potential for deposition of *Arundo* propagules in this reach

Other Features

Other features not already incorporated into the *Arundo* impact score are also indentified and, if present, provide an additional factor of ‘1’ or ‘-1’ depending on the feature observed. These include salt water intrusion that limits *Arundo* growth at the river mouth, and anthropogenic features that could potentially influence *Arundo* impacts on a river reach. Features specific to each stream are discussed in the next section.

5.1.5.3 Santa Margarita River

Table 5.5 shows the *Arundo* impact scores for the Santa Margarita River study reaches (Figure 5-1.1 shows reaches). Note that the case study Sub-reaches 1 through 6 conform to Reaches 4 through 9 in the GIS mapping in Chapter 5.1.3.

Table 5-1.15. Santa Margarita River *Arundo* impact scores.

Reach	**Reach length (mi)**	**Case Study Sub-Reach**	***Total Score***	***Arundo* Impact Scores**				
				Width Ratio	***Arundo* Coverage**	**Floodplain Width**	**Bed Slope**	**Other Features**
1	1.52		***-1***	-1	0	0	1	-1
2	1.47		***-1***	-1	0	0	0	0
3	1.70		***0***	0	0	0	0	0
4	0.42	1	***2***	2	0	0	0	0
5	0.90	2	***6***	2	3	0	1	0
6	1.30	3	***2***	2	1	0	-1	0
7	0.42	4	***7***	2	3	1	1	0
8	1.60	5	***4***	0	3	0	0	1
9	0.77	6	***0***	-1	0	0	0	1
10	1.21		***0***	-1	0	0	0	1
11	1.89		***-1***	-1	0	0	0	0
12	4.11		***-1***	-1	0	n/a	n/a	0

Table 5-1.15 shows that Reaches 4 through 8 (Sub-reaches 1 through 5) are the most susceptible to changes in river form and process from *Arundo* infestation. For the most part, these reaches have low slopes, wide floodplains with abundant opportunity for *Arundo* establishment and propagation, and historically large areas of *Arundo* stands. Other features that affect *Arundo* distribution and potential impacts on river characteristics includes salt water that limits *Arundo* growth in Reach 1 and groundwater recharge from Lake O'Neill and infiltration ponds in Reaches 8, 9 and 10 that provides additional water.

Table 5-1.15 identifies sub-reaches 2 and 4 as those where *Arundo* is likely to exert the greatest impact on river characteristics. Such a result is reasonably consistent with the case study observations in section 5.1.4. Sub-reach 4 does show a rise in the water surface profile compared to the base case (Figure 5-1.11) and other modifications to the reach hydraulics occur. Sub-reach 2 shows no rise in the water surface profile (Figure 5-1.11); instead, the increased flow through the main channel is accommodated by increases in velocities. The highest scoring contiguous river sections (Reaches 4 to 8) is about 8 miles long. This is a significant portion of the river.

5.1.5.4 San Luis Rey River

Table 5-1.16 shows the *Arundo* impact scores for the San Luis Rey study reaches. Based on this table, the greatest modification to river characteristics from *Arundo* impacts are expected to be in Reaches 2 and 4. *Arundo* has also historically been well established in Reaches 3 and 5 but they do not score very high due to floodplain confinement by urban levees. Further upstream, in Reaches 8 through 11, a score of -3 was assigned in Other Features to reflect that these steeper reaches have little or no *Arundo* in their floodplain vegetations, suggesting that *Arundo* has not successfully colonized this area. This may be a result of steep bed slopes in these upper reaches that reduce opportunities for *Arundo* establishment, or lack of source propagules or plants.

The overall scores for the San Luis Rey River reaches are considerable less than for the Santa Margarita River reaches suggesting that *Arundo* impacts on river forms and processes may be less significant. However, Reaches 2, 4 and 6 constitute most of the functional lower river (9 mi), and these areas are impacted. Reaches 3 and 5 only function to convey water, and they have limited geomorphic or biologic function.

Table 5-1.16. San Luis Rey *Arundo* impact scores.

Reach	**Reach length (mi)**	***Total Score***	***Arundo* Impact Scores**				
			Width Ratio	***Arundo* Coverage**	**Floodplain Width**	**Bed Slope**	**Other Features**
1	0.86	***-1***	-1	0	0	1	-1
2	1.66	***3***	-1	3	0	1	0
3	5.79	***-1***	-1	0	0	0	0
4	5.53	***2***	0	1	0	1	0
5	0.62	***-1***	0	0	-1	0	0
6	5.07	***1***	0	0	1	0	0
7	3.73	***-2***	-1	0	-1	0	0
8	3.73	***0***	2	0	0	1	-3
9	2.03	***-1***	2	0	0	0	-3
10	2.01	***-5***	0	0	-1	-1	-3
11	1.16	***-1***	2	0	n/a	n/a	-3

5.1.5.5 Santa Ana River

Table 5-1.17 summarizes the *Arundo* Impact scores for the Santa Ana River reaches (Figure 3-2 shows reaches). Based on these scores, the greatest modification to river processes and form are expected to occur in Reaches 1 and 2. Note that Reach 1 is in the Prado Flood Control Basin and *Arundo* establishment and spread will be different than in other reaches because of basin filling during large runoff events and long-term sediment deposition.

Reach 2 has a meandering channel that flows through a shallow valley. The wide floodplain provides substantial opportunity for *Arundo* establishment and the gradual reduction in slope down the reach and its location downstream of a steeper, more confined Reach 3 also contribute to the high score. Impacts of *Arundo* on river form and process are expected to similar to those observed in the Santa Margarita River here. It should be noted that Reach 2 is very long (8 mi), equaling the length of 3-5 reaches on the San Luis Rey or Santa Margarita. Impacts to reaches 1 and 2 total 10 miles, and this is most of the broad floodplain on the river.

Table 5-1.17. Santa Ana River *Arundo* impact scores.

Reach	Reach length (mi)	*Total Score*	*Arundo* Impact Scores				
			Width Ratio	*Arundo* Coverage	Floodplain Width	Bed Slope	Other Features
1	3.16	***5***	2	0	1	1	1
2	12.17	***4***	0	3	1	0	0
3	2.08	***-1***	-1	0	-1	1	0
4	2.35	***0***	-1	0	1	0	0
5	9.67	***0***	-1	0	0	1	0
6	3.98	***-2***	-1	0	-1	0	0
7	3.44	***-1***	-1	0	n/a	n/a	0

5.1.5.6 Application of Scoring System

The scoring system proposed above is preliminary and might be modified based on experience and further analyses of river response to *Arundo* infestation by adjusting scoring or weighting of the different scores. At this time, the scoring system can be used to identify and rank those river reaches where *Arundo* establishment is likely to have significant effects on river hydraulics, sediment transport and morphology. This could be used to prioritize areas for additional monitoring to look at: flood risk damage (bridges and overbank), sediment retention and loss, as well as setting control priorities and/or temporary reduction of vegetation to maintain flows.

5.1.6. Conclusions and Recommendations

The overall goal of this study was to describe the potential effects of *Arundo* establishment and growth on the hydraulics, sediment transport characteristics and morphology in Southern California Rivers. The study results are based on literature review, GIS analysis of river and floodplain vegetation characteristics, and hydraulic modeling of four floodplain vegetation scenarios on the Santa Margarita River.

Arundo is a highly aggressive, non-native plant species that has invaded riparian areas and floodplains of the sandy, braided Southern California Rivers, displacing native plants and degrading habitats. These historically braided and laterally unstable channels are transformed by *Arundo* into narrower, more laterally stable single thread channels with root-stabilized, steep banks. Inspection of historical air photos suggest that there has been much less channel widening from recent large floods than occurred earlier, presumably because of the replacement of native floodplain vegetation with much denser *Arundo* stands. In any event, it appears that if sufficient soil moisture is available *Arundo* will out-compete native vegetation on the disturbed floodplains and re-establish mature stands on much of the floodplain in the time interval between very large floods.

Plant colonization stabilizes bar and floodplain surfaces, increasing channel roughness and sediment trapping efficiency, thereby creating a mechanism for further sediment capture, deposition and vertical accretion. Long-term observed rates of vertical accretion on the floodplain vary widely in the reported literature but are as high as 0.8 ft/yr. Several feet may accumulate locally during a large flood.

Accretion rates likely vary with the volume of sediment in transport as well as the specific river conditions. There may be an upper limit on vertical accretion, which would about correspond to the elevations of typical floods. This may be reached fairly soon if the channel bed incises or does not accrete as rapidly as the floodplain. If the channel bed fills as the floodplain accretes, this limit may not be reached for a long time. Human modification to upstream and downstream reaches (such as levees or bridges) and to flood flows and sediment supply (such as by reservoir construction or groundwater recharge) may alter river and *Arundo* establishment processes and affect the above observations on river response to *Arundo* establishment and growth.

Hydraulic modeling and field inspection suggests that the mature *Arundo* stands essentially eliminate flow conveyance during low and moderate floods on the portions of the floodplain that they occupy, increasing the portion of the flow passing through the low flow or active channel. During large peak flows, when water levels are about 5 feet higher than the floodplain surface, flow that is conveyed over the mature *Arundo* stands also slows as considerable roughness is created by the stems and leaves. During very large flow events, the *Arundo* rhizomes and stems may be carried downstream, substantially altering local resistance to flow. Modeling of different floodplain vegetation scenarios suggested that the conversion from native vegetation to complete coverage by mature *Arundo* stands has three important implications. First, 100-year water levels are raised by the increased roughness. Second, the portion of the total discharge carried in the main channel increases and, thus, depths and velocities for a particular return period flood. Third the conveyance on the floodplain is much less. The hydraulic model does not include morphologic change that results from the altered depths and velocities and these may eventually mute the increases in water levels during floods.

There are some interesting subtleties suggested by the hydraulic modeling. First, there appears to be a threshold for *Arundo* coverage before there are significant effects on hydraulics. The exact portion of the floodplain that must be occupied for a significant effect is not fully understood. Second, the threshold for observing significant effects and the percentage increase in velocities and sediment transport capacity in the main channel seems to depend on the ratio of the main channel width and floodplain width. Where the channel is wide relative to the floodplain, there is less effect on velocities and sediment transport capacity for a particular flood than where the channel is narrow compared to the floodplain. This is thought to occur because there is less conveyance on the narrower floodplains compared to the main channel, so there is a smaller increase in flows in the main channel when *Arundo* coverage is complete and conveyance on the floodplain is reduced.

The results of the hydraulic model studies are limited because they do not account for the channel adjustments that are likely to occur rapidly in response to the altered hydraulics on the floodplain and in the main channel. Stream power calculations, which were adopted as a proxy for sediment transport, show greatly increased stream power in the main channel and greatly reduced stream power exerted on the floodplain under complete *Arundo* coverage, when compared to native vegetation, and a smaller increase and smaller decrease for partial coverage (Scenario 4). The consequences of the changes in stream power when banks are less erodible because of *Arundo* establishment are expected to be increased depths in the main channel and sediment trapping and accretion on the floodplain and in overbank areas. Regime considerations suggest that channel depths should increase to accommodate frequent floods, as compensation for the narrowed channel. Part of this increase may result from higher floodplain elevations rather than from channel incision or bed lowering.

Both channel responses described above change the sediment storage in the project reach on the Santa Margarita River and potentially affect the delivery of sediment from the upper watershed to downstream reaches and the Pacific Ocean. Considering the sediment balance for sand, and basing accretion rates on those observed in the literature, it appears that the trapping of sand on the floodplain in *Arundo* stands is large compared to the inflow from the upper watershed. The trapping on the floodplain may be partly compensated by erosion of the stream bed to accommodate flood flows with the narrower channel but this gain to downstream reaches appears to be considerably smaller than the trapping on the floodplain. These conclusions are also appropriate for the Santa Ana and San Luis Rey Rivers but different ones might be drawn for rivers with much wider or much narrower floodplains, or those where channel filling or other conditions allows extensive floodplain accretion. In the long-term, as accretion on the floodplain slows, the sand transported out of the study reaches will return to being about equal to the supply from the upper watershed.

Based on the above results, the study developed a qualitative scoring system that can be applied to measured river and floodplain vegetation characteristics to identify those reaches where significant impacts on river processes may occur. Total scores that reflect potential *Arundo* impacts were developed by summing scores for the ratio of low flow channel width to floodplain width, the percentage of *Arundo* on the floodplain and the changes in floodplain width and channel slope from one reach to the next downstream one. The scoring system was reasonably consistent with the modeled hydraulic impacts on the Santa Margarita River and thus was thought to be appropriate for the Santa Ana and San Luis Rey Rivers.

Application of the scoring systems suggests that impacts on river form and process are less significant in the Santa Ana and San Luis Rey Rivers than in the Santa Margarita River project reaches, with the possible exception of Reach 2 of the Santa Ana River.

While the scoring system is preliminary it provides a simple procedure to identify those reaches where the riverine response to *Arundo* infestation may be most severe and also provides a useful tool to identify those reaches where monitoring may be concentrated.

5.2 Geomorphology and Hydrology: Spatial Analysis

5.2.1 Arundo's Distribution Within Geomorphic Forms

5.2.1.1 Methods

Geomorphology Attributes and Methods

Methods used to delineate floodplain geomorphic forms involved visual interpretation of imagery and topological data within a GIS. Due to time constraints and budget, groundtruthing and follow-up field *surveys were not possible at this time. Guidelines for defining geomorphic forms were based on the Riparian Ecosystem Restoration Plan for the Otay River Watershed (Army Corps of Engineers 2006) and consultations from staff at NHC.* Issues involving criteria for delineating terraces within the floodplain and the subjectivity of this classification was thoroughly discussed. Considering the subjectivity, several rounds of sample data and images were reviewed to determine the efficacy in characterizing geomorphic forms for each analysis. The most recently available imagery was used for each watershed.

San Luis Rey was used as a test case to work through the methodology. Other watersheds were completed after an approach was established. Using base imagery from ESRI, Google Earth, and Bing 3D pictometry (where available), areas of interest were reviewed to develop visual recognition of the potential terrace structures. Additionally, several sample locations and field photos taken by the analyst previously from the *Arundo* field mapping exercise were used to further visually train the analyst in the separation of terrace forms. A significant number of images were gathered including several panoramas of the river valley that illustrate elevation changes.

The mapping delineation always started within the low flow channel and built out from this classification using the *Auto-Complete Polygon* tool in ArcGIS. The digitization was completed at a scale of 1:5,000. The following classifications (as described in Section 5.1.3.3) were selected:

- *Low Flow Channel* – The part of the main channel where water was flowing at the time of the aerial photos. In those cases where the riverbed is dry, the area appearing to have the most recent flows were delineated as low flow.
- *Bar / Channel / Floodplain - unvegetated* – Main channel or floodplain areas with less than 50% vegetation cover, usually consisting of bar surfaces, dry channel beds, or recent deposition or scour.
- *Floodplain - vegetated* – Areas on the river floodplain with more than 50% vegetation cover.
- *Floodplain / Low Terrace – vegetated* – Areas on either the river floodplain or an adjacent low terrace with more than 50% vegetation cover.
- *Upper Terrace - vegetated* – Areas on higher ground adjacent to the low terraces with more than 50% vegetation cover. This classification was rarely used in part because nearly all of the upper terrace areas on most rivers had been leveed or developed. The mapping did not go beyond levees or roads in most cases. In some specific areas where there were *Arundo* records, the levee sides were marked using this category. Hillslopes were typically not tagged unless they were surrounded by an apparent floodplain or if *Arundo* was present.

Terraces edges were extremely subjective because the field verification was not feasible and high-resolution elevation data was not available for all areas. One of several visual cues used to help delineate between terraces was based on the type and amount of vegetation present (USACE ref.).

There were instances where the imagery used to map geomorphology (usually 2006) did not match the same time period in which *Arundo* was mapped. These temporal mismatches caused alignment problems when *Arundo* stand mapping was compared to geomorphology mapping. Initial mapping/analysis placed large historical stands of *Arundo* in what are now the main low flow channel or sand bars. But in the time period when the *Arundo* stands were present, these areas were floodplain. The two rivers with the largest number of mismatched data were the San Luis Rey and Santa Margarita, which have had significant *Arundo* control. Both rivers had mapping data from the late 1990's and early 2000's reflecting areas that were controlled. Therefore, select geomorphic records were altered to match their historical form based on imagery that matched the mapping date of the *Arundo*. *Arundo* removal on the Santa Margarita has influenced the river channel geomorphology to change course and in many cases it allowed the river to revert back to having more open bars and seasonal channels.

5.2.1.2 Results

The area of interest (AOI) covers the six most *Arundo* invaded watersheds within the study area. This represents 77% of the gross *Arundo* acreage calculated for the entire study area (Figures 5-2.1 & 5-2.2). Since these are the most invaded areas, it is important to examine the distribution of *Arundo* within geomorphic forms found in the riparian zone.

The overall level of *Arundo* invasion for the AOI was 13% cover of the riparian zone (all geomorphic forms) (Figure 5-2.3, Table 5-2.1). Invasion levels of *Arundo* ranged from 8% to 16% cover for the AOI on the watersheds examined. There seem to be two levels of invasion on these large, broad watersheds: a higher level of 12-18%, and a lower level of 8-9%. Individual reaches within a riparian system can have much higher *Arundo* cover. Highly invaded reaches on Santa Ana and Santa Margarita had invasion levels >40%. Establishing a 'peak level' of invasion over large areas is difficult to assess, but an upper range of 40-45% seems plausible (as the Santa Margarita River illustrates – Section 5.1).

An examination of *Arundo*'s distribution across geomorphic forms reveals that *Arundo* is relatively absent from the low flow channel (Figures 5-2.4 & 5-2.5, Tables 5-2.2 & 5-2.3). If *Arundo* was evenly distributed across geomorphic forms in proportion to a geomorphic class's acreage, it would have a distribution shown in Figures 5-2.6 to 5-2.11. There is less *Arundo* on all watersheds in the channel areas than would be predicted. This represents the high energy and dynamic riparian zone that has flows every year. Establishment and persistence of *Arundo* is difficult and little *Arundo* acreage (52 acres or 1.5%) of this form is invaded. Each watershed's geomorphic structure is shown in Figure 5-2.4 and Table 5-2.2 to allow examination of which forms dominate each system.

The bar/channel zone also has low cover of *Arundo* (102 acres of 6,575 acres, or 1.5 %). Much lower cover is present on each watershed than would be predicted if an even distribution of *Arundo* occurred (Figures 5-2.5 to 5-2.10). This is an active portion of the riparian floodplain with little vegetation, so it would be expected to have low cover of *Arundo*.

Most *Arundo* acreage is found in the floodplain and low terrace geomorphic forms (Figure 5-2.3, Tables 5-2.2 & 5-2.3). Floodplains have consistently high levels of invasion with an average of 19.7. As presented by watershed, *Arundo* cover exceeds predicted levels of distribution on all six watersheds (Figures 5-2.5 to 5-2.10). This is an important observation, as high *Arundo* cover in this geomorphic form tends to lock the low flow channel in a set location (Section 5.1).

Low terraces were also found to have high *Arundo* cover, averaging 15.4% (Table 5-2.3). Observed acreage was equivalent to, or higher than what would be predicted if an even distribution of *Arundo* occurred on most, but not all systems (Figures 5-2.5 to 5-2.10). Lower terraces, as a geomorphic form, vary significantly in acreage between watersheds (Figure 5-2.4, Table 5-2.2). Salinas and Santa Margarita have a significant proportion of this form, while Santa Ana has little. This is reflected in the *Arundo* acreages found on low terraces within these systems. Santa Clara is distinctly different due to a very low proportion of floodplain and terrace acreage. However, the floodplain and terrace acreage that does occur within a system is highly invaded with *Arundo*. Floodplain and low terrace geomorphic forms are a subjective distinction. These are essentially the more stable portions of the floodplain. They could be combined, but separating them helps characterize different watersheds.

Upper terraces comprise a small proportion of overall geomorphic composition for most watersheds (Figure 5-2.4, Table 5-2.3). Many of these areas have been developed or modified and are no longer part of the riparian system (examined in section 5.2.2). Where upper terraces do exist, they have a lower proportion of *Arundo* acreage than would be predicted if *Arundo* were evenly distributed. This is likely a result of the high elevation, which makes establishment and persistence of *Arundo* less common than the more hydrologically favorable floodplains and lower terraces

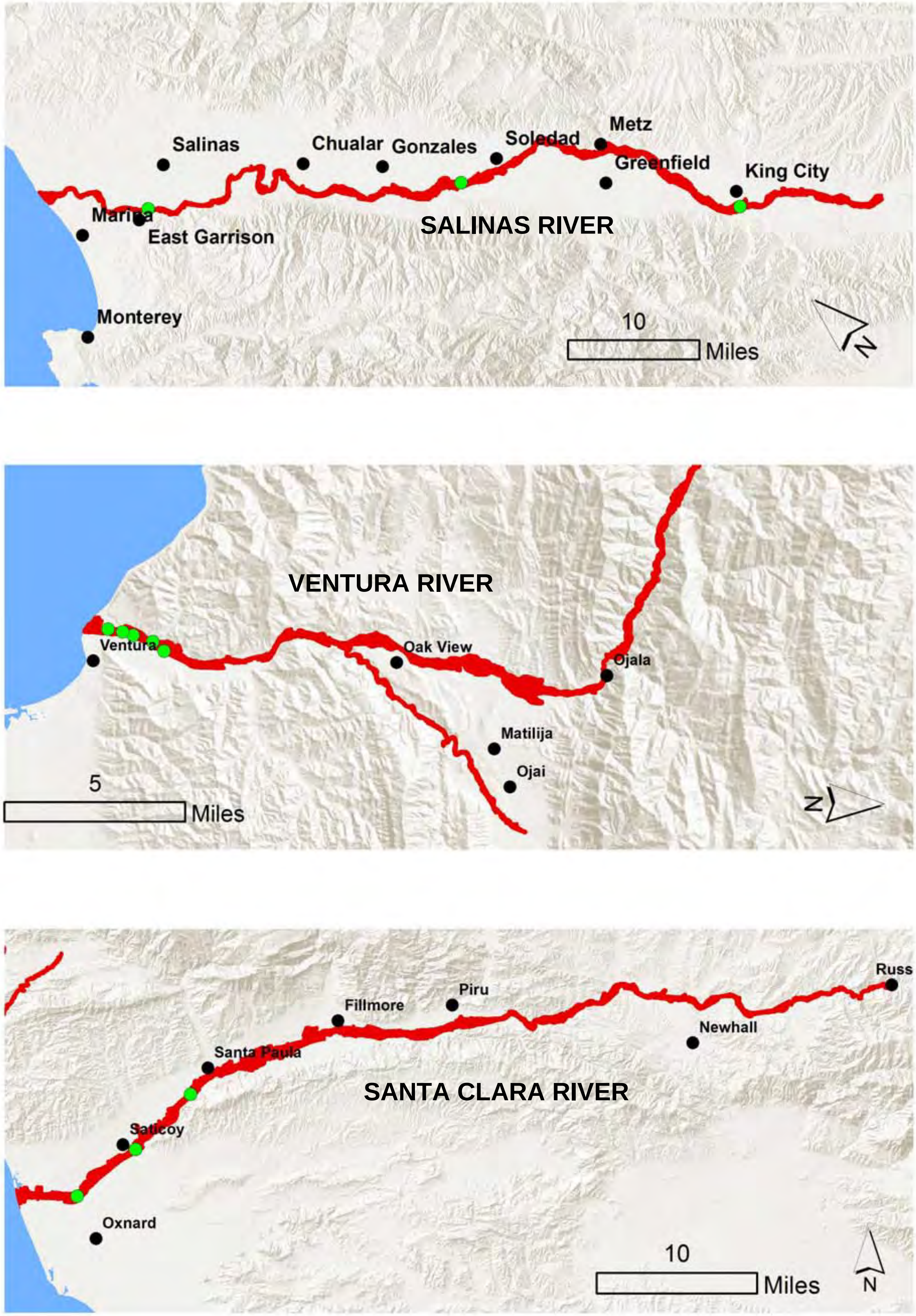


Figure 5-2.1. Location of the Area of Interest and cross-sections (northern watersheds).

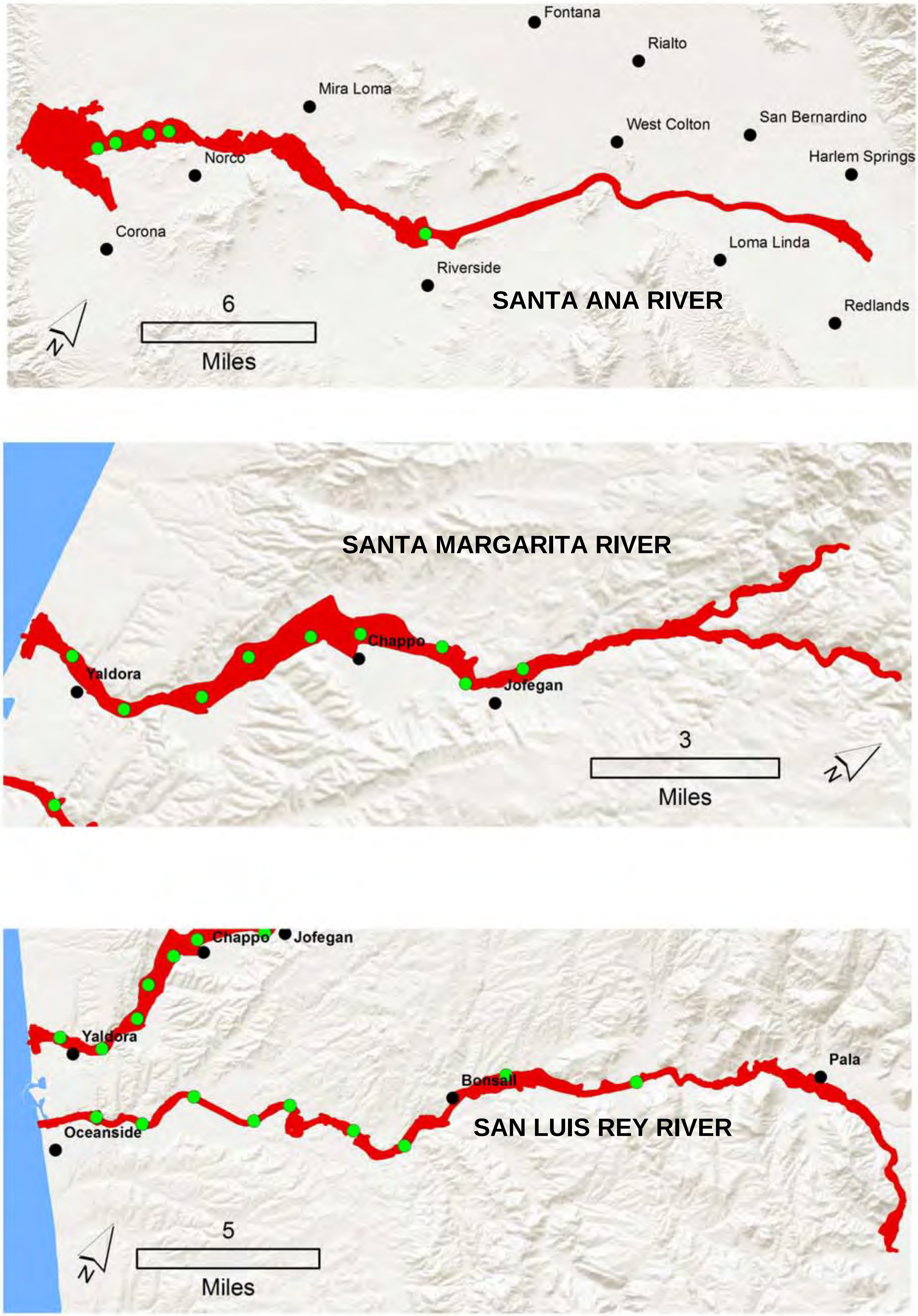


Figure 5-2.2. Location of the Area of Interest and cross-sections (southern watersheds).

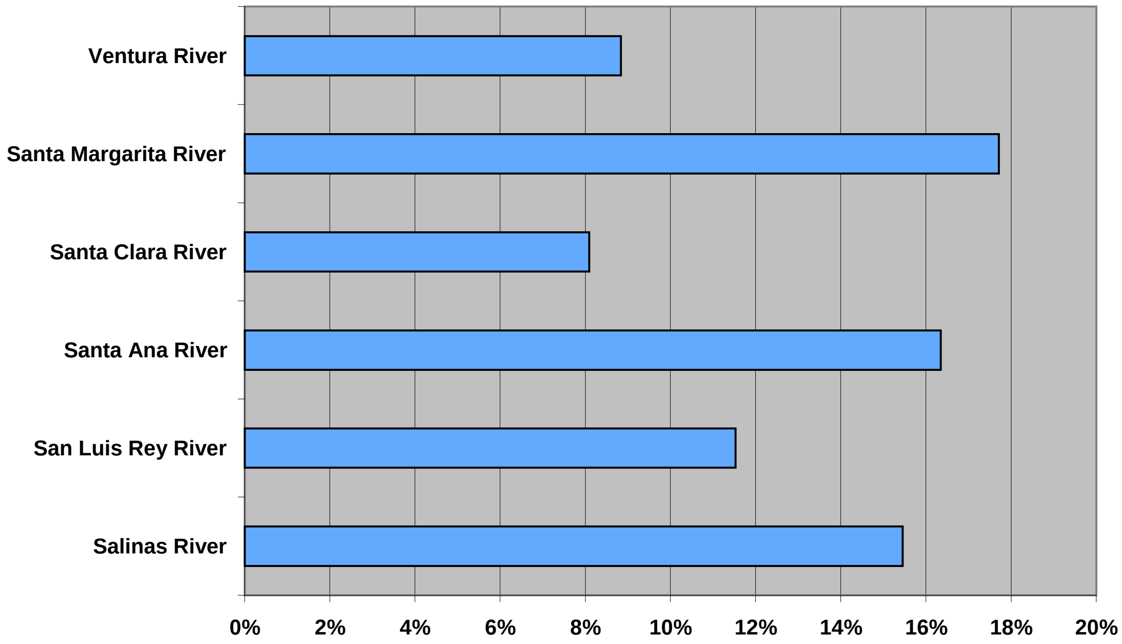


Figure 5-2.3. *Arundo* acreage as a percent of system acreage within the Area of Interest (AOI).

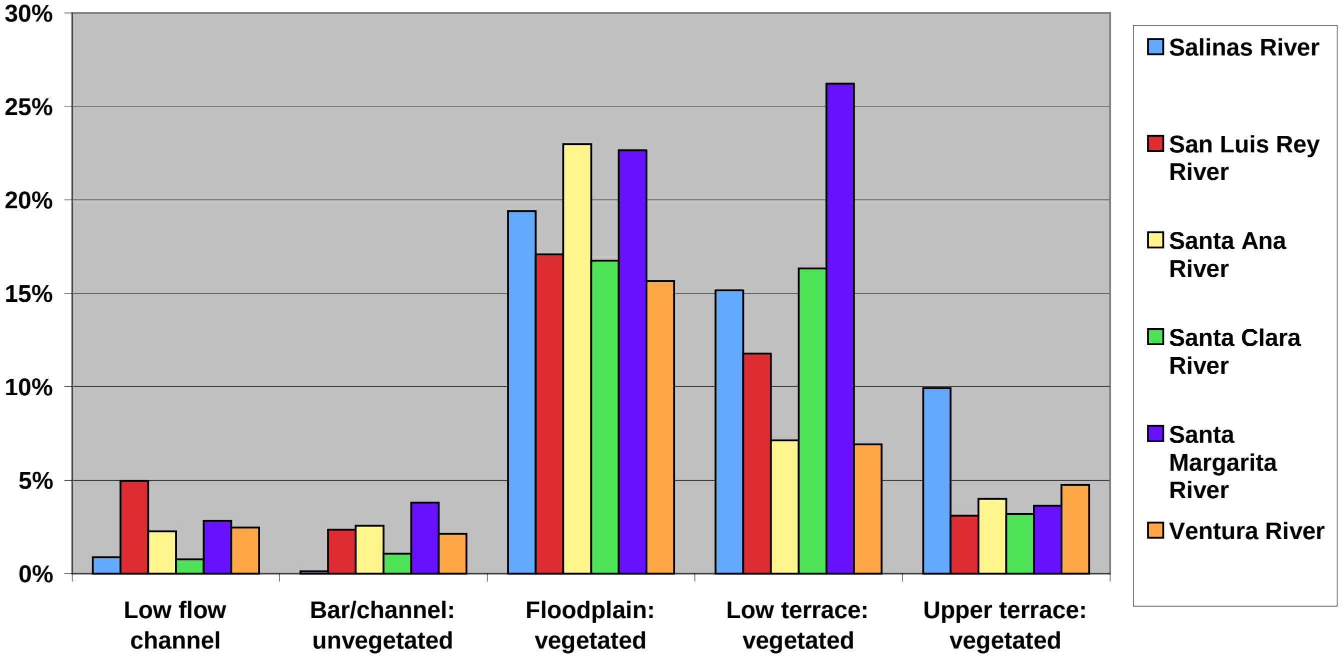


Figure 5-2.4. Percent of geomorphic form invaded by *Arundo* for the Area of Interest (AOI). This shows that the highest levels of invasion are in the floodplain and low-terrace geomorphic forms, regardless of the acreage of the geomorphic form itself.

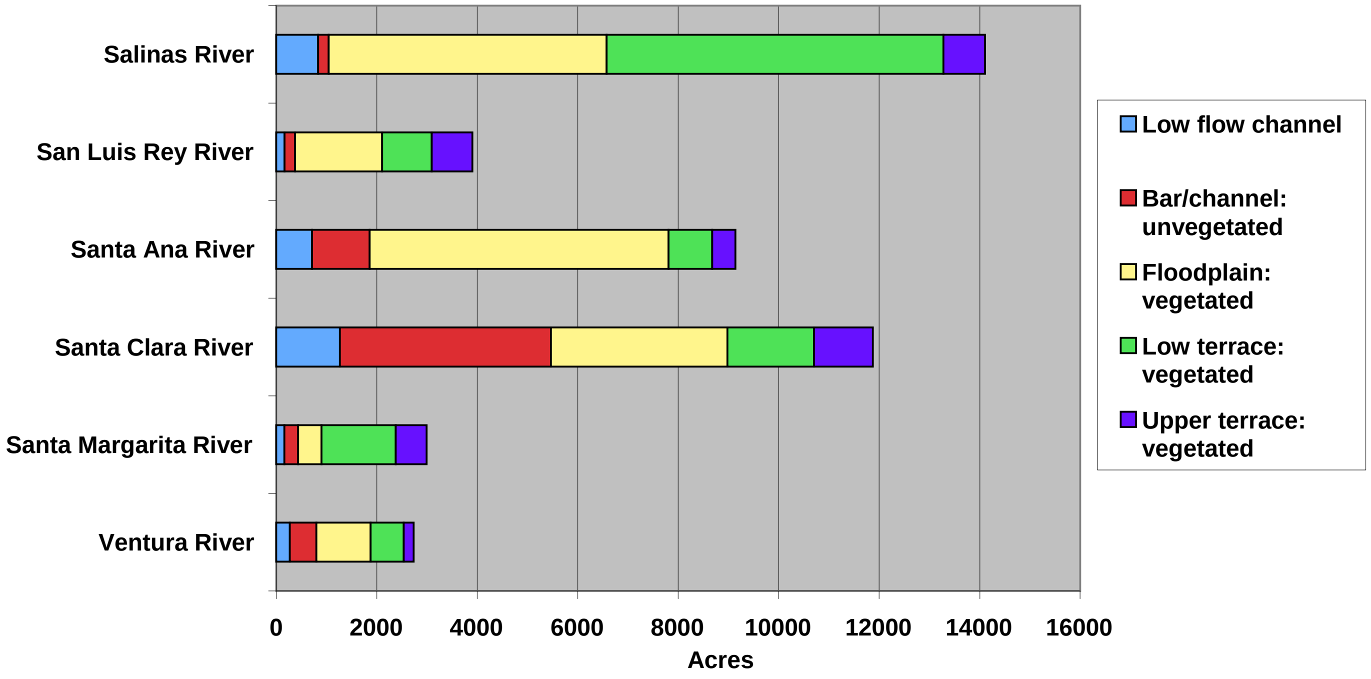


Figure 5-2.5. Acreage of geomorphic forms mapped within the Area of Interest (AOI). This shows that the floodplain and terrace forms dominate most systems (within the AOI).

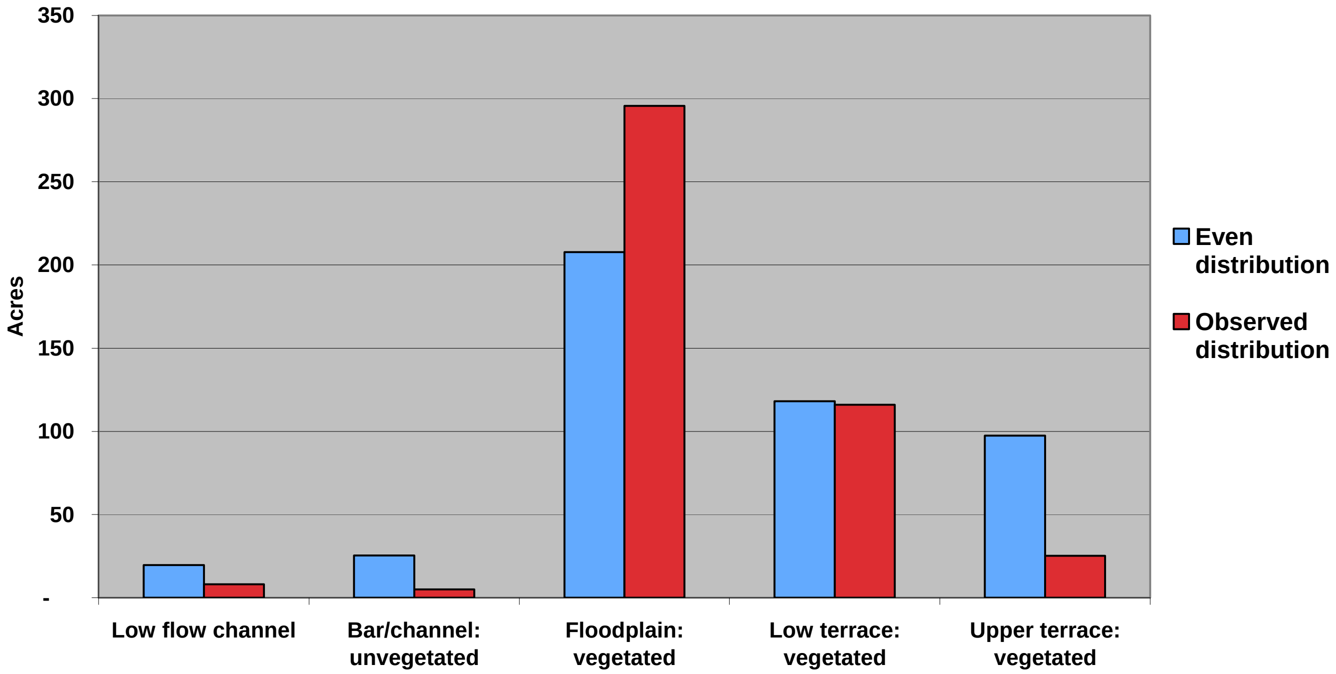


Figure 5-2.6. Observed and expected even distribution of *Arundo* acreage on the San Luis Rey watershed by geomorphic class.

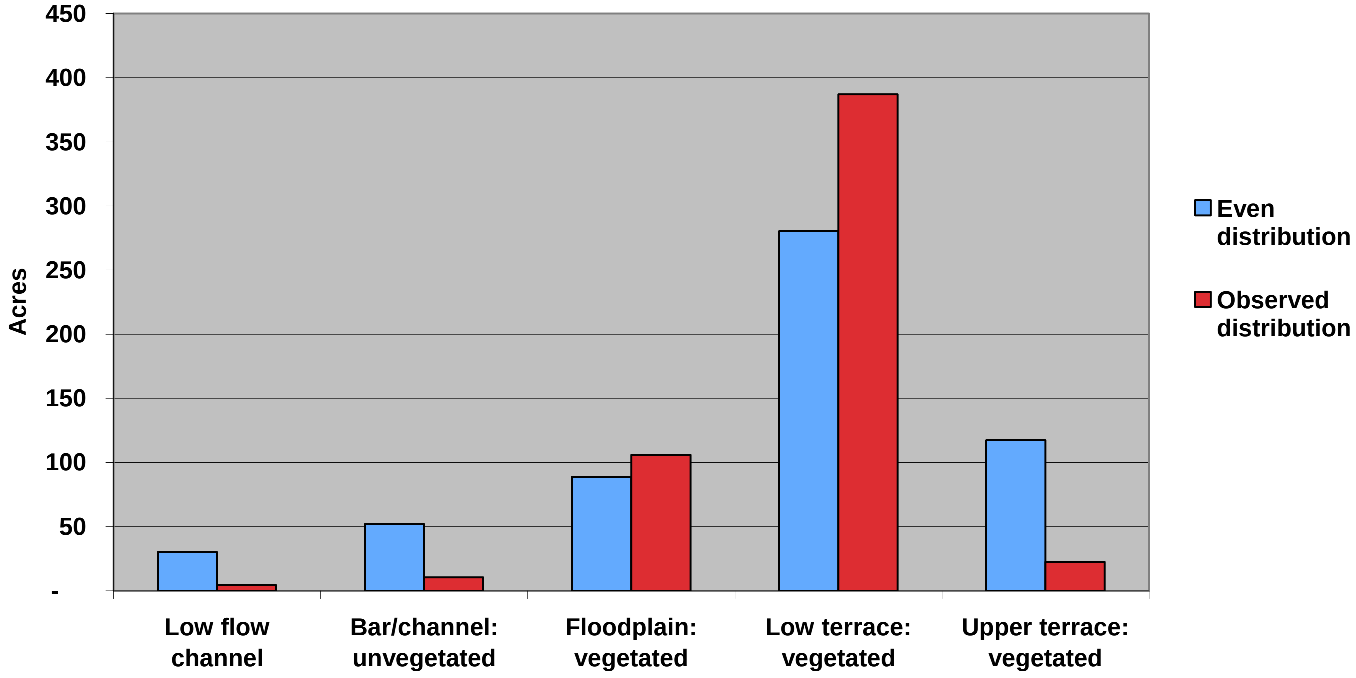


Figure 5-2.7. Observed and expected even distribution of *Arundo* acreage on the Santa Margarita watershed by geomorphic class.

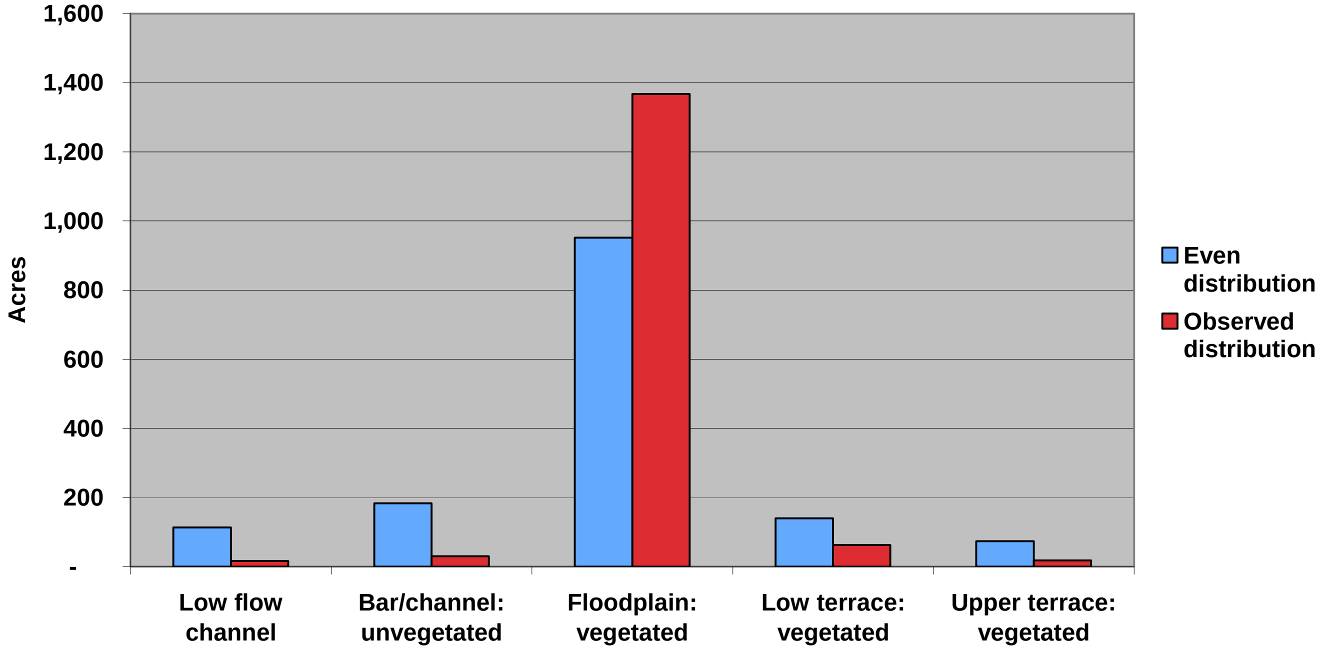


Figure 5-2.8. Observed and expected even distribution of *Arundo* acreage on the Santa Ana watershed by geomorphic class.

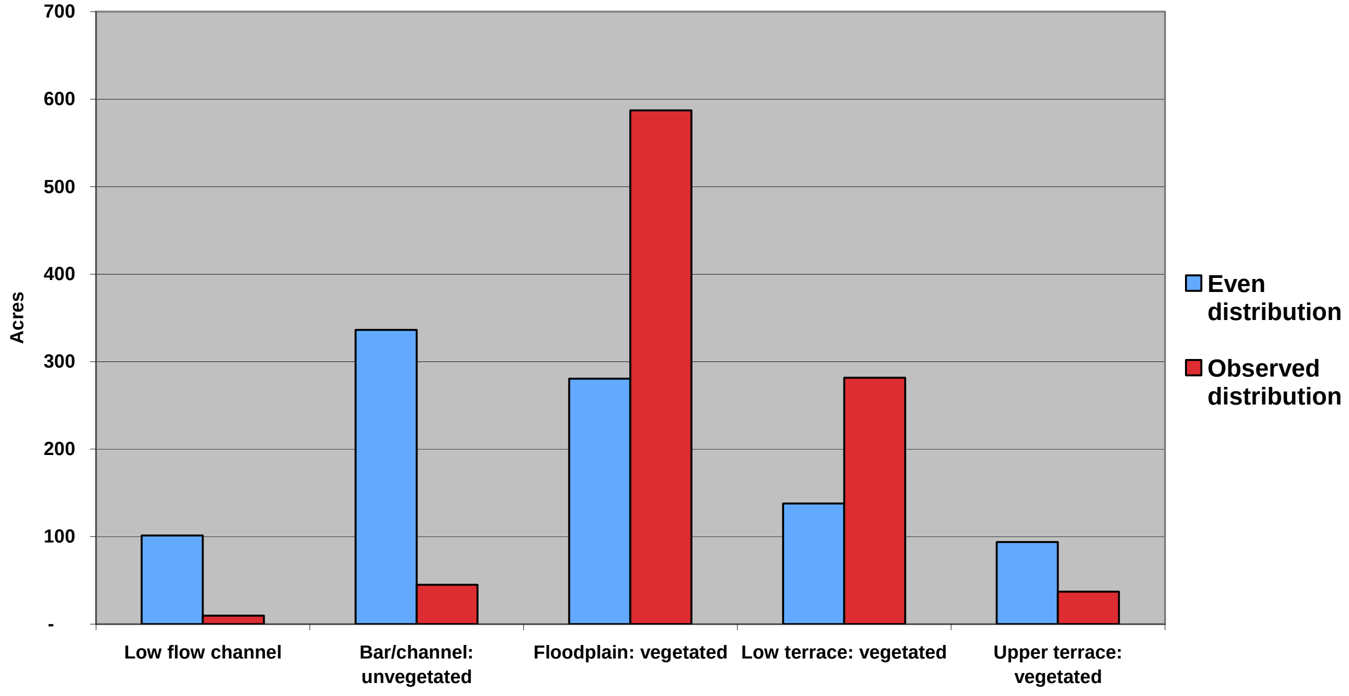


Figure 5-2.9. Observed and expected even distribution of *Arundo* acreage on the Santa Clara watershed by geomorphic class.
Santa Clara has much more low flow channel and bar/channel than the other systems.

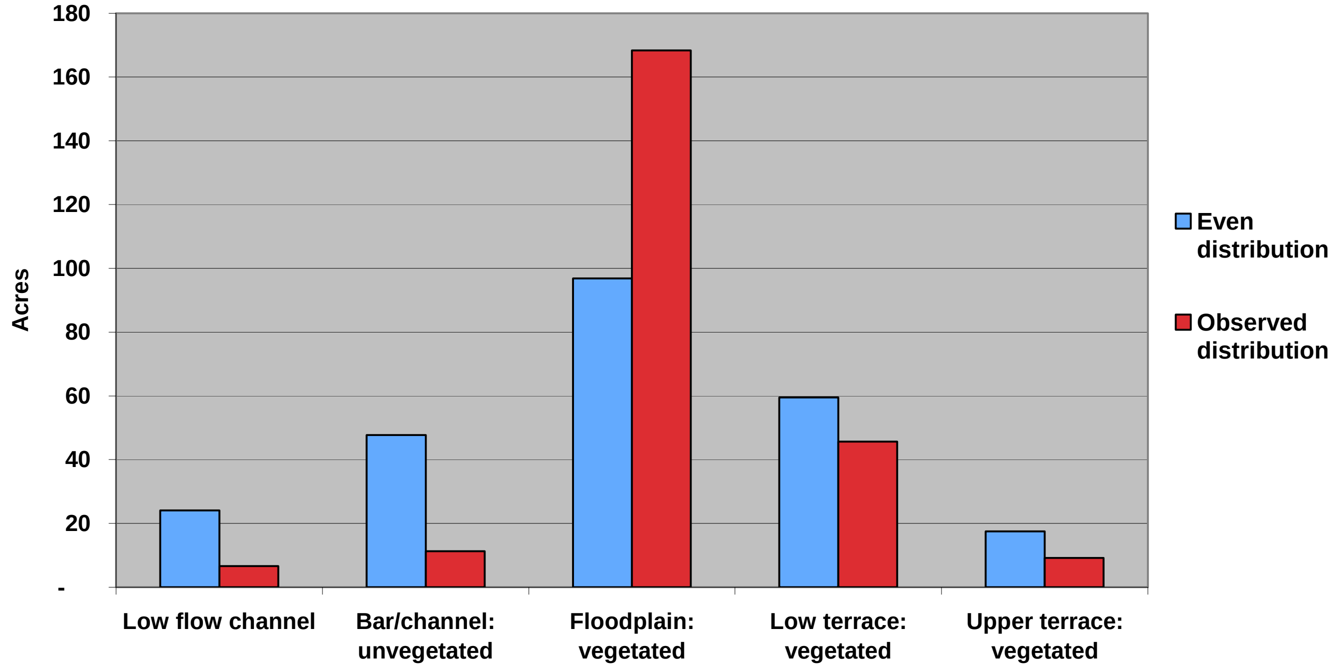


Figure 5-2.10. Observed and expected even distribution of *Arundo* acreage on the Ventura watershed by geomorphic class.

