ANALYSIS OF LOWER THOMES CREEK, TEHAMA COUNTY
CALIFORNIA: ECOLOGICAL RESPONSES TO
CHANGES IN LAND USE

A Thesis
Presented
to the Faculty of
California State University, Chico

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Geography

by
Jason McGlynn Cox
Summer 2011
ANALYSIS OF LOWER THOMES CREEK, TEHAMA COUNTY
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ACKNOWLEDGEMENTS

Blessed is the man who trusts in the Lord and whose trust is the Lord. For he will be like a tree planted by the water, that extends its roots by a stream and will not fear when the heat comes; but its leaves will be green, and will not be anxious in a year of drought, nor cease to yield fruit. (Jeremiah 17:7,8)

I would like to thank my wife first and foremost for all the encouragement and patience she has blessed me with through this painstaking process. I am in love with you and would not have finished this without you. I am also thankful for the help and assistance the rest of my family has given me. I would like to especially thank my father Dr. Cox, to whom I am greatly indebted to for his investment into my educational endeavors; wherewithal, I would still be welding, getting metal in my eyes and wishing I could go back and finish my schooling.

I am greatly obliged to my committee for their time and guidance: Dr. Dean Fairbanks who has given me a great deal of valuable input into this study and the writing of this manuscript; Dr. Don Hankins who has also given me ideas when I know he was trying to hide in his office from students and get work done; Dr. Tom Griggs who has also actively facilitated my undertakings to comprehend fluvial systems. My appreciation extends to Cathay Benjamin who assisted me in overcoming many technical difficulties as well as the rest of the staff at the CSU, Chico Geography Department who showed abundant support to us when Esther had to get her head surgery. Thanks to Jessica Bender, Michael Brown-Smith, and Kracker for helping me collect and prepare data.
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ABSTRACT

ANALYSIS OF LOWER THOMES CREEK, TEHAMA COUNTY
CALIFORNIA: ECOLOGICAL RESPONSES TO
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Summer 2011

The Thomes Creek drainage basin lies on the leeward side of the North Coastal range in western Tehama County, California. The upper reaches of Thomes Creek drains areas of the eastern Franciscan Formation whose sedimentary character and steep slopes renders it highly susceptible to mass wasting. Intensive cattle and sheep grazing occurred on the lower reach of the creek as part of the land-use dynamic for a 70 years until the 1920s when timber harvesting started to become a major land-use in the upper headwaters of the watershed. Peak timber harvest was from the late 1950s -1970 when hill slope failure increased 400% in the headwater reaches due to the addition of logging harvest roads on the unstable substrate. The sedimentary input into this fluvial system was subsequently augmented; this was particularly displayed in the culminating event of December of 1964 when warm rain hit the snow pack in the headwaters and
flushed hundreds of thousands of cubic yards of clastic material into the creek channel, aggrading it from around the town of Paskenta to the Sacramento River confluence.

This study used a series of sequential thematic land-cover/land-use maps from 1938, 1958, and 2005 to statistically analyze the effects that changes in land management practices have had upon the spatial patterning of the lower Thomes Creek landscape mosaic. It was determined that the nature of lower Thomes Creek has changed during the timeframe of analysis for this study. Little change was seen in the land-cover classes from the 1938 to 1958 timeframe. The 1938 imagery showed many parcels of dryland small grain agriculture having furrows around mature valley and blue oaks specifically upon the upland terraces of the Paskenta and Flournoy landscapes. By 1958, most of these were fallow and observed to be converted to grasslands. This shift from row crop production to grassland is the primary reason for the decrease in the upland terrace landscape homogenization in lower Thomes Creek, while the conversion of many large grassland areas to orchard production was the primary cause for the increased landscape diversity in the Henlyville and the Delta landscape sub-sections. The Thomes creek floodplain seemed to be relatively uniform in its location for both 1938 and 1958; although the active channel was in different locations during these two times, as signs of flooding were apparent throughout the riparian areas.

After 1958, the Thomes Creek landscape became more diverse in its landscape mosaic but had seemingly changed in its “naturalness.” Upland areas were larger and less complex. Many of the mature individual oaks and cottonwoods were removed or had died after 1958 and have showed little evidence of recruitment in the
2005 analysis. The upper two reaches included in this study showed signs of succession in many areas after 2005 from predominantly willow patches to cottonwood-willow and from cottonwood-willow to cottonwood valley oak. The lower two sections included in this study showed no significant changes to riparian vegetation patch size, but spatial patterning became more linear and aggregated restricted to the edges of the Thomes Creek channel where gravel mining activities annually remove material from these sites.

The analysis concludes that historical land-use within the headwater reaches from timber harvesting activities have altered the nature of the lower reaches of Thomes Creek by augmenting sedimentary inputs into the system, particularly during the 1964 flooding event that has aggraded the entire study area. Changes in the terrace land-use and management have decreased the ability for Thomes Creek riparian vegetation to have access to historical channel braiding and surface flows due to restricted channel migrations, ground water pumping and water extraction to irrigate agricultural production systems. The introduction of gravel mining operations after 1958 has denuded favorable habitat for willow species within the active channel and changed their highly dynamic spatial patterning in the last 10 km of Thomes Creek to one that is more linear and persistent.
CHAPTER I

INTRODUCTION

Changes in Nature and Focus of this Study

A fluvial system is simply the response and downward route of precipitation-runoff events. It is also the subsequent aggregation of diverse ecosystems connected by a strong directional and linear flow. All ecosystems, in general, develop in part, due to landform elevation, aspect, parent materials, grade, and local atmospheric conditions (Swanson et al. 1988). Local flooding regimes and sediment allocation within a fluvial or riverine ecosystem dictate biotic composition and fecundity. Arguably, humans are the primary influences in creating these current fluvial landscapes displayed today.

Historical anthropogenic interactions with landscapes have tended to negatively impact riverine ecosystems by altering the natural processes; and thus, changing the variables that uphold healthy ecosystems. Degraded water quality and species homogeneity is the result of altering nutrient and disturbance cycles in these fluvial environments. In the study presented here, lower Thomes Creek located on the west side of Tehama County is spatially examined over a relatively long temporal period to assess the land-cover changes as a result of changes in land-use and hydrology in the basin.
Most previous studies conducted on Thomes Creek have focused on the sedimentary contributing nature of the Franciscan geological formation within the headwater reaches as disturbed by past forestry logging practices and road building as they pertain to sediment allocation to the lower reaches of the creek channel (Jones et al. 1972; Serr 1979a, 1979b, 1981; Howard and Varnum 1982; Hoover 2006). The United States Department of Agriculture (USDA) Forest Service (USFS 1997) has extensively reviewed ecological conditions for the upper reaches of the watershed. There is, however, no current review or analysis of the ecological and land cover conditions surrounding the lower reaches of Thomes Creek as it enters the alluvial fan environment of the Sacramento Valley, that have occurred resulting from sedimentation and land-use/land-cover changes there with before flowing into the Sacramento River.

The current spatial pattern of the Thomes Creek riparian vegetation is a function of hydrological dynamics, sediment allocation, succession, and changes that have occurred in the surrounding upland land-use and their management practices. It has been documented that shifts in terrestrial processes are to be expected when hydrological alterations are introduced into a drainage basin (Williams 1978; Bradley and Smith 1986; Knopf and Scott 1990; Rood and Mahoney 1990). Through temporal quantification of those variables that influence biotic fecundity and species distributions, one may gain insight into an ecosystem and consequently identify how the current patch mosaic is the result of changes of land usage and management decisions. According to Ward (1998), analysis of fluvial environments should account for the longitudinal, lateral, and temporal dimensions: where upstream-downstream interactions comprise the longitudinal dimension, exchanges between the stream and its
floodplain are the lateral dimension, and these processes extending over time create the temporal dimension.

In this study, I attempt to address the synergy of sedimentation, hydrology, and land-use/land-cover (LULC) changes in the lower reaches of a dynamic stream on the west-side of the Sacramento Valley by using mapped land-use/cover data from three specific time periods. Thomes creek was selected because, (1) of its role in high sedimentation to the Sacramento River which adversely affects native salmon and steelhead habitat (Lisle and Lewis 1992); (2) represents a dynamic fluvial system, having unstable substrate and adjacent wide-ranging land-uses throughout its drainage basin, offering an exceptional environment to quantify changes within vegetation compositions, extents, and interconnectivity at the landscape level (Apan 2002; Weins 2002); and (3) ecological conditions and their responses to changes in land-use and hydrological changes in the lower Thomes Creek watershed have been little assessed.

