The Proliferation of *Arundo donax* in Arroyo Las Posas

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Abstract

This study examines the growth of vegetation and *Arundo donax* in particular, in the Arroyo Las Posas section of Calleguas Creek, a formerly ephemeral stream which now carries water on a perennial basis as a result of runoff that originates from surrounding areas undergoing increased development. The establishment of arundo in riparian systems is a growing problem in the southwestern U.S. as this species reduces habitat quality, changes fire regimes in riparian areas, transpires greater amounts of water than native plant species, and is a contributing factor in erosion and flooding.

In this investigation, a series of aerial photos taken between 1980 and 2005 was used to map vegetation and other landcover in the river channel and its immediate environs. Changes in the areal extent of riparian vegetation and the open channel area were assessed quantitatively using a GIS system. Precipitation and stream gauge data for the 25-year period were obtained and evaluated for their role in vegetation establishment and growth, as well as in channel scouring and erosion. The proportion of vegetation attributable to arundo was determined for the photos where the quality of images permitted, and its progression mapped. Temporal changes in the abundance of arundo were quantified and possible factors contributing to these changes were assessed.

The results of the study show the increasing establishment of vegetation in the channel since 1980. Although vegetation has been periodically diminished in the channel during episodes of heavy precipitation, when accompanying heavy flow volumes scoured channel surfaces, vegetation has increased more than three-fold between the years of 1980 and 2005. Arundo now constitutes a significant part of all channel vegetation, and by 2005 more than half of the area mapped was infested with this plant. In contrast, the total area covered by all types of channel vegetation in 1980 constituted less than one-third of the area mapped.

Channel recovery from the severe storms of 2005 is likely to result in an even greater abundance of arundo owing to the increasingly perennial nature of flow in Arroyo Las Posas. Consequences of this proliferation are likely to be further degradation of the riparian environment, and more serious channel erosion in the future.

Introduction

Non-native, invasive plant species are an increasingly significant problem in riparian systems of the American southwest. The most widely studied is tamarisk (*Tamarix* spp.) which has proliferated in ephemeral and intermittent streams. In southern California, *Arundo donax*, or giant reed, has become a prominent feature in many rivers and streams.

Arundo is a problem plant for several reasons, all of which can be attributed to its superior competitive ability against native plant species. It typically grows in dense clusters and possesses a high growth rate, which enables extensive monocultures to become quickly established. Its tendency to invade and colonize areas of riparian vegetation crowds out native species, which not only reduces habitat quality, but also negatively impacts fluvial processes, such that flooding and erosion result. As arundo reproduces vegetatively through extensive underground rhizomes (seeds in North America are not viable and seedlings are not observed), the rate and extent of its spread in southern California waterways would likely be related to streamflow volumes and flood events.

This paper will describe the spread of arundo in Arroyo Las Posas using GIS and a series of aerial photographs taken between 1980 and 2005. Once arundo becomes established in the environment is difficult to eradicate. The increasing extent of its presence will not only require proportionately larger amounts of funding to remove it, but also to repair the damage it causes to native habitat areas and human infrastructure such as bridge pilings and storm drains.

Hypothesis

The proliferation of *Arundo donax* in Arroyo Las Posas has been facilitated by various high flow and flood events, as flow dislodgement of established rhizome masses distributes the vegetative matter downstream, further enabling the establishment of additional arundo colonies.

Background

Invasive, non-native species, both floral and faunal, are a problem of increasing significance. There are an estimated 50,000 non-native plant and animal species in the United States which cause environmental damage and losses of approximately $137 billion dollars annually (Pimentel *et al*. 2000). In southern California, non-native species are especially problematic in riparian areas. These areas are important transition zones between terrestrial and aquatic habitat systems and support significant numbers of flora and fauna. However, in southern California, as much as 90% of historically riparian habitat has been eliminated as a function of increasing urban development. Arundo has become the predominant non-native species in many of the remaining riparian areas (Bell 1993).

Riparian Areas

Riparian areas are the bands of vegetation that lie adjacent to stream channels. They serve a variety of functions which include flood control, storm damage prevention, and water quality protection. They also contribute to the biodiversity of ecosystems by providing habitat for a wide variety of species (Donaldson 1997). In arid and semi-arid regions, riparian areas are often the most productive ecosystems (Herrera and Dudley 2003) owing to the mosaic of species they support (Bell 1993). Fredrickson and Reid (1986) indicate that more than 50% of riparian and wetland areas of the contiguous U.S. have been destroyed, and that only a small percentage of those that remain exist without having sustained adverse impacts. In California, it is estimated that only 5% of native riparian ecosystems retain their natural physical and biotic structure (Cal PIF 1998). The degradation and loss of riparian areas are primarily attributed to changes in herbivory and hydrologic regimes, and conversion to agricultural and urban land use (Stromberg 2001).

The dynamic structure and form of riparian areas are strongly influenced by the fluvial processes of erosion, and sediment transport and deposition (Bendix and Hupp 2000, Steiger *et al*. 2003). In Mediterranean climates, such as the study area, it is typical for channel hydrographs to be "flashy", as channel flows rise quickly and intensely in response to precipitation, and recede just as rapidly. Episodic flooding and channel migration are not only common (Bendix and Hupp 2000), but are necessary to riparian habitats as new layers of sediment provide seed beds for native species (Bell 1993), which rely on hydrochory as their primary method of dispersal (Steiger *et al*. 2003). Flood regimes characterize the diversity of species found in riparian areas (Hupp and Osterkamp 1996, Donaldson 1997, Bendix and Hupp 2000, Osterkamp and Friedman 2000). Although native riparian habitats depend on such regimes (Bell 1993), it leaves them particularly vulnerable to invasion by non-native species, as water disperses vegetative matter (seeds and propagules) and high flows create openings in existing vegetation (Pysek and Prach 1994, Donaldson 1997). According to Tickner *et al*. (2001), the dynamics between sediment deposition and propagule dispersion not only influence riparian species diversity, but also enable the distribution of non-native species. Some species may be common to riparian areas not because their structures allow them to survive flooding, but because their reproductive mechanisms allow them to rapidly colonize disturbed channel surfaces (Bendix and Hupp 2000).

Channel Processes

Alluvial channels such as Arroyo Las Posas are characterized by mobile bedloads and migrating channels. Because alluvial deposits are less resistant than bedrock, bank erosion, and the subsequent migration of the channel occur in areas where the resistance of soil is exceeded by the force of the flow (Wasson and Wasson 2000). Mobilization of bed materials in alluvial channels occurs as a result of winter storms which create flow volumes significant enough to exceed the threshold for mobilization, while channel migration may occur during periods when flows exceed bankfull discharge (Trush *et al*. 2000). The extent to which mobilization and migration occur is controlled by the length of the high flow (Hupp and Osterkamp 1996). The runoff that contributes to channel flow is governed by precipitation amounts and catchment hydrology (Wasson and Wasson 2000).

Excessive channel vegetation and its associated debris can obstruct, divert, or facilitate water flow (Tabacchi *et al*. 2000), trigger erosion and sediment deposition, or otherwise offer resistance to the erosive power of high flows (Graf 1978, 1982, 1988; Merritt and Cooper 2000, Osterkamp and Friedman 2000, Tooth and Nanson 2000). Bank resistance through the presence of vegetation occurs as a function of the increased roughness that plant structures such as roots provide (Donaldson 1997). As roughness increases, water velocity slows, and sediments are deposited because the flow is no longer fast enough to carry them. When sediment deposition increases, channels become narrower. Reduced channel capacity impedes channel function during episodes of high flow, which can trigger overbank flow and flooding (Graf 1978, 1982). Where vegetation causes flow deflection, bank erosion and channel widening often result (Graf 1978, Tooth and Nanson 2000).

Introduced Species

Invasive, non-native species are becoming an increasing concern in areas across the U.S. Invasive species are introduced plants that thrive in their new environments and increase their ranges (Dukes and Mooney 2004). Their ability to thrive may occur either because the non-native plant outcompetes native species for resources, or because it is reproductively opportunistic (Stromberg 2001). In either situation, the end result is that the introduced species negatively impacts the ecosystems into which it has been introduced. In earlier decades, most plant introductions were intentional and occurred because of the perception that the new species would offer specific benefit to its new environment. However, accidental introductions have increased significantly in more recent times due to the growth of human population, the tendency of humans toward increased migration, and human alteration of the environment (Pimentel *et al*. 2000). Morse *et al*. (1995), estimate that 5000 introduced plant species have escaped cultivation and now exist in natural U.S. ecosystems. In California, 1,109 of the state's 8,274 catalogued species have been introduced from other regions (Hobbs and Mooney 1998). Approximately 1.73 million acres of wildlife habitat in the U.S. is invaded by non-native plant species annually (Babbitt 1998).

Non-native plant species are of concern for a number of reasons, but primarily because they degrade habitat quality and cause extensive agricultural losses. Because of differences in traits, function, or behavior, invasive species are able to alter ecosystem processes and properties as their extents expand (Dukes and Mooney 2004). Pimentel *et al*. (2000) indicate than losses to U.S. crops, pastures, and forest lands by non-native invasions total several billion dollars annually.

Non-indigenous plants are able to invade environments beyond the extent of their native ranges for several reasons. This is primarily due to a lack of controlling natural enemies (which would ordinarily keep the species in check), and the availability of altered or disturbed habitats that provide a niche that the non-native species can occupy (Pimentel *et al.* 2000). Dukes and Mooney (2004) indicate that many grassland, shrubland, dune, riparian, and estuarine ecosystems of western North America have already become dominated by nonindigenous species. The ability of invasive species to disrupt native ecosystem processes has the potential cause native species extinctions to the extent that much of the character of western North America may be altered (Pimentel *et al.* 2000).

Arundo

Arundo is native to the Indian sub-continent and the Mediterranean, it is well-adapted to tropical and warm temperate regions. As a result of intentional introductions by humans, arundo has spread “into all of the subtropical and warm-temperate areas of the world” (Perdue 1958). In 1951, Robbins *et al*. documented arundo as being distributed from Texas to California, and was common in irrigation ditches throughout southern and central parts of California.

Arundo has traditionally been used to build roofs, screens, lattices, and fences. Spanish missionaries and colonists introduced arundo to the region (Perdue 1958) and it is documented as having been used in mission construction (VCRCD 2000). Frandsen (1997) notes that Spanish settlers in the region also used arundo as fuel for fires, to feed livestock, and as an erosion control agent to prevent soil losses from water and wind. In 1820, it was being gathered from the Los Angeles River for use in roofing applications and was preferred over native tule reeds (Robbins *et al*. 1951). As the population of early southern California grew, the need for building materials increased, and the planting of arundo continued (Frandsen 1997). In previous decades, arundo was also commonly planted as an ornamental in gardens (Robbins *et al*. 1951, Perdue 1958). As a source of reeds for woodwind instruments, it was also cultivated to a small extent in various areas of California (Perdue 1958, Dudley 2000) however its capacity for negative environmental impacts outweighs its commercial value (Bell 1997). The invasive populations of arundo that presently exist in southern California have resulted from displacement or escapes of the plants from areas of managed cultivation (Dudley 2000).

Arundo is a perennial, giant grass (Poaceae) that grows 2.75 m to 9 m tall (Dudley 2000) (Fig.1). Under optimum conditions, arundo can grow up to 6.3 cm day^{-1} (Rieger and Kreager 1989). It is reed or bamboo-like in structure. It has hollow, segmented stalks (culms) 1 to 4 cm in diameter that grow from rhizomes. The rhizomes typically grow in dense, segmented masses, with fibrous roots 1.5 m long (Frandsen 1997). Bladed leaves grow from the culms in opposite intervals and may typically be 10 to 70 mm wide and 20 to 80 cm long (Clayton *et al.* 2005).

Arundo spreads by vegetative reproduction – as seeds in North American environments appear to not be viable – either by sprouting from stem sections or rhizome pieces (Fig.2), or extension of underground rhizomes (Else 1996, Dudley 2000). Arundo spreads to greater extents when rhizomes are carried downstream by flood waters (Else 1996, Boose and Holt 1998, Dudley 2000) (Fig. 3). If arundo stalks are cut or otherwise removed from the main plant, the release of new basal stems is triggered (Frandsen 1997).

As a hydrophyte, arundo favors areas of high moisture availability, such as riparian areas, streams, and seeps (Perdue 1958, , Hoshovsky 1986, Bell 1993). It has also been observed on hillsides (Frandsen 1997). Arundo grows in a variety of soil types (Perdue 1958), but is most commonly found in sandy substrates near water sources (Rieger and Kreager 1989). Arundo is tolerant of high soil salinity, which also allows

Figure 1: The arundo in this image is approximately 5m tall.

Figure 2: Arundo rhizomes and sprouts.

Figure 3: Dislodged and partially buried piece of arundo rhizome. Section is approximately 45 cm in length.

it to colonize tidal marshes and beaches. It can also withstand periods of extended drought, and its rhizomes can tolerate desiccation over periods of several months, retaining sufficient amounts of energy to sprout once reintroduced to moist substrates (GISD 2006).

Arundo is problematic for several reasons, and once it becomes established, is difficult to remove. Where arundo is present, habitat quality is reduced. As the growth rate of arundo exceeds that of native riparian vegetation (Else 1996, Bell 1997, Dudley 2000), maintenance and regeneration in riparian areas becomes impaired as arundo monopolizes available space and moisture (Dudley 2000) and shades out native species (Rieger and Kreager 1989). Arundo has been documented to reduce species diversity (Bell 1997) in riparian areas, particularly among birds (Frandsen 1997) as well as the insect species many birds forage upon (Herrera and Dudley 2003). Many bird species common to riparian areas depend on a multi-story forest for nest sites. However the lack of structural diversity provided by stands of arundo makes it unsuitable for nesting (Bell 1997, Herrera and Dudley 2003). It is additionally problematic to birds because dense stands are too thick to fly through (Fig. 4). Arundo also does not provide forage for native species. Its leaves and stems contain silica and alkaloids, which cause it to be undesirable as a food source. An additional implication of arundo's leaf composition is that few biologic controls exist in environments that are outside its native range (Bell 1997). The simple architectural structure of arundo also creates insufficient amounts of shade for aquatic environments. This increases water temperatures, which is detrimental to many species. Higher temperatures can cause algal blooms which alter aquatic oxygen levels (Bell 1998, Dudley 2000).

Figure 4: Arundo lacks structural diversity necessary for nesting birds and is too dense to fly into and through.

Arundo also changes fire regimes in riparian areas. Riparian areas in their native states create natural fire breaks. However, once colonized by arundo, they serve as conduits and further spread fire. Arundo produces copious amounts of dry detritus (Fig. 5), which has been estimated to more than double the available fuel for wildfires (Scott 1994). Arundo's flammability introduces fire into riparian environments on a more frequent basis. When increased fire frequency is coupled with arundo's fast growth rate, indigenous species are eventually eliminated owing to their slower rates of growth and recovery, which converts the vegetation of typical riparian systems to an arundo monoculture (Bell 1993).

Figure 5: Arundo processes excessive amounts of dry detritus.

An acre of arundo has been estimated to use 5.62 acre-feet of water annually. This amount is triple that used by native riparian vegetation, which uses approximately 1.87 acre-feet per year (Iverson 1993). As a result, it is able to desiccate riparian areas (Dudley 2000). The water lost as a result of arundo's high transpiration rates would otherwise be available for beneficial uses such as groundwater recharge and drinking water supplies (Iverson 1993).

Owing to the dense manner in which it grows, arundo also contributes to flooding and erosion. Erosion is triggered by obstructions that redirect flow and increase scouring (Tabacchi *et al*. 2000; Steiger *et al*. 2003; Merritt and Cooper 2000; Graf 1978, 1982; Bendix and Hupp 2000; Tooth and Nanson 2000). Arundo not only impedes flow (Robbins *et al*. 1951), but forms channel obstacles as it is easily undercut during periods of heavy flow because its root system lacks the depth of native vegetation (Dudley 2000) (Fig. 6). Flooding and overbank flow result from reductions in channel carrying capacity. Arundo traps larger amounts of sediment than native riparian vegetation, which decreases channel size (Frandsen and Jackson 1993) and alters flow regime (Bell 1997) (Fig. 7).

The density of arundo biomass also creates debris dams as it becomes tangled among itself and also traps other floating debris. Debris dams can damage bridge pilings (Fig. 8) and other physical infrastructure, which incurs not only debris removal costs, but repair costs as well (Frandsen 1997). For example, clogging from arundo debris may have factored into a levee burst on the Santa Margarita River. The burst damaged areas of the Camp Pendleton military base, which required $12.5 million dollars to repair (La Rue 1996). In alluvial, braided channels such as the Arroyo Las Posas, the effects of overbank flooding triggered by flow impediments are especially apparent (Schumm 1985, Trush *et al*. 2000) due to the inherently erosive nature of many alluvial soils, especially if they are composed of a large percentage of sand.

Figure 6: An arundo stand in the process of being undercut.

Figure 7: An arundo island (background) created as a result of arundo's ability to trap sediment.

Post Flood Establishment

The rapid peak and decline of many high flow events in southern California can leave large sections of channel environment significantly disturbed. Arundo is well-adapted to this disturbance regime because it has a high growth rate and is able to spread vegetatively. Arundo is very susceptible to flood-fragmentation due to the brittle nature of its rhizomes and the high erodibility of many channel soils. Once root masses are dislodged, vegetative propagules are spread further

Figure 8: Arundo accumulations on Upland Road bridge in Camarillo. Some of this uprooted biomass is beginning to sprout.

downstream via water flow (Else 1996, Bell 1997, Boose and Holt 1998) (Figs. 9 and 10). Rhizome fragments can sprout after being severed from the parent plant for over 4 months (Boose and Holt 1998), and after having been buried at depths of 100 cm (Else 1996). This is due in part to the greater soil moisture availability at depth, and also because rhizome and stem segments of arundo store greater amounts of energy than the seeds of native species (Else 1996). Thus, in areas where arundo is present, its high growth rate and vegetative manner of reproduction allow rapid colonization of disturbed areas, enabling it to achieve dominance in many riparian ecosystems (Dudley and Collins 1995, Bell 1997).

Figure 9: An uprooted clump of arundo that was deposited on an upper channel terrace during a high flow event.

Figure 10: An uprooted clump of arundo that has started to sprout.

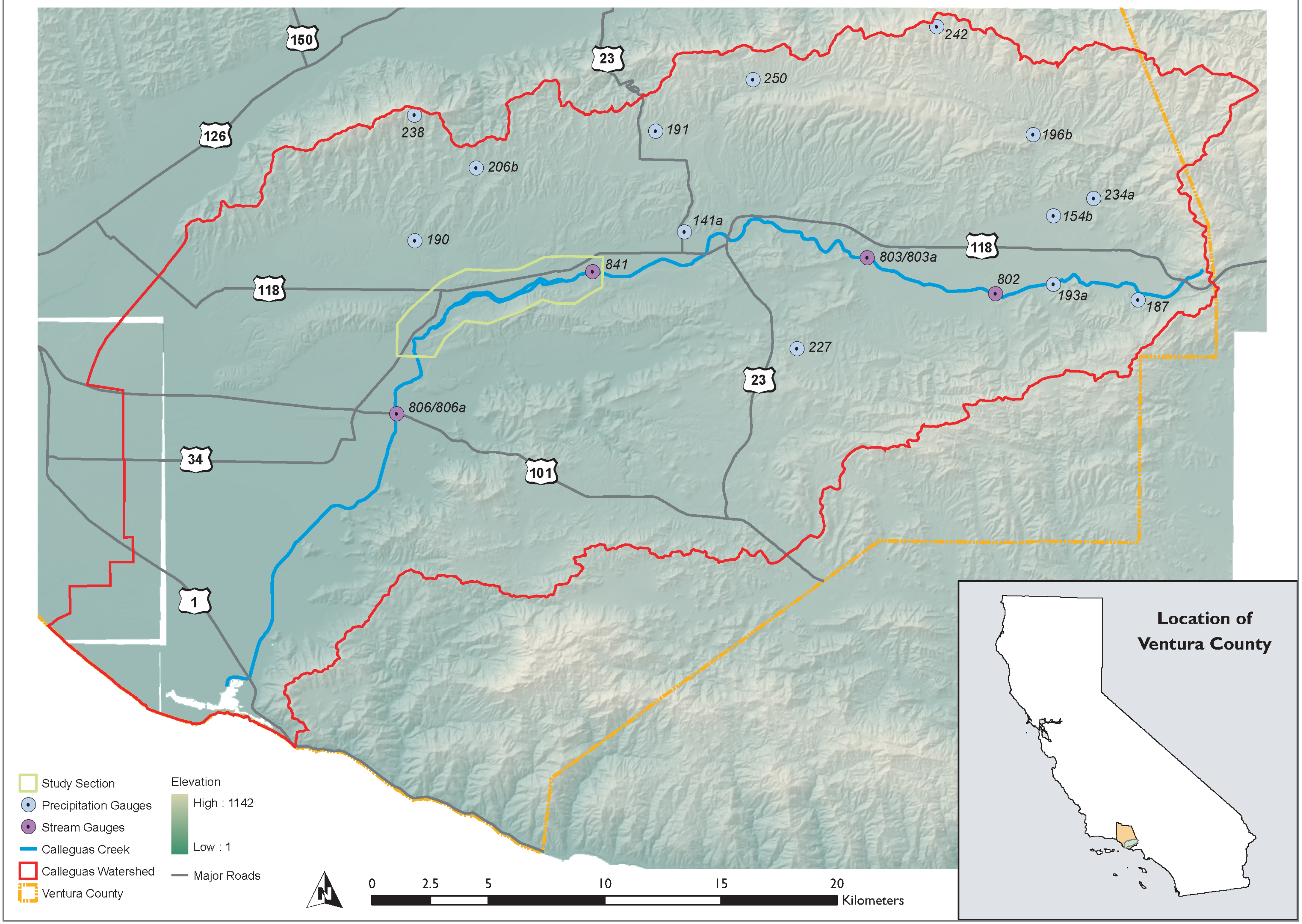
Study Area Description

Location

This study will evaluate the physical extent of arundo in a limited section of Arroyo Las Posas, in Ventura County, California (Fig. 11). Ventura County is situated along the coast of southern California, between Santa Barbara and Los Angeles Counties. The specific area of investigation is bounded by Hitch Boulevard near the western boundary of the city of Moorpark (Fig. 12), and Upland Road near the northern boundary of the city of Camarillo (Fig. 13).

