Natural Vegetation in the Central Valley of California

Prepared for:

STATE WATER CONTRACTORS AND
SAN LUIS & DELTA-MENDOTA WATER AUTHORITY

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June 2014

ACKNOWLEDGEMENTS

This work was funded by San Luis Delta-Mendota Water Authority and the State Water Contractors. This work benefited greatly from discussions with and information provided by Dr. Robert F. Holland (unpublished vernal pool GIS shapefiles), as well as Rusty Griffin, U.S. Fish & Wildlife Service (historic wetlands map). This work was coordinated with other related tasks and reviewed by Dr. Paul Hutton (Metropolitan Water District). The final report was edited by Linda Standlee (State Water Contractors).

EDITORIAL NOTE:

At the suggestion of the technical representative, Dr. Phyllis Fox agreed to include in this report (in three appendices) key documents she had previously prepared for the State Water Contractors in support of the 1987 State Water Resources Control Board Bay-Delta Hearings. Although some of these State Board exhibits have been superseded by the work presented in this report, it was agreed that the exhibits provide valuable background and historical perspective, and that inclusion of these exhibits in this report allows for wider access to the work.

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1.0 INTRODUCTION

The author's original work on natural landscape and hydrology was conducted for the State Water Contractors in support of the California State Water Resources Control Board's Bay-Delta hearings in 1987. Key exhibits developed for these hearings are provided in these documents in Appendices 1 through 3. This report summarizes recent efforts to refine and update the original work produced in 1987.

In related work, Delta outflow was estimated under the natural level of development and compared with Delta outflow under the current level of development. In both cases, the same climatic conditions were assumed to occur while varying the level of development that it encountered (natural vegetation and current conditions). (Fox et al. 2014[1]). Natural conditions are defined as those that existed prior to 1769, the year livestock raising commenced, but assuming the climate of water years 1922 to 2009 (October 1921 to September 2009).

Natural flows are calculated as a long-term annual average, assuming the climate of 1922 to 2009 repeats with the Valley Floor in a natural or undeveloped state, before livestock, flood control, levies, drainage, reclamation, irrigation, etc. These natural flows were calculated from a water balance expressed as:

Delta Outflow = Water Supply - Water Use

The water balance was calculated around the portion of the Central Valley that drains into San Francisco Bay, referred to as the "Valley Floor," shown in Figure 1. The boundary of the Valley Floor is defined by the drainage basins of the gauges used to determine rim inflows. Under natural conditions, the water supply was the sum of rim inflows and precipitation on the Valley Floor. The rim inflows are equal to the historically observed flows (or estimated historical flows), adjusted to remove the effects of upstream storage regulation and imports and exports.

Under natural conditions, the major water loss from the system was evapotranspiration by native vegetation. We estimated the amount of water used by native vegetation from the acres of each type of vegetation and an evapotranspiration factor in acre feet of water per acre of vegetation. Thus, the land area occupied by each type of native vegetation must be estimated. This report explains how we determined those land areas. The derivation of the evapotranspiration factors are presented elsewhere. (Howes et al. 2014[2]).

Water balances were calculated monthly for each water year from 1922 to 2009 for the three sub-basins that comprise the Valley Floor: the Sacramento Basin, the San Joaquin Basin, and the Delta, shown in **Figure 1**. Long-term annual average flows were calculated over this period of record. Input data were compiled (rim inflows, Valley Floor precipitation, vegetation

[1] Fox, P., Hutton, P.H., Howes, D.J., Draper, A.J., and Sears, L., 2014. Freshwater Inflow to San Francisco Bay under Natural Conditions, Submitted to Journal of Hydrology, March 2014.

[2] Howes, D., Fox, P., and Hutton, P.H., 2014. Evapotranspiration from Natural Vegetation in the Central Valley of California: Monthly Grass Reference Based Vegetation Coefficients and the Dual Crop Coefficient Approach, Submitted to the Journal of Hydrologic Engineering, March 2014.

areas, evapotranspiration) and calculations made for 16 smaller areas, referred to as "planning areas," shown on Figure 1.

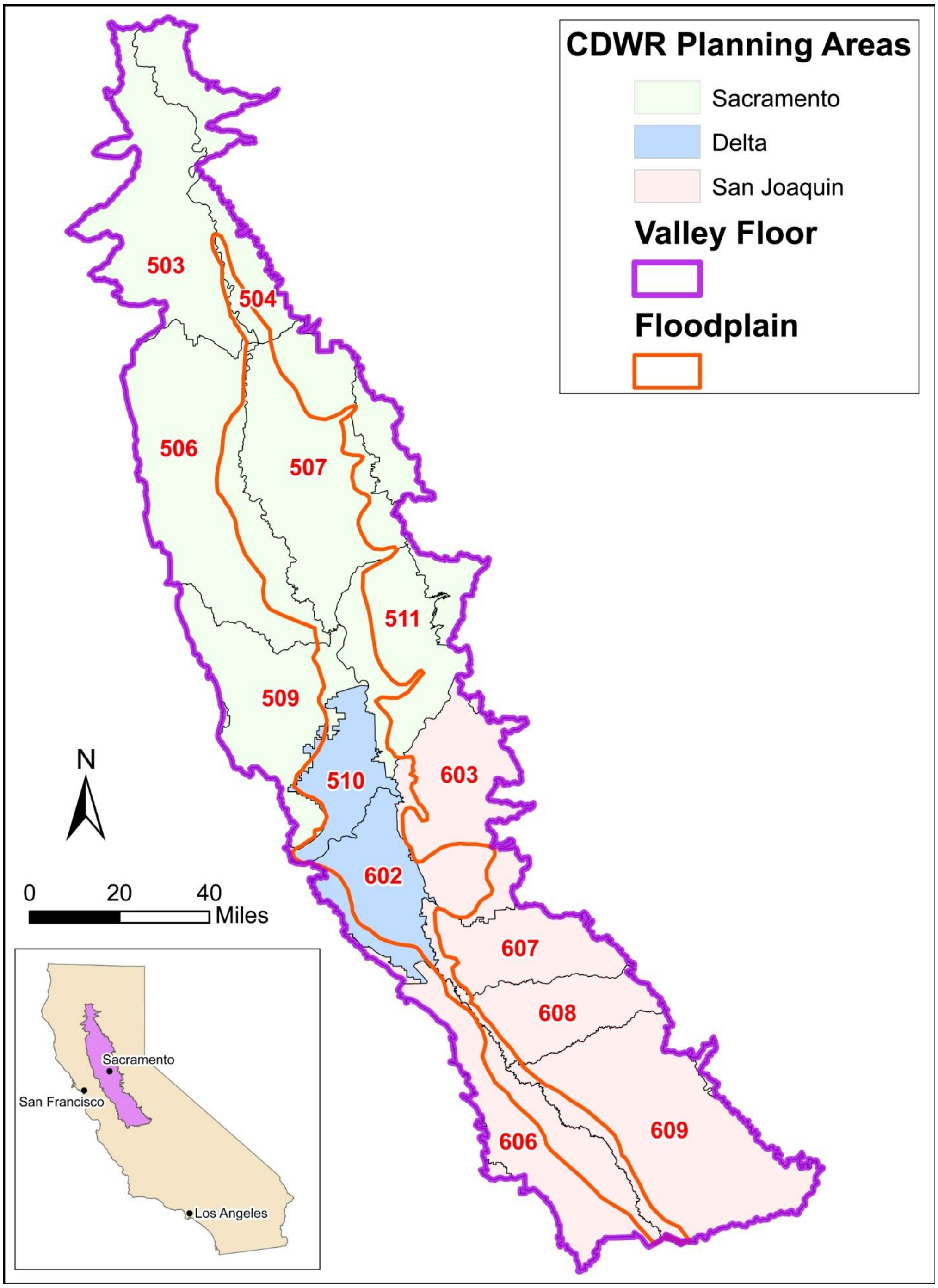

Figure 1. Valley Floor Study Area.

Note: Water use calculations were conducted by planning area and summarized by hydrologic basin. Planning Areas 502, 505, 508, 601, 604, 605 and 610 within the Valley Floor are too small to show on this map. Planning area boundaries were defined by CDWR (2005a, 2005b).

Natural Delta outflows were compared with "unimpaired" Delta outflows and current level of development Delta outflows. The calculation of unimpaired flows, estimated by the California Department of Water Resources (CDWR), uses the same rim inflows and precipitation as used in the natural flow calculation. However, rather than reducing the water supply to account for water use associated with the full extent of natural vegetation, the CDWR calculation assumes that Valley Floor water use is limited to Valley Floor precipitation and a small additional increment of water use (0.4 MAF/yr) in the Delta. Otherwise, the calculation assumes rim inflows arrive in the Delta in the current system of levees, dredged deep-water channels, flood bypass channels, overflow weirs, and headstream reservoirs. CDWR cautions against using unimpaired flows as estimates of natural flows. Unimpaired Delta outflow never existed as it ignores the natural landscape, which consumed a significant fraction of the natural water supply and altered the timing of its arrival in the Delta due to detention in flooded lands and groundwater storage.

These calculations indicate that long-term annual average Delta outflow ranged from 11.4 to 18.7 MAF/yr and was most likely about 16 MAF/yr under natural conditions, depending upon assumptions as to composition and water use by natural vegetation. Natural vegetation used 54% to 72% of the pristine water supply. In comparison, current uses consume 62% of available water supply and result in a long-term annual average Delta outflow of 15.8 MAF/yr. (Fox et al. 2014). The unimpaired flows are not representative of natural conditions as they do not include the substantial use of water by natural vegetation.

The purpose of this report is to explain the framework in which this work is set -- the natural hydrology -- and to present the methods and assumptions we used to estimate the vegetation areas that were input to water balance calculations to estimate Delta outflow under natural conditions.

2.0 NATURAL HYDROLOGY

Under natural conditions, the channels of the major rivers did not have adequate capacity to carry normal winter rainfall runoff and spring snowmelt. (Grunsky[3] 1929,[4] p. 791, CA State Engineer 1908,[5] pp. 61-62). They overflowed their banks into vast natural flood basins flanking both sides of the Sacramento (American, Colusa, Sutter, Butte, Yolo, Sacramento) and San Joaquin Rivers. (Hall[6] 1880,[7] p. 10; Grunsky 1929). Water flowed over the levees in thin sheets, until the water level on the non-river side of the levees rose and joined with the water surface in the channel. When this happened, all visible trace of a channel was lost and the area took on the appearance of a large inland sea.[8] This water could not directly drain back into the main rivers and moved in these parallel flood basin troughs along the river, some eventually draining back into it through sloughs and breaks in the levees, some remaining to evaporate during dry years. (CSG 1862,[9] p. 101; Whipple et al. 2012,[10] pp. 236-237). Localized depressions, ponds, and lakes would stay wet through the year, filled by overland flow from floods and high water tables, but disconnected from drainage channels. (Whipple et al. 2012, pp. 255-268). In the San Joaquin Valley in July 1853, for example, engineers surveying a route for a railroad, reported, "The river [San Joaquin] had overflowed its banks, and the valley was one vast sheet of water,

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3 Carl Ewald Grunsky (1855-1934): California's first Assistant Engineer in charge of Hydrographic Surveys. California Academy of Sciences Biographical Sketch Available at: http://researcharchive.calacademy.org/research/library/special/bios/Grunsky.pdf.

4 Grunsky, C.E. 1929. The Relief Outlets and By-Passes of the Sacramento Valley Flood-Control Project. Transactions of the American Society of Civil Engineers. 93, 791-811.: p. 791, "The channel dimensions of the river [Sacramento] are in places quite inadequate to carry the extreme floods, as illustrated by one stretch of the river, more than 60 miles long, where only about one-eighth of the water at such a flood stage flows in the river. The remainder, under natural conditions, spilled over the bank into the flood basins which paralleled the river."

5 California State Engineer, 1908. Report of the State Engineer of the State of California, May 11, 1907 to November 30, 1908.: pp. 61-62, "Prior to the commencement of farming on the low lands and the building of protection levees, the high waters ran over the banks filling the basins to the flood level of the stream and obliterating all trace of the channel, excepting as the banks were marked by the growth of trees. During the flood of 1853, the conditions are described as presenting to view a "sea of water" from Sutter's Fort (In Sacramento city) westward to where Davisville now is, and southward to Stockton, the water being three deep over the banks of the river."

6 William Hammond Hall (1846-1934) was the first California State Engineer. Biography available at: http://en.wikipedia.org/wiki/William_Hammond_Hall.

7 Hall, W.H., 1880. Report of the State Engineer to the Legislature of California, Session of 1880. Part 2., p. 10, "The main river channels, and more particularly, the Sacramento, as the main drain of the valley, being insufficient in capacity for the immediate passage to the bay of ordinary flood, these waters have, for ages past, poured over its banks and been temporarily lodged in the low basins by which it is flanked for miles of its course, to be drained off after the passage of the flood-water proper." See also p. 24 noting that the Sacramento River throughout its course is incapable of passing the maximum volume of the ordinary high floods and p. 73 concluding the "river channels never were capable of passing the water of ordinary floods...".

8 Grunsky 1929, p.796,"Before the water was held back by levees, any general river flood stage converted the entire west side valley trough [Sacramento] from a point in the latitude of Princeton to the ridge at Knights Landing into an inland sea nearly 50 miles long and 2 to 7 miles wide…"

9 California Surveyor-General (CSG), 1862. Annual Report of the Surveyor-General of California for the Year 1862, Sacramento. pp. 8-10, 101. Last accessed February 15, 2014. Available at: http://www.slc.ca.gov/misc_pages/historical/surveyors_general/reports/houghton_1862.pdf.

10 Whipple, A.A., Grossinger, R.M., Rankin, D., Stanford, B., Askevold, R.A. 2012. Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process. Prepared for the California Department of Fish and Game and Ecosystem Restoration Program. A Report of SFEI-ASC's Historical Ecology Program, Publication #672, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

from 25 to 30 miles broad, and approaching within four to five miles of the hills." (Williamson 1853,[11] p. 12).

On the east side of the Valley Floor, only larger tributaries from the Sierra Nevada, such as the Feather, American, Mokelumne Rivers, Stanislaus, Tuolumne, and Merced, reached the main rivers by a definite channel and often the connection was torturous. (Ransome 1893-96,[12] p. 379; Wood 1912,[13] Reed et al. 1890[14]).

Minor tributaries of the Sacramento and San Joaquin Rivers did not directly connect with the main rivers but rather spread into distributaries across their alluvial fans, discharging all of their flow into the flood basins. (Whipple et al. 2012, p. 235). They discharged into sinks before dissipating into the wetlands along the major rivers. (Sweet et al. 1909,[15] p. 7) These sinks were large collections of distributary channels and perennial and intermittent ponds, which supported a dense growth of willows, cottonwoods, oak scrub, and other shrubs, as well as patches of emergent vegetation and seasonal wetlands. (Whipple et al., pp. 294-300).

In the Sacramento Basin, most streams from the Coast Range formed low natural levees outside of the floodplain that blocked the smaller tributaries, creating small impoundments without outlets. (CSG 1862, pp. 26, 101). These formed playa lakes. This occurred in the alkali[16] lands, from about Willows in the Sacramento Basin all the way through the San Joaquin Basin. (Garone 2011,[17] p. 23; Thompson 1961,[18] p. 299).

Fremont, in his memoirs, for example, commented as to the San Joaquin, "The foot hills of the Sierra Nevada, which limit the valley, make a woodland country, diversified with undulating grounds and pretty valleys [likely vernal pools], which reach only a few miles beyond

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[11] Williamson, R.S., 1853. Report of Exploration in California for Railroad Routes to Connect with the Routes Near the 35th and 32d Parallels of North Latitude, In: Reports of explorations and surveys, to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. United States War Dept., Henry, Joseph, 1797-1878., Baird, Spencer Fullerton, 1823-1887. United States Army, Washington: A. O. P. Nicholson, printer, 1855-60.

[12] Ransome, F.L., 1893-1896. The Great Valley of California, Bull. Univ. California. vol. 1. p. 379.

[13] Wood, B.D., 1912. Gazetteer of Surface Waters of California, Part I. Sacramento River Basin. U.S. Geological Survey. Water-Supply Paper. 295.

[14] Reed, C.T., Grunsky, C.E., and Crawford, J.J., 1890. Commissioners Report of Examining Commission on Rivers and Harbors to the Governor of California.

[15] Sweet, A.T., Warner, J. F., and Holmes, L. C., 1909. Soil Survey of the Modesto-Turlock Area, California, with a Brief Report on a Reconnaissance Soil Survey of the Region East of the Area. U.S. Dept. of Agriculture, Bureau of Soils. Page 7, "A peculiar feature of the drainage [the area drained by the San Joaquin River] is that it is well defined in the eastern part of the area among the foothills, numerous small streams having their sources there, but as these reach the more gentle slope of the valley floor proper they become less clearly defined, until they are almost entirely lost, the water of which they carry during the rainy season being absorbed by the soils of the lower part of the valley [where the vernal pools were located]."

16 The term "alkali" is commonly applied to any soluble salt in the soil that leaves an incrustation at the surface when moist soil dries. It may be white, black or brown and is most commonly composed of salts of sulfates, chlorides, carbonates, and bicarbonates.

[17] Garone, P. 2011. The Fall and Rise of the Wetlands of California's Great Central Valley. University of California Press, Berkeley. 422 pp.

[18] Thompson, K., 1961. Riparian Forests of the Sacramento Valley, California. Annals of the Association of American Geographers. 51, 294-315.

the hills, the springs which supply them not being copious enough to carry them across the plains." (Landrum 1938,[19] p. 33).

Water passed through these floodways more slowly than through the river channels, reducing peak flow through the Delta. (Gilbert 1917,[20] p. 15). These flood basins contained significant surfaces that retarded the drainage of the flood basins. The flood basins contained large expanses of tule marsh, seasonal wetlands, lakes, sloughs, ridges, sandbars, sinks, and other landforms that slowed the passage of flood waters. (Whipple et al. 2012, p. 232; Holmes and Eckmann 1912,[21] pp. 6,55;[22] Olmsted and Davis 1961,[23] p. 27). Flood waters navigated "...the intricate plexus of sloughs which meander through the tule lands bordering the main river." (Ransome 1893-96, p. 379; Wood 1912, p. 23; Gilbert 1917, p. 14). Describing the Colusa and Yolo Basins, "The surface region is flat, Shallow sinks occur in which surface water remains until dispelled by evaporation." (Mann et al. 1911,[24] p. 6). Finally, the flood basins, particularly within the upper portions of the basins lacked defined drainage channels. The lower depressions filled during floods and without channels to provide sufficient drainage, formed lakes and ponds common to the tidal margins and upper basin outside of the dense tule stands. (Whipple et al. 2012, pp. 255 - 265).

Soil surveys conducted in the early 20th century are good sources of descriptive information. The 1909 soil survey of the Modesto-Turlock area was complete "except that portion occupied by the overflow lands along the San Joaquin River, a part of which, on account of high water, numerous sloughs, and cut-offs, was inaccessible..." (Sweet et al. 1909, p. 6). Hanford silt loam soils in the floodplain of the San Joaquin River were "much dissected by many deep sloughs and dry channels, left by swift flood waters...Along the edge of the lowland just below this terrace a string of lakes connected by sloughs extend throughout the greater part of the area...numerous sloughs and lakes, could not be prepared for cultivation without great expense..." (Sweet et al. 1909, p. 33). In the Woodland area soil survey, pp. 6-7, "The surface of the valley floor, west of the lowlands, resembles a slightly inclined plain...Throughout the greater part of this region the plain presents a decidedly flat appearance. The surface is dissected by numerous sloughs and creeks..." In Capay clay, "The surface is broken by occasional sloughs and creeks which have cut deep channels or flow on slightly elevated ridges. (Mann et al. 1911, p. 37). In Arbuckle gravelly sandy loam soils, "The surface is sometimes dissected by deep channels of

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[19] Landrum, E. A., 1938. Maps of the San Joaquin Valley up to 1860. A Store of the Valley as Portrayed on Maps and Described by Early Writers, Accompanied by an Annotated Bibliography of Maps, Master of Arts in Librarianship, University of California.

[20] Gilbert, G. K., 1917. Hydraulic-Mining Debris in the Sierra Nevada, Professional Paper 105, U.S. Geological Survey, Washington D.C.: U.S. Government Printing Office.

[21] Holmes, L.C., Eckmann, E.C., 1912. Soil Survey of the Red Bluff Area, California. U.S. Department of Agriculture, Bureau of Soils. At page 6, discussing the Sacramento River floodplain, from Red Bluff to Colusa, "This flood plain throughout is marked by meandering overflow channels sometimes giving sections a much eroded surface. Such areas are abandoned to a tangled growth of wild grape, cottonwood, sycamore, willow, etc."

[22] Discussing Sacramento silt loam soil in the Red Bluff area, "the surface is usually marked by overflow sloughs or abandoned channels paralleling the river in a general way."

[23] Olmsted. F.H. and Davis, G.H., 1961. Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley California, U.S. Geological Survey Water Supply Paper 1497. pp. 25-27., p. 27, "The American Basin has greater general relief than the other basins. It is pock marked with small mounds, depressions, and irregularly shaped elevated area, which are underlain by remnants of the older alluvial material."

[24] Mann, C.W., Warner, J.F., Westover, H.L., and Ferguson, J. E., 1911. Soil Survey of the Woodland Area, California. U.S. Department of Agriculture, Bureau of Soils.

foothill streams and slough." (Mann et al. 1911, p. 40). In the Chico area soil survey, in Columbia loam, which occurs on the eastern edge on the flood plain of the Sacramento River, "The surface is level and smooth, except that it is broken by numerous old water courses." In Sacramento clay in the southwestern part of the Chico area, "...this soil occupies old slough ways and flat, shallow, basinlike areas." (Watson et al. 1929,[25] pp. 44-45).

Thus, under natural conditions, the Central Valley functioned as a series of side-stream reservoirs, located in the Valley alongside the major streams, rather than at the headwaters of the streams as the reservoirs that replaced them. These stream-side reservoirs filled and drained every year. Drainage was delayed by significant roughness from vegetation, sloughs, channels, lakes and other landforms.

These flood basins were home to extensive marsh lands that evapotranspired water trapped within them. Thus, "unimpaired" rim inflows did not flow unimpeded through river channels into the Bay. Rather, those following the main river channels spilled over elevated natural levees into side-stream reservoirs, where they were retained, delayed, and diminished by evaporation and evapotranspiration. Thus, "unimpaired" rim inflows, widely used to represent natural flows, are not indicative of natural flows in terms of either volume or timing.

The filling and emptying of these flood basins had the effect of delaying the transmission of flood flows down the major rivers, reducing peak flows and velocities. (TBI 1998,[26] Sec. IV.B.1; Grunsky 1929[27]). Some of the water in these flood basins gradually drained back into the main river channels after the floods subsided, through a complex network of sloughs. Some basins drained relatively rapidly while others retained flood waters through the summer or year round. (Grunsky 1929;[28] McGowan 1961;[29] Thompson 1961;[30] Olmsted and Davis, 1961[31]). These basins were kept wet year-round by stored floodwaters, inflows from upland streams (such as late melting high altitude snow in the summer in the San Joaquin Basin), seepage from adjacent channels, high groundwater levels, and in some areas, such as Yolo and Sacramento basins, by tidal flows. (Whipple et al. 2012, pp. 213, 254). The flood basins also contained vast tracts of tule marsh, which retarded the drainage of the basins (Baptist et al. 2007[32]) and

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[25] Watson, E.B., Glassey, T.W., Storie, R. E., and Cosby, S. W., 1929. Soil Survey of the Chico Area, California. U.S. Department of Agriculture, Bureau of Chemistry and Soils, Series 1925, Number 4.

[26] The Bay Institute ("TBI"), 1998. From the Sierra to the Sea, The Ecological History of the San Francisco Bay-Delta Watershed. July 1998. Sec. IV.B.1 and IV.B.2.

[27] Grunsky, C.E. [State's first Assistant Engineer in charge of Hydrographic Surveys], 1929. The Relief Outlets and By-Passes of the Sacramento Valley Flood-Control Project. Transactions of the American Society of Civil Engineers. 93, 791-811.

[28] Grunsky 1929: p. 793, "…natural flood-flow retarding basins...had the effect of prolonging the high or flood stages of the river, thereby effectively and very materially holding down the river's peak discharge during flood conditions."; p. 796 describing natural conditions in the Sutter Basin, "water stood in some portion of the flood basin throughout the entire year."

[29] McGowan, J, A., 1961. History of the Sacramento Valley. Lewis Historical Pub. Co. vol. 1. , "These troughs, called "basins," became the reservoirs for winter flood waters, which were not released back into the river until the low water of summer months."

[30] Thompson 1961, p. 299, "Because of the flood basins' lowness and shape, such floodwater did not readily escape but persisted for much of the year, causing a luxuriant growth of tules and other marsh plants."

[31] Olmsted and Davis, 1961, pp. 25-27, "Topographically, the Yolo Basin is a flat, low area from which flood waters drain southward very slowly under natural conditions. As in the other basins, the typical soils are heavy clay and clay adobe; these support a natural growth of tules in the swampy areas."

[32] Baptist, M.J, Babovic, V., Rodriguez U., Keijzer J., Uittenbogaard, M., Mynett, R.E., and Verwey, A., 2007. On Inducing Equations for Vegetation Resistance. Journal of Hydraulic Research. 45:4. pp. 435-445.

evapotranspired residual flood waters. The resulting delayed transmission and reduced volume of flood and other natural flows is not reflected in "unimpaired" flows.

The main river channels were lined by wide levees that were built up over time from sediment deposited as rivers spread out over the floodplain. These levees were much larger and more developed along the Sacramento River than along the San Joaquin River. (Hall 1880,[33] p. 51). Along the Sacramento, the natural levees rose from 5 to 20 feet above the flood basins and ranged in overall width from about 1 to 10 miles, averaging 3 miles. (Thompson 1961, p. 297). The southern reaches of the San Joaquin River developed natural levees only poorly due to low sediment loads (Hall 1880, Part II, p. 51), and only as the river entered the valley floor (Warner and Hendrix 1985,[34] pp. 5.15 - 5.16), sustaining large freshwater marshes still found there today. (Katibah 1984;[35] Garone, 2011,[36] p. 79). However, natural levees did form along the major northern San Joaquin River tributaries -- the Tuolumne, Stanislaus, Merced, Mokelumne, Cosumnes, and northern San Joaquin. (Warner and Hendrix 1985, p. 5.15). Lush riparian forests occupied these levees. (Whipple et al. 2012, pp. 274-300).

The flood basins also received flow from sources other than flood flows spilling over the natural levees. These included upland runoff and west- and east-side streams, e.g., Stony, Cache, Putah. These were blocked from reaching the main river channels by the natural levees. They spread out over the valley floor, pooling in vernal pool complexes and expansive sinks of tule marsh and connecting to the main rivers only by subsurface flow. (Garone 2011, p. 23; Thompson 1961, p. 299). Further, breaches or "crevasses" in the natural levees and percolation of water through the relatively coarse, porous levees permitted excess waters to escape the main streams and spread over the low flood plains. (Thompson 1960, pp. 352-353).

The Sacramento and San Joaquin Rivers discharged into the Delta, which is where the downstream extents of these rivers meet the tides, providing the major source of freshwater flow to the largest estuary on the Pacific Coast. As the rivers descended from the mountains toward sea level near their confluence, their gradients decreased dramatically, reducing their velocity and ability to incise their channels. Thus, they distributed their flow into numerous sloughs that meandered across the landscape (Garone 2011, p. 27) to a common mouth into Suisun Bay. Shoals were present at the mouth of the rivers, one notably opposite Collinsville, which was an obstruction to the escape of flood waters from the Sacramento River. (Hall 1880, Part II, p. 23). An appreciable amount of Sacramento River water below Sacramento was originally routed through the Georgiana and Three-mile sloughs into the San Joaquin River. (Hall 1886,[37] p. 407).

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[33] Hall 1880, Part II, p. 51: Comparing the Sacramento River to the San Joaquin River, "It does not bring down anything like the amount of sediment that the Sacramento does, so that its shores are comparatively low and marshy. In its lower portion it has much less grade than the Sacramento, and having a more open mouth, the tidal action is greater. Indeed, it resembles an estuary or arm of the bay more than a river, below a point opposite of Grand Island."

[34] Warner, R.E and Hendrix, K.M., 1985. Riparian Resources of the Central Valley and California Desert, Final Draft. Department of Fish & Game. May.

[35] Katibah, E.F., 1984. A Brief History of Riparian Forests in the Central Valley of California, In: R.E. Warner and K.M. Hendrix (Eds.), California Riparian Forests, University of California Press, Berkeley,. pp. 23-29 at Table 1, Available at: http://publishing.cdlib.org/ucpressebooks/view?docId=ft1c6003wp&chunk.id=d0e3419&toc.depth=100&toc.id=d0e3419&brand=eschol.

[36] Garone, 2011, p. 79, "In all but the driest years, winter rains and high spring flow from snowmelt in the Sierra Nevada were sufficient to cause the river [San Joaquin] to spill over its low banks into the marshy, slough-laced land to its west."

[37] Hall, W.E., 1886. Physical Data and Statistics of California, Tables and Memoranda Relating to Rainfall, Temperature, Winds, Evaporation, and Other Atmospheric Phenomena, Drainage Areas and Basins, Flows of Streams, Descriptions and Flows of

The Delta received an annual supply of water not only directly from these rivers, but also from tides, high groundwater levels, freshwater inflows, and discharges from adjacent flood basins. Under natural conditions, the rivers were braided together within the Delta in a complex arrangement of channels weaving through flat, low-lying islands with elevations at or below sea level. These islands contain about 365,000 acres of tidal freshwater emergent wetlands (tule or *Schoenoplectus* spp.) and over 1,000 miles of associated tidal channels. (Whipple et al. 2012, p. 81).

These islands were submerged for much of the year, with water levels fluctuating with the tides and river flood stages. The islands' outer margins had small natural levees while the interior sections were marsh. When river flows were high in spring, the historical Delta was a morass of flooded island and marshes. In late summer, when river flows were low, the islands and marshes, protected by low natural levees, were often surrounded by saline water pushed upstream by tides. However, freshwater was present in the central Delta through summer months due to the storage and slow release of water from the side-stream flood basins. (Whipple et al. 2012, p. 233). Nearly 60% of the Delta was originally submerged by daily tides.

The Delta was a place of significant spatial and temporal complexity that provided important ecosystem functions. (Whipple et al. 2012, pp. 81-82; TBI 1998). Dominant vegetation in the saucer-shaped islands included tules and on higher levee ground, coarse grasses, alder, walnut, and cottonwood. (Thompson 1957,[38] Chapters 1-2, pp. 135-136; Thompson 1961, p. 299; Hall 1880, Part II; Moyle 2002,[39] p. 32; Whipple et al. 2012, p. vi, Chpts. 4-6). By the 1930s, these vast areas of Delta tidal wetlands and riparian vegetation were diked, drained, and converted into islands of farmland surrounded by high levees, now highly subsided; the sloughs were closed or re-plumbed and deepened; and sand bars removed, completely altering the natural hydrodynamics and its rich habitat for native species. (Thompson 1957; Lund et al. 2010,[40] Chapters 2, 3, 5; Whipple et al. 2012, pp. 81-83).

Finally, under natural conditions, groundwater moved generally from recharge areas along the sides of the valley towards topographically lower areas in the central part of the valley, where it discharged primarily as evapotranspiration from marshes and riparian forests. (TBI 1998, Sec. IV.B.2; Bertoldi et al. 1991,[41] pp. A17, A23, Fig. 14A; Williamson 1989,[42] p. D33;

Artesian Wells, and Other Factors of Water Supply: Mountain, Valley, Desert and Swamp-Land Areas, Topography of Stream Channels, Elevations above the Seas, and Other Topographical Features, Compiled in the State Engineering Department of California, Sacramento. At p. 407, "Furthermore, at all stages of the river, there is an appreciable escape of Sacramento waters through the Georgiana and Three-mile sloughs, below Sacramento, into the San Joaquin. In times of high flood this is generally a very large item; though at such times it varies not only with the stage of the Sacramento itself, but with that of the San Joaquin, which being low or high at periods different from the Sacramento, affords sometimes a free outlet for surplus floods, and at others scarcely an appreciable relief.".

[38] Thompson, K., 1957. The Settlement Geography of the Sacramento-San Joaquin Delta, California. Ph.D. Dissertation, Stanford University. December. Chapters 1-2, 135-136.

[39] Moyle, P. B. , 2002. Inland Fishes of California, Revised and Expanded. University of California Press.

[40] Lund, J.R., Mount, J., Hanak, E., Fleenor, W., Bennett, W., Howitt, R., and Moyle, P., 2010. Comparing Futures for the Sacramento-San Joaquin Delta. University of California Press.

[41] Bertoldi, G.L., Johnston, R.J, Evenson, K.D., 1991. Ground Water in the Central Valley, California -- A Summary Report, U.S. Geological Survey Professional Paper 1401-A, 44 pp.

[42] Williamson, A.K, Prudic, D.E, and Swain, L.A., 1989. Ground-Water Flow in the Central Valley, California. U.S. Geological Survey Professional Paper 1401-D. D40.

Davis 1959,[43] p. 86; Bolger et. al. 2011[44]). Seepage from streams and flooded areas also recharged groundwaters. Thus, groundwater was near the surface in much of the Valley. (Bryan 1915[45]). The U. S. Geological Survey estimated that under natural conditions, the groundwater table was (10 feet below the surface over about 62% or 8,000 square miles of the Central Valley. (Williamson et al. 1989, p. D40).

In the flood basins and especially within the marshes, groundwater levels were high, usually at or within several feet of the surface. (Whipple et al. 2012, pp. 213, 254, 267; Holmes and Nelson 1915[46]). The groundwater system was in a state of dynamic equilibrium. Natural recharge was balanced by natural discharge. This has been recently confirmed for the San Joaquin Valley (excluding the Tulare) using a physically based, surface-subsurface numerical model (HydroGeoSphere). (Bolger et al. 2011[47]). The natural groundwater system has been extensively altered by pumping for irrigation and other uses, resulting in widespread overdraft and land subsidence.

This landscape -- the flood basins and submerged Delta islands -- was the home of vast expanses of freshwater marsh, riparian forest, and grasslands. (Garone 2011, Chapter 1). This landscape included highly productive warm meandering waterways, sluggish river channels, oxbow and floodplain lakes, swamps, and sloughs. (Garone 2011, Chapter 1; Moyle 1976,[48] p. 30). Natural Delta outflows are lower than unimpaired Delta outflows because a significant amount of the rim inflows included in the unimpaired calculations were evapotranspired by this vegetation and evaporated in these natural features of the landscape, the flood basins and lakes, thus never reaching the Bay-Delta. Bolger et al. (2011), for example, found that 45% of the flow into the San Joaquin Valley (rim inflows plus precipitation) was evapotranspired by natural vegetation (5 MAF/yr) under pre-development conditions. (Bolger et al. 2011, p. 327). These calculations were based on Hall (1886) measured/estimated rim inflows (7 MAF/yr), which are higher than the long-term annual average unimpaired flows over the period 1922-2010 (5.9 MAF). If these longer term inflow values were used, Bolger et al.'s analysis indicates native vegetation evapotranspired half of the water inputs to the system. In other work, Shelton (1987[49]) found that natural vegetation evapotranspired almost as much water as the irrigated

[43] Davis, G.H., Green, J.H., Olmsted, F.H., Brown, D.W., 1959. Ground-water Conditions and Storage Capacity in the San Joaquin Valley, California. U. S. Geological Survey Water Supply Paper 1469. 287 pp.

[44] Bolger, B. L, Park, Y-J, Unger, A.J.A, Sudicky, E.A., 2011. Simulating the Pre-development Hydrologic Conditions in the San Joaquin Valley, California. Journal of Hydrology. 411, 322-330.

[45] Bryan, K., 1915. Groundwater for Irrigation in the Sacramento Valley, California. U.S. Geological Survey Water-supply, Paper 375-A, 49 pp + plates. , Plate 11 (showing that areas with native vegetation are located in areas with alluvium less than 25 feet below the surface), p. 19, "The Sacramento Valley is remarkable for the large area in which the water table stands close to the surface. During the summers of 1912 and 1913—two dry years—less than 20 per cent of the valley had a depth of water more than 25%." and Kooser et al. 1861, pp. 265, "Plenty of excellent water is procured by digging twenty feet.", p. 278, "Water can be found anywhere by digging or boring from fifteen to twenty feet".

[46] Holmes, L.C., Nelson, J.W. and Party. 1915. Reconnaissance Soil Survey of the Sacramento Valley, California, U.S. Department of Agriculture, Bureau of Soils.

[47] Bolger et al. 2011, p. 327: 45% of the inflow was evapotranspired; p. 327, "...surface water from the SJR can flood the land surface south of where it meets the Merced River, confirming the presence and cause of large freshwater marshes in the trough of the valley...";, p. 328, "This confirms previous claims that most groundwater exiting the subsurface was discharged as ET in the trough of the valley, and to a lesser extent, to streams during pre-development period...".

[48] Moyle, P. B., 1976. Inland Fishes of California, University of California Press, Berkeley, 1976.

[49] Shelton, M. L., 1987. Irrigation Induced Change in Vegetation and Evapotranspiration in the Central Valley of California, Landscape Ecology. 1:2. pp. 95-105

crops that replaced it, describing the tule marsh vegetation as "heavily transpiring." (Shelton 1987, pp. 99, 103).

This system was completely replumbed to reclaim marsh lands for farms, control floods, supply drinking water for the flood of new inhabitants seeking their fortune in the mines and to the post World War II boom and to facilitate the irrigation of the valley and navigation. The channels were dredged and rip-rapped, the levees were raised, the flood basins were drained, bypasses were installed, and head-stream reservoirs were built to replace the side-stream storage, provide protection from floods, and generate electricity.

3.0 NATURAL VEGETATION

The areal extent of pre-development vegetation was determined from maps prepared by others, and supplemented by inferences from early soil surveys. Several parties have made estimates of the nature and extent of native vegetation in the Central Valley. These include, Hall (1887[50]); Burcham (1957,[51] Fig. 10); Küchler (1977[52]); Roberts et al (1977[53]); Dutzi (1978,[54] Fig. 11); Fox (1987a,[55] Fig. 3); TBI (1998, Figs. G4, G6, G10); CSU Chico (2003[56]); Garone (2011, Map 2); and Whipple et al. (2012, Fig. 3.3). Most of these works focused on a single type of vegetation, e.g., tule marshes or riparian forest, or covered only a small portion of the Valley Floor, e.g., the Delta, so we were unable to use them as our primary source. Further, we were unable to piece these more limited coverage maps together in any meaningful way as they used different vegetation classification systems, from much finer, to much coarser classifications; different boundaries; and even this collection of maps did not cover the entire Valley Floor study area.

Chico State University ("CSU Chico") reviewed and digitized approximately 700 historic maps, searching numerous collections in public libraries. They pulled this collection together in a series of maps, including a "Pre-1900 Historic Vegetation Map." We used the CSU Chico pre-1900 Historic Vegetation Map (CSU Chico 2003) as our base map, modified to cover the entire Valley Floor and to further subdivide some of its vegetation classifications to match available evapotranspiration information. CSU Chico (2003) characterized its pre-1900 map as "the best available historical vegetation information for the pre-1900 period" noting it provided "a snapshot of the most likely pre Euro-American vegetation cover." (CSU Chico 2003). This map has been cited by others as representing natural vegetation. (Bolger et al. 2011; Vaghti and Greco 2007,[57] Fig. 16.1). It is based on a patchwork of sources, scales, and dates, with the earliest source map dating to 1874.

The CSU Chico pre-1900 map likely underestimates the areas of some vegetation types as extensive modifications to the landscape had been made by 1874. (Thompson 1957; Whipple et al. 2012, Figs. 1.9, 1.16 and pp. 20-26, 222, 254; CSG 1862). The riparian forests, for example, were cleared early to make way for cities and farms and harvested to supply fuel for steamboats traversing the rivers in support of the Gold Rush. (Whipple et al. 2012, p. 279).

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[50] Hall, W.H. State Engineer, Topographical and Irrigation Map of the Great Central Valley of California Embracing the Sacramento, San Joaquin, Tulare and Kern Valleys and the Bordering Foothills, 1887.

[51] Burcham, L.T., 1957. California Range Land: An Historical-Ecological Study of the Range Resource of California. CA Department of Natural Resources. Division of Forestry, 261 pp.

[52] Küchler, A.W., 1977. Natural Vegetation of California, Pocket Map, In: Barbour, M.G., Major, J. (Eds), Terrestrial Vegetation of California.

[53] Roberts, W.G, Howe, J.G, and Major, J., 1977. A Survey of Riparian Forest Flora and Fauna in California, In: Riparian Forests in California, Their Ecology and Conservation, Sands, A. (Ed.), A Symposium Sponsored by Institute of Ecology, University of California, Davis and Davis Audubon Society Institute of Ecology. Publication No. 15, May 14, 1977.

[54] Dutzi, E.J., 1978. Valley Oaks in the Sacramento Valley: Past and Present Distribution, Master of Arts Thesis in Geography, University of California, Davis, March 23, 1978.

[55] Fox, J.P., 1987a. Freshwater Inflow to San Francisco Bay Under Natural Conditions, Appendix 2, SWC Exhibit No. 262.

[56] California State University (CSU) Chico, 2003. The Central Valley Historic Mapping Project, April 2003.