This study particularly addresses the following research questions for the lower Thomes Creek watershed: (1) How has the distribution of natural vegetation habitat and land-use changed over time? (2) Are the changes in vegetation pattern related to the effects of lower reach land-use impacts, or changes in streams dynamics from increased sedimentation as a function of land-use changes in the headwater reaches, or a combination of the two spatial processes?
CHAPTER II

BACKGROUND

Fluvial Environments

Inasmuch as riverine ecosystems characteristically reflect and display the integrity of the landscape they flow over, their underpinning landform primarily dictates both aquatic and terrestrial biotic composition and distribution (Hynes 1975). The landform structure (e.g., elevation, slope, parent materials) regulates the flow of organisms and propagules, energy and water, sediments, and organic matter throughout the entire drainage basin (Swanson et al. 1988). The landform therefore influences the frequency and spatial patterning of these processes within the landscape drainage mosaic.

Hupp and Osterkamp (1996) argue that the primary landform influence upon fluvial processes is the gradient. They state that channel migrations and flooding regimes are all dictated by the slope of the landform that the waterway flows through. It is reasonable therefore to conclude that erosional processes, streamside vegetation patterning, and composition, will all inadvertently be heavily regulated by the landform gradient and the discharge of water from it (Baker et al. 1998). Gradient is characteristically highest in the headwater regions of a stream, an area commonly defined as the erosional zone (Schumm 1977), where mass wasting of hillslopes and downcutting of channels into the bedrock primarily occur. The addition of this
unconsolidated material from these processes and events; with the subsequent
entrainment of the produced clastic material, is a direct function of precipitation and
stream velocity. When this stream velocity creates a shear stress that exceeds the shear
strength of the substrate, the entrained and saltating material promotes a downcutting of
the stream floor; thus further contributing to the sediment transportation and allocation
(Naimen et al. 2005). The location of depositional zones of sediment are influenced by a
decreasing grade (or gradient), in conjunction with both the entrained material size and
the local stream discharge.

All water that flows into a fluvial landscape is initially excess precipitation,
or delayed snow-melt. The annual instream high and low flows are regulated by these
precipitation/snowpack occurrences and their sedimentary inputs. This process is
referred to as the stream’s flood regime and the associated pulse of its sediment budget
classification system, one may expect the lower stream channel reaches to be quite
sinuous or braided as a direct function of landform gradient and sediment allocation.
These sinuous lateral channel movements typically create a mélange of alluvial soils
and paleo channels of variable depth, coarseness, and fertility. It is reasonable to expect
that in altering a stream’s discharge and size, there will be a development response
within the lateral channel migration, meander cutoffs, point bars, and oxbow lake
formation; resulting in an artificial, steady and homogenous state (Miller et al. 1995;
Richter and Richer 1999).
Climatological Influences

Temperature and light are important variables in aquatic ecosystems because they affect movements of molecules, fluid dynamics, dissolved oxygen, and metabolic rates of instream organism processes (Haur and Lambert 1996). Solar radiation is the primary cause for temperature fluctuations in aquatic systems; and thus, a primary variable affecting the instream environment. Instream biotic critical life stages for fish are highly dependent upon annual fluctuations of temperature; variables such as emergence, spawning and growth are regulated by seasonal changes in temperature. The decrease in solar radiation in during the winter months affects dissolved oxygen and stream flow; thus, greatly retarding the biological activities of fish (Bjornn and Rieser 1991). Shade created by overhanging vegetation or geologic features will also influence local temperatures by restricting light and regulating primary productivity in the associated waterways (Bothwell 1985; Carpenter et al. 1987; Hill et al. 1995).

Biological Influences

The term “riparian” is used to categorize and describe vegetation communities that are adjacent to streams and rivers and are dependent upon its hydrological processes (Dixon and Johnson 1999). Riparian habitats are an integral faction of the dynamic and complex processes within the fluvial landscapes in the West (Wood 2003). The upper extent of the riparian corridor encompasses the high water mark in the stream channel, towards the uplands where dependent vegetation is restricted to its access of elevated water tables and/or flooding events. It is also dictated by the ability of the fluvial soils to offer adequate substrate for the hydrophilic species
comprising the riparian ecosystem. The idea that these riparian areas hold influence 
over the adjacent waterway is well established; however, it must be noted that the 
degree of specific influence often has been found to be variable, particularly regarding 
degree of interaction among different scales of analysis (Lammert and Allen 1999).

Riparian influences over lotic heterogeneity are initially seen in the 
provision of primary metabolic processes (Cummins et al. 1974; Bilbly 1980; Hedin 
1990) and extended into sustaining various tertiary species (Diehl 1992); where 
allochthonous input in a detritus-based system becomes the primary source of energy 
for heterotrophic communities (Benner et al. 1988; Weigelhofer and Waringer, 1994). 
This allochthonous input initially affects dissolved oxygen levels. The inflows of this 
material may include leaf fragments, floral parts, woody material and/or fruiting bodies 
that become deposited into the stream either directly or through lateral movement 
(Cuffney 1988). According to Webster and Benfield (1986), this litter initially leaches 
up to 25% of its dissolved (or labile) organic matter while exposed to colonization and 
decomposition of microbial bodies. This prepares the litter for mechanical and 
biological fragmentation, changing the course particulate organic matter into fine 
particulate organic matter and creating more surface area for benthic heterotrophs. The 
amount of litter may not be the only limiting resource for lotic organisms (Richardson, 
1991), but it heavily dictates community composition through litter forage quality 
(Kaushik and Hines 1971). However, species habitat demands extend beyond just basic 
nutrient requirements being met; instream environmental conditions for aquatic 
organisms must be also furnished.
Delong and Brusven (1994) found that invertebrate communities significantly decreased in both size and heterogeneity within an agriculturally altered, fluvial landscape. They mention that common impacts from agricultural production are: soil erosion resulting in increased sedimentation and turbidity, removal of riparian vegetation resulting in increased light (i.e., higher water temperatures) and decreased organic input, nutrient enrichment from fertilizer runoff, increased oxygen demand, and the presence of pesticides in surface waters as well as animal waste. Moyle (1976) argues that alteration of these fluvial landscapes by agricultural production has completely disrupted lowland fish assemblages in the Sacramento River Valley system of California. Changes in the upland usage adjacent to these streams and rivers have threatened entire regional faunas and confined others to isolated fragments of their native habitat ranges (Moyle and Williams 1990).

Anthropogenic Influences

Many Native American populations in the West tended to dwell near rivers and streams for most, if not all of the year (Goldsmidt 1951). Most were hunter-gatherers who subsisted off the land; eating acorns, grass seeds, tubers, deer, elk, small mammals, fish and birds. Fish were taken by hand, net, trap or by harpoons. Salmon were harpooned within shallow pools. Clover was an important food because it was the first fresh green food in the spring (Goldschmidt 1951; Vestra 2006). Many tribes were divided into numerous local groups, and not a unified tribe. Each group had a varied population, ranging from 25 to over 200 residents. Each local group typically had a central village and associated surrounding land. Each village had from five to fifty
family houses. The villages would commonly be adjacent to springs or creeks with the women and children gathering the firewood from local sources (Heizer 1963). These groups commonly had a second area of land in the higher elevations that they would move to during the summer (Goldschmidt 1951). It has been thought that human induced fire has long played a role in fluvial systems to enhance the terrestrial conditions for oak and willow management, as well as herbaceous undergrowth. This allowed for better game harvesting conditions, acorn gathering, travel corridors etc… (Pignatti 1983; Naveh and Kutiel 1986; Vernet 1990; Denevan 1992; Hankins 2005).

Soils adjacent to rivers are usually considered to be productive as a result of river meandering and flooding creating an elevated amount of hummus (or soil organic matter) within the adjoining floodplain areas. This has in turn, led to the development and denudation of these ecosystems for agricultural purposes. After reviewing historical accounts, Thompson (1997) concluded that exhaustive resource extraction had fashioned the current riparian forests of the Sacramento River Valley into a severely different ecosystem than what was present two hundred years ago. He argues that these ecosystems are now shrunken remnants of what they once were; as upland farming and ranching practices have extracted resources and poor land management have increased sedimentation.

Historically, the Sacramento Valley floor had 922,000 Hectares (ha) of riparian forests supported by a watershed of more than 64,373 Kilometers (km) Today only about 5000 ha of riparian habitat remain, half of which is highly degraded (Katibath, 1984). The Sacramento River itself once had 202,400ha of riparian forest; it now supports 4,000-6,000ha, or about 2% of the historic levels (McGill 1979; 1987).
Most of the forest was destroyed for mining camp fuel as a result of the gold rush, cut for river steamboat fuel, and by agricultural clearing (Calfed-Bay Delta program 1998). This alteration in the landscape has led to a reduction in native biological diversity, homogenization of the biotic landscape, and loss of high-value wildlife (i.e., game) species (Belsky, 1999).
CHAPTER III

DATA AND METHODS

Study Area

The Thomes Creek watershed basin (CALWATER Basin No. 52310; See Figure 1) drains the east side of the North Coast Range about 150 miles north of the San Francisco Bay. The basin lies entirely within the western portion of Tehama County, California. It drains the southeast flank of Sugarloaf Mountain and Uhl Peak in a south-southeast direction for about 12.8 km until it has its confluence with Fish Creek. It then increases in velocity as it flows southward through a narrow canyon for about 11 km and turns eastward at its confluence with Willow Creek. It continues westward through steep terrain and then enters Thomes Gorge 2.5 km east of the town of Paskenta. Lower Thomes Creek begins to meander here as the landform gradient decreases until it reaches its confluence with the Sacramento River about 49 km past the town of Paskenta. This confluence is located about 6.5 km north of the town of Corning and about 2.5 km south of the town of Los Molinos (Sacramento River Mile 225).