Arroyo Las Posas lies within the Calleguas Creek watershed, which is located in the southern

Figure 11: Location of Study Area



third of Ventura county and extends from the Ventura/Los Angeles County line in the northeast to Mugu Lagoon and the Pacific Ocean in the southwest. It drains Simi Valley, Santa Rosa Valley, Tierra Rejada Valley, the Conejo Valley, and portions of Pleasant Valley and Las Posas Valley via Calleguas and Conejo Creeks. The watershed trends roughly east to southwest. It is approximately 48.25 km long from east to west, and 22.5 km wide from north to south. It is bounded by the South Mountain and Oak Ridge to the north, the Santa Susana Mountains to the east, the Simi Hills and the Santa Monica Mountains to the south, and the Pacific Ocean to the west. The drainage area is approximately 883 km^2 (CCWMP 2004).


Figure 12: The upstream boundary of the study area.


Figure 13: The downstream boundary of the study area.

Arroyo Las Posas is a subsection of Calleguas Creek. It flows roughly from east to west, but begins a southwesterly trend near the western boundary of the study area. It flows through a broad alluvial valley where land use is primarily agricultural, although open space and areas of low-density residential and commercial developments are also present.

Climate

The Calleguas Creek watershed exhibits a temperate Mediterranean climate with long, dry summers and cool, moist winters. Average minimum January temperatures range from 5° to 8°C, while maximum January temperatures range from 17° to 20°C. Average high temperatures during the summer show significantly greater spatial variation. Near coastal areas of the watershed, the average maximum July temperature ranges from 22° to 24°C. However, July average high temperatures for inland areas of the watershed may range from 32° to 37°C. During the late spring through early summer, coastal areas of the watershed are often overcast as a result of onshore marine air flow, and the resultant advection fog. From late September through December, easterly winds known as Santa Anas can cause the maximum temperatures for this time period to reach 35°C (VCWPD 2005).

Precipitation typically occurs between the months of November and April, with very little occurring from May through August. Average annual precipitation for the watershed is 381 mm. Snowfall is rare, and is largely confined to higher elevations. Winter storms originate over the Pacific Ocean and typically move through the watershed from the western, coastal area to the eastern, interior region (VCWPD 2005).

Channel Characteristics

Within the study area, Arroyo Las Posas is a braided alluvial stream that migrates regularly within its channel (Fig. 14). It is 9.4 km long, and from 20 m to 200 m wide. The bed material consists of

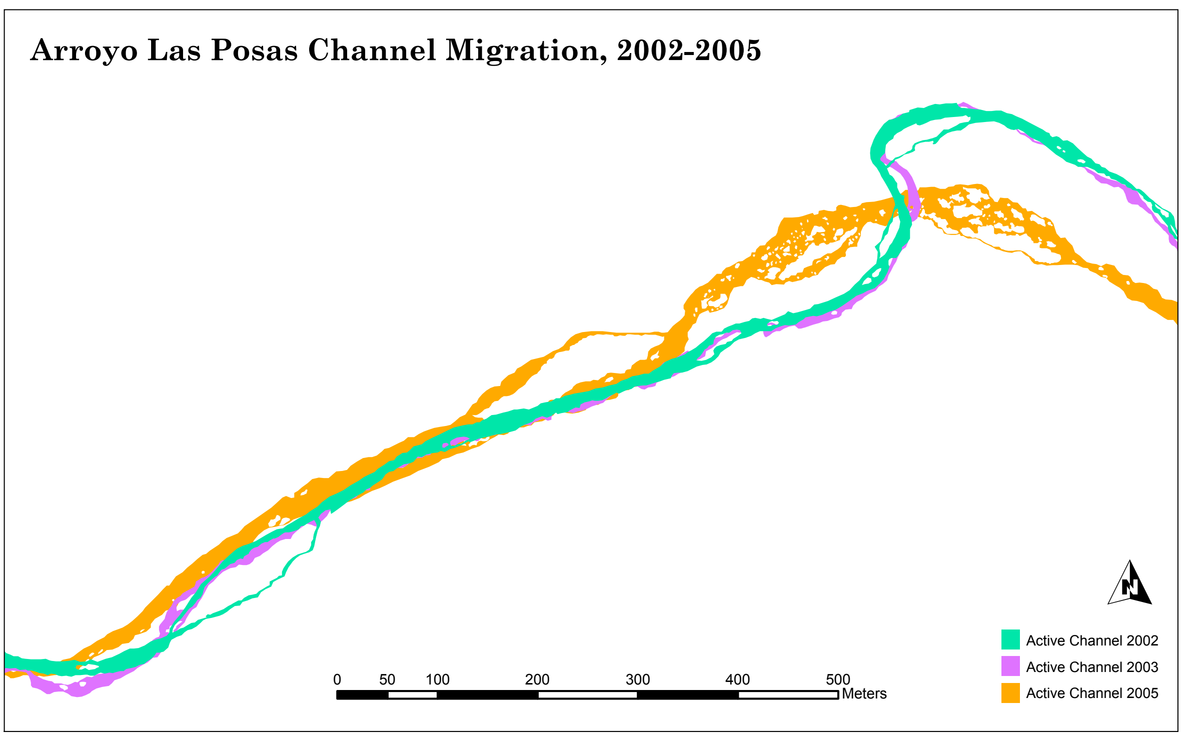


Figure 14: An example section of the channel showing the extent to which migration can occur.

alluvial sediments which range from fine silt and sand to small cobbles (Fig. 15). The stream is channelized upstream of the study area for a distance of 5.72 km, but the stretch discussed in this report is unconstrained (Figs. 16 and 17).


Figure 15: Typical bed materials found within the channel.

Flow characteristics have changed over time as the surrounding area has undergone development. Historically, runoff in the stream channel was seasonal, flowing in late winter and early spring, but agricultural and urban runoff, as well as discharge from water treatment facilities, now create perennial flow. The average annual flow rate of the channel within the study area is 40.4 cfs, as measured by the Ventura County Watershed Protection District stream gauge (Gauge 841) at the upstream boundary.


Figure 16: A view near the middle of the study area.


Figure 17: Upstream of the study area.

Landuse

The cities of Simi Valley, Moorpark, Camarillo, and part of Thousand Oaks lie within the watershed. Urban development within these communities covers approximately 27% of the watershed. Approximately 50% of these developed areas are residential. Agricultural land uses comprise an additional 28% of the watershed and consist primarily of lemon and avocado orchards and row crops. The remainder of the watershed is classified as undeveloped or vacant (CCWMP 2004).

Topography, Soils, and Geology

The Calleguas Creek watershed is located within the Transverse Range geomorphic province of California. This province is distinguished from other mountainous provinces in California in that its geologic structures trend east to west, rather than north to south. Six significant geologic structures can be found in the watershed: the Oxnard Plain, the Simi Anticline, the Los Posas Anticline, the Simi-Santa Rosa Fault Zone, the Santa Rosa Syncline, and various volcanic intrusions. The terrain in the northern and eastern portions of the basin is mountainous, while the southwestern areas consist of alluvial valleys, rolling hills, and coastal flood plains. Elevations within the watershed range from 1026 m in the mountains to sea level at the coast (CCWMP 2004).

The watershed contains a wide variety of soils. Valley soils are alluvial in nature and vary widely in profile, slope, composition, and depth. They are derived from mixed rock sources, which yield textures from sand to clay (VCRCD 2000). The soils within the channel are dominated by sandy substrates (Fig. 18), and an additional 29 soil types abut the channel (NRCS 2006). Due to their lack of cohesion, alluvial sediments are highly erodible, and contribute to the transitory nature of channel landforms (Graf 1988). Channel disturbance is common when high flows encounter unstable substrates (Bendix and Hupp 2000).

Figure 18: A section of channel bank from within the study area. Sand is the primary component.

Vegetation

Approximately 45% of the watershed remains vegetated with native plant communities. Of this, chaparral and sage-scrub cover 33%, oak woodlands and annual grasslands 8%, and riparian and wetland vegetation groups another 4%. Typical native plant species within riparian areas include a variety of willow species (*Salix laevigata*, *Salix lasiolepis*, *Salix lucida* sp. *lasiandra*, *Salix exigua*), mule fat (*Bacharris salicifolia*), and occasional cottonwood trees (*Populus fremontii*). In areas with higher moisture levels, rush (*Juncus* spp.) and cattail (*Typha* spp.) also appear. However, most wetland and riparian areas within the watershed have become dominated by invasive, non-native species (CCWMP 2004).

Arundo outcompetes native vegetation, and is the principal species in many of the riparian areas within the watershed. Native riparian vegetation has an open, multi-storey nature that is well-adapted to flood events, but the dense growth habit of arundo has transformed riparian areas into impenetrable thickets of vegetation that impede water flow during high flow events, increase fire hazard, and are unusable to native species as habitat. In the study area, arundo occurs in some places as dense monocultures, and is intermixed with native vegetation in others (Fig. 19).

Figure 19: Arundo is mixed in with native willow populations. A debris dam consisting primarily of arundo stalks is lodged against the willow trunks.

Methodology

A series of aerial photos was employed to examine the extent of arundo proliferation in the Arroyo Las Posas waterway. Annual streamflow volumes and precipitation amounts were then analyzed to determine the extent to which significant stream flow events might have contributed toward the spread of this species in the study area.

Aerial imagery was acquired for the years 1980, 1985, 1998, 2002, and 2005 from various sources willing to share data. The images from 1980, 1998, and 2005 were photographed in the month February, while the images for 1985 and 2005 (a second set) were photographed in September. The images for 2002 were photographed in July. The imagery for 1980 and 1998 originated from 9"x9" aerial photographs. These were scanned and georeferenced in order to give them proper spatial references. The remainder of the imagery originated from digital formats with accompanying spatial data, with the exception of the 1985 image which although digital, required georeferencing.

To assess the extent of arundo in the arroyo, each set of imagery was brought into a GIS system (ArcGIS 9.1). Polygons were electronically "drawn" around vegetation areas in the channel and on the banks, and then classified according to the percentage of arundo estimated to be present, or by vegetation type. A consistent limit for mapping was established and employed on each set of images. This boundary is a composite of the widest extent of the river channel in all of the years for which imagery was obtained.

Although the original intent of the study was to classify the polygons by the percent of arundo, the quality and type of the imagery obtained precluded this (Plates 1-6). Thus, a second more generic vegetation-based classification system was employed. For example, the images from 1980 are black and white, while the image for 1985 is false color infrared. The resolution of both these sets is such that it is possible to discern broad vegetation types, but not always the specific plant species within a particular type. The imagery from 1998 and later is color and of good to excellent resolution, and able to be classified by the percent of arundo present. These were additionally classified by vegetation type in order that the greatest number of years could be compared.

The categories used to classify the channel vegetation were riparian, bank vegetation, agriculture, bare soil, and open channel. The riparian classification was assigned to vegetation that was usually growing in the active river bottom and proximate to visible water sources, or that was of a color and/or density to imply that soil moisture was high. The bank vegetation classification was assigned to vegetation that generally grew on elevated terraces or on banks within the channel, and whose color and/or sparseness indicated a lesser availability of moisture. The agriculture classification included areas of row or tree crops. The bare soil classification was assigned to areas on banks that were lacking in vegetation due to anthropogenic activities such as vegetation clearing or channel infilling. The open channel classification was assigned to areas of unvegetated, active channel bottom. Where it was possible to classify channel vegetation by percent of arundo present (images from 1998-2005), the categories used were 0%, 1-25%, 25-50%, 50-75%, and 75-100%. After all areas within the mapping limit were categorized, the total area (acres) was calculated for each category within both classification systems.

Precipitation and streamflow data from various monitoring locations within the Calleguas watershed were obtained from websites maintained by the Ventura County Watershed Protection District (VCWPD 2006). Data was acquired for Water Year (WY) 1975 through WY 2005. The range of a Water Year is from October 1 through September 30; thus, Water Year 2005 is from October 1, 2004 to September 30, 2005. Although the Watershed Protection District maintains precipitation and stream gauges throughout the watershed, only gauges whose flow contributes to the study area were chosen, with the exception of one stream gauge located below the study area. Data from this gauge are incorporated as data for the stream gauge at the eastern boundary of the study area are only available from WY 1991 forward, and are also not available for WY 1996.

Ultimately, data from four stream gauges (Table 1) and thirteen precipitation gauges (Table 2) were tabulated and summarized into annual totals. Data from the gauges were then analyzed in conjuction with the aerial imagery to determine the extent to which streamflow has affected the spread of arundo in this particular waterway.

Table 1: Stream Gauges

Station ID No.	Station Name	Elevation (m)
802	Arroyo Simi at Royal Ave. Bridge	266.7
803/803a	Arroyo Simi at Madera Road	213.0
841a	Arroyo Las Posas at Hitch Blvd.	120.4
806/806a	Calleguas Creek at Highway 101	48.7

Table 2: Precipitation Gauges

Station ID No.	Station Name	Elevation (m)
141a	Moorpark-County Fire Station	160.0
154b	Simi-County Fire Station	231.6
187	Susana Knolls - County Fire Station	330.7
190	Somis - Bard	140.2
191	Moorpark - Downing Ranch	316.9
193/193a	Santa Susana	294.1
196a/196b	Tapo Canyon	463.3
206a/206b	Somis - Fuller	243.8
227	Lake Bard	307.8
234a/234b	Las Llajas Canyon	365.7
238	South Mountain - Shell Oil	682.7
242	Tripas Canyon	762.0
250	Moorpark - Happy Camp Canyon	429.7

Data/Descriptive Section

Vegetation

The presence of arundo in the study area varies across the series of aerial imagery. A total of ten land cover classification maps were derived from the available imagery: one each for the years 1980 and 1985, representing vegetation type, and two each for the years 1998 through 2005, representing vegetation type as well as percent arundo.

The total area encompassed by the mapping limit boundary is 379.8 acres. In 1980, the channel was relatively free of vegetation (Fig. 20), with the open channel area consisting of 231.1 acres (Table 3). In 1985, the extent of open channel and riparian areas increased (Fig. 21), while the areas of the remaining classifications diminished (Table 4). In 1998, riparian and bank vegetation were marked by significant increases (Fig. 22); the extent of open channel areas was reduced to 175.1 acres (Table 5). In 2002, bank vegetation showed the largest increase (Fig. 23), while areas of open channel diminished to their lowest in the study (Table 6). In first image for 2005, the extents of riparian and bank vegetation were reduced (Fig. 24), while the open channel area doubled in size (Table 7) from its extent in 2002. In the second image from 2005, extents of riparian vegetation have increased (Fig. 25), while open channel areas have diminished further (Table 8). A plot of these changes over time shows the relationship between vegetated areas and sections of open channel (Fig. 26).

Table 3: 1980 Vegetation Area

Type	Acres	% of Total Mapped Area
Bare Soil	7.6	2.0
Agriculture	33.1	8.7
Bank Vegetation	67.8	17.9
Riparian	40.4	10.6
Open Channel	231.1	60.8

Table 4: 1985 Vegetation Area

Type	Acres	% of Total Mapped Area
Bare Soil	4.9	1.3
Agriculture	24.7	6.5
Bank Vegetation	45.8	12.1
Riparian	61.1	16.1
Open Channel	243.7	64.2

Table 5: 1998 Vegetation Area

Type	Acres	% of Total Mapped Area
Bare Soil	24.8	6.5
Agriculture	13.3	3.5
Bank Vegetation	71.2	18.7
Riparian	95.5	25.1
Open Channel	175.1	46.1

In addition to the broad vegetation classifications discussed above, classification of vegetated areas according to percent of arundo was also performed for images from 1998 through 2005. The images for 1998 show that arundo was present in the channel (Fig. 27), but only established in high density in limited areas (Table 9). The imagery from 2002 indicates that the density of arundo had undergone a significant increase since 1998 (Fig. 28), with the extent of the highest density areas increasing by approximately twenty fold (Table 10). In February 2005, the overall presence of arundo declined (Fig. 29), however it still occupied approximately half of the mapping area (Table 11). By September 2005, vegetation areas had again expanded (Fig. 30), with associated increases in percent arundo (Table 12). Figure 31 shows the change in percentages of arundo during the study period, while Figure 32 shows the change in size of combined arundo percentage groups compared to the total area mapped.