[57] Vaghti, M.G. and Greco, S.E., 2007. Riparian Vegetation of the Great Valley, Chapter 16, In: Barbour, M.G., Keeler-Wolf, T., Schoenherr, A.A., 2007. Terrestrial Vegetation of California, Third Edition, University of California Press, Berkeley, 712 pp.

Widespread conversion of wetlands began in the 1850s when they were leveed, drained, cleared, leveled or filled; water entering them was impounded, diverted, or drained; and sloughs and crevasses closed to dry out the land. (Whipple et al. 2012, Fig. 1.16 and p. 254; Frayer et al. 1989,[58] p. 6; CSG 1862). The great wheat bonanza that transformed much of the Central Valley into farm land was well under way by 1874. Thus, CSU Chico's vegetation area estimates may underestimate natural land cover, and as a result, underestimate evapotranspiration from native vegetation and hence overestimate natural Delta outflow.

We confirmed the general accuracy of the CSU Chico pre-1900 map, using GIS overlays with other available natural vegetation maps. (Hall 1887; Roberts et al 1977; Dutzi 1978; Fox 1987a;[59] TBI 1998; Garone 2011; and Whipple et al. 2012). We used original shape files where available (Whipple et al. (2012), TBI (1998), Küchler (1977), CSU Chico (2003)). Other maps were scanned (400-dpi full color scanner), the scanned versions were georeferenced[60] using various data layers (e.g., county, township), and the map features were digitized by hand using editing features in ArcMap. ArcMap's geoprocessing tools were used to determine areas of the various types of vegetation. We made various modifications to the CSU Chico pre-1900 mapped vegetation areas to accommodate area registration issues and to align vegetation classes with available evapotranspiration information. The methods we used are described below.

The areas we estimated for each type of vegetation within each planning area in the Valley Floor are summarized in **Figure 2** and **Table 1**. These areas are long-term annual average areas. They are not representative of areas that would be present in specific years due to climate-driven variations, which primarily affected the grasslands and wetlands. There are many eyewitness accounts that document the reduction in grasslands, particularly as pasture for grazing cattle, horses and sheep during prolonged droughts. See reviews in Edminster 2002[61]; Burcham 1957[62]; and Landrum 1938[63]. Acreages, especially of grasslands, would have varied significantly with the amount of precipitation falling on the Valley Floor. As evapotranspiration from grasslands (rainfed, perennial, vernal pools) is the major water loss component in the water budget (Fox et al. 2014), the failure to account for year to year variation in acreages results in negative outflows from the San Joaquin Basin in many dry and critical years.

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[58] Frayer, W.E., Peters, D. D., and Pywell, H. R., 1989. Wetlands of the California Central Valley, Status and Trends - 1939 to mid-1980s, U.S. Fish and Wildlife Service Report, June 1989.

[59] Fox, P., 1987a. Freshwater Inflow to San Francisco Bay Under Natural Conditions, Appendix 2, SWC Exhibit No. 262.

[60] Transforming scanned images into maps with reference coordinates.

[61] Edminster, Robert J., Streams of the San Joaquin. El Valle de Los Tulares - The Valley of the Tules, Geographic and Ecological Considerations of California's San Joaquin Valley, Quercos Publications, Los Banos, CA, 2002.

[62] Burcham, L. T., California Range Land: An Historical-Ecological Study of the Range Resource of California, CA Department of Natural Resources, Division of Forestry, 1957.

[63] Landrum, Elizabeth Ann, Maps of the San Joaquin Valley up to 1860. A Store of the Valley as Portrayed on Maps and Described by Early Writers, Accompanied by an Annotated Bibliography of Maps, Master of Arts in Librarianship, University of California, December 1938.

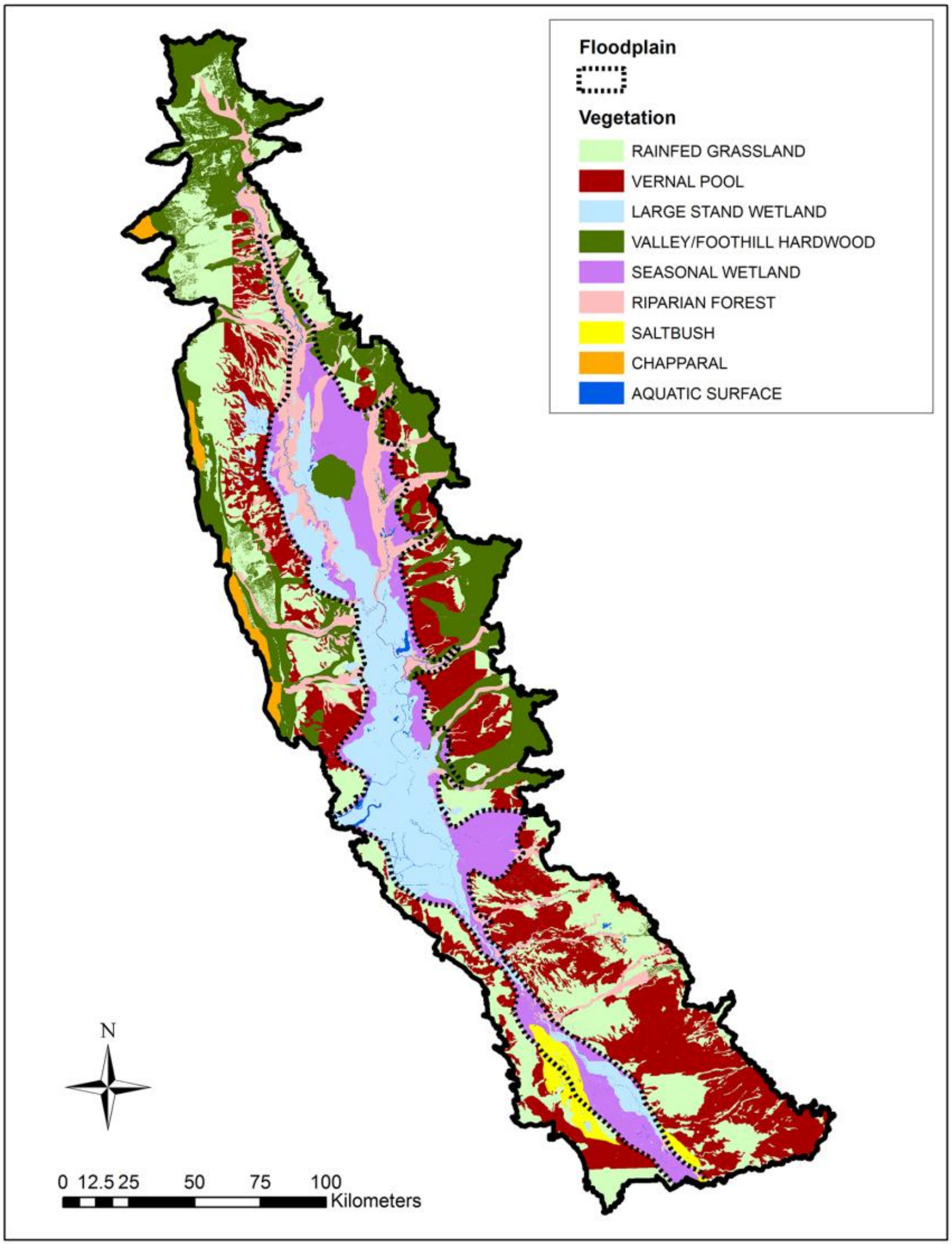

Figure 2. Natural Vegetation in the Valley Floor, Case I[64]

Note: This map portrays the areal extent of natural vegetation based on the "Case I" definition of grassland composition (i.e., all grassland area outside of the floodplain was classified as either vernal pool or rainfed grassland), as defined in Fox et al. 2014. Although this map represents a composite of several maps, the primary source of information comes from CSU Chico's pre-1900 Historic Vegetation Map (CSU Chico 2003).

[64]In Case I: (1) perennial grasslands area assumed to be zero; (2) no distinction is made between small and large stand permanent wetlands; and (3) all valley/foothill hardwoods are assumed to be foothill hardwood for purposes of estimating evapotranspiration (Source: Fox et al. 2014)

Table 1. Monthly vegetation coefficients (K_v) for non-water stressed and rainfed vegetation

	Month											
Vegetation	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfed Grassland[1]	0.78	0.72	0.64	0.58	0.35	0.06	0.00	0.00	0.03	0.16	0.47	0.73
Perennial Grassland	0.55	0.55	0.60	0.95	1.00	1.05	1.10	1.15	1.10	1.00	0.85	0.85
Vernal Pool	0.65	0.70	0.80	1.00	1.05	0.85	0.50	0.15	0.10	0.10	0.25	0.60
Large Stand Wetland	0.70	0.70	0.80	1.00	1.05	1.20	1.20	1.20	1.05	1.10	1.00	0.75
Small Stand Wetland	1.00	1.10	1.50	1.50	1.60	1.70	1.90	1.60	1.50	1.20	1.15	1.00
Foothill Hardwood[1]	0.80	0.77	0.69	0.61	0.52	0.20	0.01	0.01	0.03	0.15	0.46	0.71
Valley Oak Savanna[1]	0.80	0.77	0.69	0.62	0.54	0.40	0.40	0.40	0.40	0.41	0.55	0.71
Seasonal Wetland	0.70	0.70	0.80	1.00	1.05	1.10	1.10	1.15	0.75	0.80	0.80	0.75
Riparian Forest	0.80	0.80	0.80	0.80	0.90	1.00	1.10	1.20	1.20	1.15	1.00	0.85
Saltbush	0.30	0.30	0.30	0.35	0.45	0.50	0.60	0.55	0.45	0.35	0.40	0.35
Chaparral[1]	0.55	0.61	0.54	0.40	0.22	0.03	0.01	0.01	0.03	0.14	0.40	0.57
Aquatic Surface	0.65	0.70	0.75	0.80	1.05	1.05	1.05	1.05	1.05	1.00	0.80	0.60

[1] *Evapotranspiration from rainfed vegetation was estimated from a daily soil water balance. Valley oak savanna K_v during the summer and fall was estimated to be 0.4 to account for groundwater contribution. The vegetation coefficients shown are averages over the 88-year period and all Valley Floor Planning Areas.*
Source: Howes et al. 2014

Evapotranspiration is calculated by multiplying the acres of each vegetation type (Av) by a vegetation-specific evapotranspiration factor for each planning area (ETv). We used CSU Chico (2003) for all area estimates, except where CSU Chico did not cover the entire Valley Floor or for vegetation types (other floodplain habitat, grasslands and wetlands) that required finer resolution to match up with evapotranspiration factors. A summary of the evapotranspiration we estimated for the vegetation areas in Table 1 are summarized in **Table 2**.

We explored the accuracy of area estimates and assignment of vegetation types in water balance sensitivity analyses in which we varied both the classification (e.g., rainfed, perennial, and vernal pool grassland) and the land area based on the wetness of the year as reflected by the 8-River Index. The area of grasslands likely varied in response to the wetness of the year. The 1912 soil survey of the Woodland area, for example, describes Colusa and Yolo counties as having "luxuriant growth of wild grasses" but then goes on to explain that in 1862 and 1863 "prolonged drought occurred, which caused a scarcity of pasturage on the places..." (Sweet et al. 1911, p. 12).

The following sections discuss each type of vegetation in our analysis and the adjustments we made to the CSU Chico (2003) areas to accommodate boundary issues and match up with evapotranspiration information. Otherwise, we used GIS methods to obtain vegetation areas directly from CSU Chico (2003) shape files.

Table 2. Initial Estimated Area of Natural Vegetation Av by Planning Area Within the Valley Floor, Case I (Acres)

Valley	Planning Area	Rainfed Grasslands	Vernal Pool	Permanent Wetland	Seasonal Wetland	Valley/ Foothill Hardwood	Riparian Forest	Saltbush	Chaparral	Aquatic Surface	Total
Sacramento	502	0	0	0	0	1,710	0	0	0	0	1,710
	503	282,462	61,889	17	4	321,744	82,214	0	18,478	3,097	769,905
	504	129,903	1,069	236	2,413	192,808	85,795	0	96	1,995	414,314
	505	0	0	0	0	77	0	0	5,361	0	5,438
	506	346,691	233,967	124,529	48,629	175,577	107,201	0	23,577	6,001	1,066,174
	507	48,243	82,817	150,118	253,777	186,543	198,837	0	0	8,089	928,425
	508	18,011	9,173	0	0	213,423	13,360	0	0	1,459	255,427
	509	162,751	104,754	67,841	13,332	143,687	64,032	0	54,362	1,508	612,266
	511	44,641	185,070	51,866	62,827	126,272	43,015	0	0	7,700	521,391
Delta	510	1,773	10,533	226,867	26,070	53	1,877	0	0	12,948	280,121
	602	62,431	21,086	285,123	22,556	85	1,468	0	0	7,062	399,812
San Joaquin	601	9,601	9,574	0	6	0	2	0	0	676	19,860
	603	118,060	146,867	12,645	137,722	200,150	41,053	0	387	1,554	658,439
	604	2,712	0	0	0	1,831	768	0	0	0	5,311
	605	12,167	1,004	0	0	0	1	0	0	0	13,172
	606	205,343	175,234	29,859	142,259	0	3,166	102,315	79	2,808	661,064
	607	171,519	158,387	8,142	22,485	3,349	26,128	0	0	2,026	392,036
	608	165,031	126,374	7,505	12,219	4,173	31,623	0	0	1,180	348,105
	609	305,738	598,095	42,807	45,591	1,239	20,910	20,014	0	3,109	1,037,503
	610	16,178	929	0	0	166	11	0	0	0	17,284
TOTAL		**2,103,256**	**1,926,822**	**1,007,556**	**789,889**	**1,572,887**	**721,464**	**122,330**	**102,340**	**61,211**	**8,407,756**

Note: In Case I: (1) perennial grasslands area assumed to be zero; (2) no distinction is made between small and large stand permanent wetlands; and (3) all valley/foothill hardwoods are assumed to be foothill hardwood for purposes of estimating evapotranspiration.

Source: Fox et al. 2014.

3.1 Other Floodplain Habitat

"Other Floodplain Habitat"[65] is a category used by CSU Chico to designate areas that are a mixture of wetlands, grasslands, and riparian forest that CSU Chico could not identify directly as they had not been previously differentiated on historic maps. This vegetation type occupied 1.2 million acres, or slightly more than perennial wetlands.

In order to estimate evapotranspiration, this classification had to be further subdivided. We used Küchler's (1977) Natural Vegetation of California map to identify vegetation within this category as it is the only natural vegetation map that covers all of the "other floodplain habitat" within the Valley Floor. This map classifies this "other" habitat based on soil classification, climate, ecological niche theory, etc. Thus, we used it to determine the areas of vegetation types in "other floodplain habitat" so that we could estimate evapotranspiration. **Figure 3** overlays Küchler vegetation classifications on CSU Chico "other floodplain habitat."

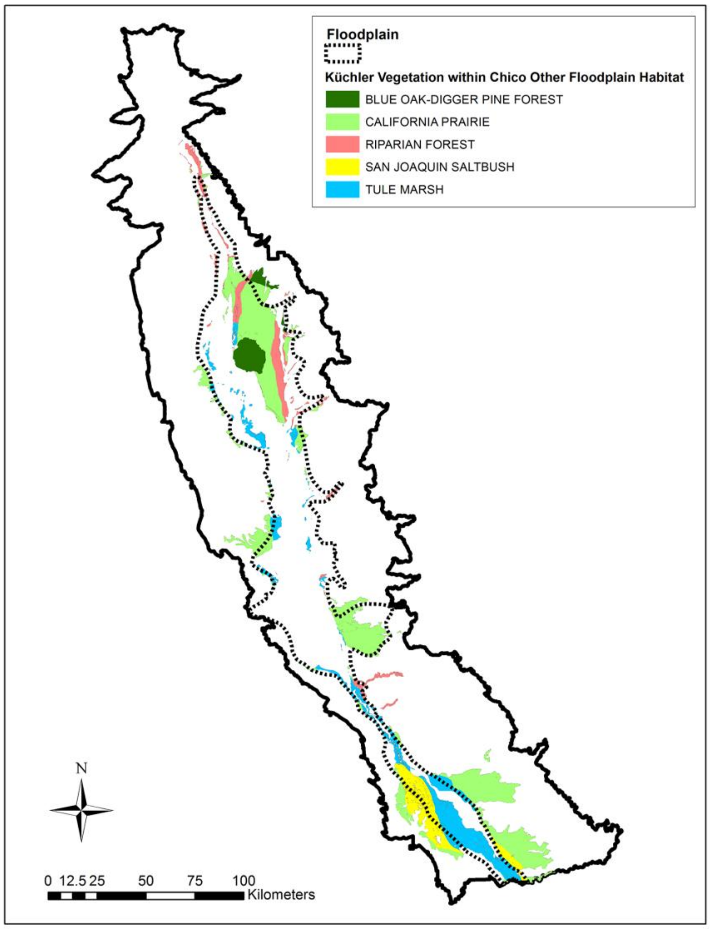

Figure 3. Küchler Vegetation Classifications for CSU Chico Other Floodplain Habitat in Valley Floor

Note: The CSU Chico pre-1900 Historic Vegetation Map assigned the category "Other Floodplain Habitat" to about 1.2 million acres of land that it could not otherwise classify. Küchler's 1977 map was used to identify vegetation and assign evapotranspiration rates within this category.

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[65] Described by Chico State as, "**Other Floodplain Habitat** – Used to denote areas that are a mixture of wetlands, grasslands, and riparian forests that were never differentiated on historic maps." Available at: http://www.gic.csuchico.edu/historic/3_1a.html.

Figure 3 shows that the areas within "other floodplain habitat" mapped by Küchler include riparian forest (117,000 acres), grasslands (647,000 acres), pine forest (16,100 acres), tule marsh (255,000 acres), and saltbush (122,000 acres). The areas of each are summarized in **Table 3**. About 684,000 acres or 59% of CSU Chico's "other floodplain habitat" falls within the approximate boundary of lands that were naturally subject to overflow in the Sacramento Basin and northern portion of the San Joaquin Basin, designated as "natural flood basin" on **Figure 4**. A considerable portion of the other floodplain habitat mapped by CSU Chico (2003) was mapped as tule marsh by Küchler (254,743 acres). Most of this Küchler tule marsh area was in the San Joaquin Basin. We rejected Küchler's (1977) tule marsh areas as they disagree with more accurate land surveys from the 19th century when much of this vegetation was still extant, which were relied on by CSU Chico (2003).

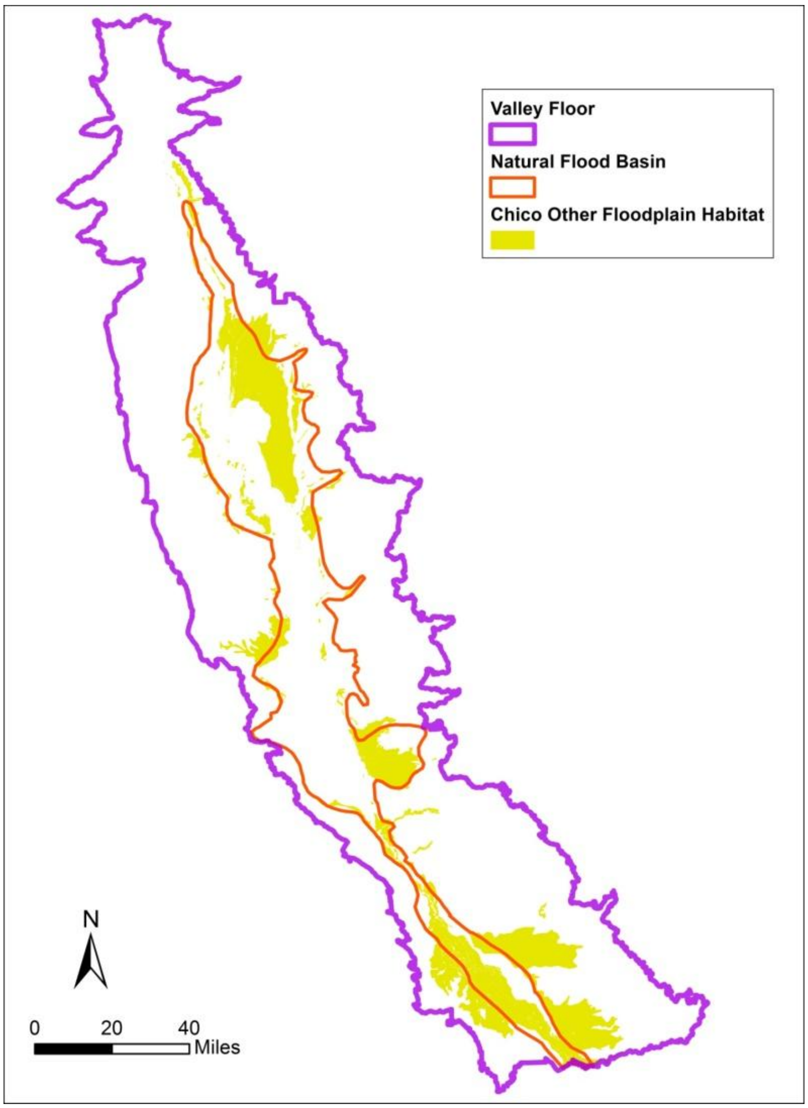

Figure 4. Lands Naturally Subject to Overflow
Superimposed on CSU Chico "Other Floodplain Habitat"
Natural Flood Basin Source: (CDWP 1931a, 1931b)

Table 3. Classification of Vegetation in CSU Chico (2003) "Other Floodplain Habitat" Based on Küchler (1977) (Acres)

	Planning Area	Blue Oak - Digger Pine Forest	Total Hardwood	Riparian Forest	Tule Marsh	California Prairie	San Joaquin Saltbush	Water	Total
Sacramento	502	0	0	0	0	0	0	0	0
	503	0	0	4,387	0	778	0	0	5,165
	504	24	24	17,033	0	2,147	0	0	19,204
	505	0	0	0	0	0	0	0	0
	506	47	47	2,252	26,058	16,909	0	0	45,266
	507	15,987	15,987	70,116	6,370	220,312	0	0	312,785
	508	0	0	0	0	0	0	0	0
	509	0	0	388	6,756	30,702	0	0	37,846
	511	21	21	5,910	8,415	13,977	0	0	28,323
Delta	510	0	0	0	13,851	13,975	0	127	27,953
	602	0	0	764	8,060	7,465	0	0	16,289
San Joaquin	601	0	0	0	0	0	0	0	0
	603	0	0	315	656	98,892	0	0	99,863
	604	0	0	0	0	0	0	0	0
	605	0	0	0	0	0	0	0	0
	606	0	0	0	114,583	38,310	102,315	0	255,208
	607	0	0	14,314	7,456	1,224	0	0	22,994
	608	0	0	1,541	11,465	3,508	0	0	16,514
	609	0	0	0	50,916	198,742	19,941	0	269,599
	610	0	0	0	0	0	0	0	0
	TOTAL	**16,079**	**16,079**	**117,020**	**254,586**	**646,941**	**122,256**	**127**	**1,157,009**

Source: Küchler (1977)

The tule lands were surrounded by belts of overflow lands historically known as the "rim lands." (CDPW 1931a,[66] p. 129 and Plate VII; CDPW 1931b,[67] p. 460 and Plate LXXIII). These rim lands were likely seasonal wetlands (Garone 2011, Map 2, Fig. 8), called "moist grassland marsh edge" by some (Cunningham 2010,[68] p. 129). Edminister reported "the trough of the valley in winter and spring was a nearly impenetrable maze and (sic) lakes, sloughs, and tule marsh…." (Edminister 2002,[69] p. 115).

Fremont, in his travels along the San Joaquin River reported in 1845, “April 3, In the bottoms are frequent ponds, where our approach disturbed multitudes of wild fowl, principally geese." (Fremont 1887,[70] p. 357). Continuing south down the San Joaquin River, On April 4, "The river is about a hundred yards in breadth, branching into sloughs, and interspersed with islands...Bearing in toward the river, we were again forced off by another slough; and, passing around, steered toward a clump of trees on the river, and, finding there good grass, encamped." On April 5, "During the earlier part of the day's ride the country presented a lucustrine appearance; the river was deep, and nearly on a level with the surrounding country; its banks raised like a levee, and fringed with willow. Over the bordering plain were interspersed spots of prairie among fields of *tulé* (bulrushes), which in this country are called *tulares*, and little ponds. On the opposite side a line of timber was visible...which points out the course of the slough,

[66] California Department of Public Works (CDPW), 1931a. Sacramento River Basin, Bulletin No. 26, 583 pp.

[67] California Department of Public Works (CDPW), 1931b. San Joaquin River Basin, Bulletin No. 29, 656 pp.

[68] Cunningham, L., 2010. A State of Change: Forgotten Landscapes of California, Heyday, Berkeley, CA. 350 pp.

[69] Edminster, R.J., 2002. Streams of the San Joaquin. El Valle de Los Tulares - The Valley of the Tules, Geographic and Ecological Considerations of California's San Joaquin Valley, Quercos Publications, Los Banos, CA.

[70] Fremont, J. C., 1887. Memoirs of My Life, Including in the Narrative Five Journeys of Western Exploration, During the Years 1842, 1843-44, 1845-6-7, 1848-9, 1853-4, Vol. 1, Belford, Clarke & Company, Chicago and New York, 1887.

which, at times of high water, connects with the San Joaquin River, a large body of water in the upper part of the valley, called the Tulé Lakes." (Fremont 1887, p. 358).

Table 3 shows that 56% of the land (646,941 acres) in "other floodplain habitat" was classified by Küchler (1977) as California prairie, 22% (254,586 acres) as tule marsh; 11% as saltbush (122,256 acres); 10% as riparian forest (117,020 acres) and 1% (16,079 acres) as pines. We rejected Küchler's (1977) classification of both tule marsh and grassland for the reasons discussed below.

Küchler (1977) defined California prairie as "[d]ense to somewhat open, medium tall bunchgrass community with many forbs. Height and seasonal aspects of this prairie can vary widely." The dominants were reported as Needlegrass (*Stipa cernua*) and speargrass (*Stipa pulchra*). (Küchler 1977, p. 930). As this grassland within "other floodplain habitat" is mostly within the floodplain (Figure 3), soil moisture would come from precipitation, seepage from flooded areas, and shallow groundwater, as well as tidal flows in areas near the Delta. (Whipple et al. 2012, p. 213).

Thus, in the calculations of evapotranspiration, it was assumed these "other floodplain habitat" grasslands would evapotranspire at the seasonal wetland rate. (Fox et al. 2016). Seasonal wetland was picked, rather than perennial grasslands, as detailed mapping by SFEI in the Delta and a portion of the Sacramento Basin indicates that 63% of the area mapped by CSU Chico in this area as "other floodplain habitat" was either permanent or seasonal wetland. Finally, the U.S. Fish and Wildlife service has prepared a pre-development map for 1850 that shows significant seasonal wetlands in these areas. (Garone 2011, Map 2; Figure 14).

These classifications of other floodplain habitat are consistent with those made by others for portions of the subject area. Dutzi (1978) classified about 41% of the other floodplain habitat, allocating 33% to valley oak woodland and savanna; 61% to grasslands; and the balance to riparian forest. SFEI classified 75,702 acres of other floodplain habitat lands, or about 6.5% of total other floodplain area, mostly in the Delta and southern Sacramento Basin. **Figure 5** overlays the CSU Chico "other floodplain habitat" on the much more detailed SFEI classification scheme.

We estimated the following breakdown for CSU Chico "other floodplain habitat" within the limited area mapped by Whipple (2012) (percentage of area mapped):

- wet meadow/seasonal wetland: 26,042 acres (34.4%)
- oak woodland/savanna: 25,427 (33.6%)
- vernal pool complex: 10,892 acres (14.4%)
- non-tidal freshwater emergent wetland: 6,569 acres (8.7%)
- alkali seasonal wetland complex: 2,573 acres (3.4%)
- tidal freshwater emergent wetland: 1,711 (2.3%)
- valley foothill riparian: 1,131 acres (1.5%)
- grassland: 813 acres (1.1%)
- aquatic: 490 acres (0.04%)

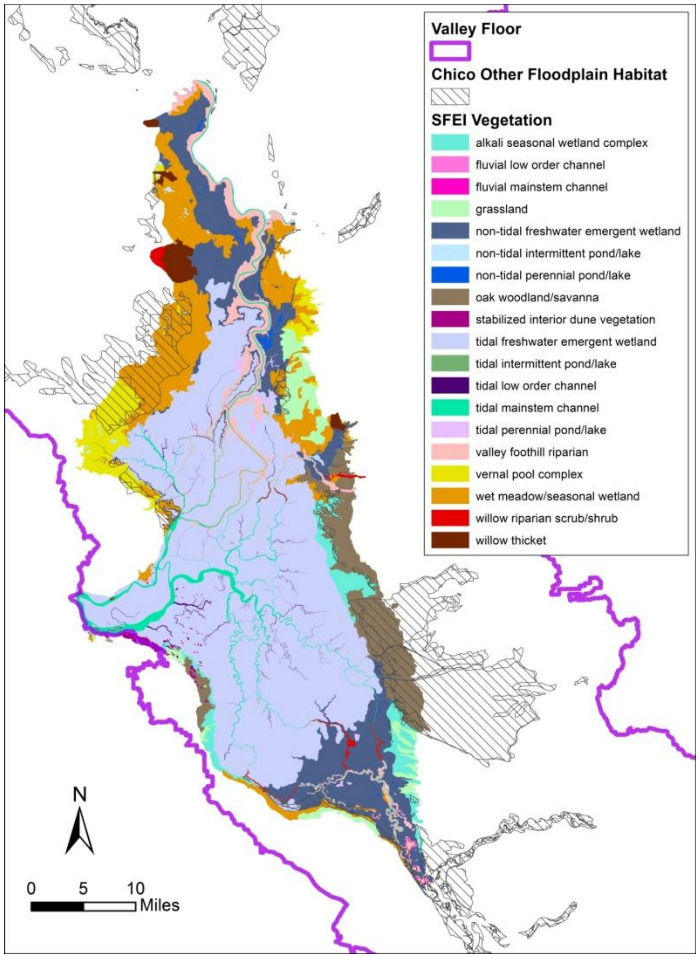

Figure 5. SFEI Classification of CSU Chico Other Floodplain Habitat

This work indicates that 63% of the area mapped by CSU Chico as "other floodplain habitat" within the area mapped by SFEI (Whipple et al. 2012, Figure 3-3) is seasonal to permanent wetland.

Based on these considerations, we mapped all "other floodplain habitat" within the floodplain that was not riparian forest, pine forest, or saltbush as seasonal wetlands, with the exception of the Sutter Buttes, which is a small circular complex of eroded volcanic lava domes which rises 2,122+ feet above the flat Valley Floor. This butte is classified by Küchler as “blue oak-digger pine forest,” which is “valley/foothill hardwood” under our classification system. In other words, Küchler's (1977) grasslands and tule marsh that fall within the floodplain were mapped as seasonal wetland, except the Sutter Buttes as it is elevated out of the floodplain (12,480 acres). Thus, 46% of "other floodplain habitat" (533,500 acres) was classified as seasonal wetland. We also mapped all of Küchler's (1977) grasslands and tule marsh within "other floodplain habitat" that was outside of the floodplain as either vernal pool, discussed elsewhere in this report, or rainfed grassland

3.2 Grasslands

Grasslands[71] once covered all well-drained areas in the Central Valley and are still the dominant vegetation but the native species have been replaced. Figure 2 and Table 1 indicate that under natural conditions, there were about 4.0 million acres of grasslands, or about half of the land area within the Valley Floor. No natural vegetation maps that we reviewed subdivided grasslands further.

The grasslands occupied smooth and nearly level lands that were formed as flood waters spread over them, leaving behind thick deposits of silt. The grasslands of today are either range for cattle or farmed land. (Schoenherr 1992,[72] pp. 520-525; Crampton 1974,[73] pp. 29-33; Heady 1988,[74] Bartolome et al. 2007[75]).

The original grasslands (before 1769 when the Spanish introduced cattle, sheep, pigs, and horses) supported large herds of pronghorn antelope, deer, and tule elk. The pristine grasslands were destroyed by the Spanish fire-based range management practices and overgrazing, especially during periods of drought. Shrubs, trees, and even tules were burned annually to promote new growth of grasses and forbs for domestic livestock. These practices decimated the native grasslands long before changes ushered in by the Gold Rush. Fremont, for example, records numerous herds of wild horses overrunning the plains in the 1840s. (Fremont 1887). Wild horses were not native; they were introduced by the Spaniards and cut loose when the missions were disbanded. Thus, eyewitness accounts after the Spanish invasion do not capture the pristine grasslands, but grasslands already a remnant of what it once was. (Edminster 2002, pp. 137-144, 157-158, 199).

The original species underwent a rapid and widespread conversion from dominance by native perennials (variously assumed to be bunchgrasses or rhizomatous grasses) to dominance by exotic cool-season annuals (Holmes and Rice, 1996,[76] pp. 233-243; Holstein 2001[77]), beginning in the Spanish mission period in 1769. (Burcham 1957; Garone 2011, p. 20). As this occurred before any botanical study, the original extent and composition of native vegetation can only be guessed and remains controversial.

The conversion was partly accident, partly to accommodate grazing. By the mid 1850s, wild oats were widely reported. (Burcham 1957; Garone 2011, p. 21; Barbour et al. 1993,[78] pp.

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[71] Described by Chico State as, "**Grassland** – Grasslands include grassy areas composed of annual plant species; they were originally composed of various perennial bunch grasses. Agricultural crops and grazing has caused the replacement of natives in many areas with introduced annual grasses. In spring and summer, large areas of grassland habitat are covered with annual herbaceous wildflower species." Available at: http://www.gic.csuchico.edu/historic/3_1a.html.

[72] Schoenherr, A.A., 1992. A Natural History of California, University of California Press. pp. 520-525.

[73] Crampton, B, 1974. Grasses in California, University of California Press, Berkeley. 178 pp.

[74] Heady, H.F., 1988. Valley Grasslands, In: Barbour, M.G. and Major, J. (Eds), Terrestrial Vegetation of California.

[75] Bartolome, J.W., Barry, W.J., Griggs, T., Hopkinson, P., 2007. Valley Grasslands, In: Barbour, M.G., Keeler-Wolf, T., and Schoenheer, A.A. (Eds.), Terrestrial Vegetation of California, University of California Press, Berkeley.

[76] Holmes, T.H., Rice, K.J., 1996. Patterns of Growth and Soil-Water Utilization in Some Exotic Annuals and Native Perennial Bunchgrasses of California. Annals of Botany. 78, 233-243.

[77] Holstein, G., 2001. Pre-Agricultural Grassland in Central California, Madroño. 48:4, 253-264.

[78] Barbour, M.G., Pavlik, B., Drysdale, F., Lindstrom, S., 1993. California's Changing Landscapes. Diversity and Conservation of California Vegetation, California Native Plant Society, Sacramento, CA. 76-80.

78-80). In parts of the San Joaquin Valley, for instance, it has been found that more than half of the herbaceous cover is comprised of alien species, mainly from the Old World. (Burcham 1957; Heady 1977,[79] p. 495; Thompson 1961, p. 294; Bartolome et al. 2007). "The most dramatic alterations anywhere in continental America occurred within California's grasslands." (Garone 2011, p. 20, quoting Preston 1998).

There is significant controversy over the composition of the original grasslands. See discussion of this controversy in Garone 2011, End Notes, pp. 281-282. Most contemporary botanists have supported the theory that the native grasslands were dominated by two species of needlegrass (*Stipa cernua, S. pulchra*), which are perennial bunchgrasses with flowering stems that grow to several feet above the ground. This is known as the perennial bunchgrass paradigm or PBP. (Heady 1988; Küchler 1977; Bartolome et al. 2007). Annual grasses and annual and perennial forbs were theorized to grow in the open spaces between clumps of bunchgrass.

Others have argued, based on early eyewitness reports (which may not be relevant due to extensive grazing-related modifications that occurred in the 18th century) and vegetation surveys, that the pristine grassland was dominated by annual forbs. (Schiffman 2007,[80] p. 55). *Leymus triticoides*, a rhizomatous native perennial grass that resembles wheat, has been theorized to have dominated most central California grasslands under pristine conditions, on sites with clay or loam soil, flat to moderately sloping topography and precipitation above 250 mm per year with moderate to high fertility.

The grasslands in the more arid San Joaquin where precipitation is less than 250 mm/yr may have been dominated by these annuals, rather than perennial species, such as spring-active forbs, and graminoid sedges. (Holstein 2001). Others have argued the pristine California grasslands may have been more of a complex mosaic of shrubs, perennial grasses, and forbs than a vast open grassland. (Hamilton 1997[81]). Some have proposed based on field studies that this conversion increased the amount of water at depth in the soil profile during the dry season and reduced evapotranspiration. (Holmes and Rice 1996; Borman et al. 1992[82]).

The grassland composition is an important consideration for determining evapotranspiration under natural conditions as perennial grasses have extensive deep systems of thick, dense roots that allow them to tap groundwater during dry seasons. These deep root systems are beyond the reach of annuals. Thus, they generally have a full, year-round water supply, unlike their annual replacements. (Holmes and Rice 1996). Some have reported that the perennial needlegrasses dry up almost as early, by early summer, as associated annual species. (Burcham 1957, p. 105).

However, most of the area classified by CSU Chico (2003) and Küchler (1977) as "grasslands" did not fit this description. Rather, most of the area mapped by others as "grasslands" was actually vernal pool wetlands, interspersed with patches of conventional grassland.

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[79] Heady, H.F., 1977. Valley Grasslands, In: Barbour, M. and Major, J. (Eds.), Terrestrial Vegetation of California, Wiley, New York, pp. 491-514.

[80] Schiffman, P.M., 2007. Species Composition at the Time of First European Settlement, In: California Grasslands: Ecology and Management, Stromberg, M.R., Corbin, J.D., and D'Antonio, C.M. (Eds.), University of California Press, Berkeley. 52-56.

[81] Hamilton, J.G., Changing Perceptions of pre-European Grasslands in California, Madroño, v. 44, pp. 311-333, 1997.

[82] Borman, M.M., Johnson, D.E., and Krueger, W.C., 1992. Soil Moisture Extraction by Vegetation in a Mediterranean/Maritime Climate Regime, Agron. J., v. 84. pp. 897-904.

Under natural conditions, relatively impermeable hardpans and claypans,[83] sometimes over 1 meter thick, were ubiquitous throughout the Valley Floor (Lapham et al. 1904,[84] pp. 1078-1079). These have been mostly plowed, blasted, ripped, leveled, burned, drained, or covered with crops, buildings, pavement, and hydraulic mining debris. (Medeiros 1976;[85] Holland and Griggs 1976;[86] Smith and Verrill 1998[87]). Massive steam combines, pulled by as many as three dozen draft animals, for example, leveled many vernal pools during the wheat boom of the 1880s. (Preston 1981[88]). Others were blasted to smithereens using Professor Hilgard's dynamite formula for "shattering of dense substrata". (Hilgard 1906,[89] p. 181; Lapham and Holmes 1908,[90] p. 17).

Under natural conditions, these impermeable soils served as effective barriers to the downward movement of precipitation, resulting in the formation of perched water tables that supported grassland and other habitats. Thus, much if not all of the grassland area was underlain by high perched water tables. The overlying topography of much of this grassland area was frequently hummocky with low irregular mounds a few feet high, separated by closed depressions. Vernal pools are formed where these depressions intercept the perched water table.

Our native vegetation map in Figure 2 returns 4.0 million acres of "grasslands," or 48% of the total land area within the Valley Floor. This includes areas that are vernal pools, or seasonal wetlands, discussed elsewhere. Others have estimated 5.3 (Fox, 1987a, Table 3) to 5.4 (Shelton 1987, Table 1) million acres of grasslands based on Küchler's native vegetation map for slightly different valley floor boundaries. In this work, we also estimated 4.4 million acres in the Valley Floor based only on Küchler's (1977) map and 5.0 million acres based only on TBI (1998), which does not cover the entire valley floor area.

The original pre-1900 CSU Chico map returned 3.9 million acres of grasslands. This is lower than our estimate for the Valley Floor as it excludes areas around the periphery of the valley that are included in our Valley Floor definition. Further, the pre-1900 CSU Chico map

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[83] A "pan" is a hardened layer of soil.

[84] In the 1904 soil survey of the Sacramento area, "Except in areas of alluvial deposits near the larger streams, the occurrence of hardpan is general throughout the valley portion of the area. It is particularly well developed in those districts that have the "hog wallow" mounds, which appear as a distinctive feature along the western margin of the survey. These mounds, however, are less prominent than those occurring in portions of the San Joaquin Valley, where hardpan is also found...It...confines the percolation of the rainfall to that part of the soil lying above the impervious stratum, with the result that the moisture finds its way to the surface to be lost by evaporation, and it cuts off the supply of moisture from the deeper soil."

[85] Medeiros, J. L., 1976. Vernal Pools and Vernal Lakes in the Eastern Central Valley of California, pp. 79-80, In: Subodh Jain (Ed.), Vernal Pools. Their Ecology and Conservation, A Symposium Sponsored by the Institute of Ecology, University of California, Davis, May 1 adn 2, 1976, Institute of Ecology Publication No. 9.

[86] Holland, R. F. and Griggs, T.F., 1976. A Unique Habitat -- California's Vernal Pools, Fremontia. 4:4. October 1976, pp. 3-6.

[87] Smith, D.W. and Verrill, W. L., 1988. Vernal Pool-Soil-Landform Relationships in the Central Valley, California, In: C.W. Witham, E.T. Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Eds.). Ecology, Conservation, and Management of Vernal Pool Ecosystems - Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA. 1998.

