Central
Coast
Watershed
Studies

CCoWS

Land Use History and Mapping in California's Central Coast Region

Wendi Newman[1]
Fred Watson[1]
Mark Angelo[2]
Joel Casagrande[1]
Bronwyn Feikert[1]

Report No. WI-2003-03
Final Report April 2003

The Watershed Institute

Earth Systems Science and Policy
California State University
Monterey Bay
www.science.csumb.edu/~ccows

100 Campus Center, Seaside, CA 93955-8001
(831) 582-4431 / 4452

Authors reside at:
[1]Watershed Institute, California State University Monterey Bay
[2]Regional Water Quality Control Board. San Luis Obispo, CA

Lead author contact details:
wendi_newman@csumb.edu

Suggested citation:

Newman, W.B., Watson, F.G.R., Author 3, Author 4 (2003)
Land Use History and Mapping in California's Central Coast Region
The Watershed Institute, California State University Monterey Bay,
Publication No. WI-2003-03, 86 pp.

It is accompanied by a map:

Newman, W.B. & Watson, F.G.R. (2003)
Land Use / Land Cover of the Central Coast Region of California
The Watershed Institute, California State University Monterey Bay,
Publication No. WI-2003-04.

Preface

TMDL funding was provided by the California State Water Resources Control Board (SWRCB Grant 9-168-130-0), with more general support from the National Aeronautical and Space Agency and the Environmental Protection Agency (EPA) (NASA Grant NAG6-6529). Additional funding was provided by the David and Lucile Packard Foundation (99-7939).

Table Of Contents

1 Introduction

1.1 The need for land use information in the Central Coast region

Land use describes how an area of land is used (e.g., farming, residential) and land cover describes what is physically on the land (e.g. types of vegetation, buildings, water bodies). Understanding land use/land cover (LULC) is paramount in any watershed study. The interactions of topography, hydrology, vegetation, and land use are inextricably linked to all watershed issues. Remote sensing data and techniques are becoming more common and important in the assessment of land use and land cover.

The Central Coast region of California is changing rapidly in response to growing population pressures and burgeoning markets for specific types of crops. Urban lands are expanding into agricultural lands. In turn, new crop agriculture and viticulture are being developed on lands formerly supporting grazing or natural vegetation.

Instream pollutants freed by disturbance can be composed of sediment, organic matter, and chemicals that attach to suspended solids in the water column such as nutrients, herbicides, pesticides, and other chemicals. Both the new land uses and processes of disturbance have lead to increased export of pollutants from land to streams.

Land use change has a long history in the region, which once held the State Capitol at Monterey. The region been transformed several times, following the introduction of Europeans and their grain crops in the 1800s, the development of groundwater-based irrigation in the late 1920s, and the expansion of vineyards and urban areas in more recent years.

Land management must be aware of the history of the land, and of its current spatial state. The early chapters of this report review the major land use systems of the region and their history. The latter chapter presents a new remotely sensed land use map of the region. The report was prepared within the context of sediment source analyses (Watson et al., 2003). Reference is made to erosion from certain land types where appropriate.

1.2 Study area

State Water Resources Control Board Region 3 is a geographically and socially diverse area, with wide variation in landscape, geology, and resources. The Region covers 7.2% of the State of California or 29,800 km^2 (11,500 mi^2). The northern area incorporates Santa Cruz, and portions of San Mateo and Santa Clara Counties. The middle and largest section includes Monterey and portions of San Benito counties. The southern portion contains San Luis Obispo, Santa Barbara, and portions of Ventura Counties.

Region 3 contains one of the State of California's largest coastal watersheds, the Salinas River watershed located principally in Monterey and San Luis Obispo Counties. The Salinas River flows to the Monterey Bay National Marine Sanctuary from the southeast to the northwest over 283 kilometers (109 miles) through the narrow and fertile Salinas valley. The river drains approximately 11,700 km^2 (4,034 mi^2) of land consisting of many different landscapes. In general, grazing and natural lands exist in the surrounding foothills and mountainous areas, while agricultural and urban developments are found throughout the Salinas Valley floor.

Precipitation in the Region begins in fall and lasts through spring, with the heaviest rainfall during January and February typically. The northernmost mountains of the Region, the Santa Cruz Mountains, were home to once vast forests of coastal redwoods. These mountains receive large amounts of annual rainfall and fog drip, and generally support many year-round flowing streams and rivers. The mountains to the west of the Salinas Valley, the Santa Lucia Range, provide most of the annual water supply to the Salinas River (Watson et al., 2003). This rugged mountainous area is extensive; forest cover is varied and in most years, many streams flow year-round. Climate of the eastern mountains, the Gabilan, Diablo, and Temblor Ranges, is significantly drier due to less precipitation. The slopes are primarily covered with some oak, pine, annual grasses, and shrubs. The streams on this side of the valley are generally dry during the summer to fall, with the exception of small, isolated sections near springs and bedrock outflows. The Santa Lucia, La Panza, and Santa Ynez Mountains border the southern-most portion of the Region. These mountain ranges are similar to ranges just north, receiving similar amounts of rainfall, and exhibiting varied vegetative cover such as oak savanna, pine forests, grasslands, and shrubland.

Figure 1.1 The Salinas Watershed study area

The historical portions of this report focus primarily on Monterey and San Luis Obispo Counties. The land use map discussed later covers the full Region Three (37° 18’ to 34° 15’ N, 122° 25’ to 119° 04’ W). Figure 1.1 shows the location of the study area within California.

2 Description of land use systems

2.1 Introduction

The study area contains a wide variety of land uses and land covers, ranging from montane forest to arid grassland, from extensive grazing to intensive vegetable crops, and from new urban developments to golf courses and tourist and recreational precincts.

This chapter describes each major land system, and its relationship to region hydrology and sedimentology.

2.2 Natural lands

The natural lands of central California exist primarily along a moisture gradient from grassland to forest.

2.2.1 Perennial grassland

The arrival of Europeans and their cattle brought a number of non-native grasses to the rangelands of the region. Annual species such as wild oats (*Avena fatua*) are now ubiquitous (Gordon, 1996). Formerly, these areas supported a higher proportion of perennial bunch grass species (e.g. *Stipa* spp., *Bromus* spp., *Elymus* spp.). Examples of this landscape are now extremely limited. Some idea of their original composition can be gained from protected areas, such as the Hastings Nature Preserve on the divide between the Carmel and Arroyo Seco valleys and Fort Ord (Fig.2.1, 2.2).

Native perennial grasses evolved to grow slowly and provide year-round structural support and protection from raindrop impact on the soil (Henson and Usner, 1993). It could then be supposed that erosion from such undisturbed areas is limited.

Figure 2.1 Perennial grasslands on Fort Ord (Photo by Thor Anderson, December 2000)

Figure 2.2 Perennial grasses at Hastings Reserve (Photo by Fred Watson, July 1999)

2.2.2 Shrubland

Native shrublands still exist over much of their pre-European range. Chaparral communities are most prominent, but maritime and coastal sage scrub (Fig.2.3) and communities are also present These communities tend to dominate on steep, well-drained soils with poor nutrition (Fig.2.4). It is not uncommon to see a contour-oriented mosaic of chaparral and grassland, with the chaparral on the steepest slopes (Fig.2.5).

Figure 2.3 Maritime chaparral community of Fort Ord (Photo by Thor Anderson, March 2001)

Figure 2.4 Steep chaparral terrain in the Ventana Wilderness (Photo by Doug Smith, January 2003)

Figure 2.5 Mosaic of oak, grass, and chaparral common in the study area (Photo by Doug Smith, October 2001)

Figure 2.6 Chamise re-sprout after fire (Photo by Thor Anderson, Spring 1999)

Most species are dependent upon fire for regeneration. Community composition undergoes a succession after each burn. Many species regenerate from sub-surface tubers or crowns after a fire (Fig.2.6). Other species have long-lived seeds or serotinous cones for which fire is the catalyst for new growth. Most chaparral species are perennial, although many reduce their leaf area significantly during long rain-free periods.

After fire, when vegetation cover is largely absent for a year or two, shrublands may erode significantly if heavy rains fall (Watson, et al., 2003). Erosion risk most likely is thereafter reduced gradually, until reaching a minimum in late seral stages that typically exhibit extremely dense closed canopies.

2.2.3 Woodland

The woodland communities of the Salinas Watershed are mainly oak-dominated, with under story often dominated by grasses. A single oak species usually dominates, such as coast live oak (*Quercus agrifolia*) on the coast (Fig. 2.8), the drought-deciduous blue oak (*Quercus douglasii*) on drier inland slopes, and valley oak (*Quercus lobata*) in flatter inland areas (Fig. 2.7). Extensive valley oak savannah is now restricted to undeveloped areas such as the Hunter Liggett Military Reservation and small interior valleys. However, it may have been the dominant landscape over much of what is now flat irrigated agricultural land in the Salinas valley floor (Fig.2.9). The eastern ranges exhibit some conifer woodlands dominated by species such as gray pine (*Pinus sabiniana*).

Figure 2.7 Valley oak savannah at Atascadero, early 1915-1916 (Courtesy of the Atascadero Historical Society Museum, AHSM)

Figure 2.8 Coastal oak woodland (Photo by Doug Smith, March 2002)

Figure 2.9 Blue oak savanna (Photo by Fred Watson, 2001)

Most natural undisturbed woodland areas are considered low erosion risks except after fire.

2.2.4 Montane forest

Large tracts of montane forest line the upper elevations of the Los Padres National Forest in the west and southwest of the Salinas Watershed (Fig.2.10). These forests receive orographic rainfall, and are the most moist, natural communities in the region. A range of plant communities is represented, including forests dominated respectively by tanoak (*Lithocarpus densiflorus*), ponderosa pine (*Pinus ponderosa*), Coulter pine (*Pinus coulteri*), Monterey pine (*Pinus radiata*), and coast redwood (*Sequoia sempervire*n) (Fig. 2.11).

The montane regions of the study area can be significant sources of sediment both after fire, and as a result of the landslides that are prominent in this tectonically active landscape.

Figure 2.10 Montane view of Los Padres National Forest (Photo by Fred Watson, October 2002)

Figure 2.11 Montane conifer and chaparral communities near Gloria Grade (Photo by Fred Watson, Summer 2001)

2.2.5 Riparian communities

Many streams in the Salinas Watershed are bordered by native riparian trees and shrubs. A range of dominant species is displayed, depending on the climatic setting. Willow (*Salix spp.*) is widespread, as are cottonwood (*Populus trichocarpa*), dogwood (*Cornaceae sericea*), and alder (*Alnus rhombilfolia, A. rubra*). Sycamore (*Plantanus racemosa*) tends to be found in more moist and sheltered sites. Drier sites may forego trees in favor of shrubs such as coyote brush (*Baccharis pilularis*) and certain saltbush (*Atriplex*) species (Fig.2.12, 2.13). Where present, these communities protect streams from bank-erosion, and intercept material transported down from surrounding slopes.

Figure 2.12 Dry riparian corridor with vegetation (Photo by Fred Watson, Summer 2001)

Figure 2.13 Wet riparian corridor (Photo by Fred Watson, October 2001)

2.3 Modified lands

2.3.1 Grazed grasslands

Grasslands used for grazing are common throughout the Salinas Watershed. The majority of this area is grazed by cattle. Historically, native ungulates such as mule deer (*Odocoileus hemionus*) and tule elk (*Cervus elaphus*) were not confined and moved often over a large landscape. During a given season, domestic grazing can reduce the vegetative cover significantly below that of un-grazed areas (Fig. 2.14).

Figure 2.14 Grazed area with scant vegetation (Photo by Fred Watson, October 2002)

Highly grazed areas are susceptible to erosion through a variety of mechanisms. Reduced vegetative cover offers little protection from splash erosion by raindrops. Domestic herds often congregate around riparian areas, walking on stream banks and grazing riparian vegetation to access water. The tracks themselves are compacted and concave, and are thus efficient pathways for delivery of water and eroded materials to streams. Grazed stream areas and other areas of topographic convergence are more susceptible to channel erosion and gully incision than areas supporting perennial vegetation (Fig.2.15).

Figure 2.15 Cattle crossing a perennial stream (Photo by Fred Watson, 2001)

Total exclusion of cattle from sensitive, moist areas is difficult in extensive, arid ranches where pooling water for domestic herds is not otherwise feasible. However the impact of these herds may be reduced by excluding access to particular areas at during certain times of the year to allow for recovery. (Savory, 1988) (Fig.2.16).

Figure 2.16 Fencing out cattle and restoration of a riparian zone (Photo by Fred Watson, 2001)

2.3.2 Vegetable crops

The Salinas Watershed is famous for its vegetable crop production (Anderson, 2000). The combination of flat land, well-textured alluvial soils, groundwater irrigation technology, long rain-free periods, and the air-conditioning effect of coastal fog associated with offshore upwelling facilitates the production of $659 million of lettuce annually in Monterey County (Agricultural Commission, 2001) Other major vegetable crops of the region include broccoli, spinach, artichoke, brussel sprouts, and celery (Fig.2.17,2.18). Production is concentrated on the northern Salinas Valley floor, closer to the coast, the flat land, and the major aquifers. Typically, two crops per year are grown, staggered to optimize marketability. On much of the land, food crops are grown only in the warmer months between spring and fall. During winter, this land is either fallow or cover cropped. For lettuce pest control, there is a two-week period around Christmas during which no lettuce may be above ground. Winter crops include biennial strawberries and artichokes, both of which are often grown on sloping soils.

Figure 2.17 Artichoke field (Photo by Fred Watson, 2000)


Figure 2.18 Row crops (Photo by Fred Watson, 2001)

All production is irrigated, and most involves the use of fertilizers, soil amendments, herbicides, and pesticides. Fertilizers may be dressed in solid form or "fertigated" with the irrigation water. Pesticides may be applied by solid granular form, fumigation, direct spraying, or aerial spraying by helicopter or fixed-wing aircraft. Monterey County ranked 4th in the State in 2001 in pounds of pesticide applied, and growers use a wide variety of pesticides annually (DPR, 2001). Today, only pesticides with reduced environmental impacts – such as those with short half-lives – may be used. Banned long half-life pesticides such as DDT were formerly used and may still be found in soils and sediments in some areas (SWRCB et al., 1998). Soil amendments include composting with organic refuse from vineyards, and more traditional liming. Organic farming occurs according to various organic certifications but is limited by lower market demand but higher prices. Water quality issues are rapidly rising to prominence in the vegetable industry, which is responding with innovations such as "Fields to the Ocean" water quality certified produce.

The industry is extremely competitive. Land and labor costs continually rise. The recent state electricity crisis has raised groundwater-pumping costs. The groundwater itself is being depleted (MCWRA et al., 2001), despite replenishments achieved through two large storages completed in the 1950s and 1960s (reservoirs San Antonio in 1965, and Nacimiento in 1957 (DWR, 1993). Following lawsuits elsewhere in the country, food retailers are passing greater liability for food safety down to the growers themselves. On the ground, this results in constraints such as buyers and packers avoiding crops produced near riparian areas where rodents may contaminate crops.

2.3.3 Vineyards and Strawberries

Viticulture has been present in the Salinas Valley since the late 1700's. The drier, sloped land of the foothills above the valley floor is favored for vineyard planting (Fig. 2.19). The wine industry first experienced a boom in the 1960's, and continues to grow today. In Monterey County in 1991 there were 21,000 acres of vineyard, and ten years later in 2001, the amount of acreage increased to 38,000, producing a crop worth $209 million (Agricultural Commission, 2001). Vineyards can help conserve soils and water by planting cover crops between rows and by use of drip irrigation. Vineyards installed on steep land can become areas of erosion during heavy rain if techniques of contouring rows and cover crops are not utilized. Vineyards can also be significant sources of sediment during start-up years due to the substantial disturbance of land required for planting preparation. Land where strawberries are grown is

Figure 2.19 Vineyard (Photo by Fred Watson, 2001)

especially vulnerable to erosion by virtue of the fact that many fields are covered in plastic, creating an impermeable surface for runoff (Fig.2.20).

Figure 2.20 Strawberry field with contoured rows (Photo by Fred Watson, 2001)

2.3.4 Orchards

Although orchards are not common in the Salinas Valley today, during the early 1900's many types of fruit and nuts were grown (Allen, 1932). There are orchards in Monterey, Santa Cruz, Santa Barbara, and San Luis Obispo Counties. The Pajaro Valley still sustains an apple crop, but most of the orchards in the Salinas Valley have been replaced by other agriculture.

2.3.5 Urban

The Salinas Valley has a current population of about 402,000 people, and by 2020 is projected to grow by 34% (Monterey County, 2002). Monterey County is currently revising its General Plan to meet the challenges presented by a combination of sprawl, agricultural land conversion, transportation, water supply, housing density and supply, and other concerns. Urban areas can contribute to poor water quality due to runoff of nutrients, pesticides, herbicides, road oils, and sediment. Seawater intrusion is also a problem in the northern Salinas Valley (MCWRA, 2001). Achieving adequate water quality and quantity from wells that supply cities as well as agriculture will continue to be a challenge into the future (Fig.2.21).