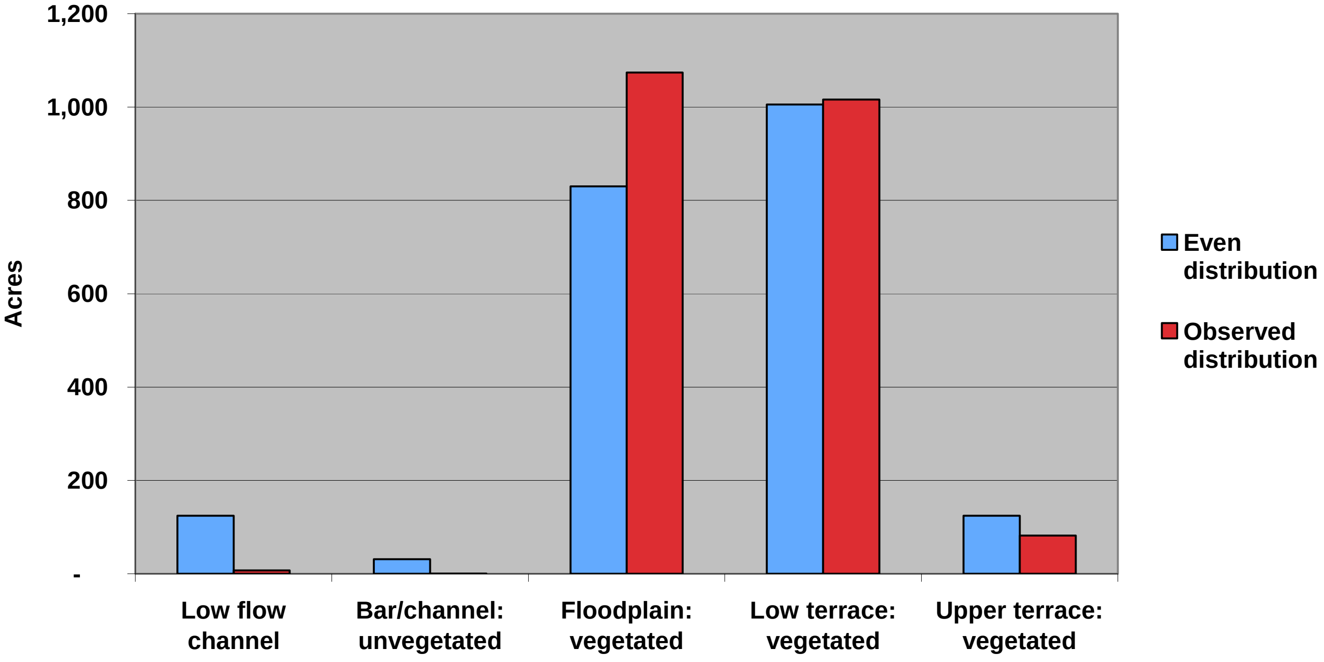


Figure 5-2.11. Observed and expected even distribution of *Arundo* acreage on the Salinas watershed by geomorphic class.

Table 5-2.1. *Arundo* and geomorphic acreage within the Area of Interest (AOI) for six selected watersheds.

Watershed (AOI area only)	***Arundo* Gross Acres**	***Arundo* Net Acres**	**Geomorph Acres[1]**	***Arundo* ac % system (net)**
Salinas River	2,845	2,180	14,105	15%
San Luis Rey River	450	450	3,903	12%
Santa Ana River	1,674	1,493	9,136	16%
Santa Clara River	1,011	961	11,874	8%
Santa Margarita River	530	530	2,994	18%
Ventura River	321	241	2,730	9%
Total:	**6,831**	**5,855**	**44,741**	**13%**

[1] Geomorph areas: the acreage where geomorphic form was mapped within the AOI.

Table 5-2.2. *Arundo* and geomorphic class acreage within the AOI of six selected watersheds.

Watershed (AOI only)	**Geomorphology Class**	***Arundo* Gross Acres**	***Arundo* Net Acres**	**Geomorph Gross Acres**	**% of geo class w/ *Arundo***
Salinas River	Low flow channel	8	7	829	1%
Salinas River	Bar/channel	0.4	0.3	209	0%
Salinas River	Floodplain	1,476	1,074	5,535	19%
Salinas River	Low terrace	1,269	1,016	6,704	15%
Salinas River	Upper terrace	92	82	828	10%
San Luis Rey River	Low flow channel	8	8	164	5%
San Luis Rey River	Bar/channel	5	5	211	2%
San Luis Rey River	Floodplain	296	296	1,731	17%
San Luis Rey River	Low terrace	116	116	984	12%
San Luis Rey River	Upper terrace	25	25	812	3%
Santa Ana River	Low flow channel	20	16	709	2%
Santa Ana River	Bar/channel	76	30	1,146	3%
Santa Ana River	Floodplain	1,492	1,367	5,948	23%
Santa Ana River	Low terrace	67	62	873	7%
Santa Ana River	Upper terrace	20	18	459	4%
Santa Clara River	Low flow channel	13	10	1,266	1%
Santa Clara River	Bar/channel	52	45	4,204	1%
Santa Clara River	Floodplain	624	587	3,506	17%
Santa Clara River	Low terrace	286	282	1,726	16%
Santa Clara River	Upper terrace	37	37	1,173	3%
S. Margarita River	Low flow channel	4	4	158	3%
S. Margarita River	Bar/channel	10	10	274	4%
S. Margarita River	Floodplain	106	106	468	23%
S. Margarita River	Low terrace	387	387	1476	26%
S. Margarita River	Upper terrace	22	22	618	4%
Ventura River	Low flow channel	10	7	267	2%
Ventura River	Bar/channel	21	11	530	2%
Ventura River	Floodplain	228	168	1,076	16%
Ventura River	Low terrace	52	46	661	7%
Ventura River	Upper terrace	9	9	194	5%
	Total:	**6,831**	**5,855**	**44,741**	**13%**

Table 5-2.3. *Arundo* and geomorphic class acreage for the entire AOI (all seven watersheds).

Geomorphologic Class	*Arundo* Present: Gross Acres	*Arundo* Present: Net Acres	Geomorphology Mapped (Current Day): Gross Acres	% *Arundo* (Net)
Low flow channel	63	52	3,393	1.5%
Bar/channel	165	102	6,575	1.5%
Floodplain	4,221	3,598	18,263	19.7%
Low terrace	2,176	1,909	12,424	15.4%
Upper terrace	206	195	4,085	4.8%
Total:	**6,831**	**5,855**	**44,741**	**13.1%**

5.2.1.3 Discussion

The most important observation is that *Arundo* has high cover in the floodplain and low terrace geomorphic forms, and low cover in the low flow and bar/channel forms, within each of the six systems examined. Given that *Arundo* has a similar distribution across geomorphic forms on all systems, it is likely that similar mechanisms are at play in the systems. It is also likely that *Arundo* is having the same impacts associated with its presence in floodplains. This is important in that it makes observations from the specific case study of the Santa Margarita River (section 5.1) applicable to other systems in the study area.

Arundo's ability to form dense monotypic stands on floodplains in all of the major systems within the study area is likely having significant impacts to channel form, channel depth, flow conveyance, and sediment transport, as well as putting infrastructure at risk. *Arundo*'s impacts on these abiotic processes has biotic impacts as well by affecting habitat for flora and fauna. The documented abundance of *Arundo* within systems, and its higher growth within specific geomorphic forms, helps to demonstrate that impacts to organisms are also transferable from system to system.

Reproductive strategies used by *Arundo* are strongly reflected in distribution data by geomorphic form. Channel and bar areas are too dynamic to sustain plant survival, growth and establishment. Floodplain and low terrace are optimal, with favorable hydrology and less frequent flow events that would remove newly established plants. Upper terraces only periodically receive reproductive material (rhizome fragments), and hydrology is not optimal for their establishment and survival.

Understanding geomorphic composition and *Arundo* distribution would be aided by a historical evaluation of geomorphic forms over time, as well as an examination of vegetation cover. It would be useful to know if current geomorphic form and vegetation condition are comparable to past conditions.

5.2.2 Geomorphology Historic Analysis

In the previous section, the distribution of *Arundo* within geomorphic forms was examined using recent or current conditions within the AOI. The current acreage of geomorphic forms within each river system was also given. But acreage and proportion of geomorphic forms is not set as they respond to flood events and human activities. This chapter section will examine how each watershed's geomorphology has changed over time, using historic air photos and cross-section based-data. In addition to change in geomorphic class, we will also examine the abundance of woody vegetation (open versus dense) within the floodplain and lower terrace areas. This will help characterize the hydrology of the system over time.

5.2.2.1 Methods

To quantify the changes in the river systems over time, a historical cross-section analysis was undertaken. Historic photography was aggregated from the UCSB Library, HistoricAerials.com, Google Earth, CaSIL (California Spatial Information Library) and the USGS. For each river system, the availability of imagery was evaluated on the range of years and reaches of the river where imagery timeframes overlapped. The number of photos was narrowed down to have optimal time differences of 10-15 years between samples, and equal distribution across as much of the river's extent as possible (where *Arundo* occurred). The San Luis Rey River had the widest array of images available by both area and year. Image availability dictated the extent of areas available for analysis on each river. Cross-section locations were at times determined by limited imagery coverage overlap on rivers, other than the San Luis Rey and Santa Margarita. Within each area of imagery coverage, a cross-section was digitized into the GIS (Figures 5-2.1&2). These areas were selected based on: a) the earliest available imagery showing a floodplain that was not naturally constrained by a narrows or other impediment, and b) when possible, level distribution across the full extent of the available imagery time sequence. Each cross-section was drawn perpendicular to the current channel. The length of each cross section was determined by where the upper terrace of the floodplain ended on both the oldest and most recent imagery (Figures 5-2.12&13). This takes into account flood events that eroded bluffs or hillslope in the intervening years. Cross-sections were opportunistically placed at locations along the river where: a) *Arundo* was abundantly present, b) the area was representational of changes over time, and c) cross-sections being perpendicular to the current channel line would not create a diagonal in the historic floodplains, as this would amplify any constriction or expansion of the river. Random or equidistant placement may have put cross-sections in areas that had little change due to geomorphic landform constraints like a narrows.

With the cross-section lines in place, the historical imagery was then georeferenced. Spatial inaccuracies may occur where ground control was not easily identifiable. It should also be noted that imagery varied in scale, which may affect the spatial and attribute accuracy of the interpretation. Each digitized cross-section was duplicated for each year of imagery. Using a scale of 1:3,000, the length of the line was split into pieces as it crossed each geomorphic form in the photo. Because linear cross-sections were used in place of generalized polygons[2], a higher level of detail was captured in the fluvial landforms. For instance, the polygon interpretation methodology (used to delineate current-day geomorphology) may broadly group a mixture of bare sand and scrub as one class *(Bar/Channel:Unvegetated),* while the cross-section method broke those same strips of bare sand and scrub into separate classes (*Bar/Channel:Unvegetated* and *Floodplain:Vegetated*). This level of detail was captured in an attempt to keep the mapping consistent over time and limit the amount of subjectivity in the interpretation across the variety of historical imagery.

Additional classes were added to this analysis so that cross-sections were the same length for each time period and all situations of floodplain changes could be described. These added classes include:

- Floodplain Modified: sand mining, grading /channelizing of the floodplain, and agriculture fields in the floodplain that are not protected by levees.

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[2] Polygon interpretation was not feasible with the time constraints and budget available for the historical analysis.

- Levee Protected Agriculture[3]: levees may be dirt or armored with rock.
- Levee Protected Developed[3]: usually a rock-armored levee with housing, industry or airport development. On two occasions, this class includes water treatment or storage ponds.

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[3] The “Levee protected” classes do not appear in the charts because they, like the hillslope, are no longer part of the floodplain.

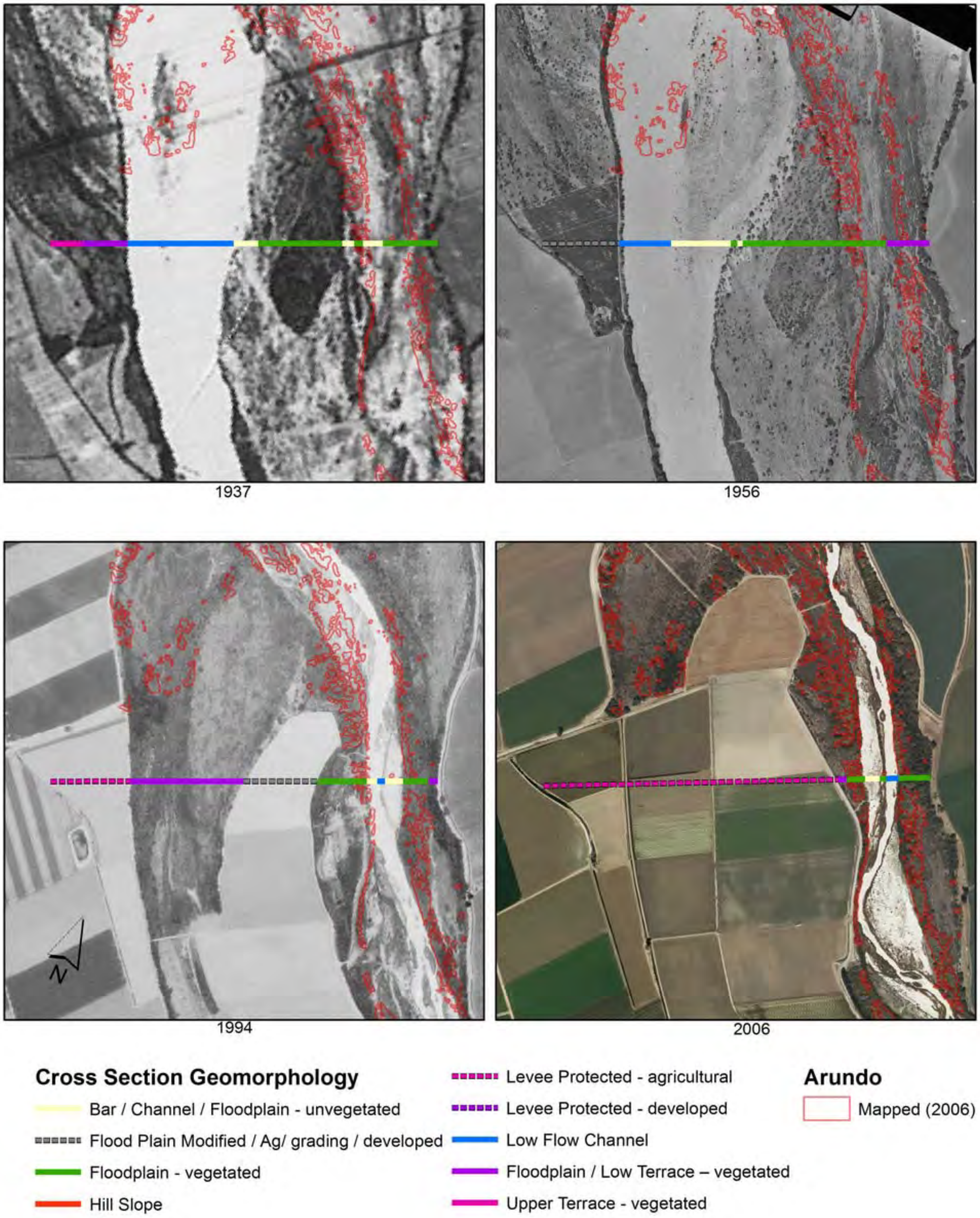

Figure 5-2.12. Cross-section geomorphology using historic aerial imagery on the Salinas watershed from 1937 to 2006.

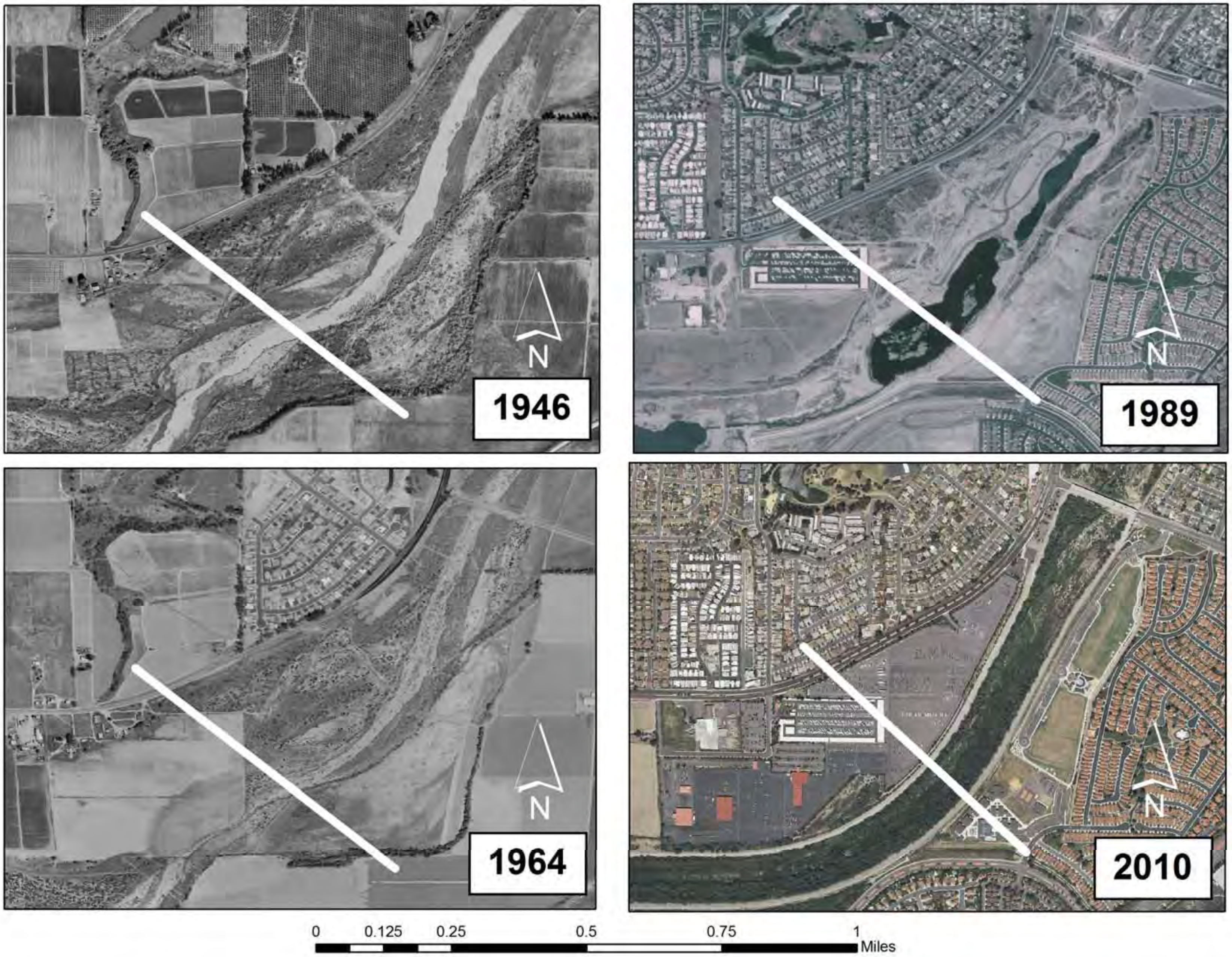

Figure 5-2.13. Historic photo analysis of geomorphic and hydrologic cross-sections on the San Luis Rey River from 1946 to 2010.

5.2.2.2 Results

There have been many changes to river systems over the past 100 years. These changes will be aggregated into two basic categories: 1) drastic increases of water in the system (from urbanization and agriculture) and 2) removal/modification of riverine areas (from development, agriculture, levees, water/flood management). High levels of water importation have transformed ephemeral riverine systems into perennial systems in southern California. This transformation occurred over time, but for the study area, this study suggests the 1960s-70s as a tipping point for most watersheds. At the same time that more water was imported and released into coastal watersheds, the functional riparian zone was reduced and modified. Use of floodplains for farming and sand mining has occurred for over 100 years. Historically these uses were not physically protected from river flows by levees and berms, so the area of activity was still functionally connected to the river. When floods occurred, these areas were inundated. However, in the 1950s and 60s permanent levees and berms were constructed in many systems. This resulted in the removal of geomorphic structure and habitat, as well as a significantly narrowing of the floodplain/riparian zone. Increased importation of water and development of riverine areas (urban or agriculture) are correlated, with both forms of development tied to increased water use.

San Luis Rey: Nine cross-sections were used. The San Luis Rey Watershed exhibited significant loss of over two-thirds of its riverine habitat from 1938 to 2010 (Figure 5-2.14). Lower and upper terraces are now nearly absent. Historic use and modification of floodplains occurred throughout the early portion of the time frame, but much of the use (agriculture and sand mining) has stopped or been permanently removed from the system. Urbanization is a significant pressure. Specifically note that open bar/channel area has drastically reduced over time (2,161m in 1938 to 175m in 2010, a 92.5% reduction; Figure 5-2.14), while floodplains are of equal, or greater, extent.

Santa Margarita: Nine cross-sections were used. The Santa Margarita Watershed has had very little riparian habitat development or permanent habitat removal. The Department of Defense manages all of the area examined in this review. This makes the Santa Margarita interesting in that is separates the two factors: loss of habitat and increased water input. As seen on the San Luis Rey, channel and bar was a large proportion of the system in 1938 (50%, 3,500m; Figure 5-2.15). A steady decline has occurred over time, and by 1997 channel/bar was 8% (of 700m) of the system. Removal of many *Arundo* stands from 1998 to 2006 may have resulted in the modest increase of channel/bar in 2010. Floodplain and terrace areas expanded from 1938 to 2010.

Santa Ana: Five cross-sections were used. The Santa Ana Watershed also had low levels of permanent development and land use change within the riverine areas of the AOI between 1938 and 2010. This is in part due to high bluffs that separate the river from upland areas. Upland areas have become highly developed, but the river bottom has not. The cessation of agriculture and sand mining activities, which was significant from the 1940's to the 1960's, has allowed most of the river to function as natural riverine areas. Trends are less clear on Santa Ana (Figure 5-2.16). Low flow channel and channel/bar areas were greatest in 1938. Ten years later they were significantly less, in part due to modification. Current and recent low flow channel and channel/bar areas are still a low proportion of the total riverine area, but it is not low as was observed on the San Luis Rey and Santa Margarita Rivers. The proportion of floodplain and terrace has been consistently high since 1980.

Ventura: Five cross-sections used. The Ventura River shows a similar pattern of permanent conversion of habitat to development and agricultural use (separated by levee) as seen on the San Luis Rey, with a 50% loss of riverine areas. Unlike San Luis Rey and Santa Margarita, Ventura has retained a large proportion of channel and bar areas (Figure 5-2.17). However, terrace areas as a class was effectively removed from the system through development and agriculture.

Santa Clara: Three cross-sections were used. The Santa Clara River has had significant development protected behind levees. The permanent land use change started as agriculture, but since 1970, it has become increasingly urbanized. Santa Clara appears to be a higher energy system than the other watersheds. A larger proportion of the system is maintained as low flow channel and bar/channel in all years (Figure 5-2.18). A slight decrease in this class has occurred, but it has been stable over the last 30 years and it is still well represented. Floodplain and terrace forms appear to be less abundant. The river has maintained open channel/bar areas, but lost floodplain and terraces, especially in comparison to 1927 and 1938.

Salinas: Three cross-sections were used. Aerial photography was difficult to obtain for the system. 1971 data is presented even though the data set was incomplete (2 of 3 cross-sections). Land use change has significantly reduced the riverine portion of the system. Protection of agriculture with levees started prior to 1971 and accelerated between 1994 and 2006. Low flow channel and channel/bar areas have decreased substantially, and the decline is linear (Figure 5-2.19). Dams have significantly reduced the riverine portion of the system. Floodplain areas are less abundant, while terrace areas have remained relatively constant.

5.2.2.3 Conclusions

Overall patterns of historical change in geomorphic forms on the six watersheds (Table 5-2.4) indicate the following:

- Significant reduction of riverine habitat (levee-protected permanent land use change) - systems are smaller (4 of 6 systems).
- A large decline of low flow channel and channel/bar (active low elevation areas) was seen on three systems.
- The retention/expansion of floodplains as a proportion of the system was observed on four of the six systems.

The long-term geomorphic changes observed on other larger river systems in the Southwest are evident on southern California coastal watersheds.

Table 5-2.4. Summary of geomorphic changes by watersheds.

Trend	San Luis Rey	Santa Margarita	Santa Ana	Santa Clara	Ventura	Salinas
Reduction in functional riverine areas	Yes >50%	No <10%	No <5%	Yes >50%	Yes >50%	Yes >50%
Reduction of low flow channel and channel/bar (in length & proportion)	Yes >70%	Yes >60%	No	Minor	No	Yes >60%
Proportion of riverine habitat that is floodplain & low terrace is stable or larger	Yes	Yes	Yes	No	No	Yes

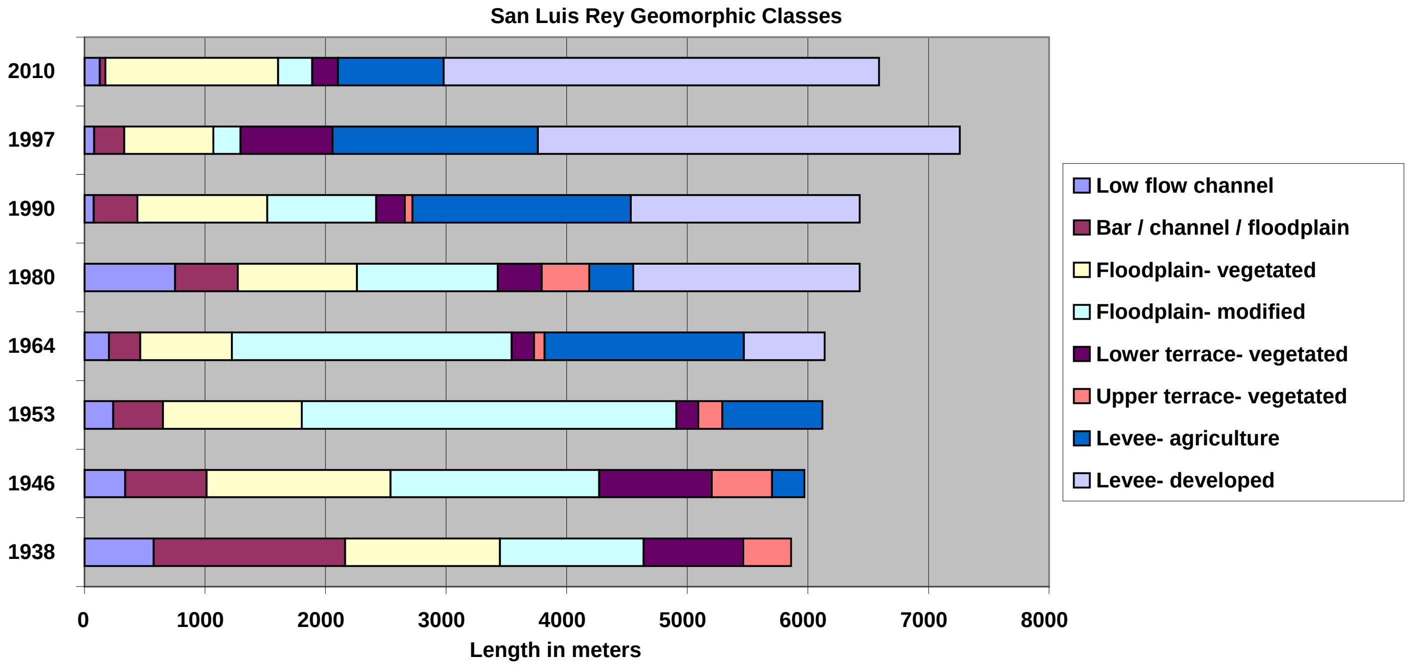

Figure 5-2.14. San Luis Rey geomorphic forms from 1938 to 2010.

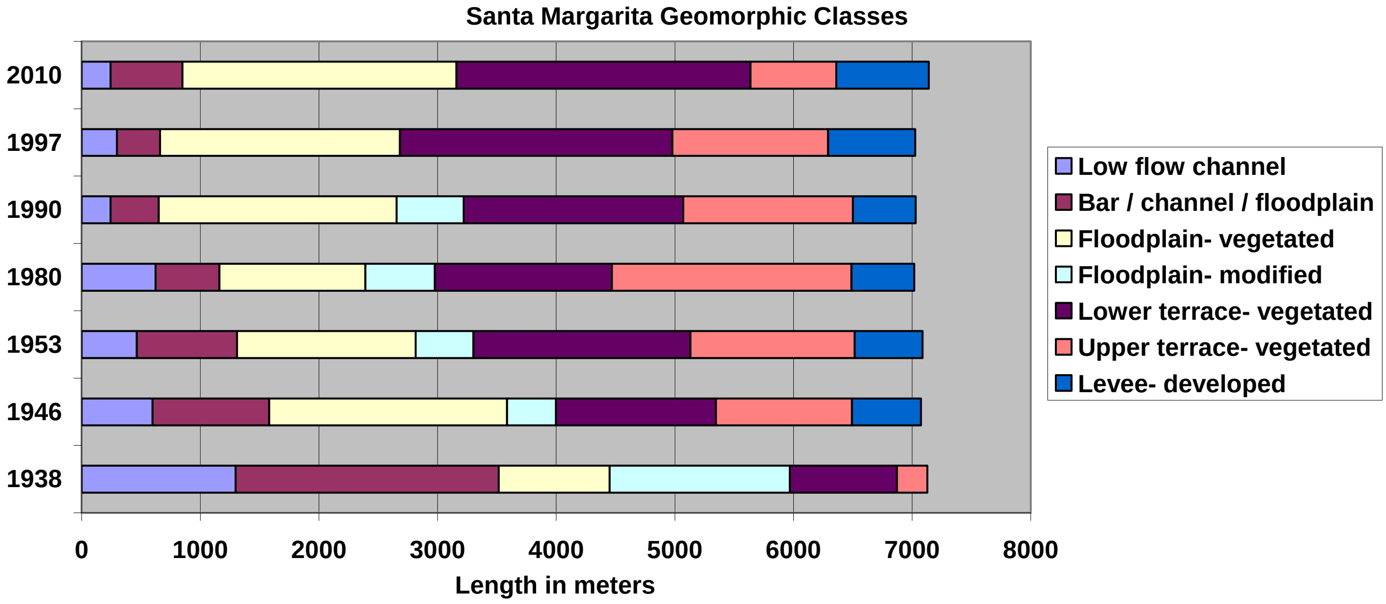

Figure 5-2.15. Santa Margarita geomorphic forms from 1938 to 2010.

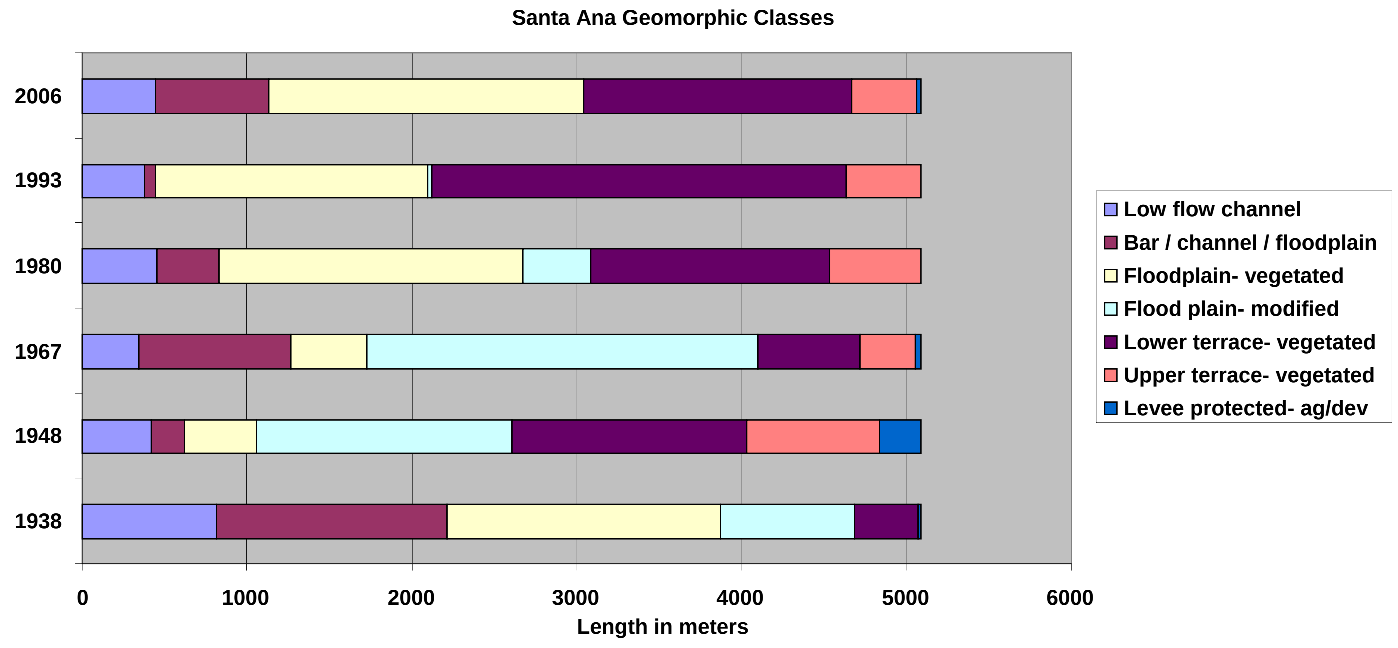

Figure 5-2.16. Santa Ana geomorphic forms from 1938 to 2006.

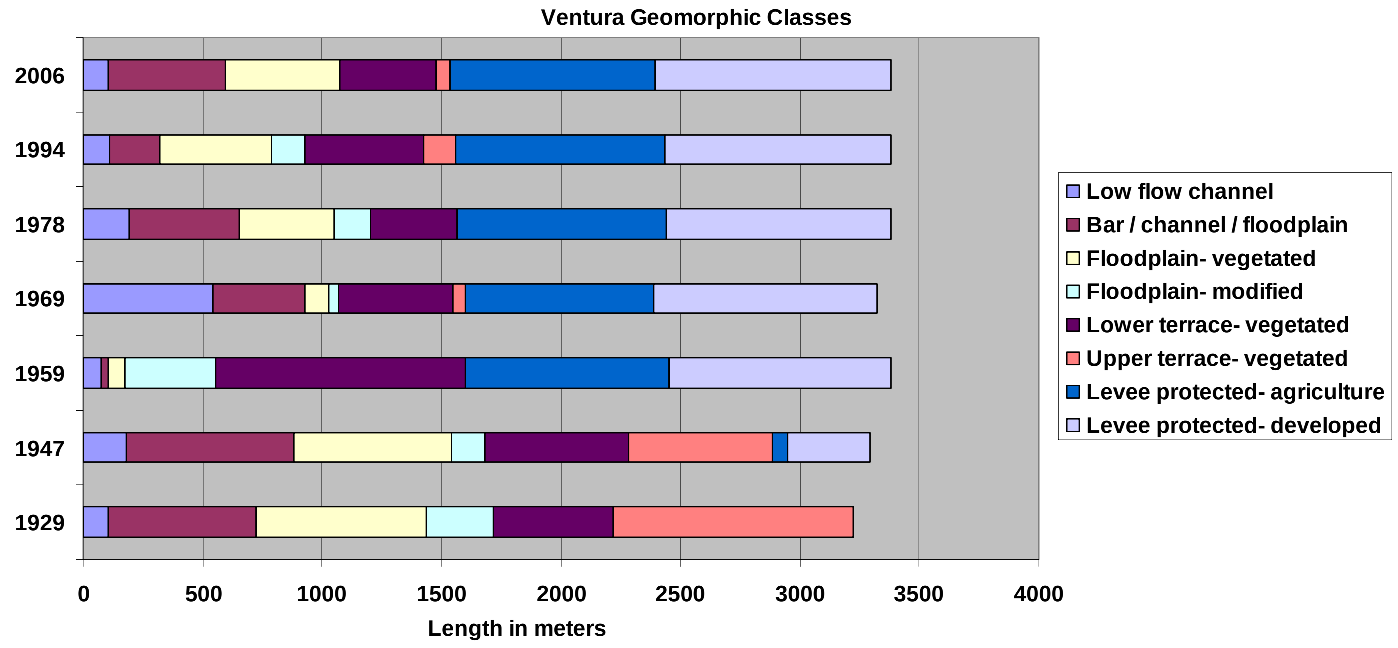

Figure 5-2.17. Ventura geomorphic forms from 1929 to 2006.

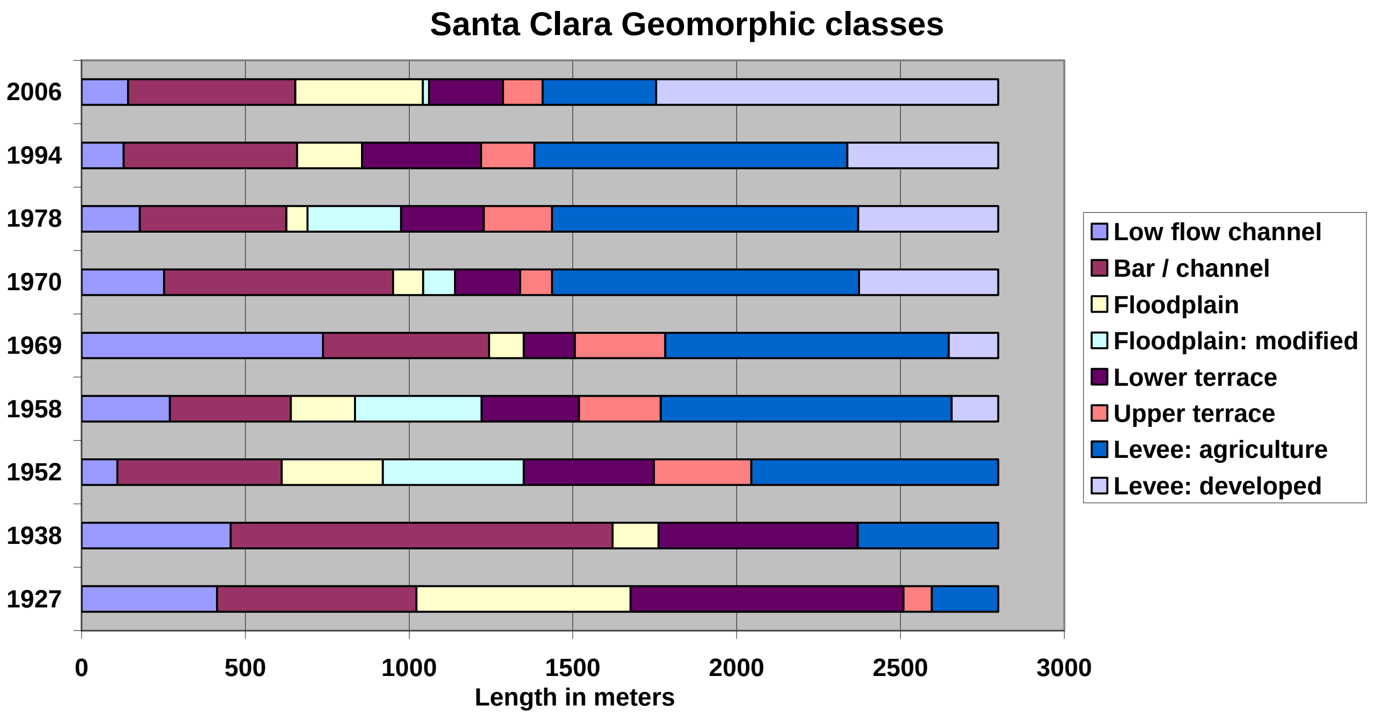

Figure 5-2.18. Santa Clara geomorphic forms from 1927 to 2006.

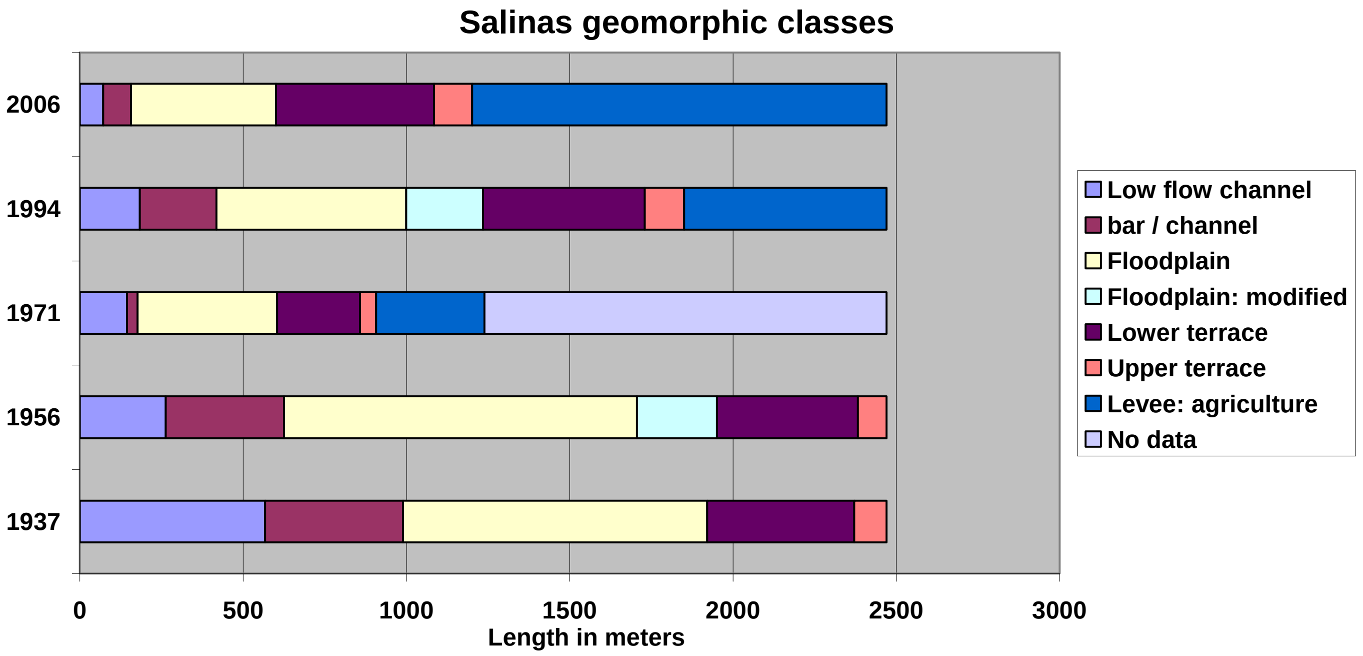

Figure 5-2.19. Salinas geomorphic forms from 1937 to 2006.

5.2.3 Vegetation Cover Historic Analysis

5.2.3.1 Methods

Preparing historic imagery for analysis reinforced a theory that many of the river systems have converted to a more heavily vegetated state over time. Supporting data was captured during the historical cross-section analysis. An attribute was added to the *Floodplain-Vegetated* and *Floodplain/ Low Terrace–Vegetated* geomorphic forms. The attribute values "dense" and "open" were used to describe the conditions and types of vegetation within these forms (see definitions below). Based on observations from the *Arundo* field mapping, the "dense" classification is the most likely place for *Arundo* to thrive, and thus, it was classified as such. An example of aerial imagery showing floodplain and terrace areas with dense and open vegetation classes marked is shown in Figure 5-2.20.

Definitions:

Dense – High woody/*Arundo* vegetation cover (>50%, typically >80%) of large, well-developed vegetation including plants like cottonwoods, sycamores, willows, mulefat and *Arundo*.

Open – Low woody/*Arundo* vegetation cover. Typically these are bare open areas, or areas with annual herbaceous cover. Areas with scattered woody vegetation and clumps of *Arundo* are also included in this category.

5.2.3.2 Results

The characterization of vegetation on the floodplains reveals a strong pattern of increasing cover of dense *Arundo* and woody vegetation. Dense woody/*Arundo* vegetation is taken to be an indicator of high water availability that allows dense vegetation to develop. Individual watersheds are illustrated over 80-90 year periods (Figures 5-2.21 to 5-2.26, Table 5-2.5). Most systems initially show low cover of dense vegetation on floodplains and terraces, except for Santa Margarita and Salinas. Over time dense vegetation cover increases, particularly on the San Luis Rey, Santa Ana, Ventura and Santa Clara from 1980 forward. The increase in proportion (percentage) of "dense" vegetation to "open" is shown in Figures 5-2.27 and 5-2.28 for all watersheds studied. A clear shift in vegetation cover is occurring. Dense cover was typically 10-30% in the 1920s and 1930s, but by the 1990s/2010 most systems were >75%. High R^2 and steep trendlines are apparent for most systems. All data aggregated show a clear upward trend, but systems apparently have different equilibrium points.

5.2.3.3 Conclusions

The strong historic trend toward greater vegetation cover on floodplain and terrace portions of river systems indicates that a major hydrologic shift has occurred within the study area. *Arundo* comprises a significant proportion of this dense vegetation. This overly vegetated condition, compared to 1928-50, seems to be moving these systems toward a more fixed geomorphic and vegetative state, with both fewer smaller size fluvial re-setting events and a faster return to a heavily vegetated state after major events. The dense growth of *Arundo* is likely compounding this effect by holding the low flow channel in a set position which converts systems from a braided unstable form to a narrow single thread that is laterally stable. The availability of water all year within riverine systems has allowed *Arundo* to drastically expand in cover. Although difficult to detect in pre-1990 aerial imagery, *Arundo* is clearly not a dominant vegetation form on systems prior to 1980. By 2000 *Arundo* has become abundant with over 40% cover on reaches of selected systems (section 5.1) and an average cover of 13% on the lower gradient floodplain areas as a whole (Table 5-2.1).

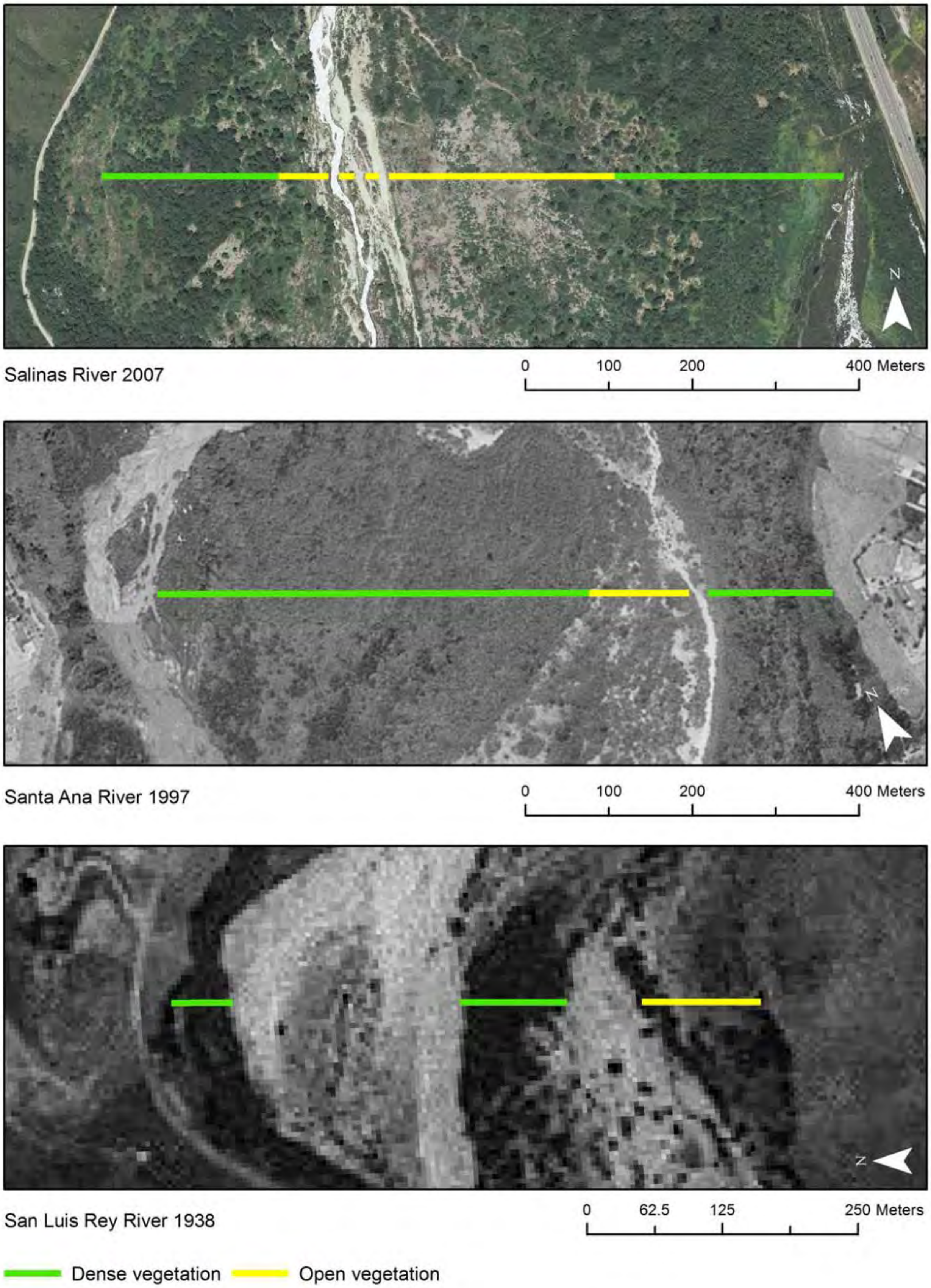

Figure 5-2.20. Aerial imagery showing floodplain and terrace areas with dense and open vegetation classes marked.