[88] Preston, W. L., 1981. Vanishing Landscapes: Land and Life in the Tulare Lake Basin, University of California Press, Berkeley.

[89] Hilgard, E.W., 1906. Soils: Their Formation, Properties, Composition, and Relations to Climate and Plant Growth in the Humid and Arid Regions. The Macmillan Co.

[90] Lapham, M. H. and Holmes, L.C., 1908. Soil Survey of the Redding Area, California, U.S. Department of Agriculture, Bureau of Soils.

classified 646,941 acres of land as "other floodplain habitat," which was classified as grasslands and other vegetation by Küchler (1977).

We subdivided grasslands into three categories for purposes of estimating evapotranspiration: (1) perennial; (2) rainfed; and (3) vernal pool. Grasslands that depend on rainfall to meet their evapotranspiration demands are referred to as "rainfed grasslands." Grasslands in areas with high water tables, such as those within the floodplain or that otherwise had a year-round water supply, are referred to as perennial grasslands. We initially assumed that perennial grasslands were zero and used water balance sensitivity analysis to bound grassland evapotranspiration. Finally, large areas of CSU Chico-classified grasslands were not classical grasslands at all, but rather vernal pool seasonal wetlands. These, for example, are identified as "wetland/upland complexes" by others. (Garone 2011, Map 2). These seasonal wetlands are discussed in the vernal pool section. Areas falling within each of these classifications were estimated as follows to calculate total evapotranspiration from lands classified by CSU Chico (2003) as "grasslands."

We made an initial estimate of the acreage of each of these classes of grasslands by planning area to facilitate calculation of evapotranspiration. This first-cut estimate is summarized in Table 1 and is designated as “Case I” in the water balance studies, reported elsewhere. (Fox et al. 2014). However, considerable additional work is required to refine our initial estimates of land areas.

Outside of the floodplain, we assumed only vernal pools and rainfed grassslands were present. Vernal pool acreage was estimated using historic soil surveys conducted in the early 1900s. See Section III.C. All other areas outside of the floodplain mapped by CSU Chico (2003) as grasslands that were not vernal pools were assumed to be rainfed grasslands. It is likely that some, and perhaps all, of the non-vernal-pool grasslands in the Sacramento Basin and the Delta were perennial grassland due to the widespread perched aquifer system and higher precipitation in those regions. This is supported by the water balance cases we evaluated.

Within the floodplain, we assumed that all CSU Chico (2003) grassland was seasonal wetlands due to the frequency of inundation compared with those outside of the floodplain. The results of these calculations are summarized in **Table 4**. This analysis indicates that of the roughly 4.6 million acres of grassland in the Valley Floor, 42% was vernal pool outside of the floodplain (1,900,154 acres); 13% was seasonal wetland (577,275 acres) within the floodplain; and 46% was rainfed grassland outside of the floodplain (2,097,823 acres).

Grasslands are the largest block of vegetation in the study area. The evapotranspiration from this land area largely controls the magnitude of annual average Delta outflow. The subdivision of this block of vegetation into components to estimate evapotranspiration is the key factor that determines the magnitude of natural Delta outflow. Grassland evapotranspiration accounts for 32% up to 50% of the natural water supply.

Substantial additional work is required to refine our initial estimates in Table 4 of the areas of each type of the grassland to accurately estimate evapotranspiration. This additional work is identified in the next section on vernal pools, Section III.C.

Table 4. Classification of Grasslands (acres)

Basin	Planning Area	Seasonal Wetlands	Vernal Pool	Rainfed Grassland	Total Grassland
Sacramento	502	0	0	0	0
	503	4	61,887	282,459	344,350
	504	2,413	1,069	129,903	133,384
	505	0	0	0	0
	506	23,566	233,147	346,502	603,215
	507	259,888	82,794	48,211	390,893
	508	0	9,173	18,011	27,184
	509	8,323	103,502	161,597	273,422
	511	54,411	185,042	44,614	284,067
Delta	510	15,521	8,137	862	24,520
	602	14,599	21,084	62,330	98,013
San Joauin	601	6	9,574	9,601	19,181
	603	137,065	146,875	117,903	401,843
	604	0	0	2,712	2,712
	605	0	1,004	12,167	13,171
	606	36,207	167,301	204,594	408,103
	607	15,367	158,134	171,070	344,571
	608	3,488	123,720	164,731	291,939
	609	6,416	586,781	304,380	897,577
	610	0	929	16,178	17,107
TOTAL		**577,275**	**1,900,154**	**2,097,823**	**4,575,251**

3.3 Vernal Pools

A vernal pool is a seasonal wetland that occupied most of the area mapped as grasslands by Küchler (1977), CSU Chico (2003), and many others who mapped the natural vegetation of the Central Valley. While they are not grasslands, they were/are nestled within grassland communities. A vernal pool is a small wetland that is present primarily or exclusively in the early part of the growing season and that typically dries completely or substantially at some point during the growing season so that a large portion of the basin has a level of moisture at least as dry as that of the surrounding uplands. (Zedler 2003,[91] p. 598). However, even when the surface is dry, vegetation specially adapted to survive under these dry conditions remain.

Vernal pools occur throughout California and elsewhere. Recent attempts at mapping extant pools suggest they formed a bathtub ring around the margins of the Central Valley, with an extra band through the center of the San Joaquin Valley. (Holland 1978,[92] p. 3; Holland and Hollander 2007,[93] Fig. 8). The following sections review and summarize what is currently known about vernal pools, based on remnant pools, removed from their original habitat. From this information, we infer the nature and extent of vernal pools in the Valley Floor under natural conditions. However, much is unknown as most of the vernal pools were removed to make way for farms, cities, and other development before they were documented and studied.

[91] Zedler, P.H., 2003. Vernal Pools and the Concept of "Isolated Wetlands." Wetlands. 23:3, 597-607.

[92] Holland, R.F., 1978. The Geographic and Edaphic Distribution of Vernal Pools in the Great Central Valley, California. California Native Plant Society. Special Publications No. 4.

[93] Holland, R.F., and Hollander A.D., 2007. Hogwallow Biogeography before Gracias, In: Schlising, R.A., Alexander, D.G. (Eds.), Vernal Pool Landscapes, Studies from the Herbarium. California State University, Chico. Number 14.

3.3.1 VERNAL POOL TOPOGRAPHY

Under natural conditions, relatively impermeable hardpans and claypans were ubiquitous throughout the Valley Floor, underlying areas classified as grasslands by others. (Holland and Jain 1981,[94] p. 25; Holland and Hollander 2007; Hilgard 1884,[95] pp. 18-19; Alexander 1874,[96] pp. 24-25). These hardpans[97] and claypans[98] were generally 2 to 3 feet thick and in some places more than 4 feet thick and located anywhere from the surface (in alkaline areas) to more than 6 feet below the soil surface, but mostly at 1 to 3 feet (Nikiforoff 1941,[99] p. 20; Strahorn et al. 1911;[100] Holmes et al. 1915; Nelson et al. 1918[101]). These were so thick and densely cemented that water from winter rains could not seep through them to lower soil columns or the regional groundwater aquifer. Thus, they served as effective barriers to the downward movement of precipitation, resulting in the formation of perched water tables.

The overlying topography in these areas was frequently, but not always, hummocky with low irregular mounds a few feet high known as mima mounds (Holland and Jain 1981, p. 25; Cox 1984[102]), separated by closed depressions. See **Figure 6**.

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[94] Holland, R.F. and Jain, S.K., 1981. Insular Biogeography of Vernal Pools in the Central Valley of California, American Naturalist. 117:1, pp. 24-37.

[95] Hilgard, E.W., 1884. Report on the Physical and Agricultural Features of the State of California, U.S. Census Office, Tenth Census, v. 6, pt. 2, pp. 649 -796.

[96] Alexander, B. S., Mendell, G.H., and Davidson, G., 1874. Report of the Board of Commissioners on the Irrigation of the San Joaquin, Tulare, and Sacramento Valleys of the State of California, 43d Congress, 1st Session. House of Representation, Ex. Doc. No. 290, Government Printing Office, Washington. 91 pages + plates.

97 Hardpans are more or less impervious sheets of material occurring in soil or subsoil, usually a fraction of an inch to several feet in thickness. This sheet arrests the percolation of precipitation, causing the surface soil to become boggy and poorly drained during times of heavy rains. (Lapham et al. 1909, pp. 46-47). They are also known as duripans.

98 Claypan is a dense, compact, impervious layer in the subsoil with much higher clay content than overlying material from which it is separated by a sharply defined boundary. They are hard when dry and plastic and sticky when wet.

[99] Nikiforoff, C.C., 1941. Hardpan and Microrelief in Certain Soil Complexes of California. U. S. Dept. of Agriculture, Technical Bulletin No. 745, April.

[100] Strahorn, A.T., Mackie, W.W., Westover, H.L., Holmes, L.C., and Van Duyne, C., 1911. Soil Survey of Marysville Area, California, U.S. Department of Agriculture, Bureau of Soils.

[101] Nelson, J.W., Guernsey, J.E., Holmes, L.C., and Eckmann, E.C., 1918. Reconnaissance Soil Survey of the Lower San Joaquin Valley, California. U.S. Department of Agriculture, Bureau of Soils, 157 pp.

[102] Cox, G. W., 1984. The Distribution and Origin of Mima Mound Grasslands in San Diego County, California, Ecology. 65:5. October. pp. 1397-1405.

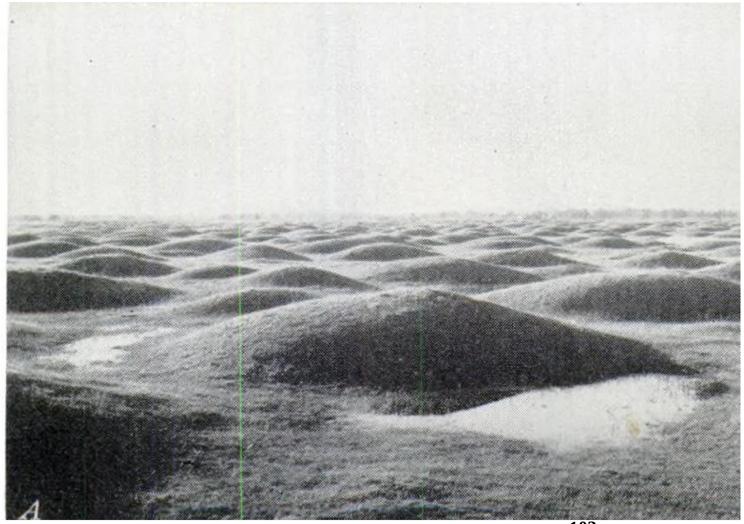

Figure 6. Vernal Pool Microrelief[103]

These hummocks alternated, seemingly randomly, with the depressions. Where the depressions shown in **Figures 6 and 7** intercepted the perched water table, pools formed. In these pools, during winter and spring, a unique flora of colorful concentric rings developed. Thus, these pools have come to be known as "vernal pools," where vernal derives from the Latin for spring. (Holland and Griggs 1976; Holland and Jain 1981, p. 25). This process continues to the present, but is much diminished due to elimination of most of the vernal pool habitat for farming and other uses.

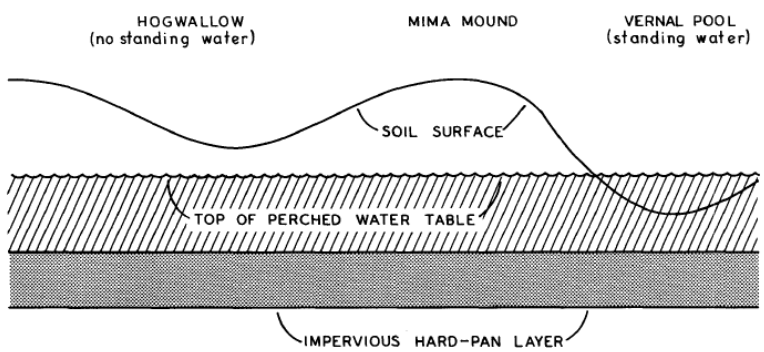

Figure 7. Formation of Vernal Pools
Source: Holland and Griggs 1976

The California Department of Public Works, in a 1931 study of the San Joaquin Valley, in a discussion of the classification of valley floor lands, described them thus, "There are also extensive areas of "hog wallow" land. This term is applied to lands having hummocks and depressions with difference in elevation two to four feet spaced 25 to 50 feet apart. The size, spacing and height vary. Such lands occur mainly on the older valley filling soils underlaid (sic) by hardpan. Where the general area is smooth the leveling of "hog wallows" alone is not difficult. Much of the hog wallow land is also rolling and with shallow hardpan which interferes with leveling." (CDPW 1931b, p. 519.).

[103] Nikiforoff, 1941. Figure 2 (northeast of Exeter, about 2 miles from the Sierra Nevada foothills. The mounds are about 40 inches high.).

The Mediterranean climate of the Central Valley, wet winters and dry summers, makes these pools ephemeral. Water stands through most of the rainy season, drying out as temperatures rise. Most vernal pools were small, less than 0.02 acres (100 m^2), but some covered tens of acres up to 300 acres and were temporary lakes. (Solomeshch et al. 2007,[104] p. 398). Due to their small size, these wetlands, with the exception of a few very large playa pools, have not been shown on maps. Attempts at determining their original location and areal extent have been primarily based on soil surveys.

Vernal pools were present throughout the Central Valley under natural conditions. (Crampton 1974, p. 74; Alexander 1874, pp.24-25). In 1874, when the great wheat bonanza that changed the face of the Central Valley was well under way (Scheuring 1983,[105] p. 12), the Board of Irrigation Commissioners reported to the 43rd U.S. Congress based on field surveys, "But throughout large areas of the valley and on the eastern side, extending in many places from the foot-hills to beyond the line of the Southern Pacific Railroad, the surface of the soil is peculiarly marked by innumerable and continuous nearly circular mounds, locally known as "hog-wallows." These mounds, lying without perceptible symmetrical arrangement, are moderately uniform in shape and size; ranging from 6 inches in height to as much as 3 or 4 feet, although by far the greater number average about 1 to 1 1/2 feet...and from 20 to 50 feet in diameter...In many places the immediate substratum of these mounds is "hard pan;" but over large areas, where they abound, there appears to be no difference between their soil and the subsoil...The farmers agree in saying that the summits of these mounds give a ranker growth of grass or grain than the low intervals between them." (Alexander et al. 1874, pp. 24-25).

The extensive occurrence of vernal pools was also recorded in early reconnaissance soil surveys, conducted in the early 20th century. In the 1904 soil survey of the Sacramento area, "The surface of the extreme western or lower portion is nearly level, but often covered by small mounds known as "hog wallows," which form a distinctive feature over much of the Sacramento and San Joaquin valley lands. These are most prominent along the western and that portion of the southwestern margin of the area lying on the north side of the American River. " (Lapham et al. 1904,[106] p. 1054).

Vernal pools were most common in acidic iron silica cemented soils including the San Joaquin (most extensive), Corning, and Redding series -- red soils with indurated ferruginous (iron-silica cemented) hardpan.[107] (Hoover 1935,[108] p. 48). They also occurred on several dozen additional soil series that share the same characteristics, but of more limited distribution. (Solomeshch et al. 2007, pp. 395-396). Thus, they were most abundant on terrace soils bordering the east side of the Central Valley at the base of the Sierra Nevada foothills (Holland and Jain, 1988,[109] p. 517; Hoover 1935, p. 48; Solomeshch et al. 2007, p. 398) and on high

[104] Solomeshch, A.I., Barbour, M., and Holland, R. F., 2007. Vernal Pools, Chapter 15, In: Barbour et al. (Eds.).

[105] Scheuring, A.F., 1983. A Guidebook to California Agriculture. (Ed.) University of California Press, Berkeley.

[106] Lapham, M. H, Root, A. S., and Mackie, W. W., 1904. Soil Survey of the Sacramento Area, California.

[107] http://davisherb.ucdavis.edu/cnpsActiveServer/SeriesDetail.aspx?seriesname=Northern+hardpan+vernal+pools

[108] Hoover, R.F., 1935. Character and Distribution of the Primitive Vegetation of the San Joaquin Valley, Master of Arts Thesis, University of California, Berkeley.

[109] Holland, R.F. and Jain, S.K., 1988. Vernal Pools, In: Barbour, M G. and Major, J. (Eds), Terrestrial Vegetation of California, California Native Plant Society Special Publication No. 9: 515-531, Sacramento.

terraces at the mouths of streams draining the eastern side of the inner Coast Range. (Holland 1978, p. 3; Keeler-Wolf et al. 1998[110]).

Dr. R. F. Hoover, a noted botanist concluded in his doctoral thesis, "In its most clearly marked aspect, this area includes much of the east side of the Great Valley from Butte County to Tulare County, extending somewhat into the Sierra foothills, and the west side from Glenn County to Merced County." (Hoover 1935, p. 47). Most reportedly occurred in Fresno, Madera, Merced, Placer, Stanislaus, Sacramento, Tehama, and Yuba counties, on the eastern side of the valley. (Solomeshch et al. 2007, p. 398; Holland and Jain 1988, p. 517; Smith and Verrill 1998; Holland and Hollander 2007, p. 41).

The characteristic hog-wallow microrelief (Figure 6) became less conspicuous with greater distance from the base of the Sierra foothills, on peripheral parts of the fans, and on the central alluvial flats. The mounds in the lower-lying areas were generally more flattened, ranging from 1 to 2 feet in height. The hog-wallow microrelief reportedly occurred only sporadically in the western part of the Central Valley, adjacent to the foothills of the Coastal Range. (Nikiforoff 1941, pp. 8-9, 42; Smith and Verrill 1998, pp. 18-19). However, the absence of hog-wallow relief does not indicate the absence of vernal pools, as they also may have occurred in flat, alkaline areas on the west side of the valley. See Sec. III.C.4.b. Some have suggested these alkaline areas developed after the cessation of flooding. (Edminister 2002, p. 146). Vernal pools reportedly did not occur at all on the most recent sediments. (Hoover 1935, p. 47).

Vernal pools reportedly do not occur on sites with slopes greater than about 3.5 percent, with most on sites at slopes of 0 to 1 percent (based on extant sites in eastern Merced County), as the erosion process generally precludes the formation of pool basins. (Vollmar 2002,[111] p. 34; Vollmar et al. 2013[112], p. 33; Smith and Verrill 1998, p. 20). However, such observational reports were made long after significant agricultural development had destroyed most of this habitat.

Vernal pools usually occur in groupings known as complexes or archipelagoes with a distinctive undulating topography. See photographs in Nikiforoff (1941). A complex is a set of pools in close proximity, often connected hydrologically. Pools can be separated by tens or hundreds of meters within a complex, but this varies depending upon location. (Holland and Jain 1981, p. 25). Intervening non-pool terrain within a vernal pool complex is commonly referred to as upland and often includes wetland or partially wetland swales that can connect pools within the complex.

3.3.2 VERNAL POOL VEGETATION

Under natural conditions, vernal pools were only one element of a regional wetland complex, with vast marshes and shallow fluctuating lakes that were interspersed with vernal pool

[110] Keeler-Wolf, T., D., Lewis, E.K., Flint, S., 1988. California Vernal Pool Assessment: A Preliminary Report, Resources Agency, CDFG, Sacramento, CA.

[111] Vollmar, J. E., 2002. Landscape Setting, Chapter 2, In: John E. Vollmar (Ed.), Wildlife and Rare Plant Ecology of Eastern Merced County's Vernal Pool Grassland.

[112] Vollmar, J, Schweitzer, J., Holland R., and Witham, C., 2013. Predictive Habitat Analysis and Maping of Four Rare Vernal Pool Species in Merced, Sacramento and Placer Counties, Great Valley, California, USA, January. Available at: http://www.vernalpools.org/2010CVPIA/Predictive_Mapping.pdf.

habitat. However, starting soon after the Gold Rush and accelerating greatly with the great wheat bonanza of the1860s through the 1880s, this system of wetlands was severely disrupted by dumping hydraulic mining debris, covering up the pools; levying the rivers, cutting off their water supply; draining the permanent marshes that they were connected with; and eliminating the vernal pools themselves by plowing, blasting, deep ripping, and burning to clear native vegetation and level and drain the land, making way for farms and other developments. (Medeiros 1976; Smith and Verrill 1998; Holland and Griggs 1976; Barbour et al. 1993, p. 83; Edminster 2002).

Much of what remains is isolated from its natural watershed, drastically altered from its natural state, and is located in disturbed areas (e.g., along gas pipeline corridors, on ranches where it is used for stock watering and grazing), limiting much of the contemporary research for reconstructing natural conditions. (Edminster 2002; Zedler 2003, p. 602; Cunningham 2010, pp. 126-129).

The hydrology of the pools largely controls plant density and composition. Water stands in the pool through the rainy winter season. This excludes or limits the growth of plants of the surrounding uplands, which are intolerant of flooding. (Keeley and Zedler 1996[113]). In the summer, rising temperatures and dry north winds evaporate the water, preventing the establishment of permanent marshland species. (Zedler 2003, p. 600).

This specific regime of inundation -- too short and unpredictable to support aquatic species but long enough to eliminate grassland species -- is what characterizes vernal pools as seasonal wetlands and differentiates them from other ecosystems. The plants that grow in such places must be adapted to long periods of submergence followed by rapid drying and complete dryness for several months. These widely varying conditions from seasonal inundation to desiccation have resulted in the development of a predominantly herbaceous annual flora to survive the extreme seasonal and year-to-year variation in hydrological regime. (Hoover 1935, p. 47; Dittes and Guardino 2002,[114] p. 65). They are mostly amphibious annuals capable of slow underwater growth in winter and rapid devlopment and reproduction in spring after the water is gone but before soils dry. Many genera and species are endemic to California. (Solomeshch et al. 2007, p. 394).

The ecology of vernal pools and their associated animal and plant communities as they currently exist has been extensively described in numerous articles and reports, reviewed elsewhere. (Barbour et al. 2003;[115] Holland and Hollander 2007; Barbour et al. 2007;[116] Sawyer and Keeler-Wolf 1995,[117] pp. 359-360; Keeler-Wolf et al. 1998; Vollmer 2002,[118] Sec. 2.8.2;

[113] Keeley, J.E. and Zedler, P. H. Zedler, 1996. Characterization and Global Distribution of Vernal Pools, In: Carol W. Witham, Ellen T. Bauder, Denton Belk, Wayne R. Ferren Jr., and Robert Ornduff (Eds.), Vernal Pool Ecosystems: Ecology, Conservation, and Management of Vernal Pool Ecosystems, Proceedings from a 1996 Conference. Available at: http://www.cnps.org/cnps/conservation/vernalpools.php.

[114] Dittes, J. C. and Guardino, J. L., 2002. Rare Plants, Chapter 3, In: Vollmar, John E., Landscape Setting, Chapter 2, In: John E. Vollmar (Ed.), Wildlife and Rare Plant Ecology of Eastern Merced County's Vernal Pool Grassland.

[115] M. Barbour, Solomeshch, A., Witham, C., Holland , R., MacDonald, R., Cilliers , S., Molina, J.A., Buck , J., and Hillman, J., 2003. Vernal Pool Vegetation of California: Variation Within Pools Madroño, v. 50, no. 3, pp. 129-146.

[116] Barbour, M.G., Keeler-Wolf, T. and Schoenherr, A.A., 2007. Terrestrial Vegetation of California, Third Edition, University of California Press, Berkeley.

[117] Sawyer, J. O. and Keeler-Wolf, T., 1995. A Manual of California Vegetation, California Native Plant Society.

[118] Vollmar, John E., Landscape Setting, Chapter 2, In: John E. Vollmar (Ed.), Wildlife and Rare Plant Ecology of Eastern Merced County's Vernal Pool Grassland, 2002.

Dittes and Guardino 2002; Buck 2004[119]). This section only provides a brief summary of vernal pool vegetation as we are interested in estimating water losses from the pools due to evapotranspiration. Many species are classified as rare, threatened, or endangered by federal and state agencies, explaining the huge amount of research devoted to them.

Vernal pools are really a sequence of habitats (**Figure 8**), with at least four phases in the Valley Floor study area (see Figure 8): (1) a summer desert-like dry state ("summer dry phase"); (2) a pre-inundation wetting phase during which germination and hatching are stimulated by the first rains; (3) a pool phase ("winter wet phase"); and (4) a spring flowering phase, during which the water evaporates and seeps away and the surface dries ("spring flower phase"). (Zedler 2003, p. 598). The "vernal" pool aspect is really present only in spring when in full bloom.

Most Central Valley vernal pools occurred in a mosaic with grasslands. (Burcham 1957; Heady 1977; Heady et al. 1992;[120] Holland 1978; Holland 1998;[121] Barbour and Witham 2004,[122] p. 8.) They also occurred under a variety of tree canopies, ranging from *Quercus douglasii* savannah to *Pinus ponderosa* forest to volcanic mudflows in Tehama County. (Holland and Jain 1988, pp. 517-518). In the Delta, they intermixed with wet meadow, seasonal wetlands, and alkali seasonal wetland complexes. (Whipple et al. 2012, p. 44).

Figure 8. Vernal Pool Habitat Sequences

The pools themselves are densely covered with a rich variety of perennial herbs, perennial grass and forb halophytes, perennial rushes, cryptophytic perennial forbs, small subshrubs, and pool-bed algae (Solomeshch et al. 2007, pp. 398. Anderson, 2006,[123] p. 29). With the exception of the genera *Eryngium*, *Eleocharis*, and *Juncus*, most are annuals, as they are able

[119] Buck, J.J., 2004. Temporal Vegetation Dynamics in Central and Northern California Vernal Pools, Master of Science Thesis, University of California, Davis.

[120] Heady, H. E., Bartolome, J.W, Pitt, M.D. 1992, California Prairie, pp. 313-332, In: R. T. Copland (Ed.), Natural Grasslands, Elsevier, New York.

[121] Holland, R.F., 1998. Changes in Great Valley Vernal Pool Distribution from 1989 to 1997, California Department of Fish and Game, June. Available at: http://www.dfg.ca.gov/biogeodata/wetlands/pdfs/Holland_ChangesInGreatValleyVernalPoolDistribution.pdf

[122] Barbour, M.G., and Witham, C. W., 2004. Islands within Islands: Viewing Vernal Pools Differently, Fremontia. 32:2.

[123] Anderson, M.K., 2006. Tending the Wild. Native American Knowledge and the Management of California's Natural Resources, University of California Press.

to tolerate highly variable timing for the onset and duration of the growing seasons and long periods of extreme dryness. (Keeler-Wolf et al. 1998; Zedler 2003, p. 601).[124]

The most conspicuous feature of vernal pools is the beautiful concentric rings of flowers. See **Figure 9**. Vernal pools are famous for these dramatic rings of color, created by sequential flowering of different species as the rainfall stops and temperatures rise in late spring, resulting in the pools drying from the edge inward. (Grossinger 2012,[125] p. 74). In general, the timing, intensity, and species composition of the floral displays depend upon the amount and timing of precipitation and ambient temperatures (Vollmer 2004, Sec. 3.3.4) and the number of consecutive days of flooding. (Zedler 1984[126]).

The descriptions of the floral displays in early eye witness accounts are likely predominately of vernal pools, as their wildflowers produced displays of color that are legendary. (Schoenherr, 1992, pp. 520-522).

Fremont, in his Memoirs, described the plains of the San Joaquin in 1847, "By the middle of March, the whole valley of the San Joaquin was in the full glory of spring; the evergreen oaks were in flower, *geranium cicutarium* was generally in bloom, occupying the place of the grass, and making on all the uplands a close sward. The higher prairies between the rivers presented unbroken fields of yellow and orange colored flowers, varieties of *Layia* and *Escholtzia California*… ." (Fremont 1887, p. 18; Landrum 1938, p. 35).

John Muir, in The Mountains of California, described the plains (as of about 1868-69), "The Great Central Plain of California, during the months of March, April, and May, was one smooth, continuous bed of honey-bloom, so marvelously rich that, in walking from one end of it to the other, a distance of more than 400 miles, your foot would press about a hundred flowers at every step. Mints, gilias, nemophilas, castelleias, and innumerable compositae were so crowded together..." (Muir 1988,[127] pp. 339-347).

The concentric ring displays are due to distinct plant associations along topographic-hydrologic gradients associated with subtle variations in water depth and length of inundation. The "vernal pool obligates" commonly occupy the basin and/or rim positions; "wetland generalists" occur in pools and other seasonal wetlands, such as swales, seasonal seeps, and meadow edges; and "upland" species dominate the grassy uplands and rarely occur in the basin

[124] It is important to consider that the original landscape has been "drastically altered" from its natural state. The remaining vernal pools from which these collections were made are disconnected from the original regional wetland complex with its vast system of marshes, shallow fluctuating lakes and high water tables and are often currently grazed. (Zedler 2003, p. 602; Dittes and Guardino 2002, pp. 120-121).

[125] Grossinger, R., 2012. Napa Valley Historical Ecology Atlas. Exploring a Hidden Landscape of Transformation and Resilience, University of California Press, Berkeley.

[126] Zedler, P.H. 1984. Micro-distribution of vernal pool plants of Kearney Mesa, San Diego Co. Pages 185-197 In: S. Jain and P. Moyle (Editors). Vernal Pools and Intermittent Streams. Institute of Ecology Publication No. 28, University of California. Davis, CA.

[127] Muir , J., 1988. The Mountains of California, Dorset Press, New York (originally published 1894). p. 339. See also continuing descriptions of luxuriant grasslands at pp. 340-347.

or rim (Hobson and Dahlgren 1998,[128] p. 108 summarizing Jokerst 1990). See also vernal pool photography.[129]

Figure 9. Photographs of Vernal Pools of California[130]

[128] Hobson, W.A. and Dahlgren, R.A., 1998. A Quantitative Study of Pedogenesis in California Vernal Pool Wetlands, In: M.C. Rabenhorst, J.C. Bell, and P.A. McDaniel, Quantifying Soil Hydromorphology, Soil Science Society of America.

[129] Vernal Pool Photography, Available at: https://www.google.com/search?q=vernal+pool+photography&espv=210&es_sm=93&tbm=isch&tbo=u&source=univ&sa=X&ei=I7iXUoaGOYHnoATFm4KoBA&ved=0CDgQsAQ&biw=1680&bih=964.

[130] https://www.google.com/search?q=vernal+pool+photography&espv=210&es_sm=93&tbm=isch&tbo=u&source=univ&sa=X&ei=I7iXUoaGOYHnoATFm4KoBA&ved=0CDgQsAQ&biw=1680&bih=964#facrc=_&imgdii=_&imgrc=mY6TI7BW-zZAzM%3A%3BGxT9EyYGOLv5uM%3Bhttp%253A%252F%252Fwww.botgard.ucla.edu%252Fhtml%252Fbotanytextbooks%252Flifeforms%252Fimages%252Faquaticplants%252FVernalpool4.jpg%3Bhttp%253A%252F%252Fwww.botgard.ucla.edu%252Fhtml%252Fbotanytextbooks%252Flifeforms%252Faquaticplants%252Fb0967tx.html%3B360%3B241

Studies of eastern Merced County's remnant vernal pools suggest geologic surface is not a factor controlling the distribution of most species, except as the surface influences the occurrence and density of associated vernal pools. (Vollmer 2004, Sec. 3.4.3; Dittes and Guardino 2002, p. 119). Some speculate that soil pH relations strongly affect species distribution. Vernal pools on the higher, older terraces and alluvial fans are very acidic while those on the lower, more level formation towards the center of the valley are more basic (alkaline). (Dittes and Guardino 2002, pp. 119-120).

Many areas reportedly remained "practically bare during the summer or supported only a scant vegetation." (Nikiforoff 1941, pp. 22, 25; Solomeshch et al. 2007, p. 396). However, these observations occurred 150 years after the pristine grasslands had been decimated by grazing cattle, horses, and sheep. Further, drought-adapted vegetation was present. When the pools dry out, mainly native annual species grow rapidly using subsurface moisture. (Barbour et al. 2003, p. 129). The summer annual grasses comprising the genera *Orcuttia* and *Neostrapfia* flower and mature seed during the summertime in vernal pools. "As the ponded rainwater evaporated from these large pools during the late spring or early summer, seedlings of *Orcuttia* and *Neostapfia* develop on the drying mud...Usually little or no other vegetation is to be in association with these unusual grasses… ." (Crampton 1976,[131] p. 23). Hoover noted the common vernal pool plant, *Neostapfia colusana*, "comes into maturity in the summer when the soil is perfectly dry and is then covered with a sticky secretion, which probably serves to reduce water loss." This species grew in both alkaline and alkaline-free soils and on both the outer margin or deepest zones of vernal pools. (Hoover 1935, p. 49). Others have also observed these annual grasses during the dry summer period. (Medeiros 1976, pp. 26-27).

Pools can usually be distinguished from surrounding uplands by a distinct change in vegetation and soil characteristics. (Holland and Jain 1981, p. 25; Keeler-Wolf et al. 1998, p. 8; Alexander et al. 1874, pp. 24-25). The vegetation on the connecting areas or mima mounds has been little considered but was likely mostly "grassland." Holstein (2001) noted that along the eastern edge of the Central Valley, the uplands between pools are frequently dominated by native annual tarweeds, which are forbs. These are annual forbs that are photosynthetically active throughout the long dry Central Valley summers and are more productive in summer than spring as they can tap summer soil water unavailable to most other species.

3.3.3 VERNAL POOL HYDROLOGY

A vernal pool is a shallow depression typically underlain by impermeable material such as a hardpan (silica-cemented duripans with some cementing by iron oxides and calcium carbonate), claypan or bedrock that hinders drainage and seasonally fills with water from precipitation, surface water flow, and groundwater seepage. Thus, they are intermittent bodies of water, such as those shown in **Figure 10**. Under natural conditions they were part of an intricate web of wetlands and drainage swales that ranged from the foothills to the valley floor.

[131] Crampton, B, 1976. Rare Grasses in a Vanishing Habitat, Fremontia. 4:4. October. pp. 22-23.

Figure 10. Flooded Vernal Pools.
Source: (Nikiforoff 1941, Fig. 10)
(Note: The water between the mounds is from 1 to 2 feet deep).

Various theories have been proposed for the formation of vernal pools and probably many come into play depending upon local topography. Recent researchers have suggested that pools could form as topographic depressions where the groundwater table is locally exposed. This has been proposed as one of the conditions that "...may partially explain the behavior of many vernal pools in the Central Valley of California." The free water surface would have been an expression of a shallow, seasonal perched groundwater table that developed during the rainy season. (Hanes et al. 1990,[132] p. 51). A noted California biologist in his doctoral thesis asserted that vernal pools did not occur where a hardpan was "deeply located or entirely absent." (Hoover 1935, p. 47). Others have reported impermeable subsurface layers were not required to form vernal pools. (Alexander 1874, p. 25). See also Section II.C.1.

The depth of water in the pools typically ranges from a few inches to one foot or more in some large pools. The surrounding soils are typically saturated to the level of the impermeable layer. (Nikiforoff 1941, pp. 22-23, Solomeshch et al. 2007, p. 396). The soil remains moist for a period and then desiccates. The pools dry due to evaporation and evapotranspiration. Small to medium-sized pools (2,500 ft^2) typically dry in mid to late spring, depending upon the amount of rainfall. Larger pools can remain inundated into the summer. (Vollmer 2002, p. 28). This cycle may repeat depending on the timing of flood flows and precipitation and pool size, with the smaller and shallower pools drying and refilling several times while the larger ones hold water continuously. In general, the aquatic phase lasts for 2 to 4 months, and soils remain saturated for an additional 1 to 3 months. The dry phase, during which most plants are dormant, extends for 5 to 8 months.

Vernal pool dimensions are a strong indicator of the timing of their hydrologic cycles. Generally, larger and/or deeper pools exhibit more extreme seasonal inundation regimes with a prolonged dry-down phase. (Keeley and Zedler 1996; Platenkamp 1998[133]). Small pools that

[132] Hanes, W.T., Hecht, B., and Stromberg, L., 1990. Water relationships of vernal pools in the Sacramento Region, California, pp. 49-60. In: D. Ikeda and R.A. Schlising (Eds.), Vernal Pool Plants, Their Habitat and Biology, Studies from the Herbarium, No. 8., CSU Chico, CA.

[133] Platenkamp, G.A.J., 1998. Patterns of vernal pool biodiversity at Beale Air Force Base. pp. 151-160 In: C. Witham, E.T. Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Eds.). Ecology, Conservation, and management of vernal pool ecosystems. Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

receive prolonged runoff from large upslope drainage areas could exhibit an inundation cycle similar to larger pools receiving shorter-duration runoff from smaller drainages. (Stone et al. 1988;[134] Vollmer 2004, p. 155). Smaller or shallower pools have a larger perimeter-to-area (or volume) ratio and thus higher rates of water loss (relative to maximum pool volume) due to transpiration from perimeter vegetation or groundwater leakage. (Leibowitz and Brooks 2008,[135] p. 37). These dimensions, in turn, affect vernal pool species composition and abundance, as they affect the duration of ponding and frequency of drying during the growing season. Deeper pools have on average a higher biological diversity than shallow pools. (Platenkamp 1998).

Vernal pools were originally protected as waters of the United States under the Clean Water Act. However, this protection was lost with the U.S. Supreme Court decision, Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers (99-1178) 531 U.S. 159 (2001), which eliminated federal jurisdiction over "isolated waters" (including isolated wetlands). (Zedler 2003, p. 597). Since this decision, there has been a concerted effort to demonstrate the "connectedness" of vernal pools with surface waters.

Vernal pool hydrology is important for water-balance work because it ultimately determines the amount of water that can be evapotranspired. Evaporation and evapotranspiration are the key water loss components in water balances reported elsewhere. (Fox et al. 2014). Although vernal pool flora has been studied in some depth to identify rare, threatened, and endangered species and to protect their habitat, very little work has been done on the supporting hydrologic regime in the Central Valley. Only a few studies have been conducted at remanant vernal pools. All studied vernal pools were isolated from their pristine habitat and in many cases surrounded by and impacted by developed areas. (Hanes et al. 1990; Hanes and Stromberg 1998;[136] Pyke 2004;[137] Raines et al. 2006;[138] Raines et al. 2008;[139] Williamson et al. 2005;[140] ESA 2006[141]).

Field studies have been conducted during only the wet phase. Pools have not been monitored into the summer, when the pool surface reportedly dries out. These "dry" surfaces, for

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[134] Stone, R.D., Davilla, W.B., Taylor, D.W., Clifton, G.L. and Stebbins, J.C.. 1988. Status Survey of the Grass Tribe Orcuttieae and Chamaesyce hooveri (*Euphorbiaceae*) in the Central Valley of California. U.S. Fish and Wildlife Service Stone Technical Report. Prepared by Biosystems Analysis for U.S. Fish and Wildlife Service, Office of Endangered Species, Sacramento, CA

[135] Liebowitz, S.G., Brooks, R.T., 2008. Hydrology and landscape connectivity of vernal pools. Chapter 3. In: Calhouh, Aram J.K.; deMaynadier, Phillip G., eds. Science and Conservation of Vernal Pools in Northeastern North America. CRC Press. Boca Raton, FL: 31-53, 2008. Available at: http://www.nrs.fs.fed.us/pubs/jrnl/2008/nrs_2008_leibowitz_001.pdf.

[136] Hanes, T. and Stromberg, L., 1998. Hydrology of Vernal Pools on Non-Volcanic Soils in the Sacramento Valley, pp. 38-49 In: C. W. Witham et al. (Eds), Ecology, Conservation, and Management of Vernal Pool Ecosystems, California Native Plant Society (CNPS), Sacramento, CA.

[137] Pyke, C. R., 2004. Simulating Vernal Pool Hydrologic Regimes for Two Locations in California, USA, Ecological Modeling. 173:2-3. April, pp. 109-127.

[138] Rains, M.C., Fogg, G.E., Harter, T., Dahlgren, R.A., and Williamson, R.J., 2006. The Role of Perched Aquifers in Hydrological Connectivity and Biogeochemical Processes in Vernal Pool Landscapes, Central Valley, California, Hydrological Processes. v. 20, pp. 1157-1175.

[139] Rains, M.C., Dahlgren, R.A., Fogg, G.E., Harter, T., and Williamson, R.J., 2006. Rains, 2008. Geological Control of Physical and Chemical Hydrology in California Vernal Pools, Wetlands, 28:2. June. pp. 347-362.

[140] Williamson, R. J., Fogg, G.E., Rains, M.C., and Harter, T.H., 2005. Hydrology of Vernal Pools at Three Sites, Southern Sacramento Valley, Final Report for Project: F 2001 IR 20, Developing a Floristic Statewide Vernal Pool Classification, and a Functional Model of Pool Hydrology and Water Quality, Report FHWA/CA/IR-2004/08, State of California Department of Transportation, April 22, 2005. Available at: http://www.vernalpools.org/documents/Hydrology%20Three%20Sites%202005%20Williamson.pdf.

[141] ESA, 2006. Phoenix Vernal Pools Land Management Plan, Prepared for California Department of Fish and Game, October.

example, may have saturated subsoils, lie over a perched aquifer, or puddled water may be present in portions of the basin. Very few studies have been conducted over several seasons.

Evapotranspiration, the principal water loss and a key input to water balances, has never been measured in the field at any California vernal pool. Only a few attempts have been made to estimate it as potential evapotranspiration in water balance calculations. (Pyke 2004; Rains et al. 2008; Williamson et al. 2005). While insights can be gained from studies of similar systems elsewhere, such as Prairie potholes, Carolina bays, cypress pond-pine flatwood ecosystems, and Mississippi forest pools (Brooks 2005;[142] Leibowitz and Brooks 2008; Boone et al. 2006[143]), there are significant differences in both the climate and soils between Central Valley vernal pools and these others.