Figure 2.21 Urban area of Salinas next to crops (Photo by Doug Smith, January 2003)

2.3.6 Golf

Monterey County is well known as a world-class golf destination, and golf is important economically to the area. RWRCB Region 3 contains nearly eighty golf courses; the Monterey Peninsula is home to eight courses alone (Course List, 2003). Golf courses use substantial amounts of water to sustain green grass year round, and efforts have been made in recent years to use recycled water. Grasses also require intensive nutrient and pesticide/herbicide/fungicide applications to maintain their appearance (Walker and Branham, 1992). Construction of new courses or refurbishment of old courses can lead to sedimentation of local watersheds, but once established, the vegetation can hold sediment and some water (Balogh and Watson, 1992). Many courses, such as those on the Monterey Peninsula, incorporate native plants as landscaping to help reduce potable water use and conserve habitat (Fig.2.22).

Figure 2.22 Golf course (Photo by Richard Newman, January 2003)

2.3.7 Mining

Gravel, sand and stone extraction comprise most of the mining activity in the Salinas Valley although there is also some mining of dolomite, limestone, and gypsum (CDC/CGS, 2000). In gravel mining operations, streambed elevation can be lowered significantly, altering the sediment load and geomorphology in a way that affects fish. During high flow events, the channelized banks increase the velocity of water, thereby increasing the chance of further bank erosion, loss of riparian habitat, and difficulty for migrating fish, such as salmonids (Kondolf, 1994) (Fig. 2.23).

Figure 2.23 Gravel mine adjacent to the Arroyo Seco River (Photo by Doug Smith, January 2003)

2.4 Other lands

2.4.1 Water

There are three major dams in the Salinas River watershed. The first built was the Salinas Dam (1942) which is across the main channel of the Salinas River near Santa Margarita. It was built as a way of supplying water to Camp San Luis during World War II and the growing community of San Luis Obispo with a reliable supply of water. The Nacimiento Dam (Fig.2.24), built in 1956, is on the Nacimiento River located approximately 18 km from its confluence with the Salinas. The San Antonio Dam (1965), on the San Antonio River, was built 13 km from its confluence with the Salinas (DWR, 1993). These last two dams were built to mitigate the frequent flooding that occurred in the valley and ensure a reliable water supply for intensifying agricultural and urban developments.

Figure 2.24 Nacimiento Dam (Photo by Richard Newman, January 2003)

3 Agricultural and land use history

The following historical background was synopsized from a number of sources. History and natural history of Native indigenous people was obtained from Baumhoff (1978), Heizer and Elsasser (1980), Breschini et al. (2000), Gordon (1996), Margolin (1978), and Hornbeck (1984). The natural history of the landscape and vegetation was derived primarily from Gordon (1996), Schoenherr (1992), and Henson and Usner (1993). City of Salinas history and regional agricultural histories came primarily from Allen (1932) and Anderson (2000), with additional information from Breschini et al. (2000), Verardo and Verardo (1989) and Paddison (1999). Some information on fire ecology was sourced from Biswell (1989), as well as Schoenherr (1992), Gordon (1996), and Henson and Usner (1993). Oil industry history was sourced primarily from Franks and Lambert (1985).

3.1 Periods of Land Use Change

The European discovery and colonization of California pre-dates colonial settlements on the Atlantic coast of America by nearly sixty years. The land use patterns of central California mirror changes that happened in much of the State. For the purposes of illustrating land use change in this report, seven periods are described below during which specific and historic changes in land use and land management took place. These seven time periods include pre-European, Spanish, Mexican, early American, and agriculturally innovative periods.

3.1.1 Pre-European Land Use to the late 1700's

The Native people of central California are divided into four primary groups: the Chumash, Salinan, Coastanoan (Ohlone), and Esselen. The Chumash lands were located furthest south in the study area, in San Luis Obispo, Santa Barbara, Ventura, and North Los Angeles counties. The Salinan people lived north of the Chumash in south Monterey/north San Luis Obispo counties. The Ohlone people resided in a large territory from north of the Salinan to San Francisco Bay. The Esselan lands were nestled on the coast between the Salinan and Ohlone lands near the Big Sur area. All of these native areas covered coastal and inland areas. The native lands were abundant with game and plants used for medicines and food. Game included deer, elk, antelope, waterfowl, and a variety of small game animals such as rabbit, skunk, and wood rat. The nearby ocean provided occasional whales, pinnipeds such as harbor seals, pelagic fish, salmon, lampreys, and abundant mollusks.

Specific plant communities were of great importance. Grasslands of the valleys were composed primarily of native bunch grasses, such as needle grasses (*Stipa* spp.), blue grasses (*Poa* spp.), rye (*Elymus* spp.) and triple-awned grasses (*Aristida*). Grasslands provided seed food as well as forage for animals that could be hunted. Oak or foothill woodlands were the most important plant community as they were composed of acorn bearing oaks and grasses. Oak woodlands also provided more diverse animal species for hunting. Chaparral was also important for seed production, but required human intervention to be most beneficial.

Gathered foods included acorns, seeds, berries, and roots. Acorns were a staple for many native Californian people. In central California, Coast live, valley, black and blue oak woodlands provided this food source. In addition to acorns, chia seed, nuts from buckeye (*Aesculus*) and hazelnuts (*Corylus*) were important foods. Seeds of grasses, sage or chia (*Salvia*), tarweed, dock (*Rumex*), and wild cherry (*Prunus*) were consumed. Many berries, such as blackberry, strawberry, gooseberry, manzanita, madrone, and wild grapes were commonly gathered. Roots of wild onion, cattail, chuchupate (*Lomatium*), yampah (*Perideridia*), and soap plant or amole (*Chlorogalum*) were gathered and tended.

Native people in central California did not practice agriculture as we know it today, but did change the land by managing it with fire. In grasslands and woodlands, fire started and tended by Natives controlled the intrusion of brush, promoted seed producing grasses, and possibly assisted hunting by creating forage areas for deer and other large mammals. Fire may have also been used as a hunting tool, driving game to the front of a fire. In chaparral, fire thinned the canopy, encouraged the growth of herbs and shrubs, and may have intentionally reduced fire hazard. Fire forced plant succession, cleared canopy under story, and created new fresh habitat for animals. It also made gathering specific plant resources easier by physically opening brush.

The Native populations in central California were very successful because of the abundance and variety of foods, resources and habitats available to them. The arrival of the Spanish drastically changed the landscape and Native people, from the development of the first irrigation systems for mission settlements, domestic herd grazing, non-native plant establishment, and alteration of Native culture and their historic relationship to the land.

3.1.2 The Spanish Mission period late 1770 to early 1800's

Mexico and its territories came under the rule of the Spanish crown in 1535. Extensive exploration of the California coast by Spain took place soon after, first by Juan Cabrillo in 1542, followed by others. Sebastian Vizcaino was the first to describe Monterey Bay in 1607. Exploration was primarily coastal until Don Gaspar de Portola led the first significant land exploration in 1769. Twenty-one missions were eventually established along the Alta California coast from San Diego to San Francisco between 1769 and 1823. Each mission was located a day's ride apart, providing good water, forage for stock, and food and shelter for travelers. The Spanish government also established the first three land grants or divisions of land in the Salinas Valley at this time. The land grants system was later expanded by Mexican rule.

The missions grew a variety of crops, raised livestock, and processed the first large scale exports of tallow and hides from California. The missions were the first to bring large scale domestic animal grazing to the Salinas Valley. It was this introduction of Mediterranean livestock that changed the grasslands of the Salinas Valley to more annual species. Annual grass seed was carried in the gut and in coats of this foreign livestock. Once introduced, annual grasses became very successful in the local mild climate, out-competing the native perennial and annual grasses.

Mission San Antonio was the first local mission to use dammed surface water for irrigation. The climate could be harsh, and missions did experience drought and failed crops. The missions were in general, very successful at the exploitation of resources of land, water, and people. The Native population was used as labor in the missions, and their numbers started to decline as they were exposed to diseases and changes in their long established way of life.

3.1.3 The Mexican Rancho period mid 1820's -1850

With each political change came more individual land ownership. Under Spanish rule, land grants were made to a very few individuals with close political ties to the Crown. With Mexico declaring independence from Spain in 1822, the mission system shut down by 1834. The new Mexican government divided the Spanish land grants into 88 ranchos in Monterey (including San Benito county), and many more people loyal to Mexico were allowed land of their own. Many of the towns of the area were established, and land was bought and sold for the first time during this period. Cattle ranching was the main activity, with crops grown mainly for subsistence. The beginning of grain farming started during this time, with barley becoming the main grain crop. With the discovery of gold in 1849, the demand for meat for miners in the foothills of the Sierra Nevada made many rancho owners wealthy. Cattle were driven north to San Francisco Bay, and slaughtered locally.

3.1.4 Statehood to mid-1860’s

In 1851, with California statehood, the land of the Salinas Valley was again resurveyed and divided further by the US government. Cattle ranching and grain farming were still the main agricultural activities of the time. Pastureland began to be impacted in the 1860’s from the numbers of grazing domestic herds of horses, cattle, and sheep. During the years of 1862-1864 a major drought resulted in loss of cattle and crops, and may have precipitated the change from grazing to grain crop agriculture. Transportation of grain and animals was still limited, but in 1866 a major shipping terminal was built at Moss Landing. This allowed local agricultural products to be shipped immediately and easily.

3.1.5 Late 1800’s

In 1883, the first commercial mill was built in Salinas, and a second was added in King City. Monterey County was the leading producer of wool in 1870 and 1880 in California.

As agriculture began to increase, cropland replaced ranching activities in the deep alluvial soils of the valley. The need for irrigation was also beginning to grow. In the beginning, gravity-fed systems were supplied from small dams across rivers or wells with “flowing” waters. Windmills were used to pump water in Salinas. The first steam-generated pumps for irrigation came into more common use as farming moved to more water intensive crops, such as sugar beets and alfalfa. Water was pumped from the Salinas River, and delivery canals channeled the water to the fields (Fig.3.1).

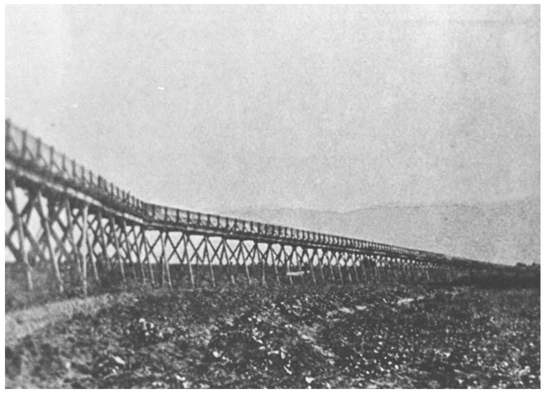


Figure 3.1 Irrigation flume, Ft. Romie, c 1900 (Courtesy of the Monterey County Agriculture and Rural Life Museum, MCARLM)

Figure 3.2 Asphaltum seeping from the ground (Photo by Fred Watson, 2000)

Figure 3.3 Oil Well in San Ardo c1900 (Courtesy of MCARLM)

In addition to agriculture, oil exploration started during this period in California. Asphaltum (Fig.3.2), a product of oil seeps near the soil surface, had been used by Native people for centuries as caulk and sealant. The first sale of petroleum oil drilled and refined in the State was in 1865. Large deposits of oil and gas were discovered in Kern, Coalinga, Santa Maria, Elk Hills, and Los Angeles by the late 1800's (Fig.3.3). Modern facilities operate at San Ardo in the Salinas Valley, as well as in south-western San Joaquin Valley, San Luis Obispo county, Santa Barbara county, and offshore of Santa Barbara county (CA Dept of Conservation, 2000).

3.1.6 Early 1900's

As better technology evolved at farms, wells began to appear, tapping into the vast groundwater system of the Salinas. The 1890's there were 60 wells in Castroville alone. They averaged 136 feet deep and were "flowing" but dry during the summer. Steam and wind power pumps were replaced by gas and later electric pumps, increasing the amount of water that could be lifted from underground. Sugar beets, dairy, wheat, and alfalfa were the primary agricultural products. Figures 3.4, 3.5, 3.6 and 3.7 illustrate farming activity of this period.

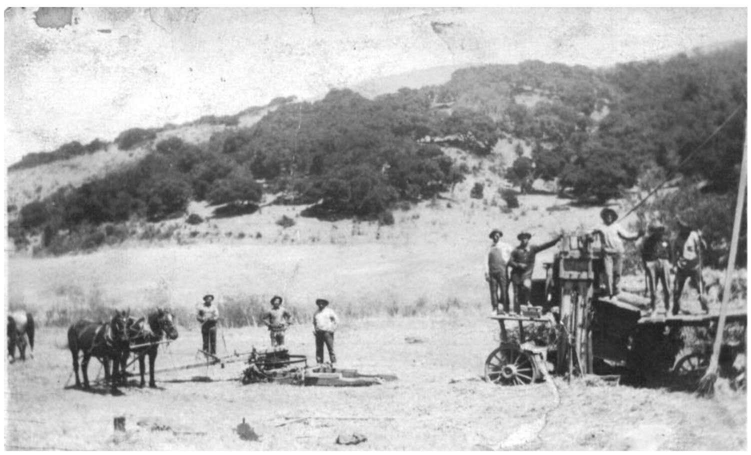


Figure 3.4 Hay baling, c 1921 (Courtesy MCARLM)

In the 1909-1910 season, there were nearly 10,000 irrigated acres in the valley. Figures 3.8 and 3.9 show crop statistics and total irrigated acres from the mid-1800's to the last decade.

Figure 3.5 Hog farming east of King City, c 1900 (Courtesy MCARLM)

Figure 3.6 Wheat harvesting, c 1900 (Courtesy MCARLM)

Figure 3.7 Sugar beet harvesting c 1900 (Courtesy MCARLM)

The production of lettuce began in the early 1920's for export to the east coast. By 1930, lettuce receipts accounted for almost half or all farm products. Lettuce began to overtake some of the old sugar beet acreage, and was extensively planted between Salinas and Castroville.

Orchards of apricots, almonds, peaches, apples, and pears were planted in 1905 between Soledad and King City. This added to the diversity of agriculture of the Salinas Valley.

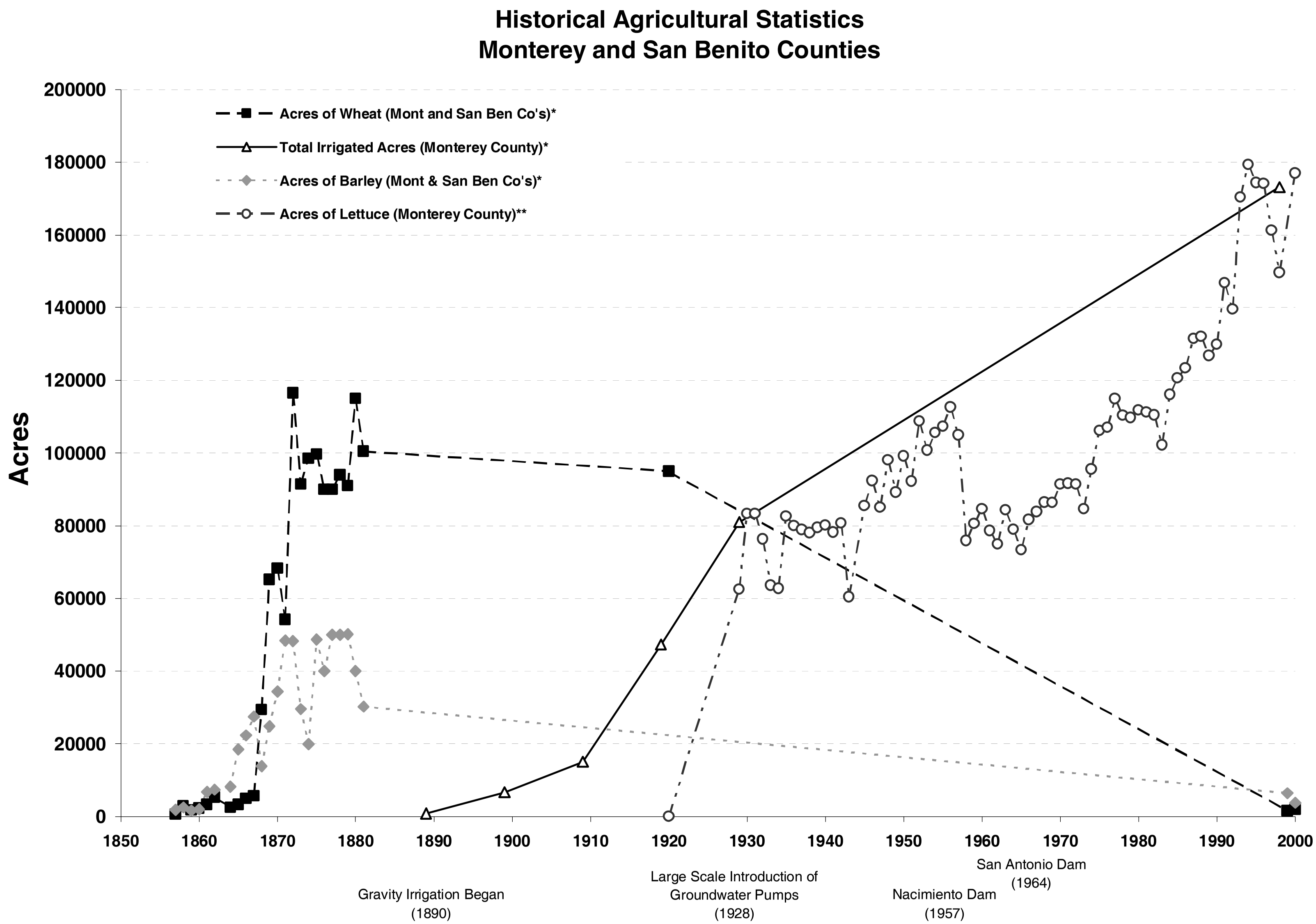


Figure 3.8 Historical agricultural statistics for Monterey and San Benito Counties.