The upper reaches of Thomes Creek drain areas of the eastern Franciscan Belt that includes the Valentine Springs Formation and the Southfork Mountain Schist. These underlay about 50 percent of the watershed (Irwin 1957; USFWS 1997). The lower reach of Thomes Creek flows through the Great Valley Province. Here there are seven principal geologic units: the Coast Range Ophiolite, the Great Valley Sequence,
the Tehama Formation, the Red Bluff Formation, the Riverbank Formation, and the Modesto Formation (Irwin 1957).

The soils that form from these formations tend to produce soils rich in chlorite clays, which are small enough to be carried the entire length of Thomes Creek as entrained or dissolved material (USFS 1997). The sedimentary character of these substrates renders them highly susceptible to mass wasting, augmenting the amount of suspended sediment and instream clastic material. Kelsey (1988) indicates that soil erosion is the greatest source of fine-grained sediments carried by 1st and 2nd order streams within the North Coast Ranges. These 1st and 2nd order streams account for over 82 percent (2,585 km) of the total stream miles in the upper Thomes Creek watershed (USFS 1997). The most exposed soils are those found in the areas of highest elevation.
near Hammerhorn to Sugarloaf Mountains within the Yolla Bolly-Middle Eel wilderness. These are primarily infertile and shallow soils displaying limited ability to produce vegetation for soil stabilization. Many of these soils are derived from Serpentine and Metagreywacke bedrock that are high in the fine montmorillonite clays.

The general natural vegetative landscape mosaic along the mid-lower elevations in the valley are primarily comprised of patches of blue oak among annual grasslands. The historical land use, depending on local tilth and soil fertility, have changed the annual-perennial bunch grasslands of Thomes Creek basin into the current grasslands comprised of introduced European annual grasses and with scattered native forbs. Typical species are Italian rye, cheat grass, rip-gut brome, wild oats, and soft chess. A unique sub-set of the remaining native grassland community is comprised of nodding needle grass found at the southernmost limit of the Thomes Creek watershed, just north of Black Butte Reservoir (Vestra Resources 2006).

Agricultural crop and orchard vegetation dominates the easternmost portion of the Thomes Creek drainage basin. These are typically homogenous landscapes with occasional patches of weedy-herbaceous plants, ornamental or native trees and shrubs surrounding the fields or adjacent to the access roads. Agriculture in this area has typically been dry-land cereal grains (wheat, rye and oats), irrigated pasture for hay production (alfalfa and grass), and irrigated orchards (walnut, prunes, olive).

The riparian vegetation within and along the stream corridor is heavily influenced by elevation and climatic conditions. In the headwater portions of the drainage basin, the riparian species are a mix of white alder and willow becoming
Figure 2. Soils prone to erosion in the Thomes Creek watershed.


predominantly cottonwood, willow, and red alder at lower elevations. In the mid-and lower elevations there are large valley oak patches along the valley terraces and floodplain adjacent to the creek. These species initially occur below its inflection point, just above Paskenta; extending to its confluence with the Sacramento River about 95 km downstream.

The climate of Thomes Creek drainage basin is Mediterranean: consisting of mild and wet winters and dry and hot summers. According to the USFS (1997) storms normally come out of the southwest, often with high winds across the ridge tops with almost 90 percent of the precipitation falling in the watershed during the five-month
period of October through April. Much of this precipitation is received in the form of snow and typically persists at elevations greater than 5,000 feet, lasting until early summer on north and east facing slopes.

The basin lies on the leeward “rain shadow” side of the North Coast Range, which tends to diminish the amount of rainfall received on the lower reach rather than on the headwaters area. Subsequently, the average annual precipitation for the watershed is around 45 inches, ranging from over 70 inches at the headwaters (5,000 ft) to 23.5 inches per year at Paskenta (elevation 743 ft), to 20.36 inches at its confluence with the Sacramento River (elevation 254 ft) based on records since 1937 (California Department of Water Resources 2009).

Data Acquisition and Preparation

In order to map the LUCC over time for the lower reach of Thomes Creek an assessment of available aerial photographic products were investigated. Complete coverage of the study area was found for only three specific time periods: 1938, 1958, and 2005. This range of temporal coverage is appropriate to the study because it represents a time period when there were many changes in the region going forward from the Great Depression, development of the Central Valley Project (Tehama-Colusa canal), USFS logging in the 1950-1970s, and construction of the Interstate 5 highway system through Tehama County in 1965. Unless noted all the imagery was acquired from the California Department of Water Resources and georeferenced into the UTM Zone 10N NAD 1983 projection system.
Scanned copies of the 1938 aerial photography with the relevant images were subsequently mosaicked and georeferenced using six identifiable reference points (maximum total root mean square (RMS) error being 17.2m and a RMS error minimum of 4.2m). The 1958 aerial photography was provided in a mosaicked format but contained many seams whereupon the unions of the original photographs are up to 5m out of alignment with each other. It should be noted however that this falls beneath the chosen Minimal Mapping Unit (MMU) of 10 Meters for this analysis. In addition, due to the type of photographic paper used in the 1950s and the scanning process the 1958 series is rather washed out and of poorer quality than the 1938 black and white imagery. The 2005 aerial imagery was acquired by from the National Aerial Imagery Program (NAIP) Statewide orthophotography (Color and Color Infrared). This ortho-imagery data product was provided rectified to National Mapping Standards at the 1:24,000 scale and has a 1 meter ground sample distance (Cal-Atlas 2009).

Mapping Procedures

The study area along Thomes Creek was determined by identifying the active channel for all three time periods and merging them into one polygon; taking then the outermost channel boundaries and putting a 300mbuffer upon them, creating the lateral boundaries for the study’s area of interest (AOI). The AOI was then split up into four distinct reaches similar to those described in Hoover’s (2006) sediment budget for Thomes Creek. Subdivision of the AOI is necessary to capture changes that may occur due to external and site-specific influences; land management history, hydrogeomorphic differences and the influences of smaller tributaries that may
contribute various inputs such as sediments, nutrients, and additional propagule species added into the analysis site (Wood 2003). These reaches will be henceforward referred to as the Delta AOI, Henlyville AOI, Flournoy AOI, and Paskenta AOI.

Polygon feature datasets were created delineating landscape characteristics for all three time periods. Emphasis was placed upon vegetation patch identification and categorization, as well as land-use categories. The minimal mapping unit (MMU) was 10 meters. Digitizing was completed at a 1:3000 scale using heads-up digitizing of the images on a Wacom tablet using ArcInfo GIS 9.3.1 (Esri 2009). Dominant vegetation alliances (Sawyer and Keeler-Wolf 2002) and California Wildlife Habitat Relationships (CWHR) were identified through Aerial image assessment and ground verification (as access permitted). These were and placed within an assigned land-cover class; as a result, some CWHR habitat classes were generalized and/or combined to accommodate a physiognomic habitat type emphasizing their vegetation structure, land usage, or lack thereof (Table 1). The CWHR system was used as it includes habitat stages defined by size classes and crown closure; life stages critical for assessing the current condition and probable disturbance history of various habitat types (Fox 2002).