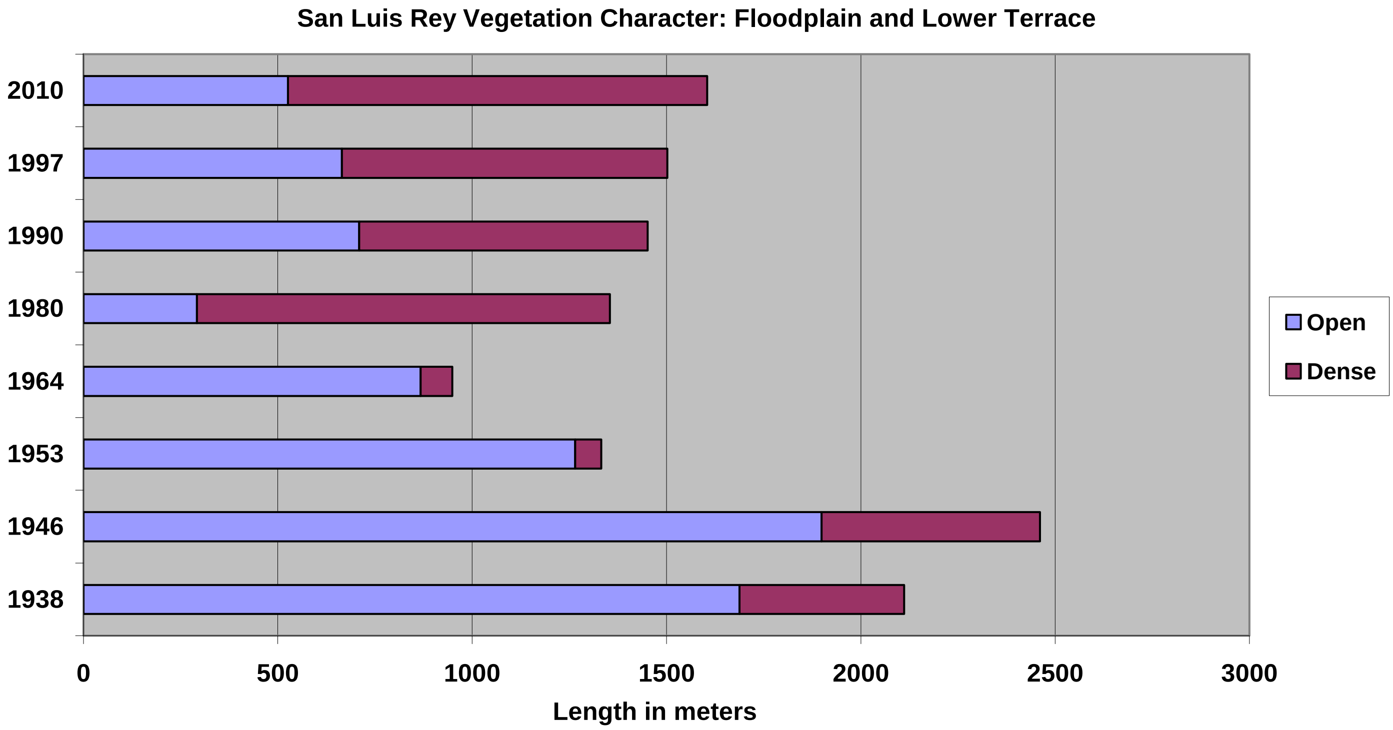

Figure 5-2.21. San Luis Rey open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

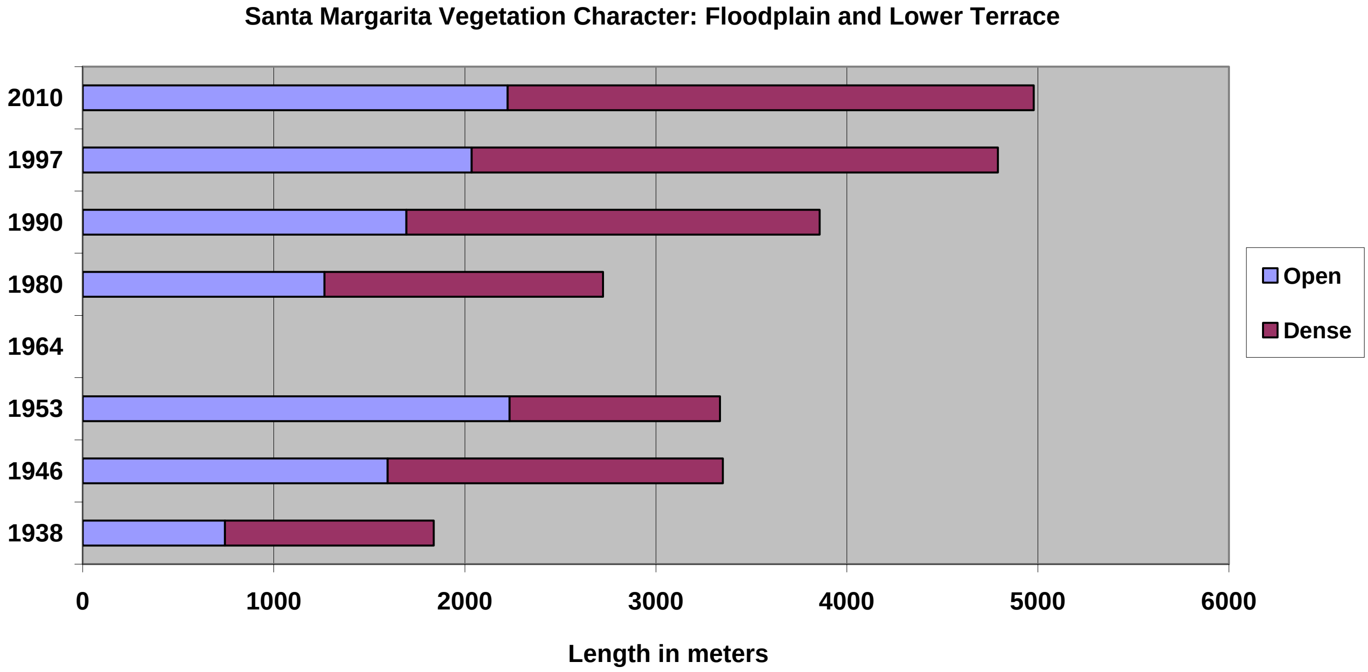

Figure 5-2.22. Santa Margarita open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

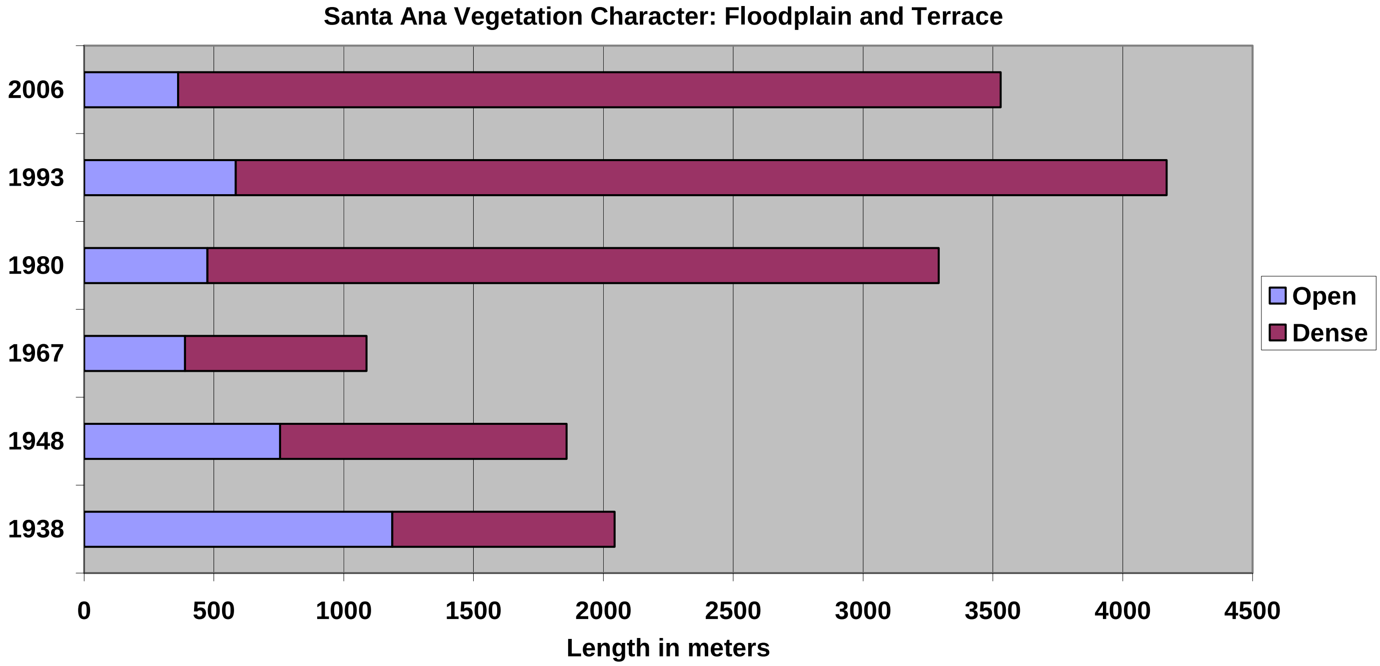

Figure 5-2.23. Santa Ana open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2006.

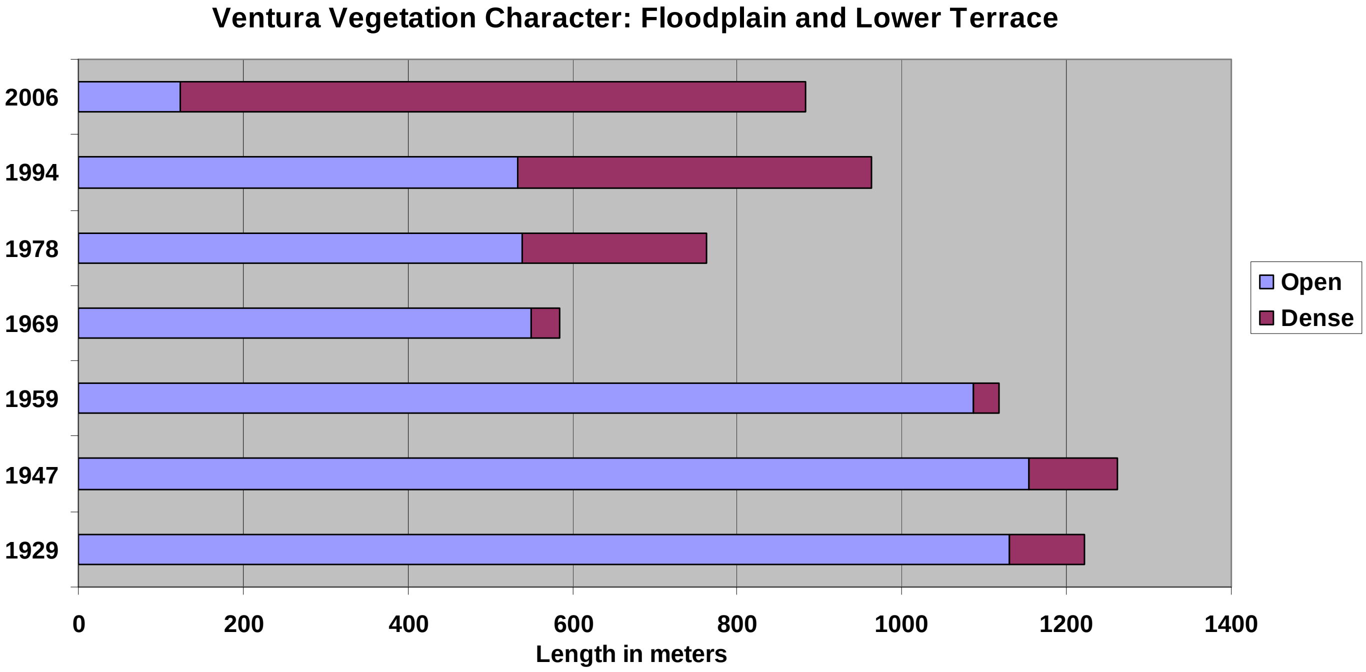

Figure 5-2.24. Ventura open and dense vegetation classification on floodplain and lower terrace areas from 1929 to 2006.

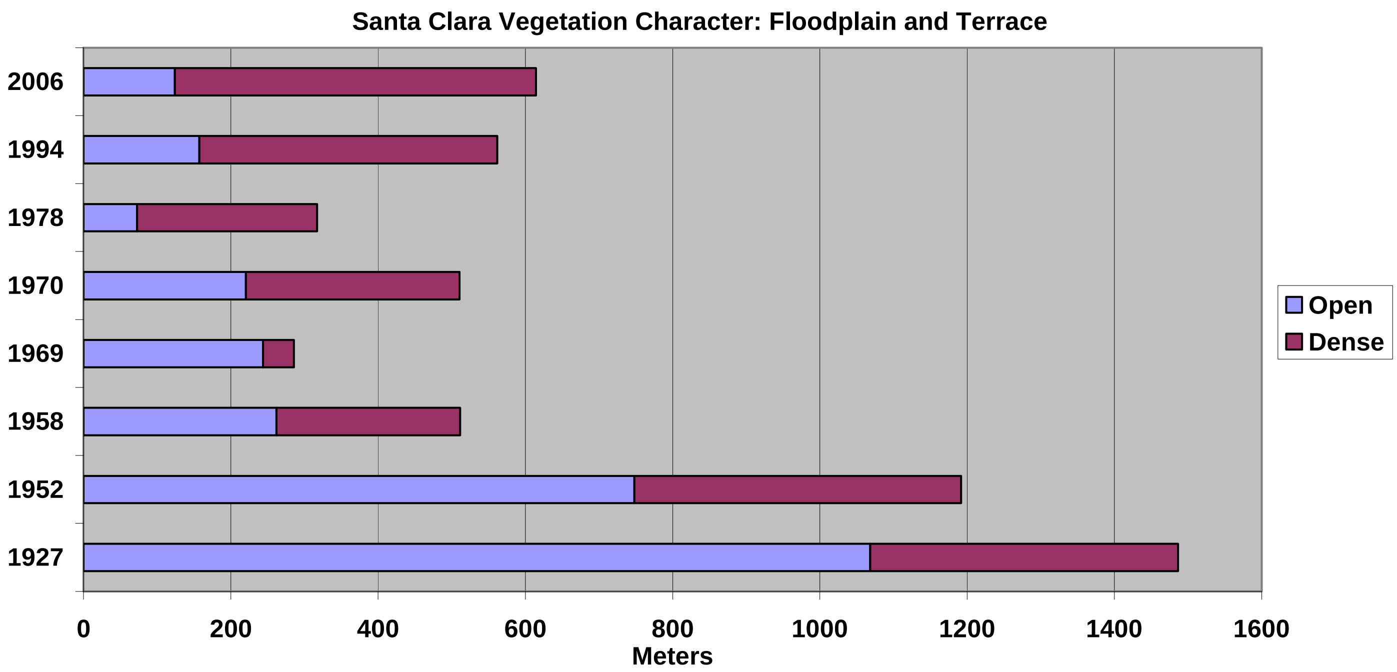

Figure 5-2.25. Santa Clara open and dense vegetation classification on floodplain and lower terrace areas from 1927 to 2006.

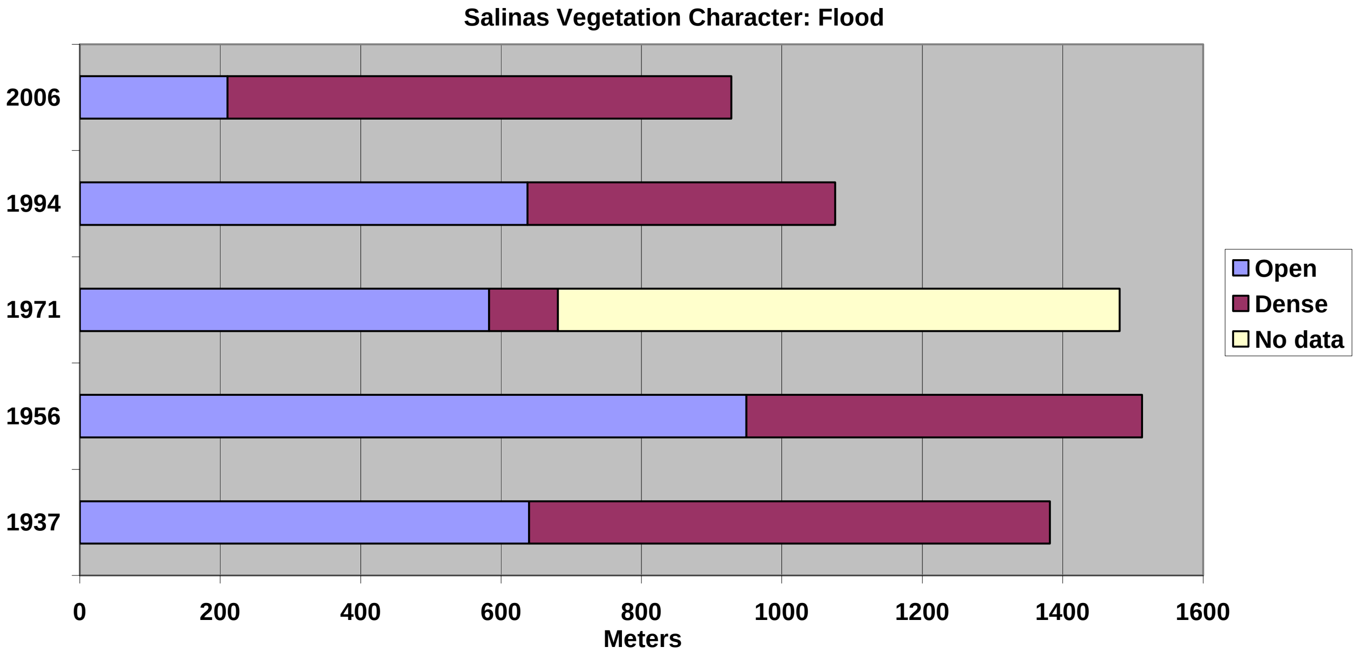

Figure 5-2.26. Salinas open and dense vegetation classification on floodplain and lower terrace areas from 1937 to 2006.

Table 5-2.5. Open and dense vegetation by year for four watersheds.

Watershed	Year	Total length (m)	Open length (m)	Dense Length (m)	% Open	% Dense
San Luis Rey	1938	2112	1688	424	80%	20%
San Luis Rey	1946	2461	1899	561	77%	23%
San Luis Rey	1953	1332	1265	67	95%	5%
San Luis Rey	1964	949	867	81	91%	9%
San Luis Rey	1980	1354	292	1062	22%	78%
San Luis Rey	1990	1451	709	742	49%	51%
San Luis Rey	1997	1502	665	837	44%	56%
San Luis Rey	2010	1605	526	1079	33%	67%
Santa Margarita	1938	1838	745	1093	41%	59%
Santa Margarita	1946	3351	1597	1754	48%	52%
Santa Margarita	1953	3336	2235	1101	67%	33%
Santa Margarita	1980	2724	1266	1458	46%	54%
Santa Margarita	1990	3857	1694	2163	44%	56%
Santa Margarita	1997	4790	2036	2753	43%	57%
Santa Margarita	2010	4978	2225	2753	45%	55%
Santa Ana	1938	2043	1187	856	58%	42%
Santa Ana	1948	1858	755	1103	41%	59%
Santa Ana	1967	1088	389	699	36%	64%
Santa Ana	1980	3292	475	2817	14%	86%
Santa Ana	1993	4169	584	3585	14%	86%
Santa Ana	2006	3530	362	3168	10%	90%
Ventura	1929	1222	1131	91	93%	7%
Ventura	1947	1262	1153	108	91%	9%
Ventura	1959	1117	1087	30	97%	3%
Ventura	1969	584	550	34	94%	6%
Ventura	1978	762	538	224	71%	29%
Ventura	1994	963	534	429	55%	45%
Ventura	2006	883	125	758	14%	86%

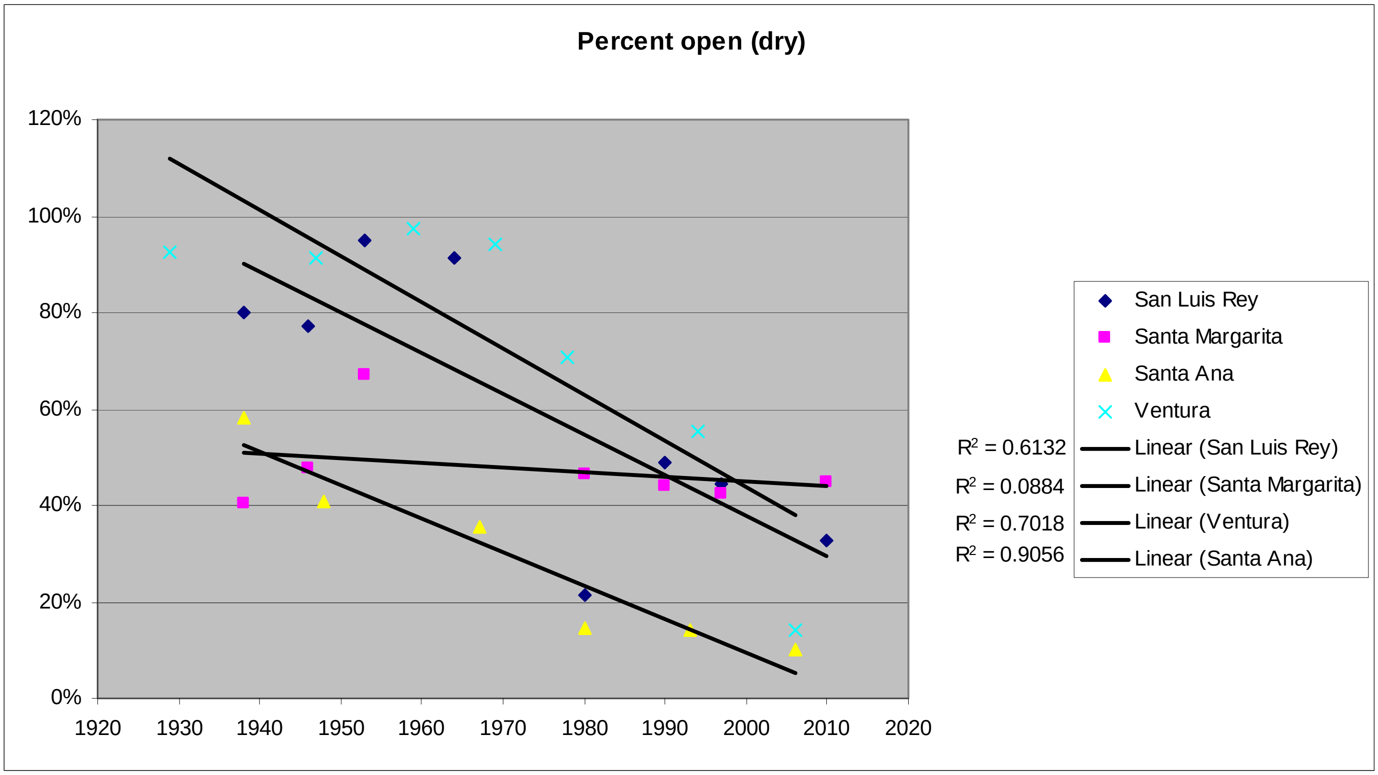

Figure 5-2.27. Trend graph of percent of the open vegetation category from 1927 to 2010 for four watersheds with the AOI.

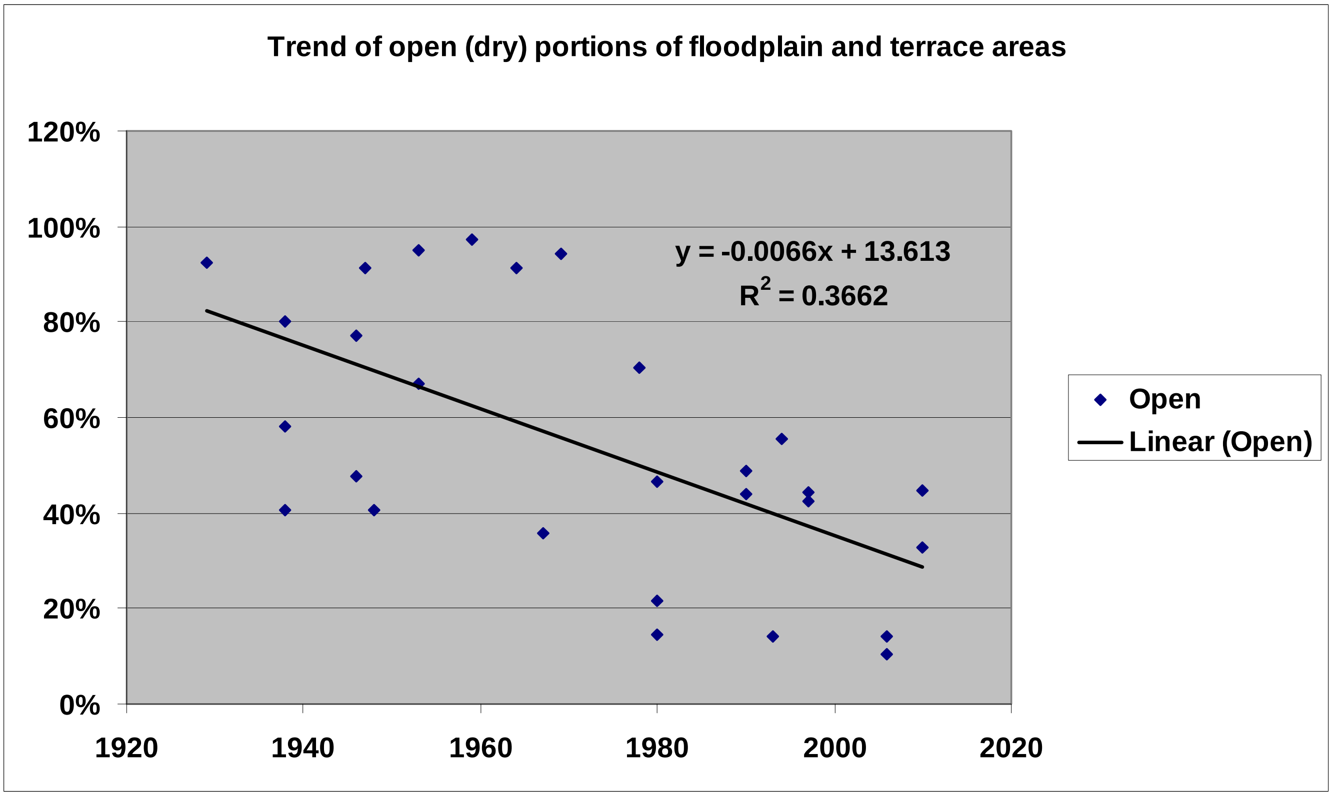

Figure 5-2.28. Trend graph of percent of the open vegetation category from 1927 to 2010 for all watersheds with the AOI.

5.2.4 Geomorphology and Hydrologic Modification by Arundo

What role does *Arundo* play in modifying geomorphic processes? This topic was examined in Sections 5.1 and 5.2 in the context of mapping geomorphic forms and investigating how *Arundo* interacts with river flows and sediment movement. What happens when *Arundo* is removed from a river system? *Arundo* was controlled over a large portion of the Santa Margarita watershed by 2000, so this provides an opportunity to look at one system after *Arundo* has been effectively removed. Large flood events have occurred in the ten years since then, so has the acreage of geomorphic forms changed? Mapping of geomorphic forms at peak *Arundo* cover (1997) and 10-year post *Arundo* removal (2010) show some interesting changes (Figure 5-2.15, Table 5-2.6). Low flow channel area decreased, but bar/channel area increased. Combined together they increased 38% from 118 acres to 163 acres. This is a sizeable change, especially given the linear decline of that class that had been occurring (Figure 5-2.15). A major shift in classification from floodplain to low terrace also occurred. These two classes are close in elevation, and the shift shows a movement to more stable native vegetation on terraces and more active zone area (but vegetated) on floodplains. The floodplain is no longer a dense wall of vegetation (*Arundo* with natives) that restricts flows, rather water now passes through the area. This change in functional flow area has broadened the active flow zone to 362 acres in 2010, a 307% increase over the highly invaded *Arundo* state in 1997 (118 acres). This is a major functional change with implications for groundwater recharge, flood risk, sediment transport and habitat function.

The lower elevation areas in the 2010 classification will likely be more 'dynamic' over time as the vegetation is not able to hold the low flow channel in place. Movement of the low flow channel, braiding, and changing bar/channel structure in the 362.5-acre zone is a significant re-establishment of fluvial forms that was in decline within the study area.

Table 5-2.6. Acreage of geomorphic forms within a portion of the Santa Margarita River in 1997 and 2010.

Geomorphic form	**1997 Acreage:** *Arundo* present	**Flows in a 15 Year event?**	**2010 Acreage:** *Arundo* removed	**Flows in a 15 Year event?**	**Percent change**
Low flow channel	74	Yes	49	Yes	-34%
Bar/channel	44	Yes	114	Yes	159%
Floodplain	536	No	199	Yes	-63%
Floodplain/low terrace	557	No	900	No	62%
Upper terrace	297	No	253	No	-15%

5.2.5 Infrastructure Impacts: Roads, Bridges, Levees, Sewer/Water Transfer, Beaches

5.2.5.1 Bridges & Levees

Reduced flow capacity (elevation of 5'), outlined in Section 5.1, is of great consequence for both bridges and levees. Bridges, particularly older structures, may not have been designed to account for this altered flow capacity during large flow events. The loss of 5 feet of profile over the width of a structure is a significant flow conveyance loss. Many older bridges have multiple, tightly spaced buttresses that tend to collect biomass during flows. *Arundo* mixed with large-sized tree trunks is a particularly problematic combination as it forms a block that catches what might otherwise have flowed through the structure. *Arundo* lodged against a Santa Ana River bridge that failed in 2004 (Figure 5-2.29). A bridge on the Santa Margarita River on Stuart Mesa Road was nearly lost in 1998, but crews pulled *Arundo* off pylons during the flow event, likely saving the structure. In 1993 the Basilone Bridge on the same river was lost and a levee protecting the Air Station was breached with severe flooding of the Air Station occurring. Although these losses cannot be fully ascribed to *Arundo* stands that were dense in the area, it was clearly a factor in these structural failures due to flow conveyance loss. An additional levee failure in the same area in 1998, resulting in damage to Air Station fuel pad, led to the baseline work of documenting *Arundo* impacts on flows (see Section 5.1). It was this study that demonstrated the 5' flow conveyance loss over *Arundo* stands. These higher flows overtopped the levee in 1998, an event size that should not have achieved this outcome. *Arundo* was specifically pinpointed as the reason why flows were higher than expected. Given *Arundo*'s demonstrated effect in 1998, it is certain that levee breaches and flooding in 1992 was of greater magnitude due to the presence of extensive *Arundo* stands. This realization was one of the impetuses for *Arundo* eradication on the Santa Margarita River.

A similar series of events has occurred on the San Luis Rey River. Two bridges were lost following 1992 flooding events at College Avenue and at Camino del Ray Ave. The College Bridge was located below large *Arundo* stands, but the Camino del Ray Bridge was not. An extensive levee system was constructed in the early 1990s on the lower San Luis Rey River. By 2005 significant flow capacity had been lost due to vegetation growth (*Arundo* and natives combined). This led to vegetation reduction and *Arundo* control activities initiated in 2008.

These events on three heavily invaded *Arundo* invaded river systems suggest there will likely be future impacts from *Arundo* on other watersheds in the study area. Impacts and cost valuation for bridge damage or loss is included in the Cost Benefit study in Chapter 8.

Figure 5-2.29. Floods stacked *Arundo* biomass against the River Road Bridge on the Santa Ana River, resulting in the bridge being pushed off its foundation in 2004.
Photo by Richard Zembal.

5.2.5.2 Biomass on Beaches

Arundo biomass on beaches following flow events is a recurring impact (Figure 5-2.30 & 5-2.31). In many areas, particularly from Santa Monica to San Diego, biomass is cleared by Municipal, County and State workers using tractors, loaders and sweepers. Estimating the magnitude and cost of these efforts is complicated due to their periodic nature, in addition to a large range in the amount of material. *Arundo* biomass is not the only material discharged by river flow events. There are also other non-native plants, native plants and refuse. It is not unusual for more than 80% of the material to be *Arundo* biomass near heavily invaded watersheds (San Luis Rey, Santa Margarita, Santa Clara, Ventura). Two of these systems will have lower *Arundo* biomass yields in the future as most *Arundo* has been removed (San Luis Rey, Santa Margarita). Santa Ana has lower *Arundo* discharge than other systems because most *Arundo* is present above the Prado Dam. Small and mid-sized watersheds may discharge large amounts of *Arundo* material, particularly watersheds in the Los Angeles basin (Douce 1993).

Figure 5-2.30. In Santa Barbara County, *Arundo* washes down the Santa Clara River and accumulates on Rincon Beach, blocking access for beachgoers and increasing the cost of beach maintenance.
Photo by David Chang.

Figure 5-2.31. *Arundo* and other biomass washed onto the beach in Long Beach after a large flow event on the Los Angeles/San Gabriel River.
Photo by Drew Ready.

Many beach areas are not maintained for public use. Some of these areas are of significant value to wildlife, particularly areas near estuaries and river mouths. These are also where *Arundo* biomass load is highest. Impact to fauna and threatened and endangered species are outlined in Chapter 7.

Approximately 21 miles of beach are likely to have routine removal of *Arundo* biomass. These areas are north San Diego, Los Angeles/Long Beach, and Ventura/Ojai. Estimates for *Arundo* biomass are based on data from Long Beach following large flood events in 2004/05 (Lopez, pers. comm. 2009, Douce 1993). The city estimates *Arundo* at 40% of total biomass/debris on their beaches. Note that the Los Angeles and San Gabriel Rivers (source of *Arundo* for Long Beach) have significantly less *Arundo* acreage compared to many other systems. Tons of *Arundo* cleared and the cost of collection are presented in Table 5-2.7. Additional flood event sizes are added to reflect a ten-year period. This data is then extrapolated to the two other regions that have higher levels of *Arundo* biomass on their beaches. Discharge of *Arundo* biomass for a single region is estimated at 875 tons/year or 8,750 tons over ten years. For the region, it would be 2,625 tons of *Arundo* biomass annually or 26,250 tons over ten years (Table 5-2.8).

5.2.5.3 Conclusions: Impacts to Infrastructure

Arundo appears to be having significant impacts to structures that cross rivers as well as structures that contain flows (levees). *Arundo* biomass combined with the loss of flow capacity are the two primary factors contributing to these impacts.

- Loss of flow capacity and presence of *Arundo* biomass is likely contributing to overbank flows and bridge loss and damage. (Section 5.2.5.1)
- Flow events mobilize large amounts of *Arundo* biomass. Part of this biomass load ends up on coastal beaches where it is frequently removed by public agencies that required an estimated annual cost of $197,000. This does not include impacts on habitat quality. (Section 5.2.5.2)

Table 5-2.7. Amount of *Arundo* biomass on beaches of Long Beach and clean-up costs for a ten-year period.

Flood Events in 10 Year Period for Long Beach (LA & San Gabriel Rivers)	Percent cost	Tons *Arundo* biomass	Cost of disposal	Cost of collection	Total cost
Large event (1 in 10)	100	5,000	$175,000	$200,000	$375,000
Medium event (2 in 10)	50	2,500	$87,500	$100,000	$187,500
Small events (2 in 10)	25	1,250	$43,750	$50,000	$93,750
No event (5 in 10)	0	0	0	0	-
10 year Total:		**8,750**	**$306,250**	**$350,000**	**$656,250**

Table 5-2.8. Estimate of the amount of *Arundo* biomass on beaches in North San Diego County, Long Beach and Ventura, and the clean-up costs for a ten-year period.

Major regions	10 yr cost	*Arundo* 10 yr biomass (tons)
Long Beach: L.A. and San Gabriel Rivers	$656,250	8,750
North San Diego: San Luis Rey, Santa Margarita	$656,250	8,750
Ventura: Ventura and Santa Clara	$656,250	8,750
10 years:	**$1,968,750**	**26,250**
Annual cost:	**$196,875**	**2,625**

6.0 IMPACTS OF *ARUNDO: Fire*

Fire is one of the most discussed impacts related to *Arundo* invasion, yet there is little documentation of its occurrence in the literature. A few studies have looked at post-fire recovery of vegetation, but no studies have examined fuel loads, fuel characteristics and ignition sources, explicitly attempted to quantify fire events that start in *Arundo*, or quantified wildfire events that burn riparian areas with *Arundo* in them. All of these subjects will be explored in this chapter.

6.1 Fuel Load

Arundo stands have greatly increased the fuel load of riparian habitat. As outlined in section 2.3, *Arundo* stands in the study area had an average dry biomass of 69 tons/acre or 155 tons/hectare (Table 2-5). This is within the range of other studies on *Arundo* biomass. Studies have shown that *Arundo* produces biomass containing large amounts of energy per unit (17 to 19.8 MJ/Kg; Table 6-1). The high productivity of *Arundo* is why biofuel generation has focused on *Arundo* as a potential fuel source. It is significantly more productive than other species used for fuel generation. One study specifically growing willows for biofuel in riparian strips with high planted density of 15,300 trees/ha (6,200 trees/ac) generated 16.8GJ/ha (for 36.8t/ha biomass, Turhollow 1999). Compare this to *Arundo*: 810 GJ/ha (for 45 t/ha annual biomass, Williams et al. 2008) or 2,790GJ/ha for a mature *Arundo* stand (for 155t/ha biomass, this study). Based on annual yield, *Arundo*'s productivity is 400% higher than riparian vegetation (Turhollow 1999). This is in excess of estimates made by Scott (1993) who proposed that *Arundo* has doubled or tripled the fuel available for fires in the Santa Ana River Basin. Examination of mature stands during collection of *Arundo* biomass for this study also indicated that *Arundo* stands retain a significantly higher amount of dry, dead biomass compared to native woody and herbaceous vegetation, and it is held higher in the canopy. The *Arundo* stand has optimal, well-ventilated structure with both wet and dry fuel present throughout the stand profile. This introduction of a unique stand structure of *Arundo*, a clonal tall grass, into an ecosystem naturally dominated by woody trees and shrubs, herbaceous vegetation and open spaces, has altered fuel types, layers, and loads (Scott 1993, DiTomaso 1998, Brooks et al. 2004). The documentation of biomass loads in Spencer et al. (2006) and this study demonstrate the high levels of *Arundo* fuel. Later portions of this chapter focus on documentation of ignition sources and fire events in *Arundo*, which demonstrates how *Arundo* can be a direct or indirect factor contributing to an increase of fire occurrences.

Table 6-1. *Arundo* energy levels per unit of dry biomass.

Energy MJ/kg	Source
19.0	Williams et al. 2008
18.3	FAIR 2000
17.0	Angelini 2004
19.8	Dahl & Obernberger 2004
18.5	**Average**

Decreased moisture content and increased surface to volume ratio of *Arundo* versus native vegetation may lead to an altered or increased length of fire susceptibility and probability of ignition in these systems, although no data currently exists to document this assertion. Addition of this novel fuel characteristic to the riparian ecosystem has increased vertical continuity (structure of fuel allows fire to spread from surface to crowns of shrubs and trees), which can in turn increase the frequency and extent of fires (Brooks et al. 2004).

Research still needs to investigate comparative moisture and surface to volume ratios, but current studies definitely indicate that *Arundo* has exceptionally high biomass levels. This directly translates into higher energy per acre.

6.2 Fire Intensity

Arundo stands contain a significant amount of energy and aboveground plant biomass, in addition to a well-ventilated, tall structure. *Arundo* stands always have large amounts of dry leaves, primary and secondary leaves that drop off canes as they grow. As it was discussed in sections 2.2 and 2.3, when a cane matures from the first year of growth to the second year, with the emergence of secondary branches, more than half of the leaves on the cane senesce (Figures 2-18 &6-1). Senescence of leaves on secondary branches also occurs periodically as the canes age. In addition to leaf senescence, both primary and secondary leaves frequently have portions of the leaf that are dry and non-photosynthetic (Figures 2-3 & 4). There is also a highly variable amount of dead cane material, in addition to the large amount of dry leaf material found both at the base of the stand and throughout the canopy. Within a stand, 0 -30% of the biomass is dead cane and leaf material (Spencer et al. 2006, Figure 6-1). This study did not directly measure dead cane biomass, but we observed a low density of dead canes within the plots sampled, averaging less than one cane per m^2 (n = 16, Table 2-4). However, sites can certainly be found with high amounts of dead cane biomass. Often these are areas where material has collected within the stand during flow events (photos in Chapter 5). Stands growing in dry areas will also have significant dead biomass, but these stands also have shorter stature and lower cane density (i.e. lower overall biomass). *Arundo* stand structure (tall height and high cane density per square meter) is an important factor in conveying fires high into the riparian canopy.

Movement and intensity of the fire are also related to weather, but conditions do not need to be favorable for a fire to occur in *Arundo*. *Arundo* can burn any time of the year under varying conditions. *Arundo* stands contain enough dead dry fuel that they can be ignited and carry a fire even under poor fire conditions, such as low wind speed, cool weather, and even when humidity is high or during light rains. This was demonstrated by the fire event on October 2006, which started at night during a light rain and low temperatures (Figure 6-2). Fires have also been observed during light rains and cool temperatures on the San Luis Rey River. Successive heavy rains will reduce *Arundo* stand flammability, but for many areas in the study region heavy rainfall only occurs for 6-10 weeks of the year. High fire threat weather conditions (low humidity and high winds) are not required to start or carry *Arundo* fires. The greatest risk of fire is still in the late summer/fall when stand moisture is low and Santa Ana conditions can exacerbate fire events.

The large amount of biomass per unit area along with a favorable structure for burning generates fires that burn intensively. This is illustrated by fire behavior and an examination of post-fire site conditions. Low intensity fires leave unburned material. Ash levels and color can also be used to gauge fire intensity. *Arundo* fires usually leave little unburned biomass and ash is usually white (Figures 6-3 & 4, also section 6.4 photos).

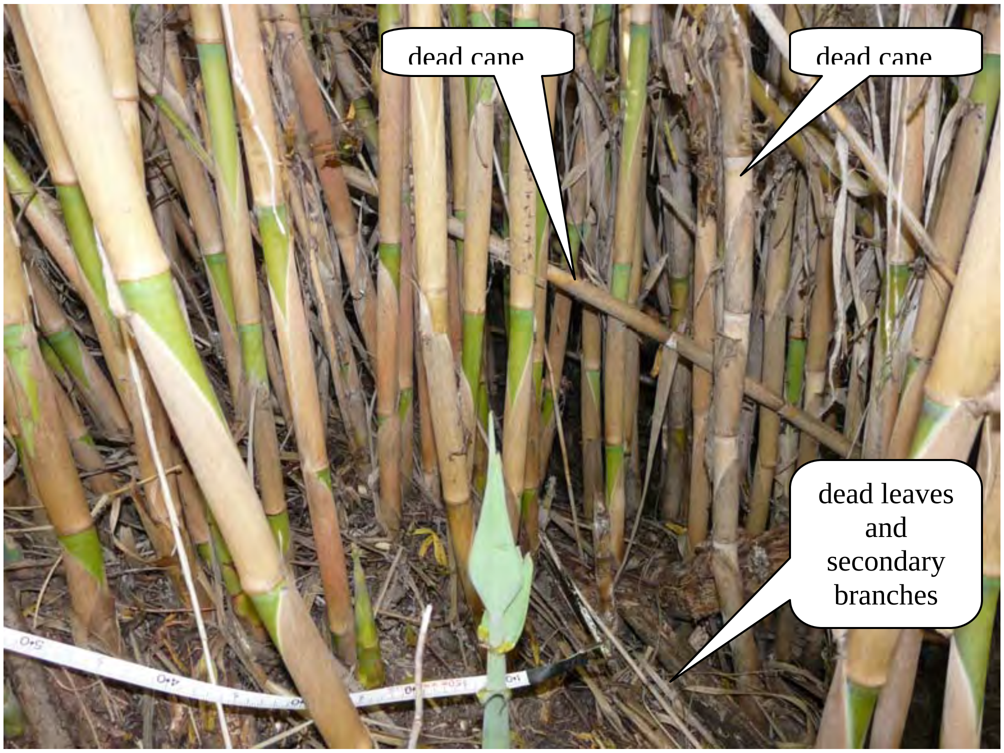

Figure 6-1. Large amount of dead/dry *Arundo* fuel.
While only a small percent of the overall stand biomass is dead and dry, it is enough to start and maintain fires.

Figure 6-2. This fire started in *Arundo* at night during a light rain in October 2006.
Photos from San Diego News outlets (Fires SLR#1-3).

Figure 6-3. Burned *Arundo* stands on the San Luis Rey River (Fire SLR #6).

Figure 6-4. Burned *Arundo* stands on the San Luis Rey River (Fire SLR #6).

6.3 Ignition Sources

Fires must have an ignition source in order to burn. Two main groups of ignition sources have been observed for fires that burn *Arundo* stands: local ignition sources (people in or around *Arundo* stands) and wildland fires. Wildland fires may be started by humans, or may start from lightning, although this is an increasingly infrequent occurrence (Keeley & Fotheringham 2005). Most wildfires start from arson, campfires, vehicle fires, power lines, and other human activities (CalFire and Ventura incident reports, Keeley & Fotheringham 2001).

6.3.1 Human Ignition Sources:

This report documents that *Arundo* directly increases the probability of fire ignition due to *Arundo* stands supporting human activities that lead to fires. *Arundo* stands offer concealment and shelter, which results in encampments and use by transients (Figure 6-5). Activities by transients within *Arundo* stands directly start fires. The following examples are from the San Luis Rey watershed, which has had documented camps and fires within *Arundo* stands for the past 10 years. Camps often have open fires for cooking and heat (Figures 6-6 & 7). Some camps even have portable heaters and ovens (Figure 6-8). Humans frequently smoke and use substances that must be ignited or heated for use, or may process these materials in camps (Figure 6-9). Humans have also intentionally set fires to *Arundo* stands (NLF 2006/7). Fireworks and firearm discharge may also lead to fires. Concealment, availability of water, and remoteness in some areas has also led to the cultivating of cannabis on several watersheds (documented on the San Luis Rey and Santa Ana). These operations have resulted in at least one fire event from an area where the workers had an open campfire (Figure 6-10). Transient activities and encampments are the primary ignition source for fires that start in *Arundo* stands. Direct evidence of the ignition source is usually present at the fire site.

Figure 6-5. Camp on San Luis Rey River with *Arundo* folded over to make an enclosure.

Figure 6-6. Camp on San Luis Rey River in *Arundo* stands showing tent, tarp and fire ring. *Arundo* surrounds the camp.

Figure 6-7. Camp on San Luis Rey River within *Arundo*, showing multiple lighters, cooking area and burned *Arundo* canes.

Figure 6-8. Camp on San Luis Rey River in *Arundo* showing tent and cooking area with a portable oven connected to propane.

Figure 6-9. Small methamphetamine lab on the San Luis Rey River within *Arundo* stands.

Figure 6-10. Open fire associated with workers of a cannabis plantation.
This was the ignition source of a wildfire that started within *Arundo* on the San Luis Rey River (Fire SLR #6).

An excerpt from the North County Times on January 23, 2007, referred to the fires on the San Luis Rey River:

> “The fires all started in areas widely known as hideouts for transients that set up camps among the brush and ‘bamboo’ that clogs the riverbed,” authorities said. "We've always had fires occur in the river bottom due to the homeless population," Lawrence said. "But transients normally go through great effort to keep fires from spreading, so we're surprised to find uncontained vegetation fires when we arrive. Normally they're small cooking fires." Patricia Clutter, who lives near the river, said that she has witnessed five fires in the last four years and many neighbors are concerned.

Between 2000 and 2009, 34 encampments in *Arundo* stands were documented on the San Luis Rey River (Figure 6-11, Table 6-2). San Luis Rey data indicate that approximately one camp occurs for every 2 miles of invaded river. Encampments in *Arundo* on other rivers were recorded as encountered through reports or during the mapping phase of this project. While this is an incomplete data set, it indicates that encampment use of *Arundo* stands occurs on all large watersheds (Figure 6-11): San Diego (6 recorded), Santa Ana (3), Los Angeles (3), and Ventura (5 recorded with very high density). More focused surveying over a longer time period would likely reveal similar levels of encampment use as seen on the San Luis Rey River. This study’s data, coupled with the San Luis Rey long-term monitoring data, clearly show a fairly high density of encampments in *Arundo* stands occurring in urbanized areas (homeless transients) as well as agricultural areas (agricultural workers).

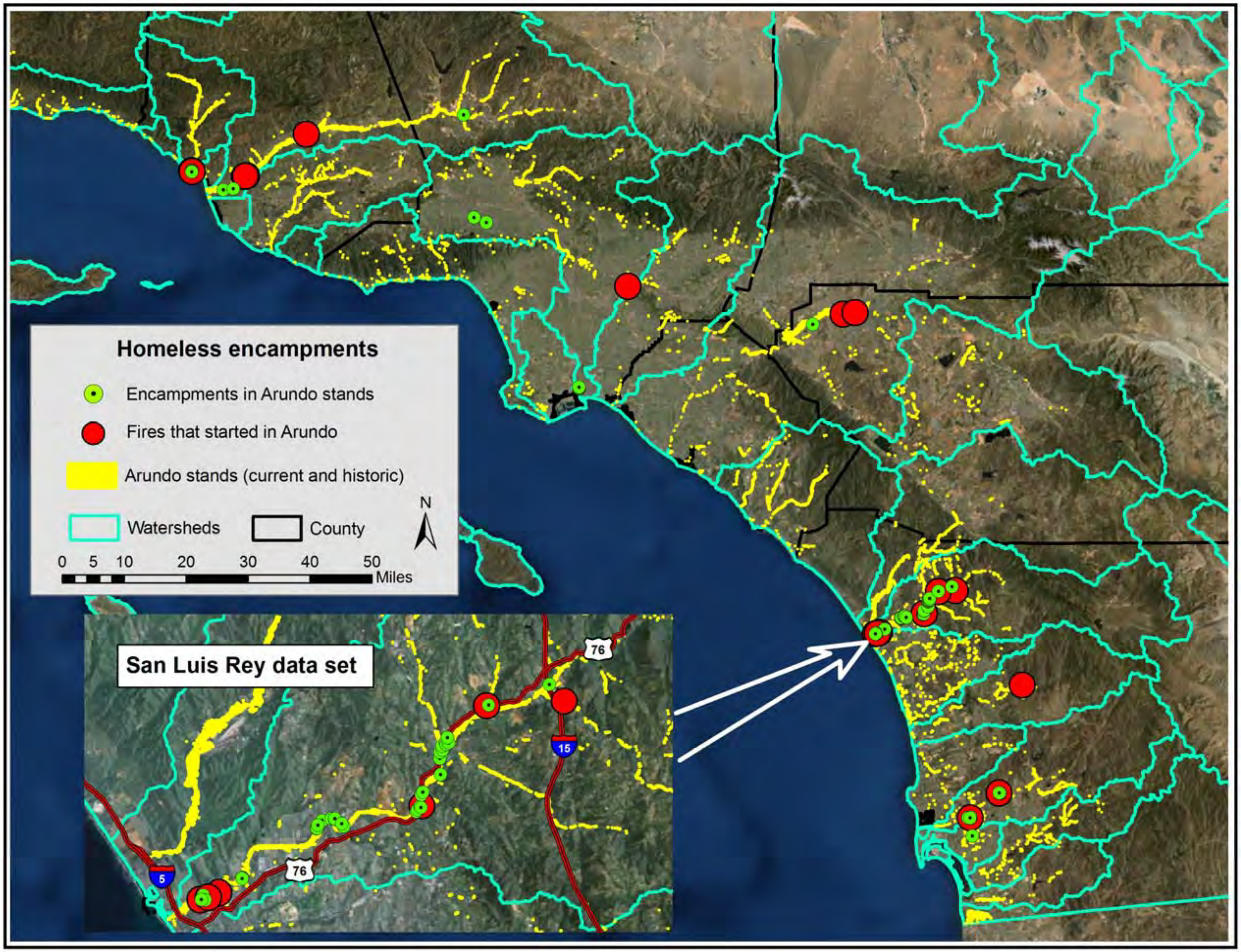

Figure 6-11. Location of *Arundo* fires for some southern California watersheds.