*   Data provided by Breschini et. al., 2000).

**   Data provided by The Monterey County Agriculture Commission (1998 & 2000)

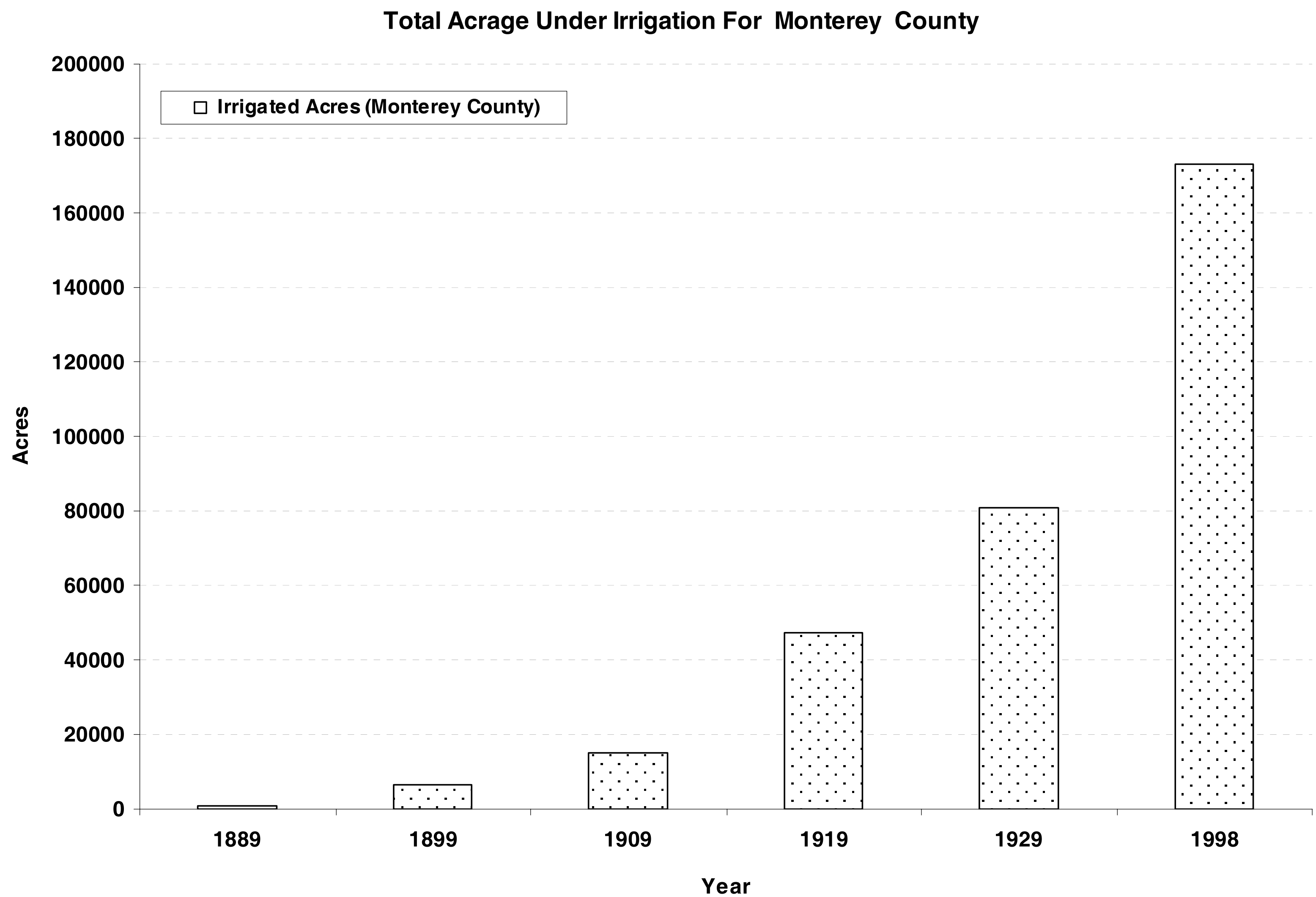


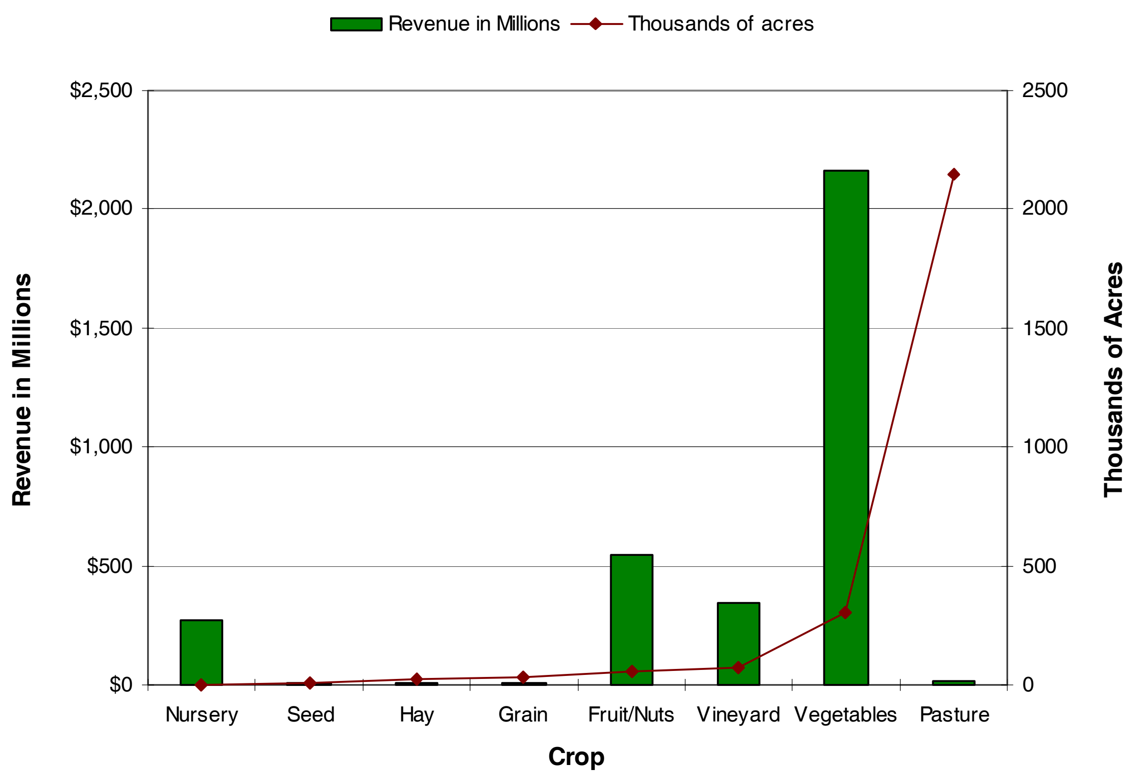
Figure 3.9 Total acres of land under irrigation for Monterey County (Breschini et al., 2000)

3.1.7 1930 to present

As early as 1930, the Salinas Chamber of Commerce was concerned about overdraft of water from the groundwater basin. Wells were present all over the valley, supplying the variety of crops we see today. Lettuce became a major crop for the area, and with lettuce, more water was needed.

Agriculture is one of central California's primary sources of jobs and revenue. The combined annual revenue for San Luis Obispo and Monterey counties accounts for $3.4 billion. Figure 3.11 below shows the acreage and revenue for different segments of agriculture.

Figure 3.11. Combined revenue and acreage totals for San Luis Obispo and Monterey Counties, 2001 (Agricultural Commission, 2001; San Luis Obispo Co. Weights and Measures, 2001)



3.2 Yesterday and today–summary of change

All present day photographs were taken by Bronwyn Feikert in the summer of 2001 except where noted. (Figs.3.12, 3.13, 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, and 3.20).

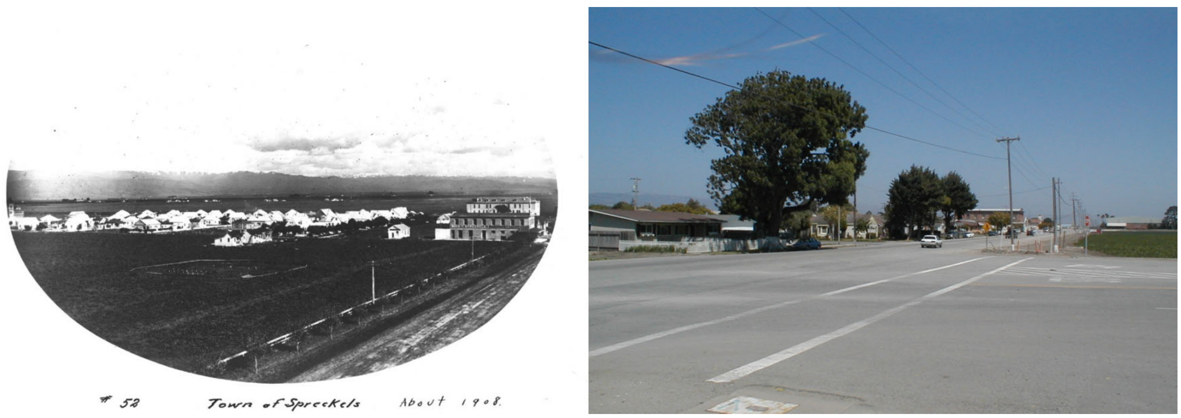


Figure 3.12 The town of Spreckles on Spreckles Blvd. c1908 (Courtesy of MCARLM)

Figure 3.13 Curbaril Bridge crossing the Salinas in Atascadero 1920 (Courtesy of AHSM) The new bridge for Highway 41 is located downstream of the original bridge, which still exists.

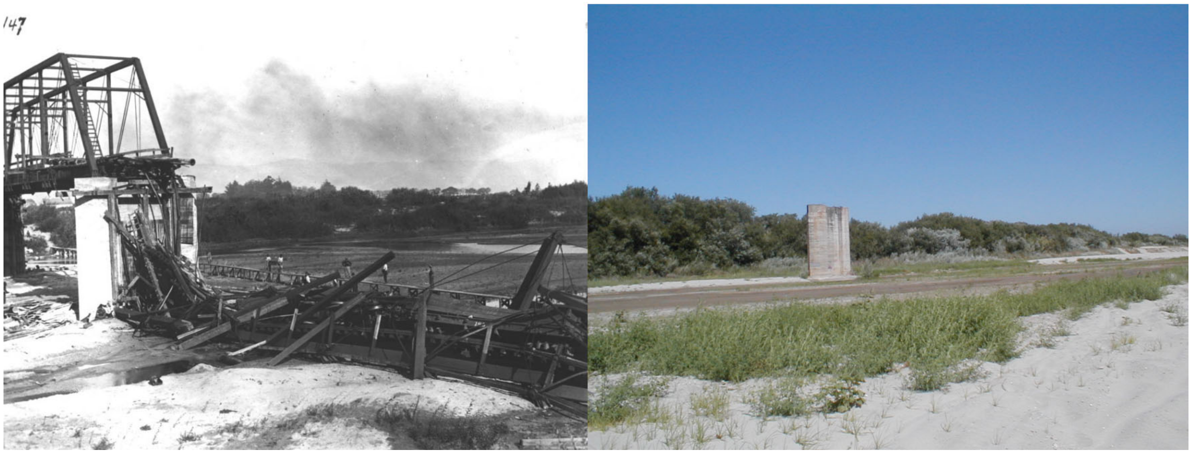


Figure 3.14 Buena Vista bridge in Spreckles 1935 (courtesy of MCARLM)

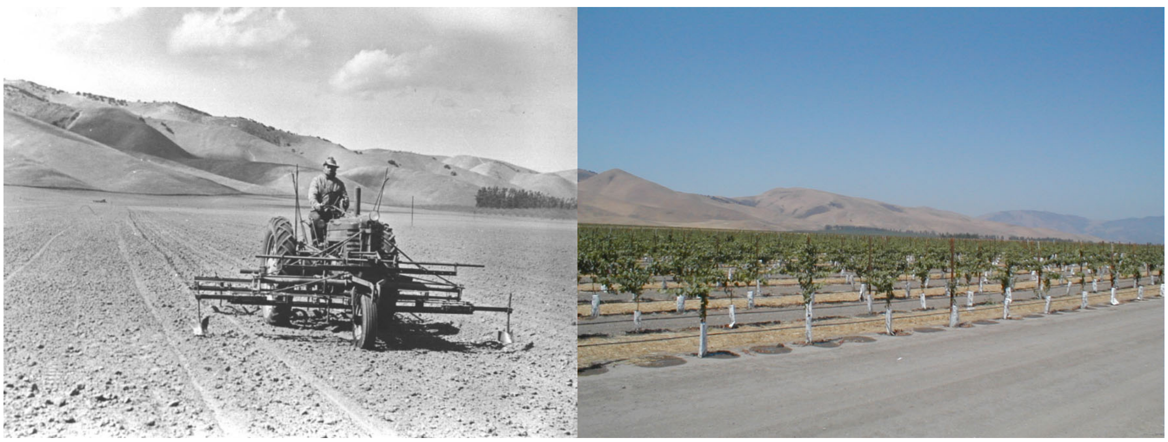


Figure 3.15 Joe Amarel on his tractor west of Hwy 101 between King City and Greenfield looking west 1948 (Courtesy of MCARLM)

Figure 3.16 Salinas River near Toro Creek 1935 (Date unknown) (Courtesy of MCARLM)

Figure 3.17 Les and Bill Smart in Monroe Canyon (Courtesy of MCARLM)

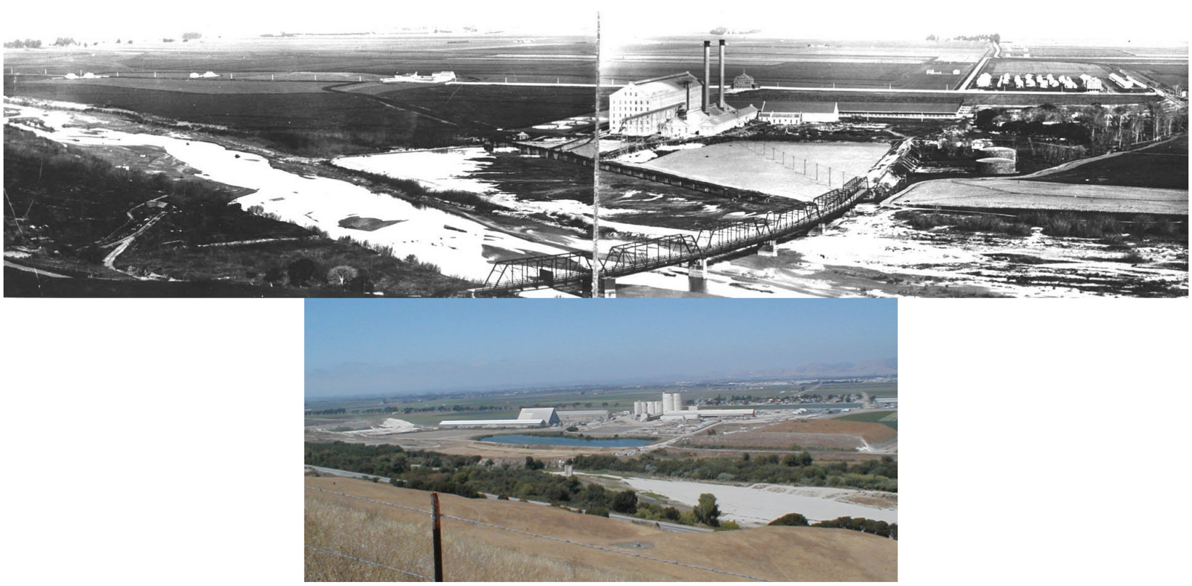


Figure 3.18 Spreckles Sugar factory from Toro Hills 1935 (Courtesy of MCARLM)

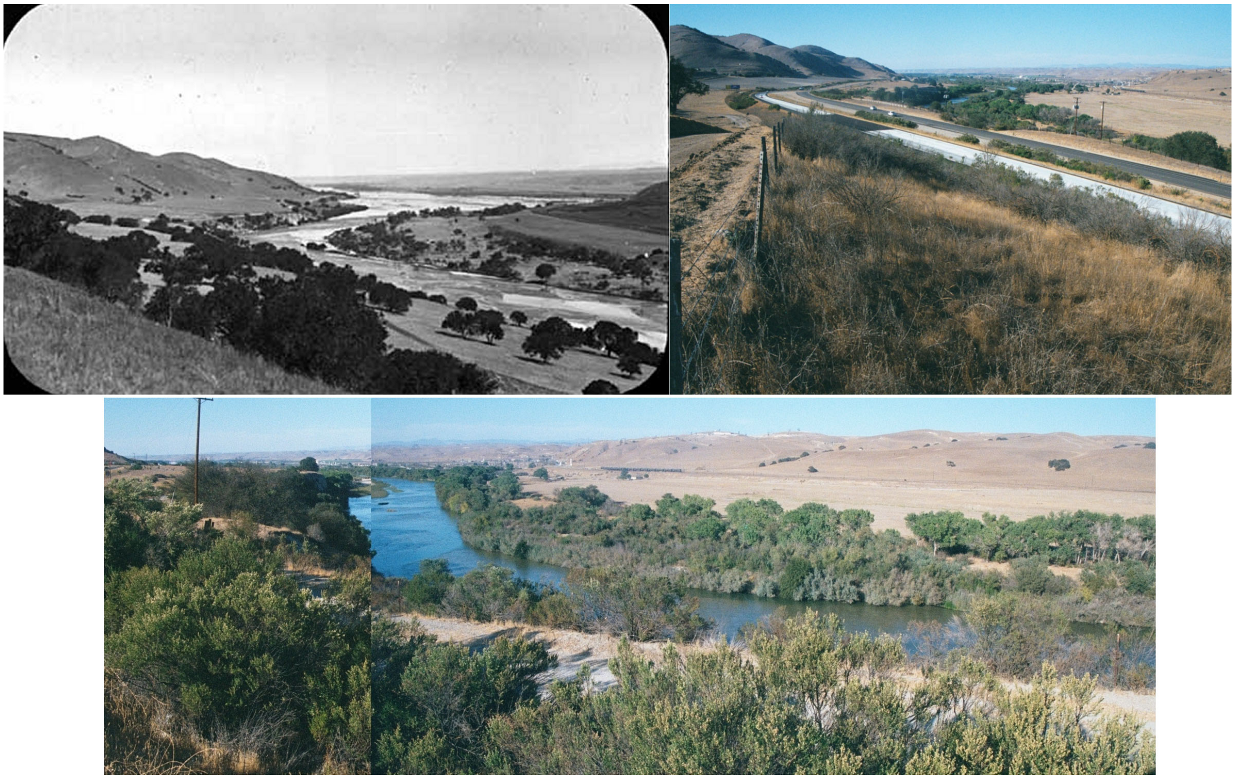


Figure 3.19 Salinas River near San Ardo 1900-1915 (Courtesy of UC Berkeley Geography Department) (Present day photos taken by Fred Watson, 2002)

Figure 3.20 Pine Mountain from Salinas River in Atascadero 1972 (Date unknown) (Courtesy of AHSM)

4 Existing land use/land cover data

4.1 Data prior to 1970

Few early land use maps exist for the Salinas Valley. The earliest map found, shown in Figure 4.1 was part of a scope of agricultural history of the Salinas Valley (Allen, 1932). It is hand drawn and although is strictly agricultural in context, presents a snapshot of crops from the 1930's.