Stream Flow and Precipitation

Precipitation data for the 25 years encompassed by this project indicate that WY 1998 was the wettest, while 2002 was the driest. The annual average precipitation during this time period was 447.5 mm yr^{-1}. Precipitation amounts

Table 6: 2002 Vegetation Area

Type	Acres	% of Total Mapped Area
Bare Soil	31.6	8.3
Agriculture	12.5	3.3
Bank Vegetation	159.4	42.0
Riparian	92.5	24.3
Open Channel	84.3	22.2

Table 7: 2005 Vegetation Area (Feb)

Type	Acres	% of Total Mapped Area
Bare Soil	28.4	7.5
Agriculture	9.3	2.4
Bank Vegetation	95.4	25.1
Riparian	84.4	22.2
Open Channel	162.7	42.8

Table 8: 2005 Vegetation Area (Sept)

Type	Acres	% of Total Mapped Area
Bare Soil	58.3	15.4
Agriculture	7.1	1.9
Bank Vegetation	78.9	20.8
Riparian	122.0	32.1
Open Channel	113.8	30.0

Table 9: 1998 Percent Arundo Present

Percentage	Acres	% of Total Mapped Area
0%	55.1	14.5
1-25%	69.7	18.3
25-50%	29.6	7.8
50-75%	47.6	12.5
75-100%	2.9	0.8
Total Arundo	149.8	39.4

Table 10: 2002 Percent Arundo Present

Percentage	Acres	% of Total Mapped Area
0%	54.4	14.3
1-25%	119.0	31.3
25-50%	51.1	13.5
50-75%	16.6	4.4
75-100%	54.8	14.4
Total Arundo	241.5	63.6

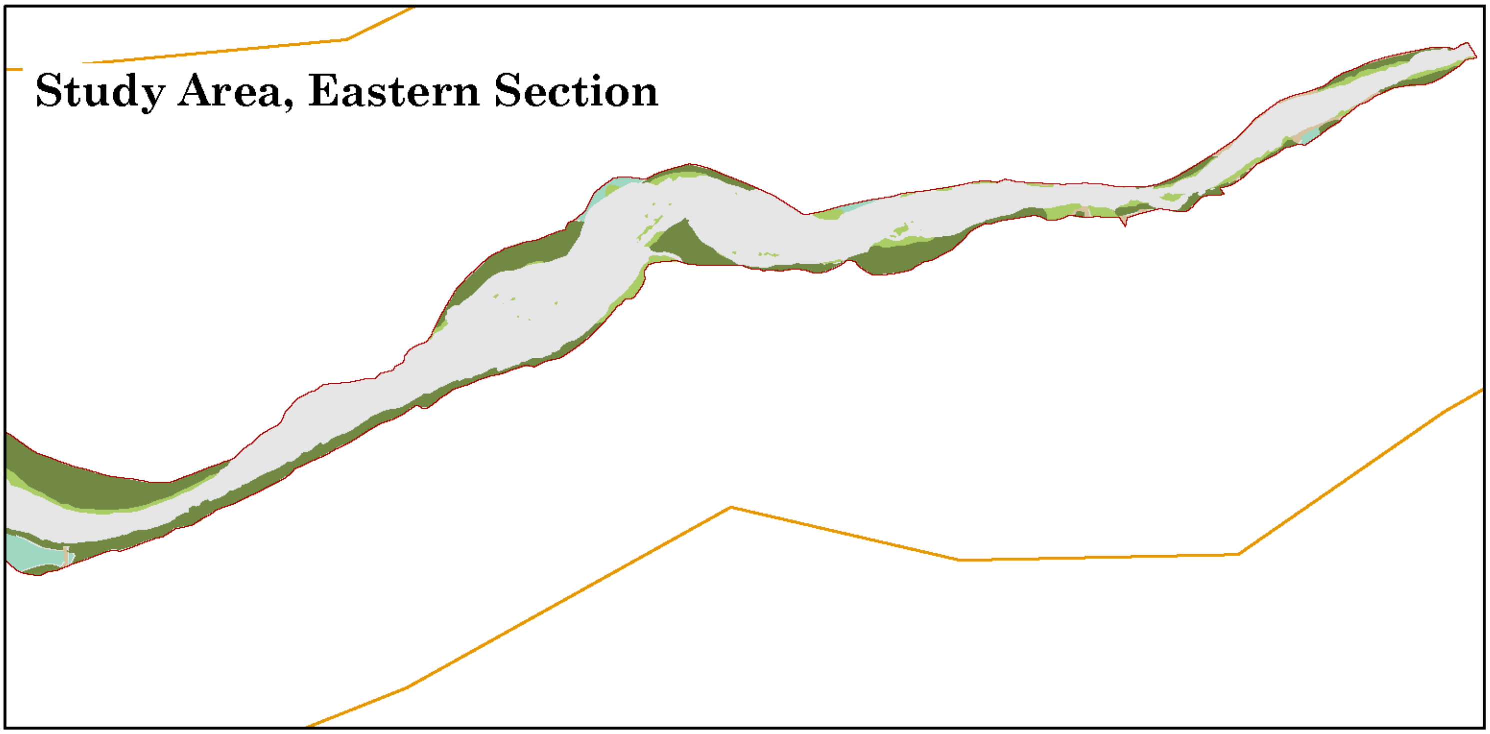
also varied significantly from year to year, and it was not uncommon for wetter-than-average years to be followed by drier-than-average years (Fig. 33). Closer examination of the precipitation data also show that much of the rainfall occurs in short, concentrated events usually lasting one to two days, separated by dry periods of one to two weeks or more.

Table 11: 2005 Percent Arundo Present (Feb)		
Percentage	**Acres**	**% of Total Mapped Area**
0%	40.8	10.7
1-25%	71.3	18.8
25-50%	35.6	9.4
50-75%	33.5	8.8
75-100%	36.2	9.5
Total Arundo	176.6	46.5

Table 12: 2005 Percent Arundo Present (Sept)		
Percentage	**Acres**	**% of Total Mapped Area**
0%	70.9	18.7
1-25%	100.8	26.5
25-50%	20.8	5.5
50-75%	35.7	9.4
75-100%	38.2	10.1
Total Arundo	195.5	51.5

The streamflow data show that the volume of discharge in the channel has a strong positive correlation to the precipitation data (Fig. 34). Periods of high flow events occur only during the rainy season, and typically last for a period of three to five days. Once flows peak, a decline occurs as rapidly as the initial increase. Similar to precipitation events, periods of high flow are also separated by a number of weeks. During the dry season, gauges 802, 803/803a, and 806/806a indicate that there is little or no flow in the channel. Gauge 841 indicates the presence of a low base flow which occurs independently of precipitation events.

Figure 20: Vegetation, 1980



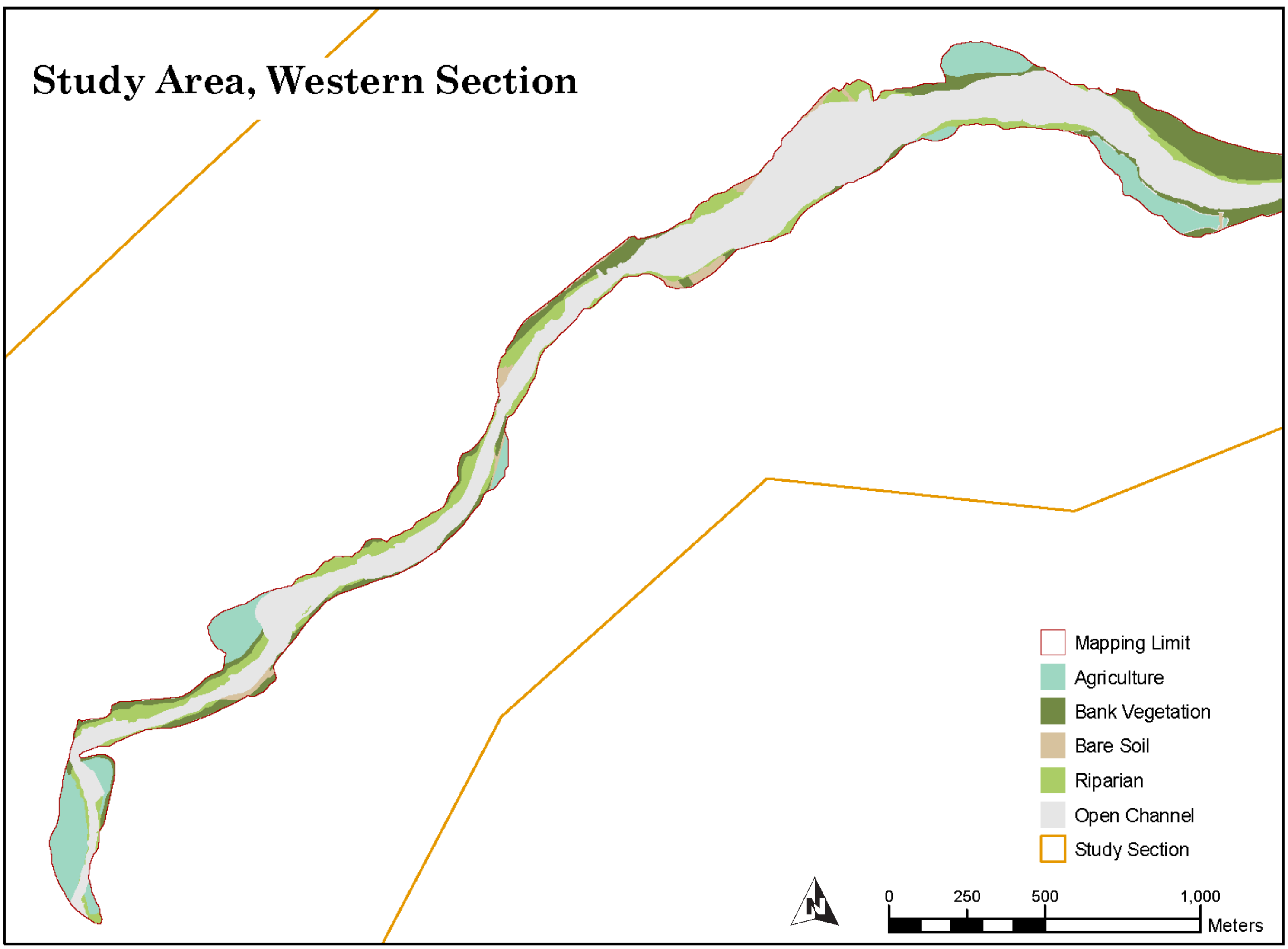
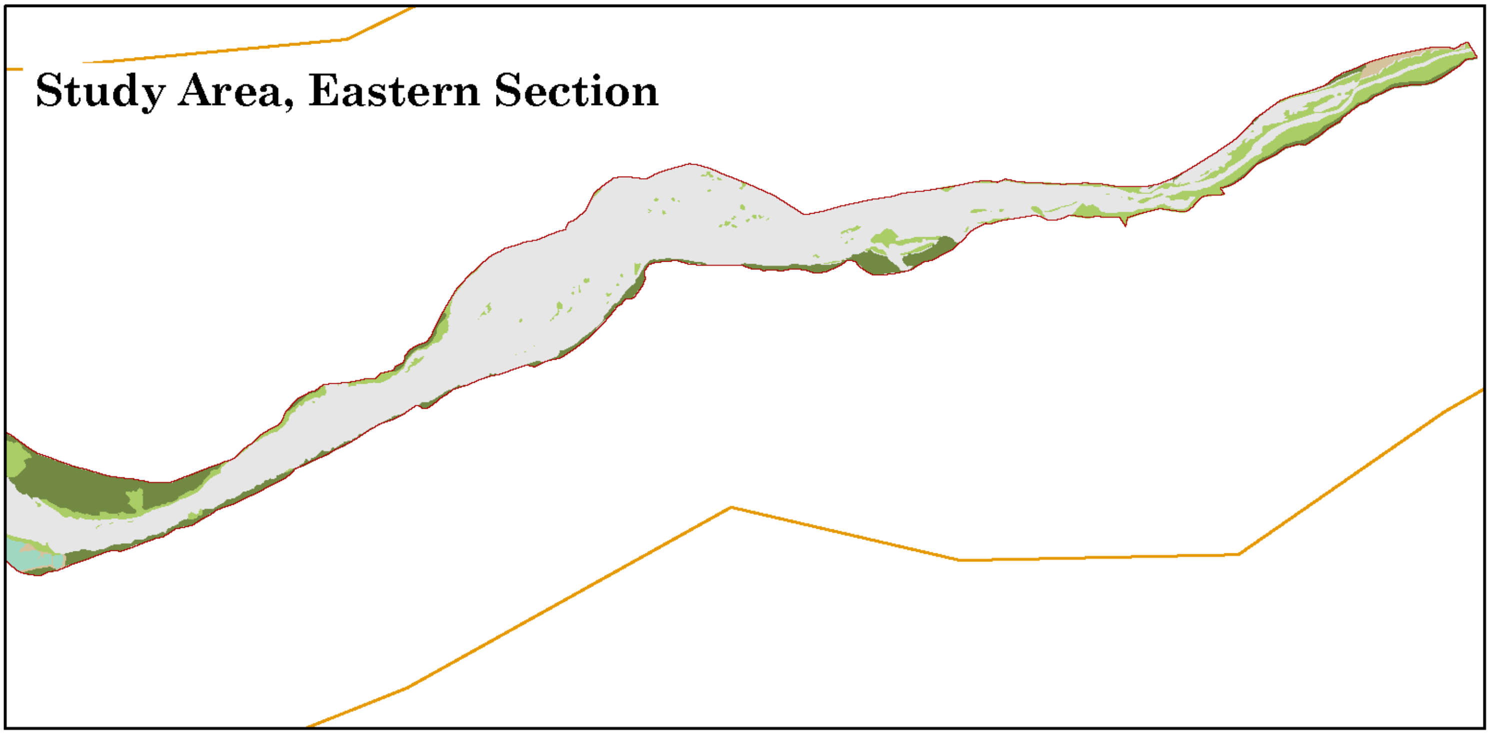


Figure 21: Vegetation, 1985



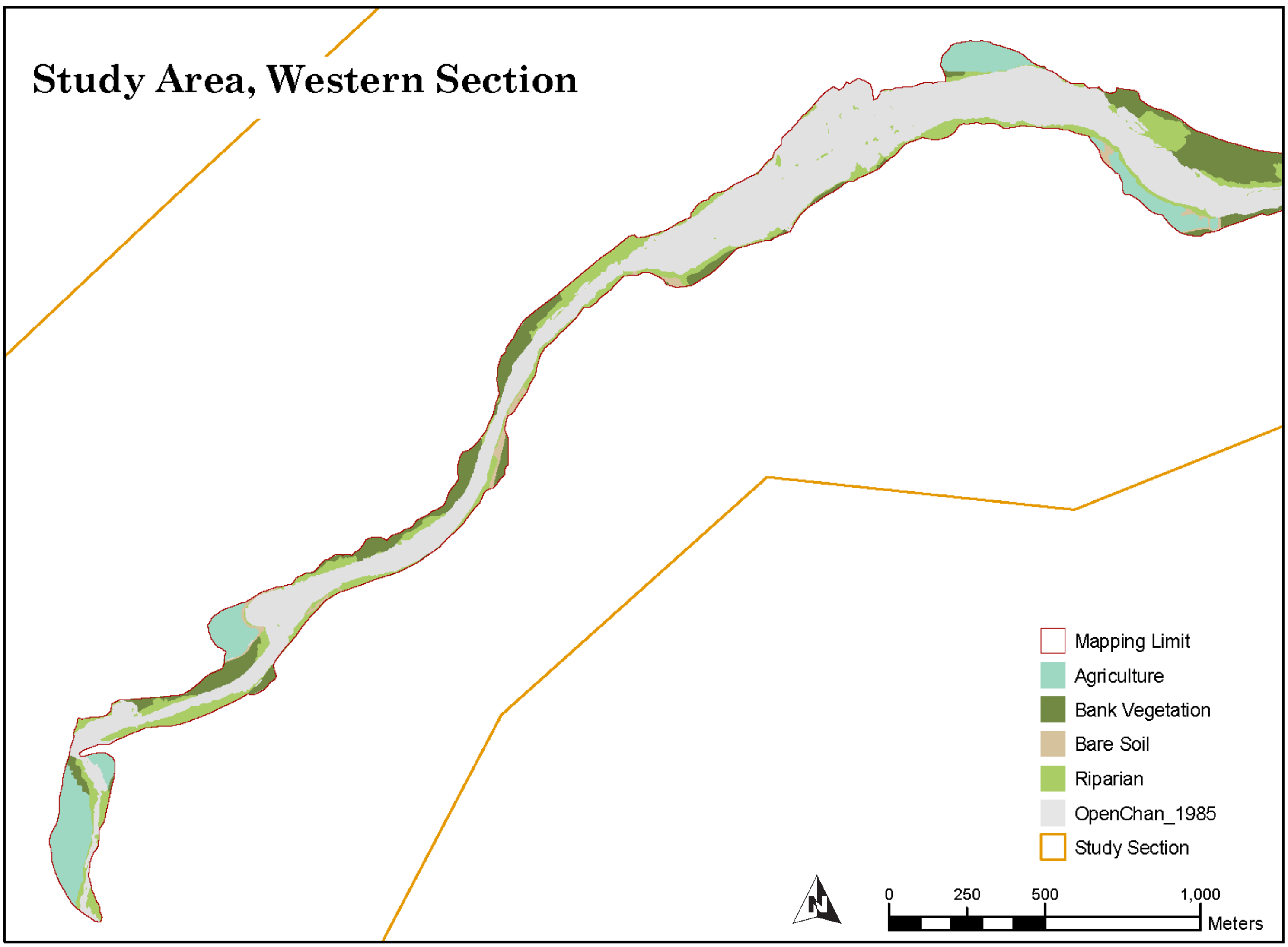
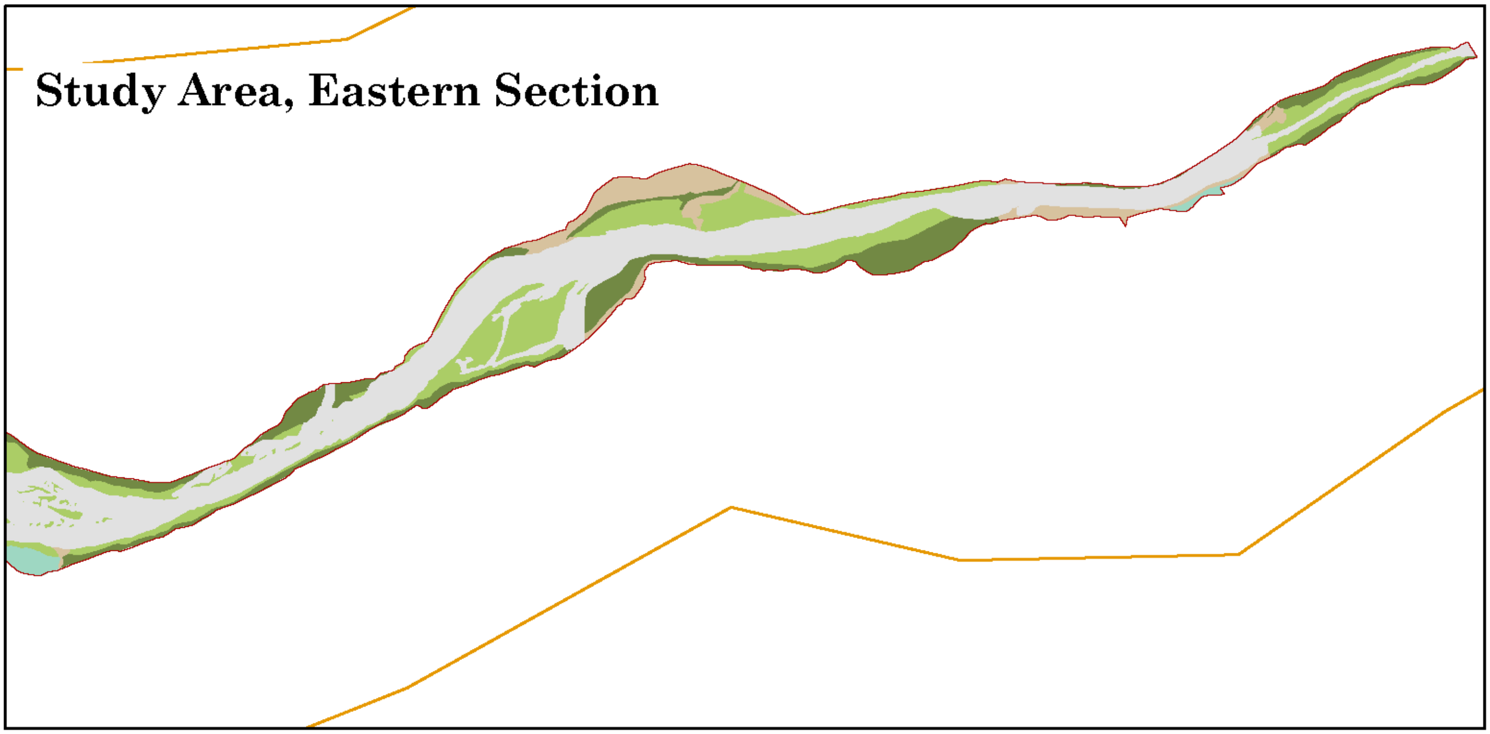