Display of landscape phenomena is limited in that it places ecosystem processes into discrete categories that meet analysis criteria; thus, error and vagueness are inherent products of mapping landscape characteristics. These categories are usually assumed to be mutually exclusive or exhaustive in that they capture the entire nature of the phenomenon. Distinct boundaries are created delineating changes within landscape to produce and a map that will display a particular theme. The term commonly associated with creating themed maps with categories such as these are called *crisp sets*. 
Table 1. Description of delineated LULC classes

<table>
<thead>
<tr>
<th>LULC Name</th>
<th>Description</th>
<th>California Wildlife Habitat Relationship</th>
<th>California Alliance Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Oak</td>
<td><em>(Quercus douglasii)</em></td>
<td>BOW</td>
<td>71.020.00</td>
</tr>
<tr>
<td>Blue Oak-Valley Oak</td>
<td><em>(Quercus douglasii-Quercus lobata)</em></td>
<td>BOW, VOW</td>
<td>71.040.02</td>
</tr>
<tr>
<td>Cottonwood</td>
<td><em>Populus fremontii</em></td>
<td>VRI</td>
<td>61.130.00</td>
</tr>
<tr>
<td>Cottonwood Willow</td>
<td><em>Populus fremontii-Salix spp.</em></td>
<td>VRI</td>
<td>61.130.12</td>
</tr>
<tr>
<td>Cropland</td>
<td>cereal grains, row crops and hay production</td>
<td>AGC</td>
<td>92.000.00</td>
</tr>
<tr>
<td>Developed</td>
<td>rural and urban; large paved roads</td>
<td>URB</td>
<td>91.000.00</td>
</tr>
<tr>
<td>Grassland</td>
<td>Bromus, Hordeum, Avena, and Lolium spp</td>
<td>AGS</td>
<td>42.026.00, 42.041.00, 41.321.00</td>
</tr>
<tr>
<td>Gravel</td>
<td>Gravel bars, islands, areas of clastic deposition</td>
<td>BAR</td>
<td>None</td>
</tr>
<tr>
<td>Gravel Mine</td>
<td>Gravel bars, islands, areas of clastic deposition</td>
<td>BAR</td>
<td>None</td>
</tr>
<tr>
<td>Orchard</td>
<td>Almonds, olives, prunes, walnuts</td>
<td>DOR</td>
<td>92.000.000</td>
</tr>
<tr>
<td>Sedge</td>
<td><em>Carex and Juncus spp.</em></td>
<td>WTM</td>
<td>45.110.00</td>
</tr>
<tr>
<td>Valley Oak</td>
<td><em>Quercus lobata</em></td>
<td>YOW</td>
<td>71.040.00</td>
</tr>
<tr>
<td>Valley Oak-Cottonwood</td>
<td>Quercus lobata-Populus fremontii</td>
<td>VFR</td>
<td>61.130.00</td>
</tr>
<tr>
<td>Willow</td>
<td><em>Salix spp</em></td>
<td>VFR</td>
<td>61.200.00</td>
</tr>
</tbody>
</table>

(Woodcock and Gopal 1999). This form of categorizing a landscape is not always appropriate due to processes and an interaction occurring through and around these boundaries (ecotones); it is also logical to assume that there will be some categories more correct than others. This is often the case when creating classes that represent a continuum of landscape variables, such as soil classes and vegetation cover.

The use of fuzzy logic accommodates and accounts for the vagueness introduced by the conventional mapping of complex systems. Fuzzy sets (as opposed to crisp sets) are useful whenever we have to describe ambiguity, vagueness, and ambivalence; all of which are the product of placing landscape characteristics into crisp
sets (Kandel 1986). I therefore found it appropriate to combine the DFG (2009b) *Fuzzy Logic Rules for Accuracy Assessment of Vegetation Mapping* with Woodcock and Gopal (1999) to better decipher the quality and accuracy of my three sequential Thomes Creek maps before I analyzed change between them.

**LULC Class Accuracy Assessment**

The accuracy evaluation sites along Thomes Creek were dictated by accessibility limitations, as the AOI is mostly comprised of privately held lands. Although there is no accepted standard method of accuracy assessment or reporting, the topic has matured to the extent that the predominant components of a mapping exercise can be identified. Typically, for example, the mapping community is urged to base accuracy assessment on discrete levels of class membership and to provide at least one quantitative metric of classification accuracy together with appropriate (>80%) confidence limits (Foody 2001; DFG 2009b).

Using a modified composite methodology for field verification (DFG 2009b; Woodcock and Gopal 1999), LULC classes were field verified as access permitted (Figure 3). These were subsequently assigned a ranking based upon degree of uniformity between remotely sensed data and field evaluation from these testing sites. The ranking was as follows:

1. **(5) Absolutely right:** No doubt about the match. Perfect.
2. **(4) Good answer:** Would be happy to find this answer given on the map.
3. **(3) Reasonable and acceptable answer:** Maybe not the best possible answer but it is acceptable; this answer does not pose a problem to the user if it is seen on the map.
Figure 3. Locations of LULC field verification.
(2) *Understandable but wrong*: Not a good answer. There is something about the site that makes the answer understandable but there is clearly a better answer. This answer is a problem.

(1) *Absolutely wrong*: This answer is absolutely unacceptable and completely wrong.

With LULC classes having been assigned ranking from 1 to 5 at the evaluations sites, they were further evaluated by comparing with DFG Wildlife Habitat Relationships and California Vegetation Alliance Codes to expose and account for inconsistency; either in vegetation alliances or associations. Assigning discrete levels of class membership to the evaluation samples does not use the full use of fuzzy sets; wherein values typically range from 0 to 1 (Woodcock and Gopal 1999). This methodology does however provide for avoidance from binary analysis where classes either are unconditionally correct or not.

**Data Processing and Analysis**

In order to conduct a temporal and spatial analysis of the lower reach each AOI subdivision was separated into separate GIS files and used to clip the vector LCLU maps for each year. The vector data was then converted into a raster format with 10m resolution to retain the polygonal shapes of the LCLU classes mapped for further analysis in the Land Change Modeler ArcGIS extension (Clark Labs 2008), landscape ecology software FRAGSTATS 3.3 (McGarigal et al. 2002) and the Patch Analyst extension for ArcGIS (Rempel et al. 1999).
Proportional changes in LULC across years within the entire study area and by each subdivision AOI were determined by using the Land Change Modeler extension. This analysis allowed for the assessment of gains and losses, net change, persistence and specific transitions between mapped classes over time. The tool is able to provide an effective means of generalizing the trend in switches, persistence or expansions between mapped years, and thus allows for a more focused evaluation of the main driving forces of change along the entire lower reach and by AOI subdivision. Results are provided both in mapped and graphical forms.

A defined set of landscape, patch and class metrics that were deemed to best characterize the arrangement of vegetation were calculated (Table 2). Class metrics are computed for every patch type or land cover class in the AOIs. There are two basic types of metrics at the class level: (1) indices of the amount and spatial configuration of the class, which can be referred to as primary metrics, and (2) distributional statistics that provide central tendency (e.g., mean and area weighted mean) and variance (e.g., standard deviation and coefficient of variation) statistical summaries of the patch metrics for the focal class (McGarigal et al. 2002). Two landscape metrics were calculated and fourteen class and patch level metrics were used in the analysis.

Statistical analysis software was used (StatSoft 2009) to perform a one-way analysis of variance (ANOVA) for all LULC patch level metrics to determine significant ($P< 0.05$) changes across the four lower Thomes Creek AOI study sections and over the three timeframes of analysis. All variables were checked for normality; no numerical transformations were required for this analysis.
### Table 2. *LCLU landscape and patch/edge metrics*

<table>
<thead>
<tr>
<th><strong>Landscape Metrics</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>SHEI</td>
<td>Shannon’s Evenness Index measure of patch spatial distribution and occurrences.</td>
</tr>
<tr>
<td>SHDI</td>
<td>Shannon's Diversity Index measures relative patch diversity of the landscape mosaic.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Class level Metrics</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>Number of Patches- The density of land-cover class occurrences within the area of analysis.</td>
</tr>
<tr>
<td>MPS</td>
<td>Mean patch size (hectares) is the ratio of total land-cover class area to the NP.</td>
</tr>
<tr>
<td>MPSSD</td>
<td>Mean patch size standard deviation is a measurement of absolute variation among the patch sizes for the different land-cover classes.</td>
</tr>
<tr>
<td>MSI</td>
<td>Mean shape index is a metric indicating the average perimeter to area ratio.</td>
</tr>
<tr>
<td>MPE</td>
<td>The mean patch edge metric is a function of edge density divided by the Number of Patches in the area of analysis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Patch Level Metrics</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>GYRATE</td>
<td>Radius of gyration is a measure of patch extent; thus it is effected by both patch size and patch compaction.</td>
</tr>
<tr>
<td>PARA</td>
<td>Perimeter-area ratio is a simple measure of shape complexity, but without standardization to a simple Euclidean shape (e.g., circle).</td>
</tr>
<tr>
<td>SHAPE</td>
<td>Shape equals patch perimeter divided by the minimum perimeter possible for a maximally compact patch of the corresponding patch area.</td>
</tr>
<tr>
<td>FRAC</td>
<td>Fractal dimension index is appealing because it reflects shape complexity across a range of spatial scales (patch sizes).</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>Circle equals 1 minus patch area (m²) divided by the area (m²) of the smallest circumscribing circle.</td>
</tr>
<tr>
<td>CONTIG</td>
<td>Contagion is an index of the degree to which classes are aggregated or clumped in the landscape; it is inversely related to edge density.</td>
</tr>
<tr>
<td>PROX</td>
<td>Proximity equals the sum of patch area divided by the nearest edge-to-edge distance between the patch and the center of corresponding patches.</td>
</tr>
</tbody>
</table>

CHAPTER IV

RESULTS

Mapping Accuracy

The fifteen LCLU classes were sampled as access permitted. Three small (<.03 ha) sedge patches were identified in the aerial imagery interpretations; two of which had disappeared by the 2005 analysis and one was inaccessible to ground validation. Ninety-six total ground validation samples were taken and all three LCLU maps were given an accuracy rating of 85.5% (Table 3).