Table 6-2. Encampments found within *Arundo* stands on the San Luis Rey River.

Camps	People	Time Frame	Completeness
34	84	2000-2009	Very complete, but likely an underestimate

The second most common ignition source is likely from cigarettes being thrown out of vehicles on bridges above *Arundo* stands. This has resulted in frequent fires in the San Diego, San Luis Rey, and Santa Ana Rivers. Areas under bridges and overpasses are also high use areas for transients, so differentiating ignition sources can be difficult, but some fire events occurred in areas that have little use by transients.

Arundo fires started by human activities are usually suppressed quickly. The fires can occur at any time during the year. They frequently occur during conditions that are not optimal for fire events, helping fire suppression/response teams. These fires usually have smaller footprints than wildland fires. There is no recorded example of a fire that started in *Arundo* developing into a large wildland fire, but the number of *Arundo* fires that have already been documented increases the potential for this to occur.

6.3.2 Wildland Fire As An Ignition Source:

Wildfires that pass through an area where *Arundo* is present will ignite and burn *Arundo* stands. The presence of *Arundo* changes how the fire behaves within the riparian zone. *Arundo* can have three important impacts on wildfires: 1) *Arundo* causes the fire to burn hotter and more completely within the riparian area, 2) *Arundo* causes the wildfire to burn larger areas within the riparian zone, and 3) *Arundo* conveys the wildfire through the riparian area into adjacent landscapes, causing more area to burn (urban, rural, or wildland areas). These impacts will be explained in the next section.

6.4 Spatial Distribution and Frequency of *Arundo* Fires

Two types of fire events that burn *Arundo* were mentioned in the previous section: 1) fires that start in *Arundo* and 2) wildland fires that burn *Arundo* stands. The frequency and spatial distribution of these events within the study area will be discussed in this section.

6.4.1 Fires Starting in Arundo

Due to the difficulty of detecting fires on aerial imagery (unless they happen to be taken right after a fire event), only the San Luis Rey River watershed can be used as a comprehensive estimate of *Arundo* fire events over time. Boundaries of fires were captured by examining aerial imagery and ground-based photography, and digitizing the footprint of the fire. In some instances the fire line had been walked with a GPS immediately after the fire events to document the extent of the fire. The San Luis Rey River watershed is a good system to examine as it had abundant *Arundo* acreage and is fairly characteristic of coastal watersheds with various land uses (urban, rural, and open space). Additionally, as outlined in the previous section, data on ignition and encampments has been collected for the San Luis Rey. The number of fires, acreage of fires, and impacts associated with fire suppression were recorded.

6.4.1.1 San Luis Rey Watershed Case Study

A total of six separate fire events initiated in *Arundo* stands were recorded between 2000 and 2007 (Figure 6-12, Table 6-3). Fire events occurred within all reaches of the watershed where *Arundo* was abundant, from the coast to inland areas.

Three fires (SLR #1 to 3) occurred near the river mouth between October 2006 and March 2007 (Figures 6-2, 6-12 to14). These fires were reported in local newspapers and observed by Jason Giessow (this study). Fire suppression clear zones as well as fuel break strips were created to contain the fire (Figures 6-13&14). The ignition source for at least one fire was believed to be an arsonist. Transient use of the area was also high. The fires burned a total of 27.7 acres, and 5.6 acres of habitat were cleared during fire suppression activities (Table 6-3).

Proceeding upstream, the next fire (SLR #4) occurred at the Highway 76 bridge over the San Luis Rey River near East Vista Way in June 2005. This fire burned 1.40 acres (Figures 6-12 & 15). No specific ignition source was identified, but it was likely either a discarded cigarette from the highway overpass or a transient camp. Both uses occur in that specific area. No fire lines were cut around the fire because the river channel and a road surrounded it.

A large fire occurred on June 17, 2007 near Gird Road and Highway 76 (SLR #5; Figures 6-3 & 4, 6-12 & 16). This struck during high fire season and burned a larger area than the other fires on the river. The fire was 64.31 acres in size and fire suppression activities disturbed an additional 0.90 acres. This fire had active suppression, but would likely have been much larger were it not for a vertical 30-foot river bank that served as a natural fuel break on the southern edge of the fire line. The ignition source was likely a campfire related to cannabis cultivation within the central portion of the *Arundo* stand (Figure 6-10). Irrigation tubing was observed leading into the stand area from the river.

The most upstream fire within the study area occurred on a tributary near the confluence of the San Luis Rey River and Keys Creek (SLR #6; Figures 6-12 & 17). This fire occurred in 2001 and was 10.37 acres in size. Local residents speculated that it was kids playing with fire/fireworks/guns. The area has no use by transients and it is not close enough to the highway for cigarettes to have caused the fire. No fire suppression disturbance was recorded, but impacts could have occurred.

Table 6-3. San Luis Rey Watershed: Data on fire events fires that started in *Arundo* between 2000 and 2007.

Fire Name	Date	Fire acreage	Acreage of Impacts from suppression	Total
SLR Fire #1-3	Oct 2006-Mar 2007	27.7	5.6	33.3
SLR Fire #4	June 2005	1.4	0	1.4
SLR Fire #5	June 17, 2007	64.3	0.9	65.2
SLR Fire #6	May 2004	10.4	?	10.4
	Total:	**103.8**	**6.5**	**110.3**

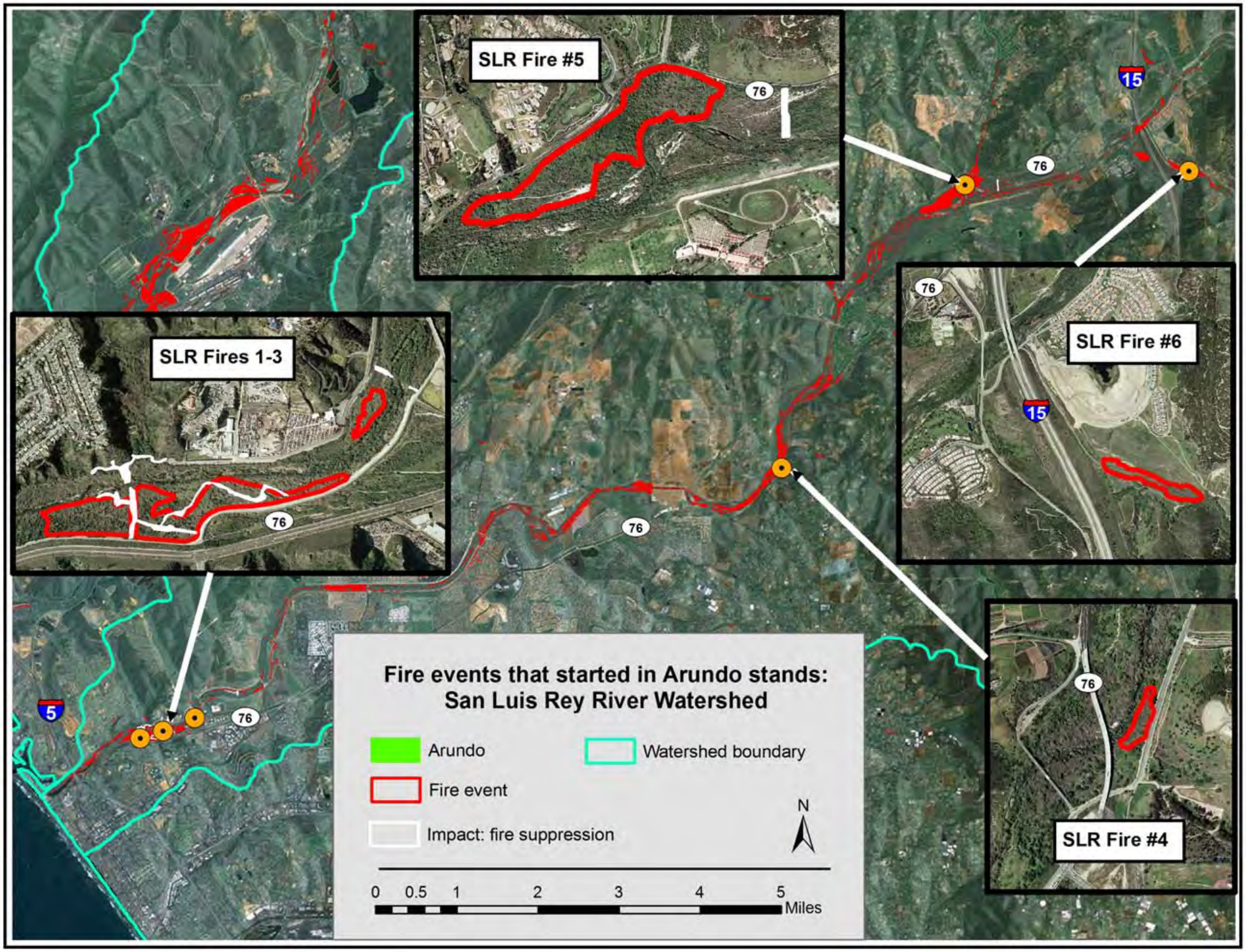

Figure 6-12. Fire events that started in *Arundo* stands on the San Luis Rey River from 2000 to 2007.

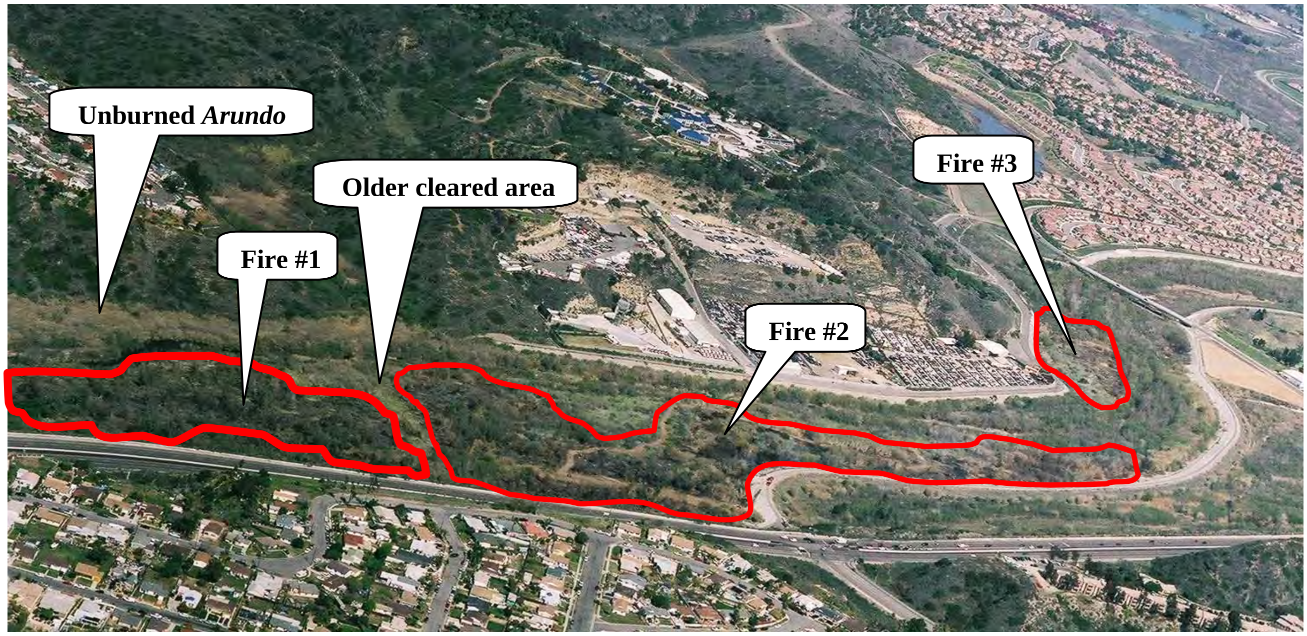

Figure 6-13. Footprint of fires # SLR 1-3 on the San Luis Rey River.

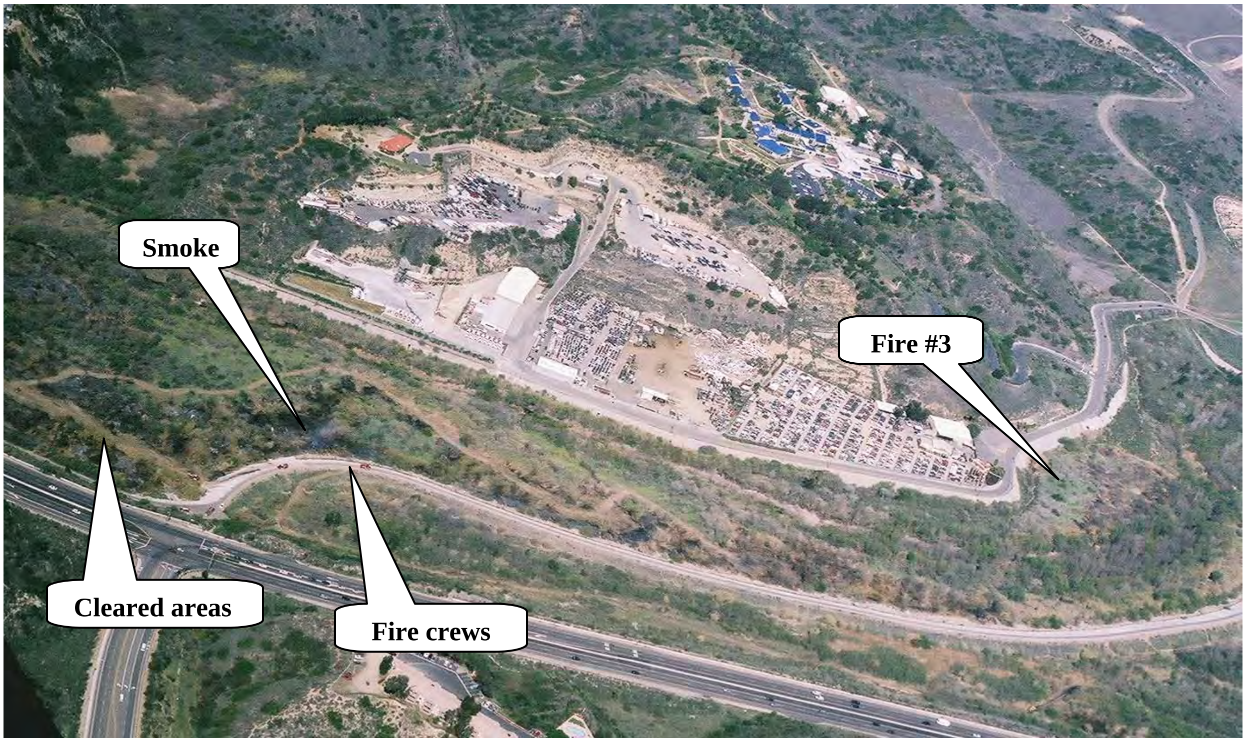

Figure 6-14. Location of fires # SLR 1-3 and fire containment cleared areas on the San Luis Rey River.

Figure 6-15. *Arundo* resprouting after a fire on the San Luis Rey River. Native trees are either dead, or still dormant (Fire SLR #5).

Figure 6-16. Immediately after a fire that burned an *Arundo* stand on the San Luis Rey River, leaving only ash and very little unburned material (Fire SLR #6).

Figure 6-17. Shortly after a fire through *Arundo*-infested riparian habitat on the San Luis Rey River. This demonstrates the quick and dense resprouting of *Arundo* before any native vegetation (Fire SLR #7).

6.4.1.2 Summary of Fire Impacts: Fires Initiated in *Arundo* Stands

For the eight-year period between 2000 and 2007, a total of 103.8 acres of riparian habitat burned during six recorded events (Table 6-4). *Arundo* dominated stands were 43.28 acres of the burned area and native dominated vegetation was 60.54 acres. *Arundo* stands on the San Luis Rey totaled 684.2 acres. During the eight-year period, 6.3% of the *Arundo* stands burned in fires that started in *Arundo* (Table 6-5). A total of 6.9% of *Arundo* stands either burned or were impacted during fire suppression for these events. The average acreage burned each year was 13.0 acres with an additional 0.8 acres impacted during fire suppression. These relationships will be used to extrapolate the fire and fire suppression impacts to other watersheds.

Table 6-4. San Luis Rey Watershed: Acreage summary of impacted vegetation for fires started within *Arundo* stands over an eight-year period (2000 to 2007).

Interval	**Acreage Burned: Fires Started in *Arundo***			**Acreage impacted during fire suppression**			**Total riparian acreage**
	Arundo	*Native*	*Riparian*	*Arundo*	*Native*	*Riparian*	*Total*
8 yr	43.3	60.5	103.8	3.7	2.8	6.5	110.3
Annual	5.4	7.6	13.0	0.5	0.4	0.8	13.9

Table 6-5. San Luis Rey Watershed: Acreage of *Arundo* that burned in fires started within *Arundo* stands over an eight-year period (2000-2007).

Fires started in *Arundo* (documented)	**Gross *Arundo* Acres**	***Arundo* burned acres over 8yrs**	**% *Arundo* burned in 8 yrs**	**Annual % *Arundo* burned in 8 yrs**
San Luis Rey	683.9	43.28	6.3%	0.8%

A key finding in this San Luis Rey River fire history is that *all recorded fires that started in the river were initiated in Arundo.* This does not mean that riparian habitat lacking *Arundo* cannot burn. The fires that started in *Arundo* burned large sections of riparian habitat (60.54 acres) that had little or no *Arundo*. What this shows is that un-invaded riparian habitat is not typically ignitable and usually only burns if a hot, well-developed fire is actively burning. This happens when *Arundo*-initiated fires start or when wildland fires occur.

6.4.1.3 Fires That Started Within *Arundo* Stands: Other Watersheds

A second data set was also prepared on behalf of the San Diego River Watershed for known fires that began within *Arundo* stands. The data set is most likely incomplete as less background information was found for the system. Two fires were mapped: 1) a 1990 8.4-acre fire that occurred on the lower watershed and 2) a January 2008 0.9-acre fire on the upper watershed. Over this 19 year time there were 9.3 acres of *Arundo* fires. This represents 6.2% of the *Arundo* stands on the San Diego River (150.5 acres), but over a longer time frame then the San Luis Rey fire documentation. There are more reports of fire events on the lower and upper San Diego River, but it was not possible to quantify them. Operators of a golf course along 1.5 miles of the heavily invaded upper river report frequent fire events over the past 15 years. Ignition source was likely a mix of transient use (which is high in that area) and discarded cigarettes from the highway that runs over the river. The lower San Diego River also has had additional fire events that are tied to homeless activity, but these could not be tied to specific locations and/or *Arundo* stands. The San Diego River *Arundo* fires show the same general pattern of ignition and fire pattern as the San Luis Rey River.

To help illustrate those fires that originate in *Arundo* stands are not isolated occurrences, we prepared a data set of all fires reported/encountered within *Arundo* for the project area (Figure 6-11). We mapped 12 fires that started in *Arundo* stands on other watersheds. This data set grossly underestimates the number of fires starting in *Arundo*, as it is limited to citations in reports, media coverage, fire response reporting, and discussion with program proponents on other watersheds. Even as a conservative representation of *Arundo* fire events, it shows that fires initiated within *Arundo* are indeed common events that have been observed on most watersheds with dense stands of *Arundo*. A brief qualitative overview demonstrates that each affected watershed has similar fire patterns - fires tend to occur where there are dense *Arundo* stands and ignition sources (encampments, bridges). Level of urbanization and transient use is highest along the coast for select watersheds (Ventura, San Luis Rey, San Diego), although interior cities and towns are found along rivers on others (Santa Ana, Santa Clara, Salinas). Agricultural use and migrant worker camps are found in the centralized portions of the watersheds (San Luis Rey, Santa Clara, Salinas). Remoteness, allowing cannabis cultivation and its associated fire impacts, has been observed in San Luis Rey and Santa Ana. These operations usually are not discovered until *Arundo* control is initiated. Highway and road overpasses occur at numerous points along each watershed creating conditions where stands can burn from discarded cigarettes. Highway bridges in dense and moderate urban/agricultural areas are particular attractants for transients and homeless use.

Since the pattern and frequency of fires appears to be similar across watersheds, applying the relationships outlined on the San Luis Rey Watershed seems reasonable. This holds true as an approximation of acreage burned on an annual and decade basis for each watershed and the overall study area, with two exceptions (Table 6-7). The Salinas Watershed was adjusted downward as humans report fewer fires there, likely due to a combination of different climatic conditions and lower use of the river. Also, the Santa Margarita River is mostly owned and managed by the Department of Defense, so there is limited use by transients in riparian areas. The lack of fires initiated within *Arundo* on the Santa Margarita River, where there are no encampments, supports that this is a primary ignition source.

6.4.2 Wildland Fires That Burn Arundo Stands

Arundo stands have two main effects on wildfires: 1) when a wildfire burns riparian habitat containing *Arundo*, it burns hotter than the habitat would have without the presence of *Arundo* and 2) *Arundo*-infested riparian habitat can act as a fire conveyor across the landscape. This can increase the size of riparian fires and may spread fires to upland areas that would normally have been separated by less flammable native riparian vegetation.

Wildland fires that burned riparian habitat containing *Arundo* stands are noted in Figure 6-18 and Table 6-6. Events that burned large riparian areas on San Dieguito, Santa Margarita, Santa Ana, and Santa Clara watersheds, as well as smaller events on San Luis Rey, San Diego and Otay watersheds, are noted. These are events that started in upland areas, and then developed into large wildland fires. These large wildfire events will often burn riparian vegetation regardless of how much *Arundo* is present. However, when an area infested with *Arundo* does burn, there is significantly more biomass present than would occur in comparison to uninvaded habitat (see section 6.1 on biomass). *Arundo* fuel loads are more vertical and well ventilated than native vegetation. Wildland fire events frequently have unburned patches within them, and vegetation with higher water content does not burn as well. For this reason, riparian zones often have more unburned or lightly burned areas. Presence of *Arundo* within the riparian zone increases the completeness of the burn, as well as the intensity. Wildland fire events that burn *Arundo* stands also lead to type conversion of those sites to *Arundo* dominated habitat (section 6.5.1).

The increased fuel load within *Arundo*-infested riparian habitat, and the resulting hotter and more complete fire, likely leads to riparian areas acting as fire corridors or areas of connectivity. This was documented for a fire on the Santa Clara River in June 2006 (Figure 6-19). This fire started on the north side of the river, burning 8,474 acres of uplands (A). The fire then moved into a riparian area with dense *Arundo*, crossed the 0.43 mile wide river, and then set the southern upland mountain range on fire (B). This fire burned an additional 107,560 acres, including setting the river on fire again 40 miles downstream (C). The fire crossed the river again, but did not set the north range uplands on fire. Agriculture and development blocked the fire's path (D). *Arundo*-infested riverine areas acting as fire corridors could be occurring in other areas, but it is difficult to prove because the effect of the *Arundo* is not always known. For the 2007 San Dieguito Watershed fire that burned 197,990 acres, there could have been areas that would not have conveyed the fire if *Arundo* had not been present, or there may have been larger central portions within the fire boundary that would not have burned (Figure 6-18). Similar patterns occurred in the 'freeway complex fire' that burned upland, riparian, and urban areas on the Santa Ana (Figure 6-18). The fire moved through *Arundo*-infested riparian habitat areas during early stages of the fire.

Table 6-6. Acreage of *Arundo* by watershed that burned during documented wildfires over a ten-year period.

Watershed	Gross *Arundo* Acres	*Arundo* acreage burned over 10 yrs (gross)	% *Arundo* burned over 10 yrs	Annual % *Arundo* burned over 10 yrs
Calleguas	231.5	71.5	30.9%	3.1%
Otay	18.6	0.5	2.5%	0.3%
San Dieguito	175.0	134.9	77.1%	7.7%
San Luis Rey	683.9	15.6	2.3%	0.2%
Santa Ana	2,723.9	95.7	3.5%	0.4%
Santa Clara	1,081.3	220.5	20.4%	2.0%
Sweetwater	42.3	6.0	14.2%	1.4%
Total:	**4,956.5**	**544.6**	**11.0%**	**1.1%**

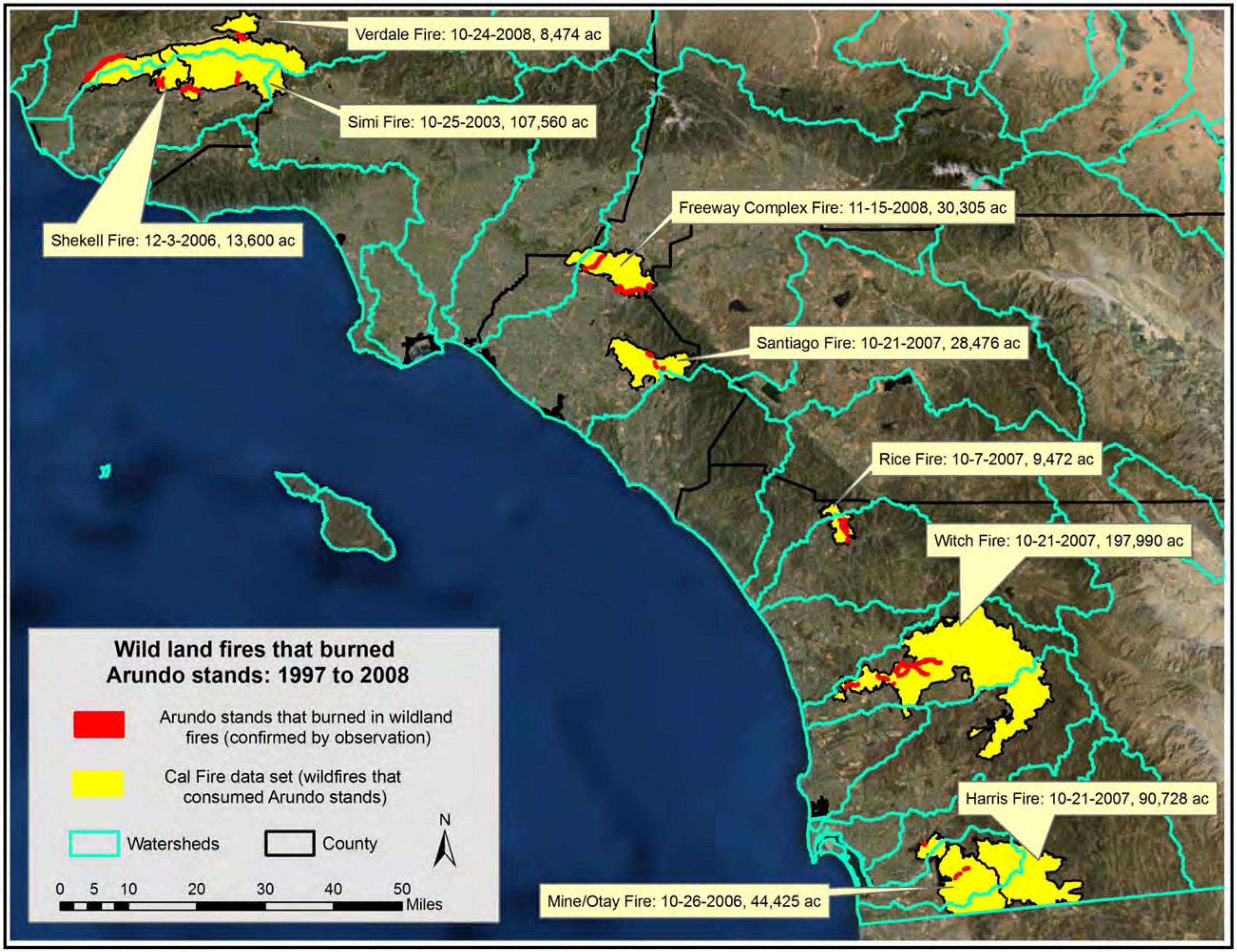

Figure 6-18. Location of wildland fires that burned *Arundo* stands within the project area from 1997 to 2008.

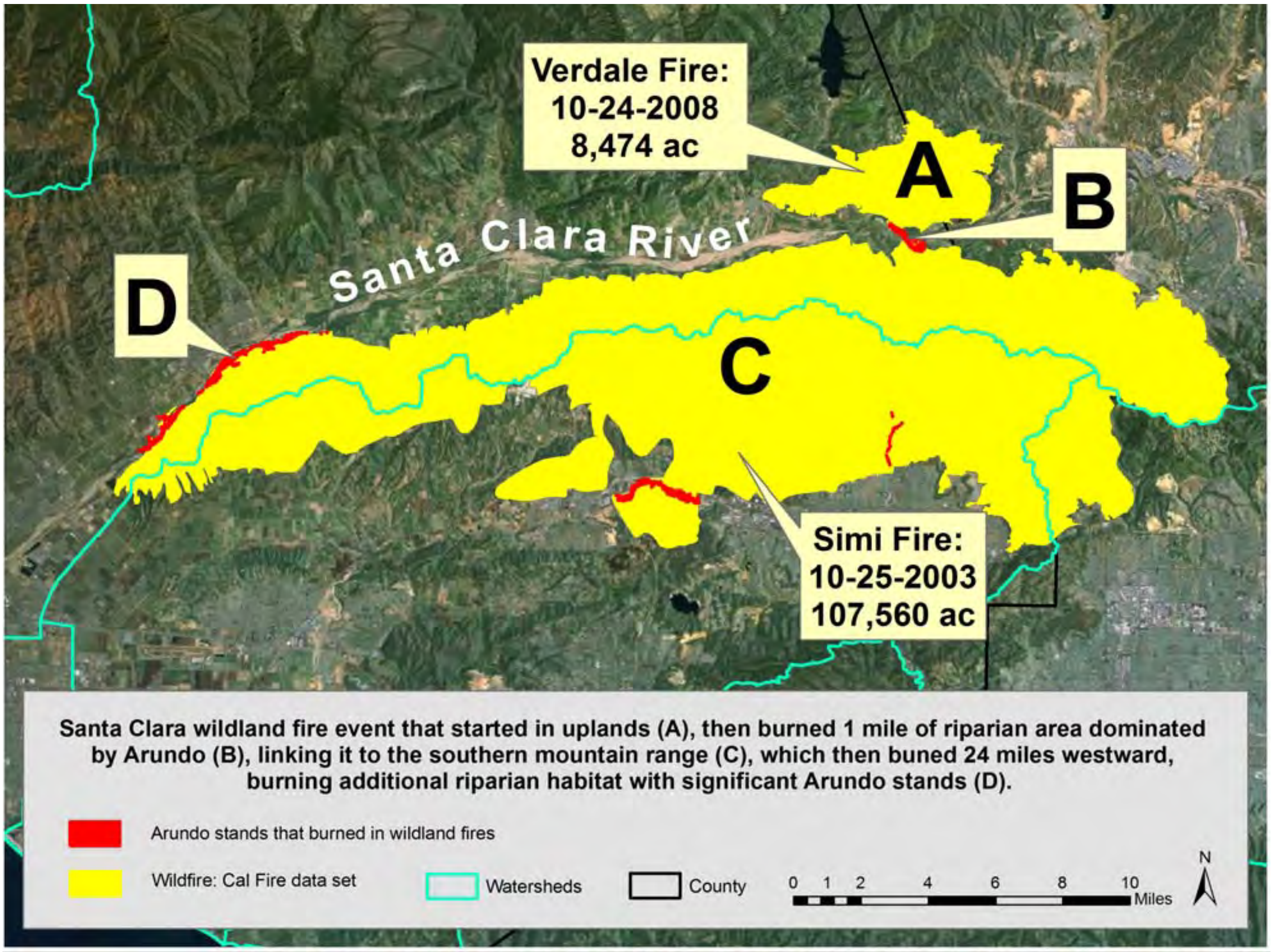

Figure 6-19. Wildfire on the Santa Clara with points A, B, C and D marked.

Conclusions:

- Watersheds with significant *Arundo* stands experience fire events that are due to the presence of *Arundo* (this study). The occurrence of these *Arundo*-initiated fires is quantifiable, both as percent of stands burned and acreage burned (this study).
- *Arundo* is a significant fire threat due to high fuel levels (Spencer et al. 2006, this study) in combination with harboring ignition sources. Fires that start in *Arundo* stands are observed on nearly all watersheds in the project area (this study).
- Wildland fires that burn riparian areas containing *Arundo* burn hotter and more completely due to higher fuel levels associated with the presence of *Arundo* (based on higher fuel loads – Spencer et al. 2006, this study).

Although fire was once a natural part of shrubland ecosystems that characterize the coastal southern California landscape, large riparian ecosystems provided natural firebreaks because native vegetation retains foliar water that resists ignition (Hanes 1971, Naveh 1975, Bell 1997, Rundel 1998, Keeley and Fotheringham 2001). This ‘firebreak’ function is lost if *Arundo* is present, and is even reversed, whereby riparian areas become 1) a fire source, or 2) a corridor of fire conveyance. Riparian ecosystems infested by *A. donax* adjacent to fire-prone shrublands in southern California appear to be on a trajectory to an invasive plant-fire regime cycle (Brooks et al. 2004). Clearly wildland fires are burning *Arundo* stands in riparian areas. While it was not documented in this study, it is also likely that *Arundo*-initiated fires will lead to wildland fires given the frequency and intensity of *Arundo* fire events.

Fire Districts/Departments are keenly aware of the fire risks associated with *Arundo* stands. This led the City of Oceanside (San Luis Rey) to enact an ordinance under its code enforcement allowing action to be taken if private property has *Arundo* stands that are a fire risk. This action was driven by two factors: fires occurring in *Arundo* and the identification of wildland fire risk due to fires moving down *Arundo*-infested riparian corridors into urban areas.

6.5 Fire Impacts

In the previous section, it was established that *Arundo* impacts fire events in two general situations: fires that originate in *Arundo* stands (resulting from high fuel load combined with ignition sources) and wildland fires that burn *Arundo*-infested riparian habitat. This chapter will examine and quantify, based on the *Arundo* spatial data set, the impacts that these *Arundo*-driven fires cause.

6.5.1 Type Conversion to Arundo-Dominated Habitat

Arundo stands have high fuel loads and a tall growth form. Infestations of *Arundo* mixed with native species spread fire vertically into the canopy of riparian trees, as well as burning trunks (Figures 6-15 to 17 & 6-20; Ambrose and Rundel 2007). After a fire, *Arundo* immediately (1-2 weeks) begins regrowth from its rhizomes, whereas native riparian plants can remain dormant for several months. High mortality of native trees and shrubs is frequent in comparison to *Arundo*. Furthermore, *Arundo* grows much faster than native plants, up to 3-4 times faster than native riparian plants after fire on the Santa Clara River (Ambrose and Rundel 2007). A year after the fire, *Arundo* dominated the area, comprising 99% relative cover and a 24% increase in relative cover compared to pre-fire conditions (Ambrose and Rundel 2007).

Figure 6-20. *Arundo* one year after a fire, already 2-3 feet high, at the site of fire SLR #6.

A positive-feedback cycle is created whereby the high growth rate of *Arundo*, the fire adapted phenology of *Arundo*, and increased nutrient levels after fire contribute to type conversion. This domination by *Arundo*, in turn leads to more fires, creating an invasive plant-fire regime cycle (Ambrose and Rundel 2007, this study). Results from the mapping data also show that areas with mixed-*Arundo*/native vegetation prior to fire events are dominated by *Arundo* after the fires. This type conversion is important because it is a significant reduction in habitat value (section 7.1, Table 6-5). Fires started within *Arundo* combined with wildfires burned 12% (1,058 ac) of the *Arundo* acreage on all watersheds over a ten-year period (Table 6-7). Type conversion feeds the positive feedback loop. *Arundo*-dominated sites have higher biomass than mixed or patchy stands, increasing the likelihood of fire.

It should be noted that fire only affects within site spread/invasion. It does not allow or cause invasion to the broader system. Invasion outside the site still only occurs through movement of live plant material (flood action and/or human movement of rhizomes). However, the larger the *Arundo* sites, the more material there is for flood-based dispersal.

Table 6-7. Burned *Arundo* acreage from fires that start in *Arundo* and wildfires that burn *Arundo* (for one year and ten-year periods).
Acreages are calculated based on San Luis Rey watershed documented fire events, which is 0.8% of the gross *Arundo* acreage burned annually.

Watershed	**Gross *Arundo* Acres**	**Fires that start in *Arundo***		**Wildfires that burn *Arundo***		**Combined *Arundo* fire totals**	
		Burned *Arundo* acreage* (1 yr)	**Burned *Arundo* acreage (10 yrs)**	**Burned *Arundo* acreage (1 yr)**	**Burned *Arundo* acreage (10 yrs)**	**Burned *Arundo* acreage (1 yr)**	**Burned *Arundo* acreage (10 yrs)**
Calleguas	231.5	1.9	18.5	7.2	71.5	9.00	90.0
Carlsbad	147.9	1.2	11.8	-	-	1.18	11.8
Los Angeles River	132.8	1.1	10.6	-	-	1.06	10.6
Otay	18.6	0.1	1.5	0.1	0.5	0.20	2.0
Penasquitos	23.6	0.2	1.9	-	-	0.19	1.9
Salinas[1]	2,006.1	1.6	16.0	-	-	1.60	16.0
San Diego	150.2	1.2	12.0	-	-	1.20	12.0
San Dieguito	175.0	1.4	14.0	13.5	134.9	14.89	148.9
San Gabriel	44.6	0.4	3.6	-	-	0.36	3.6
San Juan	175.2	1.4	14.0	-	-	1.40	14.0
San Luis Rey	683.9	5.5	54.7	1.6	15.6	7.03	70.3
Santa Ana	2,723.9	21.8	217.9	9.6	95.7	31.36	313.6
Santa Clara	1,081.3	8.7	86.5	22.1	220.5	30.70	307.0
Santa Margarita [2,3]	688.9	0.6	5.5	-	-	0.55	5.5
Santa Monica	18.6	0.1	1.5	-	-	0.15	1.5
South Coast	29.8	0.2	2.4	-	-	0.24	2.4
Sweetwater	42.3	0.3	3.4	0.6	6.0	0.94	9.4
Tijuana	135.6	1.1	10.8	-	-	1.08	10.8
Ventura	332.0	2.7	26.6	-	-	2.66	26.6
Total:	**8,841.7**	**51.3**	**513.3**	**54.5**	**544.7**	**105.8**	**1,058.0**
% of Gross Ac:			**5.8%**		**6.1%**		**12%**

[1] Annual fire rate lowered to 10% of that for southern California due to weather conditions and lack of fire reports.
[2] Fires starting in *Arundo* are less common on Camp Pendleton (DoD facility), lowered to 10% for the watershed.
[3] Most *Arundo* had been removed in areas where wildfires burned riverine areas, so no acreage was counted.

6.5.2 Impacts to Fauna,

Fires that are started within *Arundo* stands and wildfires made worse by *Arundo* stands can result in direct mortality of fauna, especially species that cannot escape rapidly. Mortality will vary depending on the season in which the fire occurs. During nesting season, fires may result in direct loss of eggs and young birds. Arroyo toads remain buried during portions of the non-breeding season, and may not survive a fire, depending on the intensity. The addition of ash and other mobilized material (erosion) into breeding pools/ponds may impact fish and amphibians, and the loss of vegetation along waterways may impact shading and water temperature regulation.

After a fire, the habitat is degraded to a condition that does not support species for an amount of time that depends on the fire's intensity and season. One year of functional loss and a degraded condition for 2-5 years are evident on most sites. When the habitat does come back, it may not return to pre-fire conditions and may not be able to support the same abundance and diversity of fauna and flora. Areas that burned may be more open and have more weedy species. If *Arundo* was present before the fire, this is especially a concern, as it re-grows faster than the native species (see Sec 6.5.1).

The degradation of riparian habitat from *Arundo*-initiated fires is estimated for all watersheds based on data from San Luis Rey (Table 6-8). Riparian areas that burn during *Arundo*-initiated fires exceed the *Arundo* acreage that burns (705.8 ac vs. 513.3 ac). Suppression activities impact 32.1 acres of riparian habitat and 43.6 acres of *Arundo* habitat. Cumulatively this covers 1,200 acres of riparian habitat over a ten-year period. This is a significant amount of acreage and it does not include wildfire impacts.

Estimation of the *Arundo* acreage that burns is presented in Table 6-5. Wildfires can burn riparian vegetation during certain conditions, so the entire event cannot be ascribed as an *Arundo* fire impact. The presence of *Arundo* does increase the intensity, and *Arundo* may convey wildfires. These impacts are difficult to quantify and to identify spatially, complicating exploration of their impacts on flora and fauna. No specific accounting of these impacts is presented.

However, fires initiated *within Arundo* stands that result in mortality of fauna and flora are fully ascribed as impacts caused by the *Arundo*. Quantifying this presents challenges, but detailed mapping of fires on the San Luis Rey watershed (Section 6.4.1) present an opportunity to explore this. Very detailed survey data (aggregated from USGS, CalTrans, and ACOE) for least Bell's vireos, Southwestern willow flycatchers, and Arroyo toads indicate that *Arundo* fires that burn riparian habitat have directly impacted occupied habitat for endangered wildlife species (Figure 6-21, Table 6-9). These *Arundo*-dominated areas are of moderate habitat quality to begin with, but flora and fauna utilize pockets of native vegetation. *Arundo* fires can also spread into adjacent higher quality native riparian habitat. Fire suppression activities impact both *Arundo* and native habitat. The area of fires SLR#1, #2 and #3 is very near the mouth of the river, which is at the edge of least Bell's vireo habitat range. Least Bell's vireos were present on the edges of all the fire areas. Fire SLR#4 had least Bell's vireo use on the upstream edge of the fire area. Fire SLR#5 was a fire that occurred during breeding season in a high-use least Bell's vireo area. Mortality likely occurred. Arroyo toads could also have occurred on-site in low numbers. Site SLR#6 is in core, high density Arroyo toad habitat, and mortality likely occurred. Least Bell's vireo use could also occur in this area (only limited surveying was completed for this site, but they are abundant nearby).

In addition to direct take of fauna, habitat that was burned in all of the areas has a significantly reduced habitat value and function. Areas with *Arundo* present would have nearly 100% *Arundo* cover post-fire, while burned native vegetation takes over five years to recover structure and productivity.

Table 6-8. Summary of acreage impacted by burning and fire suppression from fires that start in *Arundo*.
Burned acreage and suppression acreage for watersheds is calculated based on San Luis Rey watershed-documented fire events (multiplying percentage from San Luis Rey by gross *Arundo* acreage for each watershed).

Fires that start in *Arundo*		**Fire: *Arundo***		**Fire: Riparian**		**Suppression: *Arundo***		**Suppression: Riparian**		**All Riparian Impacts**	
Watershed	**Gross *Arundo* Acres**	**Annual burn ac (0.8%)**	**10 year total**	**Annual burn ac (1.1%)**	**10 year total**	**Annual impacted ac (0.068%)**	**10 year total**	**Annual impacted ac (0.051%)**	**10 year total**	**Annual ac**	**10 year total**
Calleguas	231.5	1.9	18.5	2.5	25.5	0.2	1.6	0.1	1.2	4.7	46.7
Carlsbad	147.9	1.2	11.8	1.6	16.3	0.1	1.0	0.1	0.7	3.0	29.8
Los Angeles River	132.8	1.1	10.6	1.5	14.6	0.1	0.9	0.1	0.7	2.7	26.8
Otay	18.6	0.1	1.5	0.2	2.1	0.0	0.1	0.0	0.1	0.4	3.8
Penasquitos	23.6	0.2	1.9	0.3	2.6	0.0	0.2	0.0	0.1	0.5	4.8
Salinas[1]	2006.1	1.6	16.0	2.2	22.1	0.1	1.4	0.1	1.0	4.0	40.5
San Diego	150.2	1.2	12.0	1.7	16.5	0.1	1.0	0.1	0.8	3.0	30.3
San Dieguito	175.0	1.4	14.0	1.9	19.2	0.1	1.2	0.1	0.9	3.5	35.3
San Gabriel	44.6	0.4	3.6	0.5	4.9	0.0	0.3	0.0	0.2	0.9	9.0
San Juan	175.2	1.4	14.0	1.9	19.3	0.1	1.2	0.1	0.9	3.5	35.3
San Luis Rey	683.9	5.5	54.7	7.5	75.2	0.5	4.7	0.3	3.4	13.8	138.0
Santa Ana	2723.9	21.8	217.9	30.0	299.6	1.9	18.5	1.4	13.6	55.0	549.7
Santa Clara	1081.3	8.7	86.5	11.9	118.9	0.7	7.4	0.5	5.4	21.8	218.2
Santa Margarita [2]	688.9	0.6	5.5	0.8	7.6	0.0	0.5	0.0	0.3	1.4	13.9
Santa Monica	18.6	0.1	1.5	0.2	2.0	0.0	0.1	0.0	0.1	0.4	3.8
South Coast	29.8	0.2	2.4	0.3	3.3	0.0	0.2	0.0	0.1	0.6	6.0
Sweetwater	42.3	0.3	3.4	0.5	4.7	0.0	0.3	0.0	0.2	0.9	8.5
Tijuana	135.6	1.1	10.8	1.5	14.9	0.1	0.9	0.1	0.7	2.7	27.4
Ventura	332.0	2.7	26.6	3.7	36.5	0.2	2.3	0.2	1.7	6.7	67.0
Totals:	**8,841.7**	**51.3**	**513.3**	**70.6**	**705.8**	**4.4**	**43.6**	**3.2**	**32.1**	**129.5**	**1,294.8**

[1] Annual fire rate lowered to 10% of that for southern CA due to weather conditions and lack of fire reports.
[2] Fires starting in *Arundo* are less common on Camp Pendleton (DoD facility), lowered to 10% for the watershed.

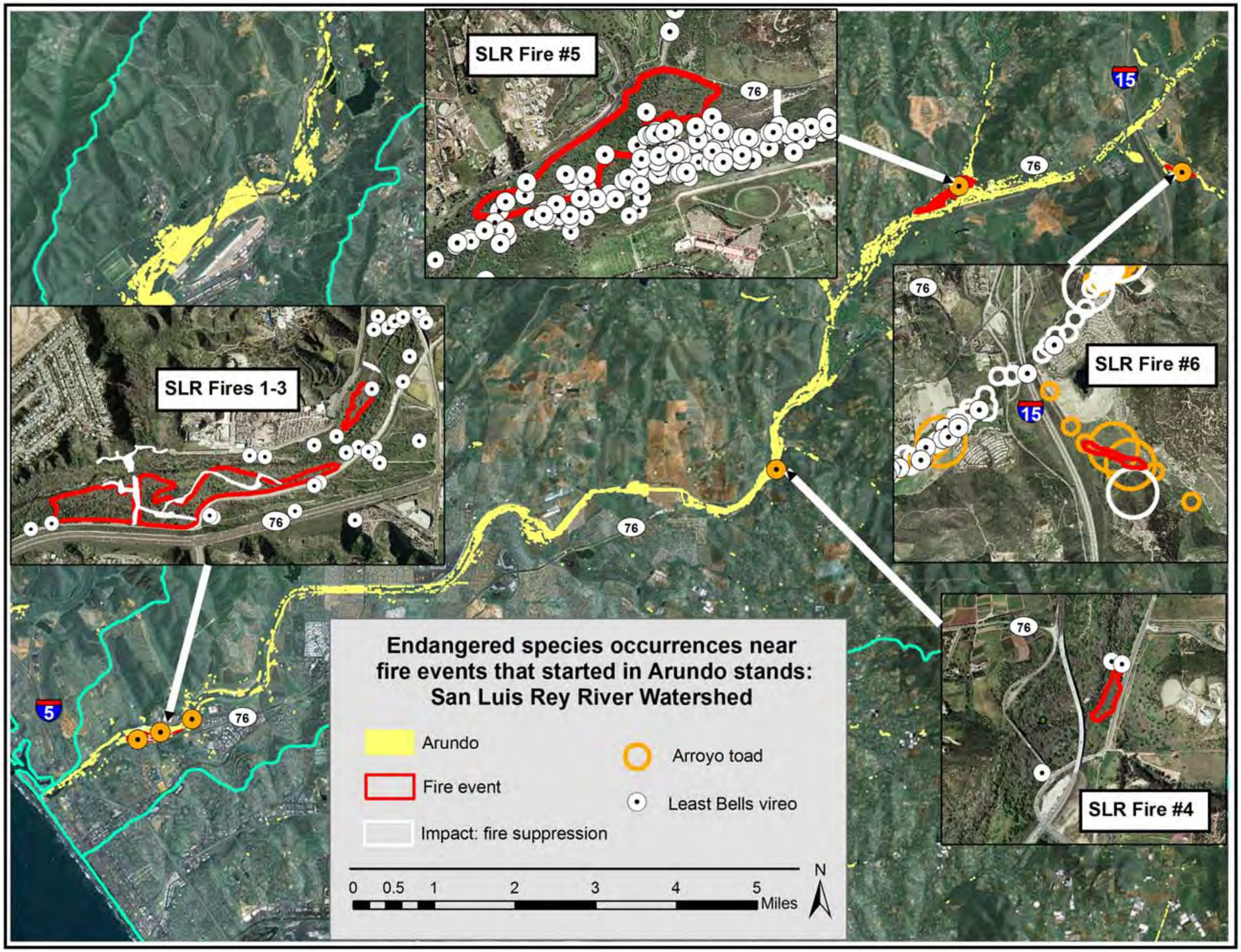

Figure 6-21. Fire events that started in *Arundo* stands on the San Luis Rey River showing sensitive species locations.

Table 6-9. Summary of San Luis Rey River *Arundo* fire impacts on federally endangered species.

Fire Event	Least Bell's vireo	Arroyo toad	Tidewater goby	Southwestern willow flycatcher
SLR#1,2&3	Low	None	Low	Possible
SLR#4	Medium	None	None	Possible
SLR#5	High	Low	None	Possible
SLR#6	Low	High	None	Possible

6.5.3 Impacts from Emergency Acts

Prior to or during fire events, actions are sometimes carried out to reduce the spread of a fire. These actions generally involve clearing vegetated areas to form fire breaks. These cleared areas tend to become weedy due to the disturbance of the soil and removal of established vegetation. If cleared areas are within or near *Arundo* stands, their creation may spread *Arundo* fragments throughout the area and establish new *Arundo* populations. Disturbed areas retain modified topography and poor quality habitat until there is a flow event that resets the geomorphology and allows native recruitment to occur. Depending on the location of the cleared area within the profile, this may occur quickly or after a prolonged period of time.

Emergency actions may also directly impact flora and fauna, as seen in Figure 6-21, where cleared areas were within least Bell's vireo (SLR#1,2,3 & 5) and arroyo toad habitat (SLR#5). The federally endangered plant *Ambrosia pumila* (San Diego ambrosia) also occurred near the disturbance on fire SLR#5.