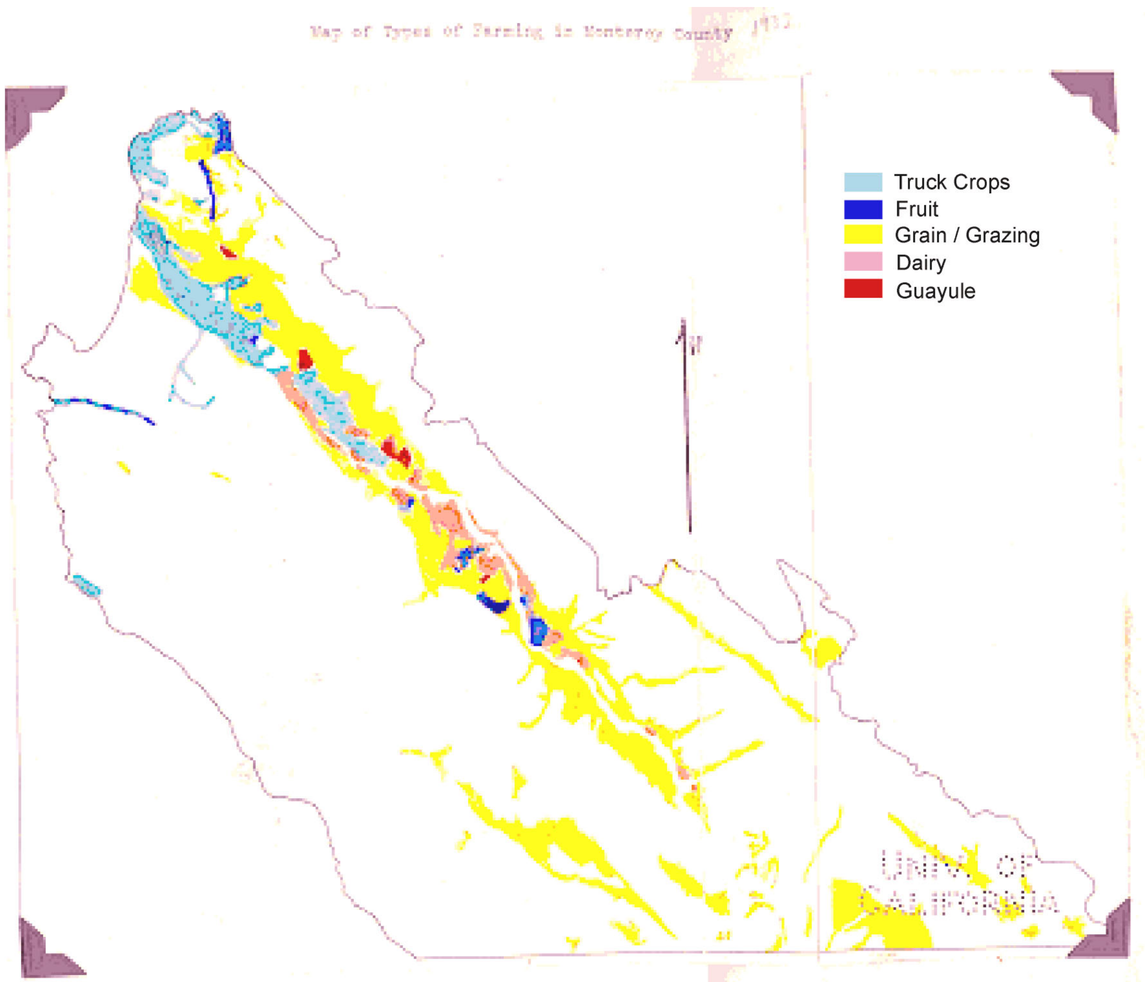


Figure 4.1 Land Use in 1932 (Allen, 1932)

4.2 Data from the 1970's

The oldest electronic geographic information system (GIS) data available are USGS land cover layers dated approximately from the late 1970's (Fig. 4.2). These data are statewide, vector based, and at a relatively coarse scale. This layer is part of a larger data set known as Watershed Analysis Tool for Environmental Review (WATER) first published on CD-ROM in 1997 by the California Coastal Commission. It is currently freely distributed on the web from the Central Coast Joint Data Committee website (CCJDC, 2003).

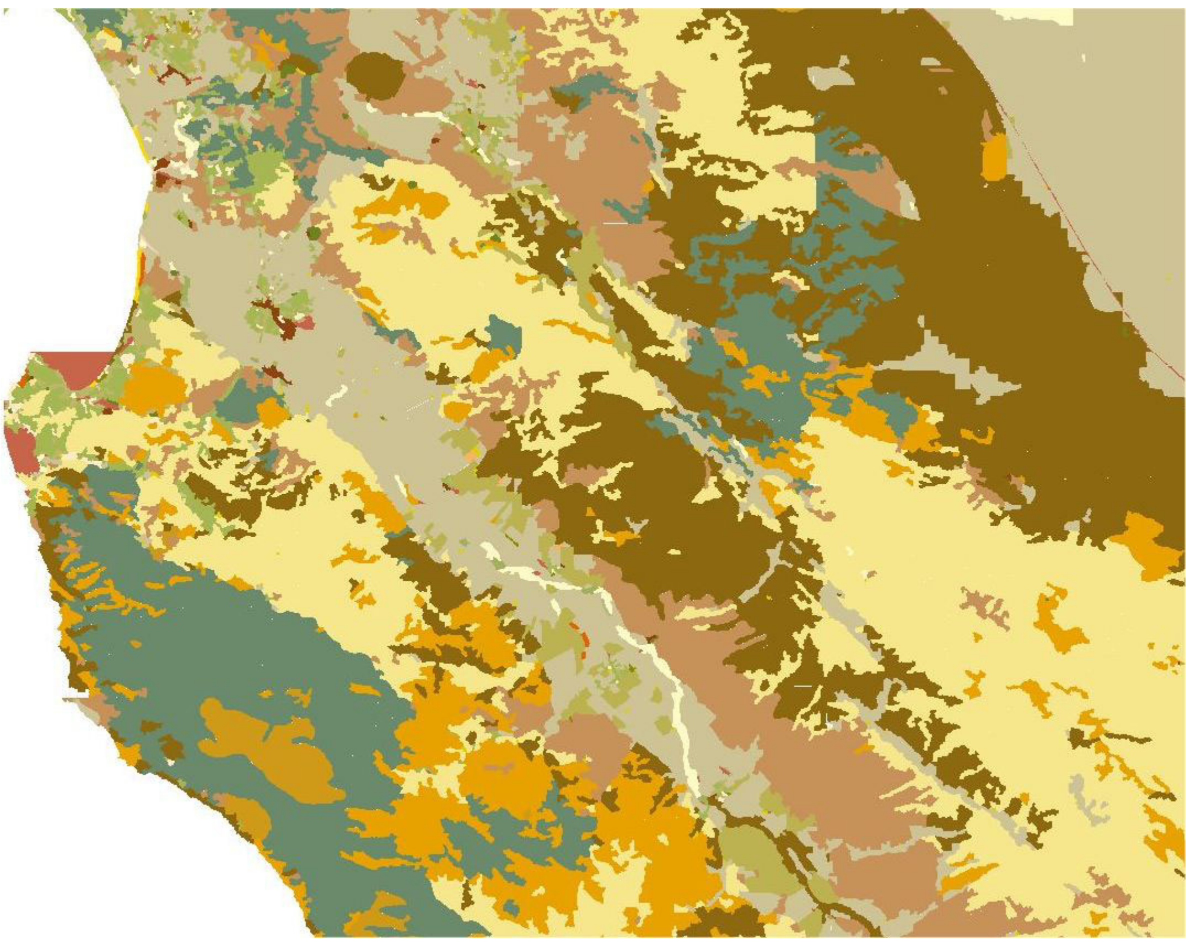


Figure 4.2 USGS land use in the early 1970's, WATER data set

CalVeg, shown in Figure 4.3 was GIS data layer created in 1977 by the United States Forest Service Regional Ecology Group. These data are vegetation specific, vector based, and have a minimum map unit of 400 acres (CalVeg, 1981).

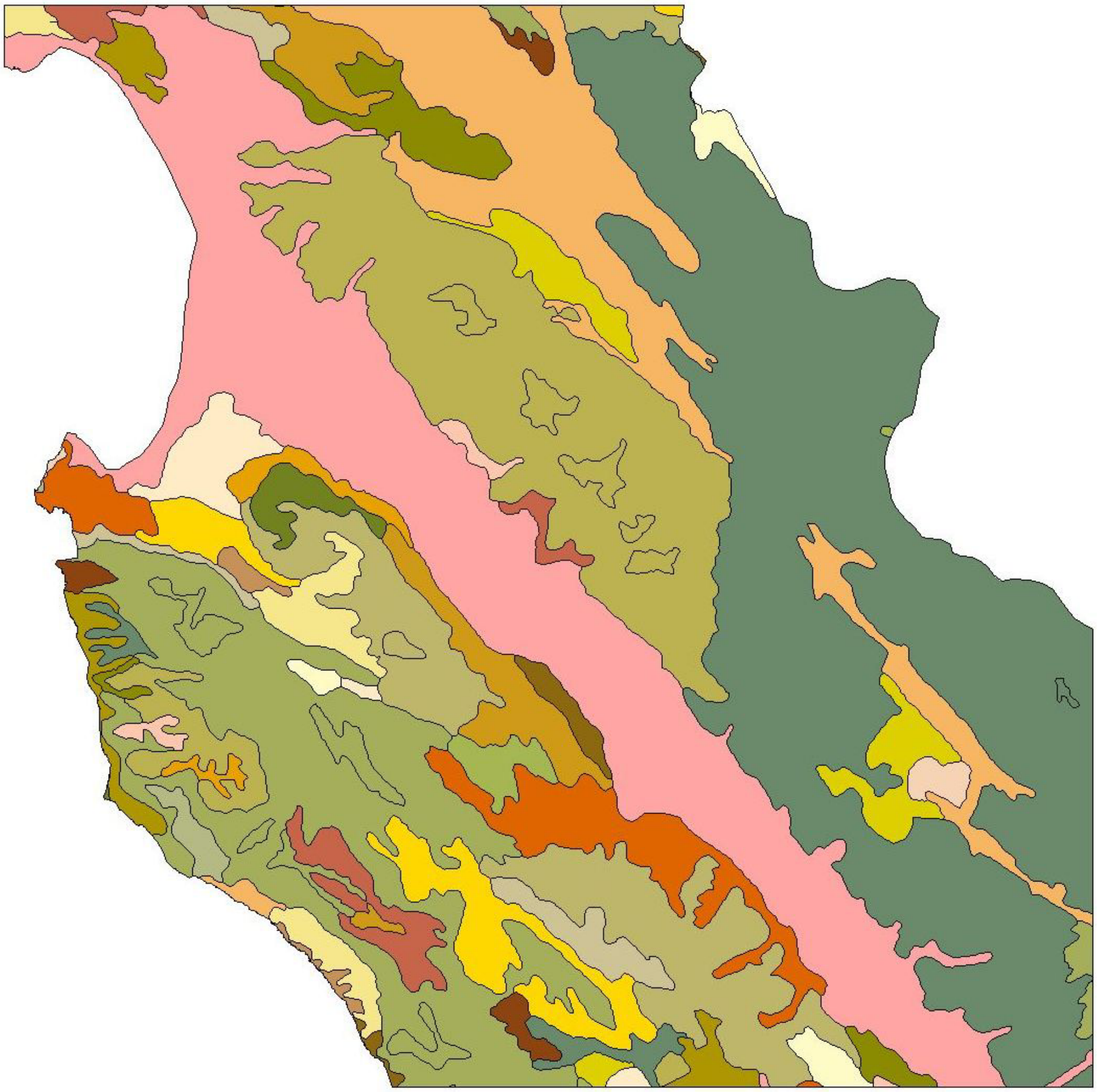


Figure 4.3 CalVeg land use, 1970's, WATER data set

4.3 Data from the 1990's

California Geographic Approach to Planning for Biological Diversity (CA GAP Analysis Project) data are derived from a 1990 TM scene and aerial photography (Davis et al., 1998). The vector based GAP data has a minimum mapping unit of 100 hectares for uplands and 40 hectares for wetlands (Davis et al., 1998). (Fig.4.4)

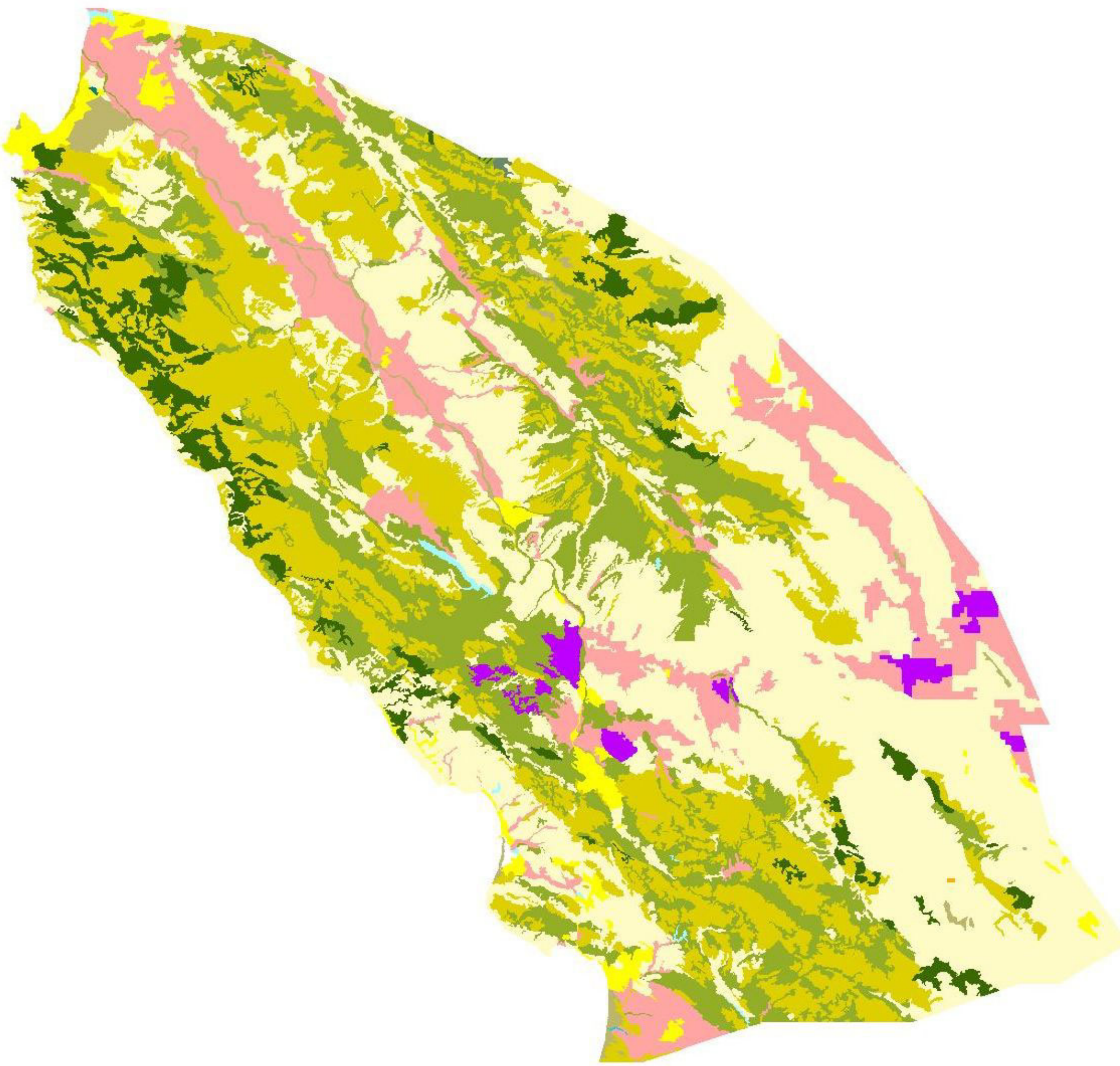


Figure 4.4 California GAP Analysis Data 1998, WATER data set

The Association of Monterey Bay Area Governments (AMBAG) produced a vector based land use layer in 1997. These data are based on TM images from 1990 and 1993, and were processed by Pacific Meridian Resources (now Space Imaging, Incorporated). These data are more detailed than earlier data sets (30 meter), but are nearly 10 years old. (Fig. 4.5)