Figure 22: Vegetation, 1998



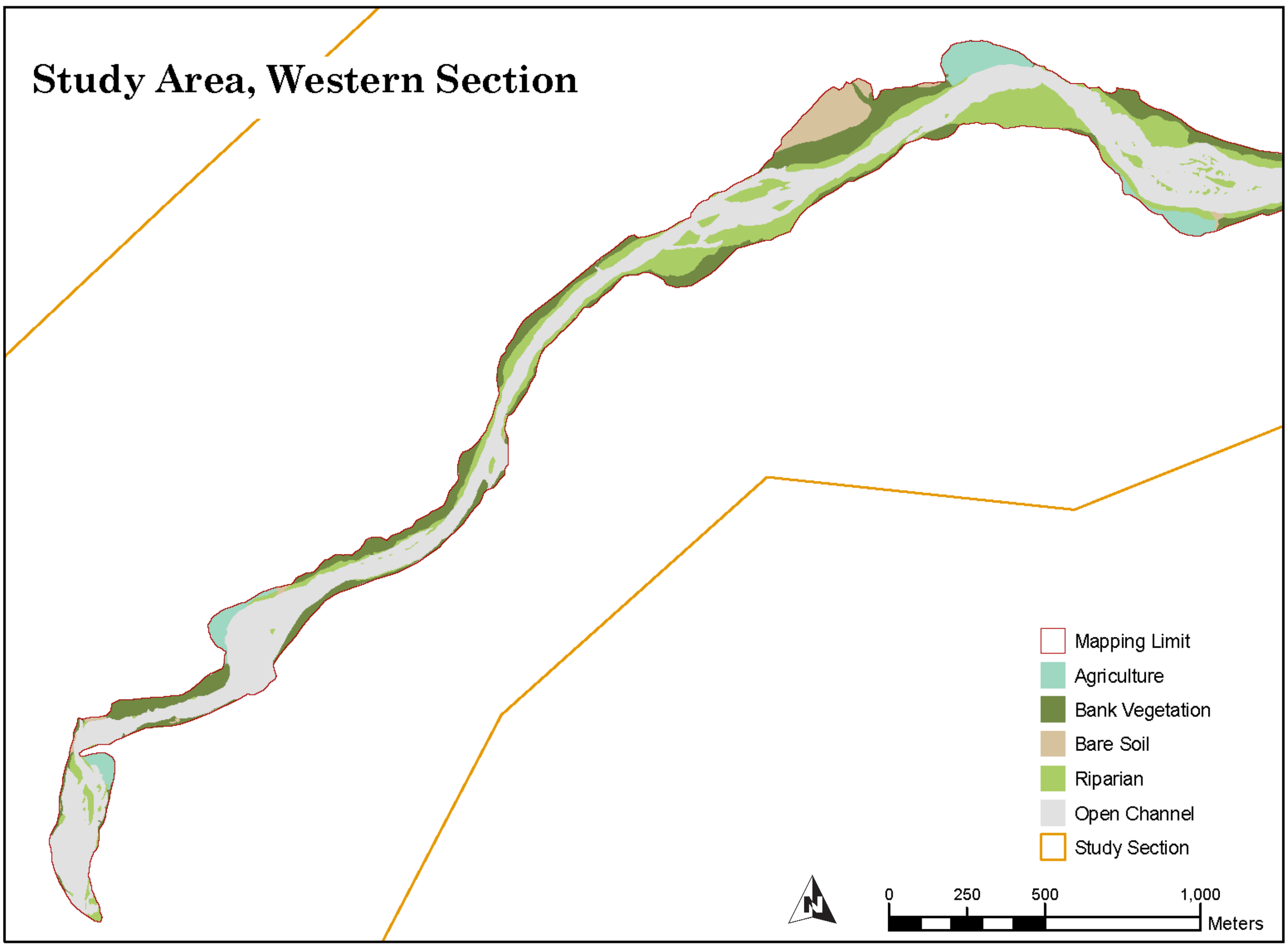
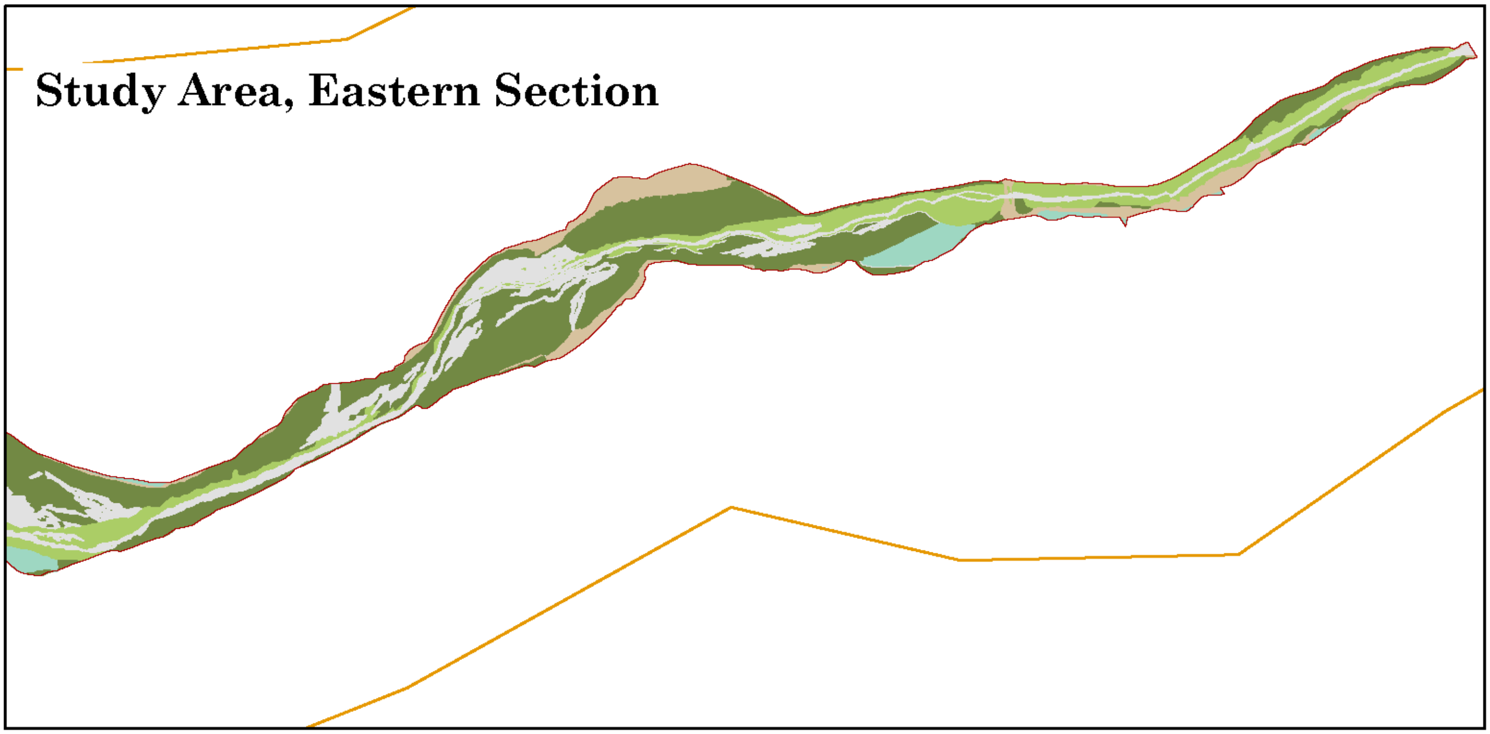