Although acreage impacted seems minor at first, fire suppression impacts of 43.6 acres of *Arundo* and 32.1 acres of native riparian habitat (Table 6-8) are generated for the study area over 10 years. Many of these impacts are severe modifications (e.g. grading) of occupied threatened and endangered species' habitat.

6.6 Conclusions: Fire Impacts

Arundo significantly changes the intensity, frequency and behavior of fires. It has transformed heavily invaded riparian habitat, which includes many coastal river systems in southern California, from a vegetation type that is normally resistant to fire to a source of fire events. Areas invaded with *Arundo* are flammable, harbor ignition sources, and spread fires both within riparian habitat as well as across the landscape.

- *Arundo* stands are highly flammable throughout the year with large amounts of fuel (15.5 kg/m^2 of biomass), a large amount of energy (287.1 MJ/m^2), and a tall well-ventilated structure with dry fuels distributed throughout the height profile. (Section 6.1)
- Fires frequently start in *Arundo* stands. The primary ignition sources are transient encampments and discarded cigarettes from highway overpasses. (Section 6.1)

- *Arundo* stands strongly attract transient use (dense cover and shelter). This was documented throughout the study area with numerous high use locations noted in both urban and agricultural areas. (Section 6.3.1)
- Fires initiated in *Arundo* stands occur due to fuel and ignition source occurring at the same location. This is a newly defined class of fire events. (Section 6.4.1)
- Fires that are initiated in *Arundo* burn both *Arundo* stands and native riparian areas. In addition, suppression of fires also impacts riparian habitat. Impacts were calculated for all watersheds using San Luis Rey as a case study. Over a ten-year period for the study area, *Arundo*-initiated fire events are estimated to have burned 513 acres of *Arundo* and 706 acres of native riparian habitat. Fire suppression over a ten-year period has impacted 44 acres of *Arundo* and 32 acres of native riparian vegetation. (Section 6.5)
- Wildfires burn a significant acreage of *Arundo* stands. Over ten years, 11% of *Arundo* stands (544 acres) burned within the study area. (Section 6.4.2)
- Due to high fuel load and stand structure, areas with *Arundo* burn hotter and more completely then native vegetation during wildfire events. (Section 6.4.2)
- *Arundo* stands appear to be conveying fires across riparian zones- linking upland vegetation areas that would have been separated by less flammable riparian vegetation. This can have catastrophic impacts like those observed in the 2008 Simi fire. The 8,474-acre fire crossed the Santa Clara River and then burned an additional 107,560 acres. (Section 6.4.2)
- *Arundo* fires accelerate the dominance of *Arundo* in invaded areas due to rapid re-growth and low mortality of *Arundo*. (Section 6.5.1)
- *Arundo* fire events lead to both direct mortality of wildlife and plants (some of which are sensitive) as well as a longer-term quality reduction of burned riparian areas (post-fire recovery of vegetation and structure). (Section 6.5.2)
- Emergency actions tied to *Arundo* fire suppression also result in impacts (disturbance of both *Arundo* and riparian vegetation) that degrade riparian habitat and/or may result in mortality of species. (Section 6.5.4)

7.0 IMPACTS OF *ARUNDO*: Federally Endangered and Threatened Species

7.1 Examination and Characterization of *Arundo* Impacts on Flora and Fauna

Arundo's impacts on federally listed species will be evaluated and described. These species have been intensively studied with: documentation of distribution, assessment of stresses on their habitat, and identification of ecological constraints to their ability to persist in the habitats that they occupy. This allows a thorough exploration of impacts caused by *Arundo*, as well as the subjective ranking of the impact level. The determination of critical habitat areas and extensive survey data collected for the species also allows for a spatial assessment of their interaction with *Arundo* distribution at the watershed level (using the *Arundo* spatial data collected for this study). A total of 22 federally listed species will be examined representing five taxonomic groups: amphibians (4), birds (8), fish (4), mammals (1), and plants (5).

To determine the impacts of *Arundo* on federally listed species, we reviewed documents prepared by the U.S. Fish and Wildlife Service during their evaluations for listing and recovery. We restricted the focal species to federally listed species in order to 'standardize' the individual species descriptions and treatment (biology, reproduction, distribution, review of impacts and stresses). The documents used include: Critical Habitat Designations, Recovery Plans, Incremental Reviews (5 year, 10 year, etc.), and Biological Opinions (Section 7 and 10) issued for projects that may adversely impact listed species. A significant amount of the data presented in this chapter is taken directly from numerous Biological Opinions issued by the USFWS. Many of these Biological Opinions are for *Arundo* control programs on the watersheds within the study area, including: Salinas, Ventura, Santa Clara, Santa Ana, San Juan, Santa Margarita, San Luis Rey, Carlsbad CHU, and San Diego River. Additional Biological Opinions and documents prepared by NOAA/NMFS for programs carrying out activities (channel maintenance, sand extraction, etc.) in the project watersheds were also reviewed. These documents are a significant resource as they specifically examine: population status (distribution and abundance, sometimes trends), general biology (reproduction, foraging, movement/migration, predation, habitat needs), and stressors for the species (abiotic, biotic, and anthropogenic). Impacts caused by *Arundo* invasion are evaluated for each of these areas.

7.1.1 Determine Arundo Impact Score

Information from USFWS documents, this report, and other data, literature, and expert opinions was used to determine an 'Impact Score' for each species on a 10-point scale (Table 7-1). Impacts of *Arundo* on each sensitive species are described in Section 7.2, with evaluation of general ecological and habitat needs, reproduction, movement, range and other impacts/threats. Higher scores reflect significant *Arundo* impacts to both abiotic and biotic modification of riparian systems. A general discussion of *Arundo* impacts (both biotic and abiotic) is presented in section 2.7.

Table 7-1. *Arundo* Impact Score for each sensitive species.

Score	Impact Level	Impacts
10	Very severe	Very significant alteration of abiotic structure and biological function, and direct take of individuals
9	Severe	Significant alteration of abiotic structure and biological function and direct take of individuals
8	Very high	Alteration of abiotic structure and biological function, direct take possible
7	High	Alteration of abiotic structure and biological function: impacts on mobility
6	Moderate/High	Moderate alteration of abiotic structure and/or biological function
5	Moderate	Minor alteration of abiotic structure and/or biological function
4	Low/Moderate	Low abiotic or biotic impacts
3	Low	Slight changes in food resources, harboring pathogen/predator OR Minor changes to estuary systems
2	Very low	Minor interaction: mobility
1	Very low/Improbable	Difficult to describe any interaction with *Arundo*
0	None	No interaction

7.1.2 Determine Arundo and Federally Listed Species 'Overlap Score'

To characterize the level of interaction between each sensitive species and *Arundo*, a watershed specific 'Overlap Score' was created (Table 7-2). This metric measures the abundance and distribution of *Arundo* and the sensitive species, with a specific focus on overlap in spatial distribution. The score for the metric captures the level of interaction between *Arundo* and the listed species. The *Arundo* spatial data set was examined with GIS data for each listed species (Maps 1-30, Appendix B).

A listed species with large populations high on the watershed where *Arundo* does not occur would be ranked with a low score, even if the watershed has high *Arundo* abundance overall. A high metric score (10) requires frequent occurrence of the sensitive species within portions of the watershed that have high *Arundo* abundance. Low scores are given for species that have low occurrences within areas of low *Arundo* cover. Intermediate scores are given for co-occurrence, where there are moderate levels of abundance for *Arundo* and/or sensitive species. Species that occur at or near the end of the watershed may not have significant co-occurrence with *Arundo* stands, but they may have significant *Arundo* upstream of them that is modifying abiotic processes or generating *Arundo* biomass into the sensitive species habitat (*Arundo* debris, or modified hydrology). These interactions, which are often for estuarine or river mouth species, have a full range of overlap/interaction scores from low to high.

Table 7-2. Definition of overlap scores that are assigned to federally listed species.

Overlap Score	***Arundo* abundance** (nearby or upstream of sensitive species)	**Listed species *relative* abundance & distribution**	**Interaction Level**
10	Very High	Very high (core area)	High interaction
9	High	High	
8	High	Moderate	
7	Moderate	High	
6	Moderate	Moderate	Moderate interaction
5	Low	High	
4	High/Moderate	Low	
3	Low	Moderate	
2	Low	Low	Low interaction
1	Any	Historic range* or a few records of more ‘abundant species	Possible or potential interaction
0	Any	Not recorded	No interaction

* Sensitive species not currently known to occur in the area, but has confirmed historic distribution.

7.1.3 Calculate 'Cumulative Arundo Impact Scores'

The 'Impact Score' for each species is then multiplied by the 'Overlap Score' on each watershed to generate a 'Cumulative *Arundo* Impact Score' for each sensitive species. This data can be examined for each species, taxonomic group, and watershed. Scores highlight species and those watersheds that are most impacted by *Arundo*.

7.2 Species Descriptions and *Arundo* Impacts Elucidated

Each federally listed species is evaluated below for potential impacts caused by *Arundo*. These impacts may be either indirect (modification of habitat) or direct (loss of life- such as fire or emergency response to fire or flood). All types of impacts are explored and relative importance/magnitude of the impact is described for each species. A general discussion of *Arundo* impacts (both biotic and abiotic) is presented in section 2.7.

Interaction of *Arundo* distribution and species occurrences is presented by watershed in Table 7-3 and Appendix B. Information on the biology and distribution of each species is taken from USFWS documents and other reports, which are listed at the end of each species’ summary. Citations to particular studies within these documents are not listed here.

7.2.1 California Tiger Salamander (*Ambystoma californiense*)

Federal status:	Endangered for the Santa Barbara Distinct Population Segment (September 2000). Critical habitat was designated in August 2005, but may change as it is under review.
State status:	Threatened (May 2010).
Arundo impact score:	1

General Ecological Needs/Habitat Affinities:
The California tiger salamander is a stocky, terrestrial amphibian. Adult males are about 20 cm (8 in) long, and females a little less than 18 cm (7 in). It is restricted to grasslands and low foothill regions (typically below 2000 feet/610 meters) where lowland aquatic sites are available for breeding. They prefer natural ephemeral pools, or ponds that mimic them (e.g. stock ponds that are allowed to go dry). While on land they are generally underground in burrows. They are poor burrowers, therefore require refuges provided by ground squirrels and other burrowing mammals in which to enter a dormant state called *estivation* during the dry months.

Arundo impacts: *Arundo is not typically abundant on the low order streams and steeper hilly terrain that are favored by the tiger salamander. No significant alteration of abiotic process would occur.*

Breeding/Life History:
California tiger salamanders require lowland aquatic sites for breeding. They prefer natural ephemeral pools, or ponds that mimic them. Around November, salamanders come out of their burrows, usually on a wet, stormy night. They may travel as much as a mile to a pond to breed. They prefer natural ephemeral pools, or ponds that mimic them. Females lay eggs singly or in small groups. They may lay as many as 1,300 eggs. These are usually attached to vegetation. Eggs hatch in about 10 to 14 days. Larvae require significantly more time to transform into juvenile adults than other amphibians such as the western spadefoot toad and Pacific tree frog. Around late spring, salamanders leave the ponds to find burrows. Adults reach sexual maturity in 4 or 5 years. Although they may live as long as 10 years, they may reproduce only once, or not at all. Some salamanders die before they reach sexual maturity, and others may not find a suitable pond for mating in very dry years. The main predators of the California tiger salamander are birds such as egrets and herons, fish, and bullfrogs.

Arundo impacts: *Little impact as Arundo not abundant enough to impact hydrology of pools.*

Diet:
Adults mostly eat insects. Larvae eat algae, mosquito larvae, tadpoles and insects.

Arundo impacts: *Little impact as Arundo not abundant enough to impact food resources or habitat that food resources depend on.*

Movement:
A California tiger salamander spends most of its life on land underground. It uses burrows made by squirrels and other animals. Around November, usually on a wet night, salamanders come out of their burrows and may go as much as a mile to a pond to breed. In late spring, salamanders leave the ponds to find burrows.

Arundo impacts: *Little impact as Arundo not abundant enough to impact movement of salamanders or change distribution of mammals that create micro habitat needed by the species.*

Status/Distribution or Historic and Current Range:
This species is restricted to California and does not overlap with any other species of tiger salamander. They are found in grassland and oak savannah plant communities with vernal pools and/or seasonal ponds (including constructed stock ponds). They predominantly occur from sea level to 2,000 feet in central California. In the Coastal region, populations are scattered from Sonoma County in the northern San Francisco Bay Area to Santa Barbara County (up to elevations of 3,500 ft/1,067 m), and in the Central Valley and Sierra Nevada foothills from Yolo to Kern counties (up to 2,000 ft/610 m).

Arundo impacts: *There is very low interaction between Arundo distribution and salamanders. Critical areas have almost no overlap and occurrence data has a few points of interaction (Appendix B). Pajaro River in San Benito would be the greatest interaction and Salinas is very low (based on current Salinas survey data). If salamanders were found to occur in the Salinas River itself significant revision of impact scores would be needed.*

Decline and Threats:
The primary cause of the decline of California tiger salamander populations is the loss and fragmentation of habitat from human activities and the encroachment of non-native predators. All of the estimated seven genetic populations of this species have been significantly reduced because of urban and agricultural development, land conversion, and other human-caused factors. A typical salamander breeding population in a pond can drop to less than twenty breeding adults and/or recruiting juveniles in some years, making these local populations prone to extinction. California tiger salamanders therefore require large contiguous areas of vernal pools (vernal pool complexes or comparable aquatic breeding habitat) containing multiple breeding ponds to ensure re-colonization of individual ponds.

Arundo impacts*: No additional Arundo interaction with decline and threats.*

Overall impact metric for *Arundo* on CA tiger salamander: Very low/improbable impact, score of 1

Interaction of *Arundo* distribution and CA tiger salamander occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Species Account, California Tiger Salamander (*Ambystoma californiense)*, U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office.

7.2.2 Arroyo Toad (*Bufo californicus*)

Federal status:	Endangered, December 16, 1994. Critical habitat designated April 13, 2005. Recovery plan completed in 1999.
State status:	Not listed?
Arundo impact score:	10

General Ecological Needs/Habitat Affinities:
Arroyo toads breed and deposit egg masses in shallow sandy pools, which are usually bordered by sand-gravel flood-terraces. Optimal breeding habitat consists of low-gradient sections of slow-moving streams with shallow pools, nearby sandbars, and adjacent stream terraces. Stream order, elevation, and floodplain width appear to be important factors in determining habitat capacity. High stream order (i.e., 3rd to 6th order), low elevation (particularly below 3,000 ft/914 m) and wide floodplains seem to be positively correlated with arroyo toad population size. However, small populations are also found in 1st and 2nd order streams up to 4,600 ft (1,402 m). Outside the breeding season, arroyo toads are

essentially terrestrial and use a variety of upland habitats including (but not limited to): sycamore-cottonwood woodlands, oak woodlands, coastal sage scrub, chaparral, and grasslands.

Arundo impacts: *Changing geomorphic processes- rivers and streams move away from complex multi-channel structure with elevational complexity to a single narrow channel. The single channel is also deeper, typically transporting sediment out of the system under low flow events. Larger events also may not be generating as much sediment deposition in open areas. Because there are fewer open areas sediment is being trapped within Arundo stands which themselves have low arroyo toad use (Camp Pendleton management reports). Arundo has a very strong affinity for the same areas favored by arroyo toads: low elevation, broad floodplains and especially high stream order systems. Direct take of the species can occur during Arundo fire events and fire suppression efforts.*

Breeding/Life History:
Breeding is typically from February to July on streams with persistent water. Eggs are deposited and develop in shallow pools with minimal current and little to no emergent vegetation. Substrate is generally sand or fine gravel overlain with silt. Eggs hatch in 4-5 days, and hatchlings are immobile for 5-6 days. They then disperse from the pool margin into surrounding shallow water and develop for 10 weeks. After metamorphosis (typically June/July) the juvenile toads remain on the bordering gravel bars until the pool dries out (8-12 weeks, depending on site and rainfall/conditions).

Arundo impacts: *Arundo does not typically occur within pools/stream channel, but it may overhang pools/stream channel. Arundo does use large amounts of water, which could alter hydrology of the stream, potentially accelerating the dropping of the water table and the drying of pools. Arundo biomass in pools would likely be a negative impact. The greatest impact is that the system has fewer areas for pools to form. The areas that would be open/bar habitat are filled in with Arundo (Sections 5.1 & 2). This restricts pools to the narrow channel zone where pools are less likely to form. Pools that do form are also at greater risk of late season flow events that purge pools of egg masses and possibly even breeding adults.*

Diet:
Arroyo toad tadpoles feed on loose organic material such as algae, bacteria, and diatoms. They do not forage on macroscopic vegetation. Juvenile toads feed almost exclusively on ants. By the time they are 0.7 to 0.9 inch length they forage on beetles and ants. Adults consume a wide range of insects and arthropods.

Arundo impacts: *Arundo litter provides limited food for aquatic insects (Going & Dudley 2008) in comparison to native litter. This would reduce forage for aquatic insects which could be a food source for tadpoles. Decaying Arundo litter would be little nutritional value for insects. Arundo does support ants (particularly non-native argentine ants), but diversity and abundance is low for other arthropods (Herrera & Dudley 2003, Lovich et al. 2009). Arundo stands also are a barrier to toad movement and studies looking at toad use of Arundo showed little use, presumably indicating a low function for foraging.*

Movement: Arroyo toads have been observed moving one mile within the stream reach and 0.6 miles away from the stream into upland native habitat and agricultural areas. Movement may be regulated by topography and channel morphology. Toads are critically dependent on upland terraces and the marginal zone between stream channels and upland terraces during the non-breeding season, especially during periods of inactivity (generally late fall and winter). Toads generally burrow within sandy or loamy substrate with no associated canopy cover, within mulefat scrub, or within arroyo willow patches. The majority of individuals tracked in one study were located immediately adjacent to the active channel or within the bench habitats within the flood prone areas.

Arundo impacts: *Movement of toads both within and through the system is significantly restricted in highly invaded systems. Arundo can also be abundant in the area between the channel and terraces, filling open spaces in the habitat. This area is specifically noted as being a critical portion of the habitat for the first year toads. Chapter 5 demonstrates that this is where Arundo is most abundant and dense.*

Status/Distribution or Historic and Current Range:
Current estimated distribution is shown in Appendix B. Critical habitat areas have been designated. Survey data is of high quality in San Diego and Orange Counties and lower quality as one moves north. Santa Clara and Salinas in particular have not had substantial uniform survey work, but these areas do not have large populations (according to Biological Opinions). Distribution and abundance levels have been assessed from FWS data, CNDDB data, critical habitat areas, and verbal descriptions in USFWS Biological Opinions (all watersheds). Arroyo toads have disappeared from 75% of occupied habitat in California. Arroyo toads once occurred on 22 river basins from Monterey County (upper Salinas) to San Diego County southward to San Quintin, Baja CA, Mexico. In Orange and San Diego Counties the species occurred from estuaries to the headwaters of many drainages. Populations now are restricted to headwaters and small isolated populations along streams/rivers. The arroyo toad is principally along coastal drainages, although it has also been found on the desert facing slopes of San Gabriel and San Bernardino Mountains. Core populations occur on: Santa Margarita, San Luis Rey and San Juan Watersheds. Secondary watersheds are San Dieguito and Sweetwater. Additional smaller populations occur on San Diego, Los Angeles, Santa Clara and Salinas Watersheds.

Arundo impacts: *Arundo is abundant within core population areas as well as satellite populations. Arundo is less abundant in some of the more mountainous areas where toad populations occur. Significant overlap in Arundo and toad distribution exists (Table 7-3).*

Decline and Threats: Dam building and operation (modification of hydrologic regime and flushing events). Urban and agriculture development, sand and gravel mining. Impacts from vehicle and recreation activities. Non-native predators (bull frogs, fish, crayfish, etc.). Non-native plants (*Arundo* and tamarisk). Loss of habitat, modification of hydrology, and non-native predation have caused arroyo toads to disappear from a large portion of previously occupied habitat. Currently the greatest threats to arroyo toads are continued stream modification, development, and pressure from non-native organisms. Most systems have already had significant hydromodification.

Arundo impacts: *Arundo does interact with human hydromodification and flood management. Clearing of areas for reduced flood risk increases dispersal and spread of the plant. Reduced flow capacity and higher flood risk, exacerbated by Arundo stands, can lead to engineered solutions that contain and restrict flows.*

Overall impact metric for *Arundo* on Arroyo toad: Very severe impacts (10)

Interaction of *Arundo* distribution and occurrence of arroyo toads is presented by watershed in Table 7-3 and Appendix B.

Sources:

Arroyo toad (*Bufo californicus*) Five Year Review: Summary and Evaluation, U.S. Fish and Wildlife Service, Ventura, CA. August 2009. http://ecos.fws.gov/docs/five_year_review/doc2592.pdf

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

Formal Section 7 Consultation for Invasive Plant Removal in the San Juan Hydrologic Unit, Orange County, CA, U.S. F&WS, Carlsbad Fish and Wildlife Office, Carlsbad, CA.

7.2.3 California Red-Legged Frog *(Rana aurora draytonii*)

Federal status:	Threatened, May 23 1996. Critical habitat was first designated in 2001, but has been changed several times, with the most recent designation occurring in 2010.
State status:	None
Arundo impact score:	3

General Ecological Needs/Habitat Affinities:

California red-legged frogs live from sea level to about 5,000 ft/1,524 m in California and Baja California, Mexico, and may be found in a variety of habitats. The frogs breed in aquatic habitats such as streams, ponds, marshes and stock ponds. Larvae, juveniles and adults have been collected from streams, marshes, plunge pools and backwaters of streams, dune ponds, lagoons, and estuaries. They frequently breed in artificial impoundments such as stock ponds, if conditions are appropriate. If riparian vegetation is present, red-legged frogs spend considerable time resting and feeding in it. The moisture and camouflage provided by the riparian plant community apparently provides good foraging habitat and may facilitate dispersal in addition to providing pools and backwater aquatic areas for breeding. Frogs may move through upland habitats, primarily in wet weather. For the California red-legged frog, suitable habitat is potentially all aquatic and riparian areas within the range of the species and includes any landscape features that provide cover and moisture.

The riparian and upland habitats adjacent to aquatic areas used by the California red-legged frog are essential in maintaining frog populations, and for protecting the appropriate hydrological, physical, and water quality conditions of the aquatic areas. The frog uses both riparian and upland habitats for foraging, shelter, cover, and non-dispersal movement. One researcher who studied California red-legged frog's terrestrial activity in coastal forest and grassland habitats recommends at least a 328 ft (100m) buffer zone for protection of adjacent aquatic and upland habitat, as well as seasonal restrictions for activities within this zone. In a recent study also specific to the California red-legged frog, the recommendation was for establishing zones around breeding habitat, non-breeding habitat, and migration corridors that are sufficient to protect function of the amphibian habitat. However, the study authors discourage setting specific distances for these zones due to differences in biological or site-specific requirements; they further state that any distances set for avoidance of upland habitat should be made on a case-by-case basis, taking into account the need to protect breeding and non-breeding habitat as well as any migration corridors. Without protecting and maintaining the upland areas surrounding breeding and non-breeding habitats the quality of the water feature may deteriorate to such an extent as to not support the California red-legged frog.

***Arundo impacts:** Red legged frogs have very wide distribution among habitat types but tend to occur in steeper terrain than Arundo. Arundo is typically not abundant enough to alter abiotic factors that would severely degrade frog habitat.*

Breeding/Life History:

Red-legged frogs breed from November through March, though earlier breeding has been recorded in southern localities. Males appear at breeding sites 2-4 weeks prior to females. Females deposit egg masses on emergent vegetation so that the masses float on the surface of the water. Eggs hatch in 6 to 14 days, and larvae undergo metamorphosis 3.5 to 7 months after hatching. Sexual maturity is attained at 2 years by males and 3 years by females. Adults may live 8 to 10 years, although the average life span is considered much lower.

Arundo impacts : *Impacts would be minor as breeding pools are not usually in close proximity to Arundo stands. Arundo is not abundant enough to alter hydrology and pool duration.*

Diet:

The diet of the red-legged frog is highly variable. Tadpoles probably eat algae, and invertebrates seem to be the most common food of adults. Larger frogs can eat vertebrates such as Pacific chorus frogs and California mice. Feeding activity probably occurs along the shoreline and on the surface of the water. Juveniles have been found to be active diurnally and nocturnally, but adults are largely nocturnal.

Arundo impacts: *Minor impacts, if any, as Arundo is not abundant enough to typically affect abundance of food resources.*

Movement:

Juvenile and adult California red-legged frogs may disperse long distances from breeding sites throughout the year. They can be encountered living within streams at distances exceeding 1.8 miles from the breeding site, and have been found up to 400 feet from water in adjacent dense riparian vegetation. During period of wet weather, some individuals may make overland excursions through upland habitats, mostly at night. In Santa Cruz County, red-legged frogs made overland movements of up to 2 miles over the course of a wet season. Most of these long-distance movements were over variable upland terrain. Adult California red-legged frogs may disperse from breeding sites at any time of year depending on habitat availability and the environmental conditions of the aquatic habitat. In addition, a few frogs may disperse long distances in search of additional breeding or non-breeding habitat.

Arundo impacts: *Low likely hood of impact except on Ventura River watershed where dense Arundo stands could impede movement (as seen with arroyo toads).*

Status/Distribution or Historic and Current Range:

The current distribution of the red-legged frog is primarily in the coastal drainages of central California. Today, only 28 counties have known populations. Monterey, San Luis Obispo and Santa Barbara counties have the greatest amount of currently occupied habitat. Only four areas within the entire historic range of this species may currently harbor more than 350 adults.

Arundo impacts: *Arundo does have some overlap in distribution (Appendix B). Arundo is not usually abundant in these areas- particularly on smaller size watersheds, but localized high Arundo cover can exist and could lead to impacts (fire, limited movement, impacts to breeding pools). A significant noted exception occurs on Ventura River watershed where dense Arundo overlaps with core population areas.*

Decline and Threats:

The frog and its habitat are threatened by a multitude of factors including but not limited to:
1) Degradation and loss of habitat through urbanization, mining, improper management of grazing, recreation, invasion of nonnative plants, impoundments, water diversions and degraded water quality, 2) Introduced predators, such as bullfrogs, and 3) Previous overexploitation.

Historically, the California red-legged frog was found in 46 counties. The range was thought to extend coastally from Sonoma County (but recently has been confirmed further north in Mendocino County) and inland from the vicinity of Redding, Shasta County, south to northwestern Baja California, Mexico. The frog has sustained a 70 percent reduction in its geographic range in California as a result of habitat loss and alteration, overexploitation, and introduction of exotic predators.

Arundo impacts: *Little interaction between Arundo and these factors.*

Overall impact metric for *Arundo* on California red-legged frog: Low impact, score of 3.

Interaction of *Arundo* distribution and CA red-legged frog occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Biological and Conference Opinions for Annual Removal of Giant Reed and Tamarisk in Upper Santa Clara River Watershed, Los Angeles county, CA (File No. 2004-01540-AOA)(1-8-06-F-5).

Endangered and Threatened Wildlife and Plants; Revised Designation of Critical Habitat for the California Red-Legged Frog: Final Rule. 50 CFR Part 17 [FWS-R8-ES-2009-0089], U.S. Fish and Wildlife Service.

7.2.4 Mountain Yellow-Legged Frog (*Rana muscosa*)

Federal status:	Endangered (Southern California DPS July 2 2002), Endangered Candidate List (frogs occurring north of the Tehachapi Mountains). Critical habitat for the southern California DPS designated on September 14 2006.
State status:	Candidate species
Arundo impact score:	4

General Ecological Needs/Habitat Affinities:

Mountain yellow-legged frogs live in glaciated alpine lakes, ponds, tarns, springs, and streams. Lakes used usually have grassy or muddy margins, and adults are typically found sitting on wet rocks along the shoreline, usually where there is little or no vegetation. Field research conducted by USGS and the San Diego Zoo within the current and historic range of the mountain yellow-legged frog in the San Jacinto, San Bernardino, and San Gabriel mountains has been carried out to improve understanding of habitat preferences of this species. Results indicate that adult frogs prefer deep, long, pools with little understory and ample leaf litter. Tadpoles also were more likely to be found in pools with less understory and more leaf litter, but showed no preference for pool depth or length. They did, however, demonstrate a preference for pools with rock substrate. Mountain yellow-legged frogs have been observed in the field basking in direct sunlight, sometimes in aggregations of more than 20. It is hypothesized that frogs aggregate to reduce the surface area exposed to the air and thus reduce water loss. Suitable habitat for mountain yellow-legged frogs presumably must include appropriate basking structures

Arundo impacts: *Low level of Arundo impacts due to little overlap in range. Frogs are restricted to higher elevations in general. But overlap in occurrence in two areas create the potential for interaction (Los Angeles River, in the San Gabriel Mountains and Santa Ana River in San Bernardino Mountains). Frogs appear to prefer little vegetative cover- Arundo would therefore be negatively associated with prime habitat.*

Breeding/Life History:

Breeding sites are generally located in, or connected to, lakes and ponds that do not dry up in the summer, and that are sufficiently deep not to freeze through in winter. The frogs breed in June or July.

Eggs hatch within several weeks and larvae usually transform during July or August. Larvae at high elevations, or subject to severe winters, may not metamorphose until the end of their fourth summer. Adults hibernate in water during the coldest months, under ice or near shore under ledges and in underwater crevasses.

Arundo impacts: *Arundo may add to water stress in foothill washes shortening pool duration.*

<u>Diet:</u>
Adults feed on terrestrial insects and adult aquatic insects: beetles, flies, wasps, bees, ants, true bugs, and spiders. They also consume large quantities of Yosemite toad and Pacific treefrog tadpoles and can be cannibalistic. Tadpoles graze on algae and diatoms along rocky bottoms of streams, lakes, and ponds.

Arundo impacts: *Limited impacts to food resources.*

<u>Movement:</u>
This species has no distinct breeding migration, as adults are almost always found within two to three feet of water. In some areas, there is a seasonal movement of frogs from deeper lakes to nearby breeding areas after overwintering. Frogs typically move less than a few hundred meters.

Arundo impacts: *Limited impacts to movement- very localized at stream/pool edges.*

<u>Status/Distribution or Historic and Current Range:</u>
Once common throughout much of southern California, the mountain yellow-legged frog has been decreasing in numbers since the 1970s. The frog lives in the Sierra Nevada Mountains of California and Nevada from southern Plumas County to southern Tulare County, at elevations mostly above 6,000 feet. A genetic study published in 2007 revealed that there are two distinct mountain yellow-legged frog species that do not overlap in range or interbreed: a northern and central Sierra Nevada species and a southern Sierra Nevada and southern California species. In southern California, only a small wild population of less than 200 individuals can be found in the San Gabriel, San Bernardino, and San Jacinto Mountains. For the first time in April 2010, scientists reintroduced its eggs to its former habitat at University of California Riverside's James San Jacinto Mountains Reserve.

Arundo impacts: *The frogs have isolated small populations (Appendix B). The fact that several of the San Gabriel Mountain populations co-occur with Arundo is of concern. Impacts related to water use, shading, and the frogs' preference for less vegetated pools indicates that Arundo is likely a minor to moderate stressor on habitat fitness. Arundo could become a more pronounced impact if it continued to increase in abundance at sites where overlap in ranges occurs.*

<u>Decline and Threats:</u>
These frogs are threatened by predation by introduced trout, pesticides, environmental changes from drought and global warming, disease, and habitat degradation due to livestock grazing. More than 93 percent of northern and central Sierra Nevada populations, and more than 95 percent of southern Sierra Nevada and southern California populations, are already extinct.

Arundo impacts: *Little interaction with other stressors- but the species very tenuous persistence makes low to moderate levels of impacts already outlined potentially significant for the species especially for isolated southern CA populations.*

Overall impact metric for *Arundo* on mountain yellow-legged frog: <u>Low/Moderate impact (4)</u>

Interaction of *Arundo* distribution and mountain yellow-legged frog occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

USGS, Mountain yellow-legged frogs reintroduced to wild 4/16/2010.

Mountain Yellow-legged Frog Update, Mountain Yellow-legged Frog Captive Breeding 2009 Annual Report, San Diego Zoo.

Species Profile for the Mountain Yellow-Legged Frog, U.S. Fish & Wildlife Service.

7.2.5 Western Snowy Plover (*Charadrius alexandrinus nivosus*)

Federal status: Threatened, March 1993. Critical habitat designated September 2005. Recovery Plan published in 2007.

State status: Species of special concern

Arundo impact score: 5

General Ecological Needs/Habitat Affinities:

The Pacific coast population of the western snowy plover breeds primarily above the high tide line on coastal beaches, sand spits, dune-backed beaches, sparsely-vegetated dunes, beaches at creek and river mouths, and salt pans at lagoons and estuaries. This habitat is unstable because of unconsolidated soils, high winds, storms, wave action, and colonization by plants. Less common nesting habitats include bluff-backed beaches, dredged material disposal sites, salt pond levees, dry salt ponds, and river bars. In winter, western snowy plovers are found on many of the beaches used for nesting as well as on beaches where they do not nest, in man-made salt ponds, and on estuarine sand and mud flats.

Arundo impacts: *Arundo is typically not abundant in beach and estuary habitats (although it can develop into large stands if left to persist there). The major impacts from Arundo are related to biomass accumulating in these areas. Additionally there may be impacts to sediment transport (Chapter 5) which could be effecting beach and estuaries. These impacts are speculative but possible given Arundo strong effect of fluvial and processes. Plovers have strong preference for river mouths and estuaries in comparison to beach areas along bluffs (Appendix B).*

Breeding/Life History:

The Pacific coast population of the western snowy plover breeds primarily on coastal beaches from southern Washington to southern Baja California, Mexico. Nesting western snowy plovers at coastal locations consist of both year-round residents and migrants. Migrants begin arriving at breeding areas in central California as early as January, although the main arrival is from early March to late April. Since some individuals nest at multiple locations during the same year, birds may continue arriving through June. In California, pre-nesting bonds and courtship activities are observed as early as mid-February. Eggs are laid in scrapes (depression in the sand or other substrate created by the male). The earliest nests on the California coast occur during the first week of March in some years and by the third week of March in most years. Peak initiation of nesting is from mid-April to mid-June. Nests typically occur in flat, open areas with sandy or saline substrates; vegetation and driftwood are usually sparse or absent. In southern California, western snowy plovers nest in areas with 6 to 18 percent vegetative cover and 1 - 14 % inorganic cover; vegetation height is usually less than six centimeters (2.3 inches).

Nests consist of a shallow scrape or depression, sometimes lined with beach debris (*e.g.*, small pebbles, shell fragments, plant debris, and mud chips); nest lining increases as incubation progresses. Driftwood, kelp, and dune plants provide cover for chicks that crouch near objects to hide from predators. Although driftwood is an important component of western snowy plover habitat, too much driftwood on a beach, which may occur after frequent and prolonged storm events, can be detrimental if there is not sufficient open habitat to induce the birds to nest. In southern California nests are usually located within 328 ft

(100 m) of water, which could be either ocean, lagoon, or river mouth. Invertebrates are often found near debris, so driftwood and kelp are also important for harboring western snowy plover food sources. Hatching lasts from early April through mid-August, with chicks reaching fledging age approximately one month after hatching. Fledging of late-season broods may extend into the third week of September throughout the breeding range.

Arundo impacts: *Arundo biomass significantly degrades nesting habitat by covering open sandy substrate. Additional impacts are outlined in FWS BO's: In some areas of California, such as the Santa Margarita River in San Diego County, and the Santa Clara and Ventura Rivers in Ventura County, giant reed has become a problem along riparian zones. During winter storms, giant reed is washed downstream and deposited at the river mouths where western snowy plovers nest. Large piles of dead and sprouting giant reed eliminate nesting sites and increase the presence of predators, which use it as perches and prey on rodents in the piles of vegetation.*

Diet:

Western snowy plovers are primarily visual foragers, using the run-stop-peck method of feeding. They forage on invertebrates in the wet sand and amongst surf-cast kelp within the intertidal zone, in dry sand areas above the high tide, on salt pans, on spoil sites, and along the edges of salt marshes, salt ponds, and lagoons. They sometimes probe for prey in the sand and pick insects from low-growing plants. Western snowy plover food consists of immature and adult forms of aquatic and terrestrial invertebrates.

Arundo impacts: *Arundo debris and stands reduce habitat quality for food (invertebrates); impacts feeding as well as foraging for prey.*

Movement:

While some western snowy plovers remain in their coastal breeding areas year-round, others migrate south or north for winter. In Monterey Bay, California, 41 % of nesting males and 24 % of the females were consistent year-round residents. At Marine Corps Base Camp Pendleton in San Diego County, California, about 30 % of nesting birds stayed during winter. The migrants vacate California coastal nesting areas primarily from late June to late October.

Arundo impacts: *Arundo debris piles limit movement of young.*

Status/Distribution or Historic and Current Range:

The Pacific coast population is defined as those individuals that nest within 50 miles of the Pacific Ocean on the mainland coast, peninsulas, offshore islands, bays, estuaries, or rivers of the United States and Baja California, Mexico. By the late 1970s, nesting western snowy plovers were absent from 33 of 53 locations with breeding records prior to 1970. By 2000 populations had declined further to 71 % of the 1977-1980 levels along the California coast and 27 % of the 1977-1980 levels in San Francisco Bay. However, since then populations have grown substantially, roughly doubling along the coast while fluctuating irregularly in San Francisco Bay. Recent population increases along the coast have been associated with implementation of management actions for the benefit of western snowy plovers and California least terns, including predator management and protection and restoration of habitat.

Arundo impacts: *Arundo is abundant on several key watersheds that support plover populations (Appendix B).*

Decline and Threats:

Habitat degradation caused by human disturbance, urban development, introduced beachgrass (*Ammophila* spp.), and expanding predator populations have resulted in a decline in active nesting areas and in the size of the breeding and wintering populations.

***Arundo impacts:** As indicated Arundo stands are correlated with predation as predators use stands for perching in nesting areas.*

Overall impact metric for *Arundo* on the Western snowy plover: Moderate, score of 5.

Interaction of *Arundo* distribution and the Western snowy plover's occurrence is presented by watershed in Table 7-3.

Sources:

Recovery Plan for Pacific Coast Population of the Western Snowy Plover, USFWS, 2001 http://www.fws.gov/arcata/es/birds/WSP/documents/RecoveryPlanWebRelease_09242007/WSP%20Final%20RP%2010-1-07.pdf

Powell, A.N., J.M. Terp, C.L. Collier, and B.L. Peterson. 1997. The status of western snowy plovers (*Charadrius alexandrinus nivosus*) in San Diego County, 1997. Report to the California Department of Fish and Game, Sacramento, CA, and U.S. Fish and Wildlife Service, Carlsbad CA, & Portland OR.

7.2.6 Western Yellow-Billed Cuckoo (*Coccyzus americanus*)

Federal status:	Species of Concern
State status:	Endangered
Arundo impact score:	7

General Ecological Needs/Habitat Affinities:

Western yellow-billed cuckoos typically inhabit densely foliated, stands of deciduous trees and shrubs, particularly willows, with a dense understory formed by blackberry, nettles, and/or wild grapes, adjacent to slow-moving watercourses, backwaters, or seeps. River bottoms and other mesic habitats, including valley-foothill and desert riparian habitats, are necessary for breeding. Dense low-level or understory foliage with high humidity is preferred. Field studies and habitat suitability modeling have concluded that vegetation type (*e.g.*, willow scrub and cottonwood-willow forest), patch size, patch width, and distance to water are important factors determining the suitability of habitat for yellow-billed cuckoo breeding. Patch size is an important variable determining presence of cuckoos in California, with a trend toward increasing occupancy with increased patch size. Few cuckoos have been found in forested habitat of less than 25 acres. Willow-cottonwood habitat patches greater than 1,970 ft (600 m) in width were found to be optimal, and typically anything less than 328 ft (100 m) is unsuitable.

***Arundo impacts:** Arundo and cuckoos both prefer broad river bottoms creating a significant interaction between the species. Cuckoos prefer well-developed riparian habitat that is dense with large gallery trees. Arundo displaces native vegetation and fires generate create younger serial stages that cuckoos do not prefer or utilize as habitat.*

Breeding/Life History:

Western cuckoos breed in large blocks of riparian habitats, particularly woodlands with cottonwoods (*Populus fremontii*) and willows (*Salix* spp.). Dense understory foliage appears to be an important factor in nest site selection, while cottonwood trees are an important foraging habitat in areas where the species has been studied in California. Clutch size is usually two or three eggs, and development of the young is very rapid, with a breeding cycle of 17 days from egg-laying to fledging of young. Although yellow-billed cuckoos usually raise their own young, they are facultative brood parasites, occasionally laying eggs in the nests of other yellow-billed cuckoos or of other bird species. Males and females reach sexual maturity the first year after hatching. Chicks are able to fly between 17 and 21 days after hatching and within a few weeks will migrate to South America.

***Arundo* impacts:** *Arundo significantly degrades habitat by impacting lager mature trees (fire) and displacing the dense native understory vegetation. Arundo fragments and degrades riparian habitat through fire and swaths of low value habitat isolating higher quality patches.*

Diet:
More than 75 % of the yellow-billed cuckoo's diet is comprised of grasshoppers and caterpillars, though the species has been known to eat other insects such as beetles, cicadas, wasps, flies, katydids, dragonflies, and praying mantids.

***Arundo* impacts:** *Arundo provides none of the preferred food sources and displaces native vegetation-particularly native willows and cottonwoods that are habitat for mourning cloak butterfly and caterpillars.*

Movement:
Cuckoos leave North America in August and head to their wintering grounds in northwestern Costa Rica, Panama, and west of the Andes in Columbia, Ecuador, and Peru. It is believed that western cuckoos migrate primarily to southern Central America, remaining along the Pacific, and down into northwestern South America, remaining west of the Andes.

***Arundo* impacts:** *No impact to migration. Movement within habitat is impacted.*

Status/Distribution or Historic and Current Range:
Yellow-billed cuckoos occur in the western United States as a distinct population segment (DPS). The area for this DPS is west of the crest of the Rocky Mountains. In California prior to the 1930s, the species was widely distributed in suitable river bottom habitats, and was locally common. It is estimated that in California the species' range is now about 30 % of its historical extent. Studies since the 1970s indicate that there are fewer than 50 breeding pairs in all of California. Given that only Santa Ana and Santa Clara have had reported sightings since 1989, it is possible that the species may become or is already functionally extirpated from Southern California. Sightings may be individuals migrating to the South Fork of the Kern River or the Sacramento River.

***Arundo* impacts:** *Arundo* is abundant on the two watersheds with cuckoo occurrence data collected since 1989; all other occurrence data is from the 1970s or late 1800s/early 1900s (Los Angeles region-Appendix B).

Decline and Threats:
Adequate patch size and loss of habitat are the primary threats to western yellow-billed cuckoo populations. Principal causes of riparian habitat losses are conversion to agricultural and other uses, dams and river flow management, stream channelization and stabilization, and livestock grazing. Available breeding habitats for cuckoos have also been substantially reduced in area and quality by groundwater pumping and the replacement of native riparian habitats by invasive non-native plants, particularly tamarisk and *Arundo*. Fragmentation effects include the loss of patches large enough to sustain local populations, leading to local extinctions, and the potential loss of migratory corridors, affecting the ability to recolonize habitat patches. Much of the catastrophic decline of the cuckoo in California has been directly attributed to breeding habitat loss from clearing and removal of huge areas of riparian forest for agriculture, urban development and flood control (see chapter 5.3- historic trends of geomorphology, particularly the loss of terraces, where mature gallery forest would occur). Another likely factor in the loss and modification of the yellow-billed cuckoo is the invasion by exotic tamarisk

(*Tamarisk* spp.) and *Arundo*. The spread and persistence of tamarisk and *Arundo* has resulted in significant changes in riparian plant communities. In monotypic tamarisk and *Arundo* stands, the most striking change is the loss of community structure. The multi-layered community of herbaceous understory, small shrubs, middle-layer willows, and over-story deciduous trees is often replaced by one monotonous layer. Plant species diversity has declined in many areas and relative species abundance has shifted in others. Other effects include changes in percent cover, total biomass, fire cycles, thermal regimes, and perhaps insect fauna. Conversion to tamarisk or *Arundo* typically coincides with reduction or complete loss of bird species strongly associated with cottonwood-willow habitat including the yellow-billed cuckoo

Overall impact metric for *Arundo* on the Western yellow-billed cuckoo: <u>High impact, score of 7.</u>

Interaction of *Arundo* distribution and the Western yellow-billed cuckoo's occurrence is presented by watershed in Table 7-3 and Appendix B. Note that although there is high impact to habitat function for the species- the species is only present as 'historic occurrences' on most watersheds. Santa Ana and Santa Clara still have periodic sightings. These watersheds score high in relative abundance: there are not many sightings but these are a large proportion of sightings for the species. It is not locally abundant anywhere.

Sources:

U.S. Fish and Wildlife Service Species Assessment and Listing Priority Assignment Form for: *Coccyzus americanus* (Yellow-billed Cuckoo), Western United States Distinct Population Segment. http://ecos.fws.gov/docs/candforms_pdf/r8/B06R_V01.pdf

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

7.2.7 Southwestern Willow Flycatcher (*Empidonax trailii extimus*)

Federally status:	Endangered, February 1995. Critical habitat designated October 2005. Final recovery plan completed August 2002.
State status:	Endangered, January 1991.
Arundo impact score:	8

<u>General Ecological Needs/Habitat Affinities:</u>
The southwestern willow flycatcher occurs in riparian woodlands along streams and rivers with mature, dense stands of willows (*Salix* spp.), cottonwoods (*Populus* spp.), or smaller spring fed areas with willows or alders (*Alnus* spp.). Riparian habitat is used for both foraging and breeding.

Suitable habitat typically consists of the following habitat features: 1) Nesting habitat with trees and shrubs that include, but are not limited to, willow (*Salix* spp.) species and boxelder (*Acer negundo*), 2) Nesting habitat with a dense (*i.e.*, 50- 100 %) tree and/or shrub canopy, 3) Dense riparian vegetation with thickets of trees and shrubs, 4) Dense patches of riparian forest interspersed with small areas of open water or marsh, creating a mosaic; patch size may be as small as 0.25 ac or as large as 175 ac.

Arundo impacts: *Arundo displaces native vegetation forming monotypic stands or co-occurring with native woody vegetation. Both of these situations degrade habitat value. Abiotic system changes caused by Arundo related to fire and more frequent flooding degrade habitat value by creating more areas with early serial stages.*

Breeding/Life History:

Nests are typically placed in even-aged, structurally homogeneous and dense plant communities. They usually nest in the upright fork of a shrub, but occasionally nest on horizontal limbs within trees and shrubs. Historically the flycatcher nested primarily in willows and mulefat (*Baccharis salicifolia*) with a scattered overstory of cottonwood. With changes to riparian plant communities, they still nest in willows where available, but are also known to nest in thickets dominated by the non-native shrub tamarisk (*Tamarix* species) and Russian olive (*Elaeagnus angustifolia*). Males typically arrive in California at the end of April and females arrive approximately one week later. They have a home range that is larger than the defended territory. Territorial defense usually begins in late May. Territory size varies from 0.25 to 5.7 acres, with most in the range between 0.5 and 1.2 aces. They typically raise one brood per year, with a clutch size usually 3-4. The fledglings leave the nest at age 12-15 days in early July, and usually disperse from the natal territory at age 26-30 days. In southern California flycatchers usually leave the breeding grounds by the end of August, and it is exceeding scarce in the United States after mid-October.

Arundo impacts: *Arundo degrades habitat quality as it displaces vegetation with suitable nesting structure.*

Diet:

The southwestern willow flycatcher is an insectivore that forages within and above dense riparian vegetation, taking insects on the wing or gleaning them from foliage. They may also forage in areas adjacent to nest sites which may be more open. They are active diurnally.

Arundo impacts: *Arundo appears to have little foraging value for the southwestern willow flycatcher as it supports a reduced diversity and abundance of aerial insects compared to native vegetation (Herrera & Dudley 2003). Arundo displaces vegetation that supports food species.*

Movement:

Males usually arrive in California at the end of April, and females about a week later. They generally leave in August. The migration routes and destination of the willow flycatcher are not well known. The flycatcher most likely winters in Mexico, Central America and perhaps northern South America, however, the habitat is uses as wintering grounds are unknown.

Arundo impacts: *No impact to migration- but Arundo interferes with movement within the territory-obstructing access to lower canopy and impeding foraging.*

Status/Distribution or Historic and Current Range:

Current estimated distribution of the southwestern willow flycatcher in California is shown in Figure 7-16/19. The current breeding range includes southern California, southern Nevada, Arizona, New Mexico and western Texas. The historic range in California apparently included all lowland riparian areas of the southern third of the state. In the 1930 it was considered a common breeder in coastal southern California, but it declined precipitously over the last 50 years or so.

Arundo impacts: *Arundo is abundant on two specific watersheds with large numbers of flycatchers (Table 7-3, Appendix B). One watershed has moderate interaction/overlap in distribution and eight watersheds have slight interaction. The species has a wide distribution but low populations on most watersheds.*

Decline and Threats:
The major threats to the flycatcher are the destruction, modification, or curtailments of habitat, and nest parasitism by cowbirds. Loss and modification of riparian habitat has occurred due to urban and agricultural development, water diversion and impoundments, channelization, livestock grazing, off-road vehicle and other recreational uses, and hydrological changes resulting from these and other land uses.

Overall impact metric for *Arundo* on southwestern willow flycatcher: Very high impact, score of 8.

Interaction of *Arundo* distribution and southwestern willow flycatcher occurrence is presented by watershed in Table 7-3 and illustrated in Appendix B.

Sources:

U.S. Fish and Wildlife Service. 2002. Southwestern Willow Flycatcher Recovery Plan. Albuquerque, New Mexico. http://ecos.fws.gov/docs/recovery_plans/2002/020830c.pdf

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

7.2.8 Belding's Savannah Sparrow (*Passerculus sandwichensis beldingi*)

Federal status:	Species of Concern
State status:	Endangered, 1974.
Arundo impact score:	2

General Ecological Needs/Habitat Affinities:
Belding's are ecologically associated with dense pickleweed, particularly *Sarcocornia pacifica (formerly Salicornia virginica)*, within which most nests are found.

Arundo impacts: *Arundo is not typically abundant in estuaries although it can occur there. Of more concern is biomass from upstream sources that accumulates in estuaries. Most of the estuaries where the sparrows occur are connected to smaller stream order riverine systems. Less Arundo is found on these size systems. Arundo impacts to system hydrology and geomorphic processes could be of concern in certain situations- sediment loads, biomass blocking flows. But these impacts are probably less on the size river systems that support sparrow habitat in estuaries.*

Breeding/Life History:
Breeding territories can be very small and they nest semi-colonially or locally concentrated within a larger block of habitat, all of which may appear generally suitable.

Arundo impacts: *Minimal impact.*

Diet:
Feeds mostly on the ground (seeds), generally alone or, during the non-breeding season, in small flocks.

Arundo impacts: *Minimal impact.*

Movement:
They remain within the salt marsh year round.