Further, vernal pools are predominately perched aquifer systems, which have been little studied in any setting, primarily because they typically do not yield enough water to support a drinking water source. However, they are critical to understanding vernal pools. In particular, much of the Valley Floor was underlain by perched aquifer systems under natural conditions. These were ripped out to level the land, improve drainage, and otherwise prepare it for farming before they were studied, so nothing is known about how they functioned and their interactions with surrounding wetlands, surface waters, deep underlying groundwater aquifers, and the adjacent grassland vegetation. How much water was available in this habitat for evapotranspiration? Was water exchanged between vernal pools and adjacent grasslands?

The hydrology of vernal pools is site specific, depending on topography, soil properties, vegetation, and climate, among other factors. While vernal pools may appear superficially similar, they can be hydrologically dissimilar. Thus, very few generalizations are possible. Most vernal pools are supplied by (or created) perched aquifers, precipitation, and surface waters. (Williamson et al. 2005, p. 45). There is some evidence that they were spring fed in some areas. (Lapham et al. 1904, pp. 1070, 1081). In winter, the impermeable soils underlying these pools prevent water from penetrating, saturating the upper soil and filling the basin with water, thus forming pools and small lakes. Rainfall and runoff collect in the depressions, stand through early spring or later, and then evaporate as temperatures rise and rainfall declines.

The processes that control water relationships in vernal pools include: (1) direct precipitation; (2) overland flow; (3) subsurface inflows; (4) evaporation and evapotranspiration; (5) seepage; and (6) inflows from pool sides. (Hanes et al. 1990; Colburn 2004[144]). The relative importance of these vary depending upon site-specific factors, including: (1) pool geometry (surface area, depth, connecting channels, spillway geometry); (2) characteristics of pool bottom (permeability, moisture content, texture); and (3) characteristics of adjacent uplands and mima mounds (topography including slope and height; soil characteristics including texture, structure, density, moisture content and infiltration rate; and vegetation cover).

Vernal pools have been frequently treated as isolated depressions that pond largely due to direct precipitation and drain and dry largely due to evapotranspiration and evaporation. Some

[142] Brooks, R.T., A Review of Basin Morphology and Pool Hydrology of Isolated Ponded Wetlands: Implications for Seasonal Forest Pools of the Northeastern United States, Wetlands Ecology and Management, 2005, pp. 335-348.

[143] Boone, R.B., Johnson, C.M, and Johnson, L.B., Simulating Vernal Pool Hydrology in Central Minnesota, USA, Wetlands, v. 26, issue 2, June 2006, pp. 581-592.

[144] Colburn, E.A., 2004. Vernal Pools: Natural History and Conservation, McDonals & Woodward, Blacksburg, VA.

claim that many of the original vernal pools had no outlets and displayed what has come to be known as "top-down hydrology" -- water collecting in the basins and creating a locally perched water table above a soil with very low hydraulic conductivity. (Zedler 1987;[145] Hanes and Stromberg 1998; Zedler 2003, p. 599). Some even assert that basins with continuous outflow due to inputs from surface or ground water are not considered vernal pools. (Zedler 2003, p. 599). However, these current observations of isolated pools, removed from their pristine habitat, may not reflect natural conditions and may be the result of development, which removed most of the supporting watershed-wetland systems that historically supported vernal pool hydrology throughout the valley.

Vernal pools are not always isolated hydrologically. Some remain in areas that were not attractive for farming. Those in the lava and basalt beds southeast of CSU Chico, for example, are connected by chains that allows water to run through them. Others in gravelly Redding soil complexes are connected by sheets of stony outwash material. (Nikiforoff 1941, pp. 36-38).

Solomeshch et al. (2007), for example, summarized recent studies as follows, "Recent hydrology studies show that vernal pools do not simply fill from direct precipitation, nor do they empty only by evapotranspiration. The pools are not isolated hydrologically: lateral flow imparts a high degree of connectivity among pools within a complex. The movement of water between pools sometimes travels via surface swales, and in such a situation, the connection is obvious. In addition to the surface movement, there is subsurface water flow. Once the soils have become saturated, water can move laterally above the impervious horizon, moving from hillocks into pools and vice-versa and ultimately draining down the slope within a single watershed to exit as a late-season riverine flow...This linkage between uplands and basins buffers pool volume, keeping them filled later into the dry season, and pool chemistry, permitting them to function as "miniature kidneys," much like the effect that riparian and marsh vegetation have on water that passes through them."

Very few field hydrologic studies have been conducted at Central Valley vernal pools. Some have suggested that these vernal pool hydrologic regimes can be modeled primarily based on the direct interception of precipitation and the loss of water to evaporation and evapotranspiration, a throwback to the isolation theory. (Hanes et al. 1990; Pyke 2004). In these models, evapotranspiration has been reported as the major source of water loss for other isolated ponded wetlands including Carolina bays, cypress ponds, and prairie potholes. (Leibowitz and Brooks 2008, p. 36). These studies suggest that other watershed inflows and outflows may be generally volumetrically minor, but still important.

However, this view is overly simplistic in many cases. While the hog-wallow microrelief was present in some areas so flat that water practically did not run from the surface at all, e.g., in Fresno complex soils (Nikiforoff 1941, p. 38, Fig. 18; Strahorn et al. 1911,[146] p. 27), most of this habitat was present in areas with sufficient slope to generate runoff. Overland and subsurface inflows and seepage losses occur and are often major components of water balances. Overland flow, for example, may be important in areas with steep slopes or saturated shallow soils. (Hanes et al. 1990, pp. 51-59). Subsurface inflow is important once upland soils develop a

[145] Zedler, P.H., 1987. The Ecology of Southern California Vernal Pools: A Community Profile, U.S. Fish and Wildlife Service, Washington, D.C., Biological Report 85(7.11).

[146] "The soil and subsoil of the Fresno series are gray to light brown in color. The areas have a uniform, sloping surface, or are marked by swales and depressions and in some sections by indistinct "hog wallows."

perched water table, supplying the water that is evapotranspired and stabilizing water levels in the pool through spring. (Hanes and Stromberg 1998, p. 48).

A recent study in which conductivity (measure of salinity) was measured in pond water found that the concentration tended to decline or remain stable, indicating a source of water was replacing that lost by evaporation and evapotranspiration. (Rains et al. 2006, p. 1171). In other work, Nikiforoff reported lateral movement of subsurface water from adjacent depressions. Otherwise, he observed that none of the pools had a surface outlet, and water did not run between the mounds except in rare instances of overflow. (Nikiforoff 1941, pp. 23, 38). See also Figure 10. Finally, high rates of seepage loss have been reported for pools with weakly developed or discontinuous hardpans underlying the pool bottom. Pools studied in the Sacramento area, for example, were net losers of direct precipitation to the watershed. (Hanes and Stromberg 1998, pp.40-41, 47).

These surface and subsurface inflows must be accounted for to accurately estimate evaporation and evapotranspiration. Subsurface inflows, for example, even when minor, dampen water level fluctuations during late winter and early spring and affect the amount of water available for evaporation and evapotranspiration. (Hanes and Stromberg 1998). Thus, vernal pool hydrology is very site specific and cannot always be accurately modeled by considering only precipitation and evapotranspiration.

Water exchanges between the pool and surrounding uplands are not necessarily minor. A field study was conducted at three vernal pool complexes with three pools in each complex in the Sacramento area during the wet season of 2002-2004. The pools were selected to cover a range of soil types (northern claypan, northern hardpan), pool sizes, and pool position in the drainage system. This study found that surface water and groundwater inflows can play a major role in controlling pool water levels. Surface water flow and groundwater seepage supplied 25% to 60% of the water required to fill the vernal pools to their margins. In cases where the topography was flat or gently rolling and the soil permeability low, surface water flow was the predominant source of the watershed contribution. Where the watershed sloped toward the pools and soil permeability was moderately high, both groundwater seepage and surface water flow delivered measureable amounts of water to the pool. Surface water arrived relatively quickly, during and shortly after storms, while groundwater seepage was slower, arriving over the course of days to weeks or more after storms. The wetup behavior of the study pools within each complex was similar. (Williamson et al. 2005, pp. 10-11, 45-46).

This study also demonstrated different hydrological behavior of claypan and hardpan pools. The claypan pools were less connected and lost water by evapotranspiration while the hardpan pools were more connected and lost water by lateral movement. (Williamson et al. 2005). Thus, the pools on the west side of the Valley Floor would likely have lost water primarily by evapotranspiration while those on the eastside likely lost water by lateral movement and evapotranspiration. In other work, Hanes and Stromberg (1998) in a study of hardpan pools reported significant lateral flow from surrounding uplands only when seasonal precipitation was greater than or close to average and upland soils were fully saturated. In dry years, direct precipitation was the most important water source.

Other studies have also identified lateral flow among adjacent watersheds and the pool complex, including both surface and subsurface flow and overflow drainage from vernal pools feeding into ephemeral drainages that ultimately flow into creeks and rivers. (Vollamer 2002, p. 2; Rains et al. 2006). Once the soils have become saturated, water can move laterally, ultimately draining as riverine flow. The linkage between uplands and pools buffers pool volume and can keep them filled later into the dry season. (Solomeshch et al. 2007, p. 396). These watershed contributions appear to be volumetrically minor in headwater pools (i.e., isolated pools that do not receive concentrated surface water inflows from channels or swales) as they tend to occur later in the season after the pools have largely filled. (Hanes et al. 1990, p. 52; Pyke 2004).

In a recent study at a remnant vernal pool area at Mather Regional Park in southern Sacramento, Rains et al. (2006) concluded, "...vernal pools on soils with relatively coarse-grained surface deposits overlying claypans/duripans are seasonal, surface water components of integrated surface water and perched groundwater systems. Annual rainfall infiltrates but perches on the claypan/duripan, and this perched groundwater flows downgradient toward the seasonal stream...The vernal pools are characterized by dense coverage with primarily native annual grasses, forbs, and pool-bed algae and are inundated for ~ 150 days per year, whereas the surrounding uplands are characterized by moderate coverage with primarily non-native annual grasses and are not inundated at any point during the year. The vernal pools are relatively high productivity islands in a relatively low productivity landscape and support anaerobic soils when inundated." (Rains et al. 2006, pp. 1169, 1171). Finally, vernal pools collected water, moderating seasonal flooding during storm events and delaying drainage of the flood basins.[147]

3.3.4 VERNAL POOL CLASSIFICATION

Considerable terminology chaos exists. (Holland 1976[148]). The habitat has been variously called vernal pools, vernal lakes, vernal swales, vernal marshes, low wet areas, hog wallow (or hogwallow), dried beds of winter pools, goose lands, and alkaline flats, among many others. Some report these depressions were known locally as "hog wallows." (Solomeshch et al. 2007, pp. 405-417; Grossinger 2012, p. 74; Barbour et al. 1993, pp. 81-83; Holland and Jain 1981, p. 25; Crampton 1974, p. 30). Others have called the areas on the eastern side of the valley underlain by hardpan hog wallows (Nikiforoff 1941) while similar areas on the west side of the Valley underlain by claypan which functioned in a similar manner have been called "alkaline flats." (Burcham 1957, p. 91). However, vernal pools were also present in most of the alkaline flat areas, but with less distinctive microrelief. Some have named these claypan areas "alkaline vernal pools." (Silveira 2000[149]).

There are many differences among vernal pools. Several groups have attempted to classify vernal pools based on existing habitat. Unfortunately, the natural environment has been significantly altered. The vast majority of this habitat has been destroyed by agriculture while new areas, alkaline vernal pools, for example, have been created by rising water tables from irrigation (Fortier et al. 1909[150]) or drying up the native floodplain. (Edminister 2002, pp. 145, 159). Thus, classifications based on current conditions may not be a good representation of natural conditions. However, while there are many differences among vernal pools, they share a

[147] California Wetlands Information System, Vernal Pools: Their History and Status in California's Central Valley, Available at: http://ceres.ca.gov/wetlands/whats_new/vernal_sjq.html

[148] Holland, R.F., 1976. The Vegetation of Vernal Pools: A Survey, pp. 11-15, In: Subodh Jain (Ed.), Vernal Pools. Their Ecology and Conservation, A Symposium Sponsored by the Institute of Ecology, University of California, Davis, May 1 and 2, 1976, Institute of Ecology Publication No. 9.

[149] Silveira, J. G., 2000. Alkali Vernal Pools at Sacramento National Wildlife Refuge, Fremontia, 27:4 and 28:1. January. pp. 10-18.

[150] Fortier, S., Bryant, O.W., Roadhouse, J.E., Wright, A.E., and Barber, J.H., 1909. Irrigation in the Sacramento Valley, California, U.S. Dept. of Agriculture, Office of Experiment Stations, Bulletin 207, March 15, 1909.

common inability to percolate water beyond an impermeable layer, where it is evaporated or evapotranspired.

Some, for example, have based their classifications on geomorphic setting. (Jones and Stokes 1990;[151] Smith and Verrill 1998; Rains et al. 2008). Others have used species composition of remaining pools coupled with various environmental factors, including geographic region, type of aquatard and/or underlying geology, and indicator species. (Holstein 1984;[152] Holland 1986;[153] Keeler-Wolf et al. 1998; Barbour et al. 2007). Others have used pool geometry to characterize vernal wetlands as: vernal pools, playa pools (the larger vernal pools), vernal swales, and seasonally saturated clay flats. (Vollamer 2002, Sec. 2.8.2). These studies suggest vernal pools in the Valley Floor fall into three major groups: (1) freshwater long-inundated pools; (2) freshwater short-inundated pools; and (3) saline/alkaline pools. (Barbour et al. 2007).

We have simplified this classification system into two types of vernal pool habitat: (1) alkali vernal pools; and (2) freshwater vernal pools. The alkali vernal pools were located in soils classified as "claypan" and the others in soils classified as "hardpan." (Holland and Hollander 2007, Fig. 8; Rains et al. 2008). These two types of vernal pools appear similar on the landscape when in their spring splendor, but differ with respect to soils, hydrology, and plant species.

These were the most abundant vernal pools under natural conditions. However, vernal pools also formed on other types of soils and geologic settings in the Valley Floor. Vernal pools, for example, were present on clay-rich soils on alluvial fans of the eastern Central Valley that were not alkaline with deep aquifers, as well as on lahars (mudflows of pyroclastic materials), tuff, and bedrock. (Rains et al. 2008, p. 360; Hobson and Dahlgren 1998).

3.3.4.1 Freshwater Vernal Pools

Hardpan soils are high permeability, coarse-grained igneous surface soils underlain by a low-permeability clay-rich argillic horizon and a silica- and iron-cemented Duripan. These soils were widespread in the Valley Floor. See, e.g., Strahorn et al. 1911, pp. 50-51; Lapham et al. 1909,[154] pp. 46-47; Sweet et al 1909,[155] pp. 45-48; Nelson et al. 1918; Holmes et al. 1915.

Vernal pools that form on hardpan soils are integrated surface water and perched groundwater systems due to the high permeability of the upper soil horizon and low permeability of the lower layer. These are sometimes called "perched-aquifer type" vernal pools as they depend on groundwater inflows between storms to maintain a nearly constant pool level. Others have called them "flow through" vernal pools as groundwater enters on one side and leaves from another. An impermeable layer forms a regional-scale perched aquifer that controls hydrology.

[151] Jones and Stokes, 1990. Sacramento County Vernal Pools: Their Distribution, Classification, Ecology, and Management, Prepared for the County of Sacramento, Planning and Community Department, Sacramento, CA.

[152] Holstein, G., 1984. A Classification of California Vernal Pools, In: Jain, S. and Moyle, P. (Eds.), Vernal Pools and Intermittent Streams, Institute of Ecology, Publication 28, University of California, Davis.

[153] Holland, R.F., 1986. Preliminary Descriptions of the Terrestrial Natural Communities of California, California Department of Fish and Game, Sacramento, CA.

[154] Lapham, M.H, Sweet, A.T., Strahorn, A.T., and Holmes, L. C., Soil Survey of the Colusa Area, California, U. S. Department of Agriculture, Bureau of Soils, 1909.

[155] Sweet, A.T., Warner, J.F., and Holmes, L.C., Soil Survey of the Modesto-Turlock Area with a Brief Report on a Reconnaissance Soil Survey of the Region East of the Area, California, U.S. Department of Agriculture, Bureau of Soils, 1909

(Williamson et al. 2005,[156] p. 43; Rains et al. 2006). They predominately contain freshwater as the upper permeable layer allows for continuous flow through. These pools respond slowly to precipitation, which infiltrates and perches on the impermeable layer. Water does not fill the vernal pool until this overlying permeable layer is saturated.

For most of the wet season, direct precipitation, swale flow, and groundwater discharge provide freshwater to the vernal pool, replacing any losses by evaporation or evapotranspiration. When precipitation and swale flow cease, groundwater continues to flow into the pool until upland vegetation exhausts the perched aquifer. The uplands and swales are characterized by moderate coverage with grasses while the vernal pools are characterized by dense coverage with primarily native annual grasses, forbs, and algae. (Rains et al. 2008, p. 359). These pools may be either long- or short-inundated, depending upon their size.

Long-inundated pools are characterized by high relative cover and abundance of perennial species due to deep pool bottoms that retain moisture for longer periods. Long-inundated pools are populated by extremely flood-tolerant taxa such as *Lasthenia glaberrima* and *Eleocharis macrostachya*. (Barbour et al. 2007, pp. 20-21, 48). They occurred in greatest abundance near the foothills and diminish toward the axial depression of the basin. (Nikiforoff 1941, pp. 8, 41).

Short-inundated pools are shallow and flashy. Communities in these short-inundated pools are in the order *Downingia lasthenia*. They always contain freshwater. (Barbour et al. 2007, p. 26). They occur in the eastern Valley Floor in two regions mapped by Keeler-Wolf et al. (1998, pp. 28-29, 67-68) in the northeastern Sacramento Valley region and in the southern Sierra foothill region on the eastern side of the San Joaquin Valley, atop basalt flows in the foothills. They include volcanic mudflow pools, typically small ((100 m^2) and irregularly spaced, which do not form large pool complexes. They typically have shallow soils (30 cm) and "flashy hydrology," filling and refilling many times over the wet season. (Keeler-Wolf et al. 1998, p. 29). These freshwater pools occur on various landforms (basin, low, and high terraces and soil types (hardpan, claypan)). (Barbour et al. 2007, pp. 20-21, 26.). They also occur in areas dominated by small pools, at a distance from the foothills, along the axis of the Valley. (Nikiforoff 1941, pp. 8, 41).

3.3.4.2 Alkaline Vernal Pools

Claypan soils, also called "alkaline soils," are clay-rich, fine-grained, and moderately to strongly saline and sodic throughout their profile. Silt and clay suspended in floodwaters under natural conditions settled out in the flood basins. Annual flooding washed the salts away and prevented the formation of ephemeral vernal pools. When flooding ceased during the last half of the 20th century, many of these claypan bottoms became alkaline vernal pools. (Edminster 2002, pp. 112-114, 117). They formed in arid and semi-arid regions in low places where evaporation was more rapid than drainage.

[156] Williamson, Robert J., Graham E. Fogg, Marc Cable Rains, and Thomas H. Harter, Hydrology of Vernal Pools at Three Sites, Southern Sacramento Valley, Final Report for Project: F 2001 IR 20, Developing a Floristic Statewide Vernal Pool Classification, and a Functional Model of Pool Hydrology and Water Quality, Report FHWA/CA/IR-2004/08, State of California Department of Transportation, April 22, 2005, Available at: http://www.vernalpools.org/documents/Hydrology%20Three%20Sites%202005%20Williamson.pdf.

Vernal pools were recorded in these alkaline soils in early reconnaissance soil surveys and other early studies. See, e.g., Mann et al. 1911, pp. 45-53. However, it is unclear whether the alkaline vernal pools were present under natural conditions. Some have suggested that they formed as a result of eliminating flooding in the pristine floodplain. (Edminster 2002, pp. 145-146, 159). Under natural conditions, the floodplain was crisscrossed with channels and pock-marked with washouts, potholes, open ponds, steep-banked cross channels, sloughs, and shallow scars of old stream beds. In times of yearly floods, these various depressions not directly connected to running streams remained filled with water through summer and fall, leaving behind freshwater marsh community. These are likely the alkaline vernal pools of today. (Edminster 2002, pp. 176, 184).

Thus, the so-called "alkaline vernal pools" may not have existed under natural conditions, but rather, may have been seasonal or permanent wetland. Therefore, we classified all vernal pools within the floodplain as seasonal wetland. It is likely that the alkaline vernal pool outside of the floodplain was actually also frequently flooded and the mapped boundary of the floodplain is an average, which varied depending upon the wetness of the year.

In the Sacramento Valley, alkaline areas noted in soil surveys were mostly on the west side of the Valley, about midway between the Sacramento River and the western foothills, from Glenn County southward and over both sides of the San Joaquin Valley, in low-lying areas. (Fortier et al. 1909, p. 11; Hoover 1935, p. 43).

In the Sacramento Valley, there were about 0.5 million acres of alkali lands, about 90% of which occurred west of the Sacramento River in vernal pool areas. (Holmes et al. 1915, p. 145). These occurred as generally continuous bodies across the entire southern half of the Colusa area, south and southeast of Willows, an area known as the "Colusa Plains." These were the so-called "goose lands", the ancestral wintering ground for hundreds of thousands of Canada Geese, which, prior to agriculture, grazed exclusively on the tender, alkali-stunted grasses. (Silveira 2000, p. 11).

In describing the geomorphology of the Colusa Basin, Bryan noted, "The upper part of Colusa Basin...on the west side it has many indentations due to the irregularities of the low plains. The small streams that have built up the low plains in this region have formed channel ridges of light loamy soil which extend out across the clay and adobe soils of the basin. Along this boundary line ground water escapes to the surface and evaporates, producing alkaline conditions in the soil. On account of the alkali the western part of Colusa Basin is marked by large areas of salt grass and low land covered with mounds. This part is known as the "goose lands"...." (Bryan 1923, p. 40). See also Whipple et al. 2012, pp. 301-306.

The 1915 Sacramento Valley soil survey noted that “[n]early all the soils affected by alkali on the west side of the valley lie east of the Southern Pacific railroad and correspond closely in position to the poorly drained areas discussed in the chapter on drainage.” (Holmes et al. 1915, p. 145). This area contained many small lakes or ponds that filled with flood waters from creeks and sloughs in the winter and spring or direct runoff from adjacent higher lands, but which dried out in the summer. (Lapham et al. 1909, pp. 42, 45). See also Mann et al. 1911, pp. 51-52.

The chapter on drainage in the 1915 Sacramento Valley soil survey notes, “There are extensive areas of nearly flat land along the western margins of the great basins lying west of the Sacramento River, which represent the lower and flatter eastward extensions of the valley plain soils where they merge with the basin soils of the valley trough. This territory ranges from one mile to several miles in width, has a nearly flat surface, and is often dotted with slight depressions, which receive the run-off and seepage waters from lands lying to the west. This results in numbers of small intermittent lakes, the water being removed by evaporation or slow percolation. In addition to the lack of drainage in this locality there is sometimes a high water table and a large accumulation of alkali." (Holmes et al. 1915, p. 143; Lapham et al 1909, p. 45).

In the lower San Joaquin Valley, within our study area, the 1918 soil survey reported, "The areas that are affected by alkali are confined almost wholly to the flatter slopes and to basins lying adjacent to and along the trough of the valley, with some small areas in the bottoms of the larger streams and occasional bodies on some of the smaller alluvial fans. On the east side of the valley the alkali soils occur in a belt of irregular width and outline and are confined principally to the region between the San Joaquin River and the Southern Pacific Railway from just south of Stockton to the southern boundary of the area....On the west side of the valley the alkali occurs in a more irregular and narrower belt, through in places, notably south of Dos Palos, there are very extensive areas of alkali soils. The affected soils lie in the flat basin bordering the San Joaquin River, and on the lower slopes of adjoining alluvial fans. Some small areas occur in the flood plains of some of the smaller streams entering the valley from the west, with occasional areas on the alluvial fans formed by these streams." (Nelson et al. 1918, p. 154).

These alkaline areas had poor drainage, high water tables, and alkaline soils under natural conditions, especially on the western side of the Valley Floor. (Silveira 2000, p. 11). Vernal pools that formed on these claypan soils are perched surface-water systems. These are sometimes called surface-ponding vernal pools as they do not depend on groundwater to maintain pool levels. Precipitation perches on the low-permeability surface soils and flows overland to the vernal pools in topographic lower positions. Toward the end of the wet season, there is little inflow to the lower area from direct precipitation and overland flow and little outflow beyond evapotranspiration. Thus, the remaining surface water evapoconcentrates and salt content increases. (Rains et al. 2008, p. 358).

This formed alkaline vernal pools and associated alkali meadows and alkali grasslands, mostly in flat areas at elevations typically (30 m). These present as large pools that may resemble small alkali playas with whitish salts visible at the surface of the pool areas following drying. Inundation periods and moisture periods are typically longer (until late May and June) than other pool types. Thus, plants in these pools develop later than in freshwater pools. The wildflower parade begins in February and runs through early summer. In the summer, the vast fields of wildflowers are replaced by hardpacked, mostly bare cracked ground dominated by alkali meadow halophytes such as tuctoria grasses which occur in patterns from single-species patches to complex combinations, interspersed with grasses. (Silveira 2000, pp. 12 -14). These are often inconspicuous on dry ground and can be mistaken for a layer of windblown dust by an untrained eye. (Cunningham 2010, p. 128).

The vegetation in these pools differs from freshwater pools. The alkali flats frequently supported good stands of saltgrass and alkali sacaton as well as other alkali-tolerant plants. (Burcham 1957, p. 91). Halophytes included: *Distichlis spicata* and *Plagiobothrys leptocladus*. Many of these halophytes are perennials, indicating a longer period of inundation, a shorter dry phase, and a shallower groundwater table. (Barbour et al. 2007, p. 36, Table 2.6, p. 52; Keeler-Wolf et al. 1998, p. 49; Silveira 2000, pp. 11-12).

The alkaline vernal pools were reportedly disconnected hydrologically due to low permeability soil, and thus lost water mostly through evaporation. (Barbour et al. 2007, p. 36). These pools correspond with those mapped in the Solano-Colusa Region and San Joaquin Valley Vernal Pool Region by others. (Keeler-Wolf et al. 1998, pp. 49, 64). The conceptual model used for these pools is the "mounding vernal pool model." In this model, the vernal pool itself is the source of water to the watershed. The watershed provides water to the pool predominantly as a result of surface water processes. The pool stores the water, but constantly loses water due to vertical and horizontal seepage. (Williamson et al. 2005, p. 40).

3.3.5 VERNAL POOL ACREAGE

Vernal pools were a major component of the native grasslands and thus a major water user under natural conditions. Thus, it is important to obtain a reliable estimate of their areal extent. This section lays out what is currently known about their areal extent and makes a preliminary estimate of their original land area. However, this is just a very preliminary first step. Substantial additional work is required to refine vernal pool habitat area estimates and their water use. The vernal pool area and water use are major sources of uncertainty in our natural flow water balance.

3.3.5.1 Estimate of Vernal Pool Area Under Natural Conditions

Under natural conditions, others (**Figure 11**) have estimated that vernal pools were distributed over about 4 to 7 million acres, or more than one-third to one-half of the entire Central Valley. (Holland 1978, p. 5; Holland 1998, p. 14; Holland and Hollander 2007, Fig. 8). Most of this area occupies lands classified by others as "grasslands." Our analysis, presented below, indicates that there were at least 1.9 million acres of vernal pool habitat in the Valley Floor outside of the floodplain, comprising 23% of its area. The work of others suggests our estimate is low.

Numerous studies have correlated the distribution of vernal pools as well as vernal pool endemic species with specific geologic surfaces and their associated soils. (Holland and Dains 1990;[157] Smith and Verrill 1998; Metz 2001;[158] Helm and Vollmar 2002;[159] Dittes and Guardino 2002; Holland and Hollander 2007; Vollmar et al. 2013). However, others have noted that vernal pool topography can be absent in classical vernal pool soil complexes (e.g., the hardpans) and present in regions without these classic soils. (Nikiforoff 1941, p. 6).

[157] Holland, R.F. and Dains, V.I., 1990. The Edaphic Factor in Vernal Pool Vegetation, pp. 31-48 In: Ikeda and Schlising (Eds), Vernal Pool Plants. Their Habitat and Biology. Studies from the Herbarium, Number 8, California State University, Chico, CA.

[158] Metz, J., 2001. Correlating Vernal Pool Distribution Patterns and Geologic Formations to Inform Conservation Planning in East Merced County. Master's Thesis. University of California, Berkeley, CA.

[159] Helm, B. and Vollmar, J.E., 2002. Chapter 4: Vernal Pool Large Branchiopods, pp. 151-190 In: Vollmar, J.E. (Ed.). Wildlife and Rare Plant Ecology of Eastern Merced County's Vernal Pool Grasslands. Vollmar Consulting, Berkeley, CA.

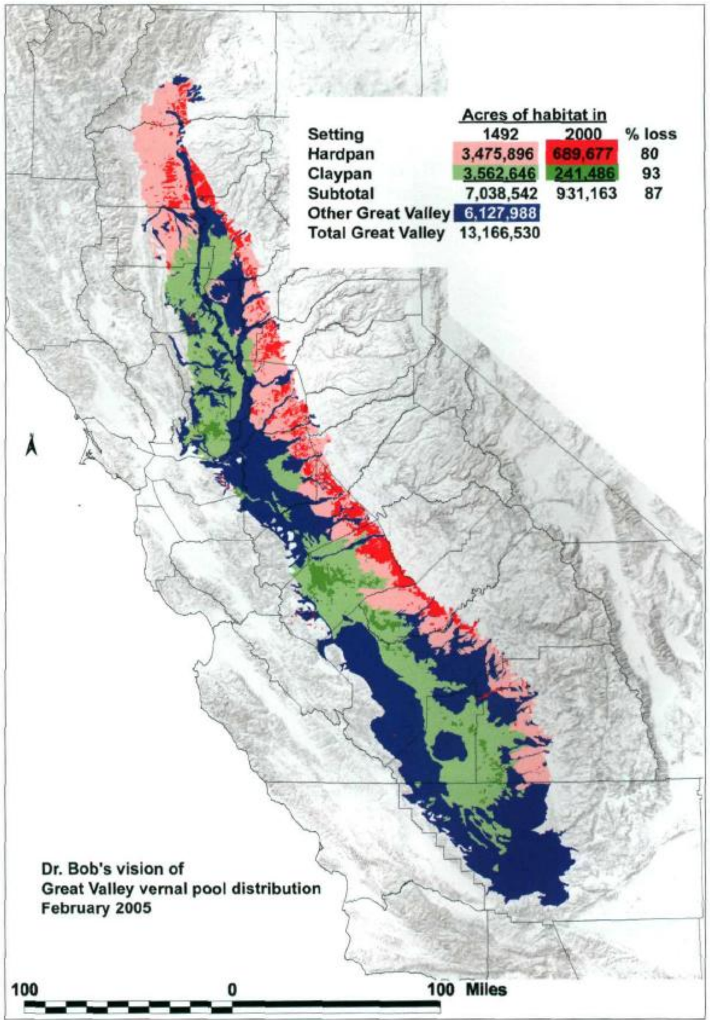

Figure 11. Vernal Pool Habitat Under Natural Conditions

Source: Holland and Hollander 2007

We estimated the pre-development acreage and distribution of vernal pools for the Valley Floor from descriptions in soil surveys conducted early in the 20th century, a time when some of the original topography and vegetation were still present. Others have noted that, "Although alteration of the extensive mound-depression landscapes in the valley was already underway, much of the valley still retained natural vegetation, microtopography, and hydrology, or had just recently undergone alteration." (Smith and Verrill 1998, p. 21).

We based our analysis on soil surveys for the Sacramento and San Joaquin Valley. These covered most of the Valley Floor. (Holmes et al. 1915; Nelson et al. 1918). We supplemented these analyses by observations from smaller subareas: Marysville (Strahorn et al., 1911); Colusa (Lapham et al. 1909); Modesto-Turlock (Sweet et al. 1909); Red Bluff (Holmes and Eckmann 1912); Woodland (Mann et al. 1911); Redding (Lapham and Holmes 1908); Sacramento (Lapham et al. 1904); and Chico (Watson et al. 1929). However, these smaller subarea surveys were not used to determine vernal pool areas due to limited resources, but rather, only to confirm the presence of vernal pool habitat identified in the region-wide surveys and to better understand the nature of the habitat, based on descriptions in these other surveys. Quotes from these smaller-area surveys are included in the footnotes.

We based our classifications on identification of hog wallow habitat specifically or topographic descriptions of this habitat, such as “basinlike depressions,” “hummocky areas,” “boggy areas,” “undulating or rolling valley plains,” “hog-wallow surface,” “hardpan at shallow depths.” (Smith and Verrill 1998). We did not classify any land as vernal pool if it only had vernal pool soil types (hardpan or claypan at depth) without an appropriate topographical notation.

These soil surveys identified many potential vernal pool soils based on soil characteristics alone, e.g., hardpan or claypan beneath the surface. However, we did not classify these as vernal pool soils unless these soil characteristics were accompanied by topographic indicia of vernal pools, e.g., hummocky areas or hog wallow topography. As these surveys occurred long after many areas had been farmed, this would underestimate vernal pool acreage. Further, we note that vernal pool habitat may have occurred in areas that would not elicit topographic commentary even if present as those surveying the soils were not biologists nor were they trained to identify this habitat. Further, it is likely they used terms differently than currently used a century later. The term "hog wallow" for example, appears to have been narrowly used for the button-like formations in Figures 6 and 10.[160]

We georeferenced the soil survey maps by latitude and longitude and digitized the soil types we determined to have vernal pools based on reviewing detailed soil descriptions that included remarks on topography and frequently on native vegetation. We then clipped the results to our study area, removed any areas falling within the flood basin, and clipped what was left to grasslands and Küchler's (1977) tule marsh within Chico’s “other floodplain habitat.” All other grasslands and tule marsh within CSU Chico’s “other floodplain habitat” falling outside of the floodplain which are not vernal pool are assumed to be rainfed grassland. Further, we assumed all grasslands and tule marsh within the natural flood basin is seasonal wetland.

We confirmed our classifications by overlaying the resulting vernal pool soil classifications on current locations (Holland 1998; Holland and Hollander 2007, Fig. 8), pre-1850 locations mapped by others (Garone 2011, Map 2), and the recent SFEI work in the Delta (Whipple et al. 2012, Fig. 3.3). These comparison showed good general agreement within the limit of accuracy of the maps and the various classification systems. A detailed discussion of our comparison with an updated version of the Holland and Hollander 2007 work (Figure 11) is presented in Section 3.3.5.2. The results of our soil mapping work are shown in **Figure 12**.

160 See also photographs in "An Example of Soil Survey Data on Landforms that Contain Vernal Pools in Butte County, Available at: http://66.147.244.88/~aquallia/wp-content/uploads/2012/03/conlin.pdf.

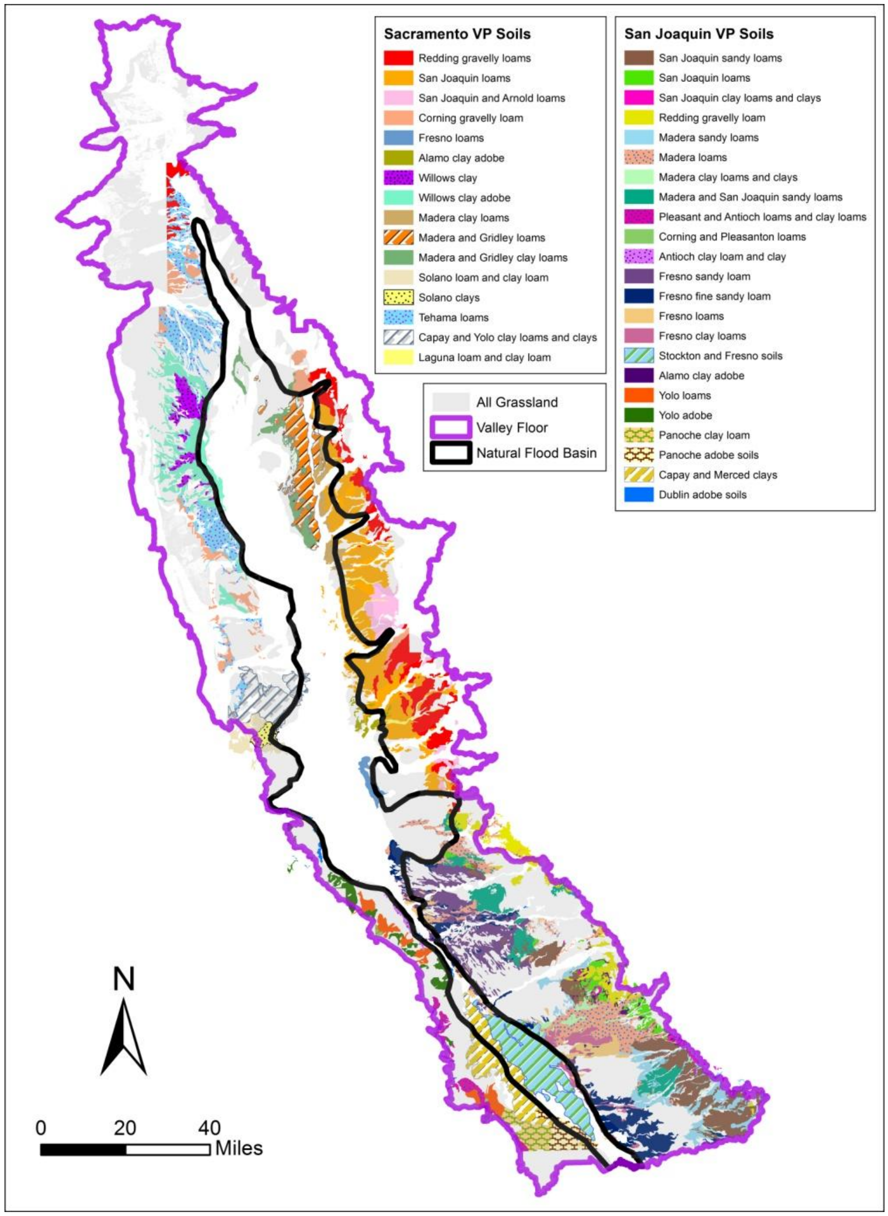

Figure 12. Vernal Pool Soil Types
Source: Holmes et al. 1915; Nelson et al. 1918

In the Sacramento Valley, vernal pools or indications of vernal pools were noted as occurring in the following soil types (Holmes et al 1915, pp. 45-126):

- Redding gravelly loams[161]

[161] The **Redding gravelly loams** are characterized at p. 45 as "the soils are periodically boggy through lack of underdrainage. A general tendency toward a "hog wallow" surface aids in producing this condition by arresting the run-off from inclosed (sic) minor depressions." p. 46 "In the more nearly level, extensive bodies of this type, there are local phases approaching a clay loam. These are often associated with small, poorly drained flats." **Redding loams (11,456 acres)**, which are extensive in the west-central portion of the Red Bluff area, are described as, "Its general surface, while rolling and marked by drainage depressions, has detailed features of topography making it, during the rainy season, a poorly-drained soil. Numerous hummocks or "hog wallows" confine much surface water or permit it to escape slowly by meandering courses, little water escaping through the subsurface layers." (Holmes and Eckmann 1912, p. 22). Redding loams (14,272 acres), in the Redding area, are described as, "The surface is frequently marked by the presence of hog wallows and small drainage depressions occupied by pools of water or by areas of check and puddled soils." (Lapham and Holmes 1908, p. 19). In the Chico area, "The **Redding soils** are sloping or rolling and hilly and have a hummocky or hog-wallow surface." (Watson et al. 1929, p. 12). **Redding clay loam** (512 acres) "occupies low mounds or terraces, slightly above the level of the adjoining recent-alluvial soils. It is level or gently sloping, with a low,

- San Joaquin loams[162]
- San Joaquin and Arnold loams[163]
- Corning gravelly loam[164]
- Fresno loams[165]

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hummocky, or hog-wallow surface configuration." **Redding clay loam, gravelly phase** (1,314 acres) "has a more pronounced hummocky surface than typical Redding clay loam." (Watson et al. 1929, p. 23).