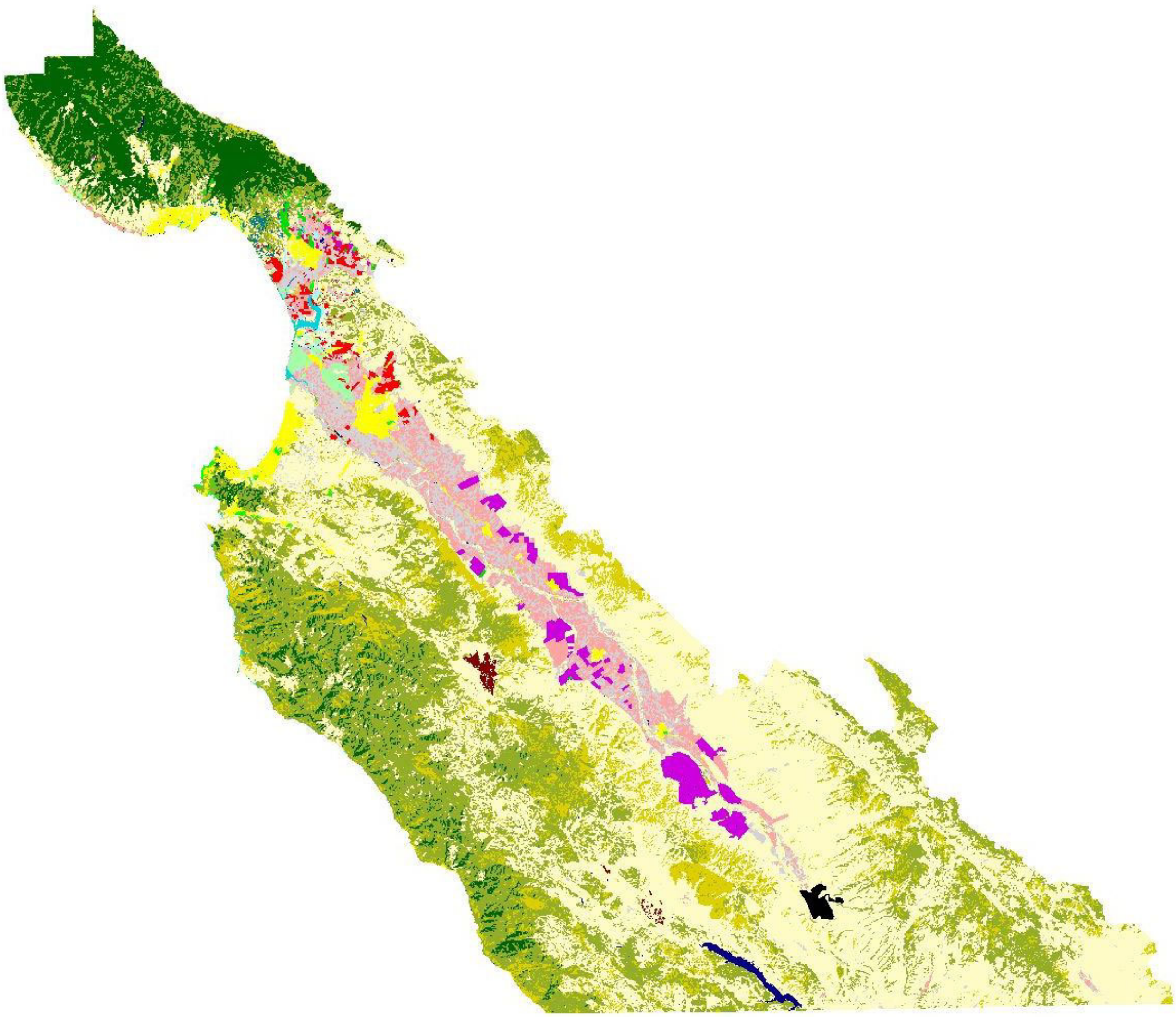


Figure 4.5 AMBAG Land Use data 1997, WATER data set

California DWR (Department of Water Resources) began land use mapping in 1947 for the purposes of long term water planning. The 1991 data are specific to urban and agricultural areas, and are based on aerial photographic surveys. Monterey County Water Resources Agency (MCWRA) then digitized these data. These vector-based data are highly detailed, but do not encompass all the land cover of the entire region. Shown below in is the 1991 data; an updated version of these data became available in 2001(DWR, 2003). (Fig. 4.6)

Figure 4.6 Department of Water Resources land use, 1991, WATER data set

The most recent land use/ land cover data obtainable are from the United States Geological Survey (USGS). The NLCD (National Land Cover Data) is conterminous US data derived from early to mid-1990's TM scenes. At the time this study was begun, these data were not available, and at the present time were still in the process of being completed. This is the first high resolution (30 meter), raster based land use data to become widely available for the U.S. (USGS, 2002) (Fig.4.7)

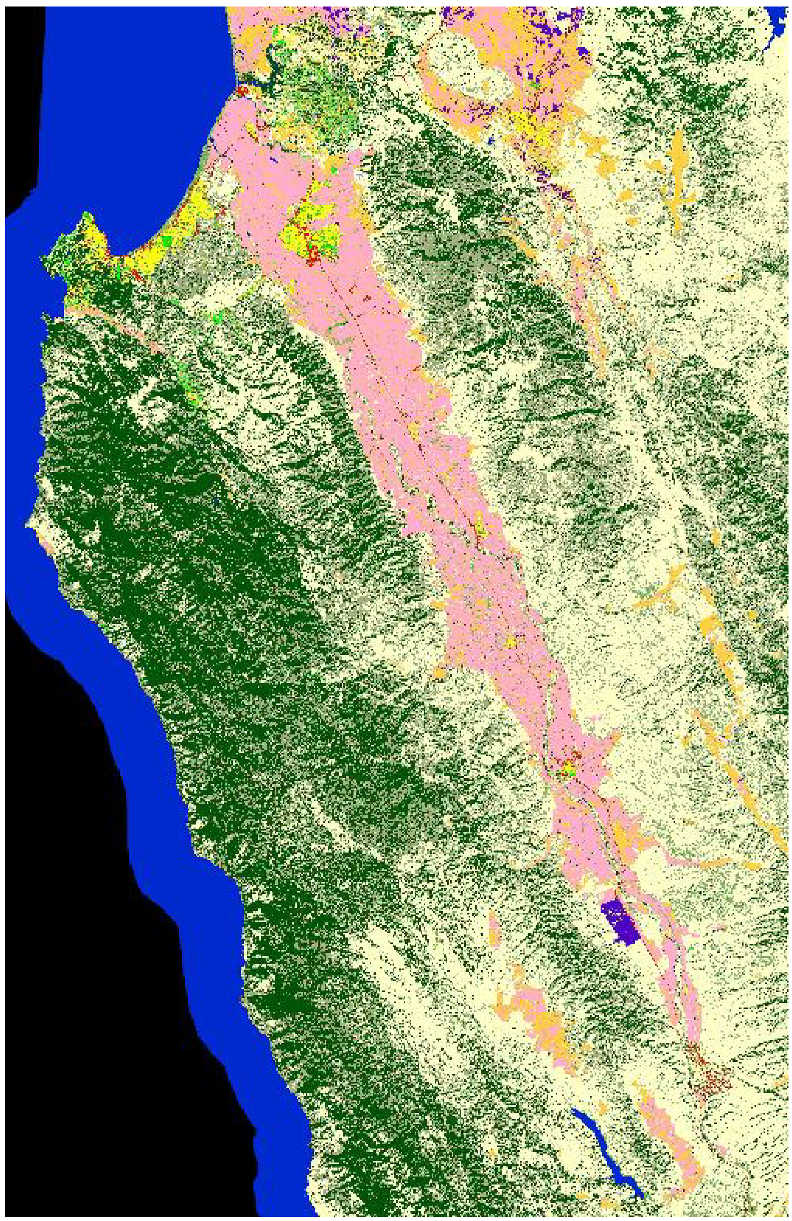


Figure 4.7 NLCD land use data, 2001

There is a real need for objective, extensive, detailed and contemporary land use mapping. No existing product fulfills these criteria.

5 Mapping LULC through remote sensing

5.1 Introduction

A land cover mapping process was required with the following characteristics:

- The map should be up to date (publishable within a year or two of data acquisition);
- The mapping process should be reproducible in subsequent years;
- The map should include the entire SWRCB Region 3 (29,800 km^2; 11,500 mi^2);
- The map should be accurate;
- The mapping process should be objective – it should discover variation in land cover automatically without the processing team being required to know by chance that certain land cover types exist, or have been recently introduced to specific areas;
- The process should be affordable.

Existing maps and mapping programs satisfy a subset of these requirements, but none satisfies all of them. For example, the detailed DWR maps of agricultural areas are detailed, accurate, and objective – but they do not encompass the entire region and they are time consuming to produce. Conversely, the USGS NLCD maps cover the entire nation, are accurate, and are reasonably objective, but they take 10 years to produce.

A satellite remote sensing based approach was determined to be the best means of achieving all the above aims. Remote sensing is extremely valuable for mapping land use and land cover because of the temporal, spatial, and spectral properties of satellite data. Temporally, many satellite sources of data are available twice a month or more, enabling vegetation studies cross-seasonally, or month to month. Spatially, imagery is available in a wide range of scales of varying resolution and extent. Spectrally, many satellite imaging systems are now multi-spectral or hyper-spectral, and are used in a wide array of land cover mapping applications.

5.2 Classes used in this study

We use a subset of previously mentioned classes in our remote sensing (Table 5.1).

Table 5.1 Class categories and descriptions used in classification

Class Categories	Descriptions
Grassland	Predominantly annual grasses (grazed and un-grazed); some dune. Also includes some areas of irrigated row crop land.
Shrub	Includes all chaparral and other scrublands. Also includes some coastal marsh.
Oak Woodland / Mixed Forest	Includes mixed woodlands and forests (e.g. oak, toyon, madrone, eucalyptus), urban trees, and riparian forest (e.g. alder, cottonwood, willow, sycamore). Also includes some overlap with conifer classes.
Mixed Conifer/Montane	Predominantly conifer and oak, urban forest, conifer with under story.
Crop	Includes mainly irrigated row crops (e.g. vegetables, strawberries) and irrigated feed crops (e.g. alfalfa). Also numerous dryland crops.
Golf / Green Crop	Predominantly golf turf grass areas and some very green crops such as lettuce.
Vineyard / Berries	Includes structured rows of grapes or berries.
Dry Soil	Reflective soils include some dryland farming, dry lakebed, dry riverbed, and mining.
Urban	Asphalt, concrete, industrial, commercial, and residential areas.
Water	Bodies of water (e.g. reservoirs and lakes).

5.3 Calibration and verification data

A variety of calibration and verification data were used in the development of both the methods and the final classification of LULC. Because the development of the methods utilized these calibration and verification data, the respective sources of these data are described first.

5.3.1 Aerial videography

A primary source of calibration and verification data was aerial videography. Digital video and a Trimble Geoexplorer Global Positioning System (GPS) were taken onboard a California Highway Patrol plane in July 2000. The flight took off from Paso Robles, flew up the east Salinas Valley, north to the Salinas River mouth, and south down the west side of the valley to King City at an altitude of 3,000 - 5,000 feet. GPS positions were taken for the duration of the flight, along with a digital video of the land cover below. This flight video was transferred to VHS, and analyzed for land cover using the video and co-registered GPS log created during the flight. Land cover data was then transferred to 1:25,000 paper topographic maps by drawing the extents of similar classes with color-coding of the estimated cover type. Particular attention was paid to agricultural areas and areas undergoing current change. These maps were then used for land use cluster identification in the classification process.

5.3.2 Ground-based survey data

Paper land use maps were created and were verified by field sampling personnel familiar with the actual land cover. Additionally, data were checked on drives through the study area over the course of a year. In general, the aerial videographic land cover maps were found to have high accuracy.

In addition to paper maps, each Landsat scene was made into poster-sized images. The purpose of this was to enable the analyst to view each scene in large format as each scene was being classified.

5.3.3 Oblique aerial still photography

Still 35mm photography was acquired on the above flight and subsequent flights in March and October 2001. These flights were at low altitude (< 5,000 feet). Commercial airline flights taking off from and landing at Monterey Airport were also used to gather higher altitude (15,000-25,000 feet) oblique imagery of land cover. Still photographs aided in the resolution of classification decisions, and in verification of the final land use/ land cover classification raster.

5.3.4 SPOT

In addition to imagery listed, SPOT (Systeme Probatoire d'Observation de la Terre) satellite imagery was used for natural lands interpretation where a geo-rectified image was needed. The imagery consists of panchromatic (black and white) imagery of the study area with 10-meter pixel size. All the imagery was acquired between 1992 and 1994.

5.4 Methods

5.4.1 Overview

Land use classification was achieved by using Landsat Enhanced Thematic Mapper (ETM) multi-band imagery and mosaicked slope data as inputs to an unsupervised K-means classification system. The software used to do all image processing, including the classification, was Microimages TNTMips. Tarsier software (Watson and Rahman, 2003) was used to process the DEM (digital elevation model). Analysis and the assignment of clusters were accomplished through the use of the ancillary data sources described above. Finished clusters were then merged, mosaicked, and smoothed for final presentation of the rasters.

Sections 5.4 to 5.7 of this report describe the first phase of the work performed on the Salinas Valley ETM scenes. Section 5.8 then describes the expansion of the work to finish mapping all Region 3.

5.4.2 Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM)

Landsat 4 and 5 TM is a multi-spectral product used for earth systems study. The Landsat 7 ETM instrument is an improvement of the prior Landsat sensors. Because of the 30-meter resolution and multi-spectral bands, Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) were considered the best choice for land use mapping. Table 5.2 describes the Landsat bands and spectral characteristics.

Table 5.2 Landsat ETM band characteristics

Band Name	Frequency range (microns)	Resolution (m)	Spectral Region	Spectral Properties[1]
1	0.45-0.52	30	Visible -blue	Shallow water mapping, Vegetation and soils differentiation
2	0.52-0.60	30	Visible-green	Green reflectance for vegetation assessment
3	0.63-0.69	30	Visible-red	Chlorophyll absorption for Vegetation assessment, Species discrimination
4	0.76-0.90	30	Near- Infrared	Vegetation type, biomass content, soil moisture
5	1.55-1.75	30	Mid-Infrared	Penetrates clouds, vegetation and soil moisture
6	10.4-12.5	60	Thermal Infrared	Thermal mapping
7	2.09-2.35	30	Mid- Infrared	Soil mapping
8	0.52-0.90	15	Panchromatic	Higher resolution land cover

[1] Lillesand and Kiefer, 2000

5.4.3 Scene selection and acquisition

A Landsat 7 ETM scene from June 30, 1999 was the first scene purchased. Table 5.3 summarizes the scenes that were used during the development of methods and in the final classification. Six scenes were used in the initial development and testing of methods. Once methods were established, additional scenes were purchased for use in the final map. Scenes were chosen on the basis of time of year, cloud cover, and image quality.