Arundo impacts*: Minimal impact.*

Status/Distribution or Historic and Current Range:
Based upon the 2010 surveys, Belding's sparrows are doing well within their range in California but particularly at Point Mugu, Seal Beach National Wildlife Refuge (NWR), Bolsa Chica, Upper Newport Bay, Sweetwater Marsh NWR, and Tijuana Slough NWR. This is associated in part with the levels and quality of hands-on efforts at these wetlands. For example, Point Mugu has one of the most active and successful Natural Resources Management programs of any of the coastal wetlands in the southern California Bight. At San Elijo and Los Peñasquitos Lagoons the ocean inlets are being monitored and kept open as much as possible. This often minimizes flooding and hyper-saline conditions that greatly reduce Belding's sparrows nesting success.

***Arundo impacts:** There is interaction between sparrow and Arundo distributions. Arundo occurs within occupied habitat in a few areas, but as noted it is not abundant in estuaries. Arundo debris is not mapped, but is predicted based on abundance of Arundo upstream of occupied sites. Many of the occupied estuaries are on smaller lower energy systems so significant Arundo biomass inputs are not likely. Calleguas Watershed is a noted potential exception but much of the estuary complex is not well connected to the river mouth. This partly protects it from Arundo debris being pulled back into the estuary complex after it has been dispersed into the ocean or from deposition as debris racks during flow events.*

Decline and Threats:
Over 75% of the coastal wetland habitats within this range have been lost or highly degraded and the remainder suffer from the effects of increasing human populations.

Overall impact metric for *Arundo* on the Belding's savannah sparrow: Very low impact, score of 2.

Interaction of *Arundo* distribution and the Belding's savannah sparrow's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
A Survey of the Belding's Savannah Sparrow in California 2010, State of California, The Resources Agency, Department of Fish and Game Wildlife Branch. Prepared by Richard Zembal and Susan M. Hoffman, Clapper Rail Recovery Fund, Huntington Beach Wetlands Conservancy, September 2010.

7.2.9 Coastal California Gnatcatcher (*Polioptila californica californica*)

Federal status: Threatened, March 1993. Critical habitat (Revised) designated December 2007.
State status: None?
Arundo impact score: 2

General Ecological Needs/Habitat Affinities:
The range and distribution of the gnatcatcher is closely aligned with coastal scrub vegetation. This vegetation is typified by low (<1m), shrub and sub-shrub species that are often drought deciduous. The coastal scrub plant communities that overlap the range of the gnatcatcher include Venturan, Diegan, and Riversidean coastal sage scrub (CSS) communities, and Martirian and Vizcainan coastal succulent scrub communities. Gnatcatchers may also occur in other nearby plant communities, especially during the non-breeding season, but gnatcatchers are closely tied to coastal scrub for reproduction.

***Arundo impacts:** Arundo is not typically found in coastal sage scrub, but CSS habitat and riparian zones are closely aligned in most areas along the coast. Impacts related to fire, both fires starting in*

Arundo and Arundo contributions to wildland fires, can have impacts to adjacent habitat. Fire impacts to CSS can result in both direct take of the species as well as degradation of habitat (short term functional loss, and potentially long term degradation- dependent on fire history and recovery of site). Gnatcatchers are also year round residents and riparian vegetation offers refuge and food resources in late summer/fall/winter when coastal sage scrub is less productive.

Breeding/Life History:
The gnatcatcher is non-migratory and defends breeding territories ranging in size from 1 - 6 hectares (2 - 14 acres). The home range size of the gnatcatcher varies seasonally and geographically, with winter season home ranges being larger than breeding season ranges and inland populations having larger home ranges than coastal. The breeding season of the gnatcatcher generally extends from late February through July (sometimes later), with the peak of nest initiations occurring from mid-March through mid-May. Nests are composed of grasses, bark strips, small leaves, spider webs, down, and other materials and are often located in California sagebrush (*Artemisia californica*) plants about 1 m above the ground. The incubation and nestling periods encompass about 14 and 16 days, respectively.

Arundo impacts: *No impact except those related to fire.*

Diet:
California gnatcatchers are ground and shrub-foraging insectivores. They feed on arthropods, beetles, spiders, leafhoppers, and other small insects. Most of their water intake is obtained through their diet.

Arundo impacts: *Little impact-although riparian areas can be used for foraging during times of low productivity in CSS, and high Arundo cover degrades this function.*

Movement:
The gnatcatcher is non-migratory. Dispersal of juveniles generally requires a corridor of native vegetation that provides certain foraging and sheltering requisites and that connects to larger patches of appropriate sage scrub vegetation. These dispersal corridors facilitate the exchange of genetic material and provide a path for re-colonization of extirpated areas. The gnatcatcher generally disperses short distances through contiguous, undisturbed habitat, but juvenile gnatcatchers are capable of dispersing long distances (up to 22km/14 mi) across fragmented and highly disturbed sage scrub habitat, such as that found along highway and utility corridors or remnant mosaics of habitat adjacent to developed lands.

Arundo impacts: *No impact.*

Status/Distribution or Historic and Current Range:
The range of the gnatcatcher is coastal southern California and northwestern Baja California, Mexico, from southern Ventura and San Bernardino Counties, California, south to approximately El Rosario, Mexico, at about 30 degrees north latitude.

Arundo impacts: *See Appendix B.*

Decline and Threats:
The main threat to the coastal California gnatcatcher is habitat loss, fragmentation, and degradation. Urban and agricultural development, livestock grazing, invasion of exotic grasses, off-road vehicles, pesticides, and military training activities all contribute to the destruction of gnatcatcher habitat.

Overall impact metric for *Arundo* on the coastal California gnatcatcher: Very low impact, score of 2. If wildland fires were documented to have greater extent due to presence of *Arundo* stands in core gnatcatcher upland areas this score should be elevated. Significant take and/or long term degradation would occur to upland habitat.

Interaction of *Arundo* distribution and the coastal California gnatcatcher's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Coastal California Gnatcatcher Five Year Review, U.S. Fish and Wildlife Service, Carlsbad, CA. September 2010. http://ecos.fws.gov/docs/five_year_review/doc3571.pdf

7.2.10 Light Footed Clapper Rail (*Rallus longirostris levipes*)

Federal status:	Endangered, October 1970. No critical habitat designated.
State status:	Endangered, June 1971

Arundo impact score: 3

General Ecological Needs/Habitat Affinities:

The light-footed clapper rail uses coastal salt marshes, lagoons, and their maritime environs. Nesting habitat includes tall, dense cordgrass (*Spartina foliosa*) and occasionally pickleweed (*Sarcocornia pacifica* – formerly *Salicornia virginica*) in the low littoral zone, wrack deposits in the low marsh zone, and hummocks of high marsh within the low marsh zone. Fringing areas of high marsh serve as refugia during high tides. Although less common, light-footed clapper rails have also been observed to reside and nest in freshwater marshes.

Activities of the light-footed clapper rail are tide-dependent. They require shallow water and mudflats for foraging, with adjacent higher vegetation for cover during high water. They forage in all parts of the salt marsh, concentrating their efforts in the lower marsh when the tide is out, and moving into the higher marsh as the tide advances.

Arundo impacts: *Arundo does not occur in the lower estuary habitat that rails use. However, biomass of Arundo from upstream stands can be deposited in estuaries (relevance is tied to abundance of Arundo on a given system). Also, larger order systems that are significantly invaded may have significant modification of flow dynamics, sediment transport, and hydrology which may affect quality of estuary habitat at the river mouth (if estuaries are still connected to the river system).*

Breeding/Life History:

Nesting usually begins in March and late nests hatch by August. Nests are placed to avoid flooding by tides, yet in dense enough cover to be hidden from predators and to support the relatively large nest. Potential predators on eggs, nestlings, or adults include California ground squirrels, old world rats, striped skunk, feral house cats, dogs, gray fox, red fox, Virginia opossum, and raptors.

Arundo impacts: *Arundo harbors a range of mammals and predators that use the physical structure.*

Diet:
Light-footed clapper rails are omnivorous and opportunistic foragers, which rely mostly on salt marsh invertebrates such as beetles, garden snails, California horn snails, salt marsh snails, fiddler and hermit crabs, crayfish, isopods, and decapods.

***Arundo* impacts**: *No impact.*

Movement:
The light-footed clapper rail is resident in its home marsh except under unusual circumstances. Within-marsh movements are also generally confined and usually of no greater spread than 1,312 feet (400m). However, a banded captive-bred female rail which was released at Point Mugu in August of 2004 was found in December of 2004 at Upper Newport Bay, a distance of 145 km (90 mi) along the coast. Minimum home range sizes for nine clapper rails that were radio-harnessed for telemetry at Upper Newport Bay varied from approximately 0.8 - 4.1 acres. The larger areas and daily movements were by first year birds attempting to claim their first breeding territories.

***Arundo* impacts:** *No impact.*

Status/Distribution or Historic and Current Range:
The historical range of the light-footed clapper rail was originally described as extending from Santa Barbara County, California to San Quintin Bay, Baja California, Mexico. In the early 1900s, ornithologists noted a decrease in the abundance of rails and observed that they were no longer found in areas, which were formerly occupied. Since 1900, 75 %of the coastal estuaries and wetlands in southern California have been destroyed or adversely modified. Light-footed clapper rails have not been detected in Santa Barbara County since 2004 or in Los Angeles County since 1983. The range in California now extends from Ventura County in the north to the Mexican border in the south.

***Arundo* impacts:** *Rails occur in estuaries of both large and small watershed systems- particularly in San Diego County (Appendix B). Rails can extend fairly far into the watershed (where pickleweed occurs), but some of these are historic records. Arundo is abundant on some of these watersheds.*

Decline and Threats:
Continued loss and degradation of salt marsh habitat.

Overall impact metric for *Arundo* on the light-footed clapper rail: Low impact, score of 3.

Interaction of *Arundo* distribution and the light footed clapper rail's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Light-footed Clapper Rail Five Year Review, U.S. Fish and Wildlife Service, Carlsbad, CA. August 2009. http://ecos.fws.gov/docs/five_year_review/doc2573.pdf

7.2.11 California Least Tern (*Sterna antillarum browni*)

Federal status:	Endangered June 2, 1970. Final Recovery Plan 1980, revised 1985.
State status:	Endangered, June 27, 1971.
Arundo impact score:	4

General Ecological Needs/Habitat Affinities:
California least terns nest on beaches, usually choosing locations in an open expanse of light-colored sand, dirt or dried mud close to a lagoon or estuary with a dependable food supply. Formerly, sandy open beaches were used, but human activity on beaches has forced terns to nest on mud and sand flats back from the ocean, and on man-made habitats. In addition to nesting areas, California least terns also require secure roosting and foraging areas. Roosting areas are of two kinds: pre-season nocturnal roosts and post-season dispersal sites where adults and fledglings congregate. Terns forage primarily in nearshore ocean waters and in shallow estuaries and lagoons.

Arundo impacts: *Arundo is not abundant in the beach and estuary habitat- but there can be locally occurring stands and occurrences of the plant. Arundo debris and to a lesser degree hydrologic and geomorphic alteration of river systems can have impacts on terns.*

Breeding/Life History:
Most least terns begin breeding in their third year. Mating begins in April or May. The nest is a simple scrape in the sand and may be lined with shell fragments, pebbles, twigs. Typically there are 2 eggs. Both parents incubate and care for the young. They can re-nest up to two times if eggs or chicks are lost early in the breeding season. Nesting season extends from approximately May 15 into early August, with the majority of nests completed by mid June. A second wave of nesting occurs from mid-June to early August. These are mainly re-nests after initial failures, and second year birds nesting for the first time. Predators of the California least tern are larger birds, mammals such as raccoons and foxes, and domestic dogs and cats.

Arundo impacts: *Most tern breeding areas are nearly devoid of vegetation and plant debris (observation of nesting sites in San Diego and Ventura Counties). Arundo debris and live plant structure is a degradation of habitat. Debris reduces useable area. Any structure fosters predation from birds and any concealment encourages predatory mammals.*

Diet:
California least terns eat small fish.

Arundo impacts: *No impact.*

Movement:
The California least tern is migratory, usually arriving in its breeding area by mid April and departing again in August. However, terns have been recorded in the breeding range as early as March 13 and as late as October 31. Adult terns move south along the California coast with their fledglings in the autumn, stopping to rest and feed along the migration route.

Arundo impacts: *No impact.*

Status/Distribution or Historic and Current Range:
Historically California least terns nesting in large colonies spread along undisturbed beaches. However with development of the California coast and fragmentation of large beach areas, birds now nest in the small fragments of habitat remaining in the same general areas. The nesting range in California is discontinuous, with large colonies spread out along beaches at estuaries. The northern limit for nesting is San Francisco Bay, and the southern limit is in Baja California, Mexico. Today the tern is concentrated in three southern California counties: Los Angeles, Orange and San Diego.

Arundo impacts: *Arundo is abundant on several watersheds in Orange and San Diego Counties (Appendix B).*

Decline and Threats:
California least terns were apparently once abundance and well distributed on barrier beaches and beach strand along the southern California coast. The reduction in tern numbers was apparently gradual and associated with human population increases in the area. The species was noted as seriously declining within its range before the 1930s. Today the tern is concentrated in three southern California counties: Los Angeles, Orange and San Diego. Since 1973 there has been on overall increase in least tern in California due to recovery efforts such as site management and protection of known nesting sites (fencing, predator control, monitoring, research). Decline of the California least tern is due to loss and degradation of beach habitat, impacts and disturbance from human and domestic animal use of beaches, and loss and fragmentation of wintering habitat.

Overall impact metric for *Arundo* on the coastal California least tern: Low/Moderate, score of 4.

Interaction of *Arundo* distribution and the coastal California least tern's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

California Least Tern Five Year Review Summary and Evaluation, U.S. Fish and Wildlife Service, Carlsbad, CA. September 2006. http://ecos.fws.gov/docs/five_year_review/doc775.pdf

Revised California Least Tern Recovery Plan, U.S. Fish and Wildlife Service, Portland, Oregon. April 1980. http://ecos.fws.gov/docs/recovery_plan/850927_w%20signature.pdf

7.2.12 Least Bell's Vireo (*Vireo bellii pusillus*)

Federal status:	Endangered, May 1986. Critical habitat designated February 1994. Draft recovery plan completed in 1998.
State status:	Endangered, October 1980.
Arundo impact score:	9

General Ecological Needs/Habitat Affinities:
Least Bell's vireo is a small, olive-grey migratory songbird that nests and forages almost exclusively in riparian woodland habitats. Primary constituents of critical habitat for the vireo include riverine and floodplain habitat, and adjacent coastal sage scrub, chaparral, or other upland communities. Nesting habitat typically consists of well-developed overstories and understories, and low densities of aquatic and herbaceous cover. The understory frequently contains dense subshrub or shrub thickets. These thickets are often dominated by sandbar willow (*Salix hindsiana*), mulefat (*Baccharis salicifolia*), young individuals of other willow species, such as arroyo willow (*Salix lasiolepis*) or black willow (*Salix gooddingii*), and one or more herbaceous species. Important overstory specie include mature arroyo willow and black willows; occasional cottonwoods (*Populus* spp.) and western sycamores (*Platanus racemosa*) occur in some habitats. Additionally, coast live oak (*Quercus agrifolia*) can be a locally important overstory component, as can mesquite (*Prosopis* spp.).

Arundo impacts: *Arundo and vireos prefer the same broad coastal riparian habitat types. Significant impacts from abiotic modification of the riverine system impact ecosystem to the detriment of the vireo. There changes include fire, geomorphic impacts that interfere with vegetation succession, and outright displacement of vegetation that vireos are dependent on. Direct take and long term degradation of habitat occurs after fires initiating in Arundo stands as well as wildland fires that are larger are more intense when Arundo is present.*

Breeding/Life History:
Following pair formation, it takes approximately 5 - 7 days for them to finish nest construction and egg laying. Young typically fledge within 20 - 24 days after eggs are laid. The egg laying and incubation periods are critical to the nesting success, as disturbance at this point may result in abandonment of the nest.

Arundo impacts: *Arundo displaces native vegetation reducing available habitat for nesting. Arundo does not have suitable structure for vireo nests.*

Diet:
They are almost exclusively insectivorous, and forage in riparian woodland and suitable adjacent upland habitat.

Arundo impacts: *Arundo support a low abundance and diversity of insects, particularly in comparison to native vegetation (Herrera & Dudley 2003, Going & Dudley 2008). Vireos are rarely seen feeding on Arundo as the plants has few insects that directly feed on it. Birds are rarely seen feeding in Arundo.*

Movement:
Least Bell's vireos generally begin to arrive from their wintering range in southern Baja California and establish breeding territories by mid- to late March. Most breeding vireos depart by the third week of September and only a very few individuals are found wintering in California. Most vireos occupy home ranges that are typically from 0.5 - 4.5 acres, but a few may be as large as 7.5 acres. Once the young are fledged they wander widely throughout the parents' territory.

Arundo impacts: *Arundo stands inhibit movement of avian species as the feed, spatially segregating the habitat. Territories frequently include Arundo stands but there is always a native component of the territory. Territories are roughly drawn- it would be interesting to see if territory size is larger when Arundo is present.*

Status/Distribution or Historic and Current Range:
Historically the vireo was described as common to abundant in the appropriate riparian habitat from as far north as Tehama County, CA to northern Baja, Mexico. Habitat loss has fragmented most remaining populations into small, disjunct, widely dispersed subpopulations. Currently the largest population of vireos is on Marine Corps Base Camp Pendleton in San Diego County. This population combined the population in the Prado Basin represent approximately 60 % of all known territories in California.

Arundo impacts: *Arundo is abundant on the three largest population centers for the vireo: Santa Margarita, Santa Ana, and San Luis Rey. Vireos are in greater abundance on larger systems, but they do occur on smaller watersheds if riparian vegetation is well developed (Appendix B). Vireos also occur in greater abundance in urban riparian areas then other federally listed species.*

Decline and Threats:
Decline of vireos is primarily the result of habitat loss and degradation, and cowbird nest-parasitism. The historic loss of wetlands (including riparian woodlands) has been estimated at 91 %. Much of the potential remaining habitat is infested with non-native plants and cowbirds. Ongoing causes of destruction or degradation of habitat include: removal of riparian vegetation; invasion of non-native species (e.g. *Arundo*, cowbird); thinning of riparian growth, especially near ground level; removal or destruction of adjacent upland habitats used for foraging; increases in human-associated or human induced disturbances; and flood control activities, including dams, channelization, water impoundment or extraction, and water diversion. Vireos are also sensitive to many forms of human disturbance, including noise, night lighting, and consistent human presence in an area.

Overall impact metric for *Arundo* on least Bell's vireo: Severe impact, score of 9.

Interaction of *Arundo* distribution and least Bell's vireo occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

Programmatic Biological Opinion for the Salinas River Watershed Permit Coordination Program, Monterey County, CA (1-8-02-F-19), US Fish and Wildlife Service, Ventura, CA. 2002.

7.2.13 Tidewater Goby (*Eucyclogobius newberryi*)

Federal status:	Endangered, March 7 1994. Critical habitat designated November 20 2000.
State status:	none
Arundo impact score:	7

General Ecological Needs/Habitat Affinities:

The tidewater goby, a species endemic to California, is found primarily in waters of coastal lagoons, estuaries, and marshes. The species is benthic in nature, and its habitat is characterized by brackish, shallow lagoons and lower stream reaches where the water is fairly still but not stagnant. Tidewater gobies prefer a sandy substrate for breeding, but they can be found on rocky, mud, and silt substrates as well. The species is typically found in water less than 1 m deep. Tidewater gobies have been documented in waters with salinity levels from 0 - 42 parts per thousand (ppt), temperature levels from 8 - 25 ° C (46 - 77° F), and water depths from 25 200 cm (10 to 79 in). Critical habitat includes the stream channels and their associated wetlands, flood plains, and estuaries.

***Arundo* impacts :** *Alteration of geomorphology and accumulation of excessive dead biomass in habitat areas are the primary impacts. It is possible that abundant Arundo is extremely detrimental to the species as they have not been observed on the Salinas River, Santa Clara, and Santa Margarita, and San Luis Rey Rivers in recent time frames. River channels could be becoming too deep for the species on some systems (such as San Luis Rey) resulting from excessive vegetation on floodplains (see chapter 5). The species now seems to occur on smaller river/creek systems, many of which have no or little Arundo on them (areas of Camp Pendleton and Estero Bay).*

Breeding/Life History:

The tidewater goby is typically an annual species, although some variation has been observed. Reproduction occurs year-round although distinct peaks in spawning, often in early spring and late summer, do occur. Male tidewater gobies begin digging breeding burrows in relatively unconsolidated, clean, coarse sand (averaging 0.5 mm diameter), in April or May after lagoons close to the ocean. Female tidewater gobies can lay 300 - 500 eggs per clutch, and can lay 6 - 12 clutches per year. Male tidewater gobies remain in the burrow to guard the eggs that are attached to sand grains in the burrow ceiling and walls. The male tidewater goby cares for the embryos for approximately 9 - 11 days until they hatch. Tidewater goby larvae are planktonic for 1 - 3 days and then become benthic from that point on. Tidewater goby are preyed upon by native and non-native fish, and by fish eating birds.

***Arundo* impacts:** *Accumulated biomass within the channel near the river mouth would cover substrate needed for reproduction.*

Diet:
Tidewater gobies feed mainly on small animals, usually mysid shrimp, amphipods, ostracods, and aquatic insects. Juvenile tidewater gobies are generally day feeders, although adults mainly feed at night.

Arundo impacts: *Unknown if biomass would impacts aquatic food resources. Excessive channel depth would negatively affect feeding (individuals prefer a water depth of up to 1 m).*

Movement:
The tidewater goby appears to spend all life stages in lagoons, estuaries, and river mouths. Tidewater gobies may enter marine environments only when flushed out of lagoons, estuaries, and river mouths by normal breaching of the sandbars following storm events. Tidewater gobies generally select habitat in the upper estuary, usually within the fresh-saltwater interface. Tidewater gobies range upstream a short distance (up to 1.5 miles/2.41 km) into fresh water, and downstream into water of up to about 75 % sea water (28 ppt).

Arundo impacts this by: *The preferred habitat zone frequently has significant Arundo on the banks (in highly invaded systems) It is possible that Arundo debris in these systems interferes with movement during and after flood events- particularly if there are large rafts vegetation (Arundo canes and native vegetation).*

Status/Distribution or Historic and Current Range:
Tidewater gobies are endemic to California and historically ranged from Tillas Slough near the Oregon border to Agua Hedionda Lagoon in northern San Diego County, and are found today entirely within the original known range of the species. The known localities are discrete lagoons, estuaries, or stream mouths separated by mostly marine conditions. Tidewater gobies are absent from areas where the coastline is steep and streams do not form lagoons or estuaries. Tidewater gobies have recolonized areas where they have been extirpated.

Arundo impacts: *Arundo and goby distributions are shown Appendix B. As noted, the species has not been found in several large and heavily invaded watersheds since 2001. But there are smaller watersheds with populations nearby. Goby populations and distribution may naturally fluctuate in response to large flooding events. It will be informative to see if they return to systems that have had Arundo neatly eradicated (Santa Margarita and San Luis Rey).*

Decline and Threats:
The tidewater goby is threatened by modification and loss of habitat as a result of coastal development, channelization of habitat, diversions of water flows, groundwater overdrafting, and alteration of water flows. Potential threats to the tidewater goby include discharge of agricultural and sewage effluents, increased sedimentation due to cattle grazing and feral pig activity, summer breaching of lagoons, upstream alteration of sediment flows into the lagoon areas, introduction of exotic gobies and rainwater killifish, habitat damage, and watercourse contamination resulting from vehicular activity in the vicinity of lagoons.

Arundo impacts: *Arundo effects several of these parameters (water availability, sediment transport), but it is unclear exactly how these factors interact with goby habitat.*

Overall impact metric for *Arundo* on the tidewater goby: High impact, score of 7.

Interaction of *Arundo* distribution and tidewater goby occurrence is presented by watershed in Table 7-3 and Appendix B. It is important to note that there are many smaller watersheds that have no or very low *Arundo* presence and therefore impacts are non-existent. Goby have occurred on large systems- and they are in significant decline or do not occur on these systems over the time period when *Arundo* has become a significant impact. Other hydrologic factors have also changed significantly over that time frame (water flows, sediment transport, etc.) so several factors may be at play.

Sources:

Programmatic Biological Opinion for the Salinas River Watershed Permit Coordination Program, Monterey County, CA (1-8-02-F-19), US Fish and Wildlife Service, Ventura, CA. 2002.

U.S. Fish and Wildlife Service. 2005. Recovery Plan for the Tidewater Goby (*Eucyclogobius newberryi*). U.S. Fish and Wildlife Service, Portland, Oregon.

7.2.14 Unarmored Three Spine Stickleback (*Gasterosteus aculeatus williamsoni*)

Federal status:	Endangered, October 13 1970. Designation of critical habitat remains pending. Recovery Plan completed in 1985.
State status:	Endangered, June 27 1971.

Arundo impact score: 8

General Ecological Needs/Habitat Affinities:

The unarmored three-spine stickleback inhabits slow moving reaches or quiet water microhabitats of streams and rivers. Favorable habitats usually are shaded by dense and abundant vegetation, but in more open reaches algal mats or barriers may provide refuge. The best habitat seems to be a small clean pond in the stream with a constant flow of water through it. Adults are found in all areas of the stream and tend to gather in areas of slower moving or standing water. In areas where water is moving rapidly, adults tend to be found behind obstructions, or at the edge of the stream, particularly under the edge of algal mats. No adults have been found to be living permanently in ponds isolated from the main stream.

Arundo impacts: *Arundo occurs within the core stickleback population area of the upper Santa Clara Watershed. There is Arundo present within much of the stickleback's range and significant Arundo in the fish's lower range on the main stem of the river. For more invaded portions of the river changes to sediment transport and high water use of Arundo could be impacting pool persistence and quality. Arundo fires in more invaded habitat would also cause impacts.*

Breeding/Life History:

There is some reproduction during almost every month. A large increase in reproductive activity occurs in the spring in about March, and continues at lower levels throughout summer and fall. Males build nests of aquatic vegetation on the bottom within his territory. Nests are located where there is ample vegetation and a gentle flow of water. After the female lays the eggs, the male fertilizes them, guards them, and fans them. Young sticklebacks hatch in a nest from eggs which have been brooded for several days by the adult male. The exact amount of time the young stay in the nest is unknown. Larger juveniles and sub-adults tend to be found in the protection of vegetation, in slow moving or standing water. Fish apparently only live for one year.

Arundo impacts: *Pool/channel water quality and duration may be impacted.*

Diet:

The stickleback feeds mostly on benthic insects, small crustaceans, and snails, and to a lesser degree flat worms and nematodes. Males may also eat stickleback eggs.

***Arundo* impacts:** *Pool/channel water quality and duration may be impacted- which could effect abundance and diversity of food resources.*

Movement:
The unarmored three-spine stickleback remains within stream channels and ponds within the stream area. No adults have been found to be living permanently in ponds isolated from the main stream.

***Arundo* impacts:** *Minimal impacts.*

Status/Distribution or Historic and Current Range:
Historically they were distributed throughout southern California, but are now restricted to the upper Santa Clara River and its tributaries in northern Los Angeles and Ventura Counties, San Antonio and Canada Honda creeks on Vandenberg Air Force Base in Santa Barbara County, and San Felipe Creek in San Diego County. The Canada Honda and San Felipe Creek populations were transplanted.

***Arundo* impacts:** *Arundo and stickleback overlap in distribution (Appendix B).*

Decline and Threats:
Habitat degradation from flood control and channelization are the primary threats to the unarmored three-spine stickleback. Habitat degradation also occurs from trampling of stream banks by humans and livestock, causing increased soil erosion and sedimentation which reduces availability of plants and insects for habitat and food. Damage to emergent vegetation along stream banks degrades the nursery areas. Stream channelization allows increased water velocity in pools, eliminates shallow backwaters and reduces aquatic vegetation. Channelization also increases peak flows during floods, and large flood events scour the channel and wash stickleback individuals downstream. Urbanization has caused a degradation of water quality due to increased run-off, siltation, nutrients, pesticides and other pollutants. These pollutants affect the health of the sticklebacks and can cause deformities. Introduced predators and competitors negatively affect the stickleback by directly removing individuals or restricting them to habitats that predators cannot enter. Other threats to the stickleback include genetic introgression, agricultural impacts, oxygen reduction, groundwater removal, possibly water loss due to transpiration from increase plant growth, and off-road vehicle use.

***Arundo* impacts:** *Arundo stands on floodplains can create many of the same hydrologic and flow conditions as man-made channelization such as faster flows, high erosion within channels, etc. These factors may contribute to the sticklebacks decline by decreasing the elevation and channel complexity that stickleback may prefer over a simple deeper channel form. These factors are more relevant in the lower portions of the sticklebacks' range on the Santa Clara.*

Overall impact metric for *Arundo* on unarmored three-spine stickleback: Very high, score of 8.

Interaction of *Arundo* distribution and unarmored three-spine stickleback occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Unarmored Threespine Stickleback Recovery Plan (Revised), U.S. Fish and Wildlife Service, Portland, Oregon, 1985.
Biological and Conference Opinions for Annual Removal of Giant Reed and Tamarisk in Upper Santa Clara River Watershed, Los Angeles county, CA (File No. 2004-01540-AOA)(1-8-06-F-5).

7.2.15 Southern Steelhead (*Oncorhynchus mykiss*)

Southern California Distinct Population Segment (DPS)
Federal status: Endangered August 18 1997. Critical habitat was designated on September 2 2005.
South-Central California Coast DPS
Threatened Jan 5 2006, Critical habitat designated September 9 2005.
Arundo impact score: 7

General Ecological Needs/Habitat Affinities:
Southern steelhead can survive a wide range of temperature conditions, but require streams with adequate dissolved oxygen. Adult steelhead migrate from the ocean to freshwater spawning grounds. Spawning habitat consists of gravel substrates free of excessive silt. Adults do not feed during their upstream journey, rather use their energy reserves. Once they are large enough, smolts migrate downstream to the ocean, and to successfully complete this journey they require refuge areas with good cover and water quality.
Riparian vegetation provides cover and protection from predators and areas of refuge from high velocities. Riparian vegetation is also important in maintaining low stream temperature, stabilizing banks, and providing food sources for migrating steelhead. To provide these benefits, riparian vegetation needs high vigor, density, and species diversity, including a mixture of canopy trees, brush and grasses. Areas of lowered velocity or reverse flow areas within the channel allow steelhead to use energy reserves efficiently during migration in order to save energy for spawning. Sediment removal of sandbars reduces flow-field complexity, particularly of edgewater eddies and low velocity zones. This likely results in adult steelhead migrating through higher velocities and consuming higher levels of reserved energy. If too much reserved energy is consumed, and sufficient resting pools are not available, adults could be unable to reach spawning grounds, or have less energy for reproductive development. Furthermore, modification of sandbars and velocities could also simply increase the amount of time it takes for steelhead to reach spawning grounds. Removing and/or altering sandbars also reduces the convergence of flows through pools, thus reducing the processes that maintain pools. Pools provide cover and refuge. During the upstream migration steelhead rest in pools and during downstream migration smolts take refuge in pools during the day. Adults and smolts both require adequate flows for migration; they need enough water flow to travel up and down the river/stream, and to keep the river mouth open to the ocean.
Steelhead metabolism can be impacted by high water temperatures and the associated reduction in dissolved oxygen. Temperatures above 20° C have been known to stop fish migration, and temperatures above 25° C can be lethal to salmon and trout. High levels of suspended sediment (e.g. 3,000-4,000 mg/L), generally the result of large storm events or channel grading activities, can significantly impact fish migration and survival. Fish can suffer from gill abrasion and reduced visibility, and suffer mortality after exposure of two or more days. Fish at the mouth of a river would be delayed 1-2 days until the initial flush of sediment passes after a storm.

Arundo impacts: *Arundo has a significant number of impacts on river systems- some of which are negative and others that may be positive. Arundo typically occurs in areas that steelhead pass through so impacts to migration are important to explore. Arundo is not good at stabilizing eroding banks stands and clumps break off and are undercut by flows. This may increase erosion rates locally. Arundo does form dense stands of vegetation on floodplains. These dense stands create conditions that deepen low flow channels and push systems to single thread form in comparison to more complex braided systems or broader shallow systems. This single deep channel may aid migration of steelhead. However, single thread narrow channels have higher velocity and fewer areas to rest; this could be a detriment. Single thread channels also tend to transport (carry) greater suspended loads under a larger* *range of flow events. This could also be a detriment to steelhead, particularly if there a large number of sediment inputs (such as agricultural inputs or other disturbed sites). Highly invaded systems may have Arundo water use that reduces duration of surface flows- this would be a severe impact to steelhead. Water use may be lower at the time of year when fish migration occurs, partially offsetting transpiration rates. Arundo biomass could be a significant stressor as both a physical hindrance to passage and as a contamination in the water column. Water temperature impacts for portions of the habitat where fish passage is occurring are extremely difficult to quantify. It is not clear that large systems would have significant shading of the channel from mature gallery trees. Arundo shades a narrow band of the bank if the low flow channel is directly adjacent to the bank. More complex, but probably more relevant is water depth which may be strongly affected by Arundo stands (by effecting channel depth- chapter 5). Shading would be more relevant in upper portions of the watersheds where fish develop; these areas do not typically have Arundo in them.*

Breeding/Life History:
Adult steelhead migrate from the ocean into freshwater streams to spawn between December and April. Female steelhead dig a nest in a stream area with suitable gravel composition, water depth, and velocity. Females may deposit eggs in four to five nests. Steelhead eggs hatch three to four weeks after being deposited. Juvenile steelhead typically spend one to two years rearing in freshwater before migrating to estuarine areas as smolts and then into the ocean to feed and mature. The majority of smolts enter the ocean at age two in March and April. They migrate at night and seek refuge and feed during the day. Steelhead can then remain at sea for up to three years before returning to fresh water to spawn.

Arundo impacts: *Arundo impacts on migration have been reviewed. Arundo debris in estuaries and Arundo effects on sediment movement could degrade estuarine habitat where smolts reside prior to entering the ocean.*

Diet:
Young steelhead fry feed mostly on zooplankton. Adult steelhead eat aquatic and terrestrial insects, mollusks, crustaceans, fish eggs, minnows, and other small fishes.

Arundo impacts: *Little impact as Arundo is not typically present or abundant in the upper portions of watersheds where juveniles develop. There could be greater impacts on Ventura River, Estero Bay and Santa Ynez, but spawning grounds are not clearly indicated on data sets.*

Status/Distribution or Historic and Current Range:
Steelhead within the Southern California DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in streams from the Santa Maria River, San Luis Obispo County, California, to the U.S.-Mexico Border. South-Central California Coast DPS includes all naturally spawned anadromous steelhead from the Pajaro River (inclusive) to, but not including, the Santa Maria River, California. An estimated 30,000 - 50,000 steelhead once spawned in southern California rivers, but the recent runs in four major river systems were made by fewer than 500 adults total. Steelhead could once be found in 46 watersheds in the region, but only remained in 17 - 20 drainages by 2002. Many of these creeks and rivers now sustain only the resident form of steelhead, rainbow trout. Anadromous steelhead currently occur in only four large river systems in southern California: the Santa Maria, Santa Ynez, Ventura, and Santa Clara rivers. But periodic sightings have occurred on San Mateo (San Juan HU) and the San Luis Rey River.

Arundo impacts: *Arundo occurs in abundance on several critical watersheds and may occur on portions of spawning areas on a subset (Appendix B).*

Decline and Threats:
Decline is due to long-standing human induced factors such as lack of flows due to groundwater pumping, dams and water diversions, blocked access to historic spawning and rearing areas upstream of dams, and channel modification.

Arundo impacts: *Arundo has significant impacts on water use, channel form, and sediment transport. These are complex hydro geomorphic processes explored in chapter 5. Most impacts would appear to be strongly negative, others could facilitate migration.*

Overall impact metric for *Arundo* on the southern steelhead: High impact, score of 7.

Interaction of *Arundo* distribution and southern steelhead occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Programmatic Biological Opinion for the United States Army, San Francisco District Corps of Engineers' permit pursuant to 404 of the Clean Water Act for Monterey County Water Resources Agency regional General Permit for the Salinas River Channel Maintenance Program; National Marine Fisheries Service, Southwest Region, Long Beach CA. July 2003.

7.2.16 Santa Ana Sucker (*Catostomus santaanae*)

Federal status:	Endangered, April 12 2000. Critical habitat has not been designated.
State status:	Species of special concern.
Arundo impact score:	6

General Ecological Needs/Habitat Affinities:
The sucker is fairly general in its habitat requirements, occupying both low-gradient, lowland reaches, and high-gradient, mountain streams. The sucker seems to do best in small to medium streams with higher gradients, clear water, and coarse substrates, such as the east fork of the San Gabriel River. Flowing water is essential, but can vary from slight to swift. It is typically associated with gravel, cobble, and boulder substrates, although it is also found over sand and mud substrates.

Arundo impacts: *Arundo abiotic impacts are of particular concern for the sucker, particularly high water use and modification of geomorphology and sediment transport on the Santa Ana. Arundo is not abundant in the low channel areas where fish occur. The Los Angeles River is steeper in gradient and Arundo, though present, is not abundant enough to significantly impact water availability and fluvial processes.*

Breeding/Life History:
They live three to four years, but reach sexual maturity in one year and have high fecundity. Spawning generally occurs from late March to early July, with the peak in May and June.

Arundo impacts: *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana.*

Diet:
The sucker feeds mostly on algae, diatoms, and detritus scraped form rocks and other hard substrate. Aquatic insects comprise only a small part of their diet.

***Arundo* impacts:** *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana.*

Movement:

Little is known about sucker movements, however other species in the same family are known to be high vagile and undertake spawning migrations.

***Arundo* impacts:** *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana. Modification of sediment transport and fluvial processes would also affect channel forms and movement.*

Status/Distribution or Historic and Current Range:

Historically the sucker occupied the Los Angeles, San Gabriel, and Santa Ana Rivers from near the Pacific Ocean to their uplands. It was described as common in the 1970s, but has since experienced declines throughout most of its range, and now persists in isolated, remnant populations. Approximately 70-80% of its historic range in the Los Angeles, San Gabriel and Santa Ana Rivers has been destroyed. Currently the sucker is found 1) in portions of Big Tujunga Creek between the Big Tujunga and Hansen dams along the Los Angeles River, 2) in the west, east and north forks of the San Gabriel River above Morris Dam, and 3) reaches of the Santa Ana River between the city of San Bernardino and the vicinity of Anaheim. There is also a population of suckers in the Santa Clara River that is thought to be introduced and that has hybridized with the Owen’s sucker, so it is not included within the range of the native sucker.

***Arundo* impacts:** *Arundo significantly overlaps with the Santa Ana population and to a lesser degree the Los Angeles River population (Appendix B). There is also a hybridized population on the Santa Clara that may be introduced. There is significant Arundo within this populations range. The Santa Clara watershed is given a distribution score (Appendix B) but it is lowered to reflect the questionable genetic integrity of the resident population. If revisions to the Santa Clara's population value are made a higher impact interaction score should be given.*

Decline and Threats:

Threats that have contributed to the decrease in the sucker include 1) destruction and degradation of habitat through urbanization, channelization, flood control structures, water diversion, water withdrawal, and water quality reduction, 2) direct loss of suckers due to water diversion, 3) competition and predation from non-native species, and 4) loss of connectivity.

Overall impact metric for *Arundo* on the Santa Ana sucker: Moderate/High, score of 6.

Interaction of *Arundo* distribution and Santa Ana sucker occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Biological Opinion on the Prado Mainstem and Santa Ana River Reach 9 Flood Control Projects and Norco Bluffs Stabilization Project, Orange, Riverside, and San Bernardino Counties, California; U.S> Fish and Wildlife Service, Carlsbad, CA, December 2005.

7.2.17 San Joaquin Kit Fox (*Vulpes macrotis mutica*)

Federal status:	Endangered, March 11, 1967. No critical habitat has been designated.
State status:	Threatened, June 27, 1971.

Arundo impact score: 1

General Ecological Needs/Habitat Affinities:
This species historically inhabited grassland, scrubland, and wetland communities in the San Joaquin Valley and adjacent habitat. Today kit foxes are found in grassland and scrubland communities, most of which have been extensively modified by humans.

Kit foxes use dens for temperature regulation, shelter from adverse weather and protection from predators. They either dig their own dens, use those constructed by other animals, or use human-made structures (culverts, abandoned pipelines, or banks in sumps or roadbeds). Kit foxes often change dens and many dens may be used throughout the year. The majority of their dens lie in relatively flat terrain or gently sloping hills, in washes, drainages, and roadside berms.

Arundo impacts: *Arundo is not abundant within the habitat occupied by foxes. However, it does degrade the habitat as foxes prefer very open habitat with little or no vegetation structure to avoid predation. Arundo creates structure and may interact with dens that occur on washes.*

Breeding/Life History:
Kit foxes can breed when one year old. Adult pairs stay together all year. During September and October, females begin to clean and enlarge their pupping dens. Mating occurs between December and March. Litters of two to six pups are born in February or March. Pups emerge from the den after about a month.

Arundo impacts: *Very minor impacts related to potentially higher predation and lower denning quality.*

Diet:
Kit fox eat small mammals such as mice, kangaroo rats, squirrels and rabbits. They also eat ground-nesting birds and insects. They are primarily nocturnal hunters.

Arundo impacts: *No impact likely.*

Movement:
The kit fox is mostly nocturnal, but can be active in the daytime during cool weather. Home ranges of approximately one to twelve square miles have been reported. Development has significantly degraded movement and dispersal corridors for young kit foxes. Juvenile survival and successful dispersal has been declining in recent years. Three occurrences of kit fox movement have been documented between the Salinas-Pajaro region and the Carrizo Plain Natural Area. Although the total movement of kit foxes between these areas is unknown, land development along the natural movement corridors between Carrizo Plain and the Salinas Valley, as well as development within Salinas Valley has probably reduced immigration of kit foxes into the Salinas Valley, possibly contributing to their decline.

Arundo impacts: *Dense Arundo stands may inhibit movement to new areas as kit foxes prefer open areas. Riparian corridors are extremely important for movement of wildlife. Foxes may use roads as alternate corridors if riparian zones are overly vegetated (Arundo), leading to increased mortality from vehicles. Arundo is not abundant enough on the upper Salinas to significantly discourage use of riparian habitat as a corridor- but migration and use of riparian habitat downstream (north) in Salinas valley could be reduced by Arundo, particularly below King City where Arundo cover is very high.*

Status/Distribution or Historic and Current Range:
In the San Joaquin Valley before 1930, the range of the San Joaquin kit fox is believed to have extended from southern Kern County north to Contra Costa County on the west side and near La Grange, Stanislaus County, on the east side. Until the 1990s, Tracy was the farthest northwest record, but now there are records from the Antioch area of Contra Costa County. By 1930, the kit fox range had been reduced by more than half, with the largest portion remaining in the southern and western parts of the Valley. By 1958, an estimated 50% of the Valley's original natural communities had been lost, due to extensive land conversions, intensive land uses, and the use of pesticides. In 1979, only about 6.7% of the San Joaquin Valley's original wildlands south of Stanislaus County remained untilled and undeveloped. Today many of these communities are represented only by small, degraded remnants. Kit foxes are, however, found in grassland and scrubland communities, which have been extensively modified by humans with oil exploration, wind turbines, agricultural practices and/or grazing. The kit fox population is fragmented, particularly in the northern part of the range.

Arundo impacts: *Arundo and foxes co-occur in the Salinas watershed (Appendix B).*

Decline and Threats:
Kit foxes are subject to competitive exclusion or predation by other species, such as the nonnative red fox, coyote, domestic dog, bobcat, and large raptors. Loss and degradation of habitat by agricultural, industrial, and urban developments and associated practices continue, decreasing the carrying capacity of remaining habitat and threatening kit fox survival. Such losses contribute to kit fox declines through displacement, direct and indirect mortalities, barriers to movement, and reduction of prey populations.

Overall impact metric for *Arundo* on the San Joaquin kit fox:
Extremely low/improbable, score of 1. If high quality habitat was identified north of Salinas range where Salinas River could serve as a corridor, then Impact score should be increased.

Interaction of *Arundo* distribution and the San Joaquin kit fox occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Programmatic Biological Opinion for the United States Army, San Francisco District Corps of Engineers' permit pursuant to 404 of the Clean Water Act for Monterey County Water Resources Agency regional General Permit for the Salinas River Channel Maintenance Program; National Marine Fisheries Service, Southwest Region, Long Beach CA. July 2003.
Species Account SAN JOAQUIN KIT FOX (*Vulpes macrotis mutica)*, U.S. Fish & Wildlife Service, Sacramento Fish & Wildlife Office.

7.2.18 San Diego Ambrosia (*Ambrosia pumila*)

Federal status:	Endangered, July 2 2002. Final critical habitat designated November 30 2010.
State status:	None?
Arundo impact score:	7

General Ecological Needs/Habitat Affinities:
Ambrosia pumila is a perennial herb in the sunflower family (Asteraceae). It occurs primarily on upper terraces of rivers and drainages. Within these areas, the species is found in open grassland of native and nonnative plant species, and openings in coastal sage scrub, and primarily on sandy loam or clay soils. The species may also be found in ruderal habitat types (disturbed communities containing a mixture of

native and non-native grasses and forbs) such as fire fuel breaks and edges of dirt roadways. Non-native grassland and ruderal habitat types provide adequate habitat for *A. pumila*; however, non-native plants can out-compete *A. pumila* plants for resources in some situations. *Ambrosia pumila* consistently occurs in areas near waterways such as upper terraces of rivers or other water bodies. These areas do not necessarily provide high levels of soil moisture, and *A. pumila* is adapted to dry conditions. *A. pumila* may require periodic flooding for some segment of its life cycle. Additionally, areas subject to periodic flooding may be less amenable to competing non-native and native plants. *A. pumila* is a clonal herbaceous perennial plant that spreads vegetatively by means of slender, branched, underground root like rhizomes from which new aboveground stems (aerial stems or ramets) arise each year. Aerial stems of *Ambrosia pumila* sprout from their underground rhizomes in early spring after winter rains, and flower between May and October. However, aerial stems have been observed sprouting under dry conditions in late fall. The aerial stems senesce after the growing season, leaving the rhizome system in place from which new aerial stems may sprout when environmental conditions are appropriate. Little is known about its reproductive system, but it is presumed to be wind-pollinated. It is thought to have limited sexual reproductive output due to low production of viable seed. The dispersal strategy of *A. pumila* is unknown and the seeds lack structures that facilitate dispersal by wind or passing animals. It may depend on periodic flooding of nearby waterways for dispersal of seeds and rhizomes that can produce new aerial stems. The longevity of individual plants and of seeds, and the potential for buried seed banks to develop in the soil are unknown.

Arundo impacts: *Arundo and A. pumila overlap in range and in habitat. This creates the potential for direct competition and for impacts related to water use, fire and modification of geomorphic processes. These are slightly mitigated by the fact that ambrosia is present in the higher elevation portions of the riparian zone- higher terraces and transition/eco-tones with scrub and grass lands. Arundo debris may cover plants habitat. Arundo fires may result in take and or type conversion. Modified flood and sediment transport may decrease habitat fitness and interfere with seed dispersal of ambrosia.*

Status/Distribution or Historic and Current Range:

Ambrosia pumila is distributed in southern California from northwestern Riverside County, south through western San Diego County, to northwestern Estado de Baja California, Mexico. It is generally found at or below elevations of 487 m (1,600 ft) in Riverside County, and 183 m (600 ft) in San Diego County. At the time of listing, 15 native occurrences of *A. pumila* were considered extant in the United States: 3 in Riverside County and 12 in San Diego County (native is used here to differentiate these from occurrences derived from plants translocated to another site).

Arundo impacts: *Ambrosia is present on highly invaded watersheds, specifically San Diego and San Luis Rey (Appendix B). The strong overlap in range makes larger scale impacts to ambrosia relevant. On Santa Ana one population near Lake Elsinore appears to above the river and little Arundo is present up stream or nearby. The other Santa Ana population is historic (1940), but is near large Arundo infestations on the main river. If new populations were found there could be greater potential for impacts on Santa Ana.*

Decline and Threats:

Loss and degradation of *Ambrosia pumila* habitat is the result of development, non-native plants, fuel modification, altered hydrology and fragmentation. Development results in direct loss of habitat. Competition from non-native plants, primarily non-native grasses and forbs, pose a significant threat to the species throughout its range. No research has been done to clarify the specific effects of non-native plants on *Ambrosia pumila*, but a recent study by the Center for Natural Lands Management in San Diego County demonstrated that reduction of non-natives increased percent cover of *Ambrosia pumila*. Fuel modification activities that can negatively affect *Ambrosia pumila* include weed abatement, fire suppression, and landscaping practices (including mowing, discing, and plowing). Altered hydrology has the potential to impact *Ambrosia pumila*. It almost always occurs on the upper terraces of rivers/streams or near the margins of vernal pools, where under natural conditions the plants would likely be subjected to inundation during large-scale flooding events. If *Ambrosia pumila* is dependent on these periodic flooding events for some aspect of its life history (e.g., seed germination, dispersal) or control of competing plants, altering the flooding regimes of associated waterways or vernal pools could have a significant impact on the species. However, it is unknown if and to what degree *Ambrosia pumila* is dependent upon periodic flooding or other aspects of its proximity to waterways.

Overall impact metric for *Arundo* on the San Diego ambrosia: High impact, score of 7.

Interaction of *Arundo* distribution and San Diego ambrosia occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Ambrosia pumila (San Diego ambrosia) 5 Year Review and Summary, US Fish and Wildlife Service, Carlsbad Office, CA, July 15 2010. http://ecos.fws.gov/docs/five_year_review/doc3557.pdf

7.2.19 Marsh Sandwort (*Arenaria paludicola*)

Federal status:	Endangered, August 3, 1993. Critical habitat has not been designated.
State status:	Endangered, February 1990.

Arundo impact score: 4

General Ecological Needs/Habitat Affinities:

Marsh sandwort is an herbaceous green perennial in the Caryophyllaceae family that is often supported by surrounding vegetation. The trailing stems often root at the nodes and can be up to 1 m long. The opposite leaves are lanceolate and narrowly sharp pointed with a solitary mid-vein. It blooms from May to August. Flowers are small, white and borne singly on long stalks. Marsh sandwort is found in freshwater marshes from elevations to about 1,476 ft (450 m) with saturated soils and acidic bog soils, predominantly sandy with high organic content. Vegetation around the Black Lake Canyon population includes emergent freshwater marsh species and some riparian woodland or wetland tree species, mainly willow and wax myrtle. The two existing populations of marsh sandwort in San Luis Obispo County are found in freshwater marshes located within a system of active to partly-stabilized sand dunes.