<table>
<thead>
<tr>
<th>LULC Name</th>
<th>Number of Sample points</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Oak</td>
<td>5</td>
<td>92%</td>
</tr>
<tr>
<td>Blue Oak-Valley Oak</td>
<td>4</td>
<td>75%</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>5</td>
<td>92%</td>
</tr>
<tr>
<td>Cottonwood Willow</td>
<td>8</td>
<td>94%</td>
</tr>
<tr>
<td>Cropland</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Developed</td>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>Grassland</td>
<td>7</td>
<td>88%</td>
</tr>
<tr>
<td>Gravel</td>
<td>8</td>
<td>100%</td>
</tr>
<tr>
<td>Gravel Mine</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Orchard</td>
<td>2</td>
<td>90%</td>
</tr>
<tr>
<td>Sedge</td>
<td>0</td>
<td>N/A%</td>
</tr>
<tr>
<td>Valley Oak</td>
<td>14</td>
<td>100%</td>
</tr>
<tr>
<td>Valley Oak-Cottonwood</td>
<td>19</td>
<td>80%</td>
</tr>
<tr>
<td>Willow</td>
<td>16</td>
<td>86%</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>85.5%</td>
</tr>
</tbody>
</table>
Changes in Vegetation Land-Cover

The Paskenta and Flournoy reaches showed a consistent and significantly ($p<.05$) higher amounts of blue oak patches that were large and persistent; whereas the Henlyville and Delta reaches had primarily singular and mature trees dotting the upland areas. There was observed to be an increase in the blue oak-valley oak vegetation patches in the Paskenta and Flournoy during the 1958 and 2005 analysis, causing differences for the PARA, SHAPE, FRAC, CIRC, CONT indices for longitudinal analysis. No significant ($p<.05$) differences was observed for this class during the temporal analysis, indicating that increase in these patches was uniform and constant in the Flournoy and Paskenta sections during the timeframe of this study.

The Henlyville and Delta reaches had a consistently and significantly ($p<.05$) higher amounts of valley oak, and willow patches, subsequently they also display significant differences in their patch and edge indices for the longitudinal analysis (Table 4). Relative and significant temporal changes to the vegetation are presented in Table 5 and Figures 4 through 31:

Blue Oak

Blue oak patches increasingly became more spread out and smaller in size within the Delta AOI (Table 2); fragmenting into 34 patches in 7.2 ha (a 97% decrease). The blue oak class had minimal occupation of the upland terrace in the Henlyville AOI section. It exists only in one small area and has decreased from three patches in 1938 to two in 1958, to finally one in 2005. The Flournoy AOI had an 11% increase in patch area and significant decrease in patch complexity. The Paskenta AOI became
Table 4. One-way ANOVA significance levels comparing land-cover metrics across the four study-site AOI sections (Delta, Henlyville, Flournoy, and Paskenta)

<table>
<thead>
<tr>
<th>Land-cover Class</th>
<th>AREA</th>
<th>GYRATE</th>
<th>PARA</th>
<th>SHAPE</th>
<th>FRAC</th>
<th>CIRCLE</th>
<th>CONTIG</th>
<th>PROX</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue oak</td>
<td>0.647</td>
<td>0.553</td>
<td>0.553</td>
<td>0.568</td>
<td>0.866</td>
<td>0.358</td>
<td>0.838</td>
<td>0.160</td>
</tr>
<tr>
<td>2005</td>
<td>0.900</td>
<td>0.460</td>
<td>0.374</td>
<td>0.121</td>
<td>0.121</td>
<td>0.263</td>
<td>0.001</td>
<td>0.120</td>
</tr>
<tr>
<td>blue oak-valley oak</td>
<td>0.332</td>
<td>0.098</td>
<td>0.186</td>
<td>0.023</td>
<td>0.014</td>
<td>0.129</td>
<td>0.168</td>
<td>0.002</td>
</tr>
<tr>
<td>2005</td>
<td>0.530</td>
<td>0.353</td>
<td>0.075</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.023</td>
</tr>
<tr>
<td>cottonwood</td>
<td>0.381</td>
<td>0.338</td>
<td>0.023</td>
<td>0.319</td>
<td>0.004</td>
<td>0.001</td>
<td>0.387</td>
<td>0.346</td>
</tr>
<tr>
<td>2005</td>
<td>0.281</td>
<td>0.200</td>
<td>0.381</td>
<td>0.319</td>
<td>0.319</td>
<td>0.109</td>
<td>0.038</td>
<td>0.161</td>
</tr>
<tr>
<td>cottonwood-willow</td>
<td>0.733</td>
<td>0.614</td>
<td>0.651</td>
<td>0.492</td>
<td>0.348</td>
<td>0.048</td>
<td>0.612</td>
<td>0.101</td>
</tr>
<tr>
<td>2005</td>
<td>0.240</td>
<td>0.356</td>
<td>0.118</td>
<td>0.663</td>
<td>0.663</td>
<td>0.869</td>
<td>0.112</td>
<td>0.049</td>
</tr>
<tr>
<td>grassland</td>
<td>0.502</td>
<td>0.501</td>
<td>0.320</td>
<td>0.245</td>
<td>0.213</td>
<td>&lt;0.001</td>
<td>0.295</td>
<td>0.172</td>
</tr>
<tr>
<td>2005</td>
<td>0.400</td>
<td>0.014</td>
<td>0.007</td>
<td>0.034</td>
<td>0.093</td>
<td>0.109</td>
<td>0.066</td>
<td>0.090</td>
</tr>
<tr>
<td>valley oak</td>
<td>0.032</td>
<td>0.001</td>
<td>0.007</td>
<td>0.010</td>
<td>0.134</td>
<td>0.018</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2005</td>
<td>0.008</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>valley oak-cottonwood</td>
<td>0.303</td>
<td>0.757</td>
<td>0.903</td>
<td>0.999</td>
<td>0.352</td>
<td>0.376</td>
<td>0.913</td>
<td>0.084</td>
</tr>
<tr>
<td>2005</td>
<td>0.031</td>
<td>0.073</td>
<td>0.572</td>
<td>0.356</td>
<td>0.367</td>
<td>0.406</td>
<td>0.486</td>
<td>0.011</td>
</tr>
<tr>
<td>willow</td>
<td>0.165</td>
<td>0.275</td>
<td>0.023</td>
<td>0.061</td>
<td>0.098</td>
<td>0.178</td>
<td>0.026</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2005</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2006</td>
<td>0.003</td>
<td>0.039</td>
<td>&lt;0.001</td>
<td>0.436</td>
<td>0.257</td>
<td>0.127</td>
<td>&lt;0.001</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Table 5. One-way ANOVA significant levels comparing land-cover metrics against three timeframes of analysis and grouped by AOI section

<table>
<thead>
<tr>
<th>Landcover Class</th>
<th>Area</th>
<th>OYRATE</th>
<th>PARA</th>
<th>SHAPE</th>
<th>FRAC</th>
<th>CIRCLE</th>
<th>CONTIO</th>
<th>PROX</th>
</tr>
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*** Indicates not enough data for statistical analysis.

Note. Bolded figures represent significant numbers—under 0.005.
Figure 4. Changes in the Delta AOI Blue oak land-cover class.
Figure 5. Changes in the Delta AOI Blue oak-valley oak land-cover class.
Figure 6. Changes in the Delta AOI Cottonwood land-cover class.
Figure 7. Changes in the Delta AOI cottonwood-willow land-cover class.
Figure 8. Changes in the Delta AOI grassland-cover class.
Figure 9. Changes in the Delta AOI valley oak land-cover class.
Figure 10. Changes in the Delta AOI valley oak cottonwood land-cover class.
Delta Section Area of Interest

Changes in land-cover from 1938 to 2005

Figure 11. Changes in the Delta AOI willow land-cover class.
Figure 12. Changes in the Henlyville AOI blue oak land-cover class.
Figure 13. Changes in the Henlyville AOI blue oak-valley oak land-cover class.
Figure 14. Changes in the Henlyville AOI cottonwood-willow land-cover class.
Figure 15. Changes in the Henlyville AOI grassland-cover class.
Figure 16. Changes in the Henlyville AOI valley oak land-cover class.
Figure 17. Changes in the Henlyville AOI valley oak-cottonwood land-cover class.
Figure 18. Changes in the Henlyville AOI willow land-cover class.
Figure 19. Changes in the Flournoy AOI blue oak land-cover class.
Figure 20. Changes in the Flournoy AOI blue oak-valley oak land-cover class.
Figure 21. Changes in the Flournoy AOI cottonwood-willow land-cover class.
Figure 22. Changes in the Flournoy AOI grassland-cover class.
Figure 23. Changes in the Flournoy AOI valley oak land-cover class.
Figure 24. Changes in the Flournoy AOI valley oak-cottonwood land-cover class.
Figure 25. Changes in the Flournoy AOI willow land-cover class.
Figure 26. Changes in the Paskenta AOI blue oak land-cover class.
Figure 27. Changes in the Paskenta AOI cottonwood-willow land-cover class.
Figure 28. Changes in the Paskenta AOI grassland-cover class.
Figure 29. Changes in the Paskenta AOI valley oak land-cover class.
Figure 30. Changes in the Paskenta AOI valley oak-cottonwood land-cover class.
Figure 31. Changes in the Paskenta AOI willow land-cover class.
consistently more variable in patch size for all three timeframes of analysis as MPSSD changed from 2.4 ha in 1938, to 3.9 ha in 1958, and to 3.5 ha in 2005.