Figure 23: Vegetation, 2002



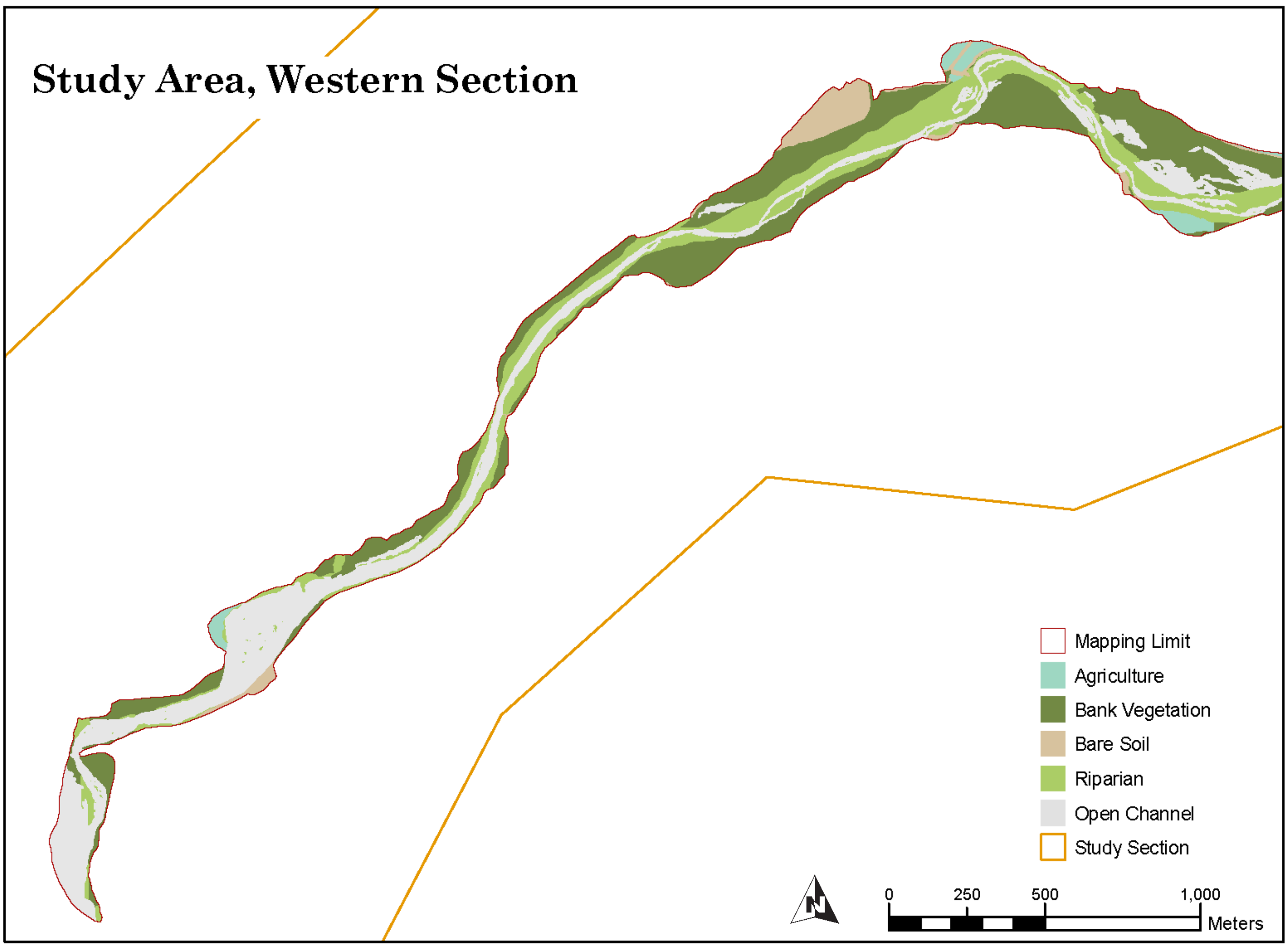


Figure 25: Vegetation, September 2005

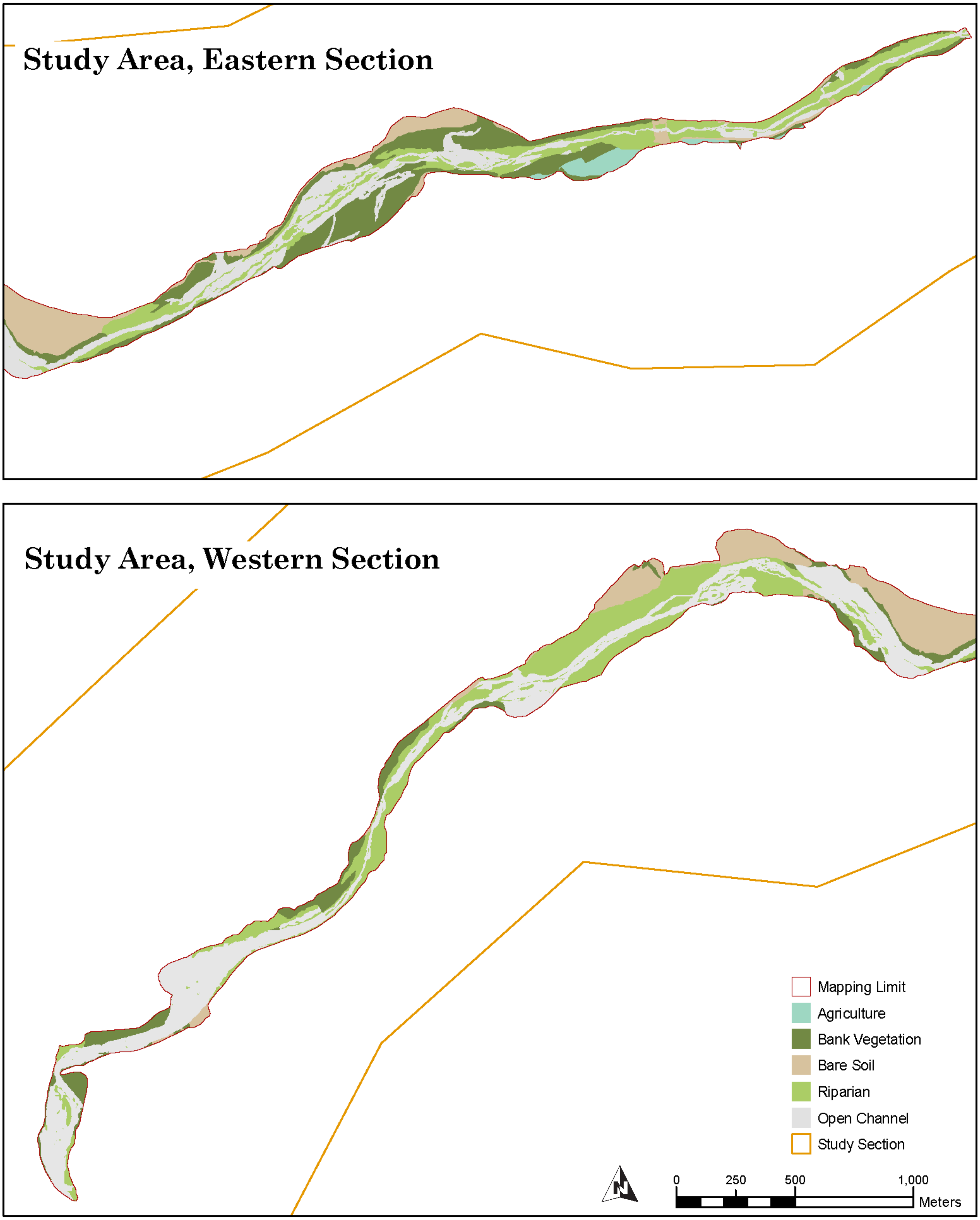


Figure 24: Vegetation, February 2005

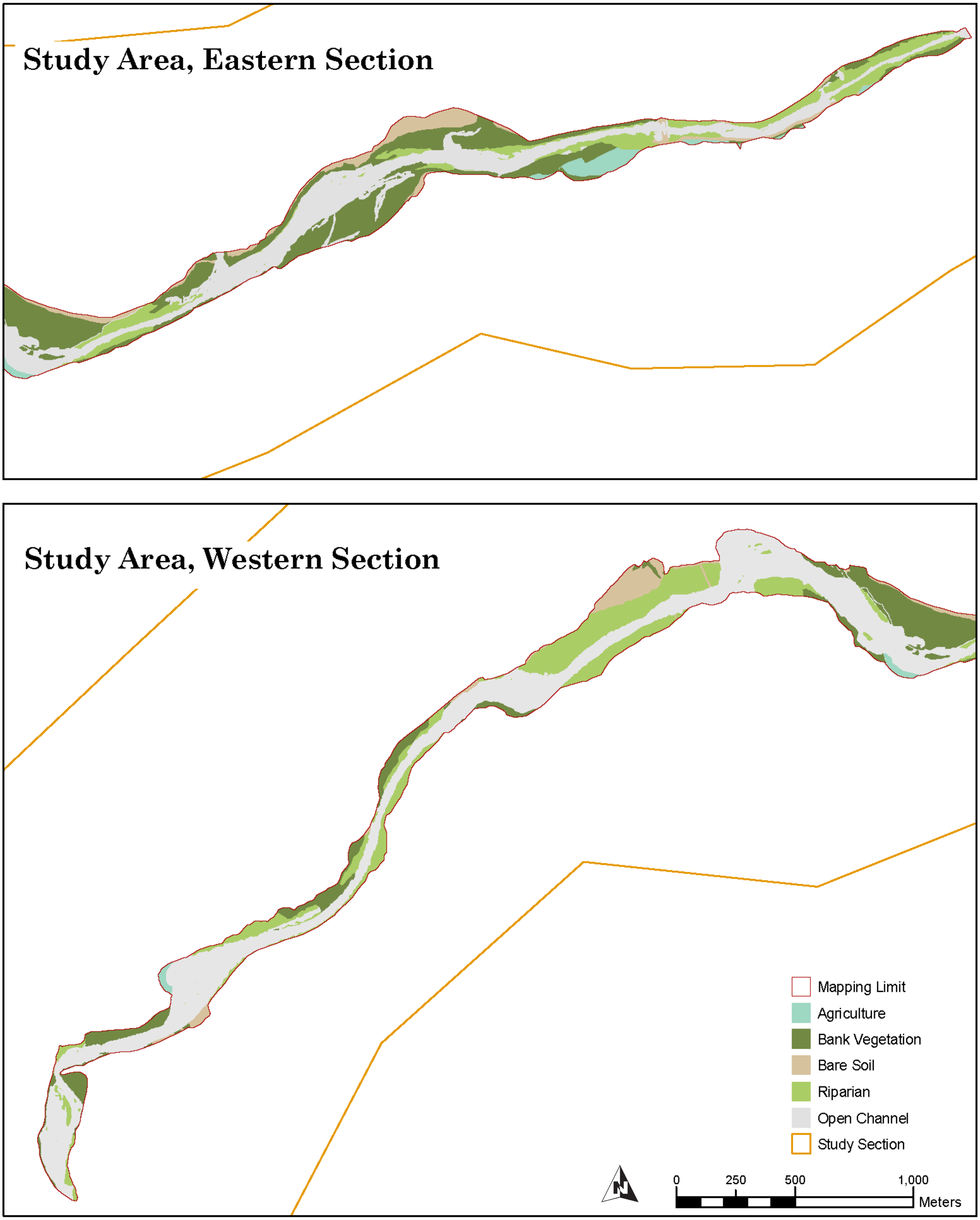


Figure 26: Change in Cover Types, 1980-2005

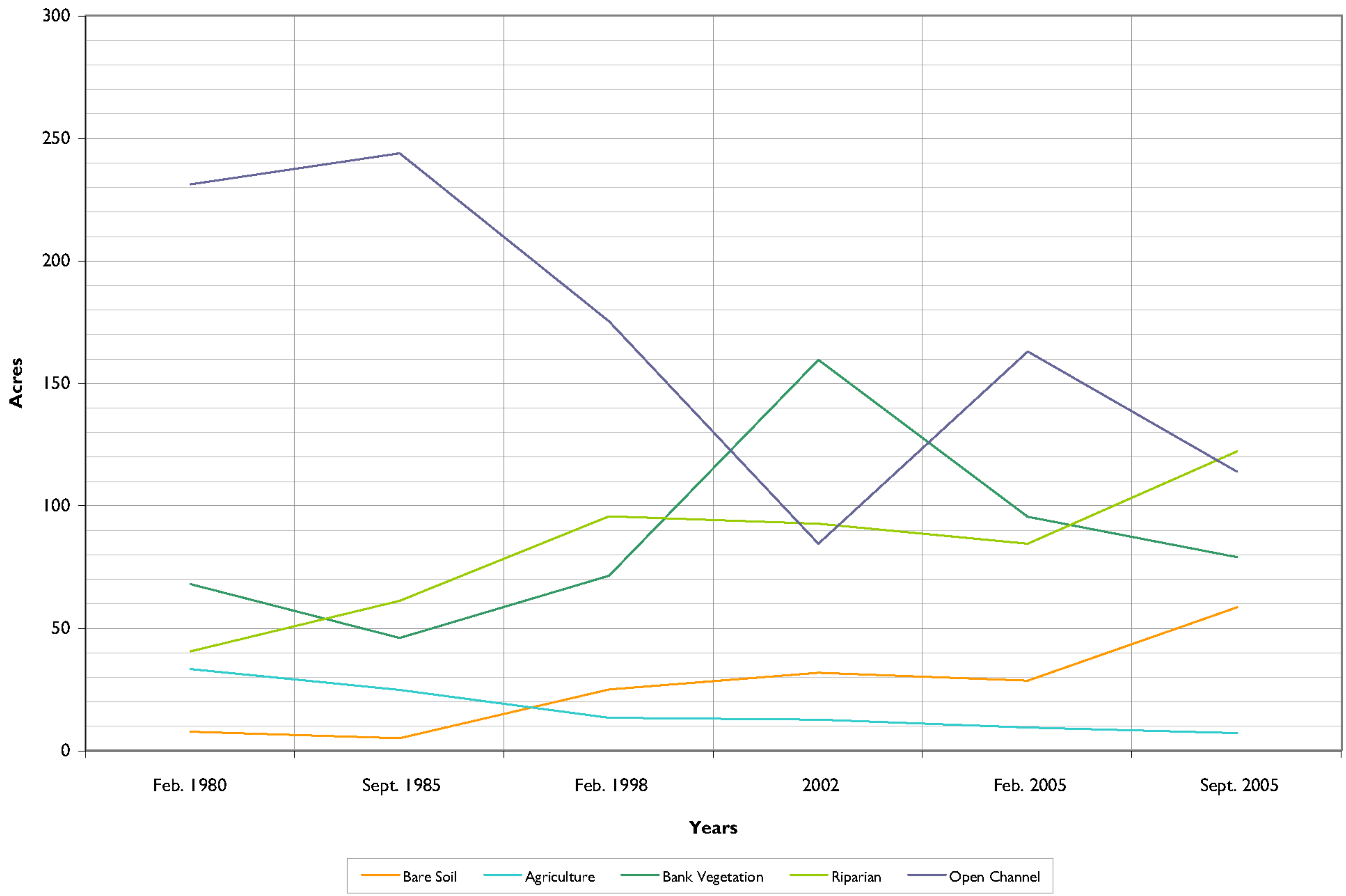


Figure 27: Percent Arundo, 1998

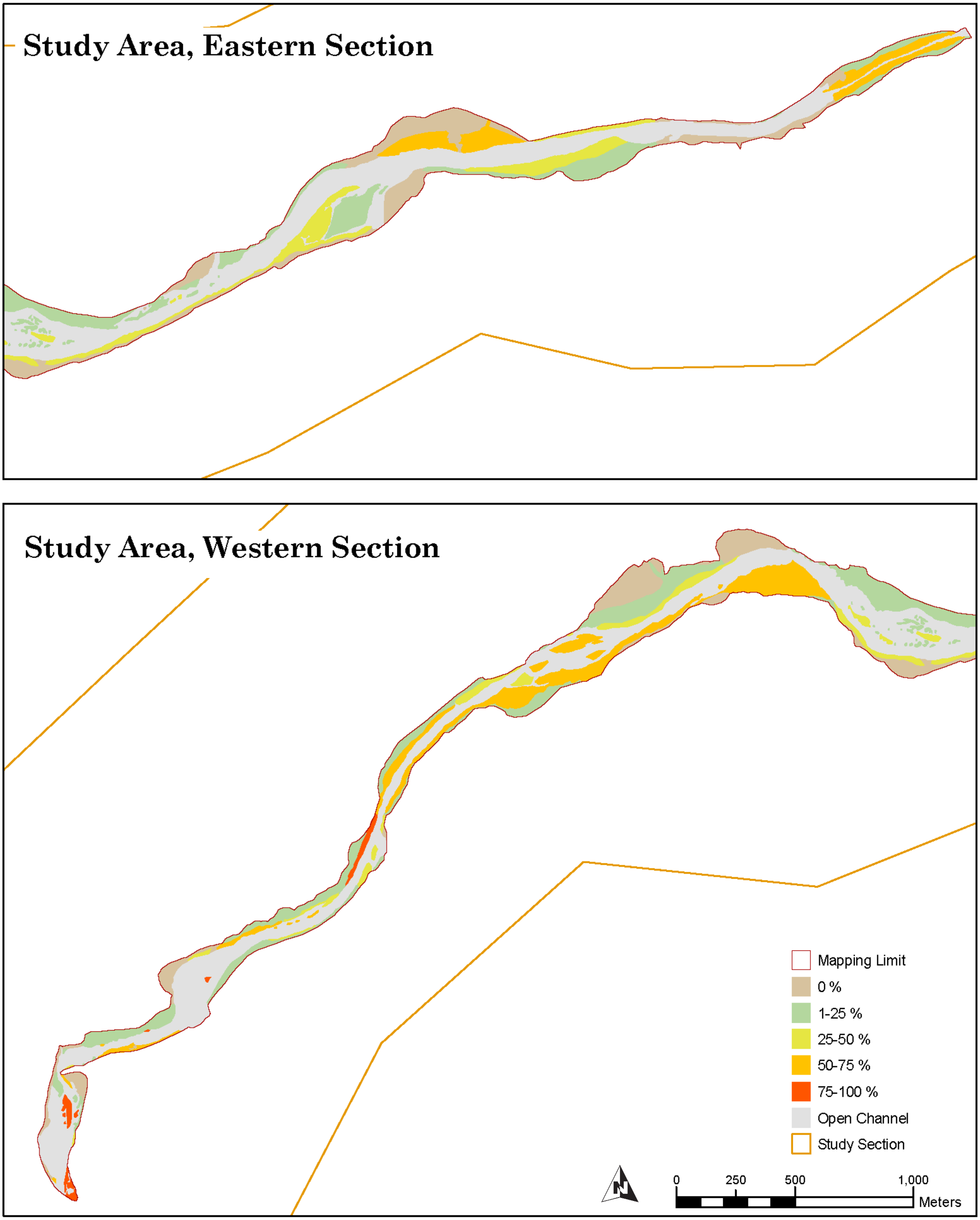


Figure 28: Percent Arundo, 2002

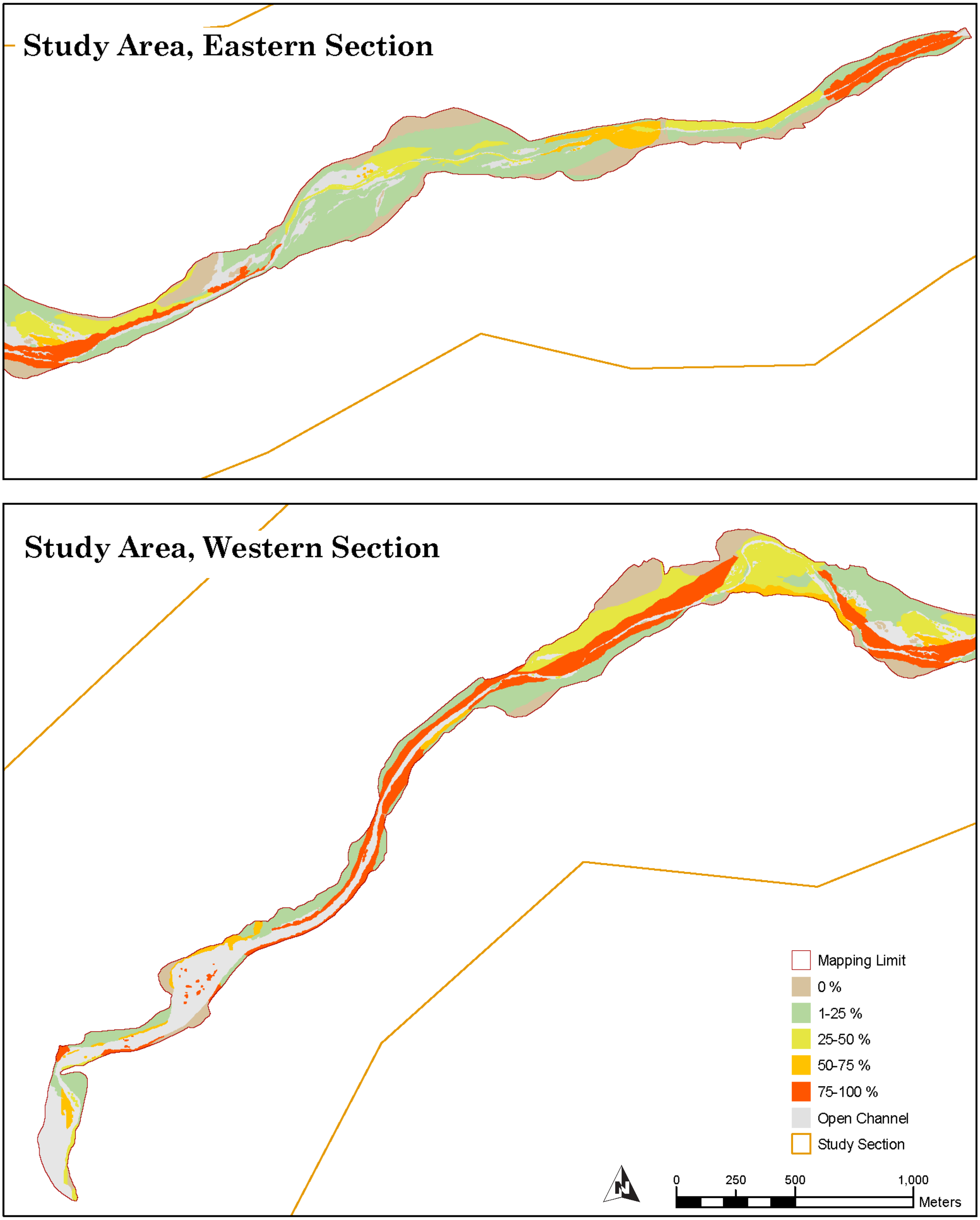
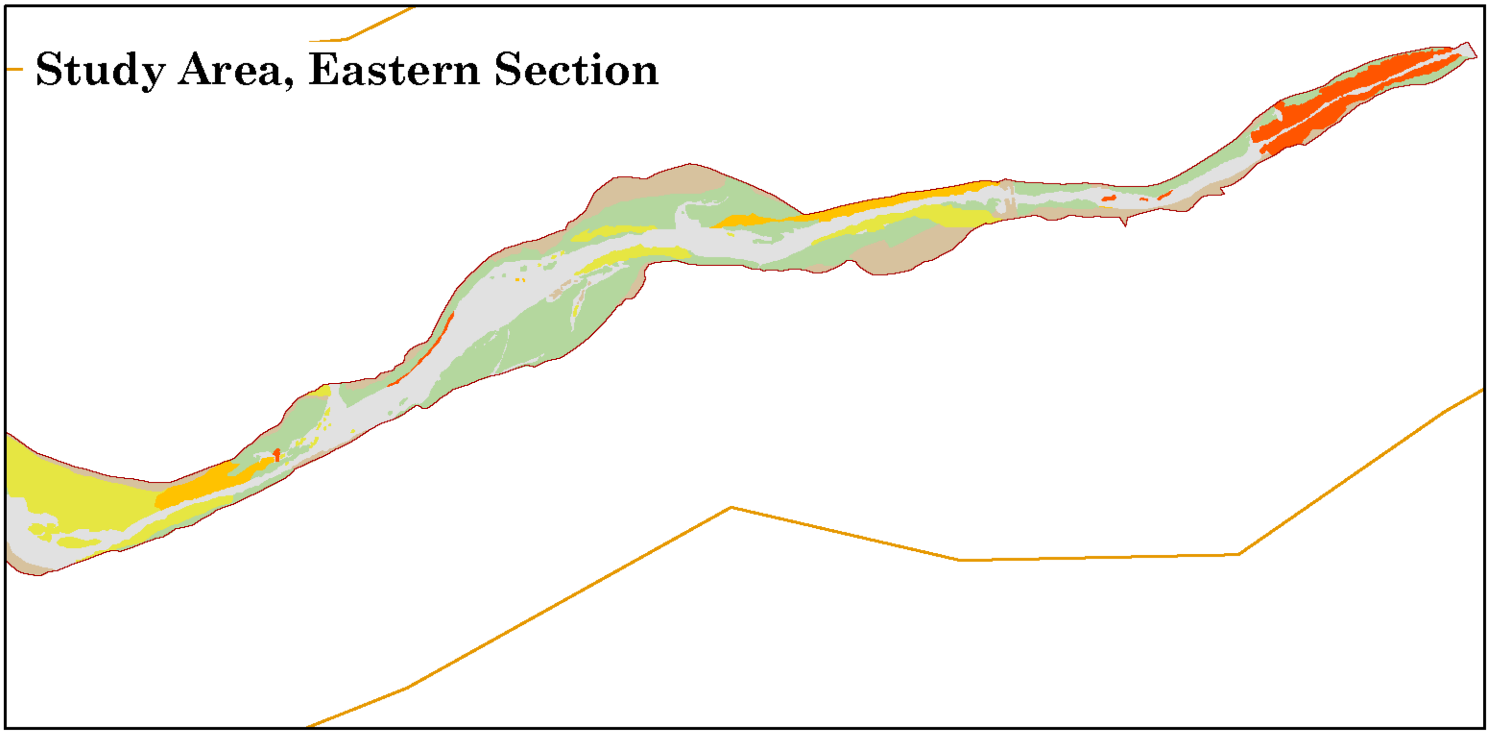