[162] The **San Joaquin loams** are characterized at p. 47 as "...the hardpan and the usual development of "hog-wallow" mounds with inclosed (sic) depressions retard subsurface drainage and run-off, and boggy conditions during the rainy season are the rule." p. 48, "The soil is usually heavier, sometimes with adobe tendencies, in the many low/undrained depressions which characterized the surface...the general tendency of this type to become water-logged during the wet season makes it difficult to handle..." p. 50, "Nearly all the surface of the types is marked by what are locally called "hog wallows," which are rather striking small mounds a few inches to 2 to 3 feet or more in height with intervening depressions. These are rather uniformly distributed over both flats and slopes. They are usually from 10 to 50 feet in diameter, closely set, and include numerous inclosed (sic) depressions...." See also Lapham et al. (1909) for Colusa Area: (1) p. 24 for San Joaquin gravelly loan, "It is frequently dissected by small intermittent streams and marked by small bluffs, "hog wallow" mounds, or depressions a few yards in diameter." (2) p. 25 for San Joaquin fine sandy loam, "In drainage features it is similar to the more elevated San Joaquin gravelly loam...marked by slight unevenness of surface and by puddled depressions usually but a few yards in extent." See also Strahorn et al. (1909) for the Marysville Area. "The **San Joaquin Fine Sandy Loam** consists of from 30 to 36 inches of a reddish-brown fine sandy loam, underlain either by a darker fine sandy loam, by a red loam, or by a red or mottled hardpan [classical vernal pool soil]...This area has an uneven surface marked by low knolls, ridges, and depression...To secure the greatest return the larger part of the land will require leveling to fill the numerous depressions... ." (Strahorn et al. 1911, p. 32). "**The San Joaquin sandy loam** consists of from 18 inches to 6 feet or more of a red sticky sandy loam...Where the sandy loam is less than 6 feet in depth it is underlain by a tenacious red clay loam, seldom more than a foot in thickness, and in turn underlain by a dense cemented red hardpan [classical vernal pool soil]...In the southern portion of this area the "hogwallow" formation, characteristic of this class of soils, is well developed. To the north this peculiarity becomes less evident and the surface irregularities consist of extensive ridges or occasional knolls." (Strahorn et al. 1911, p. 33). "**The San Joaquin loam** consists of from 16 inches to 3 feet of dark-red sticky loam of compact structure showing adobe tendencies in depressions or wherever the soil is slightly heavier than normal. This surface soil is underlain by a very heavy compact red clay loam or occasionally by a red clay to depths ranging from 3 to 6 feet." [This is classic vernal pool soil.]...On account of the heavy subsoil and hardpan there is absolutely no drainage through the soil, and in the rainy season the area occupied by this soil is almost a bog." (Strahorn et al. 1911, pp. 34-35). In the Chico area, "The soils of the San Joaquin series...occupy the flat or gently rolling valley plains and have a hummocky or hog-wallow configuration." See Plate I.B, "Characteristic hummocky surface and small ponded depressions on San Joaquin sandy loam." (Watson et al. 1929, pp. 11-12). The San Joaquin sandy loam (only one small area, 384 acres) occurs in the Chico area. "It is slightly rolling with a hummocky surface (pl. 1, B), the hummocks being 1 or 2 feet high, from 5 to 12 feet in diameter, and occupying one-half of the surface of the soil. In the depressions between the mounds the soil is in places darker or grayer in color and heavier in texture than typical. Because of the imperviousness of the hardpan, the subdrainage is very poor, and during periods of rainfall the soil becomes saturated and boggy...Blasting is usually resorted to in planting fruit trees if the hardpan is less than 3 feet from the surface." (Watson et al. 1929, p. 22).

[163] The **San Joaquin and Arnold loams** are characterized at p. 53, "The surface is frequently marked by "hog-wallow" mounds and depressions, and there are local poorly drained areas."

[164] The **Corning gravelly loams** are characterized at p. 55, "The surface is usually sharply rolling, eroded by small streams, and quite often has a pronounced hog-wallow configuration...The Corning gravelly loam...has good drainage as a rule, but many small depressions collect water which at times does not readily escape through subsurface layers." **Corning gravelly loam** (18,752 acres) in the Red Bluff area is described as, "The surface is usually sharply rolling, eroded by small streams, and marked by a hog-wallow surface...has a general surface favoring good drainage, but the many small depressions collect much water which does not readily escape through the dense subsurface layers." (Holmes and Eckmann 1912, p. 28). **Corning loam (9,280 acres)** in the Red Bluff area is described as, "...a mild tendence to clod and puddle is noted...Its surface is gently rolling to level, with occasional small cuts or washes and a few local depressions. A slight tendency to form hogwallows sometimes exists." (Holmes and Eckmann 1912, pp. 25-26). In the Chico area, **Corning gravelly sandy loam**, "This soil occupies knolls or low hills or terraces a few feet above the general level of the valley floor. It is gently sloping, with evidences of some erosion. Stream ways are slightly intrenched (sic). The land has a subdued, hummocky or hog-wallow surface with undrained intervening depressions...The shallow phase of most of the soil in this area has a very pronounced hummocky surface. Drainage is very poor, as most of the depressions between the mounds have no natural outlet and as the underlying beds are mostly impervious." (Watson et al. 1929, p. 21).

[165] **Fresno loams** are characterized at p.65 as "Numerous small hummocks or "hog-wallows" characterize the surface, and the drainage is predominantly poor, owing to the slight slope and high water table, which cause the group to be flooded over a considerable part of its extent." In the Modesto-Turlock area, the surface where **Fresno sandy loam** (111,616 acres) occurs "...is hummocky or marked by numerous depressions or "hog wallows," the latter being almost certain indications of shallow soil and indurated hardpan." (Sweet et al. 1909, p. 20). For **Fresno fine sandy loam** (26,496 acres), "At a depth of 15 inches to 5 feet or more it is underlain by the same silty subsoil found under the sandy loam, but the hardpan seems to be more firmly cemented and the surface more generally uneven than that of the sandy loam, often being marked by the "hog-wallow" depressions."

- Alamo clay adobe[166]
- Willows clay[167]
- Willows clay adobe[168]
- Madera clay loams[169]
- Madera and Gridley loams[170]
- Madera and Gridley clay loams[171]
- Solano loam and clay loam[172]
- Solano clays[173]
- Tehama loams[174]

(Sweet et al. 1909, p. 21). **Fresno loam** (15,552 acres) "...is characterized by a hummocky, uneven surface, although some of the areas are comparatively level, and by the frequent occurrence of barren white spots on the surface [alkali]...its uneven surface, puddling tendencies, and the comparatively high percentage of alkali" (Smith et al. 1909, pp. 23-24).

166 **Alamo clay adobes** are characterized at p. 68 as "occupies flat, poorly-drained depressions or low position in the general region where the upland-plain soils merge with the lower lying basin or lowland types. In many instances it receives considerable run-off wash from minor streams." "**Alamo clay loam adobe** is a heavy clay loam possessing marked adobe characteristics...The average depth of this surface stratum is abut 30 inches, though it may vary in thickness from 1 foot to 6 feet. It is invariably underlain by the dense red hardpan common to this series." [classic vernal pool soil]...When wet, it is practically a bog...The surface is on the whole level, but occasional shallow depression show a tendency toward formation of hogwallow. Drainage conditions are poor, and much of the type is subject to overflow when the river levees fail." (Strahorn et al. 1911, pp. 35-36). In the Fresno area, alamo clay adobe "...is marked by hog wallows, but the mounds are not so prominent as on the San Joaquin series." (Strahorn et al. 1914, p. 39).

167 **Willow clay** is characterized at p. 81, "The surface is dotted by shallow depressions, the sites of intermittent lakes following the rainy season. Waterlogged soils and subsoils may occur for considerable periods...Practically the entire type contains injurious accumulations of alkali...Salt grass and similar plants usually accompanying alkali conditions constitute the vegetation." In the Woodland area soil survey, "The impervious character of the soil prevents the downward movement of water into the subsoil and frequently produces a water-logged condition during wet weather...Deficient drainage and presence of excessive quantities of alkali are characteristics of the larger bodies. The soil type occurs principally in the low depressed areas of the plain and receives the overflow and seepage water from higher elevations, which collects and slowly drains away or evaporates. The existing vegetation consists of alkali weeds and grass." (Mann et al. 1911, p. 45). This soil type likely was alkaline vernal pool.

168 **Willow clay adobe** is characterized at p. 82, "This type occupies areas in local draws or depressions in the valley plain...The general topography is slightly undulating or more frequently quite level. The surface is often flat or depressed and in such places drainage is deficient." In the Woodland area soil survey, "The surface is often flat or depressed, and in such places the drainage is deficient. The general topography is slightly undulating or, more frequently, nearly flat. Alkali in dangerous quantities is quite often present in the soil and subsoil...The vegetation consists of a scattered growth of cottonwoods or oaks near the streams and of alkali weeds and wild grasses. (Mann et al. 1911, p. 46). This soil type likely was alkaline vernal pool.

169 **Madera clay loams** are characterized at p. 86, ""Hog-wallow" conditions often prevail and smaller areas of inclosed (sic) San Joaquin loam are recognized. Much of the group is overflowed during the rainy season, or forms a collecting place for the run-off from nearby areas."

170 **Madera and Gridley loams** are characterized at p. 87, "...the surface is slightly uneven, being marked by numerous shallow depressions without drainage outlets...the main body of this group is without any natural surface drainage. The movement of water is largely into the subsoil, and this is often hindered by the hardpan. As a consequence, the plain is dotted during the rainy season with numerous shallow bodies of water." "The **Gridley loam** consists of 2 to 6 feet of light reddish-brown loam, underlain by a heavy, sticky, dark reddish brown clay loam [classic vernal pool soil]...this type appears as an extensive level plain. The surface is, however, slightly uneven, consisting of numerous shallow depressions without drainage outlets...The movement of water through the subsoil is usually prevented by the hardpan. As a consequence the plain is dotted by numerous shallow bodies of water during the rainy season...Under the old system of dry farming grain the water retaining depressions did not seriously interfere with cultivation. Under the new system -- intensive agriculture -- these depressions are a serious inconvenience as the growing of fruits and alfalfa in these places is impracticable" (Strahorrn et al. 1911, pp. 41-42).

171 **Madera and Gridley clay loams (undifferentiated)** are characterized at p. 89, "...the depressed bodies are soggy...A large part of the area...is saturated throughout the rainy season...A hog-wallow surface characterizes the large body north of Biggs, except where recent stream action modifies the surface... ."

172 **Solano loam and clay loams** are characterized at p. 99, "A rather marked tendency toward a "hog wallow" surface is apparent over much of the group, being in parts of the clay loam very pronounced."

173 **Solano clays** are characterized at p. 100, "The soils of this group occupy a flat, poorly drained region containing numerous intermittent lakes..The surface is not subject to much diversification other than that afforded by hog wallows and drainage ways."

- Capay and Yolo clay loams and clays[175]
- Laguna loam and clay loam[176]
- Dunnigan clay[177]
- Salinas grey adobe[178]
- Tuscan stony clay loam[179]
- Tuscan gravelly clay loam[180]
- Anita clay loam[181]

Vernal pool soil types in the Sacramento Basin (outside of the floodplain) total about 0.7 million acres. There were an additional 0.3 million acres within the floodplain. Thus, there was a total of about 1 million acres of vernal pool soils in the Sacramento Basin under natural

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[174] **Tehama loams** are characterized at p. 103, "Over much of the surface of this phase there are small minor depressions having no outlet, oftentimes giving the appearance of a "hog-wallow" topography… ." **Tehema silt loams** (29,888 acres**)** in the Red Bluff area are described as, "Over almost the entire surface occur small minor depressions without outlet, oftentimes giving the appearance of a hog-wallow topography. With a heavy burden of surface water completely saturating the soil and filling the small depressions, this condition is still further aggravated by a puddling tendency of the soil and the impervious nature of the subsoil." (Holmes and Eckmann 1912, p. 31). **Tehema clay** (1,536 acres) in the Red Bluff area is described as, "...is always poorly drained during the rainy season, irregularly defined, and of small importance." (Holmes and Eckmann 1912, p. 32).

[175] **Capay and Yolo clay loams and clays (undifferentiated)** are characterized at p. 118, "A "hog-wallow" surface is encountered in some of the alkali areas...The native vegetation consists of grasses, with some tree or shrub growth along a few drainage ways." In the Woodland area, **Yolo clay loam** (27,520 acres) is described at p. 30, "The surface is flat or undulating..." **Yolo silty loam** (13,504 acres) is described as, "The surface is uniformly flat but slightly undulating." (Mann et al. 1911, p. 30).

[176] **Laguna loam and clay loams** are characterized at p. 126, "A tendency toward hog-wallow features of surface is often found in the areas removed from recent stream activities."

[177] The **Dunnigan clay** (8,576 acres) was not mapped as it was not identified as vernal pool habitat in the Sacramento Basin soil survey. In the Woodland area, Mann et al. (1911) report at p. 19, "The **Dunnigan clay** is known in some sections as "hog-wallow" land..limited to a number of long, narrow areas or smaller bodies near the west side of the Yolo and Colusa basins. It occupies depressions or low, flat, poorly drained areas. The surface is generally slightly uneven, owing to the presence of "hog-wallow" depressions. It occupies a position between the Yolo and Colusa basins and the upland, and is subject to overflow during seasons of high water...Alkali is always present..."

[178] The **Salinas gray adobe** (12,672 acres) was not mapped as it was not identified as vernal pool habitat in the Sacramento Basin soil survey. In the Sacramento area, Lapham et al. (1904) report at pp. 1070-1071, "They occupy the slopes of rolling, domelike ridges, or flat-topped table-lands...The higher slopes are sometimes marked by occasional springs and marshy or boggy spots. The soil is extremely sticky when wet, and is capable of absorbing large quantities of water. The soil of both the upper and lower slopes is likely to become soft and boggy during rainy periods. …The valley phase...occurs as numerous irregular bodies throughout the valley plain, generally occupying local drainage depressions or sinks."

[179] The **Tuscan stony clay loam** (20,288 acres) was not mapped as it was not identified as vernal pool habitat in the Sacramento Basin soil survey. In the Chico area, "It...appears as a broad plain with its surface covered with hog wallows, or low, broad mounds a foot or more in height with intervening depressions and shallow channels...Surface drainage is only fair, as many of the depressions do not have a natural outlet. Subdrainage is entirely lacking." (Watson et al. 1929, p. 24).

[180] The **Tuscan gravelly clay loam** (3,136 acres) was not mapped as it was not identified as vernal pool habitat in the Sacramento Basin soil survey. In the Chico area, "It occupies broad, gently sloping alluvial fans, generally a foot or more lower than the areas of Tuscan stony clay loam. The hummocky, uneven surface configuration is not so pronounced as in the stony clay loam. However, numerous shallow channels and depressions occur between slightly higher mounds." (Watson et al. 1929, p. 25).

[181] The **Anita clay loam** (4,672 acres) was not mapped as it was not identified as vernal pool habitat in the Sacramento Basin soil survey. Most of this soil type was cultivated at the time of the 1929 survey so topographic descriptions are not reliable indicators of natural habitat. "The soil occupies level or gently rolling alluvial-fan slopes having a smooth surface or cut by a few stream channels. Surface drainage is poor in many places..." It is likely vernal pool habitat due to the description of the "redish phase" (5,568 acres) which was used for pasture, "Areas are level, with a surface that is marked by hog wallow, shallow channels, and depressions between mounds a foot or more high and from 10 to 20 feet broad. In the depressions the soil is commonly heavier in texture and browner in color than that of typical areas, consisting of grayish-brown, plastic, sticky clay. Included within the areas of this soil as mapped are many small, shallow, undifferentiated areas of Anita clay adobe...Surface drainage is rather deficient, and many of the depressions are undrained...The natural covering was grasses and short weeds." (Watson et al. 1929, pp. 25-26).

conditions or about half of the 2.1 million acres mapped as grasslands by CSU Chico (2003) in the Sacramento Basin (Table 4).

We prepared a similar analysis of the San Joaquin Valley. However, this soil survey is more difficult to interpret as it rarely mentions native vegetation, perhaps due to extensive agricultural development at the time of the survey. (Nelson et al. 1918, pp. 16-29). The identification of venal pool habitat thus usually relied on topographic descriptions, such as “basinlike depressions,” “hummocky areas,” “boggy areas”, “undulating or rolling valley plains”, “hog-wallow surface”, “hardpan at shallow depths,” etc. (Nelson et al 1918). This would underestimate vernal pools as these classic topographic features would have been leveled in many areas to facilitate farming. (Smith and Verrill 1998, pp. 21-22). Nikiforoff (1941, p. 7) reported, "A thorough leveling of the surface is a common practice of preparing the hog-wallow land for irrigation." The following soil types were reported to have vernal pool topography, in agreement with many of Nikiforoff’s (1941, p. 6) classifications:

- San Joaquin series[182]
- San Joaquin sandy loams[183]
- San Joaquin loams[184]
- San Joaquin clay loams and clays[185]
- Redding gravely loams[186]

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[182] **San Joaquin Series** is characterized at p. 60 as occupying, “sloping to undulating or rolling valley plants, usually intermediate in elevation between the foothills or mountains…and the lower lying, more nearly level recent-alluvial soils….The general topography favors good surface drainage, but subsurface drainage is retarded by the hardpan, and the characteristic hog-wallow mounds with their associated depressions interfere with the run-off in places, so that boggy conditions occur in rainy seasons.”

[183] **San Joaquin sandy loams** are described at p. 61, “Surplus water accumulates above the hardpan in wet weather and causes the soil to become so boggy that travel is difficult except on well-developed roads.” p. 62, “The group as a whole…has a pronounced hog-wallow surface with the hardpan occurring at shallow depth in depressions…The surface over a large part has a generally level appearance, except for the hummocks and depressions. The slopes usually are sufficient to give good surface drainage, except in low spots where rain water collects and remains for long periods in wet weather…The soils of this group are extensively farmed, but owing to the uneven, hummocky surface and the shallow soil…” In the Sacramento area survey, "It extends from the lower level valley floor of the western margin of the area upward to the base of the foothills. The lower levels are frequently marked by the hog-wallow mounds, while the valley slopes in the vicinity of Fairoaks and Orangevale are quite rolling and hilly...Upon the level or slightly sloping valley plains, where the surface drainage is insufficient during heavy rains, the soil often becomes very soft and boggy, the impervious underlying hardpan allowing little or no percolation to lower depths."" (Lapham et al. 1904, pp. 1058-1059). In the Modesto-Turlock area, **San Joaquin sandy loam** (75,328 acres), "Over a large part of the area the surface is that of a comparatively level valley floor, except where pitted by small hog wallows or slightly larger shallow depressions...when wet it puddles easily and upon drying bakes very hard..." (Sweet et al. 1909, pp. 25-26). In the Fresno area, "Where the land has not been plowed and leveled for irrigation it is covered by low, rounded mounds ("hog wallows"), from 1 to 3 feet in height and from 20 to 50 feet in diameter. Plate II, figure 1, gives a very good idea of the appearance of the surface of this soil type." This figure is captioned: Fig. 1. -"Hog Wallows" on San Joaquin Sandy Loam. (A characteristic of the surface of soils of the San Joaquin series.) (Strahorn et al. 1914, p. 35).

[184] **San Joaquin loams** are described at p. 64, “The depth of soil and subsoil above the hardpan varies widely. The hardpan is exposed locally in depressions or on hummocks, but may lie more than 6 feet below the surface. It restricts subdrainage so that the soil becomes boggy and at times practically impassable…These soils have a gently undulating, sloping, or slightly rolling topography…considerable areas are strongly eroded, being more or less dissected by degrading channels and having a very hummocky surface. Numerous small depressions, occurring among the hummocks, are poorly drained in wet periods. Surplus rainfall collects in such places as small ponds, which remain until the water evaporates.”

[185] **San Joaquin clay loams and clays** are described at p. 67, “It occurs principally as small areas associated with the clay adobe, but also in minor depressions in the clay loam and gravelly clay loam areas. As a rule it is badly puddled …Drainage usually is well developed except for minor depressions in which surface water collects in wet weather. When saturated the adobe members retain moisture well, and these types can usually be distinguished at a considerable distance in the spring by their unusually heavy growth of grass and wild oats.” In the Fresno area, "The hog-wallow knolls are sometimes a sandy loam in texture, while the intervening depressions may contains a heavy silty loam, occasionally showing an adobe structure...In topography its is similar to the San Joaquin sandy loam, i.e., a sloping plain dotted with innumerable hog-wallow mounds." (Strahorn et al. 1914, pp.36-37).

- Madera sandy loams[187]
- Madera loams[188]
- Madera clay loams and clays[189]
- Madera and San Joaquin Sandy Loams, undifferentiated[190]
- Pleasanton and Antioch loams and clay loams, undifferentiated[191]
- Corning and Pleasanton loams, undifferentiated[192]
- Antioch clay loam and clay[193]
- Fresno sandy loam including brown phase[194]

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186 **Redding gravelly loams** are described at p. 56, "The general surface drainage is good, but the soils are periodically boggy because of the poor underdrainage. A general tendency toward a "hog-wallow" surface accentuates this condition by arresting the run-off from the enclosed minor depressions." p. 57, "The soil in small depressions frequently is water-logged during wet weather, giving it a puddle structure…In places the loam…is boggy and sticky when wet…", p. 58, discussion of Redding gravelly clay loam, "In low, slightly depressed spots among hog wallow, the soil has a grayish or dark-grayish color and is more or less puddle." A photograph of a hogwallow surface typical of the Redding series is shown on Figure 1 (following p. 80). The caption reads, "This plain is occupied mainly by soils of the Redding series. The illustration shows the general topography and the hogwallow surface typical of the series."

187 **Madera sandy loam** is described at pp. 70-71, "…the type occurs either as small, elevated, or slightly depressed areas among types of the San Joaquin series or as distinct bodies near areas of the Oakley and Madera sands, undifferentiated…The areas of this group of soils have gently undulating or rolling to nearly level topography. The western extensions are generally more uniform, but frequently become more uneven and hummocky as the eastern foothills are approached…Drainage is good in most places, but seepage and the accumulations of alkali occur locally in the level or slightly depressed areas." In the Fresno area, **Madera sandy loam** is described as, "The surface of this type is characterized by hog wallows, although they are not so prominently developed as on the San Joaquin sandy loam." (Strahorn et al. 1914, p. 42). **Madera fine sandy loam** is described as, "The type occupies portions of the gently sloping or nearly level valley plains of smooth to slightly undulating surface...Hog wallows occur in a few places, but are never very conspicuous." (Strahorn et al. 1914, p. 44).

188 It appears that only a small portion of this soil type was vernal pool based on descriptions such ason p. 72,"Locally, small, hummocky areas...," "In places the loam is marked by hummocks and depressions…," "Drainage usually is good except in local flats and in depressions between hummocks where the land becomes quite boggy in the rain seasons." In the Fresno area, Madera loams are described, "The surface is level to gently sloping and of smooth to occasionally hummocky configuration." (Strahorn et al. 1914, p. 45).

189 **Madera clay loams and clays** are described at p. 73, "In poorly drained areas the soil and subsoil are gray or dark gray and the hardpan is grayish, as in the Stockton soils. Such areas are generally heavy and badly puddled…The Madera clay is…usually sticky when wet and locally puddled when dry." At p. 74, "A few small hummocks…are included."

190 **Madera and San Joaquin sandy loams** are described at p. 75, "The crests of hummocks frequently are occupied by material of the San Joaquin series, and the intervening depression and more nearly level areas by soils of the Madera series."

191 **Pleasanton and Antioch loams and clay loams**, undifferentiated are described at p. 79, "Drainage is good in all the rolling areas, and only intermittently poor in the flatter parts, where the water after heavy rainfall sometimes disappears slowly owing to a dense subsoil. Depressions among hummocks or hog-wall mounds in places collect surface water."

192 **Corning and Pleasanton loams**, undifferentiated are described at p. 80, "There are some hummocks and associated minor depressions, with local poorly drained flats. Owning to the dense subsurface layers the depressed areas and flats collect surface water in the rainy season and the soils become boggy…" The subsoil "is only a few inches thick, and overlies compact gravelly substrata which often contain layers of silty or clayey material relatively free from gravel.", p. 81 "When wet the soil is boggy…Even in the latter instances, however, there usually is a slight unevenness of surface not characteristic of the recent-alluvial soils. Drainage is adequate except for short periods during the wet season, when the escape of water is retarded by the compact subsurface layers."

193 **Antioch clay loam and clay** soils are described at p. 82, "A hummocky surface occurs in some places. Drainage is good except in some flat areas or in small depressions that retain water in the rainy season." At p. 83, "…hardpan layers are not typical" for the subsoils… The surface is slightly uneven or marked by hog wallows and occasionally is undulating…Drainage usually is good, except in the flatter, heavier areas or in the hog-wallow areas where the run-off may be slugging in the wet season."

194 **Fresno sandy loam include brown phase** is described at p. 87, "The type is variable in color and texture, with surface hummocks…and intervening depressions, which usually constitute 60 per cent or more of the surface…puddle heavy sandy loams to light loams…In detail the surface frequently is hummocky…Surface drainage is poor, and in wet weather water stands for weeks on the slight depressions and flats." Describing **Fresno sandy loams**, p. 88, "At a depth of 2 to 6 feet a …compact layer is encountered, which in places is indurated. This layer, or hardpan…usually is dense enough to check the free movement of roots and water…Over large areas, the hardpan is below the depth of 6 feet…Small rather flat, slightly depressed areas…occur. These spots are compact and more or less puddle, water standing on the surface for periods in wet seasons. They

- Fresno fine sandy loam including brown phase[195]
- Fresno loams[196]
- Fresno clay loams including heavy phase[197]
- Stockton and Fresno soils, undifferentiated[198]
- Alamo clay adobe[199]
- Yolo loams including dark-gray phase[200]
- Yolo adobe soils[201]

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also have more compact subsoils and the hardpan is nearer the surface than usual." At p. 89, "The deeper areas have few, if any, hummocks and are well drained, while the shallower and flatter parts are frequently hummocky, with inclosed (sic) puddle depressions, are poorly drained…" In the Fresno area, **Fresno sandy loam** has harpan at 6 feet. In areas not under agricultural development, "Outside of these sections the surface breaks into a series of more or less connected ridges 5 to 10 feet in height, with intervening flat-bottomed depressions." (Strahorn et al. 1914, pp. 48-49).

[195] **Fresno fine sandy loam including brown phase** soils are described at p. 90, "At 18 inches to 4 feet the subsoil is underlain by a fine-textured hardpan, ranging from compact beds to semicemented or indurated layers." At p. 91, "The Fresno fine sandy loam is used almost entirely for pasture on account of its puddle and alkali condition…The soil may extend to a depth of 6 feet or more without variation, but typically it has a distinct subsoil and a variable hardpan. At 2 to 6 feet or more the subsoil rests upon…, constituting a hardpan. This usually is rather impervious to roots and water.." At p. 92, "The brown phase…has a very gently sloping or slightly undulating to nearly level topography…Locally there is a tendency toward the formation of hummocks, but this is less pronounced than on the typical soil." In the Fresno area, "It ranges from slightly rolling to very uneven, areas being dotted with low mounds and sinuous ridges rising above small playalike depressions." (Strahorn et al. 1914, p. 52).

[196] **Fresno loam** soils are described at p. 93,"…in flat or slightly depressed area, puddle…hummocks…At a depth of 18 inches to 4 feet a compact, semicemented or indurated, silty hardpan occurs…the soil packs into a rather refractory mass where water stands on the surface in wet weather… .", at p. 94, "They have in most places an uneven or hummocky surface. Poorly drained and puddle flats and slight depressions are common, and drainage is in general defective, with indications of alkali. A number of sloughs occur, and water collects in these and in low places in wet weather."

[197] **Fresno clay loam including heavy phase** soils are described at p. 94, "The subsoil, which lies at depth of 1 to 4 feet or more, usually consists of a heavy, compact clay loam or a clay." At p. 95, "At various depths the silty hardpan layer common to the series appears….This subsoil is dense and variable, and overlies a hardpan and substratum similar to those described as occurring in the clay loam…In its puddle condition…this type is similar to the clay loam…Broadly, this group occupies a very gently sloping to nearly level plain, but it has many minor depressions, 1 foot or more below the general level of the surface, and low hummocks which make the surface irregular. A number of sloughs and abandoned stream ways which carry water only in flood periods traverse the type. The group has stagnated drainage, and the presence of alkali is indicate over much of the surface by white, barren spots, although there is, in general, a moderate growth of salt grass and other alkali-resistant plants." As to the "heavy phase", at p. 96, "The soil usually is more or less puddle…The subsoil is very compact, and has poor moisture-retaining properties. At a depth of 12 to 48 inches a gray, silty hardpan is encountered…influenced to a considerable extent by flood waters…The surface is nearly level to slightly uneven with many low, rounded hummocks. Small sloughs dissect the surface in places, and carry water in flood periods. The soil is poorly drained and frequently is water-logged for long periods each year. Alkali is present over much of the surface…puddle and periodically water-logged condition."

[198] **Stockton and Fresno soils, undifferentiated** soils are described at p. 99, "The Stockton clay adobe, comprises possibly 25 to 25 per cent of this area…occupies irregular-shaped, lower-lying areas, dotted with numerous slight elevations or hummocks of soils…" At p. 100: The Merced soils are present in "somewhat basinlike position… ." At p. 101, "the basinlike or flattened surface appears quite even…but is very irregular in detail. Hummocks, slight ridges, and depressions, the result of water action, occur over much of the area of the group…The knobs, ridges, and similar slightly elevated areas are more often occupied by soils of brown or gray color. In all the minor depressions among hummocks and the more continuous ones among the gentle ridges excess surface water accumulates in rainy season…In this manner a single acre often contain several bodies of soil having very different drainage conditions. The small knolls and ridges…shed the rainfall into the adjoining puddle areas…The sloughs, remnants of stream channels, and swampy depressions sometimes support a growth of tule. Much of the group is flooded for considerable periods in seasons of heavy rainfall, or, if not covered by water, is isolated by flooded areas bordering the main slough ways. A large part has a high-water table and contains alkali in injurious quantities."

[199] **Alamo clay adobe** soils are described at p. 105, "…resting upon a red ferruginous hardpan…The type is normally smooth or nearly level and slightly depressed below the surrounding soils. Both the surface and subsurface drainage usually are restricted in the rainy season, but the soil is free from alkali."

[200] **Yolo loams** including dark-gray phase soils do not appear to be vernal pool as no hardpan is noted. However, the soils southwest of Los Banos and northwest of Patterson differ from the typical soils and are described as having "a hog-wallow or hummocky surface." p. 109.

[201] **Yolo adobe soils** are described at p. 113, "While usually smooth, the surface may be more undulating than is characteristic of the Yolo clay loams and Yolo loams. Slight ridges and shallow depressions are of frequent occurrence…Some of the lower lying areas are subject to periodic overflow, the surplus water remaining on the surface until evaporated or removed by percolation."

- Panoche clay loams[202]
- Panoche adobe soils[203]
- Capay and Merced clays, undifferentiated[204]
- Dublin adobe soils[205]
- Modesto loam[206]

Vernal pool soil types in the San Joaquin Basin outside of the floodplain total about 1.2 million acres. There are an additional 0.3 million acres within the floodplain. Thus, there was a total of 1.5 million acres of vernal pool soils in the San Joaquin Basin under natural conditions or half of the approximately 3 million acres mapped as grasslands by CSU Chico (2003) in the San Joaquin Basin.[207]

Thus, based on the reconnaissance soil surveys for the Sacramento and San Joaquin Basins, the total vernal pool acreage outside of the floodplain was 1.9 million acres with an additional 1 million acres within the floodplain.

3.3.5.2 Comparison With Other Work

Our analysis indicates that there were about 1.9 million acres of vernal pool habitat in the Valley Floor outside of the floodplain, comprising 23% of its area. This compares favorably in magnitude with other work, but the locations of the habitat are notably different.

Dr. Robert Holland published the first estimate of vernal pool acreage in 1978 and has continued to update his analysis (Holland 1978, p. 5; Holland 1998, p. 14; Holland and Hollander 2007, Fig. 8). Dr. Holland has updated his 2007 vernal pool map, but the updated map has not been published. We obtained the latest version of Dr. Holland's GIS shape files and compared the amount and location of his vernal pool acreage with ours.

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[202] **Panoche clay loam soils** are described at p. 116, "…have a tendency to puddle when wet..Much of the surface is marked by hog wallows and other minor surface irregularities characteristic of the older valley-filling soils."

[203] **Panoche adobe soils** are described at p. 117, "…there is no cemented hardpan…The area is marked in places by low hog-wallow mounds, shallow basinlike depressions, and other minor irregularities."

[204] **Capay and Merced clays, undifferentiated soils** are described at p. 128, "Practically all the soil is very heavy in texture, of compact or puddle structure, posses an uneven or hog-wallow surface, and is affected by injurious accumulations of alkali…The Capay clay…is more often puddle or poorly granulated…Hardpan or distinct gravelly substratum does not occur, but the subsoil becomes adobelike in structure on exposure…" pp. 129-130 "Over broad area the brown Capay clay occupies the small mounds or ridges of hog-wallow areas and the dark-colored Merced clay occupies the intervening depressions or flats, so that many soil bodies occur within a single acre…Hummocks varying in height from a few inches to 2 feet or more are present. These range in diameter from a few feet to 50 feet or more, are sometimes closely set, and occupy more than 50 per cent of the surface. In places they are scattered and subordinate to the flatter, puddle intervening areas. In places the surface is slightly ridged, as a result of erosion. The drainage of these soils is sluggish during the rainy season. Surplus water from the foothills collects in the depressions or escapes slowly to the valley trough through meandering drainage courses…The hog-wallow surface and the character of the subsoils are evidences of some of the changes that have taken place through weathering."

[205] **Dublin adobe soils** are described at p. 132, "The soils occupy gently sloping to nearly level alluvial fans or basinlike depressions…many of the low depressions are inundated for short periods in the winter." The more elevated parts of the alluvial fans are well drained; many of the low depressions are inundated for short periods in the winter."

[206] **Modesto loam** (8,896 acres) was not included in the San Joaquin survey. However, in the Modesto-Turlock area survey, it is described as, "The surface...as a whole is uneven, consisting of comparatively level stretches, marked by slight, almost circular or elongated mounds. Other parts have hog-wallow depressions, with intervening mounds, giving the entire surface a hummocky appearance...When wet it puddles badly, and upon drying becomes very hard." (Sweet et al. 1909, p. 40).

[207] The soil survey for San Joaquin Basin does not extend as far north as our definition of the San Joaquin Basin. However, the Sacramento Basin soil survey extends further south than our definition of the Sacramento Basin. Thus, some of the soils we have mapped as vernal pool in the San Joaquin Basin were thus mapped based on the Sacramento Basin soil survey.

Dr. Holland's work returns about 6 million acres of vernal pool habitat in the Central Valley or about half of the land area under natural conditions. It identifies 2.4 million acres of vernal pool habitat in the Valley Floor outside of the floodplain. This value is within 23% of our estimate, which is surprisingly close, given that the work was done independently, each with no knowledge of the other, using different methods of identifying vernal pool habitat. We relied solely on topography as described in early soil reports, while Dr. Holland classified vernal pool habitat based on the intersection of observed occurrences of unique vernal soil plant species with soil types, topography, climate, etc. Dr. Holland's method should yield more accurate estimates, but for the fact that it is based on remnant vernal pools, which may not be representative of pristine conditions. These two very close estimates confirm the widespread occurrence of vernal pools in the pristine Valley Floor. However, there is significant disagreement as to where these vernal pools were located.

The location differences are shown in **Figure 13**, which overlays our vernal pool areas (blue) onto Dr. Holland's (orange). The areas of overlap are shown in brown on Figure 12. There are several major differences.

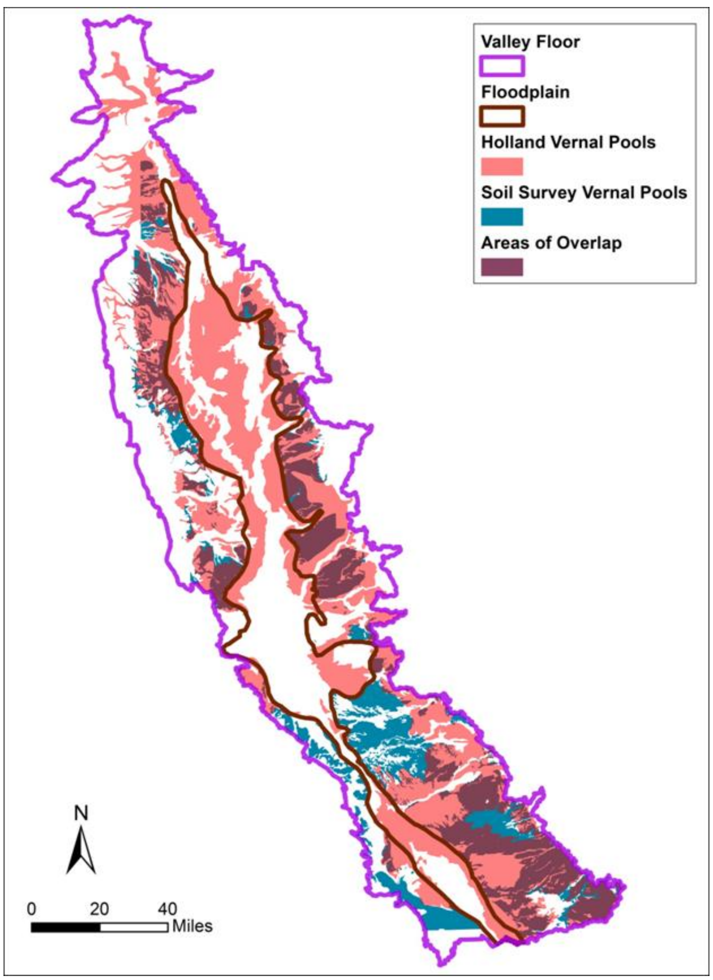

Figure 13. Comparison of Vernal Pool Maps

First, Dr. Holland mapped large areas of vernal pool habitat within the floodplain (1,140,650 acres). We also mapped vernal pool soils within the floodplain (**Figure 14**), but we classified them as either: (1) permanent wetland based on more accurate historic surveys, (2) seasonal wetland based on their flooded condition, or (3) riparian forest based on the Küchler 1977 natural vegetation map. We concluded that vernal pool vegetation would not have survived within the floodplain under natural conditions due to long-term flooding. We also mapped much less vernal pool habitat within the floodplain (554,791 acres) than Holland (1,140,650 acres).

Others have also concluded vernal pools would not be found in the floodplain under natural conditions. Research has shown that if vernal pools stay wet "too long," which could happen within the floodplain, vernal pool flora is replaced by marsh grasses and other permanent wetland species. (Williamson et al. 2005, p. 14). Smith and Verrill (1998), in a study of vernal pool-soil-landform relationships, concluded that vernal pools were not common in the flood basins, "Judging from the low landscape position and the soils that have formed, these basins probably once contained seasonal wetlands which were inundated for long periods (from many weeks to months during most years) due to historical flood conditions (overbank flooding and rising groundwater). The lowest areas were probably flat marshes." (Smith and Verrill 1998, pp. 16, 18).

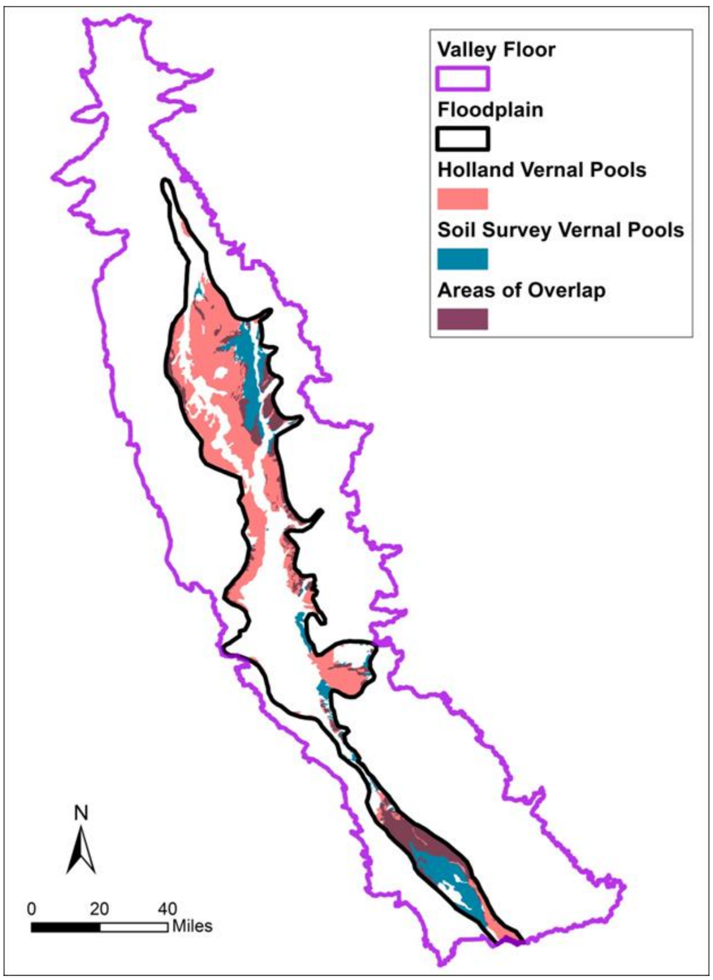

Figure 14. Comparison of Vernal Pool Habitat Within Floodplain

We believe vernal pools were likely present within the floodplain in the post-development period, as recorded in some of the early soil survey reports. However, these vernal pools likely formed from the drying out of the floodplain and thus are not natural vegetation. Soils that were originally within the floodplain and that were flooded annually were saturated and mostly supported permanent and seasonal (tule marsh) wetland vegetation. The old floodplain soils that were not converted to other uses formed terrace soils, which support vernal pools. The vernal pools along the Sacramento River and San Joaquin River (Figure 14), for example, formed after flood control, irrigation, and drainage projects lowered the regional groundwater table, replacing permanent and seasonal wetland with vernal pools. (Holland 1978, pp. 4-6; Edminster 2002, pp. 110, 112-114, 117, 145-146). Smith and Verrill (1998, p. 18), for example, note, "Basin rim landforms did not develop in the transition from basins to natural levees bordering the Sacramento River." However, Holland maps vernal pools in this location. Thus, they were not natural vegetation.