**Cottonwood**

In 1938, there was 1.5 ha of cottonwood occurring in 19 patches throughout the Delta AOI. These existed until 1958, but decreased to only two patches covering a total of 0.3 ha in 2005 (an 80% decrease in total area and a 60% decrease in the number of patches). In 1938, there were 2.2 ha of cottonwood in the Paskenta AOI, this decreased 13% by 2005. Most of the losses seen in this class were isolated large trees previously occupying the streamside terraces alongside the active channel of Thomes Creek.

**Cottonwood-Willow**

The cottonwood-willow class is very dynamic in that it has shown little uniformity in its spatial patterning and complexity between time periods. Yet, it has shown very little significant changes between AOI sections and timeframes of analysis about 5% persisted in the Delta AOI section and after 1958 this class grew significantly less complex and more aggregated (Table 2) as shown by This class experienced a 32.1 ha (50%) loss in the Henlyville AOI. The primary loss in this section occurred in an area where there was observed to be a northward lateral migration of the Thomes creek active channel. In 2005 the area previously occupied by the 10 ha cottonwood-willow patch was determined to have become patches of valley oak and valley oak-cottonwood. Further upstream, the cottonwood-willow class in the Flournoy AOI became more fragmented, increased shape complexity, and less evenly distributed along this section.
The Paskenta AOI cottonwood-willow decreased 20.6 ha (28.8%) in total area with very little patch persistence between the three years of analysis.

**Grassland**

The grassland patches in the Delta AOI section increased 246%; going from 56.6 ha in the 1938 landscape to 196.4 ha in 2005. The only significant change was observed in this class’s indices was the PROX index where such increases also translated to distances between patches decreasing. Most of the grassland patches lost was due to changes in land-use, (field observations verified that current land-use associated with grassland-cover was for livestock production; specifically, cattle production) in the persisting patches became significantly closer in proximity, less fragmented, and less complex. One partial contributor in this significant increase (Table 2) observed for this class was the conversion of gravel patches on both sides of the Thomes Creek channel after 1958. The grassland class for the Paskenta AOI section has displayed much patch persistence through the three timeframes of analysis; it has also doubled from 396.5 ha in the 1938 analysis to 668.1 ha in 2005.

**Valley Oak**

The primary significant changes throughout the entire Thomes Creek AOI for the valley oak land-cover class indices were due to the loss of many singular mature individuals that had occupied the upland terraces in 1938 and w removed by 1958. Gains were seen at the confluence of the Thomes Creek and the Sacramento River in the Delta section AOI in 1958 and 2005. Patches here tended to increase in size and become incorporated into each other but the southward lateral migration of the Sacramento River was the cause of 14 ha loss in valley oak patches. The Henlyville
total class area increased four-fold during the analysis. Data shows that along with the increase in patch sizes and area, the patch distribution and complexity also significantly increases across the three timeframes of analysis. The largest patch occurrence was created after 1958; where previously it had been dominated by mature cottonwoods located adjacent to the Thomes Creek channel. The canopy structure and distribution of these species is starkly contrasted to the cottonwoods and willows that occupied the area beforehand. It should also be noted that in the 2005 analysis, signs of flooding were not noticed as were seen in 1958 and 1938.

The Flournoy AOI section had very little persistence during the timeframes of this analysis. Data shows significant changes in 1958 for patch PERIM and CONTIG; indicating a change in complexity and aggregation on the landscape. One of the primary contributors to this change observed after 1938 was the loss of a 7 ha valley oak patch that had recruitment of cottonwood trees into its canopy. At this spot in particular, the active channel migrated horizontally through this patch in 1958 and became incised on the north side of the creek. In 2005, this patch was delineated as valley oak-cottonwood with an area of 6.8 ha.

About 7 ha of valley oak were lost from the Paskenta AOI section during the three timeframes of analysis. Most of the patches lost were mature canopies that became removed from upland areas, including many that occupied both sides of the creek where the town of Paskenta has expanded.

Valley Oak –Cottonwood

The Delta AOI valley oak-cottonwood had a net increase of 1.9 ha over this timeframe of analysis; starting at 9.3 ha in 1938, to 11.2 in 2005. From 1958 to 2005,
there was significant decrease in AREA, PERIM, GYRATE, SHAPE, and suggesting that patches started growing in smaller and less complex shapes in this section after 1958. The Henlyville valley oak-cottonwood class indices show slight increase in size and variability among patches with much persistence in patch location throughout the entire timeframe of analysis. In the Flournoy AOI section there was a net increase of 59 ha between 1938 and 2005. The entire class resides within areas that are, or have previously been part of the Thomes Creek active channel. Much of the increase in this class was from patches that succeeded from the cottonwood-willow land-cover class. Patches increased a net of 16.5 ha from 1938 to 2005 in the Paskenta AOI section; many of these patches were decreased by 1958 along the channel; and were subsequently identified as cottonwood-willow patches. Persistent patches in this area were usually adjacent to the active channel of Thomes Creek. Most gains in 1958 were seen along the narrow sections of the active channel, about 1 km upstream from Paskenta. These patches did not persist into 2005; however increase was seen again back at the other end of the Paskenta AOI by the Corning Bridge as vegetation shifted back from the cottonwood-willow class into the valley oak-cottonwood.

**Willow**

The Delta AOI section had 20 ha of willow in 1938 that decreased to 9.2 ha in 2005. Data suggest that the willow patches were highly variable in size and shape in 1938, becoming more uniform and significantly less complex in 1958. In 2005, the patch complexity was still determined to be uniform throughout the class; however, they increased their PERIM, becoming more complex in shape than in 1958. The Henlyville willow total class area almost doubled in size between 1938 and 2005 (net
increase of 17 ha) and also showed tendency to significantly increase in patch size. The predominant characterization Henlyville AOI willow is that it has shown very little persistence between the time periods of observation and that it has become significantly more distributed throughout the landscape mosaic. The 1958 timeframe of analysis showed some temporary and yet significant changes to the willow land-cover class both temporally within each AOI (Table 2) and spatially-temporally amongst AOIs (Table 3). The Paskenta AOI section willow patches showed a slight net increase for all the three timeframes of analysis. This Class displayed a highly dynamic nature as almost no persistence was seen between any of the timeframes. Consistent to observations made in other AOI sections, all patch occurrences are located within or adjacent to, the Thomes Creek active channel; furthermore, new gains and losses for the willow land-cover class occurred alongside the lateral channel migrations. After 1958 these patches also became significantly closer to each other in proximity. All gains for this class have been upon, or adjacent to the areas identified to be the Thomes Creek active channel or floodplain; wherewithal primary losses to this class have been observed south of the channel as the active channel has tended to move northward in many areas.

Changes in the Landscape Mosaic

Delta

The Delta AOI section increased in both evenness and patch diversity throughout the entire timeframe of analysis (Figures 32 and 33). The 1938 Delta AOI landscape was dominated by both cropland (41%) and the gravel patches of the Thomes Creek active channel (34%). The natural vegetation LULC classes comprised about
Figure 32. Thomes Creek AOI subsections for Landscape Mosaic Patch richness.

Figure 33. Thomes Creek AOI subsections for Landscape Mosaic Patch evenness.
25% of the 1938 Delta AOI section landscape. The cropland class had decreased to 12% and the active channel to about 6% in the 2005 analysis. The natural vegetation patches more than doubled during this time. The willow LULC class was the largest contributor of the increase of riparian vegetation patches; it went from being 1% of the landscape in 1938, to being about 3% in 2005.