Figure 29: Percent Arundo, February 2005



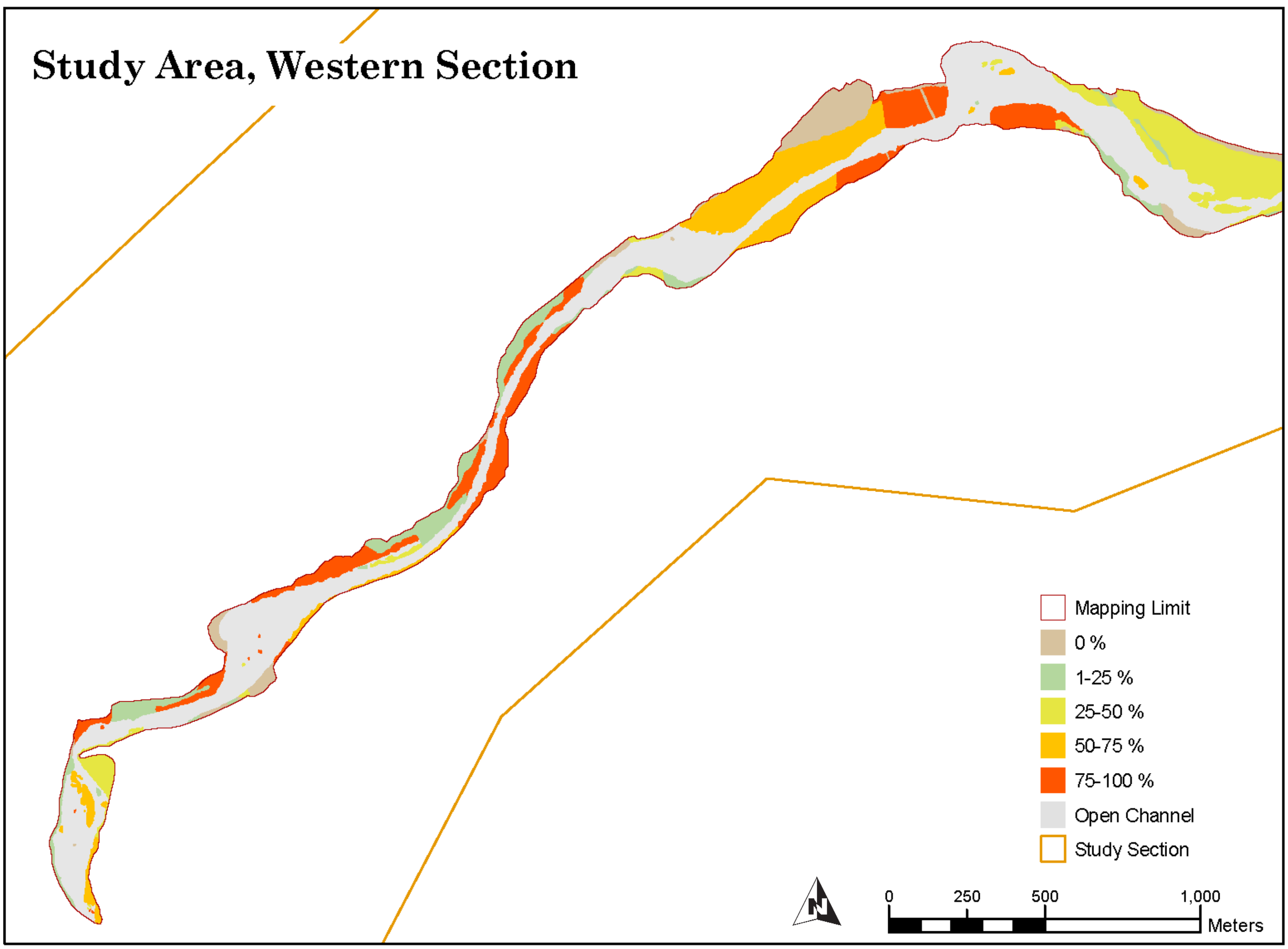


Figure 30: Percent Arundo, September 2005

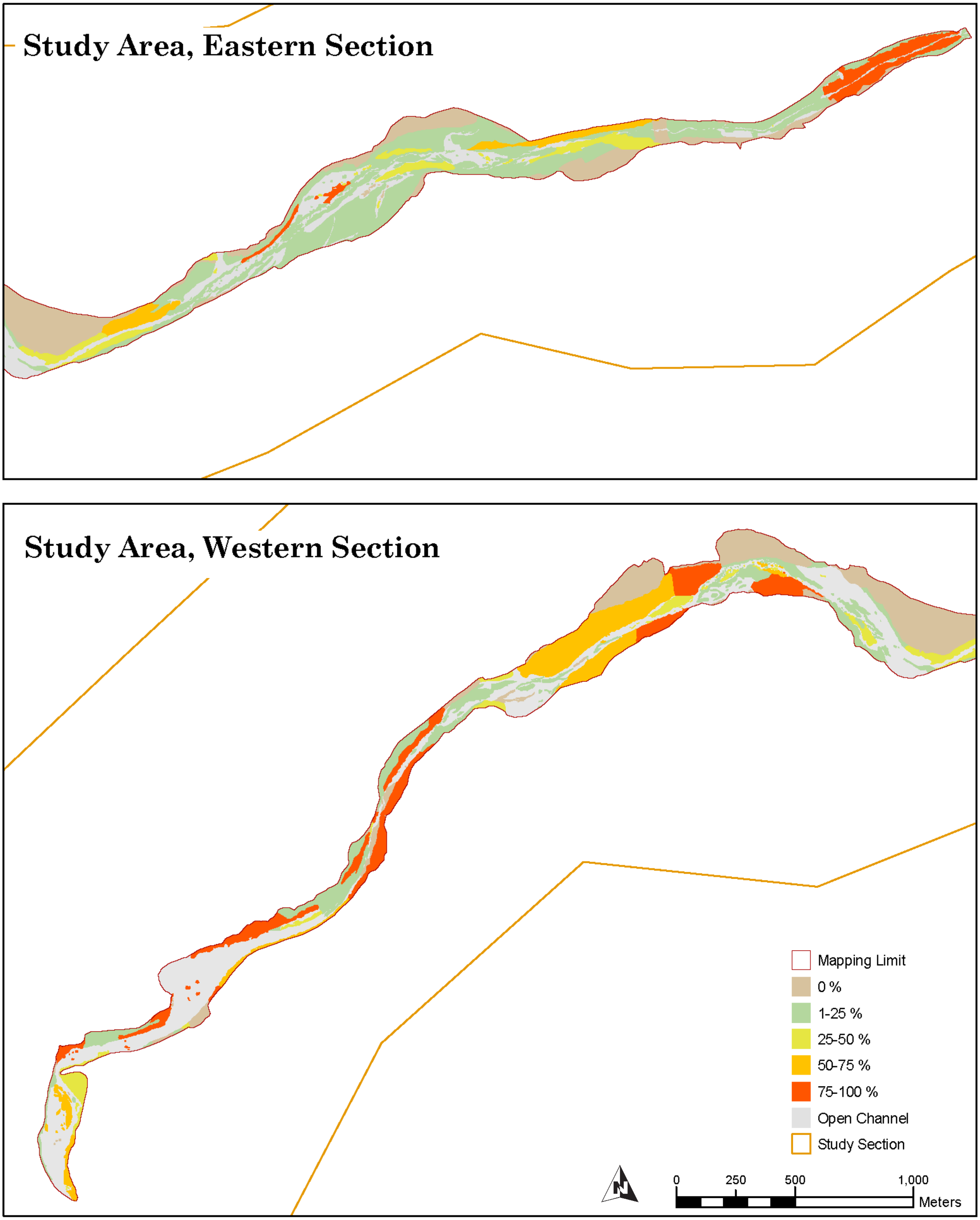


Figure 31: Change in Percent Arundo, 1998-2005

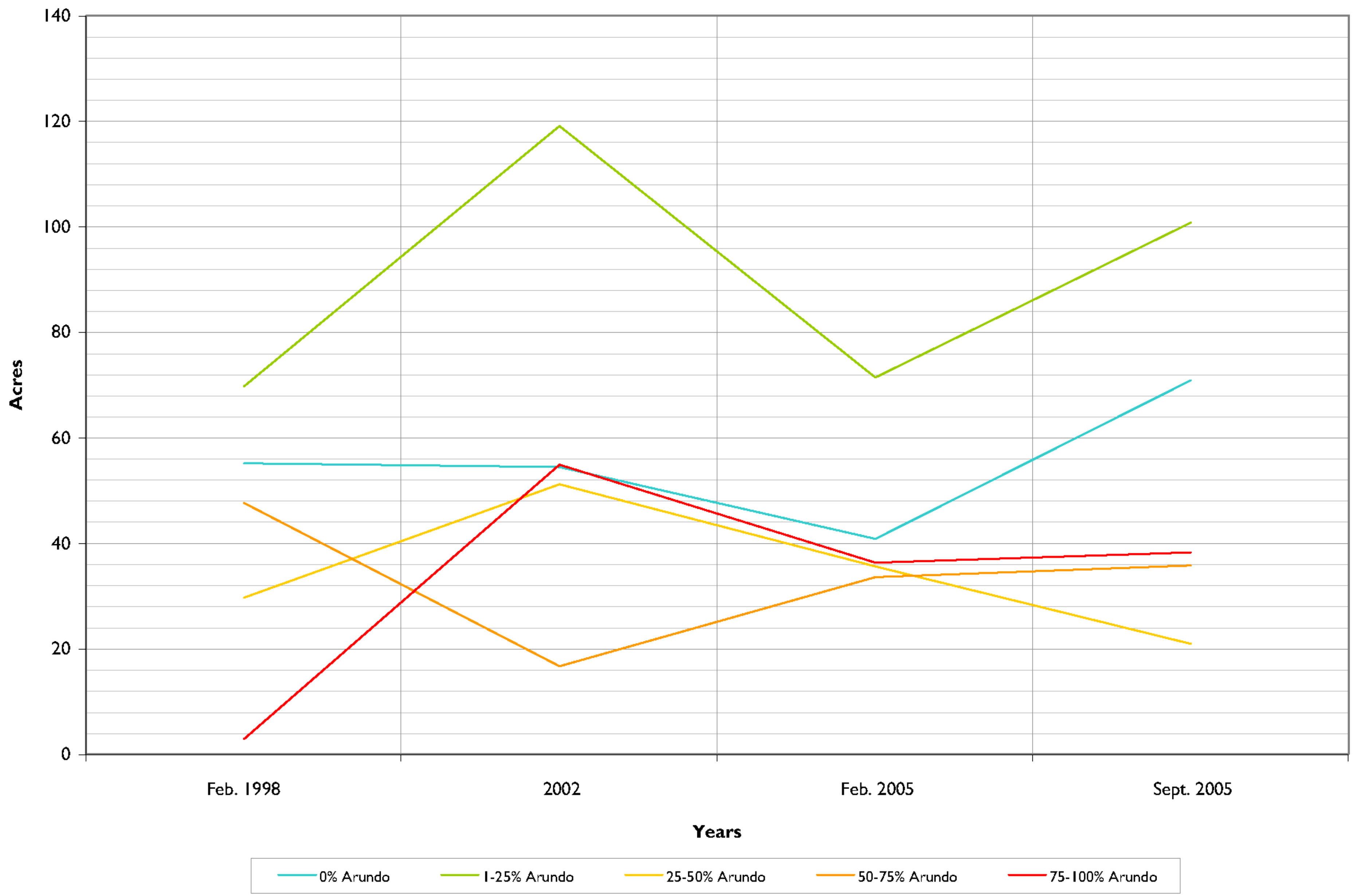


Figure 32: Acres of Arundo

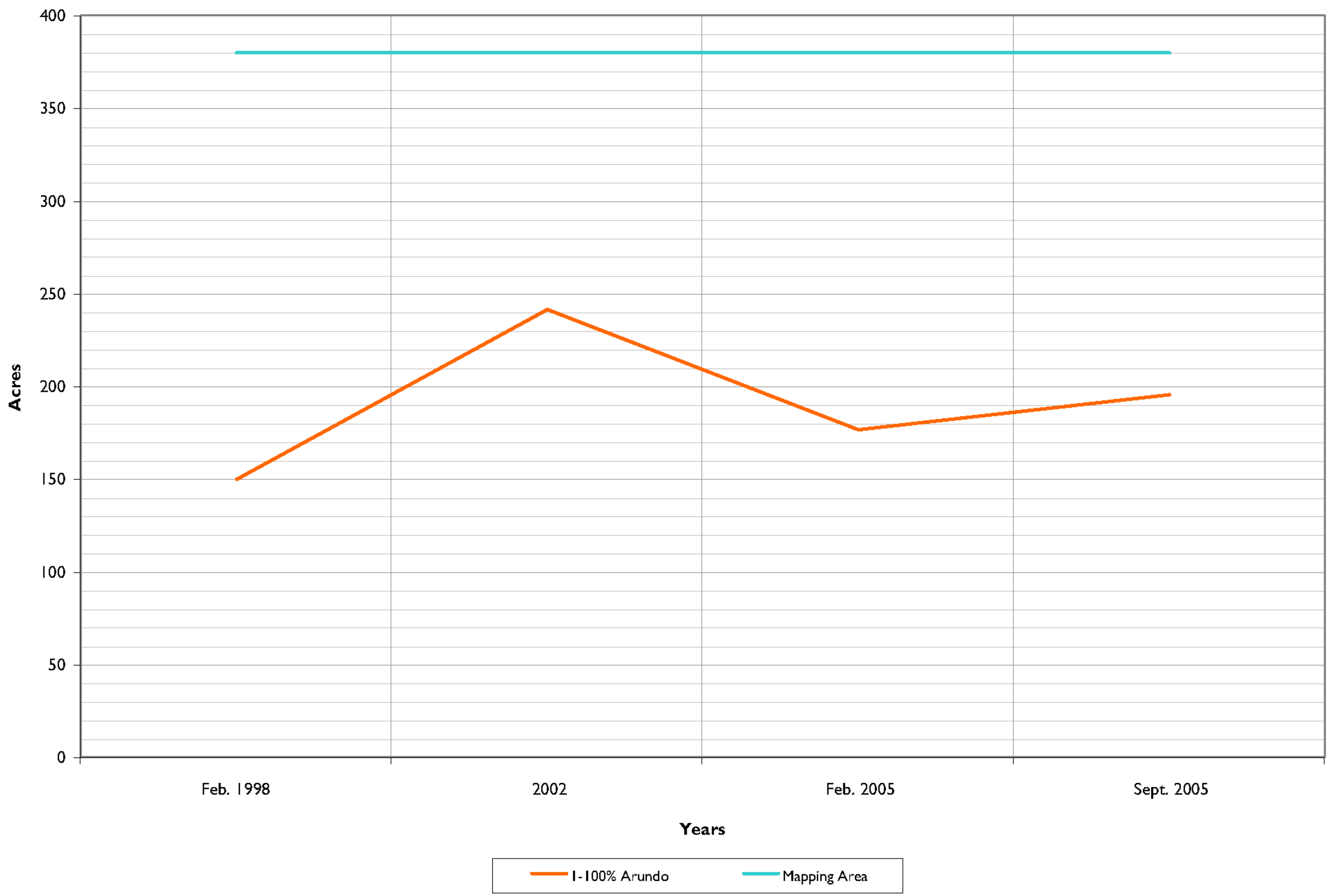


Figure 33: Precipitation Totals by Station, 1976-2005

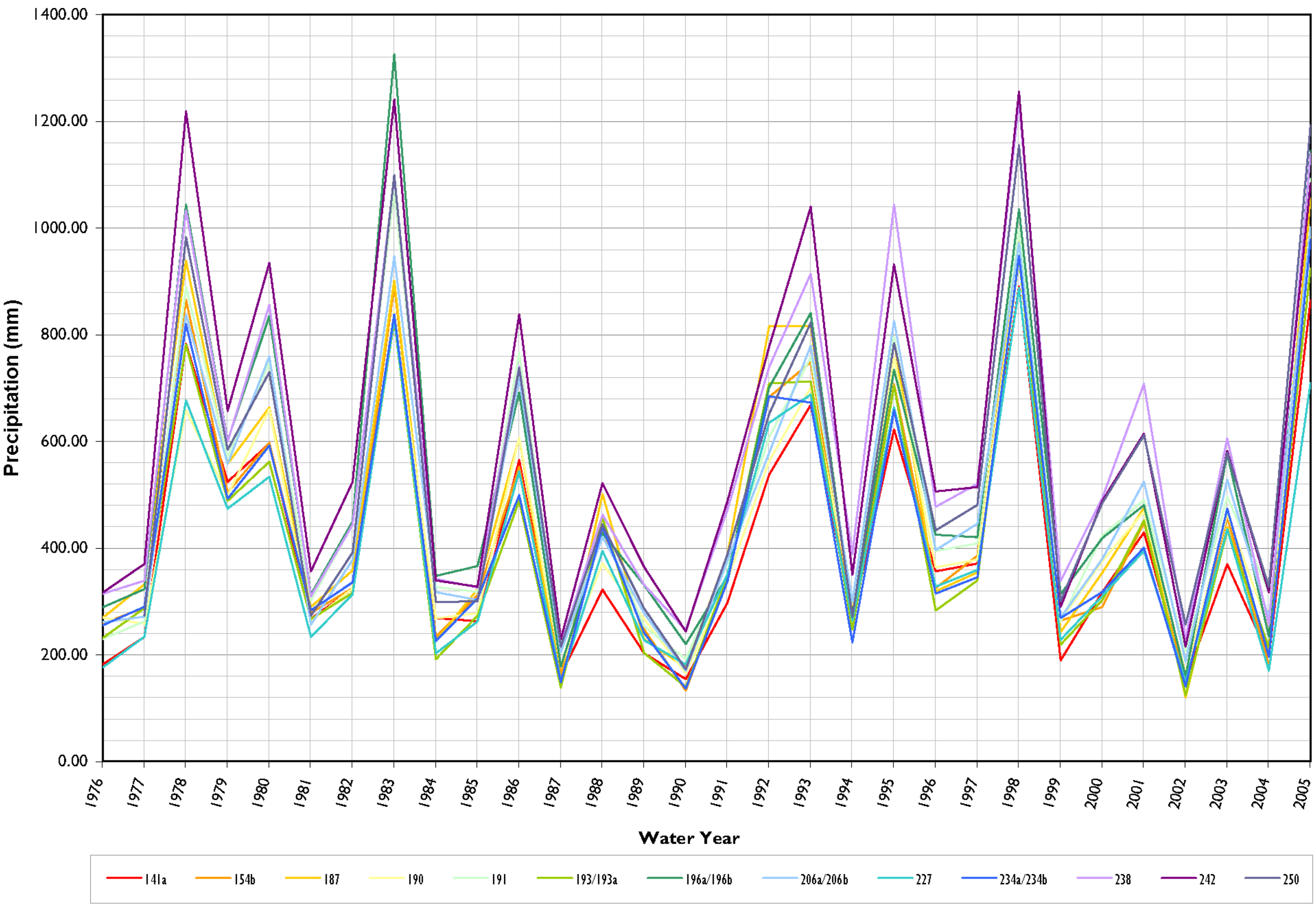
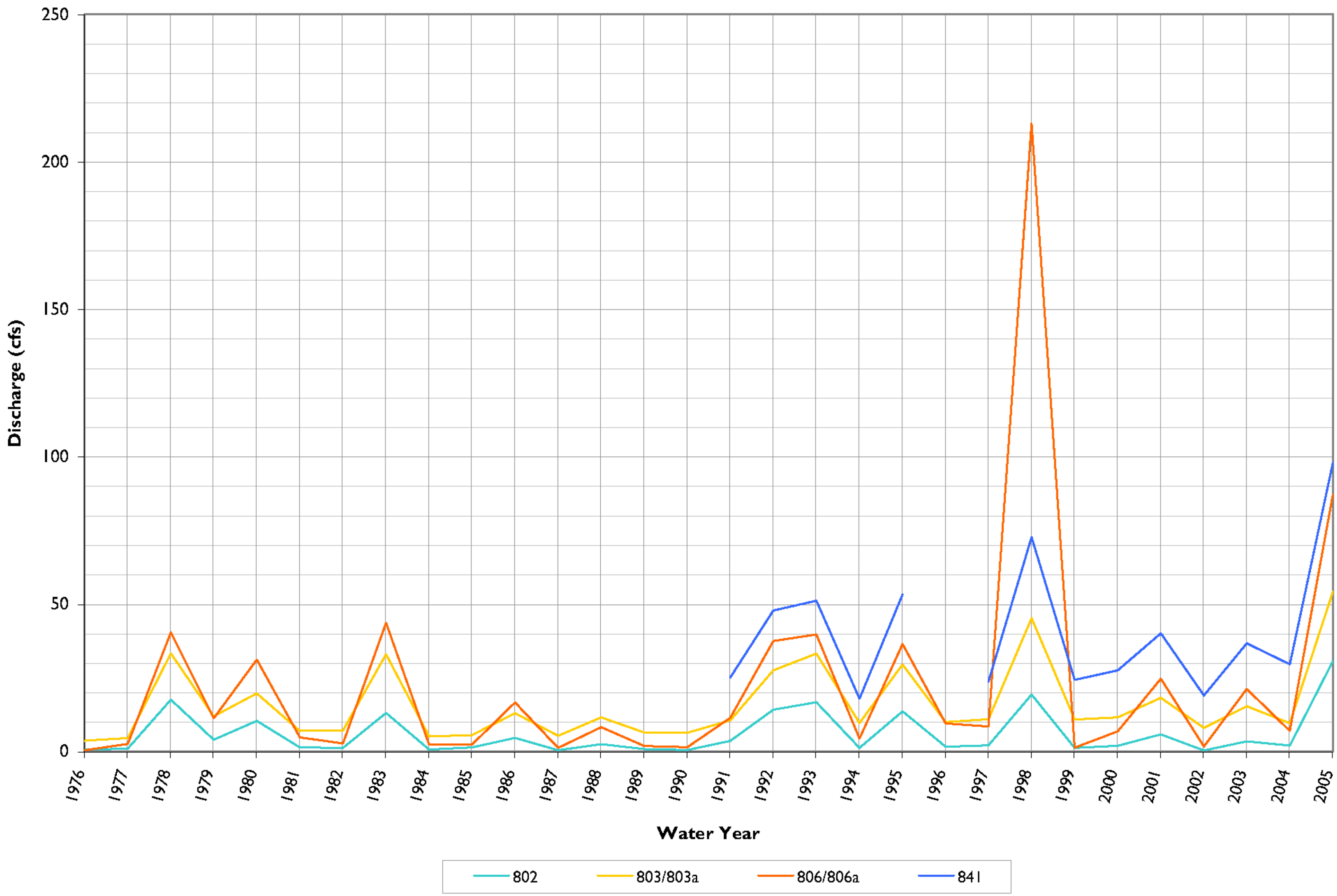


Figure 34: Average Annual Stream Flow by Station, 1976-2004



Interpretation

Figures 20-25 and 27-30 indicate that the channel has undergone significant changes during the past 25 years. These are discussed below.

1980 (Figure 20)

The images for 1980 were photographed on February 23, and reveal a relatively open channel, free of vegetation. The amount of rainfall that occurred for WY 1980 was 696.7 mm, as averaged from the gauges included in the project, or 46% above average. The total rainfall for gauge 141a, the gauge most proximate to the upstream end of the study area, recorded 595.1 mm. Of this total, 307.6 mm fell between January 29 and February 21, and an additional 41.1 mm fell on March 3. The average flow at gauge 803/803a (data for 841 are not available until 1991) for this time period was 189.6 cfs (the average rate is 40.4 cfs), with a peak of 1670 cfs on February 16. In comparison, gauge 806/806a downstream of the study area, averaged 367 cfs, with a peak on February 16 of 2650 cfs.

While the aerial imagery obtained for the project precludes knowledge of the extent of vegetation in the channel prior to 1980, it is likely that the open condition of the channel and corresponding lack of vegetation, bears a positive correlation to the concentrated amount of precipitation sustained in this area of the watershed in the days prior to the capture of the photograph. The resulting high streamflows as well as their duration would have facilitated extensive scouring and erosion in the channel and the displacement of shallow-rooted vegetation.

The channel bed consists of sedimentary material that ranges from fine sand to coarse gravel. As flow speeds vary, the bed material is transported either by saltation or in suspension. Sand grains are less cohesive than silt particles owing to their larger surface areas and increased roughness. As a result, they are more easily entrained by water and can be eroded by flows as low as 20 cms^{-1} (Bloom 1998).

1985 (Figure 21)

The image for 1985 was photographed on September 12, and reveals an increase in open channel area from the 1980 image. The precipitation for WY 1985 was 303.5 mm or 36% below the average.

The precipitation for WY 1984 was 275.3 mm, also below average. However, precipitation for WY 1983 was 978.7, 105% above average. At gauge 141a, 825 mm was recorded for WY 1983. The nature of precipitation in 1983 differed from 1980 as it occurred over a greater number of days and at less intense levels. However, WY 1983 was still characterized by significant storm events. For example, 53.8 mm was recorded on November 30, 163.1 mm between January 19 and January 29, and 240.8mm between February 26 and March 4. Stream flow at gauge 803/803a during this time period was correspondingly high for the single-day rain events, however, the precipitation of January 19-29 generated average flows of 162 cfs, with a peak of 619 cfs on January 27, while the precipitation of February 26 to March 4 generated average flows of 652 cfs, with a peak of 3610 cfs on March 1. At gauge 806/806a, corresponding high flows also occurred at the same time as the single-day storm events. At this gauge, the precipitation of January 19-29 triggered average flows of 307.7 cfs, with a peak of 1030 cfs on January 27, and the precipitation of February 26 to March 4 generated average flows of 1026.9 cfs, with a peak of 5460 cfs on March 1. The channel was most likely widened through scouring and erosion that occurred owing to the heavy rainfall of WY 1983.

Although WYs 1985 and 1984 were much drier than WY 1983 and received lower than average precipitation, this lack of moisture may well have been a factor in the large extent of open channel in the 1985 image. Existing vegetation, or vegetation that had reestablished after the heavy flow of 1980, would have been dislodged and carried downstream by the heavy flows of 1983. Average flows at gauge 803/803a were 5 cfs for WY 1984, and 5.5 cfs for WY 1985. At gauge 806/806a, average flows were 2.3 cfs for both years. While the low flows of WYs 1984 and 1985 probably did not cause any additional scouring, they also did not favor extensive establishment of new vegetation. It is more likely that they served to preserve the open, scoured nature created by the 1983 flow, as moisture availability is a limiting factor in the recruitment and establishment of vegetation.

1998 (Figures 22 and 27)

The images for February 10, 1998 indicate that conditions in the channel were favorable to vegetation recruitment and establishment. The open channel areas declined in area by 28% and riparian vegetation increased by 56.6% over their 1985 values. The average precipitation for WY 1998 was 1016.3 mm, 112.8% above normal. It was the highest precipitation year for the period 1980 to 2005. The amount of rainfall recorded at gauge 141a was 890 mm. Of this total, 123.2 mm fell in a single event on December 6 and 391.7 mm fell between February 2 and February 24. As in previous years, high stream flows occurred at times corresponding to individual storm events. The average flow at gauge 803/803a for the December 6 storm was 601.3 cfs, and the was peak was 1100 cfs. The extended precipitation period that occurred in February generated average flows of 326 cfs, with a peak of 1600 cfs on February 23. Gauge 841 peaked at 1380 cfs during December, and 3290 cfs for the extensive rain that fell in February. At gauge 806/806a, the average flow for the December 6 storm was 1111.6 cfs, with a peak flow of 2240 cfs. For the precipitation that occurred during the month of February, this gauge recorded an average flow of 1275.7 cfs, with a peak of 4710 cfs on February 23.

Although significant precipitation had occurred prior to the photography date (February 10), the channel sustained its peak flows later, so the imagery does not reveal the extent to which high flow volumes impacted the channel. It is also important to consider that other significant precipitation events had occurred during the time that elapsed between this set of images and those of the previous study year (1985). Of the twelve WYs that this time span represents, only two received near-average precipitation. Six years fell below average, and the remaining four were above average. In the three years immediately preceding this WY (1998), 1995 was 61% above average, 1996 was 20% below average, and 1997 was near average.

Although the channel sustained four episodes of above-average streamflow in the interim between photographs, and each may have provided opportunities for channel scouring and erosion to occur, overall amounts of vegetation increased. This WY (1998) is the first for which maps estimating the percentage of arundo present were generated. Arundo was present to varying degrees on 149.78 acres. Of the total mapped area (379.8 acres), only 55 acres did not contain arundo. The category containing the greatest number of acres was 50-75% arundo, at 47.6 acres.