Table 5.3 Landsat scenes purchased for the study area

Scene Date (DD, MM, YYYY)	Path	Row	Sensor	Cell Size (meters)	Area of Coverage	Used for	Datum/ Projection	Source[1]	Format	Correction level[2]	Cloud cover (%)	Cost
01/11/1989	43	35	TM 5	30	Salinas Valley	Testing	UTMWGS84	1	NLAPS	S	0	$425
30/06/1999	43	35	ETM 7	30	Salinas Valley	Testing	UTMWGS84	1	HDF	S	21	$600
08/01/2000	43	35	ETM 7	30	Salinas Valley	Testing	UTMWGS84	1	NLAPS	S	1	$600
29/04/2000	43	35	ETM 7	30	Salinas Valley	Testing/ Final	UTMWGS84	1	NLAPS	S	0	$600
18/07/2000	43	35	ETM 7	30	Salinas Valley	Testing/ Final	UTMWGS84	1	NLAPS	S	0	$600
07/11/2000	43	35	ETM 7	30	Salinas Valley	Testing	UTMWGS84	1	NLAPS	S	0	$600
16/11/2000	42	36	ETM 7	30	San Luis Obispo	Final	UTMWGS84	1	NLAPS	S	0	$600
18/07/2000	43	34	ETM 7	30	Modesto	Final	UTMWGS84	1	FastL7A	S	0	$600
10/06/2001	44	34	ETM 7	30	San Francisco	Final	UTMWGS84	1	FastL7A	S	8	$600
30/07/2001	42	35	ETM 7	30	Bakersfield	Final	AlbersNAD83	2	NLAPS	T	0	$95
11/03/2002	42	35	ETM7	30	San Luis Obispo	Final	AlbersNAD83	2	NLAPS	T	0	$95

[1] 1: EROS Data Center http://edcsns17.cr.usgs.gov/EarthExplorer/; 2: Multi-Resolution Land Characteristics 2000 http://edcsgs9.cr.usgs.gov/products/satellite/mrlc2000.html

[2] S=Systematic Level 1, T=Terrain

5.5 Image classification

5.5.1 Layers input to the classification process

Unsupervised classification was chosen to minimize human intervention and to maximize automated repeatability on multiple historic images over large areas. The layers input to the classification included both spectral bands and terrain layers. Although trials were run using all of these bands, the final images used bands 1, 2, 3, 4, and 5. The final image was produced using a DEM-derived terrain slope raster as an additional input. Other layers used during trials included elevation, aspect, and TM mid-infrared (MIR) band 7.

5.5.2 The DEM

A variety of DEM products were assessed, and each one proved to have problems except the last method utilizing USGS Spatial Data Transfer Standard (SDTS) DEMs. Special mosaicking software was developed for the process of mosaicking multiple SDTS files using the Tarsier software framework (Watson & Rahman, 2003). In total, three different DEMs were created for the different phases of classification methodology development. The first DEM was a small raster of the north and central Salinas Valley used in the early classification runs. The second was a DEM that covered the scene extents of all Path 43 / Row 35 for the second phase of methodology development. The third and final DEM used the most up to date data available and yielded the final land use / land cover product for Region 3.

After this study, the USGS issued new DEM products, including 30-meter seamless data as of the Fall 2002. The seamless products became available too late for delivery of this project.

5.5.2.1 1997 USGS quads

Mosaicking was performed by Tarsier software to produce the seamless raster. This became the first DEM of the north Salinas Valley used for the initial classification experiments.

5.5.2.2 US Fish and Game seamless DEM of California

The SWRCB GIS department supplied the project with a zipped, seamless 30-meter DEM of California originally processed by California Department of Fish and Game. Unfortunately these data were too large for most standard GIS packages and medium level processing labs such as ours, so further processing attempts at processing these data were discontinued.

5.5.2.3 Early Shuttle Radar Topography Mission Elevation Data

Shuttle Radar Topography Mission (SRTM) elevation data are derived from radar instrumentation aboard the Space Shuttle Endeavor in February 2000 (JPL, 2002). These data will eventually be the most accurate elevation data available, once the level of processing has improved.

5.5.2.4 USGS Spatial Data Transfer Standard (SDTS)

The final set of data examined were SDTS DEMs from USGS. Each DEM file corresponds to an individual 1:24,000 USGS map sheet. SDTS DEMs are free and downloadable from a number of topographic product distributors on the Internet. DEMs were downloaded, mosaicked, and used in the second phase of classification experiments. In September 2001, new refined SDTS files with greater horizontal accuracy became available from the USGS. For the final DEM, all SDTS data files were updated to the newer format files. The final DEM of over two hundred and seventy SDTS files was mosaicked and completed in July 2002.

5.5.3 The K-means technique

K-means unsupervised classification (similar to that described by Likas et al., 2002) were run using GIS software TNTMips V6.4 (Microimages, 2000). Previous USGS mapping (NLCD) used K-means unsupervised classification for successful LULC mapping (Vogelmann et al., 1998), so this method was also used in the present exercise. Small extracts of the 1999 image were created for pre-classification experimentation.

K-Means is an unsupervised iterative method of classification. The K-Means algorithm in TNTMips analyzes a sample of the input, and determines a specified number of initial class centers. Cells are assigned to classes by closest class centers (minimum Euclidean distance). Each iteration reassigns new class centers by finding the point that minimizes the sum of squared distances from each point to the class center, until each shift in center falls below a specified value or maximum iterations reached (Microimages, 2000). An optional distance raster can be generated simultaneously. Options for the process are the number of classes (20), maximum iterations (10), initial minimum cluster distance (10), maximum movement for steadiness (5), and minimum steady cluster percentage (80) (default values are in parentheses).

5.5.4 Development of methods using the June 1999 image

5.5.4.1 Pre-slope raster classifications

The June 1999 image was used for most of the preliminary classification experiments. The classification process proceeded as follows:

- The rasters were selected and parameters set for the classification;
- Classification ran; the finished raster opens with all classes automatically colored;
- Each class was then selected individually and changed to a bright color that could be easily identified across the raster,
- The land cover was identified and class-colored according to ancillary ground truth data.

Extractions of 800 km^2 areas of the central and northern Salinas Valley were made to shorten processing time. The north valley extract was particularly important as the ground truth was known intimately. Initially bands 3, 4, 5, and 7 were used based on information about the USGS MRLC land cover assessment methods (Vogelmann et al., 1998). Classification parameters were set to default for the first runs. The 3, 4, 5, 7 band classifications with 10 classes showed unsatisfactory discrimination between highly reflective areas (grassland and some urban), and between types of woody vegetation. To increase the accuracy, the number of classes was increased to 20. The added classes improved results, but there was still poor discrimination between some sand and soils. The number of classes was increased incrementally from 25, 50, 75, to 100 classes. Discrimination was especially poor for vegetation in areas of hilly terrain. Visible-light bands 1 and 2 were added for enhanced spectral input.

Bands 1, 2, 3, 4, 5, and 7 were run in 10, 20, 30 and 100-class processes. The 10 and 20-class runs showed mixed pixel classes with regard to separation of woody vegetation. With the addition of more classes, woody vegetation discrimination improved, but confusion still existed in agricultural, shrub, and grassland classes. A new approach was conceived to add a DEM to the set of spectral bands for classification, hoping that terrain-based slope data would yield better distinction in all classes of land cover.

5.5.4.2 Post-slope raster classifications

After the creation of a slope raster, classification was repeated at using bands 1, 2, 3, 4, 5, 7, slope, and 10, 20, 30, and 100 class parameters.

The 10-class process showed improvement in woody vegetation discrimination but confusion of agriculture with golf and grassland classes. The 20 and 30-class runs showed improved class discrimination class pixels. The 100-class process finally presented good results in most categories including some vineyard distinction. Some shrub, agriculture, and grasslands still showed minimally mixed pixels. Next, the entire Salinas Valley scene was processed in the classification routine.

5.5.5 Classification of the entire Path 43/ Row 35 Scene

A more intensive process of classification began next and results are shown below in Table 5.4. A normalized difference vegetation index (NDVI) was created to help distinguish agriculture from shrub and grasslands. An NDVI raster is a computed ratio between bands 3 and 4 and is commonly used in vegetation studies. The NDVI raster was used in some preliminary runs.

For the purposes of discussion, the term “classes” and class or vegetative “categories” are interchangeable. These terms refer to the output grouped pixels of the classification process. The terms “areas” and “lands” are also interchangeable in that they describe vegetation or land cover on the ground.

As the classification rasters were critically examined, it was determined that the slope raster needed smoothing. This was evident in hilly areas and transition areas of hills to valley bottom. The smoothing was accomplished by processing

Table 5.4 Preliminary classification runs and results

Bands used	Added Rasters	Scene	No. Classes	Results
123457	Slope, NDVI	6/99	100	Good but some confusion in shrub/ crop
23457	Slope, NDVI	6/99	100	Not as good as above
12345	Slope, NDVI	6/99	100	Better, band 7 not needed
12345	Slope, NDVI	6/99	200	Still some confusion, but best yet
543,543	Slope	6/99,1/00	200	Not as good as previous run

it in an averaging spatial filter with a 5 by 5-pixel kernel using TNTMips spatial filter default settings. A 200-class process was run again using bands 1, 2, 3, 4, 5 and the new slope with significant improvement. Another cross-temporal band 5, 4, 3 classification was done using the filtered slope raster in hopes of clarifying the mix of agriculture, shrub, and vineyard. The results were poor, with confusion between agriculture and vineyard, and grass to shrub.

The slope raster needed additional smoothing, so the pixel processing kernel was increased from 5 by 5 to 9 by 9-pixels. Classification was run again, using bands 1, 2, 3, 4, 5 and the 9 by 9 filtered slope, with the best results yet for 200 classes. Some minor confusion still existed in the agriculture, shrub, grass and vineyard pixels, but results were the best to date. This last experimental run was copied, similar colors of classes were merged, and a 5 by 5-modal filter routine applied in the TNTMips classification software performed to try to eliminate single, scattered pixels. This final raster became the model for all classification runs.

The classification processing for other TM scenes is summarized below in Table 5.5. All 200-class processes were run according to the above model using bands 1, 2, 3, 4, 5 and the 9 by 9-averaged slope. All scenes required importation into TNTMips native format, trimming, and resampling a copy of the 9 by 9-filtered slope to each scene's trimmed extents.

Table 5.5 Classification results of other scenes

Scene date	Problems with Classification
January 2000	Confusion of conifer and oak woodland, small amount of confusion between grass and dormant vineyard.
November 2000	Small amount of mix of agriculture to grass, and dormant vineyards and grass.
April 2000	Agriculture confused with shrubs, grass. Vineyards not clear.
July 2000	The clearest and easiest scene to identify vegetation. Good vineyard classes, a small amount of confusion with agriculture and shrubs and grass.
November 1989	The most difficult scene to work. Much confusion between agriculture, shrub, grass, bare soils. (Only TM scene; all others ETM)

The final ten classes evolved to be Grass, Oak Woodland / Mixed Forest, Mixed Conifer/ Montane, Shrub, Crop, Vineyard, Bare soil, Urban, Golf/Green crop, and Water.

The problems encountered with the two November scenes, especially the 1989 scene may be due to low sun angle as each scene had some shadowing in the small sub-watershed valleys adjacent to the Salinas Valley. The January scene may have had some similar problems with low sun angle, but also may not have been an optimal time of year for vegetation. This scene was most helpful for the analyst in distinguishing senescent vegetation versus evergreen vegetation. The April scene was good for emerging vegetation, early crops, and natural lands. April may have been too early in the year for good vineyard discrimination.

The July 2000 scene was by far the easiest scene to analyze and classify. It presented good distinction of vineyards and all other nine classes. All rasters were copied, class merged, and filtered to smooth class pixels.

5.6 Verification and Comparison

Two methods were employed to assess error in all the classification rasters. Only class-merged and hole-filled rasters were used for scoring. One method used known areas of ground truth to judge accuracy; the second method compared results of all classifications and yielded a score.

5.6.1 Comparison of classifications to known ground truth

The first method of verification used a hand drawn vector layer of twenty-four circular polygons. Each polygon was an average 3.5 square kilometers in size. The polygons were drawn over areas for which known ground information was either verified by photo, or known by ground assessment. The view in the GIS software was set at 1:10,000, and the polygon layer overlaid on each classification raster. The polygon attributes were compared with the raster class in the view. Each polygon was scored 3-10 (10 best) for percentage of target land cover in each circle. If a polygon touched a target land cover class without containing any of that class, it was scored a 2. If the polygon showed no target land cover but the land cover was in the view, the polygon received a 1. Zero meant a complete miss. Each raster was scored for each polygon in this manner. The Total Possible Truth Score was derived from the number of polygons represented by each class with a possible top score of 10. For example, the agriculture class had three polygons represented in the vector layer. If each of these polygons had a 100% true score of 10, the Total Possible Truth score equaled a value of 30. The results of method one are shown below in Table 5.6. AMBAG land use / land cover data were used to verify results but did not have exactly the same extents of coverage as the Landsat data, resulting in low scores merely because of coverage. The 1989 scene did not have as accurate a georeference as the 1999 and 2000 scenes, and therefore was not evaluated for error.

Table 5.6 Results of July 2000 scene comparison with each classification raster.

	Total Polygon Area (km^2)	Truth Class	Total Possible Truth Score	AMBAG LULC	Jun-99	Jan-00	Apr-00	Jul-00	Nov-00
	0.654	Agriculture	30	10	18	20	13	30	25
	0.384	Shrub	40	2	21	27	12	16	25
	7.62	Grass	30	10	30	27	24	29	23
	0.071	Oak Woodland	30	18	18	5	6	15	11
	0.425	Conifer	20	12	20	17	20	20	16
	0.143	Urban	20	12	20	11	20	20	16
	0.223	Water	10	0	10	10	10	10	10
	0.019	Golf	20	20	20	20	15	20	2
	1.016	Vineyard	30	30	26	21	15	29	8
	0.074	Dryland Farm	10	1	10	4	10	10	9
Total	**10.629**		**240**	**115**	**193**	**162**	**145**	**199**	**145**
Accuracy (%)				**48%**	**80%**	**68%**	**60%**	**83%**	**60%**

5.6.2 Comparison using an evenly spaced grid of polygons

A second comparative analysis required creating an evenly spaced grid of thirty-nine smaller 0.002 km^2 area circular polygons spaced approximately 22 km^2 apart for a total of 39 polygons. This method used the July 2000 scene as a base layer for polygon land cover identification, since its classification yielded the best results. Each polygon was assigned an attribute of primary land cover based on the July 2000 classification raster. Only the six most common land uses were represented in this test due to the grid placement (smaller area land use categories were missed by the grid). Scoring of the rasters was the same as above. The results are shown in Table 5.7. The highest scoring raster was July 2000 as expected as all rasters were compared to it. The AMBAG layer accuracy % number is corrected to show only those polygons within the same extents as the comparative analysis grid.

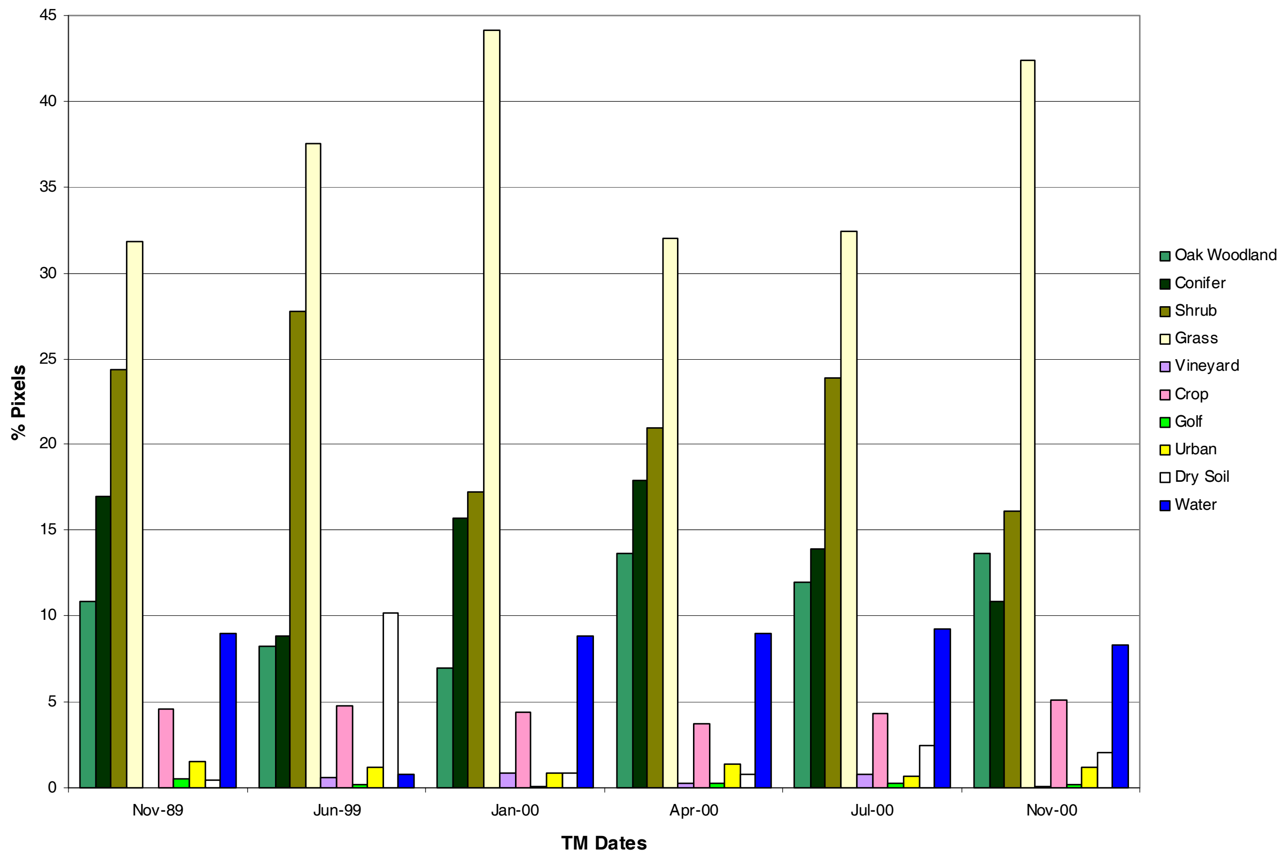
Table 5.7 Comparison of classifications based on polygon grid

Classes	Total Polygon Area (km2)	Total Possible Truth Score	AMBAG	Jun-99	Jan-00	Apr-00	Jul-00	Nov-00
Row Crop	0.00594	30	30	19	29	29	29	29
Shrub	0.01386	70	24	51	19	29	55	19
Grass	0.03168	160	30	158	145	97	152	136
Oak Woodland	0.0099	50	1	11	4	19	43	20
Conifer	0.01386	70	10	28	38	53	63	27
Urban	0.00198	10	10	3	1	10	9	9
Total	**0.07722**	**390**	**105**	**270**	**236**	**237**	**351**	**240**
Accuracy (%)			**66%**	**69%**	**61%**	**61%**	**90%**	**62%**

The June and November scenes rated highly because of the number of grid polygons that occurred in the shrub and grass areas, as of these rasters were evaluated as having an over-estimate of shrub and/or grass overall. The June scene also showed row crop classes mixed with grass and shrub, leading to a lower score for row crop areas. The April scene contained close to the correct abundance of grass and shrub lands, but exhibited more mixed oak woodland and conifer classes than that of the other scenes. The July 2000 was the most balanced in all classes, and therefore was chosen as the most correct land use/ land cover classification. See Tables 5.9 and 5.10 for more discussion on the individual raster classification results.