Second, Figure 14 shows that Dr. Holland identified much more vernal pool habitat within the floodplain than we did. Our only areas of overlap are along the eastern and western flood basin rims in the Sacramento Basin and in the northern portion of the San Joaquin floodplain. Others have concluded that the basin rims, near the distal end of low terraces, had "mound-depression microrelief and saline-sodic soils with perched water tables" where vernal pools occurred. Of the six Sacramento Valley flood basins, the western margins of Yolo and Colusa Basins were reportedly "the site of extensive basin-rim pools.". (Smith and Verrill 1998, p. 18). These are shown in Holland's work (Figure 13) but not ours. Our map, for example, excludes vernal pools in the northwestern portion of the Sacramento Basin as the soil survey we relied on did not cover this area. The boundary of our soil survey in this area is shown as a sharp vertical line (Figure 12).

Third, in the Sacramento Basin, Dr. Holland classifies large areas as vernal pool habitat that were not reported as having classical vernal pool topography in the Sacramento soil survey we relied on (Holmes et al. 1915). This could be due to several factors including: (1) incomplete coverage of the Valley Floor by the Sacramento soil survey we relied on; (2) the presence of alkaline vernal pools on the west side of the Sacramento Valley that did not display classical hog-wallow topography; and (3) the presence of large areas where vernal pool habitat had already been cleared for farming at the time of the survey. (Smith and Verrill 1998, pp. 21-22).

Fourth, in the San Joaquin Basin, Dr. Holland does not identify vernal pool habitat in the northeastern part of the basin. This area is indicated as vernal pool habitat in the San Joaquin soil survey (Nelson et al. 1918) and in the work of others. Dr. Holland also reports large areas of vernal pool habitat in the southeastern part of the San Joaquin Basin where none is indicated in the San Joaquin soil survey. Most of this area was farmed early so its omission from the soil survey is not surprising.

Our vernal pool acreages, based on Figure 13, are compared with Dr. Holland's in **Table 5**. This comparison is for areas within the floodplain. As also shown by Figure 13, it confirms that Dr. Holland reports higher acreages of vernal pool habitat in all planning areas in the Sacramento Basin and planning areas 602, 608, and 609 in the San Joaquin Basin than we do, accounting for most of the difference.

Table 5. Comparison of Vernal Pool Areas (Acres)

Basin	Planning Area	Fox/Sears Vernal Pool	Holland Vernal Pool	Difference
Sacramento	502	0	0	
	503	61,887	144,429	82,542
	504	1,069	75,551	74,483
	505	0	0	0
	506	233,147	292,895	59,748
	507	82,794	110,869	28,075
	508	9,173	12,525	3,352
	509	103,502	158,029	54,527
	511	185,042	210,054	25,013
Delta	510	8,137	11,413	3,276
	602	21,084	47,701	26,617
San Joauin	601	9,574	2,253	-7,321
	603	146,875	189,018	42,143
	604	0	0	0
	605	1,004	0	-1,004
	606	167,301	56,555	-110,746
	607	158,134	102,852	-55,283
	608	123,720	180,075	56,355
	609	586,781	759,387	172,607
	610	929	999	70
TOTAL		1,900,154	2,354,607	454,453

Others have mapped seasonal wetlands in the grasslands, though they have not called them "vernal pools." The U.S. Fish and Wildlife Service has mapped extensive areas of "wetland/upland complexes" on the eastern side of the Valley Floor but few areas on west side, compared to our work and Holland's. (Garone 2011, Map 2). We overlaid our mapped grassland area onto a copy of the USFWS map, shown in **Figure 15**, which indicates a significant fraction of grasslands on the east side of the valley were "wetland/upland complexes," which our work identifies as vernal pools and other seasonal wetlands within the floodplain. We did not attempt to obtain areas from Figure 15 as the original base map is poor quality and registration is not good.

Additional work is required to refine the vernal pool acreage estimates used in our work and specifically to address the following issues.

First, the two soil surveys we used did not cover 100% of the study area. Other surveys are available that cover the missing areas, but our budget did not allow including these. Holland's work, presented in the next section, covered the entire Valley Floor and shows large areas of vernal pool habitat that were outside of the boundaries of the soil surveys that we relied on, for example, in the northwestern portion of the Sacramento Basin.

Second, the two surveys we relied on occurred after extensive agricultural development had removed vernal pool habitat by cut and fill leveling of the land surface and blasting to increase soil permeability. (Smith and Verrill 1998, p. 21; Edminster 2002). Thus, vernal pool topography would have been removed in many areas, underestimating acreage based on soil surveys conducted in the early 20th century. This source of underestimate could be eliminated by using modern soil surveys coupled with current knowledge of the soils that supported this habitat, similar to the work of Smith and Verrill (1998) and Holland and Hollander (2007). A more accurate estimate, for example, could be obtained by expanding vernal pool soil types to include all of those underlain by hardpan or claypan.

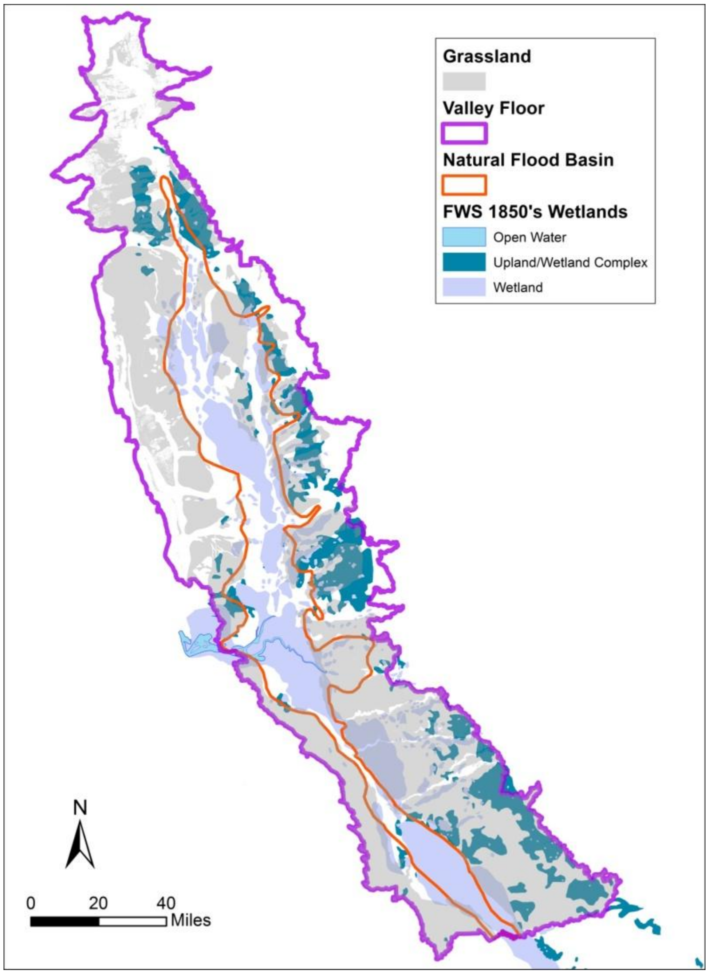

Figure 15. Wetland Extent in Central Valley in 1850s
Source: Garone 2011, Map 2

Third, work needs to be completed to confirm the type of vegetation present within vernal pool areas within the floodplain mapped based on soil characteristics. We have assumed that all such areas were seasonal wetland. However, some of these areas, particularly along the rims of the floodplain, may be true vernal pool.

Fourth, a soil series, the basis of our mapping, is conceptual, especially in the early soil surveys. These reconnaissance soil surveys include smaller inclusions of other types of soils, which may or may not have been vernal pool habitat, e.g., one soil type may occur on the mounds and another in the pools. (Smith and Verrill 1998, p. 20). Our vernal pool mapping work should be updated with more detailed, recent soil surveys.

Fifth, the actual cover of vernal pool habitat within a given landscape may not be 100%. Vernal pools were intermixed with grasslands, their density varying with location in the landscape. Others have estimated vernal pool coverage at 1% to 15% (Mitsch and Gosselink 1993,[208] p. 336; Witham et al. 2012[209]), based on remnant pools. The 1929 Chico area soil

[208] Mitsch, W.J. and Gosselink, J.G., 1993. Wetlands, 2nd Ed., John Wiley, New York.

[209] Witham, C. W., Holland, R.F., and Vollmar, J.E., 2012. 2005 Great Valley Vernal Pool Map, Plus Merced, Placer and Sacramento County Losses 2005- 2010, USFWS Grant Agreement 80270-G509, Final Report, January 31, 2012.

survey estimated coverage in San Joaquin sandy loam soils, a key vernal pool soil type, at "one-half of the surface of the soil." (Watson et al. 1929, p. 22). We did not find any other coverage estimates for natural conditions, which we believe were much higher than the current upper bound. As the pools interact with their surrounding landscape, e.g., exchange water, as discussed in Section III.C.4, we have assumed 100% of the mapped vernal pool habitat evapotranspired at the vernal pool rate.

Sixth, the evapotranspiring vernal pool surface area was assumed to be flat in our calculations. However, the pools were basins with sloped or rounded sides. Thus, the surface area of the transpiring surface was greater than that of a flat surface. This factor may partially offset the coverage issue.

Seventh, we classified vernal pool soil types that fell within the floodplain as seasonal wetland rather than vernal pools as the drying out of the floodplain over the past century created conditions that promoted the formation of new pools that were not present under natural conditions. (Edminister 2002, p. 110; Holland 1978, pp. 4-6). Under natural conditions, we believe these soils would have supported seasonal or permanent tule wetland.

Eighth, all vernal pools cannot be identified solely based on topography, as we have done in this work due to limited resources. As discussed elsewhere in this report, vernal pools differed widely in characteristics, including soil type, topography, vegetation, and hydrology. Section III.C. Others have noted that vernal pool topography can be absent in classical vernal pool soil complexes (e.g., the hardpans) and present in regions without these classic soils. (Nikiforoff 1941, p. 6). Thus, all vernal pool areas cannot be identified solely based on topography as reported in soil surveys. Holland's use of other indicators is a preferable, more inclusive approach. Our work should be expanded to incorporate the Holland approach and information or replaced by Holland's estimates outside of the floodplain.

Ninth, vegetation surrounding the vernal pools will transpire moisture drawn from the pools, known as lateral seepage to transpiring adjacent vegetation. This effect was not considered in the water balances reported elsewhere. (Fox et al. 2014). The rate of water loss from vernal pools is directly related to the length of shoreline per acre of basin area. The rate of evapotranspiration from the water surface and vegetation is greater for pools with a high shoreline length per acre of basin area. Nothing is known about this interaction in vernal pool habitats, i.e., would it increase transpiration of surrounding grasslands or decrease transpiration from the pools? (Millar 1971;[210] Mansell et al. 2000[211]). The water balance calculations reported elsewhere ignored this effect, treating 100% of the vernal pool area as a flat surface with no surrounding grasslands.

Finally, accurate estimates of evapotranspiration require further subdivision of vernal pool habitat, along the lines suggested in Section III.C.4.

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[210] Millar, J.B., 1971. Shoreline-Area Ratio as a Factor in Rate of Water Loss from Small Sloughs, Journal of Hydrology, v. 14, pp. 259-284.

[211] Mansell, R.S., Bloom, S.A., and Sun, G., 2000. A Model for Wetland Hydrology: Description and Validation, Soil Science, pp. 384-397.

3.3.5.3 Current Vernal Pool Habitat Acreage

Current locations of vernal pool complexes within the Valley Floor were mapped using high resolution 2005 imagery and GIS techniques are shown in **Figure 16**. (Witham et al. 2013). This distribution of vernal pools is consistent with work reported elsewhere. (Holland 1998; Keeler-Wolf et al. 1998; Solomeshch et al. 2007, Fig. 15.8; Holland and Hollander 2007, Fig. 8). While the current distribution is indicative of pre-development vernal pool locations, this is not uniformly true.

First, Figure 16 shows that most of the remaining pools occur in higher elevation rim locations that have been disturbed much less than lower terraces that formerly contained a high density of vernal pools (mapped as grasslands by both CSU Chico (2003) and Küchler (1977)). Extensive landscape altering occurred in the early 20th century including cut and fill land leveling of mounds and depressions, excavations of drainage ditches to lower shallow water tables, and deep ripping and blasting to increase permeability of subsoils. These land clearing methods decimated vernal pools formerly on the lower terraces. (Smith and Verrill 1998; Alexander et al. 1874, p. 25).

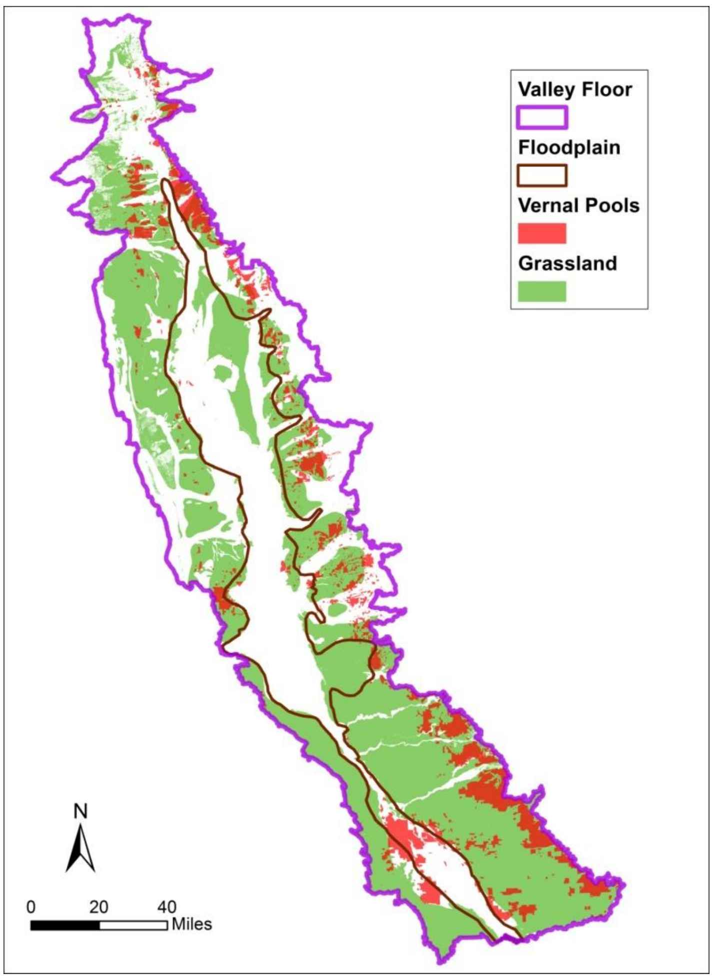

Figure 16. Current Locations of Vernal Pools Based on Holland 1998

Second, Figure 16 includes new vernal pool areas that formed over the last 100 years from drying out of the floodplain. As explained elsewhere in this report, flood control and drainage projects have eliminated annual flooding and dried out the floodplain, creating new vernal pool habitat. Thus, existing vernal pools within the floodplain were not part of the natural vegetation.

We estimate, based on Figure 16, that about 0.7 million acres of vernal pools were present as of 1998 in the Valley Floor that would have been present under natural conditions (excluding the new pools along the San Joaquin River). This acreage has continued to decline. In updated work, vernal pool acreage in the Valley Floor had declined to 0.6 million acres. (Holland and Hollander 2007, Fig. 8). The total area of actual current vernal pool vegetation in our study area is no doubt a small fraction of its pre-development geographical range as this figure is based on aerial imagery and thus represents the range of complexes. (Keeler-Wolf et al. 1998).

3.4 Wetlands

The CSU Chico pre-1900 map identified 1.0 million acres of "wetlands," but did not distinguish among permanent and seasonal wetlands nor large stand and small stand wetlands, factors that significantly affect evapotranspiration rate. We subdivided wetlands into these categories based on available information.

We ignored large stand/small stand, even where specifically identified in soil surveys, as we did not have adequate resources to develop this classification. We assumed 100% of the wetlands mapped by CSU Chico (2003) were large stand. This assumption underestimates wetland evapotranspiration for several reasons. First, the vegetation found in these marshes often grow in patchy, long, narrow strands only 1 to 10 meters in width, rather than as large undivided areas. Second, the periphery of the wetlands were strips, perhaps even fractals with large lineal areas, in what Bryan described as a "crenulated border" (Whipple et al. 2012; Bryan 1923[212]). Third, small-stand strips occurred along numerous topographic features, including sloughs and perennial lakes that dotted the floodplain outside of the permanent tule marshes. (Whipple et al. 2012, pp. 255-268; CSG 1856[213]). Warmer, dryer air can move easily through this stripped vegetation causing advective transfer of energy and elevated evapotranspiration, known as the “oasis” or “clothesline” effect. (Allen 1998;[214] Allen et al.1992,[215] 1998[216]). Further, soil surveys specifically identify some small-stand areas, such as in the American Basin. See Section II.D.2.

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[212] Bryan, K., 1923. Geology and Ground-Water Resources of the Sacramento Valley, California, U.S. Geological Survey Water-Supply Paper 495, 285 pp. + pocket map.

[213] California Surveyor-General (CSG), 1856. Annual Report of the Surveyor-General of the State of California. Document No. 5. In Senate, Session of 1856, Sacramento, pp. 211, 261. 278. Last accessed February 15, 2014. Available at: http://www.slc.ca.gov/misc_pages/historical/surveyors_general/reports/marlette_1855.pdf.

[214] Allen, R.G., 1998. Predicting Evapotranspiration Demands for Wetlands, Presented at ASCE Wetlands Engineering and River Restoration Conference, Denver, CO, March 20-29.

[215] Allen, R.G., Preuger, J.H., and Hill, R.W., 1992. Evapotranspiration from Isolated Stands of Hydrophytes: Cattail and Bulrush, Transactions of the ASAE. 35:4. July-August.

[216] Allen, R. G., Pereira, L. S., Raes, D., and Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper No. 56. FAO Irrigation and Drainage Paper No. 56. Food and Agricultural Organization of the United Nations, Rome, Italy.

3.4.1 PERMANENT LARGE-STAND WETLANDS

The permanent wetlands, or "tule marshes", were located in the overflow basins, in the tidal channels of the Delta and throughout the Valley Floor in the floodplain "wherever there is adequate water and the drainage pattern is such as to permit the saturation of the soil, or to permit water to stand on the soil." These wetlands were dominated by reed-like plants that grew in water-saturated soils and standing water. They are classified by the U.S. Fish and Wildlife Service as "persistent emergent wetlands." This classification implies the presence of species of vegetation that are rooted in marsh soils, emerge above the water level, and generally persist, or remain standing, until the beginning of the next growing season. (Garone 2011, pp. 25-27; Fox 1987a, pp. A2-30 to A2-31).

The characteristic vegetation in these marshes included sedges and cattails in the deeper water, and, in shallower water, rushes, spikerushes, knotweeds and smartweeds, docks, and aquatic grasses such as wild millet. (Garone 2011, p. 25). The most common plants were tules (*Schoenoplectus* spp.), cattails (*Typha latifolia* and *angustifolia)*, the common reed (*Phragmites australis*), water plantain (*Alisma plantago-aquatica*), arrowhead (*Sagittaria spp.*), yerba mansa (*Anemopsis californica*), spike rushes (*Eloechans* spp.), and sedges (*Carex* spp.). (Mason 1957;[217] Hoover 1935; Burcham 1957; Atwater, 1980;[218] Schoenherr, 1992, pp. 526-532.)

Our native vegetation map in Figure 2 returns about 1.0 million acres of perennial wetlands, or 12% of the Valley Floor area. This estimate is confirmed by a number of primary sources, including the federal surveys done pursuant to the Arkansas Swamp Act of 1850, comparable California surveys, independent surveys by the California State Engineer, and technical summaries based upon surveys.

One of the most significant of these reports confirming the extent of the tule marshes was prepared by Professor Hilgard, generally regarded as the father of modern soil science and the first director of the Agricultural Experiment Station at Berkeley. His report was prepared for the 1880 U.S. Census. It separately listed the area of tule lands in each county, showing a total of 1.2 million acres tributary to the Bay. Another authoritative source, Marsden Manson, assistant to California's first State Engineer, published an estimate of about 1.0 million acres tributary to the Bay in a refereed and archival journal, based on State Engineer surveys. Thus, the value returned by the CSU Chico pre-1900 map is consistent with historical surveys. Finally, Küchler's statewide Natural Vegetation Map returns 1.3 million acres of tule marsh within the Valley Floor.

The areas shown as "wetland" in Figure 2 are based on California Surveyor-General surveys. These surveys were conducted in the dry season, in the late summer and fall, after the flood basins had drained and the land was passable. (CSG 1858,[219] p. 11; CSG 1862, p. 10; CSG 1856, p. 211;Thompson 1957, pp. 189-190; Flushman 2002[220]). They had to be wet and unfit for

[217] Mason, H.L., 1957. Flora of the Marshes of California, University of California Press.

[218] Atwater, B.F., 1980. Distribution of Vascular-Plant Species in Six Remnants of Intertidal Wetland of the Sacramento-San Joaquin Delta, California, U.S. Geological Survey Open-File Report 80-883.

[219] California Surveyor General (CSG), 1858. Annual Report of the Surveyor-General for 1857. January 7, 1858, "The U.S. Deputy surveyor…seeing the land only during the day in which he is engaged upon the survey, reports as much of it dry land as he can find over which to stretch his chain. This may be, and often is done during the driest part of the year." Available at: http://www.slc.ca.gov/Reports/Surveyors_General/reports/Brewster_1857.pdf

[220] Flushman, B.S., 2002, Water Boundaries. Demystifying Land Boundaries Adjacent to Tidal or Navigable Waters. John Wiley & Sons, Inc. 389 pp.

cultivation as of September 28, 1850 and required both levees and drains to reclaim. (Flushman 2002). Further, general descriptions of others, summarized by Whipple et al. 2012, p. 338, indicate that water remained within the tules until sometime between July and September.

Thus, "wetlands" shown on Figure 2 are generally equivalent to "permanent" swamp. These surveys likely underestimate acreages because they excluded lands that had been reclaimed prior to the surveys. (Thompson 1957, p. 191; Whipple et al. 2012, Fig.1.16, pp. 64, 222). Thus, perennial wetland acreage is likely underestimated. Others have also concluded that the flood basins supported "perennial wetlands." (Whipple et al. 2012, p. 207). In mapping native vegetation in the Delta, SFEI generally found "swamp and overflowed" land boundaries to define the perennial wetlands but found exceptions due to particular interpretations of surveyors. (Whipple et al. 2012, Box 2.3, pp. 65-66).

The evapotranspiration from wetlands depends upon its layout. Very high evapotranspiration can occur where a small taller stand of vegetation is surrounded by shorter vegetation. This effect is called the "clothesline effect" as air can move more efficiently between the vegetation, lowering the humidity outside of the leaf and creating a greater potential for a higher ETv. (Allen et al. 2011[221]). Thus, we developed Kv values for both small stand and large stand perennial wetlands. (Howes et al. 2014).

Numerous eye witness accounts, historic surveys, photographs, and other evidence indicate that the wetlands mapped by CSU Chico (2003) supported dense, tall (usually over 10 ft) growth, indicating the tules were present in large stands, except perhaps around the edges of the marsh. (Whipple et al. 2012, p. 220; Fox 1987a,[222] Figure 3). Thus, we used the large-stand, perennial wetland ETv values to estimate evapotranspiration from areas classified by CSU Chico as "wetland."

However, these dense stands of tule marsh were surrounded by or interlaced with lakes and sloughs that were bordered with small stands of emergent vegetation, such as tules and reeds. These are described for the North Delta in Whipple et al. (2012), pp. 255-268. They have not been mapped by anyone to our knowledge. Further, the periphery of the large stand wetland itself is small stand and likely a fractal with a large perimeter area.

3.4.2 PERMANENT SMALL-STAND WETLANDS

We assumed that 100% of the CSU Chico wetland was large-stand wetland. However, this assumption needs to be revised. Review of soil surveys and other historic information indicate that there were likely large areas of small-stand permanent wetland. The soil survey for Marysville, for example, reports for Sacramento clay soils, "The area occupied by this soil is commonly spoken of as the "tule lands," on account of the dense, impenetrable growth of this plant, which often reaches a height of 12 feet. In Sutter Basin, this growth of tule is continuous from the Buttes southward to below Kirkville. In the American Basin, the growth is not so continuous, but occurs in scattered patches, each of considerable extent. (Strahorn et al. 1911, p. 30). This amounted to 108,330 acres of small-stand tule marsh within the floodplain in

[221] Allen R.G., Pereira, L.S., Howell, T.A., and Jensen, M.E., 2011. Evapotranspiration Information Reporting: I. Factors Governing Measurements Accuracy, Agricultural Water Management, v. 98, pp. 899-920.

[222] Fox, P., 1987a. Freshwater Inflow to San Francisco Bay Under Natural Conditions, Appendix 2, Figure 3, SWC Ex. 262.

Sacramento clay soils that we have analyzed as large-stand, thus underestimating evapotranspiration and overestimating natural flows.

3.4.3 SEASONAL WETLANDS

Under natural conditions, the Valley Floor contained both permanent and seasonal wetlands (Garone 2011). The two native vegetation maps that we relied on mapped only permanent wetland and classified seasonal wetlands as either other floodplain habitat or grasslands. Our analyses indicate about 802,323 acres of seasonal wetland were present within the floodplain. Vernal pools are also considered by many to be seasonal wetlands, based on their vegetation and hydrology. However, they differ in important ways from the seasonal wetlands within the floodplains. These seasonal wetlands were variously classified as either "other floodplain habitat" or grasslands by CSU Chico (2003).

The lands classified as "tule marsh" by CSU Chico (2003) were permanent wetlands. These perennial wetlands (tule marsh) transitioned to less frequently inundated and less saturated seasonal wetlands (including alkali and vernal pool complex). (Whipple et al. 2012, pp. 73, 211, 232-233 and Table 2.2). Flood basin seasonal wetlands were the so-called "rim lands," between the permanent tule marsh and flood basin boundary. These wetlands were complexes, with no clearly defined boundary, as they intergraded with grassland, ponds, and patches of tule. (Whipple et al. 2012, p. 73).

Others have identified at least two distinct types, wet meadow/seasonal wetland and alkali seasonal wetland complex. (Whipple et al. 2012, Table 2.2, pp. 43-44). The soil survey analysis we performed for vernal pools identified about 0.6 million acres of vernal pool habitat (based on topography/soil type) within the floodplain or nearly one-quarter of the total floodplain area. In this work, we have classified these vernal pools as seasonal wetland because they intermixed with permanent wetlands within the floodplain, rather than grasslands outside of the floodplain. Further, research has shown that if vernal pools stay wet "too long," which could happen within the floodplain, vernal pool flora is replaced by marsh grasses and other permanent wetland species. (Williamson et al. 2005, p. 14).

These lands within the floodplain but beyond the perennial wetlands relied on periodic flooding from side streams pouring across the low plains in broad sheets, river discharge over the levees (Bryan 1923, p. 10), seasonal rainfall, and groundwater recharge as the primary sources of moisture. (Whipple et al. 2012, p. 213). Once the floodwaters receded, stored soil moisture was depleted, and winter and spring precipitation ended, these wetlands would likely dry down until the next season when rainfalls and floods again occurred. While the flood basins could become dry late in the season, "[l"[ocalized depressions, ponds, and lakes would stay wet through the year, filled by overland flow from floods and high water tables, but disconnected from means of drainage." (Whipple et al. 2012, p. 237).

In the Sacramento Basin, this would have been winter and spring floods. In the San Joaquin Basin, there were two flood periods: (1) winter floods from rainstorms combined with melting snow (November to May, sharp short duration peak flows); and (2) summer floods (April to August) of considerable duration (up to 1 month) from melting of high elevation snow and spring rains. (CDPW 1931b, p. 464; Whipple et al. 2012, p. 233). This difference occurs as a greater proportion of the contributing watersheds on the Sacramento River are at lower elevations than on the San Joaquin, including many rain-fed Coast Range streams. (Whipple et al. 2012, p. 233). Thus, it is likely that the period when these seasonal wetlands were dry, especially in the San Joaquin Basin, was short. (Whipple et al. 2012, p. 235).

The SFEI mapping project used soil types to identify these seasonal wetlands. (Whipple et al. 2012, Tables 2.6, 2.7). They concluded that several soil types, including clay loams, silty clay adobes and loams, likely supported seasonal wetland complexes based on descriptions in soil reports from the early 20th century. (Whipple et al. 2012, pp. 73-76). We extended their approach to other soils in the Valley Floor for which we had historic soil maps.

We estimated flood basin seasonal wetland as all of the area within the floodplain that was not mapped by CSU Chico (2003) as tule marsh, or by Küchler (1977) as riparian forest, pine forest, or saltbush.

3.5 Valley/Foothill Hardwood

The pre-1900 CSU Chico map reports "valley/foothill hardwood" vegetation, which it described as "dominated by oaks such as Valley Oak (*Quercus lobata*), Blue Oak (*Quercus douglasii*), and Interior Live Oak (*Quercus wislizenii*). Other trees present include Foothill Pine (*Pinus sabiniana*) and California Buckeye (*Aesculus californica*)."[223] Others have segregated these hardwoods as follows: (1) the open woodland around the rim of the Central Valley; (2) savannas with trees widely spaced and scattered over grasslands; and (3) the densely wooded, thickly canopied oak riparian areas on the upper edge of levees along rivers (valley oak riparian forest). (Griffin 1988,[224] pp. 387-405; Vaghti and Greco 2007, pp. 425-55; Allen-Diaz et al. 2007;[225] Shelton 1987; Dutzi 1978; Pavlik et al. 1991, pp. 9, 63-64;[226] Anderson 2006, pp. 30-32).

In addition, other types of hardwood grew within the valley floor that were not mapped by CSU Chico. These included hardwoods in the foothill areas outside of the area mapped by CSU Chico. Further, CSU Chico (2003) classified some hardwood as "other floodplain habitat." Thus, we expanded valley/foothill hardwood, based on Küchler (1977), to include these additional communities.

Under natural conditions, a nearly continuous band of oak woodland surrounded the Central Valley, about 900 miles in circumference and extending between 300 and 3,000 feet in elevation. These woodlands typically graded into grasslands, described elsewhere. Only the lower edge of this band is within the Valley Floor. This lower edge is a woodland grading into savannas of large, widely spaced oaks that shade grassland herbs. Tree canopy covers less than 30 percent of the ground and there are fewer than 20 trees per acre. Woodland trees are small, 15 to 45 feet tall and usually less than 2 feet in diameter. The dominant trees are blue oak (*Quercus douglasii*), interior live oak (*Quercus wislizenii* var. *wislizenii*), and foothill pine (*Pinus sabiniana*). The California buckeye (*Aesculus californica*) is often present in cluster.

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[223] Available at: http://www.gic.csuchico.edu/historic/3_1a.html.

[224] Griffin, J.R. Oak Woodland, Chapter 11 In: Barbour and Major, 1988, pp. 387-405.

[225] Allen-Diaz, B., Standiford, R., and Jackson, R. D., 2007. Oak Woodlands and Forests, Chapter 12, In: M.G. Barbour and others (Eds.), Terrestrial Vegetation of California, 3rd Ed.

[226] Pavlik, B. M., Muick, P. C., Johnson, S. G., and Popper, M., 1991. Oaks of California. Cahuma Press and the California Oak Foundation. p. 9 and pp. 63-64.

(Barbour 1986,[227] pp. 18 -24; Barbour et al. 1993, pp. 83-86; Jepson 1910,[228] pp. 214-217). In the 1904 soil survey of the Sacramento area, this vegetation is described thus, "Valley oaks in considerable numbers frequently occur upon the undulations of the valley plain and in the vicinity of the river bottoms, while the stream courses are frequently fringed with oaks, cottonwoods, and willow... In the lower foothills…"the slopes are frequently covered with quite a heavy growth of valley oak and liveoak, California buckeye, "digger" or gray-leaf pine, coffeeberry, manzanita, species of ceanothus, and other characteristic trees and shrubs of the lower Sierra Nevada foothills. (Lapham et al. 1904, p. 1054).

As the hilly country levels out, the foothill woodland community gives way to the valley oak savanna. (Küchler 1977, p. 929; Dutzi 1978, pp. 17-18). These occurred on the Valley Floor, occupied relatively flat, well-drained areas, and supported a sparse canopy, generally less than 5% of ground surface, with an extensive understory. (Rawlings and Airola, 1997;[229] Pacific Southwest Research Station, 1996[230]). They were most extensive on the east side of the valley. The scattered distribution is likely due to water scarcity. (Dutzi 1978, p. 17, citing Cannon (1914)). The density of oaks increases where the savanna merges with riparian forest. Küchler (1977) shows no valley oak savanna in the study area, the first appearance being in the Tulare Basin in the Kaweah River delta. However, Dutzi (1978) believed that remanants currently scattered throughout the Valley indicate this community once formed a mosaic with the California prairie. It has not been separately mapped and is likely mostly shown as grassland in the CSU Chico pre-1900 map.

The third category mapped by CSU Chico as "valley/foothill hardwood" is oak forest occurring on the upper zone of the riparian corridor, furthest from the water. This zone was dominated by immense Valley oaks (*Quercus lobata*) (Griffin 1988, 387-405) that grew in loam soils (Holmes 1915) and occurred in areas with water supplies within reach of their root system. (Griffin 1988, pp. 405-406; Jepson 1910, pp. 206-207; Pavlik et al. 1991, pp. 53-54). Valley oak is one of the largest oaks in the world. Trees in this zone reached heights of over 100 feet (Jepson 1910, p. 204 ("commonly 40 to 75 but not rarely 100 feet tall")), trunk diameters of 25 feet, crown diameters of 150 feet, and ages of 300 to 500 years. Equally large California sycamores (*Platanus racemosa*) accompanied the oaks. (Barbour et al. 1993, pp. 74-75; Jepson 1910, pp. 204-209).

As reported by noted botanist Jepson, "Trees of remarkable height, span of crown, or diameter of trunk are rather numerous and often have more than a local reputation." He continues to identify then existing large trees that included specimens that were 150 feet tall with

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[227] Barbour, M.G., 1986. Community Ecology and Distribution of California Hardwood Forests and Woodlands, In: Proceedings of the Symposium on Multiple-Use Management of California's Hardwood Resources, Pacific Southwest Forest and Range Experiment Station, Report PSW-100, pp. 18 -24.

[228] Jepson, W.L., 1910. The Silva of California, Memoirs of the University of California, v. 2, The University Press, Berkeley, p. 204.

[229] Rawlings, M.S. and Airola, D.A., 1996. An Ecosystem-based Approach to Valley Oak Mitigation, In: Pillsbury, Norman H.; Verner, Jared; Tietje, William D., technical coordinators. 1997. Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues; 19–22 March 1996; San Luis Obispo, CA. Gen. Tech. Rep. PSW-GTR-160. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. Available at: http://www.fs.fed.us/psw/publications/documents/psw_gtr160/psw_gtr160_04h_rawlings.pdf.

[230] Pacific Southwest Research Station, 1996. Forest Service, U.S. Department of Agriculture, Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues; 19–22 March 1996, San Luis Obispo, CA. Gen. Tech. Rep. PSW-GTR-160. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. Available at: http://www.fs.fed.us/psw/publications/documents/psw_gtr160/psw_gtr160_04h_rawlings.pdf.

trunk diameters of 25 feet at 4 feet above ground. (Jepson 1910, pp. 205-206). Jepson goes on to explain, "The great size attained by these oaks is readily accounted for. They inhabit the most fertile loams and live in situations where the water-table is only twenty to forty feet, or frequently but ten feet, below the surface...the largest individuals, as well as the largest groves are characteristics of, although not peculiar to, delta lands or half-drained valleys. Such areas are subject to overflow in the winter with the rains, or in the spring with the "spring-rise" from melting snow in the mountains." (Jepson 1910, pp. 206-207). He speculated, based on ring diameter, that the growth of these oaks was stunted in the Kaweah River area in Tulare Basin due to irrigation diversions reducing their water supply. Similarly, Pavlik et al. (1991) noted that "Where groundwater pumping has drastically lowered the water table, valley oaks have become slow growing and haggard." (Pavlik et al. 1991, p. 11). Thus, it is reasonable to anticipate that the immense riparian oaks would evapotranspire more water than the smaller plains woodland oaks.

Thus, the hardwoods in this vegetation class have different water-using strategies depending upon their location and root systems. Therefore, we subdivided valley/foothill hardwoods into two subclasses for purposes of estimating evapotranspiration (but not vegetation areas) to address the differences in water use strategies: (1) valley oak savannas and (2) foothill hardwoods (Howes et al. 2014).

The foothill hardwoods grew in areas with deep water tables, relied on soil moisture, and were drought-resistant. The valley oak savanna, on the other hand, was typically present in lower elevation areas with shallower water tables and was rooted to the permanent water table (Howes et al. 2014; Dutzi 1978). Early settlers, for example, called the valley oak in these areas "swamp oak" or "water oak", names indicative of their preferred habitat, floodplains and valley floors subject to winter overflows with abundant water supplies. (Cunningham 2010).

We had no basis for estimating the acreage of each of these subclasses. The areas shown in Figure 2 and summarized in Table 1 are the sum of valley oak savanna and foothill hardwood, called "valley/foothill hardwood." As the evapotranspiration from these two classes differ due to differences in depth to groundwater and root systems, we estimated the range of evapotranspiration from valley/foothill hardwoods by assuming an area range from 100% foothill hardwood to 100% valley oak savanna in water balance sensitivity analyses in Fox et al. 2014.

The area of each type of hardwood by planning area is summarized in **Table 6**. The total hardwood within the Valley Floor was about 1.6 million acres. This included about 1 million acres of valley/foothill hardwood as mapped by CSU Chico plus additional areas in the foothills and floodplains as follows:

- Blue oak-digger pine forest: 558,322 acres (of which 16,079 acres was within "other floodplain habitat");
- Northern yellow pine forest: 57,724 acres;
- Sierran montane forest: 2,003 acres; and
- Coast range montane forest: 1,461 acres.

3.6 Riparian Vegetation

Riparian vegetation[231] was found along all of the low-velocity waterways in the Central Valley, but the largest areas occurred on the rivers with the largest natural levees. The riparian forest extended from the banks to the edge of the moist soil zone, and, in many cases, as far as the hundred-year flood line, up to 4 to 5 miles on each side on the lower Sacramento River, where natural levees were widest. (Garone 2011, pp. 24-25; Katibah 1984, p. 24; Barbour et al. 1993, p. 75). They were also present along tributaries of the main rivers and the upper San Joaquin River. (Roberts et al. 1977, Figure 2; Warner and Hendrix 1985, pp. 5.10 - 5.11; Whipple et al. 2012 , pp. 274-300; Williamson 1853, p. 12 ("This river, as indeed are all the rivers flowing into the San Joaquin and the lakes, is fringed with trees.").)

Table 6. Classification of Valley/Foothill Hardwoods (Acres)

		Kuchler Omitted From Chico									
		Foothill Hardwood					**Other Floodplain Habitat**	**Sutter Butte**	**TOTALS**		
Planning Area		Yellow Pine Forest	Blue Oak Digger Pine Forest	Coast Range Montane Forest	Sierran Montane Forest	Total Foothill Hardwood	Blue Oak Digger Pine Forest	Blue Oak Digger Pine Forest	Total Hardwood Küchler	Total Hardwood Chico	**TOTAL HARDWOOD**
Sacramento	502	1,641	69			1,710			1,710	0	1,710
	503	38,661	38,356	1,461		78,478			78,478	243,265	321,743
	504	17,422	56,949		2,003	76,374	24		76,398	116,409	192,807
	505		77			77			77	0	77
	506		96,758			96,758	47		96,805	78,772	175,577
	507		17,314			17,314	15,987	12,482	45,783	140,761	186,544
	508		199,623			199,623			199,623	13,799	213,422
	509		31,254			31,254			31,254	112,392	143,646
	511		11,814			11,814	21		11,835	114,437	126,272
Delta	510					0			0	53	53
	602					0			0	85	85
San Joaquin	601					0			0	0	0
	603		14,608			14,608			14,608	185,542	200,150
	604		1,680			1,680			1,680	151	1,831
	605					0			0	0	0
	606					0			0	0	0
	607					0			0	3,349	3,349
	608					0			0	4,173	4,173
	609					0			0	1,239	1,239
	610		70			70			70	95	165
	TOTAL	**57,724**	**468,572**	**1,461**	**2,003**	**529,761**	**16,079**	**12,482**	**558,322**	**1,014,522**	**1,572,844**

The riparian zone consisted of an elevational sequence of communities that extended back from the river, typically progressing through willow thicket, cottonwood forest, and valley oak forest. (Barbour 1986, p. 18). Others have characterized these forests as dominated by oak (*Quercus* spp.) and California sycamore (*Platanus racemosa*) in the canopy and willow (*Salix* spp.) in the understory. (Whipple et al. 2012, p. 211). CSU Chico (2003) included the oak forest in its valley/foothill hardwood classification. Most of the trees in the riparian zone were confined to the streamside environment or other areas with plentiful subsurface moisture.

[231] Described by Chico State as, "**Riparian** – Riparian habitats in the valley are associated with low velocity waterways. They include freshwater bodies, watercourses, estuaries, and surface emergent aquifers. They generally have deep alluvial soils and a high water table. The dominant canopy species include California Sycamore (*Platanus racemosa*), Valley Oak (*Quercus lobata*), Fremont Cottonwood (*Populus fremontii*), White Alder (*Alnus rhombifolia*), Oregon Ash (*Fraxinus latifolia*), and numerous species of Willows (*Salix spp.*). The lower layers of vegetation include California Box Elder (*Acer negunde subsp. californicum*), Coyotebrush (*Baccharis pilularis* ssp. *consanguinea*), Blackberries (*Rubus* spp.), Sand Wild Rose (*Rosa californica*), and various annual and perennial herbaceous species. California Grape (*Vitus califonica*), Poison Oak (*Toxicodendron diversilobum*), and Dutchman's Pipe (*Aristolochia californica*) are the resident vine species that inhabit the riparian zone." Available at: http://www.gic.csuchico.edu/historic/3_1a.html.