**Henlyville**

The Henlyville AOI section also increased for both landscape diversity and evenness for all three timeframes of analysis. The 1938 landscape represented 45% in grassland patches, 30% gravel in the active channel, and 11% cropland. The riparian components in this landscape made up about 13% of the 1938 Henlyville landscape. By 2005, riparian vegetation classes had stayed about the same and active channel gravel patches had decreased to being 20% with gravel mining operations being introduced after 1958. These gravel-mining operations made up about 7% of the 2005 landscape and increased about four-fold to become 6% of the landscape. The grassland class orchards decreased some in its dominance among the landscape mosaic to becoming 40% of the landscape.

**Flournoy**

The landscape mosaic diversity within the Flournoy AOI section showed a substantial decrease 1958 while patch mosaic evenness showed gradual increase for all three timeframes of analysis. The 1938 landscape was 37% cropland, 26% gravel in the active channel, and 16% grassland. The riparian vegetation made up about 15% of the landscape in the 1938 analysis. This stayed about the same into the 1958 timeframe of analysis with some small conversions of cropland patches into grassland patches. In
2005, cropland patches had further decreased to about 9% of the landscape; the gravel patches had decreased to 18% and the grassland patches had a three-fold increase and were 51% of the 2005 landscape mosaic. Riparian vegetation class’s percentage of the landscape doubled over this time and in 2005 was 30% of the landscape. Primary increases were seen in the valley oak-cottonwood class where it doubled from being 5% of the Flournoy AOI landscape in 1938 to 12% in 2005.

Paskenta

The Paskenta AOI section substantially decreased in both landscape mosaic evenness and diversity after the 1958 timeframe of analysis. 24% of the 1938 landscape was cropland, 33% was grassland, and the gravel patches in the active channel contributed 17%. The riparian vegetation classes displayed 10% coverage and upland hardwoods (valley oak and blue oak) were 11%. The only changes in the 1958 analysis were a slight increase in the blue oak class and a small decrease in the gravel patches of the active channel. The grassland patches had about doubled to comprise 56% of the landscape. By 2005, the Thomes Creek active channel had decreased by about 80 ha to become 10% of the landscape. The riparian and upland hardwood LULC classes stayed about the same throughout this analysis.
CHAPTER V

DISCUSSION

Land use in the Thomes Creek Basin

In the Thomes Creek Basin there has been some primary land-use processes introduced after 1850 that have changed its nature in such a way as to affect its fluvial processes and the associated biological habitats (USFS 1997). Starting in the 1860’s and continuing into the 1920’s, land usage in the Thomes Creek Basin was primarily intense livestock production. It has been observed that by exceeding an arid rangeland’s livestock carrying capacity and allowing unrestricted access to stream channels, soil health and water quality can become degraded; shifting terrestrial and aquatic biota into more homogenous and less productive compositions (Box 1967; Thurow et al. 1988; Bjorn and Rieser 1991). Lasting results from grazing during this time were the localized upland ground compaction causing a loss of infiltration rates; this subsequently led to higher peak flows from a more rapid delivery of intercepted precipitation (USFS 2007).

Logging activities became the significant practice in head water reaches in Thomes Creek after the 1920s. Peak timber harvesting activities occurred from about 1950-1970. Air photo analysis shows a 400% increase in active landslides during this time when soil disturbance from logging activities became widespread throughout drainage basin (California Department of Water Resources 1982; Hoover 2006) The USFS (1997) claims about 6 km of roads within the watershed cross active slides and
about 25km cross dormant slides. Hillslope failure has increased from road building across these slide areas by reducing slope stability by cutting away the substrate on the uphill side while increasing weight below the road. The USFS also claims that about 133.6 km (16%) of the roads in the watershed are on the unstable geology having slopes over 40°. The hydrograph also changed for Thomes Creek after the increase of logging activities in the upper reaches in about 1954. The annual peak flows increased (Figure 34) during this time and the Thomes creek System became one that was flashier in its nature.

One of the primary activities introduced into the lower reaches of the Thomes Creek channel after 1958 is gravel mining. There are now eleven gravel mines along Thomes Creek that extract a total of 281,000 yd³ annually, with 80% of the permitted extractions occurring within the creek bed of the Delta AOI section. The sediment budget created for Thomes Creek by Hoover et al. (2006) states that on average, 14,500 yd³/year of bedload sediment may be stored upstream from this study area within the headwater reaches. While within the lower reach study zones approximately 30,000 yd³/year of sediment are stored within the Paskenta AOI section and an estimated 20,700 yd³/year of bedload sediment are stored in the Flournoy AOI section. Hoover et al. (2006) further stated that the mining activities in the active channel within the Henlyville AOI Section and the Delta AOI section are annually depleting by about 1000yd³/year and up to 18,500yd³/year.

Water extractions for agricultural needs along the lower reaches have also changed the hydrology of Thomes Creek. There were four diversion dams identified in
Figure 34. USGS hydrograph for Thomes Creek, annual peak flow events.
the 2005 timeframe of analysis; two of which have persisted since the 1938 time frame of analysis. These diversion dams are usually formed by moving gravel from within the active channel in early spring to create an incomplete dam that allows the passage of water to continue downstream as well as into the diversion channel. By about the 1958 timeframe of analysis there was also the installation of the Central Valley project’s Tehama-Colusa canal and the Corning canal that both siphon water from the Thomes creek active channel. Many of the agricultural areas within the drainage basin also began using use ground water pumps after the 1958 analysis to supply irrigation to pastures and orchards. Currently there is no data available to determine how much water is pumped in the basin or the effects upon the hydrological regime within the channel (Keppen and Slater 1997; USFS 1997). The suspicion is that this pumping has contributed to the lowering of the water table; causing mortality in the adjacent cottonwoods increasing the tendency for Thomes Creek to go subsurface in the lower reaches during the warmer months.

The single most defining event that has occurred within the Thomes Creek basin is the warm rain-on-snow flooding event of December 22, 1964 (Howard and Varnum 1982; Hoover et al. 2006; USFS 1997). Hundreds of thousands of cubic yards of material flowed out of the headwater reaches during this event and have aggraded the entire channel from the town of Paskenta to the confluence with the Sacramento River. Although this would normally be treated as a natural occurrence of aggradation within the Delta AOI section, the volume of bedload transport into this area by the event was significantly augmented by the preponderance of logging and road building activities in
the headwaters which allowed for the development of an abnormally high sediment yield that is not expected to decrease (USFS 1997).

**Biological Responses**

Willow LULC class had an overall decrease in its total class area with the largest losses occurring were in the Henlyville and Delta AOI sections where gravel mining activities have decreased the suitable habitat for this class within the active channel. Many of the large willow patches that occupied the banks of the Paskenta and Flournoy sections in the 1958 analysis were delineated as cottonwood-willow by 2005. This succession indicates that these patches have become disconnected from the active channel and no longer subjected to high-flow events (Turner et al. 1998).

Cottonwood class was never very large in its total class area for any of the four AOI sections over the three timeframes of analysis. There was however, a decrease in the large mature trees occupying the upland terraces of the Henlyville and Delta sections with very few gains in this regard. Many remains of these trees identified as mature in the 1938 and 1958 analysis still remain although now in a decaying stage upon the landscape. It is reasonable to conclude that with the aggregation of the Thomes Creek channel in conjunction with demands, groundwater irrigation demands for agriculture in the Henlyville and Delta AOI sections that those cottonwoods have lost access to subsurface flows.

Cottonwood-willow patches showed significant changes in their spatial patterning within the Delta and Henlyville AOI sections after 1958. They tended to become more evenly distributed throughout these reaches and became more linear in
their spatial patterning. The 2005 analysis showed that almost all of these patches had changed from residing within the main channel to growing alongside of it; somewhat parallel and in a more of a linear pattern. Field observations (Figure 35) also suggest that this is in part due to the scraping of the streambed while harvesting gravel mining within the Thomes Creek active channel decreasing the suitable habitat previously offered to this in the 1938 and 1958 analysis. Indices also show that by 2005 this class was significantly different in these two sections as compared to the Flournoy and Paskenta AOI sections where they showed successional changes, or recruitment of new woody species into the canopies while staying the same in their spatial patterning (i.e.,

![Figure 35. Delta AOI active channel, facing upstream and looking west.](image)
non-linear shapes) along the active channel and in the floodplain throughout the analysis.