Figure 5.8 below shows the distribution of classes in percent pixels for each raster. This graph shows the percentage of each land use class comprising each finished classification raster for Path 43/ Row 35.

Figure 5.8 Distribution of pixels for each classification raster



5.6.3 Discussion of mixed pixels in all classification rasters

Table 5.9 shows the most frequently confused classes for each classified raster. For the oak woodland/ mixed forest category, there was consistent confusion between conifer and montane areas. This may be due to the limited number of two classes in these categories, and it might be possible to further split these classes with better ground-truthing. These classes also tend to occur very close to each other geographically. Another commonly confused class is row crop areas mixed with grass areas. This was a problem seen in all rasters, and without masking the raster or decisions that compromised the ease of repeatability, it was decided to leave the confused pixels as they were with an underestimate of agriculture. Vineyard area was difficult to separate from grass and row crop areas, as grasses are often grown between rows of grapes and also occur spatially near row croplands. To classify them more efficiently, a scene with senescing red leaves should be used. The November scene purchased by this study just missed the optical capture of senescing leaves.

Bare soil areas were commonly confused with grass, row crop, and in one scene, urban class areas. This may have occurred because of soil reflectivity, and the sparse vegetation of grasslands and dryland farming. The first classification runs made a distinction between dry soil and dryland farming; later these classes were combined.

Table 5.9 Most frequently confused classes

	Classes confused within:					
Class	**Nov-89**	**Jun-99**	**Jan-00**	**Apr-00**	**Jul-00**	**Nov-00**
Oak Woodland/ Mixed Forest	Conifer/ Montane	Conifer/ Montane	Conifer/ Montane	Conifer/ Montane	Conifer/ Montane	Conifer/ Montane
Conifer/ Montane	Oak woodland	Oak woodland	Oak woodland	Oak woodland	Oak woodland	Oak woodland
Shrub	Oak woodland	Row crop	Oak woodland	Grass	Oak woodland	Grass
Grass	Row crop	Row crop	Row crop	Shrub	Row crop	Row crop
Vineyard	Row crop	Grass	Grass	Grass/ Row crop	Grass	Grass/ Row crop
Row Crop	Grass	Grass	Grass	Grass	Grass	Grass
Golf / Green crop	Urban					Shrub
Urban	Bare soils	Shrub	Shrub/ Grass/bare			Bare soils
Bare Soil	Grass	Row crop	Grass	Urban	Grass	Grass
Water		Fog				

Table 5.10 Comments on errors of class representations

Finished LULC Raster Date	Comments on Errors
November 1989	Under estimates of oak woodland, dryland farming, and vineyard areas. Slight overestimates of conifer, shrub and urban areas due to shadow. Row crop, water, golf, grass land areas reasonable. This Landsat 5 image was not as clear and as high a quality as Landsat 7 images.
June 1999	Overestimates of grasslands, shrub, and dryland farming areas. Underestimates of water (fog along coast in scene), oak woodland, and conifer areas.
January 2000	Highest overestimate of grassland area probably due to bare, reflective soil. Row crop area estimates are good because of the color of the alluvial soils in the valley bottom. Dryland farming areas had a low estimate because they combined with grassland areas. Oak woodland and shrub areas under-estimated probably due to time of year.
April 2000	Oak woodland and conifer areas over-estimated and some confusion with shrub areas. Grassland and shrublands somewhat confused. Dryland farming area underestimated as it was mixed with row crop classes.
July 2000	Possible underestimates of oak woodland and shrub areas. Mixing of pixels in vineyard/row crop and row crop/grassland/shrub classes, leading to a known underestimate of row crop areas.
November 2000	Overestimate of grassland and possibly row crop areas. Vineyards are leafless at this time of year, so difficult to estimate. Golf/ green crop areas are underestimated. Winter scenes had much shadow and low sun angle.

The Table 5.10 shows comments on each classification raster and makes estimates of which classes may be over or under represented. The overall accuracy of the July 2000 Salinas Valley land use/ land cover classification is estimated to be approximately 83% (Table 5.6). The USGS NLCD US Land Cover mapping project has estimated their average accuracy for Federal Regions 1-4 to be 80% (USGS, 2003).

5.7 The final results as of September 2001

The final land use map for the Salinas Valley as of September 2001 is shown below in Figure 5.11. This map includes most of the Salinas Valley watershed. The production of this product concluded the methodology development for the project. The final aspect of this study was to complete land use classification for the surrounding areas that comprise Region 3.

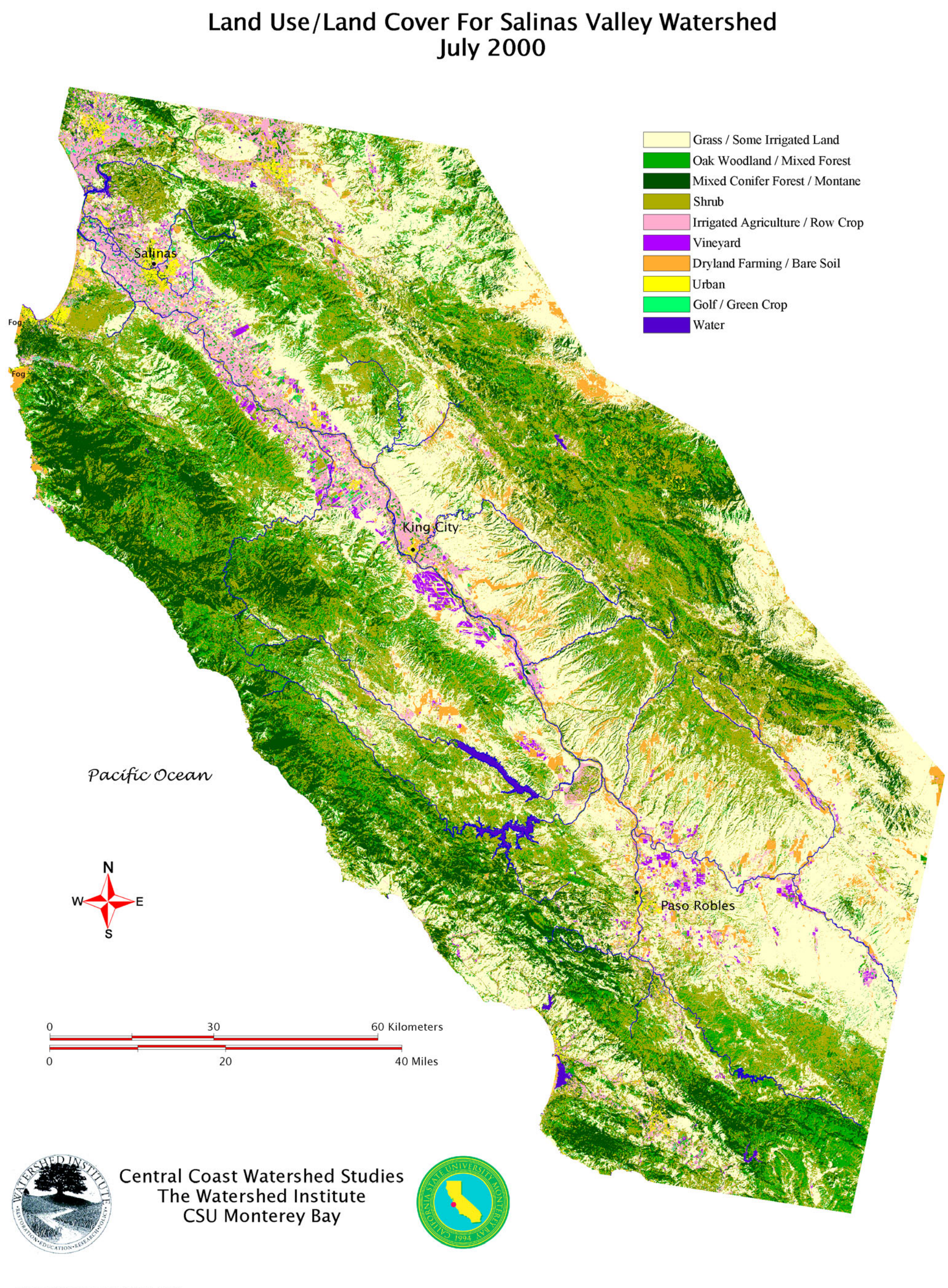


Figure 5.11 Final classification raster, September 2001

5.8 Land use mapping for Region 3

The Landsat scenes necessary for the final Region 3 were imported. A slope raster from the final mosaicked DEM was computed, filtered, and extracted to the same grid as the TM scene. A comparison classification of the July 2000 Salinas Valley scene was repeated with the final DEM to ensure that the classification would yield similar results as with the 2001 DEM. The classification

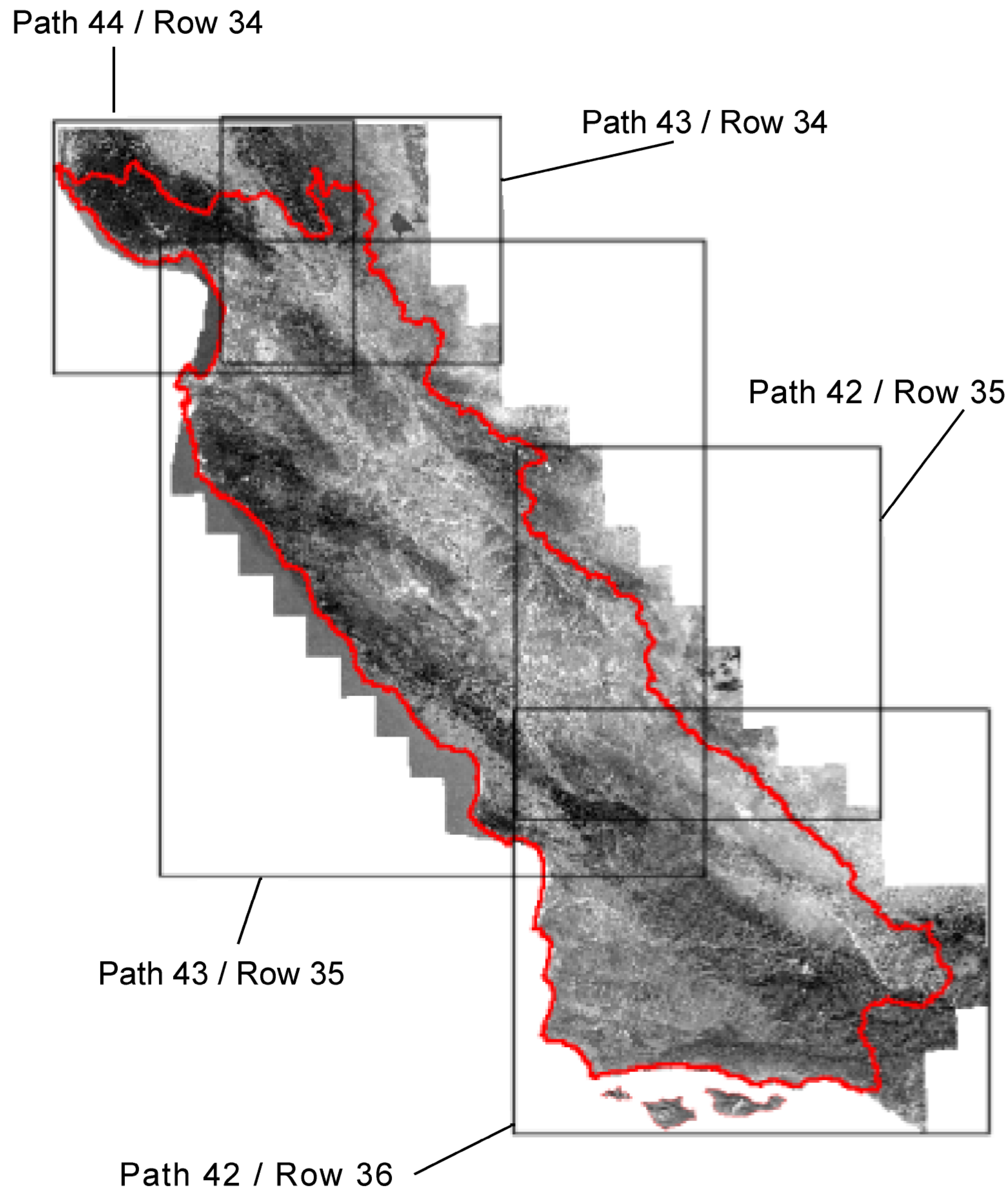


Figure 5.12 Landsat TM pieces required for completion of Region 3

output differed little from the previous summer's process, so classification of the other scenes was begun in late summer 2002. Figure 5.12 shows the Landsat pieces required to fill the Region 3 map.

5.8.1 Classification of the additional scenes

All of the additional scenes overlapped the original scene. For each scene, an extraction of TM bands was performed to match the localized extents of the DEM (primarily, ocean was trimmed out). The filtered slope raster was then extracted to each scene, and re-sampled to the corresponding TM scene. The classification process was run for each scene, analyzed, and assigned colors by the analyst.

5.8.2 Scene matching

Once the scene was classified, a process of scene matching was begun. Scenes were always compared along shared boundaries to the Salinas Valley scene first. Matching scenes in the north (San Francisco, Modesto, and Salinas Valley north) was simple and straightforward. This is probably due to distinct land cover with distinct topography that involved fewer confused classes.

Scene matching in the south was more challenging. Matching the south Salinas Valley to the San Luis Obispo and small Bakersfield scenes proved the most difficult. The primary problem was the intermixing of grass/bare/crop classes in the center of the scene. In that area, there are not many differing classes, and the topography is consistently flat. Considerable effort was spent validating with aerial photographs. Data sources for this validation were in-house aerial photos, 10-meter SPOT imagery, and local knowledge of the landscape from field crews.

Once a reasonably close match was attained, the rasters were all copied and class colors merged. Seams were again checked, and no adjustments were necessary.

5.8.3 Some final aesthetic repairs

The final process before beginning the final mosaic was the repair of some small aesthetic problems on the Salinas Valley raster. In the upper portion of the coast, from Big Sur to the Monterey Peninsula, fog obscured the land. This is a common condition in this area, and most of the scenes we ordered had some clouds in this area. The Monterey Peninsula was also obscured and partially missing due to scene cut-off; the Peninsula is included on another Landsat Path and Row (44, 35). The tip of Point Lobos (approximately 0.16 km^2) was not visible due to missing data. More data would have to have been purchased to repair these final problems and was deemed not cost effective.

The Channel Islands of San Miguel, Santa Rosa, and Santa Cruz also had cloud cover on the original scene. The Islands are obscured most of the year by clouds, so a March scene of the San Luis Obispo area was ordered and classified as a whole scene. This classification was matched to the final San Luis Obispo classification. This was done to make sure that natural areas were the same on the islands as well as mainland. The Channel Islands were extracted and mosaicked with the final layers to create the Region 3 image.

Repair of cloud cover on the coast was straightforward. Clouded areas were encircled by vector polygons in TNTMips' Spatial Data Editor. This new vector layer was co-registered to the Salinas Valley scene, and was used to extract raster information from another less cloudy image. The classification rasters were examined for cloud cover, and it was determined that the April image had the best pixels for insertion (this raster had an overall accuracy of 60% in the verification process, Section 5.6.1). The vector polygons were used in the extraction process, and resulting data were saved for the final mosaicking process.

Landsat Path 43 Row 35 included most but not all of the Monterey Peninsula. An extract of the Peninsula from a Path 44, Row 35 TM5 scene from May 1986 was used to fill in missing data. The DEM was prepared and a full two hundred-class classification run of this small scene. Using two hundred classes in a very small area ensured that present land use / land cover conditions could be met. The Peninsula is well known by first hand knowledge of the analyst, and good results were achieved. This small scene took care of any remaining aesthetic issues on the Salinas Valley raster.

The final process was the mosaic of all rasters and repairs. The process is simple, but sensitive to the layer order. The best layers are optimally positioned at the top of the "stack". The cloud repairs were loaded on the top, with Monterey Peninsula, Salinas Valley, San Francisco, Modesto, San Luis Obispo, and Bakersfield last. The single output raster was processed by the 5 by 5 modal filter as per the methodology explained in Section 5.5.4. Applying the filter at the end of the process removed any remaining seam artifacts.