Arundo impacts: *Minor impacts on the upper Santa Ana to a very old historic sighting (1899).*

Status/Distribution or Historic and Current Range:

Historically it has been collected by botanists from scattered locations near the Pacific coast in southern and central California and Washington. Only two of California's seven historical populations are known to exist today, near the southern San Luis Obispo County coast at Black Lake Canyon on Nipomo Mesa and at Oso Flaco Lake further south.

Arundo impacts: *Only one historic signing on Santa Ana River (Appendix B).*

Decline and Threats:

Immediate threats to the survival of marsh sandwort include habitat destruction, habitat degradation, and competition with non-native species for light, nutrients and space.

Arundo impacts: *Arundo would be a stressor and competitor if it were re-discovered on the Santa Ana River.*

Overall impact metric for *Arundo* on the marsh sandwort: Low/moderate impact, score of 4.

Interaction of *Arundo* distribution and marsh sandwort occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Recovery Plant for marsh sandwort (*Arenaria paludicola*) and Gambel's watercress (*Rorippa gambelii*). U.S. Fish and Wildlife Service, Portland, Oregon, 1998.

7.2.20 San Jacinto Valley Crownscale (*Atriplex coronata* var. *notatior*)

Federal status:	Endangered, October 1998. Critical habitat has not been designated.
State status:	none
Arundo impact score:	7

General Ecological Needs/Habitat Affinities:
San Jacinto Valley crownscale is an annual plant in the goosefoot family (Chenopodiaceae). It grows 4 to 12 inches (30.5 cm) tall with grayish colored leaves. The plant generally flowers in April and May. This bushy plant can have one or several gray-green stems, which turn deep yellow as it grows older and dies. San Jacinto Valley crownscale is restricted to highly alkaline and silty-clay soils. These soils are found in certain alkali sink scrub, alkali playa, vernal pool, and annual alkali grassland habitats. Habitat for San Jacinto Valley crownscale is typically flooded during winter rains and the plant emerges as waters recede in the spring.

Arundo impacts: *Crownscale does occur in wash areas/floodplain on Alberhill Creek north of Lake Elsinore, where significant Arundo stands also occur. Therefore the two species interact and compete with each other for resources and space.*

Status/Distribution or Historic and Current Range:
San Jacinto Valley crownscale has a narrow range of distribution and is only known to occur in western Riverside County. Within western Riverside County, there are four general population centers of the plant – in the floodplain of the San Jacinto River at the San Jacinto Wildlife Area/Mystic Lake; in the San Jacinto River floodplain between the Ramona Expressway and Railroad Canyon Reservoir; in the Upper Salt Creek Vernal Pool Complex in the west Hemet area; and in the floodplain of Alberhill Creek north of Lake Elsinore. The San Jacinto Valley crownscale experienced a severe decline between 1992 and 1999, when it lost 70 % of its population; it continues to decline today. Because floodwaters carry crownscale seeds over long distances, population ranges may shift from year to year.

Arundo impacts: *As shown in Appendix B Arundo and San Jacinto Valley crownscale overlap in range. Closer examination of polygon data shows clear co-occurrence within the riparian areas.*

Decline and Threats:
The San Jacinto Valley crownscale is in particular danger from increased urbanization because its habitat is nearly flat and therefore easy to develop. It is also threatened by habitat fragmentation, agricultural weed-control measures where its habitat is repeatedly disked, off-road vehicle use, alteration of hydrology, deliberate manure and sludge dumping, trampling by livestock, and competition from nonnative species.

***Arundo* impacts:** *The sites have all of these impacts: agricultural use, urban use, water management facilities. Arundo adds to the population's stress by directly competing against it. Arundo is also dense enough to add biomass debris over crownscale habitat following flood events. Fire could also impact habitat and sedimentation. Of added concern is response to fire and flood events that are of greater magnitude due to high Arundo cover. The area has heavy infrastructure (roads, water transfer, levees, agriculture use, etc.) that would likely lead to damaging emergency actions in response to events.*

Overall impact metric for *Arundo* on the San Jacinto Valley crownscale: High Impact, score of 7.

Interaction of *Arundo* distribution and San Jacinto Valley crownscale occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Species Profile for San Jacinto Valley crownscale (*Atriplex coronata notatior*), U.S. Fish and Wildlife Service, http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=Q2ZR

7.2.21 Nevin's Barberry (*Berberis nevinii)*

Federal status:	Endangered, October 13, 1998. Critical habitat designated on February 13 2008.
State status:	Endangered, January 1987.
Arundo impact score:	4

General Ecological Needs/Habitat Affinities:

Nevin's barberry is a large rounded shrubby member of the barberry family (Berberidaceae) that grows up to 13 ft (4 m) tall, with blue-green, spiny pinnate leaves. It is widely cultivated and popular in xeric gardens, in part for its bright red edible berries and bright yellow flowers that bloom March through April. Nevin's barberry generally grows within sandy, gravelly soil, on north facing slopes or low gradient washes. On north-facing slopes, it is associated with coastal scrub and chaparral habitat, while in low gradient washes it is found in alluvial and riparian scrub. In general, the plant occurs from 800-5200 ft (1,585 m) above sea level, with local distribution potentially related to the presence of groundwater. Associated plant communities are alluvial scrub, riparian scrub or woodland, coastal sage scrub, chaparral, and/or oak woodland.

***Arundo* impacts:** *Arundo occurs within population ranges of barberry when plants are located within low gradient washes. These are not usually areas where Arundo becomes overly abundant, but it be locally abundant. Direct competition between plants as sites could occur. Abiotic impacts are unlikely due to limited extent of Arundo upstream of washes where barberry occurs.*

Status/Distribution or Historic and Current Range:

The distribution of Nevin's barberry is scattered, with populations located throughout southern California in Los Angeles, Riverside, and San Bernardino counties. There have been a total of 34 occurrences of *Berberis nevinii* reported in southern California, five of which have been or are presumed extirpated and 7 considered to have been introduced. Total number of individuals is estimated at 500, with approximately half of those as naturally occurring individuals. In addition, the majority of occurrences are comprised of only one to few individuals, with little to no reproduction observed.

***Arundo* impacts:** *Arundo and barberry co-occur in Santa Clara (Arundo is scattered to dense), and several area on the Los Angeles and San Gabriel Rivers (Arundo is scattered, Appendix B).*

Decline and Threats:

Population decline is likely related to low fecundity and habitat loss. Populations that occur in alluvial washes are threatened by urban and agricultural development, competition by non-native plant species, off-road vehicle activity, road maintenance, and vegetation clearing and channelization for flood control. While population sizes vary considerably among extant groups, the majority of occurrences are comprised of only one to a few individuals, with little to no reproduction observed. Most of the historic habitat of Nevin's barberry has been eliminated by agriculture, urban development, and flood control and stream channelization.

Overall impact metric for *Arundo* on the Nevin's barberry: Low/moderate impact, score of 4.

Interaction of *Arundo* distribution and Nevin's barberry occurrence is presented by watershed in Table 7-3 and distribution is shown in Appendix B.

Sources:

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

Center for Plant Conservation, National Collection Plant Profile for Nevin's Barberry, http://www.centerforplantconservation.org/collection/cpc_viewprofile.asp?CPCNum=2777

7.2.22 Spreading Navarretia (*Navarretia fossalis*)

Federal status:	Threatened, October 13 1998. Critical habitat: October 18 2005. A proposal for revised critical habitat was initiated on June 10 2009.
State status:	None
Arundo impact score:	6

General Ecological Needs/Habitat Affinities:

Spreading navarretia is an annual plant in the Polemoniaceae (phlox family). It is a low, mostly spreading or ascending plant 4 - 6 inches (10 - 15 cm) tall. The leaves are long and finely divided into slender spine-tipped lobes and the lavender-white flowers are arranged in flat-topped, compact, leafy heads. Each seed is covered by a layer that becomes sticky and viscous when the capsule is moistened. Spreading navarretia is typically found in vernal pool (seasonal depression wetlands) habitat, particularly in Los Angeles and San Diego Counties. In western Riverside County, however, *Navarettia fossalis* is associated with seasonally flooded alkali vernal plain habitat that includes alkali playa (highly alkaline, poorly drained), alkali scrub, alkali vernal pool, and alkali annual grassland components. *Navarretia fossalis* depends on the inundation and drying cycles of its habitat for survival. It germinates from seeds left in the seed bank. Most *Navarretia* species have indehiscent fruit, or fruit with fibers that absorb water and expand to break open the fruit after a substantial rain. The timing of germination is important so that the plant germinates under favorable conditions in the spring rather than the summer, autumn, or winter. *Navarretia fossalis* abundance also varies from year to year depending on precipitation and the inundation/drying time of the vernal pool. The occurrences of plants can also vary spatially in alkali playa habitat where pools are not in the same place from year to year. After germination, the plant usually flowers in May and June as the vernal pool is devoid of water. The plant then produces fruit, dries out, and senesces in the hot, dry summer months.

Arundo impacts: *Although navarretia habitat sounds restrictive Arundo co-occurs with the Riverside San Jacinto Valley navarretia population (Appendix B). This area is a broad floodplain and is the same area where San Jacinto crownscale is found. This area has a narrow river thread heavily invaded with*

Arundo bordered by flat floodplains. Impacts described in the crownscale section ally to this species as well (risk of fire, Arundo debris, flood damage and 'emergency actions' to repair and protect infrastructure.

Status/Distribution or Historic and Current Range:
Spreading navarretia extends from northwestern Los Angeles County to western Riverside County, and coastal San Diego County in California, to San Quintin in northwestern Baja California, Mexico.

Arundo impacts this by: *As noted these species co-occur in San Jacinto Valley (Appendix B).Populations of navarretia that occur in San Diego County watersheds typically occur in vernal pools where Arundo is not present. The Santa Clara navarretia population also occurs in a vernal pool.*

Decline and Threats:
Threats include agriculture, fragmentation, grazing and urbanization.

Overall impact metric for *Arundo* on spreading navarretia: Moderate/high Impact, score of 6.

Interaction of *Arundo* distribution and spreading navarretia occurrence is presented by watershed in Table 7-3.

Sources:

Center for Plant Conservation, National Collection Plant Profile for spreading navarretia, http://www.centerforplantconservation.org/collection/CPC_ViewProfile.asp?CPCNum=2930

5-Year Review for spreading navarretia (*Navarretia fossalis*) U.S. Fish and Wildlife Service, http://ecos.fws.gov/docs/five_year_review/doc2574.pdf

Table 7-3. Examination of *Arundo* impacts on federally listed species by watershed.
‘*Arundo* impact rank’ and ‘overlap rank’ (potential for interaction between *Arundo* and listed species distribution and abundance) for each species. The cumulative impact score is in Table 7-4.

Category	Federal Listing[1]	Scientific name	Common name	*Arundo* Impact	Tijuana Estuary	Otay	Sweet-water	S.Diego/ Penasquitos	San Dieguito	Carlsbad	San Luis Rey	Santa Margarita	San Juan	San Francisquito Crk/ Newport	Santa Ana	L.A./ San Gabriel/ Santa Monica	Calleguas	Santa Clara	Ventura	S.Barbara, SouthCoast &S.Ynez	Estero Bay	Salinas	S.Cruz/ Benito	Count
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	2
Amphibian	En	*Bufo californicus*	Arroyo toad	10	-	-	5	3	7	-	10	10	7	7	-	3	-	4	-	-	-	2	-	10
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	2	5	2	3	5
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	4	-	-	-	-	-	-	-	-	-	-	4	6	-	-	-	-	-	-	-	2
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	5	1	1	1	6	-	8	-	9	-	-	0	4	0	1	-	1	-	-	-	9
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	7	-	-	1	-	-	-	-	1	0	-	7	-	-	4	-	-	1	-	-	5
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	8	-	-	2	2	3	2	10	10	3	-	6	1	-	2	-	2	-	-	-	11
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	2	3	3	3	3	3	3	-	-	-	2	2	2	6	-	-	2	-	-	-	11
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	2	3	3	3	3	3	3	4	4	3	4	4	2	2	1	-	-	-	-	-	14
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	3	2	2	3	2	2	4	2	3	-	2	-	-	1	-	-	1	-	-	-	11
Bird	En	*Sterna antillarum browni*	California least tern	4	-	1	-	3	2	4	-	7	-	1	-	1	-	1	-	-	-	-	-	8
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	9	4	4	4	4	4	3	9	10	6	6	10	4	3	3	3	1	-	-	-	14
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	7	-	-	-	-	-	4	8[a]	8[a]	-	-	-	-	3	6[a]	8	5	3	4	1	7
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	8	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	1
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	7	-	-	-	-	-	-	1	-	1	-	-	4	-	8	8	7	5	8	5	9
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	6	-	-	-	-	-	-	-	-	-	-	9	7	-	4	-	-	-	-	-	3
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1
Plant	En	*Ambrosia pumila*	San Diego ambrosia	7	-	2	-	-	7	-	7	-	-	-	2	-	-	-	-	-	-	-	-	4
Plant	En	*Arenaria paludicola*	Marsh sandwort	4	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	7	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	0
Plant	En	*Berberis nevinii*	Nevin’s Barberry	4	-	-	-	-	-	-	-	-	-	-	-	5	-	3	-	-	-	-	-	2
Plant	Th	*Navarretia fossalis*	Spreading navarretia	6	-	-	-	-	-	-	-	-	-	-	10	-	-	1	-	-	-	-	-	1

[1] En = Endangered, Th = Threatened, Sp of Concern = Species of Concern
[2] Santa Barbara Distinct Population Segment (DPS)
[3] Southern California (DPS) is endangered, South-Central California Coast DPS is threatened.
[a] Recent historic 1990s/2000

Table 7-4. Cumulative impact scores for *Arundo* impacts on threatened and endangered species by watershed.
The cumulative impact score is calculated by multiplying the *Arundo* impact rank by overlap rank. Impact scores are for each watershed and species, and are totaled for each watershed and species.

Category	Federal Listing[1]	Scientific name	Common name	Tijuana Estuary	Otay	Sweet-water	S.Diego/ Penasquitos	San Dieguito	Carlsbad	San Luis Rey	Santa Margarita	San Juan	San Francisquito Crk/ Newport	Santa Ana	L.A./ San Gabriel/ Santa Monica	Calleguas	Santa Clara	Ventura	S.Barbara, SouthCoast &S.Ynez	Estero Bay	Salinas	S.Cruz/ Benito	Total
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	**6**
Amphibian	En	*Bufo californicus*	Arroyo toad	-	-	50	30	70	-	100	100	70	70	-	30	-	40	-	-	-	20	-	**580**
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	6	15	6	9	**60**
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	-	-	-	-	-	-	-	-	-	-	16	24	-	-	-	-	-	-	-	**40**
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	5	5	5	30	-	40	-	45	-	-	-	20	-	5	-	5	-	-	-	**160**
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	-	-	7	-	-	-	-	7	-	-	49	-	-	28	-	-	7	-	-	**98**
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	-	-	16	16	24	16	80	80	24	-	48	8	-	16	-	16	-	-	-	**344**
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	6	6	6	6	6	6	-	-	-	4	4	4	12	-	-	4	-	-	-	**64**
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	6	6	6	6	6	6	8	8	6	8	8	4	4	2	-	-	-	-	-	**84**
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	6	6	9	6	6	12	6	9	-	6	-	-	3	-	-	3	-	-	-	**72**
Bird	En	*Sterna antillarum browni*	California least tern	-	4	-	4	8	16	-	28	-	4	-	4	-	4	-	-	-	-	-	**72**
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	36	36	36	36	36	27	81	90	54	54	90	36	27	27	27	9	-	-	-	**702**
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	-	-	-	-	-	-	56	56	-	-	-	-	21	42	-	35	21	28	7	**266**
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	-	-	-	-	-	-	-	-	-	-	-	-	-	64	-	-	-	-	-	**64**
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	-	-	-	-	-	-	7	-	7	-	-	28	-	56	56	49	35	56	35	**329**
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	-	-	-	-	-	-	-	-	-	-	54	42	-	24	-	-	-	-	-	**120**
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	**2**
Plant	En	*Ambrosia pumila*	San Diego ambrosia	0	14	-	-	49	-	49	-	-	-	14	-	-	-	-	-	-	-	-	**126**
Plant	En	*Arenaria paludicola*	Marsh sandwort	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	**4**
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	-	-	-	-	-	-	-	-	-	-	70	-	-	-	-	-	-	-	-	**70**
Plant	En	*Berberis nevinii*	Nevin's Barberry	-	-	-	-	-	-	-	-	-	-	-	20	-	12	-	-	-	-	-	**32**
Plant	Th	*Navarretia fossalis*	Spreading navarretia	-	-	-	-	-	-	-	-	-	-	60	-	-	6	-	-	-	-	-	**66**
			Total:	**59**	**77**	**135**	**134**	**205**	**123**	**387**	**423**	**161**	**146**	**417**	**220**	**67**	**326**	**107**	**127**	**78**	**115**	**54**	**3,361**

[1] En = Endangered, Th = Threatened, Sp of Concern = Species of Concern
[2] Santa Barbara Distinct Population Segment
[3] Southern California Distinct Population Segment (DPS) is endangered, South-Central California coast DPS is threatened.

Table 7-5. Cumulative *Arundo* impact score for each species for all watersheds combined, and sum and average for each taxa group.

Category	Federal Listing[1]	Scientific name	Common name	Cumulative Impact Score for all watersheds	Summary for Taxa Group
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	6	Sum – 686 Ave – 171.5
Amphibian	En	*Bufo californicus*	Arroyo toad	580	
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	60	
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	40	
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	160	Sum – 1,596 Ave – 199.5
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	98	
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	344	
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	64	
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	84	
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	72	
Bird	En	*Sterna antillarum browni*	California least tern	72	
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	702	
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	266	Sum – 779 Ave – 194.8
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	64	
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	329	
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	120	
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	2	2
Plant	En	*Ambrosia pumila*	San Diego ambrosia	126	Sum – 298 Ave – 59.6
Plant	En	*Arenaria paludicola*	Marsh sandwort	4	
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	70	
Plant	En	*Berberis nevinii*	Nevin's Barberry	32	
Plant	Th	*Navarretia fossalis*	Spreading navarretia	66	
			Total:	**3,361**	

7.3 Results

7.3.1 Summary by Species and Group

7.3.1.1 Impact Scores

Within the study area, 22 federally protected species were found to be impacted at some level by the presence of *Arundo*. The magnitude of the impact score ranged from 10 (very severe) to 1 (very low/improbable) (Table 7-3). Five taxonomic groups are represented: amphibian, avian, fish, mammal, and plant. All groups have a minimum of four species with the exception of mammal, which had one.

Amphibians had the widest range of *Arundo* impact scores among the groups. Arroyo toads had severe impacts from *Arundo*, both abiotic and biotic. The other amphibian species (California tiger salamander, California red-legged frog, and mountain yellow-legged frog) were less impacted due to greater habitat use in foothills and mountains where *Arundo* is less abundant. In these areas, *Arundo* is less likely to directly impact the species or to generate enough biomass to degrade habitat significantly.

Avian species fell into two general classes based on the habitat they use. Species that use riparian habitat had impact scores that ranged from high (7) to severe (9), reflecting both abiotic and biotic impacts. This included the least Bell's vireo, southwestern willow flycatcher and yellow-billed cuckoo. Species that use estuary and beach areas were also impacted by *Arundo*, usually as a function of biomass accumulating in habitat areas (discharged from upstream riparian areas), but also to a lesser degree from *Arundo* growing in estuaries and on beaches. Avian species that use beach and estuary habitat had impact scores ranging from moderate (5) to very low (2), reflecting *Arundo* impacts on breeding and predation. In addition to these two classes, the gnatcatcher had a low impact score (2), because it does not breed or feed exclusively in riparian habitat. Avian species were also, as a group, susceptible to physical changes in habitat structure, encouraging predators that use *Arundo* as perches and/or dense cover for denning.

Fish species had fairly uniform impacts from *Arundo* related to modification of abiotic processes that control geomorphology and hydrology. Modification of channel form and depth is a significant change to habitat structure. *Arundo* biomass and shading also have possible effects on habitat quality. Fish habitat varies depending on the species. It may occur only near the river mouth (tidewater goby), reside along river/stream corridors (Santa Ana sucker, stickleback), or pass through the main river corridor to headwaters that are relatively uninvaded by *Arundo* (southern steelhead). Southern steelhead also reside for part of their life-cycle in estuaries. *Arundo* impact scores ranged from very high (8) to moderate/high (6).

The only federally listed mammal species examined was the San Joaquin kit fox, which resides in the northern part of the study area. It has a very low/improbable (1) impact score from *Arundo*. The kit fox does not utilize riparian habitat frequently, and is not dependent on it. It may use riparian areas as corridors for movement.

Water use, fire, biomass and modification of geomorphology are the primary *Arundo* impacts on the five plant species examined. Four of the plant species occur on upper portions of the riparian zone (San Diego ambrosia and Nevin's barberry) or broad areas within the floodplain (San Jacinto crownscale and spreading navarretia). These four species have *Arundo* impact scores ranging from high (7) to low/moderate (4). San Jacinto crownscale and spreading navarretia occur at a single location within the San Jacinto/Santa Ana watershed, so it is possible to look at very specific interactions for these two species. The fifth plant species, marsh sandwort, occurs in inland freshwater marsh. It is a historic occurrence, so *Arundo* impacts were projected to the species' habitat preferences. Although it is unlikely that marsh sandwort still occurs at this location, *Arundo* is having abiotic and biotic impacts that degrade habitat characteristics favored by the plant.

7.3.1.2 Overlap or Spatial Interaction Scores

Overlap rank scores are given in Table 7-3. These were generated by interpreting distribution maps of *Arundo* and each listed species. Species occurring in downstream portions of the watersheds (river mouth, estuaries, beaches) can receive high scores if significant *Arundo* infestations occur upstream. Scores ranged from 1 (no interaction) to 10 (very high interaction).

Overlap scores captured the interaction between *Arundo* and each species' distribution and abundance. Avian species were the widest ranging, with high numbers of watersheds recording occurrences, particularly in the southern and middle of the study area. Fish species also had large numbers of watersheds with occurrences, but more in the middle and northern portions of the study area. Plants were the most restricted, each species typically occurring on only one or two watersheds.

7.3.1.3 Cumulative Impact Scores

The *Arundo* impact score is multiplied by the overlap score to generate a cumulative impact score for each species in each watershed. This metric highlights watersheds, species and taxa groups that are under the most significant pressure from *Arundo*. The avian group is the most impacted by *Arundo*, with a score of 1,596 (199.5 average). This is followed closely by amphibians at 686 (171.5 average). The plant group has the lowest score at 298 (59.6 average), largely due to very limited population ranges for the listed species. Mammals also rank very low, being represented by a single species with low abundance and low impacts from *Arundo*.

Several species stand out as having severe cumulative *Arundo* impact scores across the study area (Figure 7-1). The highest scoring species in the 'severe' category are the least Bell's vireo (702) and the arroyo toad (580). The southwestern willow flycatcher has a 'very high' cumulative impact score of 344. The three species are frequently cited as being under significant pressure from *Arundo* within their ranges. These data strongly supports these accounts.

The cumulative impact scores for the fish are 'very high' for two species (steelhead and tidewater goby), 'high' for the third (Santa Ana sucker) and 'moderate' for the fourth species (unarmored three spine stickleback). *Arundo* impacts on fish have not been recognized in the literature or explored in detailed studies. *Arundo*'s influence on abiotic processes indicates that significant impacts and degradation are likely occurring on heavily *Arundo* invaded watersheds.

The 'high' score for the western snowy plover (160) and the tidewater goby (266), and to a lesser degree the California least tern (72), demonstrate that estuaries, beaches and river mouth areas that support these listed species are impacted by *Arundo* on a number of watersheds within the study area. This has been alluded to in numerous studies and it appears to be a valid area of concern. *Arundo* not only degrades riparian habitat, but it also impacts estuaries and beaches, both of which are wetlands of high value and diversity.

Watershed totals for cumulative *Arundo* impact scores clearly demonstrate that those highly-invaded larger watersheds have the most severe impacts to federally listed species (Santa Margarita = 423, Santa Ana = 417, San Luis Rey = 387 and Santa Clara = 326) (Figure 7-2). The Salinas River is the exception, likely due to its more northern position and its lower diversity and abundance of federally listed species. The next tier of highly-impacted watersheds is well separated from the higher tier with scores of 220 for Los Angeles./San Gabriel/Santa Monica and 205 for San Dieguito. The moderate impact tier includes eight watersheds whose cumulative *Arundo* impact scores range from 161 to 107 (Figure7-2). These include San Juan, San Francisquito/Newport, Sweetwater, San Diego, Ventura, Carlsbad, Santa Barbara, and Salinas. The low cumulative *Arundo* impact tier includes five watersheds whose values range from 78 to 54 (Figure 7-2).:Estero Bay, Otay, Calleguas, Tijuana, and Santa Cruz/Benito. The cumulative *Arundo* impact scores highlight watersheds with *Arundo* impacts to a number of federally listed species. Low ranking watersheds may still have a high cumulative impact for a single species, such as steelhead on the Ventura watershed.

7.3.2 Discussion

Arundo impact scores are very severe (10) to moderate/high (6) for 11 out of the 22 evaluated federally listed species. This indicates that *Arundo*'s modification of abiotic and biotic ecosystem processes is having significant impacts on a wide range of species:

Listed fish as a taxonomic group has high impact scores from *Arundo*. This has not been widely recognized in conservation biology. Listed avian species that fairly exclusively use riparian habitat (least Bell's vireo, southwestern willow flycatcher, yellow-billed cuckoo) had high impact scores and are recognized as being impacted by fires and habitat degradation. Arroyo toads appear to be severely impacted by *Arundo* invasion as they are dependent on geomorphic forms and hydrology that are severely degraded by *Arundo*. Listed plants also had significant impacts tied to specific sites where populations occur.

The cumulative impact scores, which account for the interaction in actual distributions of *Arundo* and the individual listed species, highlight particular species that are under significant pressure within the study area. Five species stand out: least Bell's vireo, arroyo toad, southwestern willow flycatcher, steelhead and tidewater goby. Arroyo toad, steelhead and tidewater goby have not been previously highlighted as species under significant pressure due to habitat and ecosystem modification by *Arundo*.

The impacts described to estuarine and beach avian species are an important extension of impacts to additional habitat types. These impacts typically rank as moderate to low, but they are well documented as pressures on breeding areas, as well as predation.

Prioritization of watersheds by impacts caused by *Arundo* to federally listed species is complicated. The larger watersheds clearly have the greatest impacts on federally listed species (Figure 7-2). These systems are heavily invaded and are having the most severe modification of abiotic and biotic processes, which is reflected in impact scores. It is interesting to note that three of the four systems also have the most active and comprehensive *Arundo* eradication programs. These systems have already been prioritized in terms of on the ground activity.

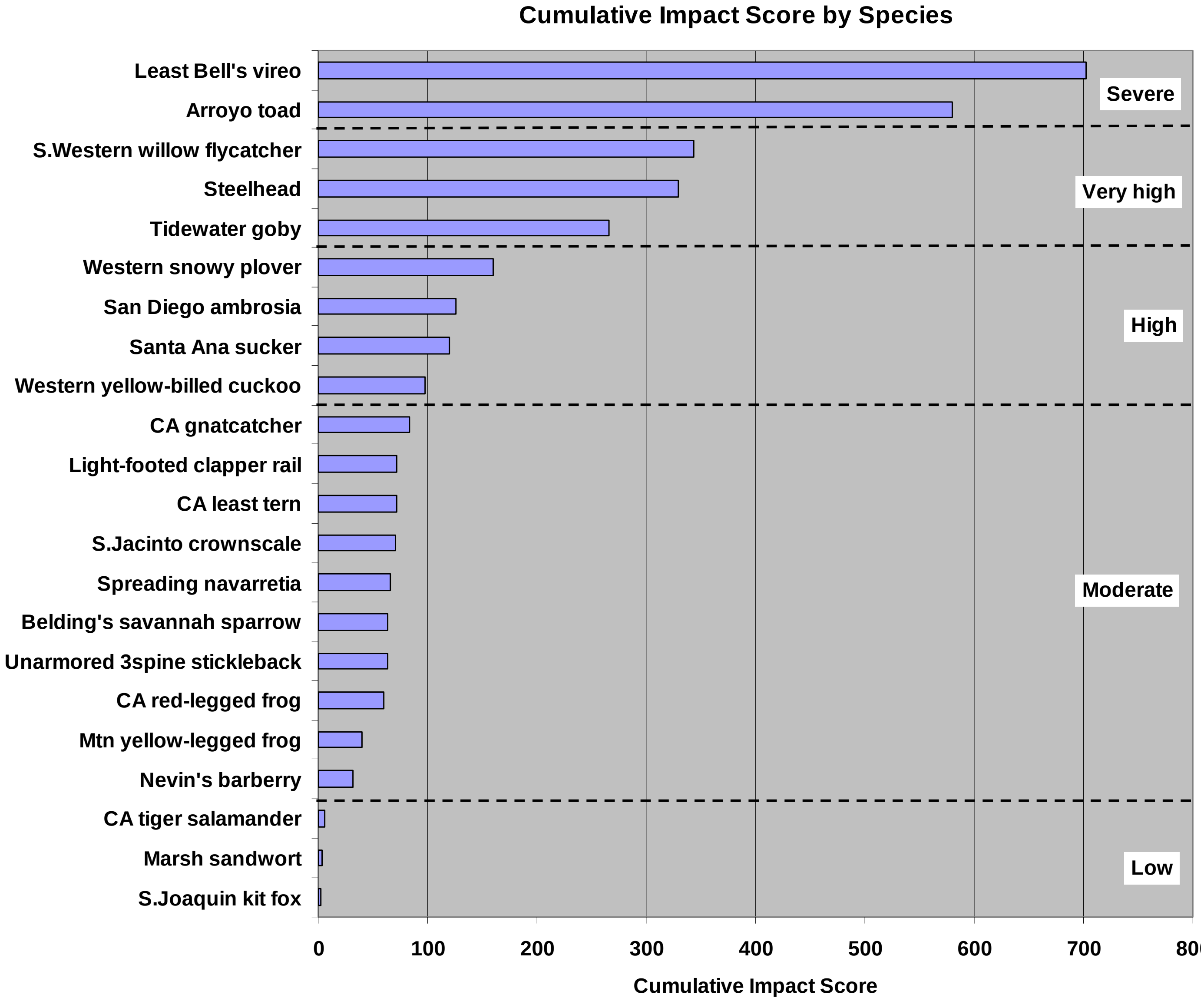

Figure 7-1. Cumulative *Arundo* impact score by species for all watersheds.

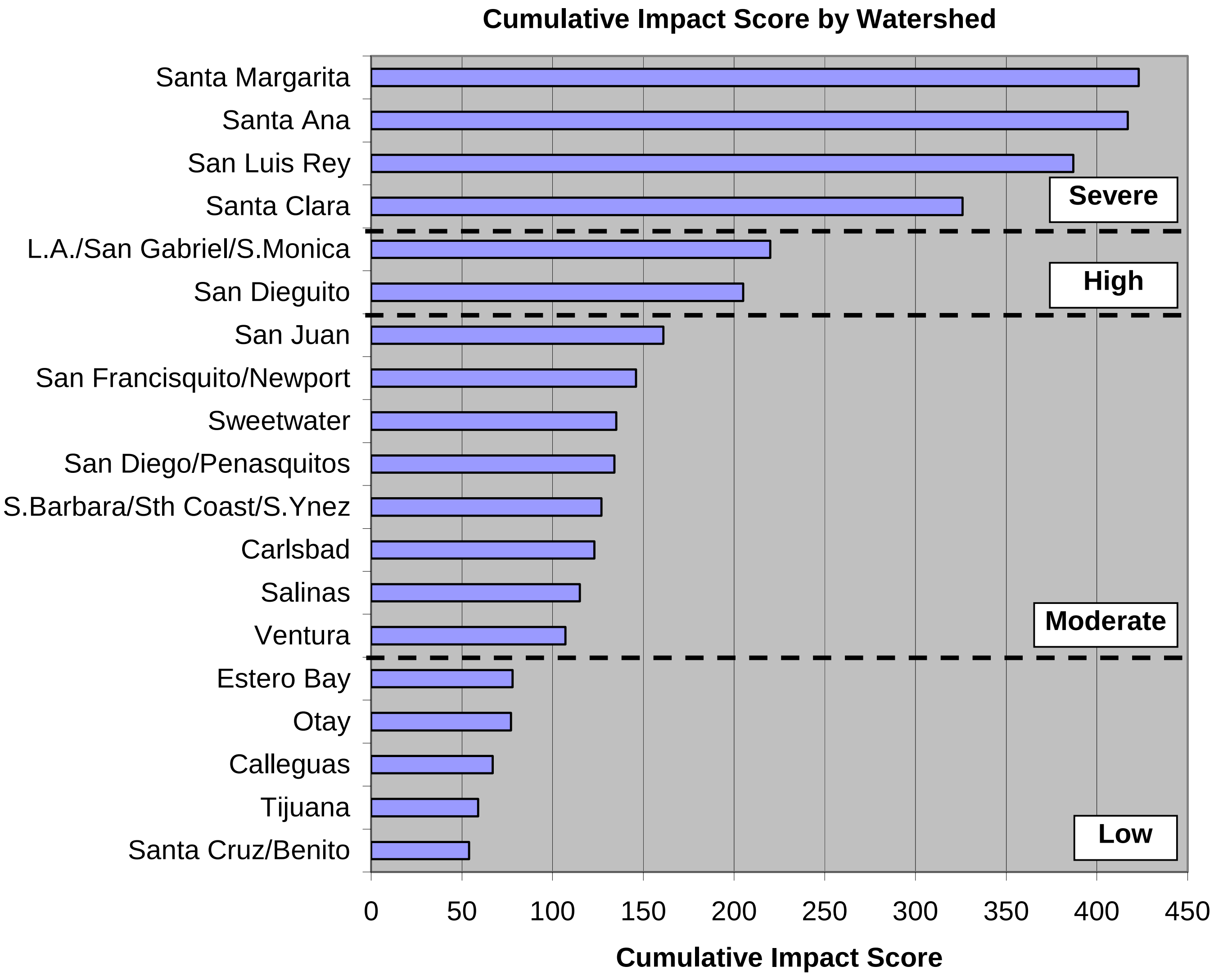

Figure 7-2. Cumulative *Arundo* impact scores by watershed for all federally listed species combined.

8.0 COST TO BENEFIT ANALYSIS

A cost-to-benefit analysis (CBA) is often used to evaluate the desirability of a given action or intervention. CBAs use a monetary valuation of costs and benefits, which are then expressed as a ratio. This allows the many impacts of an invasive species, such as *Arundo*, to be synthesized into a common measure, namely dollars. The results can then be used to show how much benefit is obtained by removing the species and where the most substantial benefits accrue. This in turn could help focus control efforts on watersheds or sites with the greatest potential benefit.

Multiple CBAs have examined the potential net economic benefit of programs to control *Arundo*. A detailed examination of benefits related to water savings on the Rio Grande River in Texas found a net benefit four to eight times greater than the cost (Seawright 2009). Broader CBAs covering multiple factors on watersheds within California have found benefit to cost ratios of 3.9:1 for the Santa Clara (Swezey 2008) and 1.1:1 for the Santa Margarita (Hastings et al. 1998). These CBAs were far less intensive analyses compared to the Seawright study. All CBAs for *Arundo* that could be found showed a positive benefit to cost ratio.

Completing a CBA for *Arundo* control is more straightforward than many that are completed for other types of environmental programs. This is due to reasonably well-defined impacts (potential benefits when *Arundo* is controlled) and applicable cost valuations. Impacts from *Arundo* within the study area have been quantified in this report using the mapped spatial distribution of *Arundo*. This information is used in this CBA, which applies to the entire study area. Cost and benefits are generated for both the peak *Arundo* distribution and current infestation level (which reflects control work over the past 15 years). A ten-year evaluation period was selected as many impacts are periodic in nature and control programs typically take many years to implement. This CBA is a rudimentary analysis and was not completed by an economist. Many complexities were excluded from the analysis including discounting and depreciation over time. As both the benefits and the costs are accrued on a similar timeline, this simplification is not likely to adversely affect the analysis. Also, unlike other CBA studies (such as Seawright 2009), this CBA did not project future increases in acreage of *Arundo* (increases the valuation of benefits in the future).

For this CBA, the costs of controlling *Arundo* will be evaluated, and then the benefits will be presented. This includes an analysis for each benefit (impact) class to clearly outline what approach was used in determining valuations. Results are then presented as a Benefit to Cost ratio to determine the net benefit or cost of controlling *Arundo* within the study area. The higher the benefit is in relation to the cost, the better the economic justification for the action.

8.1 Cost

Generating the cost of controlling *Arundo* for watersheds within the study area is straightforward. The spatial data set gives acreage for *Arundo* within each watershed, and therefore a good estimate of cost per acre for control is all that is needed. Over $70 million have already been spent controlling *Arundo* within the study area over the past 15 years. The approximate amount of money spent treating *Arundo* on each watershed is known as most programs share this information in news updates, proposals and other outreach material. For each watershed treated, acreage and cost of work completed is given in Table 8-1. This data is based on the author's knowledge of federal, state, and local funding of implementation programs, as well as information published by watershed programs. The average cost is $25,000 per acre of *Arundo* controlled. This is a strongly supported valuation based on over fifty projects within nine watersheds that have large implementation programs. This cost is subdivided into $5,000 for management and $20,000 for implementation, based on the author's knowledge of typical cost subdivisions in proposals and reports. Program management costs are high (management of contractors, right of entry agreements, permitting, etc.) as are implementation costs (treatment, biomass reduction, re-vegetation, etc.). It is not surprising that *Arundo* control is an expensive undertaking given that *Arundo* stands have high biomass per acre, are difficult to control, and exist in sensitive habitat that is highly regulated. *Arundo* is also distributed across the landscape making program implementation complex and management intensive.

It should be noted that control costs vary substantially between watersheds and projects. This can be attributed to different treatment approaches, how biomass is dealt with, efficiency, and if re-vegetation is included in the project. The $25,000 average cost per acre for control is a well-supported cost estimate for watersheds taken as a whole, or for larger implementation projects. This estimate should not necessarily be used for site-specific projects, particularly if they are small.

The total cost of controlling all *Arundo* at the peak of its acreage would have been $196 million for 7,859 net acres (Table 8-2). A significant amount of control has already occurred, and the current cost of controlling *Arundo* at current distribution levels is $124 million for 4,997 net acres.

Table 8-1. Existing program costs used to generate cost basis for *Arundo* control by watershed within the study area.

Watershed	Treated net acres	Expenditure	Cost per acre
Calleguas	1.4	-	-
Carlsbad	98.7	1,500,000	15,201
Estero Bay	1.2	-	-
Los Angeles River	16.3	250,000	15,379
Otay	-	-	-
Pajaro River	-	-	-
Penasquitos	2.2	-	-
Pueblo San Diego	0.0	-	-
Salinas	106.4	500,000	4,700
San Diego	56.2	1,000,000	17,798
San Dieguito	89.8	1,500,000	16,701
San Gabriel River	0.0	-	-
San Juan	13.1	250,000	19,025
San Luis Rey	612.4	7,500,000	12,246
Santa Ana	1006.9	40,000,000	39,724
Santa Clara	0.3	-	-
Santa Margarita	684.7	10,000,000	14,605
Santa Monica Bay	0.3	-	-
Santa Ynez	-	-	-
South Coast	7.8	-	-
Sweetwater	5.7	-	-
Tijuana	41.1	1,500,000	36,496
Ventura River	117.4	7,500,000	63,909
TOTALS:	**2861.9**	**$71,500,000**	**$24,983**

Table 8-2. Estimated control costs by watershed within the study area for peak *Arundo* levels and current *Arundo* levels.

Watershed	PEAK Net Acres	Cost peak distribution			CURRENT Net Acres	Cost current infestation		
		Management: 5k	Implementation: 20k	Total		Management: 5k	Implementation: 20k	Total
Calleguas	229	1,145,750	4,583,000	5,728,750	228	1,138,539	4,554,155	5,692,693
Carlsbad	148	739,472	2,957,889	3,697,362	49	246,088	984,352	1,230,440
Estero Bay	10	48,828	195,310	244,138	9	42,953	171,811	214,764
Los Angeles	131	656,886	2,627,543	3,284,429	115	575,608	2,302,431	2,878,039
Otay	19	92,945	371,781	464,726	19	92,945	371,781	464,726
Pajaro River	8	40,681	162,723	203,404	8	40,681	162,723	203,404
Penasquitos	24	117,737	470,947	588,683	21	106,860	427,440	534,300
Pueblo S.Diego	15	75,009	300,035	375,043	15	74,834	299,336	374,170
Salinas	1,332	6,658,544	26,634,177	33,292,721	1,225	6,126,663	24,506,651	30,633,314
San Diego	149	747,328	2,989,310	3,736,638	93	466,390	1,865,559	2,331,949
San Dieguito	175	874,894	3,499,577	4,374,471	85	425,825	1,703,299	2,129,124
San Gabriel	44	221,535	886,141	1,107,677	44	221,465	885,858	1,107,323
San Juan	173	867,083	3,468,333	4,335,416	160	801,380	3,205,519	4,006,899
San Luis Rey	684	3,419,392	13,677,570	17,096,962	71	357,237	1,428,946	1,786,183
Santa Ana	2,534	12,668,913	50,675,651	63,344,563	1,527	7,634,222	30,536,887	38,171,109
Santa Clara	1,019	5,093,858	20,375,431	25,469,289	1,018	5,092,328	20,369,313	25,461,641
Santa Margarita	689	3,444,463	13,777,850	17,222,313	4	20,972	83,890	104,862
Santa Monica	18	92,430	369,722	462,152	18	90,964	363,857	454,821
Santa Ynez	6	30,104	120,414	150,518	6	30,104	120,414	150,518
South Coast	30	149,075	596,300	745,375	22	110,003	440,014	550,017
Sweetwater	42	208,866	835,464	1,044,330	36	180,474	721,897	902,371
Tijuana	131	653,115	2,612,459	3,265,574	90	447,615	1,790,459	2,238,074
Ventura River	250	1,249,462	4,997,848	6,247,311	133	662,691	2,650,762	3,313,453
TOTALS:	**7,859**	**$39,296,369**	**$157,185,475**	**$196,481,844**	**$4,997**	**$24,986,839**	**$99,947,355**	**$124,934,194**

8.2 Benefit

The CBA included six *Arundo* impact classes. Each of these impacts is a 'benefit' when the agent causing the impact (*Arundo*) is removed. The six classes are: fire, water use, sediment trapping, flood damage, habitat enhancement, and beach debris.

8.2.1 Reduced Fire Impacts (Benefit)

Benefits related to reduced fire impacts resulting from *Arundo* control are presented in Table 8-3. This information is generated from data presented in Chapter 6 on fires that were initiated in *Arundo* stands, as well as wildfire events that burned *Arundo*. *Arundo*-initiated fires have costs associated with fire suppression (Table 8-3). A conservative fire response and suppression cost of $50,000 per event was used in generating cost estimates. The number of events over a ten-year period was based on data for the San Luis Rey watershed. This was then extrapolated to all watersheds based on their acreage of *Arundo*. Fire suppression costs are related to the number of units responding, work hours spent suppressing the fire, equipment costs, and other support. Fires usually involve multiple units that frequently use air suppression and often have fire lines cut by crews and/or mechanized equipment. The impacts from the fire suppression activities indicate the level of effort exerted during the action (suppression disturbance impacts are outlined in Chapter 6). *Arundo*-initiated fire impacts to habitat are also included in the cost estimate. The value of burned *Arundo* riparian habitat is priced lower ($20,000 per acre) then the valuation of un-invaded riparian habitat that burns ($80,000 per acre). These per acre cost valuations are based on mitigation costs associated with restoring riparian habitat, excluding easements and land purchase. Both the actual fire acreage and fire suppression acreage are aggregated in the cost estimate.

Arundo-initiated fires were estimated to generate $74.6 million of impacts over 10 years at peak *Arundo* distribution, and $38.8 million over 10 years at current *Arundo* levels (Table 8-3).

Wildfires represent a potentially open-ended impact class in terms of cost. As discussed in Chapter 6, *Arundo* stands may be conveying fires across the landscape, linking upland areas and spreading fire into urbanized areas. This seems to have occurred in Santa Clara, where a smaller 8,474-acre fire spread across the river via *Arundo* stands to the southern mountain range where it burned 107,560 acres. Other fires such as the Freeway Complex fire in Orange/Riverside County and western portions of the Witch Fire in San Diego County may also have had increased fire conveyance as the fires burned through riparian zones containing *Arundo* surrounded by urbanized areas. Impact costs were hundreds of millions of dollars with large losses to both habitat and developed areas. These landscape-level wildfire costs are too complicated to include in this CBA, but they clearly constitute a significant unmeasured cost that should be partially applied to *Arundo*. Further documentation needs to occur to more clearly define the role *Arundo* is having in wildland fires.

Wildfires can burn riparian habitat, particularly in firestorm/Santa Ana type events. *Arundo*-invaded habitat burns during these events along with un-invaded habitat. The *Arundo*-invaded areas burn much hotter than native vegetation due to the large amount of biomass per acre and the high levels of fuel per unit of biomass (Chapter 6). This results in more intense and complete fires that have a greater impact on the habitat. Post-fire recovery of *Arundo* stands is rapid, typically resulting in further domination of *Arundo* in areas that have burned (Ambrose 2007). A valuation of *Arundo's* degradation of habitat during wildfire events was valued at $2,500 per acre of burned *Arundo*-invaded habitat. This is an extremely conservative valuation of the impacts to habitat, and it specifically excludes valuation of the fire conveyance impacts that *Arundo* has during wildfire events.

Wildfires that burn *Arundo* stands were estimated to generate $17.6 million of impacts over 10 years at peak *Arundo* distribution and $10.4 million over 10 years at current *Arundo* levels (Table 8-3).

8.2.2 Reduced Water Use (Benefit)

Water use of *Arundo*-invaded habitat was estimated in Section 4.2. Specific adjustments were made for replacement vegetation. Water use and net water savings are exceedingly difficult to validate in field studies, but it seems clear from the high productivity of *Arundo* (i.e. the very high stand biomass, the high leaf area recorded in studies, and the high water use of C_3 plants in general) that it does indeed have substantially higher water use than native vegetation and/or open areas that would exist in post-control riverine sites. The calculated water savings generated are significant (Section 4.2). It is important to note that most of the areas where *Arundo* is present within the study area have water available throughout the year. Many watersheds have significant amounts of imported water that generate these year-round flows or, at a minimum, make water tables high enough to support *Arundo* throughout the growing season.

Putting a valuation on water 'saved' after *Arundo* removal is complicated. In a more comprehensive study, this value would vary by watershed and be based on the specific benefit that the saved water is generating. One key benefit may be the potential for an increase in groundwater recharge. This may benefit domestic use (Santa Ana, Santa Margarita) or heavy agricultural use (Salinas, Santa Clara) of groundwater in a system. For those watersheds (San Luis Rey, San Diego) that have only moderate use of groundwater, the focus may turn to other potential benefits. An increase of water in the riverine system can also benefit habitat and recreation. Longer baseline flows can be critical to several endangered species, particularly on systems with high levels of water management (dams and reservoirs). All of these benefits could be priced out at different rates. For this analysis, a single low value of $50 per acre-foot (ac-ft) of water was used in calculating benefit of water savings. This is a conservative valuation, particularly for southern California. A valuation of $50 per ac-ft of water was the lower end value in the Rio Grande *Arundo* water use CBA study, with the higher end coming in at $200 per ac-ft (Seawright 2009). Valuations for domestic water use are $527 per ac-ft (Metropolitan Water District) and for agricultural water range from $70 (Coachilla) to $482 per ac-ft (MWD). Much of the water is priced at highly subsidized rates. Nearly all watersheds in the study area import water at a high absolute cost. Additionally, water transfer and pumping costs range from $70–$200 ac-ft (MWD). Water recycling and conservation measures typically cost $70–$150 per ac-ft and are usually considered to be a net benefit.

The estimated valuation of water saved over 10 years by controlling *Arundo* is $78.2 million at its peak distribution and $49.6 million at current distribution level (Table 8-4).

Table 8-3. Estimated reduction of fire impacts (benefit).

Watershed	**PEAK *ARUNDO* LEVELS**					**CURRENT *ARUNDO* LEVELS**				
	Fire Started by *Arundo*				**Wildfires**	**Fire started by *Arundo***				**Wildfire**
	50k per event	**Habitat damage: *Arundo* $20K ac**	**Habitat damage: rip $80K ac**	***Arundo* fires 10 yr total**	**Wildfire: 500K per 200 ac**	**50k per event**	**Habitat damage: *Arundo* $20K ac**	**Habitat damage: rip $80K ac**	***Arundo* fires 10 yr total**	**Wildfire: 500K per 200 ac**
Calleguas	115,742	401,857	2,129,655	2,647,254	578,711	115,000	395,814	2,149,120	2,659,934	575,000
Carlsbad	73,947	256,745	1,360,629	1,691,321	369,736	24,609	98,862	459,889	583,360	123,044
Los Angeles	66,394	230,518	1,221,641	1,518,553	331,968	57,561	202,254	1,075,696	1,335,510	287,804
Otay	9,322	32,365	171,519	213,205	46,608	9,295	32,278	173,696	215,268	46,473
Penasquitos	11,810	41,004	217,300	270,114	59,049	10,686	37,407	199,700	247,793	53,430
Salinas	1,003,061	348,263	1,845,632	3,196,956	501,000	100,000	223,336	1,744,000	2,067,336	501,000
San Diego	75,111	260,787	1,382,050	1,717,948	375,557	47,000	169,675	878,336	1,095,011	235,000
San Dieguito	87,491	303,768	1,609,833	2,001,092	437,455	42,582	160,061	795,781	998,425	212,912
San Gabriel	22,281	77,359	409,967	509,607	111,404	22,146	76,929	413,873	512,948	110,732
San Juan	87,575	304,061	1,611,385	2,003,022	437,876	80,138	280,262	1,497,619	1,858,019	400,690
San Luis Rey	341,939	1,187,213	6,291,682	7,820,834	1,709,696	35,724	207,323	667,604	910,651	178,618
Santa Ana	1,361,931	4,728,624	25,059,526	31,150,080	6,809,654	820,000	2,813,396	15,324,160	18,957,556	4,100,000
Santa Clara	540,629	1,877,065	9,947,580	12,365,274	2,703,147	540,500	1,776,596	10,100,864	12,417,960	2,702,500
S. Margarita	344,446	119,592	633,781	1,097,819	1,722,231	-	-	-	0	0
Santa Monica	9,314	32,340	171,385	213,038	46,572	9,096	31,642	169,994	210,732	45,482
South Coast	14,908	51,759	274,298	340,965	74,538	11,000	39,256	205,575	255,831	55,002
Sweetwater	21,172	73,510	389,567	484,249	105,861	18,047	63,511	337,270	418,828	90,237
Tijuana	67,785	235,350	1,247,246	1,550,381	338,926	47,250	161,674	883,008	1,091,932	236,250
Ventura	165,997	576,341	3,054,344	3,796,682	829,985	94,000	257,212	1,756,672	2,107,884	470,000
TOTALS:	**$4,420,856**	**$11,138,520**	**$59,029,021**	**$74,588,396**	**$17,589,972**	**$2,084,635**	**$7,027,490**	**$38,832,856**	**$47,944,981**	**$10,424,174**

Table 8-4. Estimated reduction of water use by *Arundo* (benefit).