The increase in vegetation represented in the imagery for this particular year may have been facilitated by the lack of extreme flow in the two years immediately prior to the capture of the image, due to low precipitation. Of interest however, is the daily flow measured at gauge 841. While gauges 802, 803/803a, and 806/806a measured low or no flow for much of the year, the annual average at gauge 841 was 18.97 cfs, and flow existed on a daily basis. When the heavy flows that occurred as a result of precipitation events were excluded from this annual average, it was still more than 17 cfs. Although this is below the average for this gauge during the years included in the study, it indicates that base flow was present in the study area when flows were nonexistent in other sections of the channel.

Based on the extent to which channel vegetation expanded, the lack of significant precipitation and channel flow appear to have been favorable to vegetation recruitment and establishment. The absence of large discharge events allowed the channel bed to remain stable, and provided few opportunities for scouring and erosion to occur. Vegetation can be uprooted and destroyed during periods of high flows, thus the stability of the channel provided a suitable environment for vegetation growth. It is interesting to note that, whereas the dry years of 1984 and 1985 apparently did not promote vegetation growth, in 2002 vegetation appears to have grown and/or survived during this period of relative dryness. As in 1998, this may have been a result of the greater amount of base flow occurring in the channel. This additional moisture provided adequate irrigation during periods when precipitation did not occur, and enabled the extents of all vegetation types to expand.

February 2005 (Figures 24 and 29)

This image was captured toward the middle of the month and indicates an increase in open channel area, and a reduction in riparian and bank vegetation compared to 2002. Open channel areas increased by 48%. Bank vegetation declined by 40%, while riparian vegetation was virtually unchanged. Although arundo declined overall by 27%, the category of 50-75% more than doubled from 2002. The precipitation amounts for WY 2005 were high, second only to those for 1998. The average precipitation was 1014.2 mm, 112% above the normal amount. At gauge 141a, 864.1 mm was measured. Of this total, 134.6 mm fell in October, 147.8 mm in December, 313.9 mm in January, 200 mm in February, and 62.2 mm in March. November was the only dry month of a traditionally wet period. The storms that produced precipitation this year lasted 3-5 days on average. Channel flows during periods of high as channel scouring would have been minimal. Previous high flow events in earlier years may well have destroyed existing vegetation, but they also created new sites for vegetation establishment, and distributed arundo fragments throughout the channel. However, it is also important to note that this time period saw in increase in the amount of base flow occurring in the channel. The average flow volume for gauges 803/803a and 806/806a during this time period was 14.5 cfs. The average flow for gauge 841 during this time (it came online in 1991) was 36 cfs. Gauge 841 also indicates that flow was present in the channel on a daily basis, regardless of whether precipitation occurred. The advent of channel base flow (which can be viewed as year-round irrigation) during this time span is likely a result of the increasing amounts of development that began in the region during the late 1980s (this issue will be further addressed in the Discussion section). Base flow nurtures young plants and improves their survival rates. Thus, the combination of artificial channel irrigation and the high growth rate of arundo are likely the primary factors in the significant vegetation increases between 1985 and 1998.

2002 (Figures 23 and 28)

The image for 2002 was captured in July. The vegetation maps created for this particular year reveal further reductions in channel area, an increase in the extent of vegetation, and an increase in the extent of arundo. During this year the open channel area was at its lowest of the years studied, and arundo the extent of arundo was at its highest. The amount of open channel decreased by 51.8% from 1998. Vegetation increased by 33%. This was primarily bank vegetation as the riparian category was nearly unchanged. Arundo increased in extent by 40%, principally in the categories of 1-25% and 75-100%.

WY 2002 was the driest of the years included in 25-year span of this study. The average precipitation was 172.7 mm, 63.8% below normal. At gauge 141a, 151.6 mm of rain was recorded. The most severe of the year's storm events occurred on November 13 and November 25, 2001 and January 28, 2000, with 22.9 mm, 29.2 mm, and 15.7 mm of rain respectively. All other precipitation occurred as scattered events of 10 mm or less. Channel flows increased in response to precipitation events; the largest peak was 355 cfs at gauge 806/806a during the November 25 storm. Gauge 841 recorded a peak flow of 302 cfs for this event. Overall, average channel flow was minimal for this WY precipitation increased. At gauge 841, flow peaked at 340 cfs in October, 1740 cfs in December, 4860 cfs in January, 3270 cfs in February, and 394 cfs in March. Peak flow during the dry month November was only 21 cfs.

Prior to the capture of this photograph, 602 mm of precipitation fell, and 262.1 mm was yet to fall. Two periods of sustained high flows had already occurred. The increase in open channel areas and loss of bank vegetation can be attributed to extensive scouring and erosion that occurred from the concentrated periods of high flow. The overall consistency in area maintained by riparian vegetation may be a result of its ability to withstand flood flows. An additional factor may also have been its general positioning toward central areas of the channel – it may have served to deflect water towards the outer edges of the channel which facilitated higher rates of erosion at those locations. The presence of arundo in the channel must also be considered. The debris dams created by its dense vegetation alter flow. If dams are deposited near the central areas of channels, flow deflection also results. Where arundo was present on upper banks, substrate integrity may be compromised as arundo does not offer the same bank stabilization as native plants, due to its shallow root system.

September 2005 (Figures 25 and 30)

After the image for February 2005 was photographed, additional heavy flows occurred later that month and in March, which further scoured an already disturbed channel. This image from September illustrates the ability of riparian vegetation, as well as arundo, to reestablish itself after periods of heavy stream flow. In approximately six months, areas of open channel were reduced by 30%. Bank vegetation was reduced by 17.3%, but riparian vegetation increased in extent by 44.6%. Arundo increased by 10.6% from February levels. The number of acres now occupied by arundo was within 19% of its 2002 peak. The category experiencing the most growth was 1-25%.

Although the last significant precipitation event occurred in March, base flow was present in the channel throughout the year. The average flow volume between April and September was 16.9 cfs.

Native riparian vegetation and arundo are clearly resilient to the disturbance regimes within alluvial channels. Both have the capacity to recolonize disturbed areas, but the higher growth rate of arundo relative to native vegetation, and the extent to which its rhizomes are distributed downstream, allow it to recolonize disturbed areas faster than native species. The reproductive opportunism displayed by arundo is further leveraged by the consistent level of baseflow that exists within this portion of the channel. Expansion of the total area covered by riparian vegetation during this time may therefore be a result of arundo expansion rather than native plant growth.

Summary of Changes

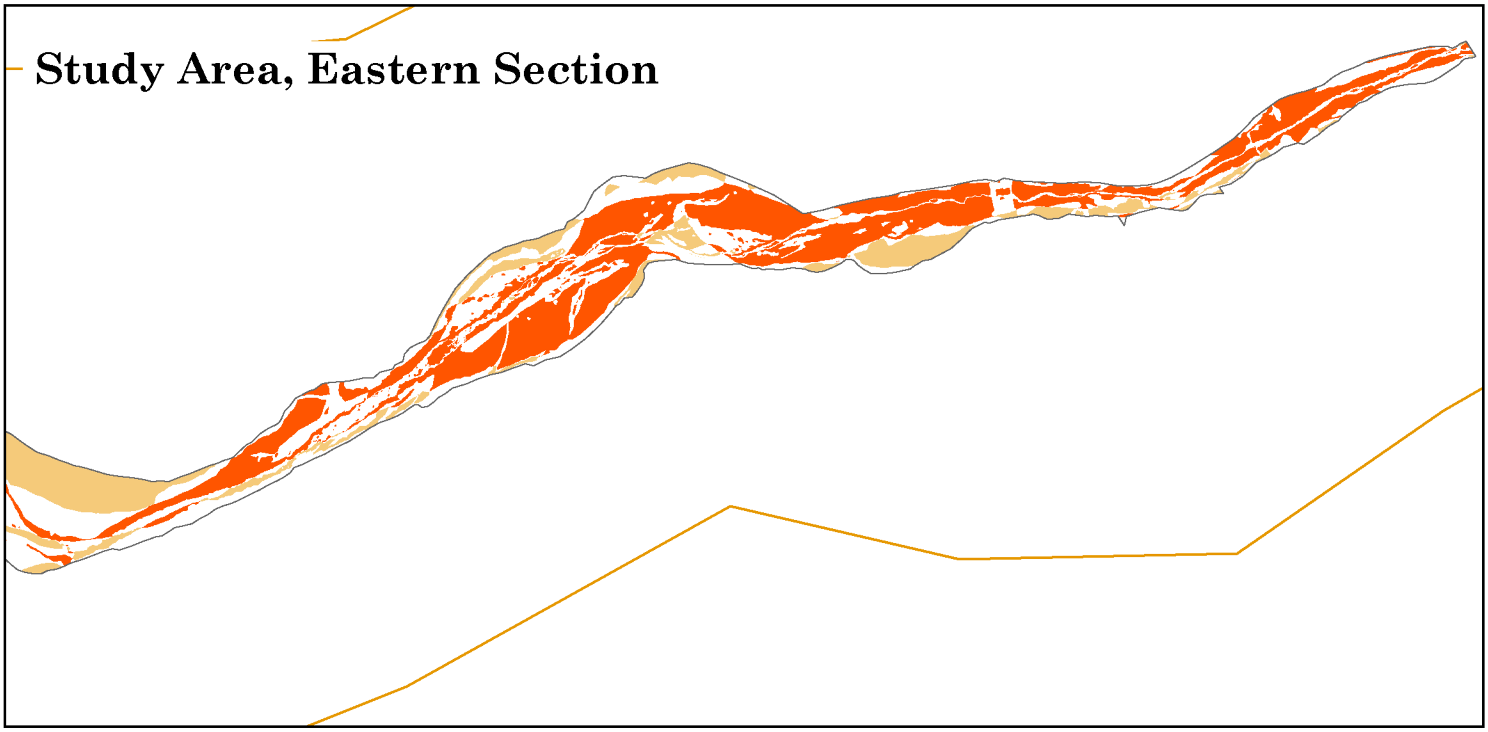
The overall change in the vegetation composition of the channel has been substantial. From 1980 to 2005 areas of open channel decreased from 231.1 acres to 113.8 acres, a loss of 50.8%. Vegetated areas increased from 108.2 acres to 200.94 acres, a gain of 85.7%, with the most significant gains occurring in the riparian classification (Fig. 35). From 1998 to September 2005 the extent of arundo in the channel increased from 149.8 acres to 195.5 acres, an overall gain of 30.5% (Fig. 36). The categories of 1-25% and 75-100% experienced the greatest changes, increasing by 44.8% and more than 12-fold respectively. It is noteworthy that these significant increases occurred despite the destruction of large amounts of vegetation in the heavy flows of the spring of 2005. The extent of arundo was actually even greater in 2002, when it occupied a total of 241.6 acres.

Discussion

High flow events serve as the medium to transport brittle arundo rhizomes downstream from established colonies. However, sufficient moisture, either in the form of surface or groundwater must be present for vegetation to grow beyond the initial point of sprouting (Graf 1982, Hupp and Osterkamp 1996). Many of the stream channels now populated with arundo historically flowed only seasonally. Native riparian species, such as cottonwood, willow, and mulefat are well-adapted to environments of intermittent flow. However, additional levels of soil moisture within the channel have become available as the region draining into Arroyo Las Posas has increased in development.

Arroyo Las Posas has historically been an ephemeral stream, flowing primarily in the winter and spring in response to precipitation events. Within the last two decades, significant areas through which

Figure 35: Change in Vegetation, 1980 to 2005



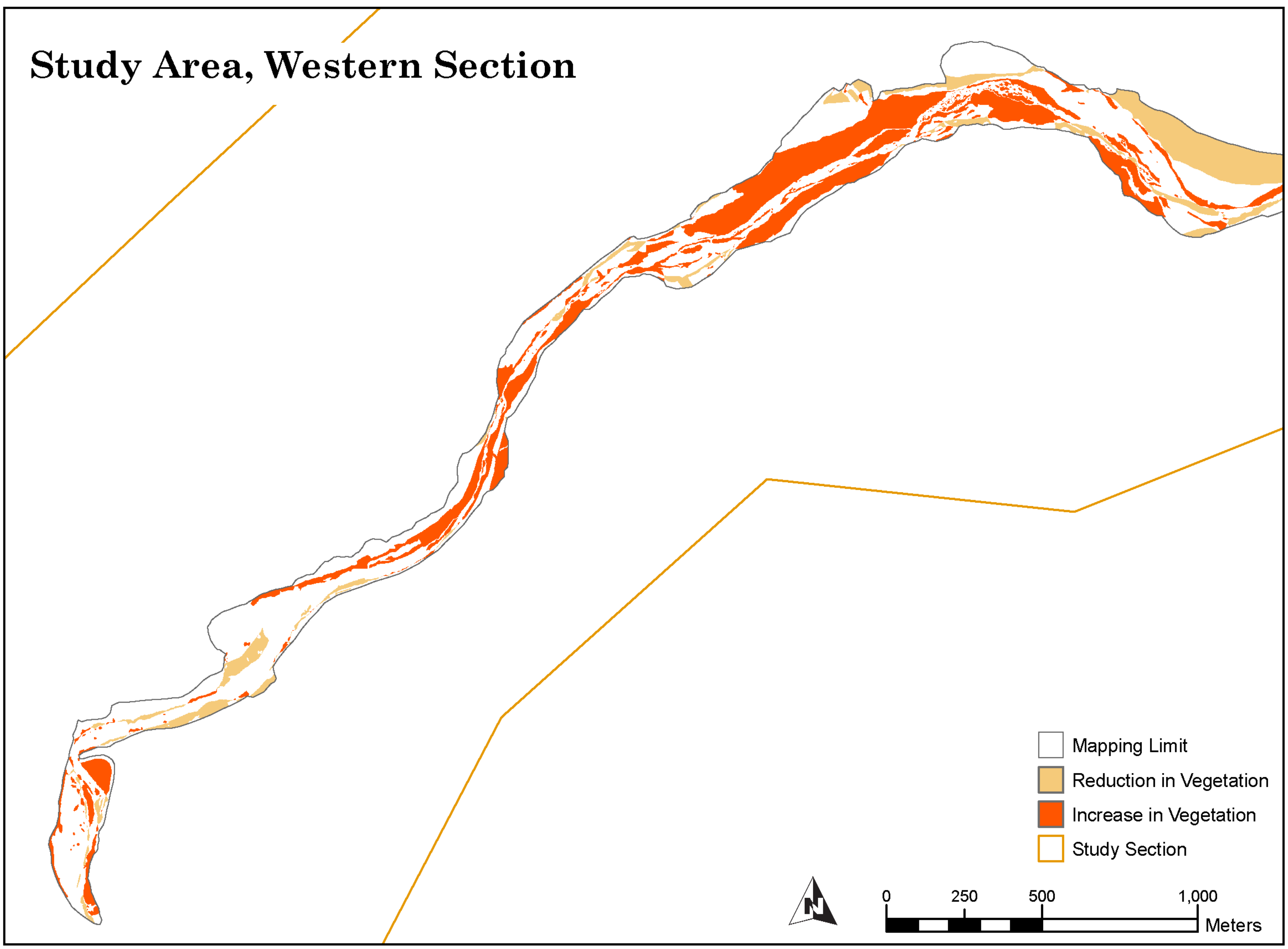
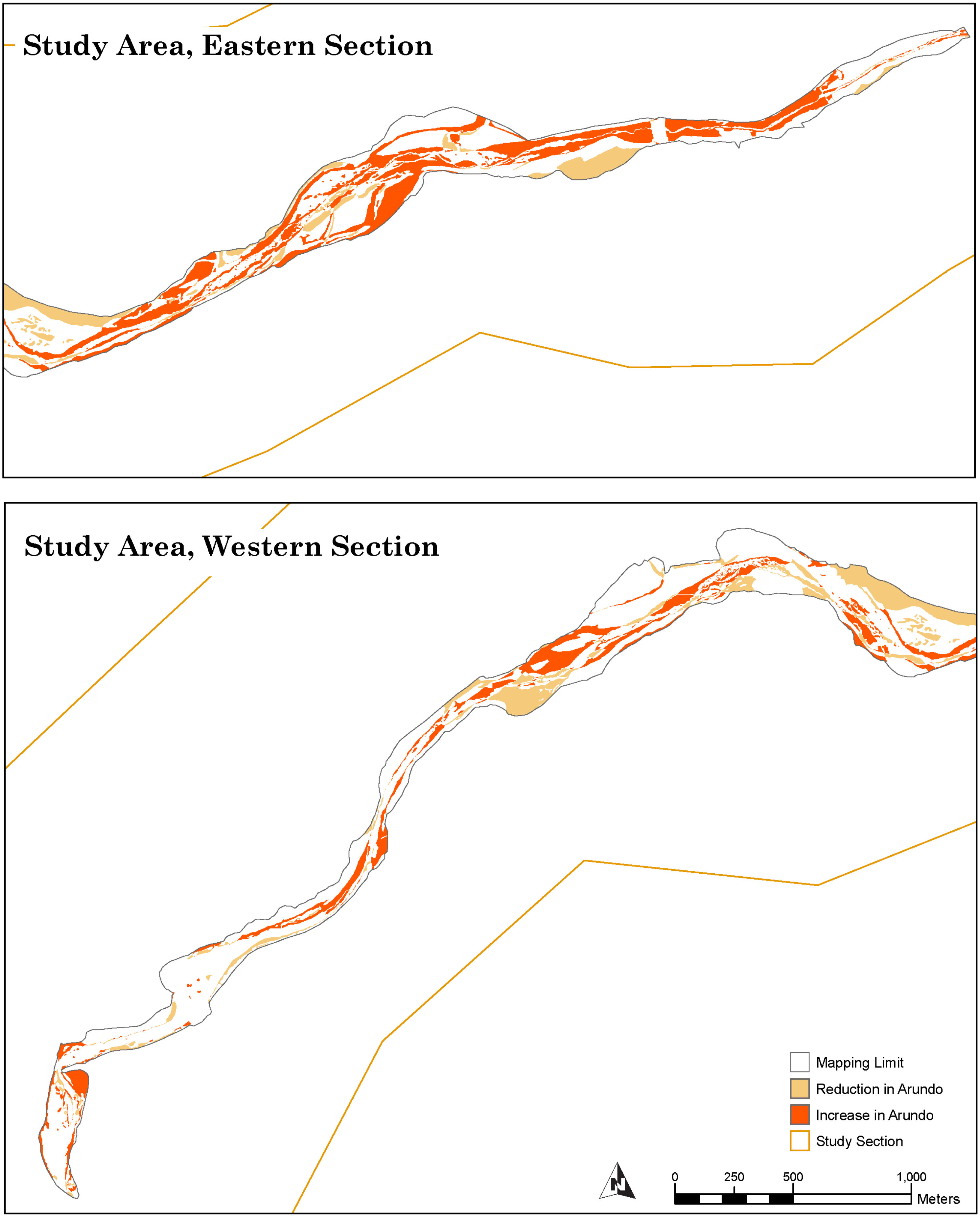


Figure 36: Change in Percent Arundo, 1998 to 2005



the channel flows (the cities of Simi Valley and Moorpark) have undergone extensive development, primarily in terms of residential and commercial areas. Agriculture is responsible for 28% of the land use in the Calleguas watershed, and developed areas within the watershed account for about 27% of land use. These land use types have the potential to negatively impact the riparian environment (Paul and Meyer 2001). Negative agricultural impacts occur from runoff that is high in sediment, pesticides and/or herbicides, and fertilizer (Allan 2004). Urban land uses typically create runoff that is high in the variety and amount of pollutants, is warmer, and carries sediment (Paul and Meyer 2001). Return flows from irrigation and discharge from water treatment plants are the two primary artificial sources of water input to stream channels (Graf 1982).

Urban run-off, water diversions, and discharge from water treatment facilities have altered riparian environments in many semi-arid regions (such as the Calleguas Creek watershed) to become areas of perennial water flow (Frandsen 1997). The conversion of ephemeral streams to perennially flowing channels encourages colonization by vegetation because soil moisture and humidity levels are kept artificially high (Graf 1982, Tooth and Nanson 2000, Hassan and Egozi 2001).