5.9 Final land cover products

Figure 5.13 shows the final map product of this project.

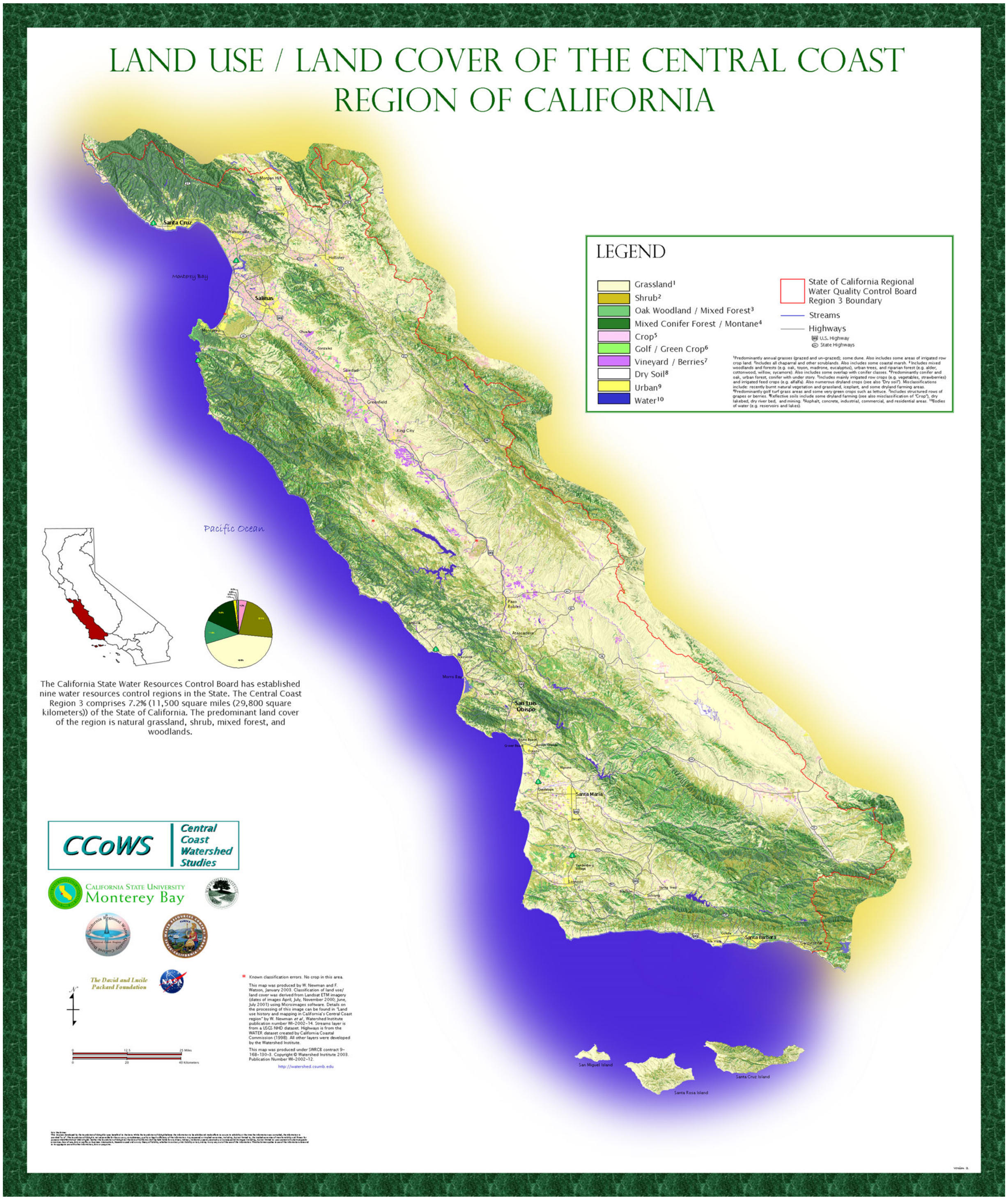


Figure 5.13 Final Land Use/Land Cover Product

5.10 Discussion of the land use raster

The land use map produced by the present study achieves many of the requirements set forth in Section 5.1. It covers the entire region and was produced using relatively objective techniques. The techniques are repeatable. The map was produced within a year of data acquisition, and new maps could be produced for subsequent years in a similar time frame. The map is reasonably accurate (approx. 80%), but may be less accurate than other maps with respect to the mapping of certain land types. Most notably, the extent of agricultural area is under-estimated when compared with the detailed mapping of the Salinas Valley floor produced by the California Department of Water Resources. The under-represented areas could have been expanded in the present study, but only at the expense of equivalent erroneous inclusion of agricultural areas in some of the dry non-agricultural parts of the watershed. A decision was made to bias the mapping toward classifying certain agricultural areas as grassland, rather than classifying certain grasslands as agriculture. It was decided that subjective intervention in the automated classification procedure at this point would compromise the primary goal of the map – to be rapidly, objectively, and affordably repeatable in future years.

The Salinas Valley classification of 2002 was estimated to have an accuracy of 83%. The entire Region 3 raster is estimated to have an accuracy of 60%-80%.

5.10.1 Future improvements

While the results achieved were good, several improvements could be developed to refine the mapping of land cover and land use change in the future. The first improvement would enhance separation of the mixed classes of agricultural, grass, and shrub classes in agricultural areas. Specific mapping of agricultural areas using additional imagery or data could be included in the classification system. Part of this refinement would be to try radiometric calibration for all classification imagery. This study's primary objective was to produce a rapid, accurate, and repeatable map. Every effort was made to save processing time. While it is possible that radiometric calibration might yield better results, experimentation would be required to test this objective. The second improvement would address a more detailed error assessment by increasing the number of land cover ground truth points for all Region 3. The final improvement would employ older satellite imagery for the purpose of land cover change detection.

5.10.1.1 Mixed Classes

Mixed classes of grass, shrub, and row crops in agricultural areas might be minimized by specifically mapping agricultural areas for texture, soil moisture, or same-season data for a leaf on/ leaf off map layer. One or all of these could be used as inputs either as an image into the classification routine, or made into a mask, as in a hybrid, unsupervised method. The leaf on/ leaf off mapped areas would be particularly helpful for identification of established vineyards. Leaf on/ leaf off would not aid in identifying newer vineyards as young vines do not have the leafy biomass needed for 30-meter data capture. Radar is effective for mapping irrigated soils and texture. Soil moisture can also be mapped with Landsat data. This study did not use this portion of the Landsat data (bands 5 and 7).

The delineation of urban boundaries might be improved by using the above methods as well. These boundaries become critical when monitoring change over time. Urban areas might also require higher resolution data for more accurate boundaries.

5.10.1.2 Error Assessment

The ground truth assessment performed in this study was simple and could be expanded. Using GIS to assess the accuracy of the land use raster is a good method of error assessment. A future improvement in the method would be to GPS more actual land cover, maintain a vector layer with these attributes, and reassess the land cover assignments.

5.10.1.3 Change Assessment

Change over time assessment would be most interesting utilizing earlier satellite scenes. Landsat Multi-Spectral Scanner (MSS) imagery was initially investigated for this study because of low cost, temporal coverage, 60-meter resolution, and its availability in three-decade sets. The 1972 scene was of particular interest because these data are some of the earliest satellite data available. Later assessment showed that the scene had significant cloud cover and was positioned more southerly than the corresponding scenes, making the possibility of scene-to-scene comparison problematic given limited time and funding. Landsat 5 data from 1989 were also used in early work but were found to be inferior to the ETM data to the extent that comparison was difficult.

MSS and early Landsat scenes require considerably more pre-processing than Landsat 7 ETM data in the form of geo-rectification, image enhancement and correction. Once these images were corrected, classification could take place. Image subtraction could yield differences in class boundaries. In this analysis, it might be helpful to target specific areas for change analysis, as Region 3 is so expansive.

5.11 Summary

The purpose of this study was to develop a rapid, repeatable, objective process for land cover classification. The process outlined herein yielded a good representation of land use and land cover, using commercially available data and software. Data availability is more accurate, extensive, and less expensive now, making this land use classification process easier than even two years ago. As data improve and method refinements advance, future land use based on the methods outlined above will enable studies to be accomplished with greater speed and accuracy.

6 References

Agricultural Commission, 2001. "Monterey County Crop Report." Monterey County Agricultural Commission, Monterey County, CA. See http://www.co.monterey.ca.us/ag/2001toc.htm

Allen, R.H.1932. Economic History of Agriculture in Monterey County, California during the American Period. Ph.D. Dissertation, University of California Berkeley. 176 pages

Anderson, B. 2000. America's Salad Bowl: An Agricultural History of the Salinas Valley. Breschini, G. and Gudgel, M. Series Editors. Monterey County Historical Society, Salinas, CA 93912. 208 pages

Balogh, J. and Watson, J.R.1992. "Role and Conservation of Water Resources: Chapter 2." Golf Course Management and Construction; Environmental Issues. United States Golf Association, Ed. By Balogh, J. and Williams, W. Lewis Publishers, Chelsea, MI 48118. 976 pages

Biswell, H. 1989. Prescribed Burning in California Wildlands Vegetation Management. University California Press, Berkeley and Los Angeles. 255 pages

Breschini, G., Haversat, T., Gudgel, M. 2000. 10,000 Years on the Salinas Plain. Heritage Media Corporation, Carlsbad, CA 92009. 208 pages

California Department of Conservation/ California Geological Survey. 2000. "California: Principal Mineral Producing Localities 1990-2000". Online Resource. See http://www.consrv.ca.gov/cgs/minerals/images/YellowMap.pdf

CALVEG, 1981. "CALVEG A Classification of Californian Vegetation". Regional Ecology Group, U.S. Forest Service. Online resource. See http://frap.cdf.ca.gov/foofoo2/veg_data/calveg_metadata.html

CCJDC, 2003. Central Coast Joint Data Committee website. Online. Downloads of data free to public. See http://www.centralcoastdata.org/

"Course List". 2003. CNN/ Sports Illustrated/Golf Magazine. Online Resource. 106 pages. See http://www.golfcourse.com/search/simpleq.cfm

Davis, F. W., D. M. Stoms, A. D. Hollander, K. A. Thomas, P. A.Stine, D. Odion, M. I. Borchert, J. H. Thorne, M. V. Gray, R. E. Walker, K. Warner, and J. Graae. 1998. The California Gap Analysis Project--Final Report. University of California, Santa Barbara, CA. See http://www.biogeog.ucsb.edu/projects/gap/gap_rep.html See also http://www.biogeog.ucsb.edu/projects/gap/gap_home.html

DPR. 2001. "2001 Annual Pesticide Use Report." Indexed by Commodity for Monterey County. http://www.cdpr.ca.gov/docs/pur/pur01rep/01_pur.htm

DWR, 1993. "Dams Within Jurisdiction of the State of California-Bulletin 17". Department of Water Resources. Online resource. See: http://elib.cs.berkeley.edu/kopec/b17/html/home.html

DWR, 2003. Department of Water Resources website. Online resource. See http://www.waterplan.water.ca.gov/landwateruse/landuse/luindex.htm

Franks, K, and Lambert, P. 1985. Early California Oil: a Photographic History 1865-1940. Texas A&M Press, College Station, TX 232 pages

Gordon, Burton, 1996. Monterey Bay Area: Natural History and Cultural Imprints. Boxwood Press, Pacific Grove CA. 93950 p 48,

Baumhoff, M.A. 1978. "Environmental Background". Handbook of North American Indians; Volume 8: California. Heizer, R., Editor. Smithsonian Institution, Washington, DC. Pgs 16-24

Heizer, R. and Elsasser, A. .1980. The Natural World of the California Indians. University of California Press, Berkeley and Los Angeles. Pgs 82-113

Henson, P. and Usner, D. 1993. The Natural History of Big Sur. University of California Press, Berkeley and Los Angeles. P172

Hornbeck, D, 1984. "The Past in California's Landscape." California Mission Studies Association. Online. Accessed November 25, 2002. See also: http://www.ca-missions.org/hornbeck.html

Jet Propulsion Laboratory, 2002. Web page for the Shuttle Radar Tomography Mission. Online resource. See: http://www.jpl.nasa.gov/srtm/index.html.

Kondolf, G. M. 1994. "Geomorphic and environmental effects of instream gravel mining", Landscape and Urban Planning. Elsevier Science, B.V. (28) 225-243

Likas, A., Vlassis, N., & Verbeek, J.J. (2002 in press) "The global k-means clustering algorithm", Pattern Recognition, in press

Lillesand, Thomas M., Kiefer, Ralph W. 2000. Remote Sensing and Image Interpretation, 4th. Edition. 724 pages. John Wiley & Sons

Margolin, M. 1978. The Ohlone Way: Indian Life in the San Francisco-Monterey Bay Area. Heyday Books, Berkeley, CA 94709 182 pages

Monterey County. 2002. Draft 21st Century General Plan Update, March 2002. Volume 1. Monterey County Planning and Building Department, Salinas, CA 93902.

MCWRA, U.S. Army Corps of Engineers, and EDAW. 2001. Draft EIS/EIR for the Salinas Valley Water Project. Monterey County Water Resources Agency, Salinas CA 93902

Microimages, Reference Manual for the TNT products V6.40, September, 2000. Microimages, Lincoln NE. Volume 3482.2.2

Paddison, J. 1999. A World Transformed: Firsthand Accounts of California Before the Gold Rush. Heyday Books, Berkeley, CA 94709 edited by author

Savory, A. 1988. Holistic Resource Management. Island Press, Washington DC 20009. 564 pages

Schoenherr, 1992. A Natural History of California. University of California Press, Berkeley. 772 pages

State Water Resources Control Board, California Regional Water Quality Control Board Region 3, California Department of Fish and Game, University of California Santa Cruz, Moss Landing Marine Labs. 1998. Chemical and biological measures of sediment quality in the Central Coast region. State Water Resources Control Board Division of Water Quality, Sacramento, California. pp 84.

Tou, Julius T. and Gonzales, Raphael C. (1974). Pattern Recognition Principles. "K-Means Algorithm" in Chapter 3, Pattern Classification By Distance Functions. Reading, MA: Addison -Wesley. Pp. 94-97.

USGS, 2002. National Land Cover Characterization Project. Online resource. See http://landcover.usgs.gov/nationallandcover.html

USGS. 2003. "Accuracy Assessment of 1992 National Land Cover Data". Online. See also: http://landcover.usgs.gov/accuracy/index.html

Verardo, J, and Verardo D. 1989. The Salinas Valley: An Illustrated History. Windsor Publications, Inc., Chatsworth, CA 208 pages

Vogelmann, J.E., Sohl, T., Howard, S.M.. 1998. "Regional Characterization of Land Cover Using Multiple Sources of Data." Photogrammetric Engineering and Remote Sensing, Vol. 64. No. 1, pp 45-47 Also see: http://edcdaac.usgs.gov/glcc/globdoc1_2.html#unsup

Vogelmann, J.E., Sohl, T.L., Campbell, P.V., Shaw, D.M..1998. "Regional Land Cover Characterization using Landsat Thematic Mapper Data and Ancillary Data Sources." Environmental Monitoring and Assessment. Vol. 51; 415-428. See Also: http://landcover.usgs.gov/mapping_proc.html#explain

Walker, W.J. and Branham, B..1992. "Environmental Impacts of Turfgrass Fertilization: Chapter 3." Golf Course Management and Construction; Environmental Issues. United States Golf Association, Ed. By Balogh, J. and Williams, W. Lewis Publishers, Chelsea, MI 48118. 976 pages

Watson, F.G.R. & Rahman, J.M., 2002. "The Tarsier environmental modelling framework." Submitted to: Environmental Modelling and Software.

Watson, F.G.R., Anderson, T, Casagrande, J, Kozlowski, D., Newman, W., Smith, D. Curry, R. 2003. Salinas Valley Sediment Sources- Draft Report. The Watershed Institute, CSU Monterey Bay, Seaside, CA 93955. Report WI-2003-01. 219 pages. See: http://earthsystems.csumb.edu/~ccows/pubs/reports/SalinasSedimentSourcesReport_030115.pdf

7 List of Abbreviations Used in This Report

Abbreviation	Meaning
AHSM	Atascadero Historical Society Museum
AMBAG	Association of Monterey Bay Area Governments
CCJDC	Central Coast Joint Data Committee
CDC	California Department of Conservation
CGS	California Geological Survey
DEM	Digital Elevation Model
DPR	Department of Pesticide Regulation (CA)
DWR	Department of Water Resources (CA)
EIR/EIS	Environmental Impact Report/Environmental Impact Statement
EPA	Environmental Protection Agency (US)
ETM	Enhanced Thematic Mapper
GIS	Geographic Information Systems
GPS	Geographic Position System
LULC	Land Use, Land Cover
MCARLM	Monterey County Agriculture and Rural Life Museum
MCWRA	Monterey County Water Resources Agency
MRLC	Multi-Resolution Land Characteristics
MSS	Multi Spectral Scanner
NDVI	Normalized Difference Vegetation Index
NLCD	National Land Cover Data
RWQCB	Regional Water Quality Control Board (CA)
SDTS	Spatial Data Transfer Standard
SPOT	Systeme Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Tomography Mission
SWRCB	State Water Resources Control Board (CA)
TM	Thematic Mapper
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WATER	Water Analysis Tool for Environmental Review