Watershed	10 Year Water Use	
	Peak *Arundo* levels	Current *Arundo* levels
Calleguas	2,290,974	2,290,974
Carlsbad	1,478,605	492,060
Los Angeles River	1,313,470	1,150,950
Otay	185,848	185,848
Penasquitos	235,419	213,650
Salinas	13,314,032	12,250,510
San Diego	1,494,312	932,570
San Dieguito	1,749,387	851,450
San Gabriel River	442,969	442,969
San Juan	1,733,768	1,602,390
San Luis Rey	6,837,215	714,310
Santa Ana	25,332,010	15,264,940
Santa Clara	10,185,377	10,185,377
Santa Margarita	6,887,344	41,940
Santa Monica Bay	184,819	184,819
South Coast	298,082	219,960
Sweetwater	417,636	360,870
Tijuana	1,305,930	895,020
Ventura River	2,498,351	1,325,080
TOTALS:	**$78,185,547**	**$49,605,686**

8.2.3 Reduced Sediment Trapping (Benefit)

As outlined in Section 5.1, it is likely that *Arundo* has impacts to sediment transport, particularly in low gradient areas where *Arundo* cover is high (>40%). Many of these areas are highly urbanized, have large-scale agricultural operations, or have significant infrastructure present. Localized sediment trapping is likely occurring in portions of these highly invaded reaches, resulting in loss of flow conveyance. *Arundo* stands on their own, not even considering sediment trapping, were demonstrated to reduce flow conveyance by five feet where they occurred (Section 5.1). This is a significant loss of conveyance, likely larger than the sediment trapping effect. If these areas are managed for flood risk, agencies (particularly ACOE, municipalities, and counties) may be forced to undertake vegetation reduction or sediment removal to maintain flow conveyance. For example, levees on the San Luis Rey River were designed to contain flows up to a 120–year event. Vegetation and *Arundo* growth reduced this to a 90–year event capacity (ACOE pers. comm. 2009). This can result in areas being designated as 'high flood risk' (i.e. raising insurance costs) or being designated as uninsurable. Both of these scenarios result in lower property values. When sediment removal and vegetation clearing are not permitted or are considered too costly, the alternative is building new levees or increasing existing levee heights. Both

Santa Margarita and San Luis Rey have required either modification or installation of levee structures and/or vegetation reduction programs to maintain flow conveyance. The Salinas River has had channel maintenance activities to reduce flood risk and bank/bridge failure. Other riverine systems in the study area are likely to have had actions in the past and/or will require actions in the future. Cost of implementing vegetation reduction and or sediment removal is also very high. While costs include the removal work itself, this is often a small proportion of the total project cost. Projects typically require complicated regulatory clearance that can take years to obtain, as well as significant mitigation for habitat disturbance/impacts. No specific cost valuation data exist other than the authors' familiarity with actions carried out on various rivers and the high costs associated with programs undertaking these types of activities. Therefore, valuations assigned in the benefit analysis are again highly conservative. Alternative activities, such as increasing levee heights or constructing new levees are not included here, but these actions do occur and the costs associated with them are high, both in terms of construction cost, permitting and mitigation for permanent wetland loss. True costs of *Arundo* impacts could be one or two orders of magnitude greater than presented here.

The valuation of avoided sediment removal or vegetation reduction costs over 10 years by controlling *Arundo* was estimated to be $2,500,000 (Table 8-5).

Table 8-5. Estimated reduction of sediment trapping (benefit).

Watershed	**Sediment Removal**
Calleguas	$250,000
Carlsbad	
Los Angeles River	$250,000
Otay	
Penasquitos	
Salinas	$1,000,000
San Diego	
San Dieguito	
San Gabriel River	$250,000
San Juan	
San Luis Rey	$500,000
Santa Ana	$250,000
Santa Clara	
Santa Margarita	
Santa Monica Bay	
South Coast	
Sweetwater	
Tijuana	
Ventura River	
TOTALS:	**$2,500,000**

8.2.4 Reduced Flood Damage: Bridges (Benefit)

Arundo biomass mobilizes during high flow events. This material can contribute or cause loss of structures that cross or are located within (power poles, sewer, gas, and water lines) the river channel. The exact proportion of damage costs associated with the presence of *Arundo* is difficult to determine. The most easily verified flood damage events involving *Arundo* are related to massive amounts of *Arundo* debris that form dams against bridges (Section 5.2.5.1). Loss of bridges has occurred on numerous watersheds that have high levels of *Arundo* invasion. Not all bridges were observed at the time of failure, but observations of bridges that have been damaged and operations to clear bridges of *Arundo* during flow events demonstrate that *Arundo* is a factor. High flow events that mobilize *Arundo* biomass also move large woody material such as trees. This combination of material collects and backs up against bridge pylons, or if flows are high enough, against the bridge itself. Older bridges with narrow spans are at greater risk of failing. Smaller bridges are also at higher risk as they typically have low clearance and narrow spans. Each watershed was reviewed for bridges (road and rail) that cross over river habitat with significant levels of *Arundo* around or upstream of them. These bridges were classified into three groups and conservative replacement costs were applied: large ($5 million), medium ($1.5 million), and small ($500,000). These valuations are extremely conservative, as bridge construction often requires costly environmental review and mitigation. Results were multiplied by 20% to estimate the likelihood of bridge loss within the 10-year period and to account for a portion of cost that is due to large flood events taking out bridges regardless of whether *Arundo* material is in the system or not.

The valuation of avoided bridge losses at peak *Arundo* distribution was estimated to be $24.2 million over 10 years. Control programs have cleared *Arundo* around and above several bridges, reducing estimated projected impacts to $17.3 million over 10 years (Table 8-6).

8.2.5 Habitat Enhancement (Benefit)

As explored in multiple chapters within this report, *Arundo* has many abiotic and biotic impacts. Some of the most severe impacts to riparian systems are to abiotic processes that are nearly impossible to quantify monetarily in terms of their environmental consequences. Changes to geomorphic form and function, hydrology, water use, and other abiotic functions affect the entire system. Most of the valuations for these types of impacts in previous sections were limited to anthropogenic costs including infrastructure, water for urban and agriculture use, or flood damage. Environmental costs were not included. This CBA will limit valuation of environmental impacts to the degradation of habitat *Arundo* has invaded. The cost of controlling *Arundo* is used as a valuation of the habitat benefit (habitat restoration as well and threatened and endangered species’ benefits). A valuation of $25,000 per acre is used to represent the benefit of habitat enhancement/restoration that occurs when *Arundo* is controlled. This is the same as the cost of the work as outlined in Section 8.1. The total cost is lower, however, reflecting the subtraction of *Arundo* acreage that was counted under the fire benefits evaluation. This avoids double counting benefits. The use of this valuation is corroborated by the common use of *Arundo* control as a form of mitigation for impacts to riparian habitat. This is still a slightly conservative valuation as many other forms of riparian 'mitigation' have higher costs per acre ($50,000 to $100,000) for restoration activities, even when land use restrictions (easements or land costs) are excluded from project costs.

The total 10 year benefit calculated for habitat restoration/enhancement was estimated to be $181 million at peak *Arundo* distribution and $110 million for current distribution levels (Table 8-7).

Table 8-6. Estimated reduction of bridge losses (benefit) by watershed at peak and current *Arundo* levels.

Watershed	**Number of Bridges: Large, Medium, & Small**	**PEAK *ARUNDO* LEVELS**		**CURRENT *ARUNDO* LEVELS**	
		Bridge loss or damage	**Flood damage: Bridge 20%**	**Bridge loss or damage**	**Flood damage: Bridge 20%**
Calleguas	Med: 8, Sm: 1	12,500,000	2,500,000	12,500,000	2,500,000
Carlsbad		0	0	0	0
Los Angeles River	Lg: 1	5,000,000	1,000,000	5,000,000	1,000,000
Otay		0	0	0	0
Penasquitos		0	0	0	0
Salinas	Lg: 4, Med: 2, Sm: 1	22,000,000	4,400,000	22,000,000	4,400,000
San Diego	Med: 1, Sm: 2	2,500,000	500,000	500,000	100,000
San Dieguito		0	0	0	0
San Gabriel River	Lg: 1	5,000,000	1,000,000	5,000,000	1,000,000
San Juan	Med: 1, Sm: 1	2,000,000	400,000	2,000,000	400,000
San Luis Rey	Med: 4	6,000,000	1,200,000	0	0
Santa Ana	Lg: 5	25,000,000	5,000,000	10,000,000	2,000,000
Santa Clara	Lg: 2, Med: 3	14,500,000	2,900,000	14,500,000	2,900,000
Santa Margarita	Lg: 2, Med: 1	11,500,000	2,300,000	0	0
Santa Monica Bay		0	0	0	0
South Coast		0	0	0	0
Sweetwater		0	0	0	0
Tijuana	Sm: 1	500,000	100,000	500,000	100,000
Ventura River	Lg: 2, Med: 2, Sm: 3	14,500,000	2,900,000	14,500,000	2,900,000
	TOTALS:	**$121,000,000**	**$24,200,000**	**$86,500,000**	**$17,300,000**

Table 8-7. Estimated habitat enhancement (benefit) by watershed at peak and current *Arundo* levels.

Watershed	**Habitat benefit: 25K per ac**	
	PEAK *ARUNDO* LEVELS	**CURRENT *ARUNDO* LEVELS**
Calleguas	5,226,429	5,190,372
Carlsbad	3,376,431	909,509
Los Angeles River	2,996,281	2,589,891
Otay	424,270	424,270
Penasquitos	537,429	483,046
Salinas	32,857,393	30,197,986
San Diego	3,410,654	2,005,966
San Dieguito	3,994,761	1,749,414
San Gabriel River	1,010,978	1,010,624
San Juan	3,955,339	3,626,822
San Luis Rey	15,612,946	302,166
Santa Ana	57,433,784	32,260,330
Santa Clara	23,122,958	23,115,310
Santa Margarita	17,222,313	104,862
Santa Monica Bay	421,728	414,396
South Coast	680,677	485,319
Sweetwater	952,443	810,484
Tijuana	2,971,387	1,943,887
Ventura River	5,526,884	2,593,026
TOTALS:	**$181,735,081**	**$110,217,679**

8.2.6 Reduced Beach Debris

Impacts from clearing *Arundo* debris from beaches in southern California was reviewed in Section 5.2.5.2. These costs are based on information collected from municipalities that remove biomass from beaches. Only watersheds that are near beaches and actively remove biomass were given benefit valuations. The estimated 10–year benefit of reduced *Arundo* biomass on beaches is $1.97 million (Tables 8-8&9).

8.2.7 Total Benefit

The total benefit of controlling *Arundo* at its peak distribution was estimated at $380 million (Table 8-8), and the benefit at its current distribution at $239 million (Table 8-9). This is a conservative valuation because several types of impacts could not be estimated or quantified, and all evaluated impacts were conservatively valued.

8.3 Benefit to Cost Ratio

The benefit to cost ratio for peak *Arundo* distribution was 1.94 to 1 ($380,767,747 to $196,481,844). Current *Arundo* distribution generates a similar benefit to cost ratio of 1.91 to 1 ($239,461,270 to $124,934,194). A 2:1 return ratio on funds invested is a significant benefit, particularly considering the additional impacts that were not assessed (due to complex valuation), as well as the conservative valuation of factors that were included.

A more rigorous CBA carried out for either specific watersheds or the entire project area would likely generate higher benefit to cost ratios. Higher cost valuations of impacts could be documented and defended, and some of the more complicated impacts, which were not included in this CBA, could be explored and included.

Table 8-8. Estimated benefits at the peak level of *Arundo* distribution.

Watershed	Water use 10 yr	Sediment removal	Flood damage: bridge & levee	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac	Habitat rest 25K	Beach debris	10 year benefit
Calleguas	2,290,974	250,000	2,500,000	2,647,254	578,711	5,226,429	-	13,493,368
Carlsbad	1,478,605	-	0	1,691,321	369,736	3,376,431	-	6,916,093
Los Angeles	1,313,470	250,000	1,000,000	1,518,553	331,968	2,996,281	328,125	7,738,397
Otay	185,848	-	0	213,205	46,608	424,270	-	869,931
Penasquitos	235,419	-	0	270,114	59,049	537,429	-	1,102,011
Salinas	13,314,032	1,000,000	4,400,000	3,196,956	501,000	32,857,393	-	55,269,381
San Diego	1,494,312	-	500,000	1,717,948	375,557	3,410,654	-	7,498,471
San Dieguito	1,749,387	-	0	2,001,092	437,455	3,994,761	-	8,182,694
San Gabriel	442,969	250,000	1,000,000	509,607	111,404	1,010,978	328,125	3,653,083
San Juan	1,733,768	-	400,000	2,003,022	437,876	3,955,339	-	8,530,006
San Luis Rey	6,837,215	500,000	1,200,000	7,820,834	1,709,696	15,612,946	328,125	34,008,816
Santa Ana	25,332,010	250,000	5,000,000	31,150,080	6,809,654	57,433,784	-	125,975,527
Santa Clara	10,185,377	-	2,900,000	12,365,274	2,703,147	23,122,958	328,125	51,604,881
Santa Margarita	6,887,344	-	2,300,000	1,097,819	1,722,231	17,222,313	328,125	29,557,833
Santa Monica	184,819	-	0	213,038	46,572	421,728	-	866,157
South Coast	298,082	-	0	340,965	74,538	680,677	-	1,394,261
Sweetwater	417,636	-	0	484,249	105,861	952,443	-	1,960,188
Tijuana	1,305,930	-	100,000	1,550,381	338,926	2,971,387	-	6,266,624
Ventura River	2,498,351		2,900,000	3,796,682	829,985	5,526,884	328,125	15,880,026
TOTALS:	**$78,185,547**	**$2,500,000**	**$24,200,000**	**$74,588,396**	**$17,589,972**	**$181,735,081**	**$1,968,750**	**$380,767,747**

Table 8-9. Estimated benefits at current levels of *Arundo*.

Watershed	Water use 10 yr	Sediment removal	Flood damage: bridge & levee	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac	Habitat rest 25K	Beach debris	10 year benefit
Calleguas	2,290,974	250,000	2,500,000	2,659,934	575,000	5,190,372		13,466,280
Carlsbad	492,060		0	583,360	123,044	909,509		2,107,972
Los Angeles	1,150,950	250,000	1,000,000	1,335,510	287,804	2,589,891	328,125	6,942,280
Otay	185,848		0	215,268	46,473	424,270		871,858
Penasquitos	213,650		0	247,793	53,430	483,046		997,919
Salinas	12,250,510	1,000,000	4,400,000	2,067,336	501,000	30,197,986		50,416,832
San Diego	932,570		100,000	1,095,011	235,000	2,005,966		4,368,547
San Dieguito	851,450		0	998,425	212,912	1,749,414		3,812,201
San Gabriel	442,969	250,000	1,000,000	512,948	110,732	1,010,624	328,125	3,655,399
San Juan	1,602,390		400,000	1,858,019	400,690	3,626,822		7,887,921
San Luis Rey	714,310		0	910,651	178,618	302,166	328,125	2,433,870
Santa Ana	15,264,940	250,000	2,000,000	18,957,556	4,100,000	32,260,330		72,832,826
Santa Clara	10,185,377		2,900,000	12,417,960	2,702,500	23,115,310	328,125	51,649,272
Santa Margarita	41,940		0	0	0	104,862	328,125	474,927
Santa Monica	184,819		0	210,732	45,482	414,396		855,429
South Coast	219,960		0	255,831	55,002	485,319		1,016,111
Sweetwater	360,870		0	418,828	90,237	810,484		1,680,419
Tijuana	895,020		100,000	1,091,932	236,250	1,943,887		4,267,089
Ventura River	1,325,080		2,900,000	2,107,884	470,000	2,593,026	328,125	9,724,115
TOTALS:	**$49,605,686**	**$2,000,000**	**$17,300,000**	**$47,944,981**	**$10,424,174**	**$110,217,679**	**$1,968,750**	**$239,461,270**

9.0 WATERSHED BASED *ARUNDO* CONTROL PROGRAMS: RECOMMENDATIONS, STATUS, AND PRIORITIZATION

9.1 Recommendations and Status of Watershed Based *Arundo* Control Programs

Given *Arundo*'s dependence on asexual propagation (it only spreads from fragments of plant material), control programs that start at the top of watersheds are undoubtedly the most efficient and effective over the long-term. Most watershed-based programs start on the upper portions of rivers and tributaries and proceed downstream to the ocean outfall. Many programs do not control all scattered infestations, such as those occurring in urbanized areas, particularly if these properties are not directly connected to drainages, creeks, or rivers. More comprehensive programs do attempt to eradicate all *Arundo* within the watershed, as any material is potentially a propagule source. Yard waste that is disposed of improperly, such as dumped along roads or creeks, is a pathway of spread. Once a watershed has had all *Arundo* controlled there is still a need to remain alert for new introductions that can occur from other watersheds as: contaminated fill, yard waste, or intentional planting of *Arundo* (even though it is a CDFA listed Noxious Weed, B rated).

General goals of control programs should be the following, but there are site-specific exceptions to these statements:

- Control programs should attempt to achieve eradication on entire watersheds, as this is the most efficient use of limited resources.
- Control programs should start in upper watershed areas and proceed downstream. This is more important on large, highly invaded watersheds that may require 10–20 years to carry out implementation. Small watersheds, or those large watersheds with little acreage, can be treated in any 'order' as long as everything is treated over a reasonable time frame.
- Programs frequently implement control projects in defined sub-sections of the watershed. The program still proceeds from the upper, to the middle, and then the lower watershed as different sub-sections are completed. Within a section, control may occur 'out of order'. This can be beneficial (fuel breaks, creating a mosaic of age classes for restored areas, multiple classes of property ownership, etc.) and is often done intentionally.
- Programs should strive to achieve 100% control within project areas. This is a difficult objective and requires both long-term commitment and substantial tracking. Most *Arundo* is controlled after 5–10 years of work, but re-sprouts will occur, particularly if project areas are large. Areas need to be checked and re-treated for 20 years to assure 100% control. Control and surveying may occur at three-year intervals for older project areas.
- Some highly invaded watersheds may have high-value habitat areas that need or require restoration or *Arundo* control before the larger program has 'reached' the area. These activities may be warranted, even though significant untreated *Arundo* remains upstream. Projects should budget periodic treatment of new *Arundo* invasion onto the property. Re-invasion of a given property is difficult to predict and would be dependent on geomorphic position, amount of *Arundo* upstream, and periodic flow events that mobilize material. Historic review of systems indicates that invasion is very episodic for the most part, and that responding after very large events will be the primary task.
- Watersheds with active programs may prioritize areas for control that have burned. Fires temporarily clear biomass from a site, representing an excellent opportunity for inexpensive

control as biomass reduction or removal is often the most expensive component of a control project.

9.1.1 Entity/Group Leading Watershed Based Work

For a watershed-based control program to succeed it typically needs either a single lead entity or an organization that brings together multiple partners. Larger watersheds without a lead entity or formal coordination have been unable to implement meaningful watershed-based *Arundo* control. There are five main reasons why a program lead is needed: funding, permitting, contracting, permission through right-of-entry agreements (ROEs), and long-term presence. Groups that are unable to receive public funds, hold permits, obtain ROEs, and garner broad support among watershed stakeholders should not attempt to lead projects or programs. Control programs on watersheds with more than 50 acres of *Arundo* or *Arundo* on more than 100 properties will likely only succeed if a program with an identified lead entity exists.

Table 9-1 identifies the specific watershed program leads within the study area. Most larger watersheds with high levels of *Arundo* invasion have already formed watershed based groups to initiate work. There are multiple types of organizations that can function as a lead. Most groups are public entities such as County Departments, Resource Conservation Districts (RCDs), and Joint Power Authorities (JPAs). But it is possible for a non-profit to function as a watershed lead (Carlsbad: San Elijo Conservancy, Tijuana: SWIA). Appealing to a broad range of landowners is a strong benefit, particularly in areas with a mix of private and public landownership. Resource Conservation Districts (RCD's) are frequently leads (Mission, Monterey) or active participants in stakeholder groups (SAWA: RCD's and water districts). Weed Management Areas or WMAs (typically formed by County Agriculture Departments or RCDs) can also play an important role in implementing projects and building watershed control programs.

9.1.2 Status of Permitting Allowing Work to Occur

Watershed programs seeking to control *Arundo* are required to obtain regulatory clearance from multiple agencies. Permits and conditions are dependent on methods being used to control *Arundo*. Typically this includes:

- CEQA: generally Mitigated Negative Declaration, Negative Declaration, or Notice of Exemption. EIRs are rarely required. This can take anywhere from 1-12 months to process depending on the path taken.
- Department of Fish and Game Streambed Alteration Permit 1600: nearly always required. This process can take one month to over a year long and CEQA should be completed first.
- U.S. Fish and Wildlife Service: Section 7/10 or a Technical Assistance Letter may be required if federally listed species are present. If take or harassment is likely to occur, a Section 7/10 is required and this can take 6-12 months or longer. If endangered species are present but impacts can be avoided, a Technical Assistance Letter can be used to outline protective measures. This can be completed in one to three months.
- Two other agencies also regulate protected species: California Endangered Species Act (under CA Department of Fish and Game) may require concurrence with U.S. Fish and Wildlife Service agreements/protective measures and National Marine Fisheries Service (under the National Oceanic and Atmospheric Administration) may require consultation.

Table 9-1. *Arundo* control programs within the study area: program leads, status of permitting and work completed on each watershed.

Watershed Unit	Total net acres	Treated net acres	Percent treated	Group leading control program	Watershed-based permitting completed	Notes
Calleguas	229	2	1%	No clear lead, multiple partners	CEQA	Ventura RCD and County active, but few projects completed to date
Carlsbad HU	148	98	67%	San Elijo Lagoon Consrvncy, San Diego Co	CEQA, DFG 1600, FWS, ACOE	Well established program (2002), strong implementation
Estero Bay	10	1	12%	San Luis Obispo County Ag Dept.	Project based	Work is project by project
Los Angeles River	131	16	12%	None	Project based	Work is project by project
Otay	19		0%	None	None	
Pajaro River	8		0%	None	None	
Penasquitos	23	2	9%	None	Project based	Work is project by project
Pueblo San Diego	15		0%	None	Project based	Work is project by project
Salinas	1,332	106	8%	Monterey RCD	CEQA, DFG,&FWS in process (& existing project based)	Project based but moving toward formal watershed-based program
San Diego	150	56	38%	San Diego River Conservancy	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Newer watershed-based program (2009), rapid implementation
San Dieguito	175	90	51%	San Dieguito JPA	CEQA, DFG 1600, FWS	Well established watershed-based program (2006), rapid implementation
San Gabriel River	44	8	19%	None	None	Work is project by project
San Juan	173	13	8%	County of Orange	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Newer watershed based program (2009), little implementation to date
San Luis Rey	684	612	90%	Mission RCD	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Well established program (2000), strong implementation
Santa Ana	2,534	1,007	40%	SAWA	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Well established program (1992), strong implementation
Santa Clara	1,019	1	0%	No clear lead, multiple parties	Some permits for LA County, none for Ventura County	Poorly formed program, no clear lead, low levels of implementation

Watershed Unit	Total net acres	Treated net acres	Percent treated	Group leading control program	Watershed-based permitting completed	Notes
Santa Margarita	689	685	99%	Lower: USMCB Camp Pendleton, Middle: Mission RCD, Upper: none	Lower and middle: NEPA/CEQA, DFG 1600, FWS, ACOE 404, SWCB 401 Upper: none	Well established program (1995), strong implementation- but no clear upper watershed lead
Santa Monica Bay	19	1	2%	None	None	Work is project by project
Santa Ynez	6		0%	Santa Barbara County Ag Commissioner	In Process: CEQA, DFG 1600	Newly forming project (2010)
South Coast	30	8	26%	Multiple parties: County, Cities	Project based	Work is project by project: some watershed units far along, some just starting
Sweetwater	42	6	14%	Sweetwater Authority	Project based	Work is project by project
Tijuana	131	41	31%	Southwest Wetlands Interpretive Assoc. (SWIA)	Project based	Work is project by project- constrained by *Arundo* in Mexico, true watershed-based management may not be possible on lower watershed
Ventura River	250	117	47%	County of Ventura	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401 (project based, but for large sections of watershed)	Well established watershed-based program (2008), rapid implementation
Totals:	**7,864**	**2,862**	**36.4%**			

- Army Corps of Engineers 404 permit may be required for larger control programs using heavy equipment. In Southern California (San Diego up to San Luis Obispo County), a Regional General Permit 41 has been issued for *Arundo* and other non-native plant control programs. This permit, when activated for a specific program or project, fulfills both ACOE 404 permitting requirements and SWCB 401 certification. Completion of the ACOE RGP 41 application process can occur in less than three months. ACOE 404 certification without use of RGP 41 is an open-ended process.
- State Water Control Board or Regional Water Quality Control Board 401 certification or discharge permits can be required for programs depending on methods and equipment used. If obtained under ACOE RGP 41, the process is fast (under a month). If obtained as a 401 certification or discharge permit, the process is open-ended.
- Coastal Commission Permit may be required for certain projects. Exemptions have been obtained for some programs deemed to be restoration. Permitting process is open-ended and typically is the last permit completed.
- Other permits: additional project or watershed-specific permits may be required. This may include California State Historic Office (notification and/or compliance) and municipal or county codes/permits.

The number and complexity of regulatory permits for carrying out *Arundo* control makes it imperative that program leads are familiar with navigating the permitting process and that efficient and competent management of programs and permitting requirements is occurring. Given the number of permits that are required for larger programs, it is of substantial benefit if watershed-based permits can be obtained. Each watershed is identified in Table 9-1 as to the type of permits that are held and programs in place (whether it is watershed or project based). Additionally, *Arundo* control is a long-term process, with projects lasting at least five years and control typically taking 10-15 years. Programs on larger systems may take 15-20 years to complete all initial control. For this reason, obtaining the longest duration permits (particularly for DFG 1600) is the most efficient use of resources, even though these permits cost more initially.

Funding agencies and mitigation programs frequently will not fund projects that have permitting 'in process' or projects that expect to obtain permits after being awarded funding. Having approved and active permits in place from all required regulatory agencies is a primary indicator of a program’s ability to execute on a specific project.

9.1.3 Work Completed to Date

Experience and track record of a watershed control program are the best indicators of a specific group’s ability to complete projects in a time-efficient and cost-effective manner. Program leads typically are in charge of selecting work areas, obtaining ROEs, obtaining and complying with permits, obtaining funding, and selecting and contracting with groups to carry out the work. These factors are usually well documented in grant and other funding applications, and it is beyond the scope of this report to evaluate successes and failures of specific programs. Table 9-1 does, however, indicate which watersheds have well-established programs, when they started, and the treated acreage. Many of these programs actively participate in sharing information on control methods, mapping methods, permitting approaches, public outreach and other information. The community of control programs across the state is, in general, open and supportive of each other.

9.1.4 Future Program Work

Programs should use mapping data to demonstrate that top-down control is occurring by indicating what has been controlled, what is proposed, and what is planned. Programs should also use high-resolution mapping of *Arundo* stands to calculate budgets presented in proposals and for tracking treated acreage in mitigation programs. The mapping completed for this study and presented in this report represents high-resolution data.

Some programs appear to be vastly over-inflating acreage of *Arundo* stands in their proposals, work plans and mitigation programs. This may not be intentional, but it is misleading, particularly when making comparisons between watersheds or even proposals within a watershed. One example of misrepresentation occurs when gross area is used in place of net area. For example, a 200 acre site that has 15 acres of *Arundo* stands scattered within it should not be characterized as '200 acres of *Arundo* control'. If there are large expanses of native vegetation within areas designated as '*Arundo* project acreage', it can be a clear indication of questionable mapping. This overestimation can easily be detected if the mapped elements are viewed over high-resolution aerial imagery.

Maps presenting project acreage with point and line data can also be particularly suspect, especially if *Arundo* acreage is high. Additionally, maps with large polygons covering long lengths of river from terrace to terrace are questionable. Even in the most invaded portions of highly invaded systems, *Arundo* rarely achieves cover greater than 50% for long lengths of river. The mapping data presented here allows general verification of mapping presented in proposals. Mapping with acreage levels that are within 20 to 30% of this study's acreage is most likely accurate. A large difference in *Arundo* acreage compared to this study's mapping may indicate that a different methodology was implemented (i.e. coarse mapping with low *Arundo* cover) or mapping protocols were of poor quality. Other clues to either a poor understanding of implementation costs ($10-30,000 per acre for a typical project), or mapping that is not accurately representing *Arundo* acreage, can appear in proposed project budgets. For example, projects outlining control of 100 acres of *Arundo* for five years cannot reasonably cost $150,000. It is recommended that future proposals and plans be evaluated to determine if they accurately represent *Arundo* acreage.

9.2 Priority Ranking of Watershed-Based *Arundo* Control

9.2.1 Factors Considered in Ranking: Impacts and Capacity

Ranking watershed programs is a complicated and potentially subjective exercise. Multiple impacts from *Arundo* invasion have been outlined in this report. Some impacts are directly tied to the level of invasion (geomorphology, flooding, fire and water use), while other impacts are tied to specific species co-occurring with *Arundo* (listed species). While different weightings could be used for each factor, this analysis will weigh all factors as equal. Active watershed groups are also assessed in terms of their ability to initiate and complete work (functioning lead entity, completed permits, past execution). A ranking or evaluation of each program's quality of execution was not performed for this assessment.

Watersheds with small amounts of *Arundo* will tend to rank low in the impact assessment, yet these areas may be among the most efficient to treat in terms of preventing future degradation. This will be discussed at the end of the section.

9.2.2 Control Priority

Overall there are three priority actions for funding of *Arundo* control:

1) Fund re-treatments of project areas that have already implemented watershed-based control. This protects the existing investment.
2) Fund control of *Arundo* on watersheds with low levels of invasion. It is more cost efficient to control *Arundo* before it becomes abundant.
3) Fund new control on invaded systems, but prioritize where watershed-based programs/ approaches are being used, and where benefit is greatest. Funding is finite, so efficient use of limited resources should occur.

Re-treatment of *Arundo* within established program areas is the highest priority. The fact that *Arundo* was abundant at these sites prior to control work indicates that these areas have the capacity to support re-establishment of large infestations if left unfinished. Over $70 million has been spent to date on well-established *Arundo* control programs within the coastal watersheds in the study area. Five watersheds have controlled a significant portion (>80%) of the *Arundo* found on their watersheds: Carlsbad HU, San Luis Rey, Santa Ana, Santa Margarita, and Ventura. Maintaining and completing *Arundo* control on the portions of these watersheds treated to date is highest priority. For the most part, funding and management agencies have recognized this and provided funding for re-treatments (years 5 to 20). Continued long-term funding support is needed for re-treatments to achieve true eradication of *Arundo* within these program areas.

Control of *Arundo* on watersheds with low levels of invasion is the next priority. Some watersheds have low levels of *Arundo*, most likely due to more recent introductions. Control of invasive plants early in the invasion process is always more cost effective than responding to a larger, more widespread invasion. Programs should be able to control *Arundo* on many of these smaller populations (Santa Ynez, Estero, Pajaro, and others) with less complicated permitting and low project implementation costs. Treated *Arundo* biomass can often be left standing if it is scattered, also greatly reducing treatment costs.

Funding *Arundo* control on more invaded watersheds should target watersheds experiencing the most severe impacts coupled with the highest likelihood of achieving success. These rankings are based on impacts caused by *Arundo* invasion (four classes) and program capacity (two classes, Table 9-2). This ranking approach is biased in that it selects for watersheds that have moderate to high levels of *Arundo* invasion (due to correlation of impact level and invasion level). Watersheds with low levels of invasion have already been recognized as being of 'high value' for control, even though few impacts may currently be occurring. It should also be noted that the impact classes reflect the magnitude of *Arundo*'s effect on the watershed, not the importance of the impact issue. For example, groundwater recharge and water savings may be a significant issue on a watershed that scores a 0. This low ranking reflects the low *Arundo* acreage, and corresponding level of impact, but not the importance of water savings on the watershed. Table 9-2 provides guidance in assigning priority among the more invaded watersheds, which may be of use. High ranked watersheds are experiencing severe impacts and have the capacity to implement control. Watersheds with high acreage in the medium class may provide less return on investment in terms of impact reduction.

Programs/projects that do not fit into a watershed-based control program should be evaluated carefully. There are situations where control of *Arundo* at a downstream site can make sense. For instance, control may help protect structures and restore important habitat, or the entity owning the land may have the resources to initiate work. These sites are, however, at significant long-term risk of re-invasion. Funds should be set aside to respond to re-invasion, which is expected to be periodic and varying in intensity. Projects that merely reduce *Arundo* biomass or only carry out one treatment are not effective long-term control projects, and should not be presented as such.

Table 9-2. *Arundo* treatment priority ranking by watershed. Based on *Arundo* impacts and program capacity.

Watershed Unit	**Total Net Acres**	**Percent treated**	**Group leading control program**	***Arundo* Impacts**				**Capacity**		**Total**	**Priority ranking**
				Water Use	**Geo-morph**	**Fire**	**Listed species**	**Exp. lead**	**Per-mits**		
Santa Ana	2,534	40%	SAWA	5	5	5	5	5	5	30	Very high
San Luis Rey	684	90%	Mission RCD	4	5	5	5	5	5	29	
Santa Margarita	689	99%	Lower: USMCB Camp Pendleton, Middle: Mission RCD, Upper: none	4	5	4	5	5	5	28	
San Dieguito	175	51%	San Dieguito JPA	5	2	4	4	5	5	25	
Ventura River	250	47%	County of Ventura	3	4	5	3	5	5	25	
Santa Clara	1,019	0%	No clear lead, multiple parties	5	4	5	5	1	3	23	High
San Diego	150	38%	San Diego River Conservancy	4	2	4	3	4	5	22	
Salinas	1,332	8%	Monterey RCD	5	5	2	3	3	3	21	
Carlsbad	148	70%	San Elijo Conservancy, S.Diego Co	2	2	2	3	5	5	19	
San Juan	173	8%	County of Orange	2	3	3	3	3	5	19	
Tijuana	131	31%	SWest Wetlands Interpretive Assoc.	2	2	2	2	4	4	16	Medium
Calleguas	229	1%	None	3	3	4	2	1	2	15	
Los Angeles	131	12%	None	2	1	3	4	2	2	14	
Calleguas	229	1%	None	3	3	4	2	1	0	13	
Santa Ynez	6	0%	Santa Barbara County Ag Dept	0	1	1	3	5	3	13	
Sweetwater	42	14%	Sweetwater Authority	1	2	2	3	3	2	13	
San Gabriel	44	8%	None	1	1	2	4	2	2	12	
South Coast	30	26%	Santa Barbara County Ag Dept	0	1	2	3	3	3	12	
Santa Monica	19	2%	None	0	1	2	4	2	2	11	
Otay	19	0%	None	0	1	2	2	3	2	10	
Estero Bay	10	12%	None	0	0	0	2	3	3	8	Low
Penasquitos	23	9%	None	0	1	2	3	1	0	7	
Pueblo San Diego	15	0%	None	0	1	2	1	0	0	4	
Pajaro River	8	0%	None	0	0	0	2	0	0	2	
Totals:	**7,864**	**36.4%**									

10.0 SUMMARY OF DATA FOR *ARUNDO*: PHYSICAL CHARACTERISTICS, DISTRIBUTION, ABUNDANCE, IMPACTS, AND WATERHSHED CONTROL PROGRAMS' STATUS AND PRIORITY

Conclusions from this impact report are presented below and based on collected data and observations for the greater study area: coastal watersheds in California from Monterey to San Diego (Figure 3-1).

Physical Characteristics and Biology

- Mature stands are taller than what has been typically reported in the literature: 6.5 m mean, range of 2.6 – 9.9 m. (Section 2.3)
- Adjustments need to be made when scaling up from cane-specific data to stand data due to canes not emerging within all areas of *Arundo* canopy. Areas along edges and gaps within stands have zero to few canes. (Section 2.3)
- Biomass per unit area is very high for mature *Arundo* stands and it is in general agreement with the literature: 15.5 kg/m^2. (Section 2.4)
- Leaf area of secondary branches is the primary photosynthetic area for older canes, and this constitutes the majority of the mature stand leaf area (75%). This has not been clearly recorded in the literature. (Section 4.1)
- Measurements of leaf area (LAI) in mature *Arundo* stands are very high (15.8 LAI). This is in general agreement with the literature. (Section 4.1)
- Additional studies examining LAI and stand structure would further establish that mature *Arundo* stands have very high LAI. Examination of native riparian vegetation LAI may also be beneficial.
- Reviewed literature demonstrates that *Arundo* spreads through asexual propagation (fragments of rhizomes and infrequently canes). Seeds are not viable. This makes *Arundo* spread dependent on flood action or anthropogenic disturbance. (Section 2.5)
- Review of historic aerial photography indicates that spread of *Arundo* within a watershed is very episodic- large magnitude (50 to 100–year) events are necessary for the plant to actively invade significant new areas in a riparian system, particularly floodplains and terraces. (Section 2.6.4)

These observations are important in that they characterize *Arundo* stands within the study area. These baseline attributes are used to quantify and explore multiple impacts associated with *Arundo* in later sections.

***Arundo* Impacts: Transpiration and Water use**

- Due to high leaf area of mature stands, stand-based transpiration is very high (E_{stand} 40 mm/day). There are two other studies evaluating stand-based *Arundo* transpiration. One study on the Santa Clara watershed (within this project's study area) is in agreement (41.1 mm/day). The other study on the Rio Grande River is lower (9.1 mm/day). (Section 4.1).
- Stand-based transpiration rates of *Arundo*, when used to calculate total water over larger areas, indicate very high levels of water use: 48 ac-ft/ac per year. (Section 4.2)
- Net water savings for areas after *Arundo* removal are high (20 ac-ft/yr), even when *Arundo* water use is lowered 24 ac-ft/ac per yr to reflect levels that may be closer to physiological water transpiration limits. (Section 4.2)

- New studies using different approaches to measure stand-based water use of *Arundo* are needed to corroborate and refine stand-based water use found in this and other studies. New studies need to be on mature stands of *Arundo*. Stands under treatment or in post-fire or flood recovery should be excluded, as these are not representative of the majority of *Arundo* stands within the study area. (Section 4.2)

Water use by *Arundo* appears to be a significant impact on invaded systems. Water use by vegetation is difficult to measure. Additional baseline and comparative studies are needed.

Distribution and Abundance

- *Arundo* mapping documented a total (gross) of 8,907 acres of *Arundo*. Net acreage, adjusted for *Arundo* cover, was 7,864 acres. This represents the peak distribution of *Arundo* in the study area prior to control activities. (Section 3.2)
- Over 3,000 gross acres of *Arundo* have been treated to date within the study area. This is 34% of the *Arundo* occurring within the study area. (Section 3.2)
- Three large, contiguous watershed units have the highest levels of *Arundo* control observed in the study area: Santa Margarita at 99%, San Luis Rey at 90% and Carlsbad at 70%. (Section 3.2)
- Most other invaded watersheds in the study area with more than 100 acres of *Arundo* have had at least 30% of their *Arundo* treated. Noted exceptions to this are Calleguas, Salinas and Santa Clara watersheds, which have less than 10% of their *Arundo* acreage under treatment. (Section 3.2)
- *Arundo* is most abundant in broad, low-gradient riparian areas where it averages 13% cover. (Section 5.2)
- *Arundo* cover can be very high for large sections (reaches > 0.5 mi long). *Arundo* was observed occurring at >40% cover on specific reaches on all three watersheds that were examined in detail: Santa Margarita, San Luis Rey and Santa Ana. (Section 5.1)

Distribution and abundance data is extremely valuable because it quantifies past and current levels of invasion on watersheds, allows detailed examination and quantification of impacts, and facilitates watershed-based control. Programs can use the spatial data to implement watershed-based control, develop proposals and budgets, and manage control programs.

Arundo Impacts: Hydrology and Geomorphology

- Mature *Arundo* stands, due to high cane density, functionally raise the elevation profile by 5 feet, lowering flow capacity. (Section 5.1.4.6)
- *Arundo* stands occur predominantly in floodplain and terrace portions of the river and are nearly absent from the low flow and active channel areas. (Sections 5.1 & 5.2)
- *Arundo* stands on floodplains adjacent to the active channel function as a wall or levee, focusing flows within channel areas. Over time this results in a deepening of the channel and a transformation of the system from a braided unstable channel form to a laterally stable single-thread channel form. (Section 5.1.4.6)
- Floodplain areas (floodplains and low terraces) have become much more vegetated on most systems over the last eighty years. This vegetation is both native woody vegetation and *Arundo*. Mature *Arundo* stands, however, have much higher stem density and biomass per unit area, generating the observed effects noted above. (Section 5.2.3)

- Active channel areas (low flow and bar channel areas with little vegetation) have significantly declined over time on most systems. (Section 5.2.2)
- The over-vegetated floodplains and narrow stable deep channels result in modifications of sediment transport and stream power during flow events. (Section 5.1.4.7)
- Most riverine systems have become significantly compressed (narrower) over time as terrace and floodplain areas have been permanently separated from the river system with levees that protect both urbanization and agricultural land use. (Section 5.2)
- Most riverine systems in the study area have converted from: broad riparian systems with little vegetation cover and channels that were laterally unstable (braided) to narrow riparian systems with highly vegetated floodplains that have a single deep channel. (Section 5.2)
- Most *Arundo* has been removed from the Santa Margarita River for 13 years. The geomorphic response to large flow events in that time has been a significant widening of the low flow and bar channel area (38% increase). Flows also actively pass through floodplain areas; this is a major change in function and process. Moderately-sized events (15 year) now flow through significant portions of channel, bar, and floodplain areas. Before *Arundo* was removed, flows were restricted to channel and bar areas. (Section 5.2.4)
- Loss of flow capacity and presence of *Arundo* biomass is likely contributing to overbank flows and bridge loss and damage. (Section 5.2.5.1)
- Flow events mobilize large amounts of *Arundo* biomass. Part of this biomass load ends up on coastal beaches where it is frequently removed by public agencies and carries an estimated annual cost of $197,000. This does not include impacts on habitat quality. (Section 5.2.5.2)

Hydro-geomorphic impacts are significant. This has ramifications to both the ecosystem and infrastructure in and around invaded rivers. Watershed-based analysis on sediment movement and impacts should be explored in greater detail to further document and quantify relationships.

***Arundo* Impacts: Fires**

- *Arundo* stands are highly flammable throughout the year with large amounts of fuel (15.5 kg/m^2 of biomass), a large amount of energy (287.1 MJ/m^2), and a tall well-ventilated structure with dry fuels distributed throughout the height profile. (Section 6.1)
- Fires frequently start in *Arundo* stands. The primary ignition sources are transient encampments and discarded cigarettes from highway overpasses. (Section 6.1)
- *Arundo* stands strongly attract transient use (dense cover and shelter). This was documented throughout the study area with numerous high use locations noted in both urban and agricultural areas. (Section 6.3.1)
- Fires initiated in *Arundo* stands occur due to fuel and ignition source occurring at the same location. This is a newly defined class of fire events. (Section 6.4.1)
- Fires that are initiated in *Arundo* burn both *Arundo* stands and native riparian areas. In addition, suppression of fires also impacts riparian habitat. Impacts were calculated for all watersheds using San Luis Rey as a case study. Over a ten-year period for the study area, *Arundo*-initiated fire events are estimated to have burned 513 acres of *Arundo* and 706 acres of native riparian habitat. Fire suppression over a ten-year period has impacted 44 acres of *Arundo* and 32 acres of native riparian vegetation. (Section 6.5)
- Wildfires burn a significant acreage of *Arundo* stands. Over ten years, 6.1% of *Arundo* stands (544 acres) burned within the study area. (Section 6.5)
- Due to high fuel load and stand structure, areas with *Arundo* burn hotter and more completely then native vegetation during wildfire events. (Section 6.4.2)

- *Arundo* stands appear to be conveying fires across riparian zones- linking upland vegetation areas that would have been separated by less flammable riparian vegetation. This can have catastrophic impacts like those observed in the 2008 Simi fire. The 8,474-acre fire crossed the Santa Clara River and then burned an additional 107,560 acres. (Section 6.4.2)
- *Arundo* fires accelerate the dominance of *Arundo* in invaded areas due to rapid re-growth and low mortality of *Arundo*. (Section 6.5.1)
- *Arundo* fire events lead to both direct mortality of wildlife and plants (some of which are sensitive) as well as a longer-term quality reduction of burned riparian areas (post-fire recovery of vegetation and structure). (Section 6.5.2)
- Emergency actions tied to *Arundo* fire suppression also result in impacts (disturbance of both *Arundo* and riparian vegetation) that degrade riparian habitat and/or may result in mortality of species. (Section 6.5.4)

Documentation and separation of *Arundo*-initiated fires from wildland fires that burn *Arundo* is an important finding. Impacts from *Arundo*-initiated fires are common and are the result of *Arundo* invasion. Harboring ignition sources in combination with combustible fuels year round creates this unique fire risk and impact. This needs to be further studied and documented. If validated, impacts to wildfire spread could be the greatest single impact.

***Arundo* Impacts: Federally Endangered and Threatened Species**

- *Arundo* impacts to 22 federally endangered and threatened species from five taxonomic groups varied from: very severe (score of 10) to very low/improbable (score of 1). (Section 7.3.1)
- Documented and potential abiotic and biotic impacts from *Arundo* are described for each species. Abitoic impacts include modification of geomorphology, hydrology, flood disturbance, fire disturbance, water use, and nutrient budgets. Biotic impacts include alteration of vegetation/community structure (displacement of native vegetation), filling in 'open' un-vegetated portions of habitat, creating physical structure that impedes movement, creation of structure in estuaries that facilitates predation, biomass debris that degrades breeding areas, stand structure that is of low value for nesting, and biomass that is of low forage value for both insects and animals. (Section 7.2)
- *Arundo* co-occurs with sensitive species on many watersheds in the study area. This overlap in distribution was evaluated using the *Arundo* mapping data and sensitive species occurrence data (Appendix B). Interaction between *Arundo* and each species was scored. *Arundo* present upstream of sensitive species was specifically accounted for as impacts occur to downstream areas from alteration of sediment loads, geomorphic forms, biomass discharge and other factors. (Section 7.2)
- A cumulative impact score was calculated using the species' specific impact score and the overlap score. This allows each species and each watershed to be evaluated for magnitude of impact. Least Bell's Vireo and Arroyo toad ranked as the most 'severely impacted'. Three species ranked 'very high', four species ranked 'high', ten species were 'moderate', and three species were 'low'. (Section 7.2)
- Several fish species ranked very high on the cumulative impact scoring. This is a group of species that have not been closely associated with *Arundo* impacts prior to this study. Most fish species had impacts related to modification of channel form (single versus braided), channel depth (shallow versus deep), sediment transport, and potential biomass/debris impacts. (Section 7.2)

- Estuaries and beaches were shown to have moderate impacts resulting from both *Arundo* stands, which create physical structure that facilitates predation, and *Arundo* debris that covers open sandy areas required by ground-nesting avian species. (Section 7.2)
- Watershed rankings of *Arundo* impacts on sensitive species shows that there are four watersheds designated as 'severely impacted', two as ‘highly impacted’, eight as ‘moderately impacted’, and five as ‘lowly impacted’. (Section 7.2)
- Three of the four ‘severely impacted’ watersheds have well-developed watershed-based *Arundo* control programs in place. (Section 7.2)

Impacts to habitat are significant. *Arundo*’s overlapping distribution with sensitive species creates pressures on a wide range of species. Impacts range from abiotic to direct biotic interaction. The most significant impacts relate to abiotic modification of the system (water, fire, geomorphic form), but these are the most difficult to document and quantify due to their scale. Additional research and documentation are needed to increase our understanding of how *Arundo* modifies ecosystem-regulating processes.

Cost to Benefit Analysis

- Cost of *Arundo* control is $25K per acre, as documented by $70 million of work completed on control programs within the study area over the past 20 years. (Section 8.1)
- This would total $196 million in control costs at the study area’s peak *Arundo* distribution and $124 million at current *Arundo* distribution levels. (Section 8.1)
- Benefits from control and reduction of impacts was calculated for fire, water use, sediment trapping, flood damage (bridges), habitat, and beach debris. Analysis was conservative. (Section 8.2)
- Benefits: $380 million at peak *Arundo* distribution and $239 million at current *Arundo* distribution levels. (Section 8.2)
- Benefit to cost ratio of 1.9:1. (Section 8.2)

Arundo control is of substantial net benefit. Many impacts were not included in the analysis, and benefits were valued conservatively. The actual benefit of *Arundo* control is likely much higher than calculated.

Watershed Programs

- Watershed-based control is a priority and is facilitated by a strong lead entity that manages the program. Effective programs must have the capacity to manage project funds, obtain right of entry agreements, and hold regulatory permits. (Section 9.1)
- Permitting is complicated and expensive, but required. Programs with broad and active permits are able to implement programs more effectively and quickly. (Section 9.1)
- Watershed programs should use accurate and standardized mapping to represent *Arundo* acreage. This allows better management of programs, facilitates comparison of projects, and increases accountability. (Section 9.1)
- A significant amount of *Arundo* control has already occurred within the study area and many watershed-based control programs have already formed. (Section 9.1)
- Priorities for *Arundo* control are: (Section 9.2)
    - Long term re-treatment of program areas that have already had initial control: this protects the investment already made.

- Control *Arundo* on watersheds with low levels of invasion: this eradicates populations before they become abundant, which is more cost effective and avoids future impacts.
- Treat watersheds with significant *Arundo* invasion based on: level of impacts and capacity of groups proposing work.

Watershed-based management of *Arundo* is greatly facilitated by the establishment of a program lead. Programs with tracking systems for work completed, in addition to long-term stability, have the greatest ability of completing true watershed based control (eradication).

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APPENDIX A. Detailed Maps of *Arundo* Distribution Within the Study Area

Arundo distribution data from Monterey to San Diego, CA
(see Chapter 3 for information on mapping methodology)

Spatial data set (GIS geo database) are available for download at:

http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

The spatial data set is also viewable at the DFG BIOS web site:

http://bios.dfg.ca.gov/

Project data sets are named:
Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

APPENDIX B. Occurrence Data and Critical Habitat Areas for Federally Listed Species and Distribution of *Arundo*.

Spatial data for federally listed species includes:

- **Critical habitat areas designated by USFWS**
- **Occurrence data compiled by the Ventura USFWS Office**
- **Occurrence data from the California Natural Diversity Database (CNDDB: CA DFG)**
- **Additional occurrence data from USGS, SANDAG, and other sources**

Spatial data set (GIS geo database) are available for download at:

http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

The spatial data set is also viewable at the DFG BIOS web site:

http://bios.dfg.ca.gov/

Project data sets are named:
Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]