Cottonwood and willow were dominant at river edge, joined by Oregon ash, boxelder, and California black walnut on lower terraces and gravel bars. Many shrubs, including buttonbush, honeysuckle, and wild rose were also common. (Fox 1987a, pp. A2-6 to A2-9; Roberts et al. 1977; Conard et al. 1977;[232] Warner and Hendrix1984;[233] Barbour et al. 1993, pp. 73-74; Jepson 1893,[234] pp. 238-247). Though valley oaks and sycamores were components, they were typically on higher terraces. The oaks thinned out to less dense woodlands away from the immediate vicinity of the river (Bakker 1984,[235] pp. 146 -147; Warner and Hendrix 1984; Katibah 1984, pp. 46 -50; Warner and Hendrix 1984, pp. 356-374) and were separately mapped by CSU Chico (2003) as valley/foothill hardwoods.

Early explorers commented upon the "great luxuriance" (Wilkes 1842;[236] "great density" Gayton 1936;[237] "dense forest;" Bryant 1848;[238] "very large trees" Cook 1960;[239] and the "immense size" of the trees, Belcher 1837;[240] Phelps 1841[241]), among others. (Fox 1987b,[242] Appx. A; Thompson 1961). Numerous eyewitness accounts by trained observers are reported in an agricultural survey of the San Joaquin River in 1861 (Kooser et al. 1861[243]) and in the Pacific Railroad Report. (Williamson 1853[244]). Many observations of the luxuriant nature of remnant

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[232] Conard, S., McDonald, R., and Holland, R., 1977. Riparian Vegetation and Flora of the Sacramento Valley, pp. 47-55, In: A. Sands (Ed.) Riparian Forests in California: Their Ecology and Conservation, University of California, Davis, Institute of Ecology Publication No. 15.

[233] Warner, R.E and Hendrix, K.M., 1984. California Riparian Systems. Ecology, Conservation, and Productive Management, University of California Press, 1984.

[234] Jepson, W.L., 1893. The Riparian Botany of the Lower Sacramento, Erythea, v. 1, pp. 238-247.

[235] Bakker, E., 1984. An Island Called California. An Ecological Introduction to Its Natural Communities, 2nd Ed.

[236] Wilkes, C., 1842. Narrative of the United States Exploring Expedition, During the Years 1838, 1839, 1840, 1841, 1842, Vol. 5, Philadelphia.

[237] Gayton, A.H., 1936. Estudillo Among the Yokuts, 1819, in Essays in Anthropology in Honor of Alfred Louis Kroeber, University of Califiornia Press.

[238] Bryant, E., 1848. What I Saw in California: Being the Journal of a Tour, in the Years 1846, 1847, Ross & Haines Inc., Minneapolis, 1967; Reprint of 1848 Edition.

[239] Cook, S.F., 1960. Colonial Expeditions to the Interior of California, Central Valley, 1800-1820. Anthropological Records. 16:6. pp. 239-292, University of California Press, Berkeley and Los Angeles.

[240] Pierce, R.A. and Winslow, J.H. (Eds), H.M.S. Sulphur at California, 1837 and 1839. Being the Accounts of Mid-Shipman Francis Guillemard Simpkinson and Captain Edward Belcher, The Book Club of California, San Francisco, 1969.

[241] Phelps, W.D., 1841. The Journal and Observations of William Dane Phelps. Arthur H. Clark Co., Glendale, California. Busch, B.C. (Ed.), Alta California 1840-1842.

[242] Fox, P. 1987b, Additional Evidence in Regard to Freshwater Inflow to San Francisco Bay Under Natural Conditions, Appendix A, Britton, A.S., Eye Witness Accounts of Riparian Forest in the Central Valley 1776 to 1862, SWC Exhibit 281 .

[243] Kooser, B. P, Seabough, S., and Sargent, F.L., 1861. Notes of Trips of the San Joaquin Valley Agricultural Society's Visiting Committee on Orchards and Vineyards, Reports of Committees, Committees Nos. 1 and 2 on Farms and Orchards, Transactions of the S.J.V. Agricultural Society. pp. 258 - 298., pp. 262, ("Numerous clusters of giant sycamore and white oak trees..."), p. 264 ("In the river bottom, white oak, ash, elm, alder, etc., with the usual varieties of willow, might be seen."), p. 275 (between the Calaveras and Mokelumne Rivers, where we show no riparian forest, "sparsely timbered with live oak, white oak, etc." and "Inclining to the west...dense willow groves and all kinds of timber usually found in swamp and overflowed land.."), p. 280 (Steamboat Slough at junction with Mokelumne River, "The banks are heavily timbered with sycamore, ash, elm, and black walnut. Many of the trees are fringed with rich drapery and dark green foliage of wild grape vines.."), p. 288 (Calaveras 7 mi. from Stockton, "banks...lined with a variegated belt of timber and shrubbery, very dense...Among the varieties of timber, the maple, ash, alder, birch, and willow, are prominent; the wild rose is intermixed everywhere in profusion, and wild grape-vines spread themselves over nearly every other tree."), etc.

[244] Williamson 1853, See, e.g., v. V, p. 11, July 18, 1853, "Leaving the San Joaquin, we passed eastward along the south side of the Tuolumne and a short distance from its left bank. Its course over the plains was distinctly marked by the green timber along its bottom-land, and we encamped on its borders in a splendid grove of oaks. The size and beauty of these trees, and the luxuriance of other vegetation, bore testimony to the depth and richness of the soil, and its adaptation for agriculture. "

riparian forest are found in soil surveys conducted in the early 20th century.[245] An etching of the subject vegetation in the Delta from an 1852 report is shown in **Figure 17.**

The original extent of riparian forest was not surveyed under natural conditions. However, maps prepared by some of the early explorers show that streams were lined with trees. Derby located riparian forest in the Sacramento Valley in 1849; Doherty at the intersection of the Sacramento and American Rivers in 1859; Nugen located forest along the lower San Joaquin River in 1853; and Gibbes located riparian forest along the San Joaquin to the mouth of the Tuolumne River in 1850; Ringgold (1852[246]) also showed riparian vegetation on his navigation charts of the lower Sacramento River. Some Mexican land grant maps also identify these forests. (Becker 1964[247]).

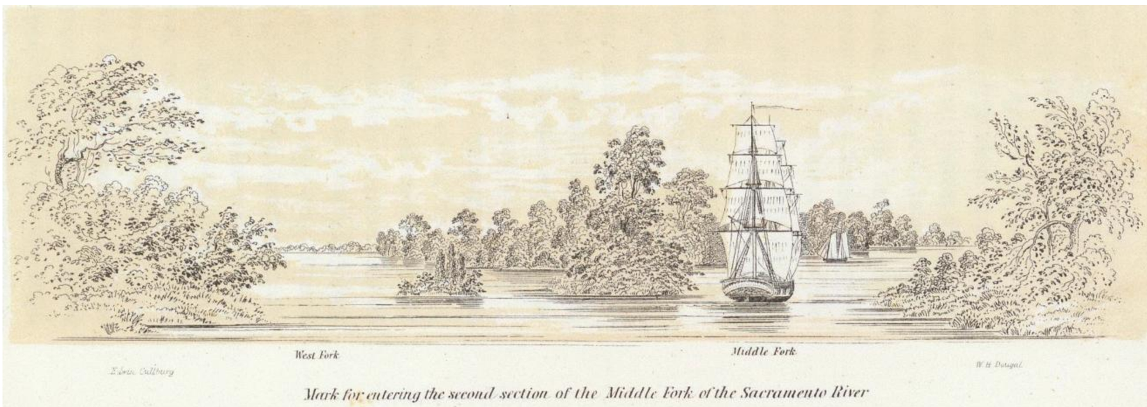

Figure 17. Middle Fork Sacramento River in Delta 1852
Source: Ringgold 1852

The CSU Chico map returns 721,460 acres, of which 594,454 acres are in the Sacramento Basin; 3,345 acres are in the Delta; and 123,661 acres are in the San Joaquin Basin. CSU Chico's (2003) estimate for the Sacramento valley (444,000 acres) is about equal to Dutzi's

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[245] For the Red Bluff area, Holmes and Eckmann (1912), p. 50 "In a natural state the Vina clay loam supports valley oaks of large size. Luxuriant growth of wild oats yield hay upon such portions as are not under cultivation." p. 53, In Sacramento fine sand, "Lofty cottonwoods, sycamores, and oaks with interlacing branches are often festooned to their tops with masses of wild grape vines. Beneath the trees occurs a tangled growth of wild rose bushes, weeds, brush, and grapevines, while masses of driftwood render the areas almost impenetrable."; p. 56, In Sacramento silt loam, "At the time when the first white settlers occupied this section of the valley the areas of this type were rather heavily wooded...The areas subject to continued flooding supported a tangled growth approaching the tropical jungle in density...There are large sections, however, which retain the tangled growth of vegetation -- chiefly oak, cottonwood, sycamore, willow, and wild grape." For the Woodland area, p. 6, "....along the Sacramento River, south of Eldorado Bend, of a tangled forest growth of willow, cottonwood, alder, and brush.", p. 30, In Yolo silty clay, "In its native state this type was covered with a thick growth of valley oak and smaller trees." (Mann et al. 1911, p. 30). For the Sacramento area, p. 1054, "In the American and Bear river bottoms this growth of trees and brush [oaks, cottonwoods, willows] is exceedingly dense... " p. 1063, In Fresno gravel, "The finer material...often supports a considerale (sic) growth of willow, small cottonwood, and other trees and shrubs of the river bottoms." For the Redding area, p. 6, "The valley bottoms support a vigorous growth of valley oak or a dense covering of cottonwood and sycamore, with an almost impenetrable undergrowth of "willows, brush, and vines." p. 25, Sacramento silt loam"...supports a moderately heavy native growth of oaks, or in the river bottoms the typical "jungle" growth of cottonwood and sycamore trees, with a dense undergrowth of bushes and vines." (Lapham and Holmes 1908, p. 26). For the Chico area, in Columbia very fine sandy loam soil, which borders the Sacramento River along the western margin, "In the natural condition this soil is covered with a thick growth of trees including willow, oak, cottonwood, ash, and a dense undergrowth of bushes, vines, nettles, and weeds." (Watson et al. 1929, p. 43).

[246] Ringgold, C., 1852. A Series of Charts, with Sailing Directions, Embracing Surveys of the Farallones, the Entrance to the Bay of San Francisco, Bays of San Francisco and San Pablo, Straits of Carquines and Suisun Bay, Confluence and Deltaic Branches of the Sacramento and San Joaquin Rivers and the Sacramento River (with the Middle Fork) to the American River, including the Cities of Sacramento and Boston, State of California, 1852.

[247] Becker, R.H., 1964. Diseños of California Ranchos. Maps of Thirty-Seven Land Grants (1822-1846) from the Records of the United States District Court, San Francisco, The Book Club of California.

(1979) estimate for this area (438,000 acres), which is not surprising as CSU Chico relied on Dutzi for its pre-1900 mapping. The difference is primarily due to differences in the boundary of the Sacramento Valley.

However, CSU Chico's estimate for the Valley Floor (721,460 acres) is low compared to estimates by others including Küchler (1977) (874,000);[248] Roberts et al. 1977 (933,660 acres)[249]; Katibah 1984 (921,000 acres); and Warner and Hendrix (1985). Warner and Hendix comprehensively reviewed estimates available through 1985 and concluded that "the present "best estimate" of pre-settlement riparian wetlands vegetation in the Central Valley is at least 1,600,000 acres...". (Warner and Hendrix 1985, p. 5.18). CSU Chico mapped areas shown by others as riparian forest as grasslands or other floodplain habitat, which use less water. Further, CSU Chico separated out the riparian oak fringe of the riparian zone in some areas, which is generally included in most estimates of riparian acreage. Barbour et al. (1993), for example, estimated 900,000 acres of riparian forest, which they described as including the fourth zone, or the valley oak forest. (Barbour et al. 1993, pp. 74-75).

3.7 Saltbush

San Joaquin saltbush is open, broad-leaved evergreen and/or deciduous shrub communities. An undergrowth of herbaceous plants may vary from dense to absent. (Küchler 1977, p. 935). This vegetation was present on the west side of the San Joaquin River, much of it within the floodplain as mapped by CDPW (1931b). CSU Chico (2003) mapped this area as "other floodplain habitat." Thus, we used Küchler (1977) to assign a vegetation type so that evapotranspiration could be estimated. We estimated 122,256 acres based on Küchler (1977). Most of the Küchler (1977) saltbush falls within areas classified as vernal pools based on soil surveys, many indicating presence of alkali from high water tables. However, the soil surveys identified some areas with alkali soils that were not identified as saltbush habitat.

3.8 Chaparral

Chaparral is the evergreen dense communities of needle-leaved and broad-leaved evergreen sclerophyllous shrubs, including manzanita, chamise, chaparral, sage scrub, grassland, and oak woodland that vary in height from 1 to 3 m. An understory is usually lacking. It dominates the cismontane side of coastal mountain ranges. It occurs at lower elevations but is absent in plains, deserts and high elevations. (Küchler 2007[250], p. 927; Keeley and Davis 2007[251]).

The chaparral in the Valley Floor is outside of the area mapped by CSU Chico (2003) so we used Küchler (2007). The Valley Floor contains 102,317 acres of chaparral, all located on the west side of the Valley (Figure 2).

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[248] As reported by Shelton 1987.

[249] The Roberts et al. 1977 map was digitized and the area determined using the "Calculate Geometry" feature in ArcMap returning 671,112 acres in the Sacramento Basin, 57,030 acres in the Delta, and 205,518 acres in the San Joaquin Basin.

[250] Küchler, A.W., 2007. Endnotes In: Michael G. Barbour, Todd Keeler-Wolf, and Allan A. Schoenherr, Terrestrial Vegetation of California, Third Edition, University of California Press, Berkeley.

[251] Keeley, J.E. and Davis, F.W., 2007. Chaparral, In: Michael G. Barbour, Todd Keeler-Wolf, and Allan A. Schoenherr, Terrestrial Vegetation of California, Third Edition, University of California Press, Berkeley.

3.9 Aquatic

Chico defined "aquatic" as including major water bodies, including lakes, reservoirs, and estuaries. Under natural conditions, the Valley Floor contained open water surfaces, including lakes, sloughs, and overflow basins. The open water surface area was determined from historic sources to be about 68,000 acres (Fox, 1987a, Table 3). This compares favorably with the CSU Chico (2003) estimate of aquatic areas of 61,212 acres. The surface area of flooded overflow basins is not included in our estimate of aquatic land area.

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Appendix A

Freshwater Inflow to San Francisco Bay under Natural Conditions

APPENDIX 2

FRESHWATER INFLOW TO SAN FRANCISCO BAY UNDER NATURAL CONDITIONS

Phyllis Fox

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ACKNOWLEDGEMENTS

The ideas in this report are the product of many minds. I am grateful for the lively discussions, assistance, and information that I have received from the following: Jerry Cox, Ed Huntley, Maury Roose, Price Schriener, Jerry Vayder, and Bob Zettlemoyer of the California Department of Water Resources; B.J. Miller, Water Consultant; and Alex Horne of the University of California at Berkeley, who beat me to the idea. I am also grateful for the assistance I have received from numerous individuals at the Water Resources Archives and Bancroft Library of the University of California, Berkeley and Sacramento State Library. Some of the planimetering and historical research were ably performed by Alison Britton. However, I alone am responsible for errors and omissions. This work would never have been conceived and implemented were it not for Dick Clemmer's early recognition of its importance and his vital support and persistence in paving the way for a new concept.

FRESHWATER INFLOW TO SAN FRANCISCO BAY UNDER NATURAL CONDITIONS

Freshwater inflow to San Francisco Bay from the Delta is presently about the same as it was under natural conditions. Drainage, reclamation, flood control, and water development in the Central Valley have not significantly affected the quantity of freshwater reaching San Francisco Bay. Early development in the Valley increased outflows while subsequent development reduced them to about their initial level. Evaporative water losses from the original marshes and riparian forests in the Central Valley exceeded present in-basin use and exports by about 10 percent. The monthly distribution of flow into San Francisco Bay was much more uniform under natural conditions than it is presently, and winter and spring pulse flows that are common today were probably rare under natural conditions.

The results of our analyses are summarized in Figure 1, which shows changes in Delta outflow as the Valley develops. We have also plotted along the bottom of this chart the historic events that were responsible for the changes. Early development in the Valley increased Delta outflow from 13 million ac-ft/yr around 1770 to about 28 million ac-ft/yr between 1850 and 1900. The increase occurred primarily because high water-using vegetation (tule marsh, riparian forest) was replaced by lower water-using crops and urban areas. This native vegetation used over 17 million ac-ft/yr of water, more than is presently exported from and used within the Central Valley. The increase in water yield that occurred when native vegetation was removed was subsequently used primarily for agriculture and domestic water supply, returning freshwater inflow to about the amount that naturally reached San Francisco Bay.

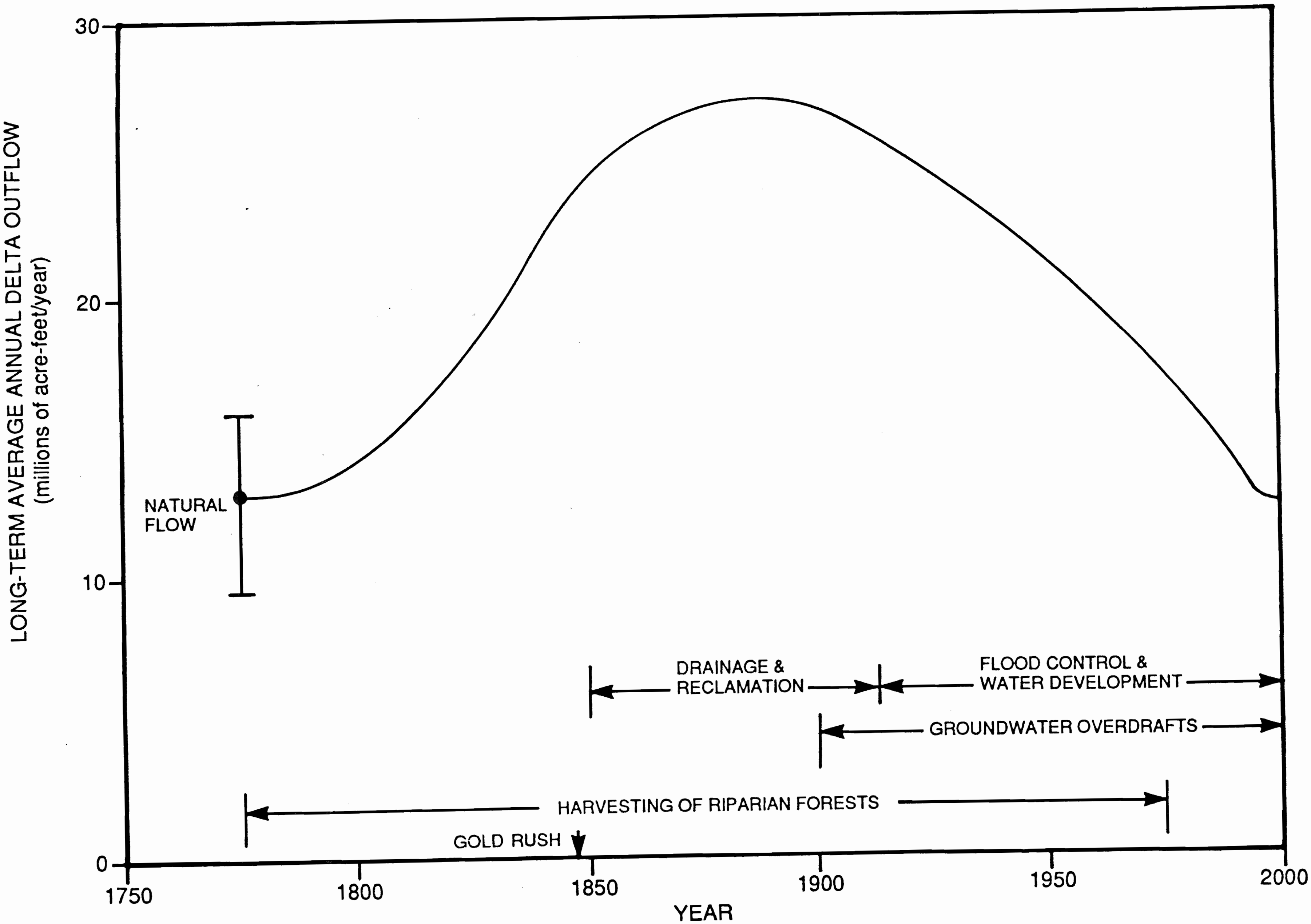

FIGURE 1. Summary of Historic Changes in Delta Outflows.

Originally, the trough of the Central Valley functioned as a reservoir filling and draining every year. Tule marshes choked these natural reservoirs and riparian forests lined the stream channels along the Valley floor. This natural vegetation took advantage of the plentiful supply of water, using far more than the irrigated crops that replaced them.

When the Central Valley was developed, the natural flood basins were drained, the tule marshes and riparian forest were replaced by irrigated crops, and the upslope forests were harvested. The original languid, slow moving, quasi-lake-like environment in the Central Valley was transformed into the highly channelized system with very short hydraulic residence times and high velocities that we know today. The principal result of upstream development has been to replace Valley reservoirs with man-made upstream reservoir storage and evaporative water losses by natural vegetation with consumptive use by agricultural crops and humans.

In this report, we estimate freshwater inflow to San Francisco Bay from tributary drainages in the Central Valley. Natural flows are defined here as those that occurred in a virgin, undisturbed state, prior to any significant human intervention. We use as our starting point the unimpaired flows calculated by the California Department of Water Resources [DWR 1987]. These estimates did not include the high evaporative water losses from natural vegetation, and they assumed present channel configurations.

THE NATURAL LANDSCAPE

The physical geography and vegetation in upstream drainages to San Francisco Bay (Sacramento Basin, the Delta region, and the San Joaquin Basin) were massively altered during early settlement and development of the Valley. This section describes the natural hydrology and primitive vegetation of the Valley and outlines its transformation into the system we know today. We have organized our discussion around the principal geomorphic features of the Valley as delineated by Bryan (1923, p. 9) — riverlands, flood basins, Delta islands, and plains. These features are shown in a schematic cross section of the Valley in Figure 2. Moving from the main rivers (Sacramento, San Joaquin) outwards are found the riverlands, flood basins, and plains.

In the following sections, we focus our discussion on the Central Valley because we intend, in the analyses that follow, to estimate freshwater inflow to the Bay using a water balance around this area. This region also contributes about 99 percent of the freshwater to the Bay. The Central Valley comprises about 20,000 square miles and extends from near Red Bluff in the north to near Bakersfield in the south, a distance of about 400 miles. The average width of the Valley is about 50 miles. We emphasize the area north of Fresno and the San Joaquin River because over 99 percent of the water of interest originates in that area. We include the Tulare Lake Basin overflow as an inflow to the Central Valley.

Riverlands and Riparian Forests

The riverlands, the flood plains immediately adjacent to rivers and streams, and their riparian forests were one of the most prominent features of the Valley. They appeared as winding ribbons of green against a monotonously flat plain and were thus extensively described by early visitors [e.g., Farquhar 1932a]. In most parts of the Valley, the riverlands comprised banks of flood-borne sediments that were locally known as "rim lands" or "natural levees." These levees occurred along the Sacramento River from Red Bluff downstream and were most extensively developed in the river's middle reach from Ord Ferry to Sacramento. They were also present along the entire length of the San Joaquin River [Davis et al. 1959, p.27], though they were less well developed there because peak flows were typically less, thus limiting their ability to pick up and carry sediment for great distances [Katibah 1984]. Natural levees were also present in most Delta channels and along major

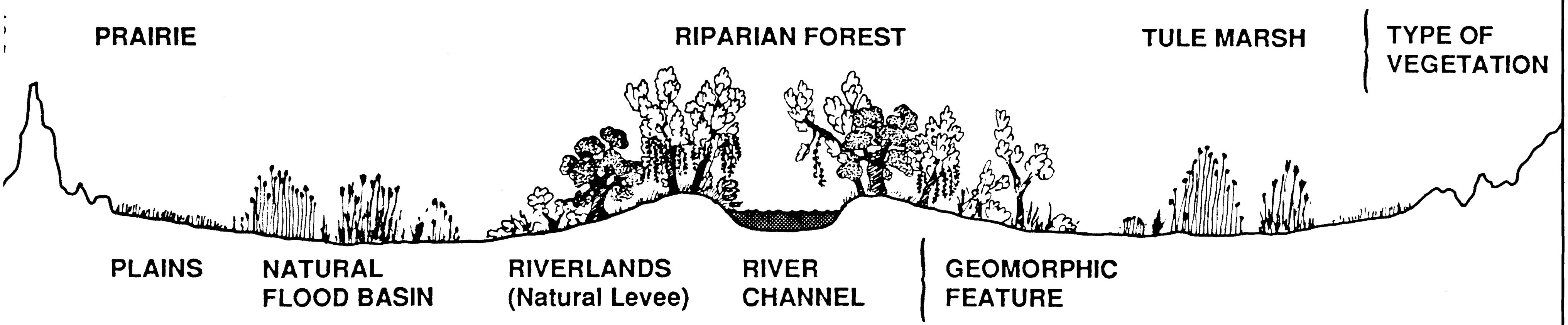

FIGURE 2. Typical Cross Section of Central Valley (Not to Scale) Showing Principal Geomorphic Features and Natural Vegetation.

tributaries, including the Feather, Tuolumne, Stanislaus, Merced, Mokelumne, Fresno, and Cosumnes Rivers. They rose some 10 to 30 feet above the normal water level and extended several miles back from the river's edge [Bryan 1923; Davis et al. 1959].

These levees confined the main streams to their regular channels when water levels were at low to moderate stages. They also prevented overland runoff from the foothills and Valley floor from entering the main channels. When winter and spring runoff were high, however, the natural levees were overtopped by annual flood flows. The levees also were more or less discontinuous, and breaks were common along the main river, allowing flood flows to escape the main channels and fill the natural basins flanking the main-stem rivers [Bryan 1923].

The natural levees were formed by repeated overflows of sediment-laden river water onto adjacent lands and occur where the valley slope is lowest and the duration of overbank flow is highest. The coarse, sandy material deposited close to the channel (sandy loams) gradually built-up, forming broad slopes that fall gently away from the river. In the Sacramento Valley, these flood plains are occupied by soils of the Columbia series [Holmes et al. 1916] and in the San Joaquin Valley, by soils of the Hanford loam series [Nelson et al. 1918]. Because they are primarily coarse sediment, these levees are extremely porous and transmit water readily.

These riverlands supported riparian forest habitat, which included Fremont cottonwood, box elder, valley oak, and various species of willow. Many shrubs, including buttonbush, honeysuckle, wild rose, and berry were also common [Bakker 1971; Jepson 1893; Thompson 1961; Roberts et al. 1977; Hoover 1935; Conard et al. 1977; Warner 1984]. Thompson (1961) has chronicled the eye witness accounts of riparian forests in the Sacramento Valley, and Landrum (1938) has provided similar information on the San Joaquin Valley. The areal extent of this vegetation has also been mapped [Kuchler 1977; Roberts et al. 1977] and is shown on Figure 3.

These riverlands were more extensively altered by man than any other natural landscape in California [Bakker 1971], and they were one of the first major losses in the natural environment [Katibah 1984; Scott and Marquiss 1984]. Limited use of these forests probably occurred during the first settlement of the Valley around 1820 and slowly increased until the Gold Rush in 1849, when such use greatly accelerated [Katibah 1984]. Estimates based upon historic accounts indicate that 775,000 to 800,000 acres of riparian forest were present in the Sacramento Valley [Smith 1977; Roberts et al. 1977; Michny 1980] around 1850. By 1972, only 12,000 acres remained [Roberts et al. 1977].

Since the riparian forests were the only significant woody vegetation on the Valley floor, they were used by early settlers for fencing, lumber, and fuel [Thompson 1961]. Steamships transporting miners and supplies upriver were heavy users of local wood fuel. In the decades following the Gold Rush, many settlers turned to farming. This agricultural development began on the natural levees because they were higher and less subject to flooding [Scott and Marquiss 1984]. Most of these lands were converted to orchards and annual row crops [McGill 1975]. Additional losses of riparian forests were caused by streambank stabilization, channelization, gravel and gold mining, and grazing [Roberts et al. 1977; Warner 1984].

The removal of riparian vegetation from the riverlands significantly altered the hydrology of the Central Valley. It is well known that forests and brush reduce stream flow and decrease maximum daily discharge and normal flood peaks [e.g., Hoyt and Troxell 1932; Love 1955; Lewis 1968; Robinson 1952; Hibbert 1971; Turner and Skibitzke 1951]. Riparian vegetation is deep rooted and uses large quantities of water [Robinson 1958; Young and Blaney 1942]. The vegetative canopy and understory also intercept precipitation, storing it for subsequent use and evaporation, thereby altering the seasonal distribution of runoff [Lewis 1968].

Natural Flood Basins and Tule Marsh

The flood basins are shallow troughs that lie between the low plains and the natural levees along both sides of the Sacramento River and San Joaquin Rivers (Figure 2). They stretched from below Red Bluff on the Sacramento south to Bakersfield in the Tulare Lake Basin, and in wet years the entire Valley was a veritable inland sea. The early history of the Valley is rife with descriptions of the floods, starting with the great flood of 1805, which allegedly covered the entire Valley except the Sutter Buttes. The flood history of the Valley has been reviewed by several writers [Thompson 1960; Simpson and Meyer 1951; Gilbert 1879; Small 1929; Grunsky 1929].

The boundaries of these ancient flood plains (or overflowed lands, as they have often been called), are shown on Figure 3. These shallow flood basins were locally known as "tules" because of the heavy growth of tules (Spanish for reed), or rushes, which they supported [Bryan 1923, p. 39]. They were the lowest and flattest parts of the valley, they had no direct surface outlets, and they gently sloped toward the center and toward the downstream end, slowly draining into the main river channels after the flood wave had passed.

In times of ordinary high water, they were filled by overland flow that poured across the low plains in broad sheets and was trapped in the flood basins by the higher natural levees along the rivers. The basins were also filled by rivers that discharged into them either through definite channels or directly over natural levees. Many of the tributaries were not connected directly with the main rivers. They drained into the flood basins through a welter of channels, losing themselves "in the intricate plexus of sloughs which meander through the tule-land bordering the main river"

[Ransome 1896]. The hydrology of each individual flood basin is described elsewhere [Hall 1880; Bryan 1923; DPW 1931a; DPW 1931c; Davis et al. 1959; Grunsky 1929].

The existence of these flood basins was documented by early explorers and settlers [e.g., Gilbert 1879; Thompson 1960]. Fages, the first Spanish explorer to describe the Valley, wrote in 1773 that "it is all a labyrinth of lakes and tulares, and the River San Francisco (original name of the Sacramento and San Joaquin Rivers), divided into several branches winding in the middle of the plains, now enters and flows out of the lakes until very near to the place where it empties into the estuary of the river" [Bolton 1931]. Lieutenant Charles Wilkes, U.S.N., one of the first Americans to report on the Valley, wrote following an expedition in August and September 1841 that "according to the testimony of the Indians, the whole country was annually innundated" [Wilkes 1850, p. 189].

State Engineer Wm. Ham. Hall, in the first scientific treatise on the hydrology of the Valley, wrote that "in the natural state of the stream the waters of the Sacramento River, at time of ordinary flood, just overtopped the banks ...." Hall went on to define "ordinary flood" as that which "passes through the channel and over the low lands once, and perhaps twice, each winter or spring, except in seasons of drought, occurring once or twice every ten years" [Hall 1880, pps. 10-11].

Some of the flood waters that were captured in these basins seeped into the alluvial aquifers and natural levees , some drained directly back into the main channels, some was evapotranspired by the natural vegetation in the basins, and the balance was evaporated from the large surface area, many times that of present-day reservoirs. The precise distribution of these floodwaters is unknown. One estimate of drainange back into the stream channel was presented by DPW (1931b).

Since portions of these natural flood basins contained standing water and water-logged soils year-round (e.g., Grunsky 1929, p. 796; Bryan 1923), they were home to extensive areas of freshwater marshes. The estimated extent of the tule marshes is shown in Figure 3. As shown by this map, these marshes are sandwiched between the prairie and the riparian forest, and their outer limit approximately follows the natural flood basin boundaries throughout their range. Since these two boundaries were determined from different data sets and physical concepts [see DPW 1931a, 1931c; Kuchler 1964], it is striking how closely they match and is confirming evidence that both are reasonable estimates of natural conditions.

These marshes are probably the most neglected habitat type in California and have received scant botanical attention. Studies by botanists began with W.L. Jepson (1893, 1975). They have subsequently only been studied by Hoover (1935), Mason (1957), and more recently by the USGS [Atwater 1980; Atwater and Belknap 1980; Atwater et al. 1979]. The characteristic vegetation in these marshes included sedges, cattails, rushes, reeds, and other types of aquatic herbaceous vegetation [Mason 1957; Bakker 1971]. The common tule (*Scirpus acutus*), the cattail (*Typha latifolia*), and a variety of other Scirpus species were the most common plants [Hoover 1935; Atwater 1980].

The existence of these marshes is amply documented in writings of early explorers of the Central Valley, who described difficulties in getting their pack animals across the Central Valley due to the extensive marshlands (e.g., Farquhar 1932a, p. 118-119). The marshes are also shown on the maps prepared by the early explorers [reviewed by Landrum 1938] and on early maps prepared by the U.S. Department of Agriculture [Holmes et al. 1916] and the U.S. Geological Survey [Bryan 1923, Plate IV].

The evidence suggests that tule marshes were present year round, even during droughts. We reviewed diaries and correspondence from these early explorations and compiled (Table 1) eye witness descriptions of the tule marshes. We subsequently determined the year type (dry, normal, wet) from precipitation records [Anon. 1886; Graumlich 1987]. These analyses indicate that tule marshes were present throughout the Valley under all types of hydrologic conditions, including drought. Present day accounts also suggest that these marshes did not dry up. Bryan (1923), describing conditions observed during the dry period of 1912-13, wrote that, "In spite of the so-called Tule Canal, which traverses Yolo Basin ..., the basin contains some water even in the dry season..." (ibid., p.43).

The water supply for most of the freshwater marshes is believed to have been springs, groundwater, sloughs, and overflow from the main channels through breaks in the natural levies. Springs were common in the Valley under natural conditions. Assistant State Engineer Grunsky [Grunsky 1929 p. 793] reported that there were many places with "a large outflow in springs. These springs have a fairly constant flow throughout the year ...." In the Sacramento Valley, groundwater was within 1 foot of the surface in much of the area supporting marsh habitat. Elsewhere, where the marshes were underlain by clayey soils, they were probably supplied by sloughs that communicated with surface streams and/or groundwater. In the Delta, marshes had a constant, year-round water supply from groundwater discharge and drainage from upslope flood basins. Some riparian species in the Delta and lower Sacramento River have even been reported to grow much larger than elsewhere due to their abundant water supply [Jepson 1893], and remnant wetlands of the Delta today produce extraordinary amounts of organic matter [Atwater and Belknap 1980].

After the riparian forest, the natural flood basins (or tule lands), were developed next. These lands had been regarded as wastelands by early settlers, who avoided

TABLE 1

EYE WITNESS ACCOUNTS OF TULE MARSH IN THE CENTRAL VALLEY

Observer/Date	Year Type[a]	Reference
Sacramento Valley		
April 1817 Arguello	Dry	Cook (1960), p.276
March 1833 John Work	Wet	Maloney (1945), p.35
September/October 1849 Lt. Derby	Normal	Farquhar (1932a), p.252
Delta Area		
April 1772 Fages	Normal	Treutlein (1972), p.335
August 1775 Canizares	Dry	Eldredge (1909), p.65-69
April 1776 Father Font	Dry	Bolton (1933), p. 388
October 1811 Abella	Below Normal	Cook (1960), p.261
August 1837 Vallejo	Above Normal	Cook (1962), p.190
September 1846/47(?) Bryant	Above Normal	Bryant (1967),p.300-301
San Joaquin Valley		
September 1806 Moraga	Below Normal	Cutter (1950), p.101,125
September 1808 Moraga	Below Normal	Ibid., p.124-125
August/October 1810 Moraga/Father Viader	Below Normal	Ibid., p.157-158; Cook (1962), p.260
May 1817 Father Duran	Dry	Chapman (1911), p.35
September 1846/47(?) Bryant	Above Normal	Bryant (1967), p.302
July 1853 Lt. Williamson	Wet	Williamson (1855) p.10, 191-192
Tulare Lake Basin		
October 1814 Father Cabot	Dry	Cutter (1950), p.205
September-November 1815 Various observers	Dry	Cutter (1950), p.208-226
1849/1850 J.W. Audubon	Normal/Wet	Audubon (1906), p.184
April/May 1850 Lt. Derby	Wet	Farquhar (1932b), p.252

[a] For the period prior to 1850, Graumlich's (1987) data for the Southern Valleys is used, which included the Sacramento Valley. For the period 1850 to 1887, precipitation records at Sacramento (Anon. 1886) are used.

them due to the difficulties they presented — for not only was the terrain nearly impossible to cross, but recurrent outbreaks of "swamp fever" (or ague) claimed Indians and settlers alike. Thus, interest in reclaiming the swamps did not develop until after the 1850 Arkansas Act, in which the Federal government transferred ownership of all "swamp and overflowed lands" to the State on the condition that they be drained. California followed with a series of Acts and statutes, culminating in the 1868 Green Act, which created regular reclamation districts [Adams 1904].

Reclamation, even with the force of these Acts, was still painfully slow because it was technically difficult and costly, about $5.00/acre [Tide Land Reclamation Co. 1869]. No coherent reclamation program ever developed, and the disorganized and senseless manner in which it was carried out was the scandal of the era [Manson 1888; Adams 1904]. Sherman Island in the Delta was one of the first successful reclamation projects [Tide Land Reclamation Co. 1869], and by 1884, 1,270 miles of levees had been built on the Sacramento and its tributaries and on the San Joaquin below the mouth of the Stanislaus [Grunsky cited in Manson 1884]. By 1910, 300,000 acres of land in the Valley were reclaimed and by 1918, this figure has risen to 700,000 acres [Karl 1979]. By 1920 to 1930, most of the Delta marshes were leveed and reclaimed for farming [Atwater et al. 1979; Thompson 1957, pp. 208-238].

This river levee program, however, was mostly unsuccessful in containing the flood waters [Manson 1884; Scott and Marquiss 1984]. The first plan for flood control in the Sacramento Valley was developed in 1880 [Hall 1880], but implementation was slow due to its great cost, complexity, and political controversy. With the federal government's involvement, the Sacramento Flood Control Project, the first in the U.S., was completed between 1928 and 1944. This massive project included 980 miles of levees; 7 weirs or control structures; 3 drainage pumping plants; 438 miles of channels and canals; 7 bypasses, 95 miles in length and encompassing an area of 101,000 acres; 5 low-water check dams; 31 bridges; and 50 miles of collecting canals and seepage ditches [Karl 1079]. This massive public works project was followed by flood control features of the Central Valley Project in 1944. Nevertheless, flooding remains a concern in the Valley, and extensive damage occurred during the 1986 floods.

Leveeing the rivers and draining and reclaiming the marshes redistributed and increased freshwater inflow to San Francisco Bay. The natural flood basins and their marshes had provided extensive surface and subsurface storage for flood waters. The basins and marshes absorbed flood energy and reduced water velocities, partially explaining the absence of currents noted by early explorers [e.g., Bolton 1933, p. 369]. After the marshes were reclaimed and river levees constructed, flood flows that formerly spilled over the much lower natural levees were routed directly through the river channels into the Bay. This increased flood peaks [Grunsky 1929, p. 793], creating the now-famous "pulses", or high winter-spring discharges from the Delta that stratify most of the Bay. The quantity of water reaching the Bay was also increased because vegetation, which used copious quantities of water, was removed.

The Delta

These flood basins included most of the Delta, which because of its unique features merits separate commentary. In its original condition, the Delta was a vast, flat water-soaked marsh, lying near sea level [Bryan 1923; Atwater et al. 1979; Dachnowski-Stokes 1936]. It was subject to periodic overflows at high stages of the rivers and was traversed by an ever-changing network of channels and sloughs that divided the marsh into islands.

As noted by Bryan (1923, p.44), "Under natural conditions these islands were covered with water throughout a large part of the year and were always flooded at high river stages. The tide raised and lowered the level of the water over large areas..." Most of these channels had natural levees that sloped away from the channels towards the centers of the islands. Each island had a saucer-shaped surface and under natural conditions was swampy in the interior [Bryan 1923, p.10].

"Peat" and "muck" form the majority of the soils in the Delta and upstream areas, as mapped and defined by the U.S. Department of Agriculture [Nelson et al. 1918; Holmes et al. 1916; Cosby 1941]. These soils were very important in the natural hydrology of the basin [Dachnowski-Stokes 1935] because they could store water for subsequent use by native vegetation. The types of peat found in the Delta can absorb seven times their weight in water and have an absorptive capacity of 2.6 to 3 acre-feet of water per acre-foot of peat [Dachnowski-Stokes 1935, p.175].