The Paskenta and Flournoy sections had no significant changes in the spatial patterning of the cottonwood-willow class but had the most succession of this class into valley oak-cottonwood. Many of these cottonwood-willow patches seen in both the 1938 and 1958 analyses showed clear signs of flooding events throughout and around them. By 2005 many of these patches had increased in both size and spatial distribution, showed no signs of flooding events, and had enough canopy recruitment of valley oak to be delineated as valley oak-cottonwood (Figure 36). The gains in the valley oak-cottonwood class in the upper AOI areas is primarily from aggradation in the channel from the 1964 flood where it increased the suitable substrate for this vegetation class and stream flows since have been insufficient to flush out the material (Howard and Varnum 1982; USFS1997). In many areas throughout these two sections, the active channel moved northwards and decreased in floodplain width. Many large patches identified as cottonwood–willow in the 1958 analysis were delineated as valley oak-cottonwood in the 2005 analysis. These successional observations agree with Griggs (2009); where several decades of depositional organic matter accumulate a layer about 1-3 meters deep, allowing valley oak and elderberry to establish and over a period of 40 to 100 years, plant associations change from a dominant willow-cottonwood to valley oak dominated canopy.
Figure 36. Paskenta AOI section active channel facing upstream and looking west.

CHAPTER VI

CONCLUSION

Summation

Soil fertility and water accessibility have been historically the primary limiting factors that regulated land-use in this drainage basin. Intensive grazing on the lower reach occurred for about 70 years as the major impact on the watershed until 1920s when timber harvesting became a major land-use impact in the mid-elevations and headwaters. Peak timber harvest was from late 1950s-1970 when hillslope failure increased 400% in the headwater reaches due to the addition of logging harvest roads. The sedimentary input into this fluvial system was subsequently augmented, particularly the culminating event in December 1964 when warm rain hit the snow pack and flushed hundreds of thousands of cubic yards of clastic material into the channel, thereby aggrading it from the town of Paskenta to the Sacramento River confluence.

Although grazing activities are still a major component for this area (primarily beef), the introduction of wells, water canals, diversion dams and synthetic fertilizers have allowed land managers to introduce or augment production of various annual crops and orchards due to increased water accessibility and regulated flooding activities along the stream channel. Much of the lower portions of the drainage basin has become large agricultural activities including orchards and irrigated hay production.
Subsequently, instream flows in Thomes Creek tend to go subsurface in many portions of the Henlyville and Delta sections more than historically recorded (USFS 1997).

The nature of lower Thomes Creek has changed during the timeframe of analysis. Little change was seen in the land-cover classes from the 1938 to 1958 timeframe. The 1938 imagery showed large parcels of dry land agriculture having furrows around mature valley and blue oaks on the upland terraces of the Paskenta and Flournoy AOI landscapes. By 1958 most of these row crop areas were fallow and observed to be grasslands. This shift from crop production to grassland is the primary reasons for the decrease in the landscape homogenization in the Paskenta and Flournoy AOI sections, while the conversion of many large grassland areas to orchard production was the primary cause for the increased landscape diversity in the Henlyville and the Delta AOI sections. The Thomes creek channel seemed to be relatively uniform in its location for both 1938 and 1958; although the active channel was in different locations during these two times, both showed signs of flooding throughout the riparian areas.

About 50% of the watershed has highly erodible soil (Irwin 1957; USFWS 1997). Having unregulated livestock access to Thomes Creek encourages erosion and water quality degradation. Grazing of the riparian vegetation causes bank erosion, directly resulting in both stream channel widening and downcutting (Kaufman and Krueger 1984; Hall and Bryant 1995; George et al. 2004). Consumption of residual streamside vegetation biomass decreases the trapping and deposition of sediments, which is a basis for maintaining or rebuilding stream banks (Clary and Webster 1989) leading to higher exposure of the stream bank to the shearing influence of the stream.
Gravel mining operations along Thomes Creek have also resulted in increased sedimentation. These activities usually run from the middle of spring until the middle of fall when the stream becomes dry. The California Department of Fish and Game (1993) are concerned with the mining operations changing the composition and integrity of the instream habitats by creating deficits of cobble and gravel as well as increasing the chloric clays found in many of the soils formed from the Franciscan formation and the Great Valley Sequence geologies. These dissolved and entrained additions into Thomes Creek decrease stream integrity as the removal of the coarser material allows the finer sediment to become exposed during times of increased flow.

Much of the Henlyville and Delta AOI sections had a wide braided and anastomosing creek channel that was seemingly unregulated in its lateral movements in 1938. There was only one small gravel mine at that time on the south bank within the Delta AOI harvesting a 1.4ha area. Access across the creek then was seasonal; half the roads had no bridges to constrain or influence lateral migrations of the creek. The riparian vegetation in general was less subjected to annual disturbance from periodic high flow events and as a result, showed less persistence from 1938 to 1958, particularly in the willow patches.

After 1958, the Thomes Creek landscape became more diverse in its landscape mosaic but the riparian LULC classes had seemingly changed in their “naturalness.” Upland areas were larger and less complex. Many of the mature individual valley and blue oaks, as well as cottonwoods were removed or have died after 1958 and have showed little evidence of recruitment as a result of the land-use practices.
There is little doubt that historical land-use within the headwater reaches from timber harvesting activities have altered the nature of the lower reaches of Thomes Creek by augmenting sedimentary inputs into the system, particularly during the 1964 flooding event which was the primary cause for aggradation in the lower reach. Changes in the terrace land-use and management have decreased the ability for the dominant riparian vegetation classes to have access to historical anastomosing surface flows, and a subsurface water table as the bed has become aggraded and groundwater pumping has lowered the water table. Many of the adjacent terrace hardwood vegetation has been removed from the landscape and the many decadent cottonwood trees in the Delta and Henlyville AOI sections have seemingly lost access to the hydrological regime that originally established them upon the landscape.

The Paskenta and Flournoy AOI sections of the Thomes Creek channel have become aggraded after the 1964 flooding event, although the primary size of the channel material here would be considered large gravel and cobble. The active channel has decreased in its ability to laterally braid as the active channel has become decreased in width in many areas due to the inflow of material during the 1964 flooding event. This material subsequently allowed recruitment of cottonwood-willow patches that ultimately had transitioned to valley oak-cottonwood patches in the 2005 timeframe of analysis. This study had no direct analysis into changes in, or current conditions for aquatic habitat within the Thomes Creek fluvial system and the habitats offered to both anadromous and sport fish populations. It has been documented that historical populations for both have declined and that rearing habitat for both salmon and steelhead is minimal in the lower Thomes Creek active channel (Maslin et al. 1996,
The diversion dams are usually put into place at times when fish would be coming down the channel and as they are unscreened, this creates substantial risk for entrapment into environments fatal to these species. Further inquiries into the Thomes Creek drainage basin should address the declined aquatic habitat to its fisheries and the potential remediation of their degradation.

Future Implications

The gravel mining activities in the Delta and Henlyville AOI sections have homogenized the instream channel and limited the favorable conditions for the willow species and cottonwoods, which once occupied the active channel, to the banks of Thomes Creek. Annual gravel mining activities in these two study areas will continue to create unfavorable conditions for any future establishment of this vegetation within the channel.

Aerial photograph examination of this entire study area showed a decrease in signs of flooding through willow and mature cottonwood-willow stands. It was observed that many of these stands had succeeded from willow to cottonwood-willow and from cottonwood-willow to cottonwood-valley oak. As the hydrology has changed in the Thomes Creek drainage basin and the topographic features have been homogenized (aggraded) due to flooding events with augmented sediment loads and gravel mining activities; it is reasonable to expect vegetation to continue succession into a rather uniform and somewhat uniform stands of valley oak and/or valley oak-cottonwood in the Paskenta and Henlyville AOI sections. It is also reasonable to expect willow patches to become mature and rather uniform in age and composition; changing
their dynamic nature in the Henlyville and Delta AOI sections by becoming persistent and linear along the edges of the Thomes Creek active channel and the associated gravel mining sites.
REFERENCE LIST


________. 1981. *Gravel recruitment on Thomes Creek under existing and post-project conditions; Memorandum Report*. Red Bluff, CA: California Department of Water Resources.


University of Massachusetts, 2000. *Fragstats metrics definitions.* Amherst, MA: University of Massachusetts Department of Geography.


APPENDIX A
# LIST OF FIGURES

## APPENDIX A

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Figure 1A. Delineation of 1938 LULC landscape features for Delta AOI.

Figure 2A. Delineation of 1938 LULC landscape features for Henlyville AOI.

Figure 3A. Delineation of 1938 LULC landscape features for Flournoy AOI.

Figure 4A. Delineation of 1938 LULC landscape features for Paskenta AOI.

Figure 5A. Delineation of 1958 LULC landscape features for Delta AOI.

Figure 6A. Delineation of 1958 LULC landscape features for Henlyville AOI.

Figure 7A. Delineation of 1958 LULC landscape features for Flournoy AOI.

Figure 8A. Delineation of 1958 LULC landscape features for Paskenta AOI.

Figure 9A. Delineation of 2005 LULC landscape features for Delta AOI.

Figure 10A. Delineation of 2005 LULC landscape features for Henlyville AOI.

Figure 11A. Delineation of 2005 LULC landscape features for Paskenta AOI.

APPENDIX REFERENCES