There are five wastewater treatment plants within the Calleguas Creek watershed. Of these five, the Simi Valley Water Quality Control Plant (SVWQCP) and the Moorpark Waste Water Treatment Plant (MWWTP), are proximate enough to the study area that their presence directly impacts channel flow within the study area. The SVWQCP is approximately 12 km upstream of the study area, and discharges its effluent directly into the stream channel on a full-time basis. The SVWQCP has been documented as having a significant impact on streamflow (Table 13). According to monitoring of flow above and below its discharge point, the volume of its effluent may account for 50% or more of the channel flow. The MWWTP lies adjacent to the eastern section of the study area. This facility only occasionally makes direct discharges to the channel, and relies primarily on the use of percolation ponds in its water treatment process. As groundwater levels in nearby areas of the watershed are shallow

Table 13: Flow Output from Simi Valley Water Control Plant

Facility	Cubic Feet/Second		Gallons/Minute		Gallons/Day		Acre Feet/Day		Acre Feet/Year	
	Low	High	Low	High	Low	High	Low	High	Low	High
SVWQCP	11.6	17.5	5,206	7,855	7,497,276	11,310,545	23	35	8,398	12,669

enough to allow surface discharge, the ponds may contribute to streamflow by increasing the level of groundwater in the immediate area (CCWMP 2004).

Wastewater flow is generally nutrient-rich, and often contains elevated levels of nitrogen (Iverson 1993). Elevated levels of nutrients also exist in agricultural runoff as a result of the fertilizers that are used to enhance crop production. Once artificial flow is introduced to ephemeral channels, rapid development of vegetation occurs (Hassan and Egozi 2001). Arundo responds positively to elevated levels of nitrogen (Perdue 1958) by producing larger rhizomes and denser cane growth (Rauterkus 2004).

Flow in the channel may also be affected by upstream pumping of groundwater. Due to the height of the water table in various areas upstream of the study area, the city of Simi Valley pumps groundwater to artificially dewater low-lying areas in efforts to prevent flooding. The pumps operate on an almost continual basis at a combined rate of 3 to 5 cfs (CCWMP 2004). The pumped groundwater is discharged into the channel and further contributes to the more perennial character of channel flow.

Although runoff and wastewater discharge may be unavoidable by-products of expanding development, the end result is the artificial irrigation of formerly ephemeral stream channels. Natural high flow events distribute arundo propagules throughout riparian environments, but arundo growth is additionally fostered by anthropogenic means.

Conclusion

As arundo is primarily a vegetative reproducer via its underground rhizomes or through nodes on above-ground stem sections, the initial hypothesis was that the rate and extent of arundo's spread would increase during periods of significant streamflow. For example, it was expected that years with lower streamflow would show arundo extents to be relatively stable, while years with high streamflow might be expected to show greater proliferation of the species as high stream discharge/flooding would likely facilitate the dispersal and diffusion of biomass downstream. This transport of arundo debris downstream might therefore be expected to enable the establishment of new arundo colonies.

However, as far as can be ascertained from the study data, other factors also impact the distribution and proliferation of arundo in Arroyo Las Posas. While it is likely that episodes of heavy flow did distribute vegetative propagules throughout the channel, the role of heavy streamflow has at times also been to scour the channel of vegetation and increase the areal extent of the open channel. Once scoured during the wet season, the ability of channel vegetation to re-establish itself depends on many factors including its propensity for reproduction, tolerance to drought and other adverse conditions, and availability of adequate moisture for sustenance. In the early 1980s, and probably in prior decades, vegetation was unable to re-establish itself quickly if subsequent dry periods occurred after channel scouring. However, since the 1980s flow in the channel has undergone a gradual shift from being largely ephemeral in nature to being nearly perennial. This is a result of increased surface runoff and effluent from water treatement operations which have occurred due to the expansion of neighboring suburban development. The advent of this year-round irrigation has supported the rapid regrowth of vegetation in the channel. Much of this vegetation is now arundo, which possesses greater reproductive opportunism than native species, monopolizes soil moisture, and spreads in extent via hydrochory. Owing to its ability to negatively impact riparian ecosystems, expansion of this species in the channel will doubtless result in further undesirable environmental consequences.

Further Work

As a result of this study, many new areas of potential research have emerged. Awareness of the extent to which arundo is present in the watershed would be valuable to many area stakeholders. Future goals for research include: a) further investigate the hypothesis that recent dry years have a lesser effect than the dry years of previous decades on the establishment and/or survival of riparian vegetation (arundo in particular), as a result of the increased base flow in the channel. The channel was heavily scoured by the storms of 2005 and vegetation was beginning to re-establish itself by September of last year. So far, 2006 has been a near average year for precipitation. It would be interesting to track the expansion of vegetation this year, to see if the channel again becomes significantly narrowed by the autumn; b) extend the mapping boundaries to incorporate the entire length of the channel, from the headwaters in the Santa Susana Mountains to Mugu Lagoon; c) acquire additional aerial imagery to increase the scope of the project and the temporal resolution; d) investigate the extent to which historical vegetation maps of the watershed are available; e) obtain groundwater data in order to evaluate the extent to which it provides sustaining moisture levels for arundo.

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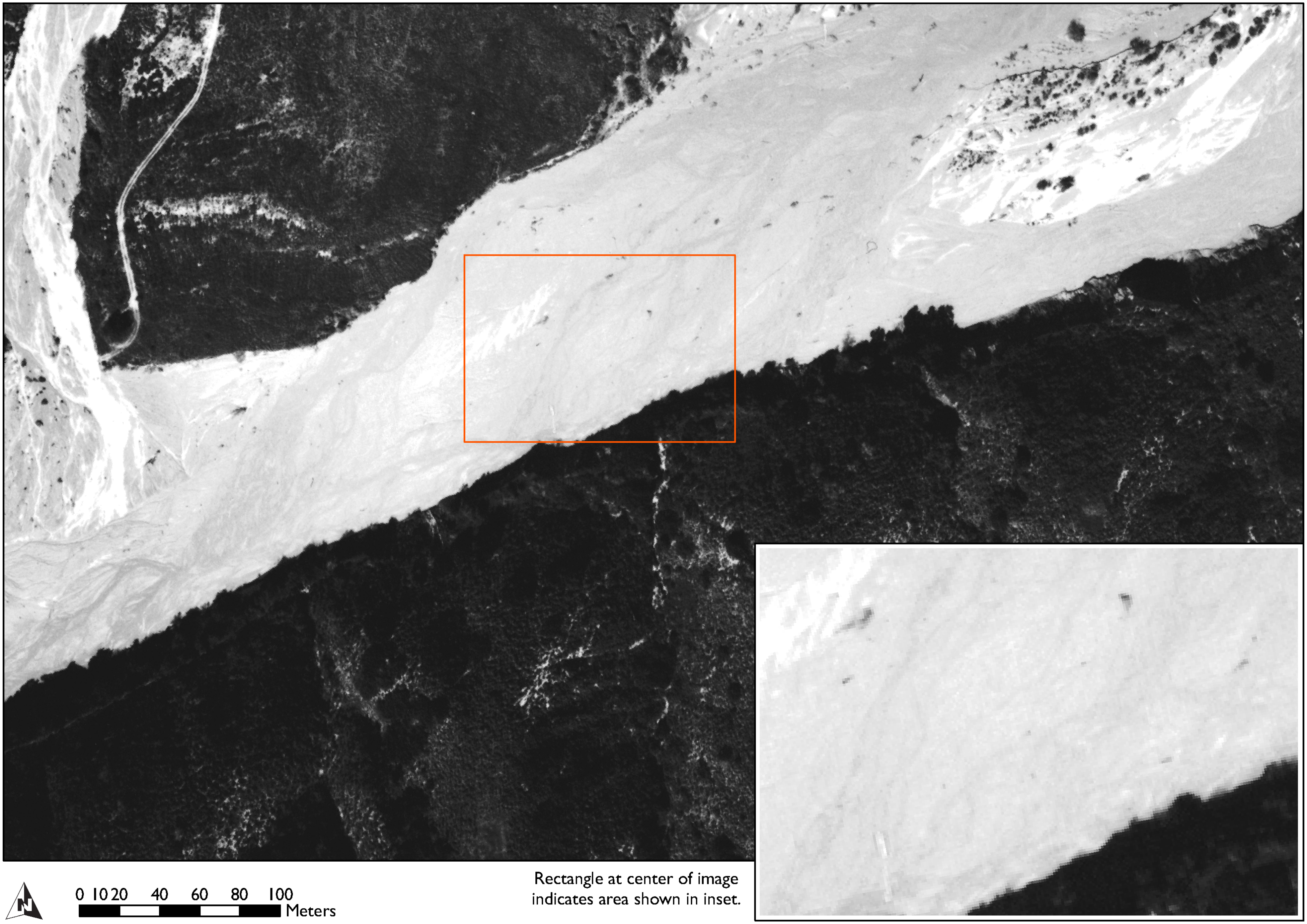
Plate 1: Example Section, 1980 Aerial Base Map

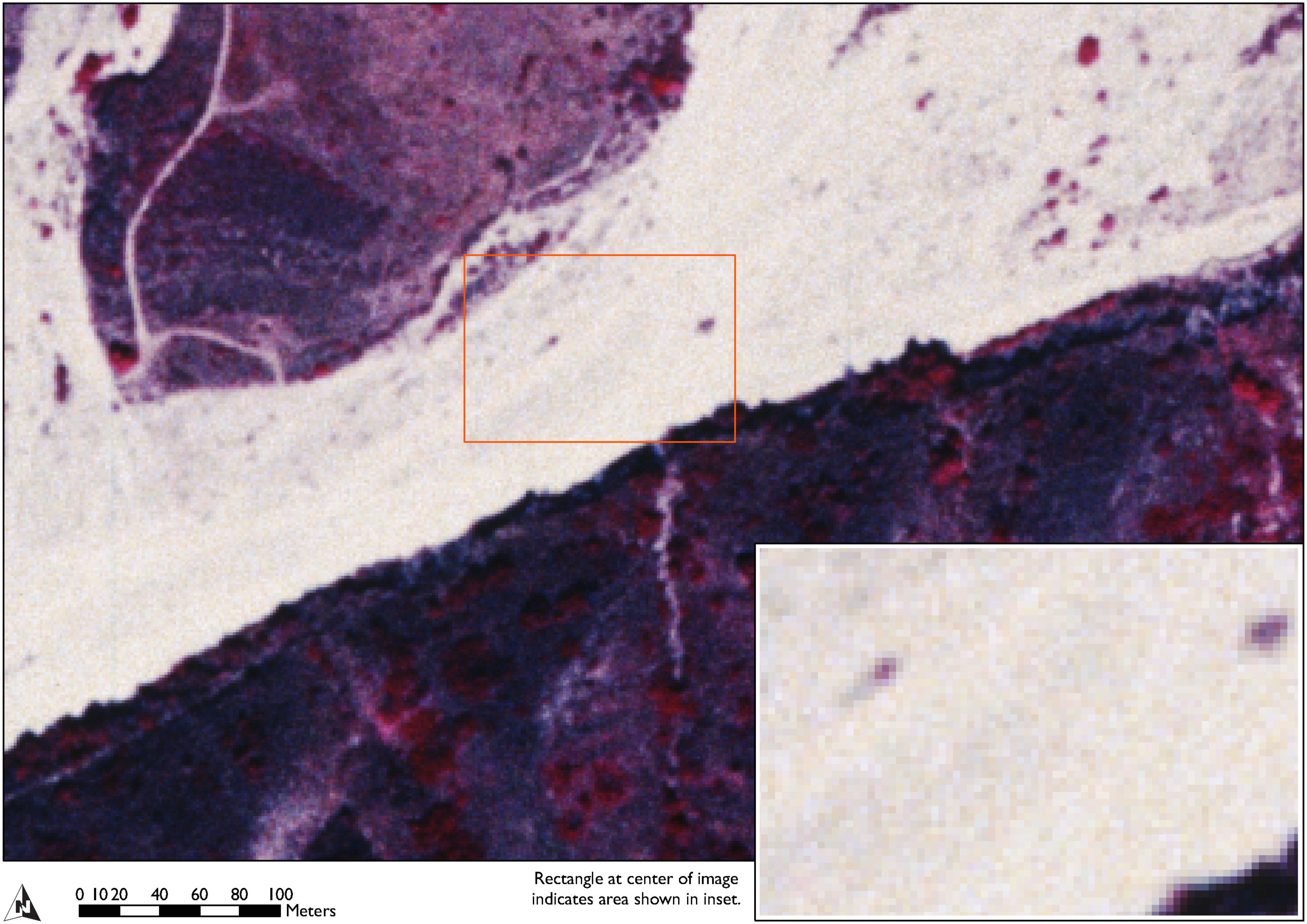
The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).



Rectangle at center of image indicates area shown in inset.

Plate 2: Example Section, 1985 Aerial Base Map

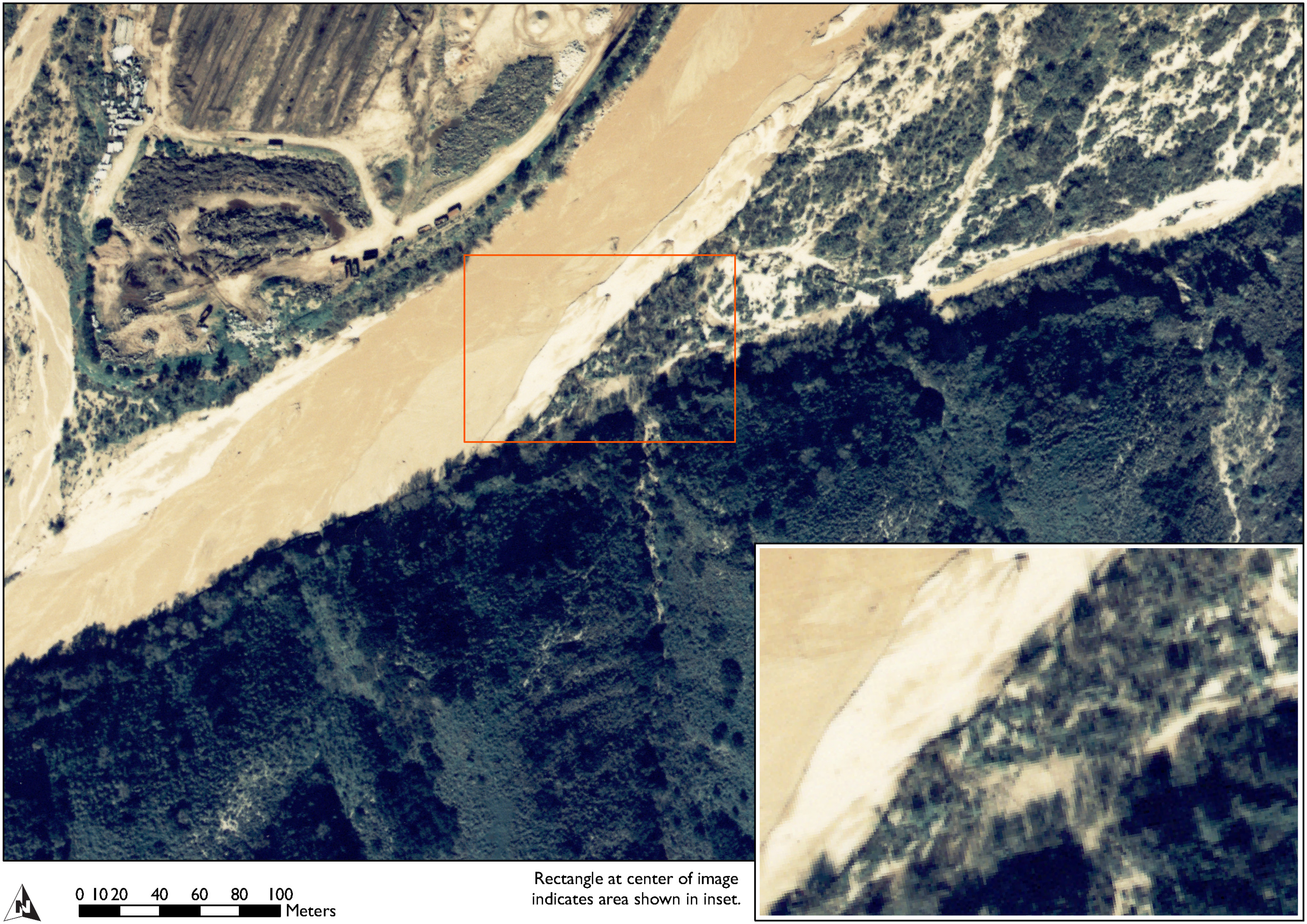
The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).



Rectangle at center of image indicates area shown in inset.

Plate 3: Example Section, 1998 Aerial Base Map

The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).



Rectangle at center of image indicates area shown in inset.

Plate 4: Example Section, 2002 Aerial Base Map

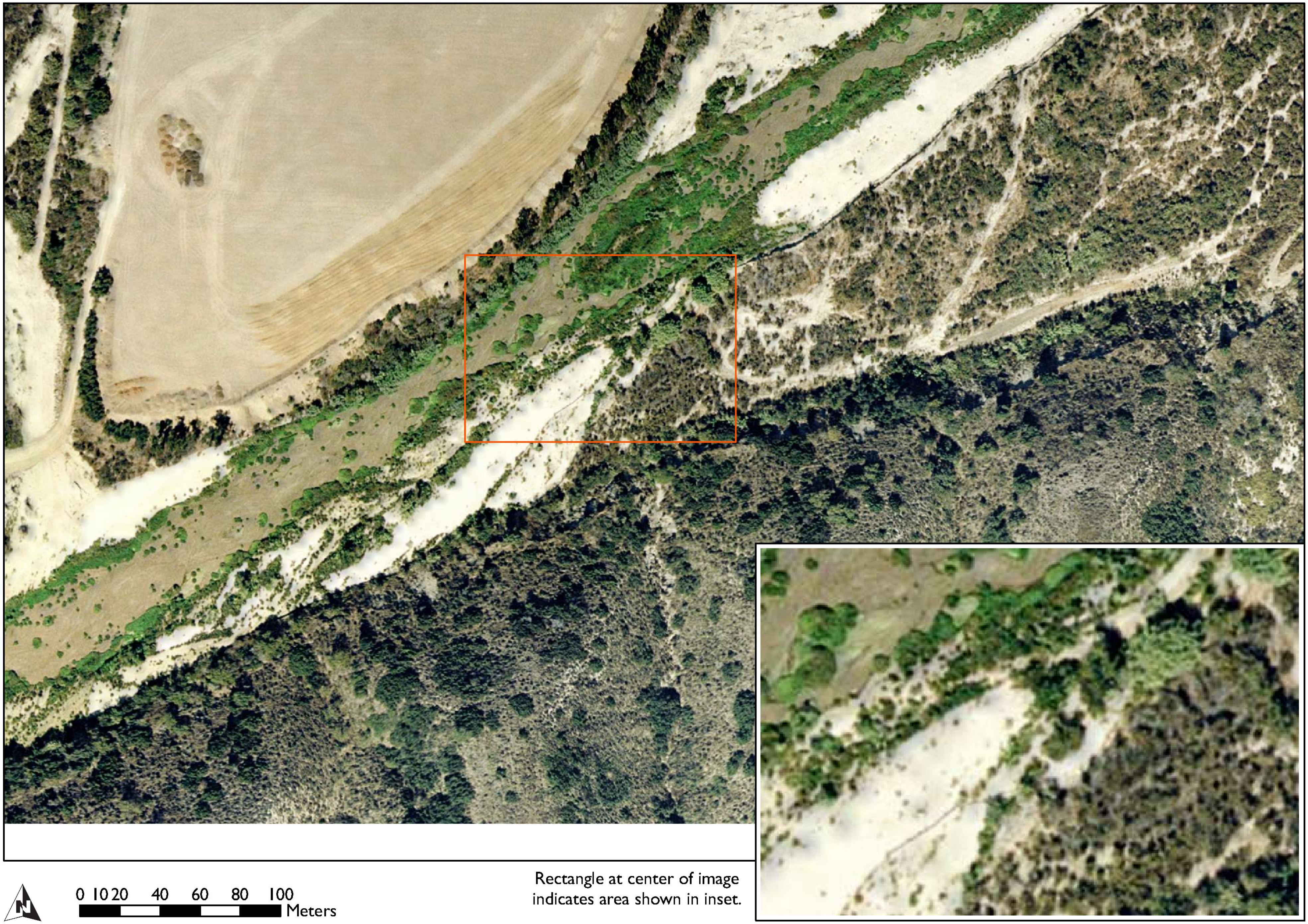
The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).

Plate 5: Example Section, Feb. 2005 Aerial Base Map

The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).

Plate 6: Example Section, Sept. 2005 Aerial Base Map

The magnification of the inset image approximates that at which actual delineation of vegetation types occurred (1:1000).



Rectangle at center of image indicates area shown in inset.