Plains and Prairie

The area stretching from the flood basins to the foothills, known locally as the plains (Figure 2), did not play as large a role in the natural hydrology as the riverlands and flood basins. These lands were sparsely vegetated with low water-using plants similar to present day vegetation. Thus, the role they played in the hydrology of the Valley is probably not very different today than under natural conditions.

The plains were smooth and nearly level lands that were formed as flood waters spread over them, leaving behind thin deposits of silt. The vegetation in the plains was prairie, as defined by Kuchler (1977) (Figure 3). The dominant species was bunchgrass (*Stipa pulchra*) [Barbour and Major 1977, p.495]. Numerous annuals and perennial grasses were associated with *Stipa* species, as listed in Barbour and Major, as well as plants with bulbs and annuals in the Compositae, Cruciferae, and other families. Hoover (1935), describing the San Joaquin Valley, noted that "one of the most striking features of the flora of the open plains of the valley in the primitive condition was the scarcity of grasses over large areas." Fremont, in his Memoirs, described the plains as "unbroken fields of yellow and orange colored flowers, varieties of *Layia* and *Escholtzia California*..." [Fremont 1964, p.18]. Some areas in the plains, primarily north of the Delta, contained alkaline patches that supported saltbush (Figure 3).

The vegetation of the plains was swiftly altered, partly by accident, partly to accommodate grazing. Today, the herbaceous cover of the plains is dominated by annual plants, many of them introduced. In parts of the San Joaquin Valley, for instance, it has been found that more than half of the herbaceous cover is comprised of alien species, mainly from the Old World [Burcham 1957].

Groundwater

The occurrence and depth to groundwater are important considerations in evaluating the natural hydrology of the Central Valley The tule marshes would have required vast areas of water-logged soils and standing water for most of the year, and the riparian forest would have required groundwater within reach of their root systems. Our examination of the available data indicates that the riparian forest's water supply was stream flow, bank storage in the natural levees, and groundwaters. The marshes, on the other hand, were located in areas where the groundwater table was at the surface, in areas underlain by clayey soils that were supplied by sloughs, or in areas that were tidally inundated year round (the Delta). Our calculations indicate that enough water to supply the marshes was stored annually in surface soil horizons. Additional water was supplied from streams via sloughs.

Studies on groundwater hydrology of the Central Valley were reviewed recently [Page 1986]. The earliest studies were conducted by the U.S. Geological Survey between 1905 and 1913 [Bryan 1923; Mendenhall et al. 1916]. We focus on these early studies, since significant pumping for irrigation was present during later work [e.g., Olmsted and Davis 1961; Davis et al. 1959].

Under natural conditions in the Valley, groundwater aquifers were filled by precipitation falling on the foothills and plains and by flood waters that filled the natural flood basins flanking the main channels. Originally, "there (was) no adequate outlet for ground waters of the Great Valley..." [Mendenhall et al. 1916, p.28] so they escaped by "capillarity" and evaporation along the valley axis [Mendenhall et al. 1916; Bryan 1923, p.85; Hilgard 1892]. This water slowly moved downslope toward the main channels, stagnating in the valley trough. It discharged "into seeps and sloughs in the basin lands where the water evaporated; by evaporation from moist lands where the groundwater stands less than about 8 feet from the surface; and by transpiration where the groundwater is within reach of the root of plants" [Bryan 1923, p.85], forming alkali deposits.

The areas that supported marshes in the Valley were and are bordered by patches of alkaline soils in most areas. These patches delineate the areas within which groundwaters used to emerge at the surface where the marshes were located. The origin, composition, and location of these salt deposits are presented elsewhere [Hilgard 1892; Kuchler 1977; Holmes et al. 1916; Nelson et al. 1918; Bryan 1923, p.85]. These areas supported saltbush, and the largest concentration of such regions was located in the San Joaquin and Tulare Lake basins (Figure 3). These deposits are greater in extent in the San Joaquin valley because the higher precipitation to the north continuously washed the deposits away in most areas [Bryan 1923, p.86].

Bryan (1923), in his classic work on groundwater conditions in the Sacramento Valley, reported that it was "remarkable for the large area in which the water table stands close to the surface. During the summers of 1912 and 1913 — two dry years — the depth to water in more than 80 per cent of the valley was less than 25 feet. " (ibid. p.82).

In describing the location of groundwater in the flood basins, Bryan (1923) goes on to report that in dry years, over large parts of the American, Sutter, and Yolo flood basins and adjacent riverlands, that the depth to water "ranges from a maximum of 20 feet along the river bank [where the riparian forest was] to only a few inches in parts of the basins [where the marshes were]. In the basins, the maximum depth is 6 feet in the very driest years." (ibid, p. 83).

FRESHWATER INFLOW TO THE BAY

We have calculated the freshwater inflow to San Francisco Bay from a water balance around the portion of the Central Valley that drains into the Bay. The geographic boundary and areas used in our analysis are shown on Figure 4. The portion of the Central Valley that drains into the Bay is Area 2, which comprises the Sacramento Valley (Area 2a), the Delta and upslope areas (Area 2b), and the San Joaquin Valley (Area 2c). These boundaries are the same as used by the DWR in their unimpaired flow studies [DWR 1987].

The water balance we performed around the Central Valley can be expressed as follows:

Delta Outflow = Water Supply – Water Use by Native Vegetation

The total water supply is equal to the sum of unimpaired rim inflows, Tulare Lake Basin overflow, and precipitation on the valley floor. We have not included evaporative losses from flooded areas because most of these areas supported native vegetation. Evaporative water losses from flooded areas with no vegetation are probably small. We have also assumed that over the long term, the net change in basin storage (groundwater, bank storage, natural flood basins, marshes) is zero. Any water that was stored during one season would subsequently be used by native

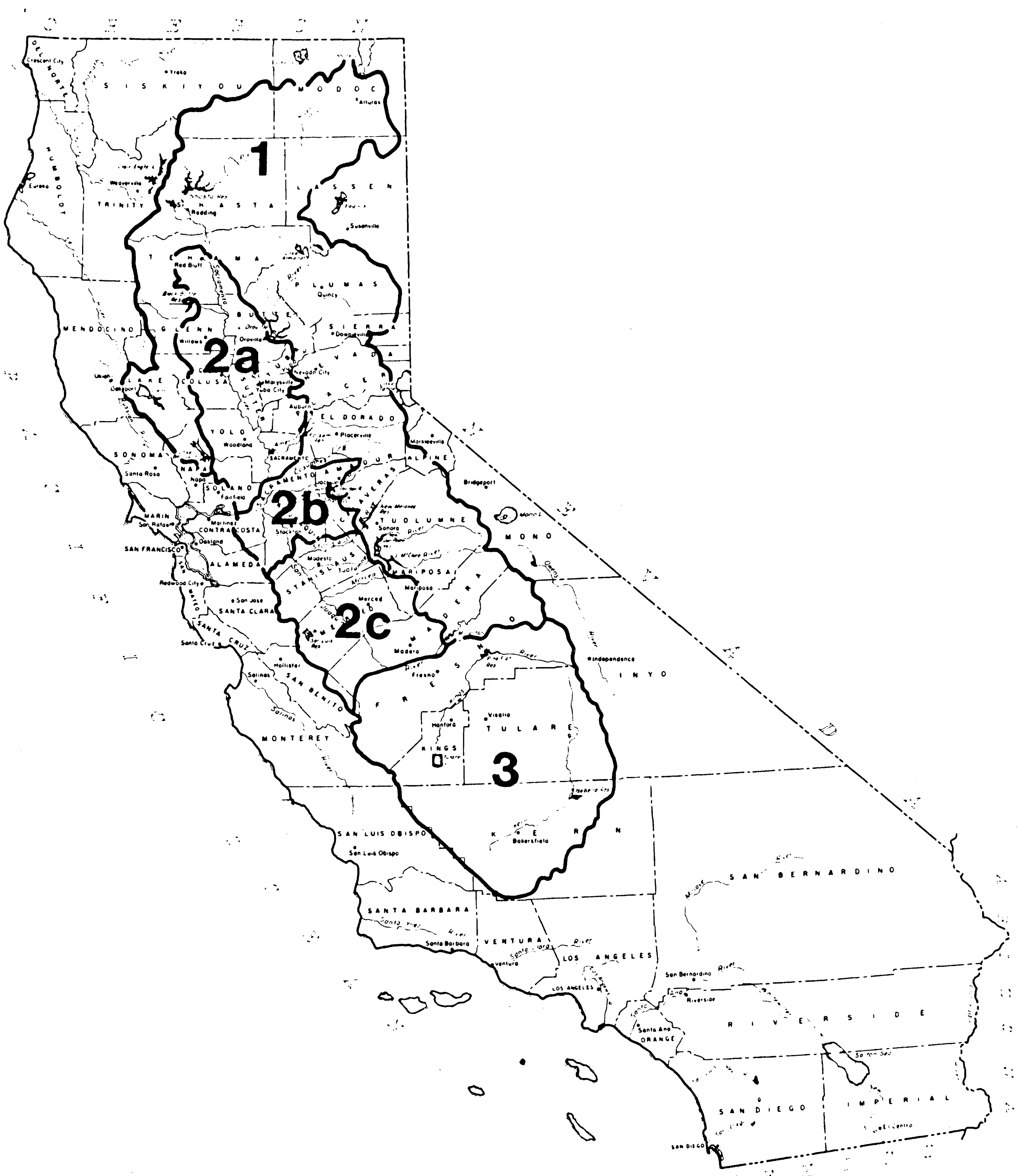

FIGURE 4. Hydrologic Units Used in Calculating Freshwater Inflow to San Francisco Bay Under Natural Conditions.

vegetation or would be released at a later time as channel flow. Our calculations are for long-term, average annual conditions.

The results of our water balance are presented in Table 2. Each element of the water balance (first column) is described and discussed in subsequent sections. This table shows the quantity of water from each source (rim inflow, Tulare Lake Basin inflow, valley floor precipitation) and the amount used by each principal type of vegetation in the Valley. We have used a range for vegetative water use because the consumptive use would have varied in different parts of the Valley.

This table shows that under natural conditions, an average of 38.8 million acre feet of water were available each year. From 51 to 80 percent of this supply was consumptively used by native vegetation and the balance entered San Francisco Bay. Slightly more than one-third of the water was evapotranspired by the riparian forests that lined all of the major streams. The balance was used by tule marshes in the natural flood basins and by prairie vegetation, in the expansive plains. The remaining 7.8 to 18.9 million acre feet annually flowed through the Delta into San Francisco Bay.

Our estimates of net water use and Delta outflow under natural conditions are compared with equivalent quantities for the "unimpaired" case and the 1990 level of development on Figure 5. Our estimates of natural net water use on this figure are the mid-points of the ranges presented in Table 2. "Unimpaired" flows are those calculated by the DWR in Exhibit 26 [DWR 1987]. These flows assume present channel configurations, no diversions, or exports, and no tule marsh or riparian forest water use. They assume that the natural flood basins and their marshes have been drained, that levees and channel bypasses are in place, and that the Valley water supply and runoff have the same characteristics as foothill areas. Although these unimpaired flows certainly never existed, their magnitude may have been

TABLE 2

FRESHWATER INFLOW TO SAN FRANCISCO BAY
CALCULATED FROM A WATER BALANCE AROUND THE CENTRAL VALLEY

Element in Water Balance		Long-term Average Annual Water (millions of ac-ft/yr)
Water Supply		
Unimpaired Rim Inflow		28.2
Tulare Lake Basin Inflow		0.2
Precipitation on Valley Floor		10.5
	Total	38.8
Water Use by Native Vegetation		
Riparian Forest		8.6 – 11.5
Tule Marsh		5.7 – 8.5
Prairie		5.6 – 11.0
	Total	19.9 – 31.0
Freshwater Inflow to San Francisco Bay under Natural Conditions		7.8 – 18.9

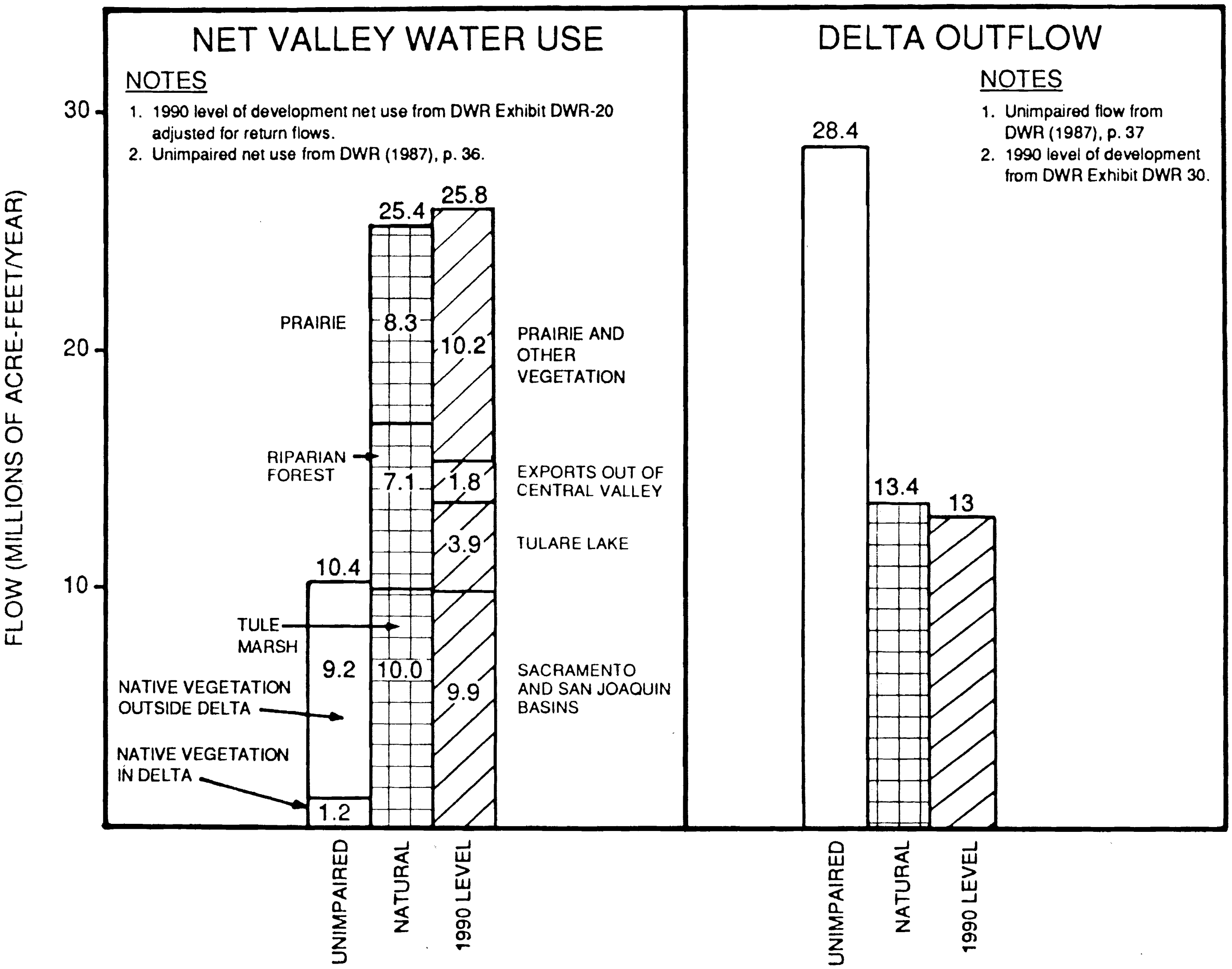

FIGURE 5. Comparison of Unimpaired, Natural, and 1990-Level-of-Development Net Water Use and Delta Outflow.

approached sometime between 1850 and 1900 (Figure 1). Considerable additional work is required to determine what the maximum outflow may have been and when it would have occurred.

Figure 5 indicates that evaporative water losses from the original marshes and riparian forests (17.1 million ac-ft/yr) were about 10 percent greater than present in-basin use and exports (15.6 million ac-ft/yr). This means that more water was used under natural conditions in the Central Valley than is used in this area today. During the first half century of California's statehood, the water supply and river flows were increased by removing the riparian forests, draining the swamps, and channelizing the streams. During the second half century, this increased supply was developed for agricultural and domestic use (Figure 1).

Figure 5 also shows that Delta outflow today is very close to what we estimate it was under natural conditions. Our calculations indicate that Delta outflow was 7.8 to 18.9 million ac-ft/yr under natural conditions, while the DWR has estimated that Delta outflow for the 1990 level of development will be 13 million ac-ft/yr [DWR Exhibit No. 30, D1485 Delta Standards], well within our range.

The following sections present the data and assumptions used to calculate the water balance discussed above.

Rim Inflows

Rim inflows are the total quantity of water from Area 1 (Figure 4) under natural conditions. They were calculated from DWR's unimpaired flow data [DWR 1987] by subtracting valley floor contributions [DWR Areas 1,12,24,17,23] from total Delta inflow (ibid., p. 35).

Land Areas

Land areas were used in a number of calculations in this work. All of the relevant areas used in our calculations are summarized in Table 3. Areas are also outlined on the map shown in Figure 3.

Flood Basins

The flood basin areas were used to calculate active groundwater storage capacity and as a rough check on the accuracy of tule marsh acreages. These areas were determined by planimetering from maps reported in DPW Bulletin 26 and 29 [DPW 1931a, 1931c] that were prepared from surveys and maps by State Engineer Wm. Ham. Hall (1880). Our estimates indicate that about 3.1 million acres of land were subject to annual innundation and that about 2.2 million acres of this was tributary to the Bay. However, even larger areas, extending into the plains, were innundated in wet years [Hall 1880, p. 8]. Our flood basin areas include the channel areas and natural levee areas, which were usually higher than the flood water level. Channel surface areas are also summarized in Table 3 from the early literature.

Tule Marsh

We planimetered the tule marsh area from Kuchler's natural vegetation map (1977), correcting it for areas that others have reported as riparian forest [Thomas et al. 1977]. These estimates indicate that there were 1.6 million acres of tule marsh in the Central Valley, and about 1 million acres were tributary to the Bay. These estimates generally compare favorably with those cited in literature prior to 1900. For example, Manson, one of Ham. Hall's assistants, wrote in 1884 that swamp lands situated on the lower San Joaquin and Sacramento rivers and their tributaries, including the Delta, encompassed about 1 million acres [Manson 1884, p. 88].

TABLE 3

LAND AREAS

Drainage Basin (Figure 4)	Flood Basin Area[a]	Channel Surface Area	Riparian Forest[f]	Tule Marsh[g]	Prairie[h]	Salt-Bush[h]	Total Valley Floor[i]
	Total Area (1,000 acres)						
Sacramento Basin (2a)	1,256	24[b]	938	295	2,256	0	3,489
Delta (2b)	588	37[c]	198	397	700	0	1,295
San Joaquin Basin (2c)	345	7[d]	298	254	2,392	148	3,092
Tulare Basin (3)	936	3[e]	515	643[j]	4,027	1,298	6,503

a Determined by planimetering the overflowed land area from Plate LXXIII [DPW 1931c] and Plate VII [DPW 1931a]. This area includes channel surface area and natural levees.

b From Hall (1880), p. 7. May include some channels in northern Delta.

c From DPW (1931b), p. 70, notes to table.

d Estimated by multiply channel area in Sacramento Basin by the ratio of the unimpaired flow from the San Joaquin Basin (6861 TAF) to that from the Sacramento Basin (24,800 TAF) for the period 1889-1929 [DPW 1931a, Table 5; DPW 1931c, Table 5).

e Estimated as in (d), but using unimpaired flow of Tulare Basin for 1889-1929 (3,510 TAF).

f Planimetered from Kuchler (1977) and Roberts et al. (1977). Kuchler was used for forest along tributaries and for all areas south of the Merced River while Roberts was used for forest along the main channels (Sacramento, San Joaquin Rivers).

g Planimetered from Kuchler (1977). Areas corrected for riparian forest along main channels as shown by Roberts et al. (1977).

h Planimetered from Kuchler (1977).

i Planimetered from Kuchler (1977). Corresponds to boundary defined by Blue Oak-Digger Pine forest and California Prairie (*Stipa* spp.). This area is the sum of riparian forest, tule marsh, prairie, and saltbush in all basins except Tulare. The Tulare Lake Basin has small quantities of other types of native vegetation that we did not consider here.

j Under natural conditions, the Tulare Valley contained a series of lakes interconnected by sloughs. The marsh and lake area varied greatly, according to historical accounts. This area is assumed to about equal the sum of marsh plus lake under average conditions.

Riparian Forest

Our riparian forest area was determined by planimetering from Robert's (1977) and Kuchler's (1977) natural vegetation maps. We used Roberts for forest areas along the main river channels (Sacramento, San Joaquin Rivers), which Kuchler showed incorrectly as tule marsh. We used Kuchler for forest along tributary streams, which Roberts underestimated by restricting the habitat to Columbia and Hanford loam soils. Our estimates indicate that there were about 1.9 million acres of riparian forest in the Central Valley, and 1.4 million acres of this were tributary to the Bay. Our estimates compare favorably with early estimates [Smith 1977; Michny 1980] but are high compared to present-day estimates derived from soil profiles. Katibah (1984) estimated that there were 921,600 acres of riparian forests in the Central Valley, and Roberts et al. (1977) estimated that there were some 771,600 acres north of the Merced River. In both cases, the forests were mapped according to soil profiles and were restricted to loams.

Precipitation on the Valley Floor

Precipitation falling on the valley floor was calculated by multiplying the area of the valley floor (Table 3) by the area-weighted average annual precipitation in feet/year. The valley floor precipitation volume for each basin (2a,2b,2c) is presented in Table 4, and the precipitation is listed in footnote (b) to that table.

The valley floor areas that we used in our calculations were obtained by planimetering from Kuchler's (1977) Natural Vegetation Map the area defined by the boundary between blue oak-digger pine forest and prairie. The area-weighted precipitation values that we used for each area (Areas 2a,2b,2c) were obtained from Schreiner (1987). They were calculated by planimetering from the annual average isohyetal precipitation map for the Central Valley for the period 1911-1960 prepared by J.D. Goodrich. The total basin areas used in these calculations were those used

TABLE 4

ELEMENTS OF WATER USE AND WATER SUPPLY BY BASIN

Basin	Natural Vegetation Water Use (1,000 ac-ft/yr)[a]				Valley Floor Precipitation[b] (1,000 ac-ft/yr)
			Prairie		
	Riparian Forest	Tule Marsh	Grasslands	Saltbush	
Sacramento Valley (2a)	5,628 – 7,504	1,770 – 2,655	2,256 – 4,512	0	5,902
Delta Valley (2b)	1,188 – 1,584	2,382 – 3,573	700 – 1,400	0	1,640
San Joaquin Valley (2c)	1,788 – 2,384	1,524 – 2,286	2,392 – 4,784	296	2,937
Totals	8,604 – 11,472	5,676 – 8,514	5,348 – 10,696	296	10,479

[a] Water use was calculated by multiplying the total land area from Table 3 by the water use. The water use used in the calculations is as follows: riparian forest: 6 to 8 ac-ft/ac; tule marsh: 6 to 9 ac-ft/ac; grasslands: 1 ac-ft/ac; saltbush: 2 ac-ft/ac.

[b] Precipitation was calculated by multiplying the total valley floor area from Table 3 by the area - weighted average precipitation for the period 1911-60 from J.D. Goodrich's (1966) isohyetal map for the Central Valley [Schreiner 1987]. The precipitation values are; Sacramento Valley - 20.3 in.; Delta area - 15.2 in.; San Joaquin Valley - 11.4 in.

by DWR in its consumptive use studies. These precipitation estimates include some foothill areas where precipitation is higher than on the valley floor. Therefore, our average precipitation values (Table 4) are slightly (<5 percent) larger than actual precipitation falling on the valley floor area. This would slightly overestimate natural Delta outflow.

Water Use by Native Vegetation

Water used by native vegetation was estimated by multiplying the area of each type of vegetation by a consumptive use value [Blaney 1954; Jensen 1973]. The areas that we used in these calculations were summarized in Table 3. The resulting water use for each type of vegetation by basin was summarized in Table 4.

This section discusses the consumptive use factors we used to estimate native vegetative water use. Normally, riparian forests and aquatic macrophytes transpire at the so-called potential rate due to the fact that their roots are continuously immersed in water. However, prairie grasses depend upon available soil moisture, and their actual evapotranspiration was probably less than the potential amount. Thus, we have selected potential evapotranspiration factors (ET) for wetland vegetation and actual (field) values for prairie vegetation.

Riparian Forest

The consumptive use of water by riparian vegetation has been determined in studies designed to save water by removing phreatophytes from along streams and canals in arid areas [e.g., Muckel 1966; Robinson 1952; Blaney 1956]. Most relevant studies have been reviewed and summarized elsewhere [Robinson 1958; Young and Blaney 1942]. Water use estimates for the principal types of vegetation occurring in Central Valley riparian forests are summarized in Table 5.

TABLE 5

WATER USE BY COMMON RIPARIAN VEGETATION IN THE CENTRAL VALLEY

Vegetation	Annual Water Use (ac-ft/ac)	Location	Reference
Field Studies			
Canyon-bottom	7.5[a]	Coldwater Canyon, CA	Blaney (1933)
Moist-land vegetation	9.4[b]	Temescal Canyon, CA	Blaney et al. (1930)
River-bottom brush	4.2	Prado, CA	White (1932)
Tank Studies			
Willows	4.4	Santa Ana, CA	Blaney et al. (1930)
Willows	2.9	Not reported	DPW (1931b)
Cottonwoods	5.2 – 7.7[c]	San Luis Rey, CA	Blaney (1957, 1961)
Alders	5.0	Santa Ana, CA	Muckel (1966)
Cottonwoods	7.6[c]	Safford Valley, AZ	Gatewood et al. (1950)

[a] Reported for the 4-month period July-October 1932 and converted to a 12-month basis using the monthly distribution of water use reported for willows (DPW) 1931b).

[b] Reported for the month of May 1929 and converted to a 12-month basis using the monthly distribution of water use for willows [DPW 1931b].

[c] Range depends on depth to groundwater, which varied from 3 to 4 feet at San Luis Rey and was 7 feet at Safford Valley.

In our estimates of evaporative water losses from riparian forests, we used an evapotranspiration (ET) range of 6 to 8 ac-ft/ac. The lower limit was calculated by weighting the water use for willows (4.4 ac-ft/ac), cottonwoods (7.7 ac-ft/ac), and river-bottom brush (4.2 ac-ft/ac) by the relative densities reported by Conrad et al. (1977) for a riparian forest along the Sacramento River (cottonwood=0.44; willows=0.20; all other=0.36). These densities are generally consistent with abundances reported by others [e.g. Warner 1984]. Our upper limit of 8 ac-ft/ac is the average of field measurements made for canyon-bottom and moist-land vegetation (Table 5).

Tule Marsh

Investigations on the consumptive use of water by aquatic macrophytes have been conducted for nearly a century, yielding a variety of contradictory results. Initially, studies were conducted in isolated tanks, which yielded rates that were up to 300 percent higher than evaporation from a free water surface [Otis 1914]. Later, it was learned that it was important to surround the tanks with similar vegetation to simulate the environment in large swampy areas [Young and Blaney 1942, p.25]. This reduced evaporation due to the insulation from surrounding vegetation.

Several other factors are now recognized as affecting water use by marsh vegetation. Canopy surface geometry (i.e., the actual surface from which water evaporates) plays an important role in evaporation from marshes. Generally, small or narrow canopies such as occur along rivers, streams, canals, and sloughs can have evaporative water losses several times greater than those from comparable open water surfaces [Blaney 1961, p.39; Anderson and Idso 1987, p. 1041]. Evaporative losses from extensive vegetative canopies such as occur in large marshes are much lower, depending upon a number of other factors, including humidity, winds, length of growing season, depth of water, age of plants, and height of canopy. Evaporative water losses from tall canopies, which are characteristic of tule marsh areas (tules and other marsh vegetation typically grow to 5 - 6 feet), are enhanced by atmospheric turbulence. A recent study reported that "evaporative water loss from a tall canopy such as cattails (*Typha latifolia*) may be as much as 40 percent greater than that from a comparable open water surface." (ibid, p. 1041). Reliable measurements of up to 90 percent greater than from a free water surface have been reported for tule marsh in California [Young and Blaney 1942; Young 1938].

We reviewed measurements of water use by tules and cattails in marsh environments similar to those of the Central Valley, and the relevant values are summarized in Table 6. Most of these values were measured in tanks (i.e., lysimeters) that were properly surrounded by native vegetation. We eliminated literature values with the following characteristics: (a) less than 12 months of data were reported; (b) abnormal growth or other anomalous conditions were described; (c) salt-water marsh (high salinity reduces evaporation).

From Table 6 and the additional considerations we summarize here, we have selected a range of 6 to 9 ac-ft/yr for tule marsh water use. The lower end of the range is probably representative of areas with lower evaporation rates (e.g., northern Sacramento Valley) and areas that lacked a full year-round water supply (i.e., probably only in Tulare Lake Basin). The upper end of the range applies to areas with a high evaporation rate (e.g., parts of Delta, San Joaquin Valley) and a full year-round supply of water (e.g., the Delta).

Our range of 6 to 9 ac-ft/ac was derived from the ratio between marsh evapotranspiration and pan evaporation first published by Young [Young 1938; Young and Blaney 1942; Anderson and Idso 1987]. The ratio of tule and cattail evapotranspiration to pan evaporation is about 1.4 and can be as high as 1.9. Since pan evaporation in the Central Valley ranges from about 5.0 to 6.5 ac-ft/ac [DWR 1979], the corresponding marsh evaporation would be 7 to 9 ac-ft/ac, which is well

TABLE 6

WATER USE BY TULES AND CATTAILS

Location	Type of Marsh	Annual Water Use (ac-ft/ac)[d]	Reference
King Island, Delta	freshwater tidal marsh	7.4 – 13.0[a]	Stout (1929-35)
Victorville, CA (Mojave River)	desert inland marsh	6.5 – 7.0	Young and Blaney (1942)
Mesilla Valley, NM (Rio Grande River)	freshwater marsh	10.1	Young and Blaney (1942)
Bonner's Ferry, ID	inland marsh	5.1	Robinson (1952)
Antioch, Delta	freshwater (?) tidal marsh	5.8[b]	Blaney and Muckel (1955)
Clarksburg, Delta	freshwater tidal marsh	9.6[c]	DPW (1931b)

[a] Value for third year of growth. Range corresponds to two different tank configurations.

[b] Calculated based on limited experiments at Joice Island in Suisun Marsh.

[c] Experiments conducted in isolated tanks and values adjusted by multiplying by a factor of about 0.5.

[d] All values measured in tank experiments in which tanks were set in natural environment unless otherwise stated.

within the range of reported evapotranspiration values (Table 6). We lowered the minimum to 6 ac-ft/ac because several of the reported values (Table 6) are around 6 ac-ft/ac.

We believe that this range is conservative and may understate the actual water use in natural Central Valley marshes. Many of the marshes in the Central Valley were supplied by sloughs, as discussed previously. The Delta, in particular, had some 37,000 acres of sloughs, and the extensive tule marsh south of the Merced River was a complex maze of sloughs. Water use by marsh vegetation growing along sloughs can be several times higher than by those growing deep within an expansive marsh [Blaney 1961, p.39; Anderson and Idso 1987, p.1041]. Actual measurements with tules and cattails suggest that water use in these fringe areas is about 20 ac-ft/ac [Young and Blaney 1942]. We have made no effort to estimate these edge effects, but they could be significant in marshes that are fed by sloughs.

Prairie

The majority of the land area in the Central Valley plains was formerly prairie (Table 3), and it initially supported a vigorous livestock industry [Burcham 1956]. Today, much of it is farmed. As discussed previously, this area was covered with a bunchgrass (*Stipa* spp.) community that included many forbs. The more alkaline soils in the Valley, located in area of groundwater discharge, supported saltbush [Kuchler 1977; Barbour and Major 1977].

We reviewed measurements of water use by vegetation similar to that occurring in the Central Valley prairie. Relevant values are summarized from the literature in Table 7. This table indicates that native prairie uses from 0.8 to 1.8 ac-ft/ac of water, or about 1.3 ac-ft/ac on the average. Saltgrass, which was common in the Valley [Barbour and Major 1977] can use larger quantities of water, up to 5 ac-ft/ac

TABLE 7

WATER USE BY NATURAL VEGETATION COMMON IN THE CENTRAL VALLEY PRAIRIE

Vegetation	Annual Water Use	Location	Reference
Field Studies			
Native brush	1.4 – 1.8	San Bernadino, CA	Young and Blaney (1942)
Native brush	1.5	Muscoy,CA	Young and Blaney (1942)
Native brush	1.2	Claremont, CA	Young and Blaney (1942)
Native brush	1.6	Palmer Canyon, CA	Young and Blaney (1942)
Native grass and weeds	0.8	San Bernadino, CA	Young and Blaney (1942)
Native grass and weeds	1.2	Cucamonga, CA	Young and Blaney (1942)
Native grass and weeds	1.0	Anaheim, CA	Young and Blaney (1942)
Native grass and weeds	1.1	Ontario, CA	Young and Blaney (1942)
Native grass and weeds	1.1	Wineville, CA	Young and Blaney (1942)
Saltgrass	2.1	Owens Valley, CA	Lee (1912)
Annual grasses, forbes, and legumes	1.2	Placer County, CA	Lewis (1968)
Tank Studies			
Saltgrass	1.1 – 3.6	Santa Ana, CA	Young and Blaney (1941)
Saltgrass	1.1 – 4.1	Owens Valley, CA	Young and Blaney (1942)
Saltgrass	2.6	Isleta, NM	Young and Blaney (1942)
Saltgrass	0.8 – 4.0	Los Griegos, NM	Young and Blaney (1942)
Annual grasses	0.8 – 1.2	Placer County, CA	Lewis (1968)
Grass	1.2	San Luis Rey, CA	Blaney (1957)
Grasslands	0.9 – 2.9	Sierra Ancha, AZ	Rich (1951)
Grasses	2.2	Sierra Ancha, AZ	Rich (1951)

[Robinson 1958]. In our analyses, we used a range of 1 to 2 ac-ft/ac for all prairie as defined by Kuchler (1977).

About 148,000 acres of saltbush (*Atriplex polycarpa*) were also present in the plains region of the San Joaquin Valley. Since we did not find water use measurements for this species, we used the mean consumptive use value (2 ac-ft/ac) determined for saltgrass (Table 7).

Native Vegetation Water Supply

The natural water supply that we described in the section, The Natural Landscape, could have supported the native vegetation that we have described. In the Sacramento valley, we believe that the principal water supply to marshes and riparian forests was a high groundwater table, springs, and bank storage. In the San Joaquin valley, the principal supply for the marshes was groundwater that was discharged through sloughs and springs.

The riparian forests were located on the permeable natural levees where channel seepage was continuously present and groundwater was within 20 feet of the surface. The predominant riparian forest species (i.e., cottonwoods, willows) have typical rooting depths of 15 to 30 feet [Robinson 1958, p.62,64], and valley oak, which were common in other areas, are known to draw water from depths in excess of 40 feet [Lewis and Burgy 1964].

Tules and other marsh vegetation, on the other hand, have shallow root systems, typically in the form of rhizomes [Jepson 1975; Mason 1957; Correll and Correll 1972; Beetle 1941]. The common cattail is reported to extend its rhizomes over a diameter of 10 feet in a single growing season and to produce aerial shoots 4 to 48 inches long (Yeo 1964). These plants probably only grew in areas where the groundwater table was within 5 feet of the surface or in regions with a surface water supply (i.e., via sloughs or springs). An examination of early maps reveals that marshes were located in areas where the groundwater table was at the surface and where soils were reported to have high absorptive capacities [e.g., Forbes 1931, Plate B-I]. Areas underlain by clayey soils that supported tule marsh were typically criss-crossed by complex assemblages of sloughs [e.g., see Bryan 1923, Plate IV; Holmes et al. 1916, Soil Map; Mendenhall et al. 1916, Plate I].

Under natural conditions, surface storage in the flood basins and groundwater storage in the underlying aquifers probably operated in concert to supply native vegetation. Today, this is practiced by spreading water on the land to recharge aquifers and is known as "conjunctive use" [DWR 1983, p.77]. Water was stored during wet periods and used during dry periods.

We investigated the potential groundwater available for native vegetation in each basin (Figure 4, Areas 2a, 2b, 2c) and found that enough water was present in storage in the top 10 feet of soil beneath the flood basins to support marshes using up to 9 ac-ft/ac of water for at least one year everywhere except in the San Joaquin Basin. There, groundwater was adequate to only support marshes at a rate of 6 ac-ft/ac. However, we believe that groundwater storage was not the sole source of water for any of the marshes. The sloughs, which were typically deeper than the main channels, and springs could also have transported surface waters into the marsh areas. Additionally, some flood water from the Sacramento River moved into the San Joaquin Valley through Delta sloughs (e.g., DPW 1931b).

Tulare Lake Basin Overflow

Under natural conditions, and through the present, water was and is exchanged between the Tulare Lake Basin (Area 3, Figure 4) and the San Joaquin Basin (Area 2c) during flood flows. Most people currently believe that the flow was from the Tulare Lake Basin into the San Joaquin Basin and hence into the Bay, because that is the direction of flow today. Many early maps of the Valley show a continuous ribbon of water running from the Delta south to the lakes of the Tulare Basin [Landrum 1938]. Fremont remarked that the Tulare lakes and the San Joaquin River in the rainy season made a "continuous stream from the head of the valley to the bay." [Fremont 1964,p.14]. However, the amount of water passing across this boundary and the direction of flow are subject to considerable conjecture.

We used DWR's estimate of the Tulare Lake Basin overflow [DWR 1987, p.33] in our natural flow calculations (Table 2). This value (174 TAF/yr) is actually the historic USGS flow measurements at James Bypass on the Fresno Slough, which connects the two drainages. These flows probably have little, if any relationship to flows that may have occurred under natural conditions.

Our calculations suggest that over the long-term, the net water exchange between the two basins was nearly zero. Drought was more common in the Tulare Lake Basin than to the north, and these lakes were often reported as dry by early explorers. Under many conditions, water moved from the San Joaquin Basin into the Tulare Lake Basin, or in the opposite direction. Nevertheless, we adopt DWR's estimate in an effort to be conservative. We reviewed the literature in an attempt to resolve the uncertainty surrounding this overflow. We also calculated a water balance for the Tulare Lake Basin. This work indicates that the long-term net exchange of water between these basins was about equal to zero.

Natural Geography and Hydrology

The San Joaquin and Tulare Lake drainage basins are separated by a natural ridge or barrier that lies immediately to the south of the San Joaquin River. Tulare, Kern, Buena Vista, and other small lakes were located in a depression south of this ridge. Normally, the San Joaquin River system drains north into the Bay, and the Tulare system drained south into these lakes. The lakes were connected by sloughs and formerly were filled by flow from the east-side tributaries, primarily the Kings and Kern Rivers. These lakes no longer exist because they were drained and reclaimed for farming. The overflow area was and remains a complex network of sloughs, the principal one being Fresno Slough.

The overflow lands bordering the slough were of nearly uniform width, averaging about 5.4 miles [Davis et al. 1959, p. 28]. The slough itself, under natural conditions, has been reported to be "like a canal...and very deep near the San Joaquin, but eight to ten miles from this river it divides up into numerous channels, which become intricate and ramified as they enter the lake." [Williamson 1853, p.192]. It was "about forty miles in length...and about two hundred and forty feet in width...." in April 1850 [Farquhar 1932b], a very wet year in the Valley [Anonym. 1886].

Under natural conditions, the Kings River discharged into this lowland area. Part of the flow moved south to Tulare Lake, which formerly covered an area varying from a few square miles in dry years to about 760 square miles in wet ones [DPW 1931c, p.76]. Part may also have moved north through Fresno Slough into the San Joaquin Basin under some conditions. Apparently, the flood waters had to raise the surface of the lake to an elevation of 205 to 210 feet from a low of 176 feet before any water moved northward into Fresno Slough and the San Joaquin River (ibid., p.483).

Historic Accounts

Contemporary technical descriptions generally indicate that transfer of water only occurred during periods of high flow in winter and spring and that there was no constant flow direction, the flow sometimes being south and sometimes north. In the earliest technical description of note, Coulter, an English scientist, reported that "The Tule Lakes are now known not to exceed 100 miles in total length, being fordable in the dry season in places; ...they discharge, during a considerable portion of the year, very little, if any, water into San Francisco. It is only immediately after the rainy season, which is usually ended by February, and during the thaw of the snow ...that there is any considerable discharge of water from them in this direction" [Coulter 1835, p.60]. Fremont, in his Memoirs, also reported flow into the San Joaquin, remarking that "In times of high water, the lake discharges into the Joaquin, making a continuous water line through the whole extent of the valley." Both of these observations, and many others like them, were based on hearsay or memory, rather than actual first-hand observations.

Later technical descriptions by professionals working in the area reported flow moving predominantly from north to south, into the Tulare Lake Basin. Lieutenant Derby explored the "Tulares Valley" in 1850, which was a wet year, in search of a site for a military outpost [Farquhar 1932b] and attempted to cross between the basins at the site of Fresno Slough in April of that year. He reported that the ground between the lake and the San Joaquin was "entirely cut up by small sloughs which had overflowed in every direction, making the country a perfect swamp....We were engaged...in getting through the mire, crossing no less than eight distinct sloughs, one of which we were obliged to raft over. In all of these sloughs a strong current was running southwest, or from the San Joaquin river to the lake."

In 1853, the U.S. War Department undertook surveys for a railroad route from the Mississippi River to the Pacific Coast. Blake, the geologist on this mission, described the overflow area, noting that "when the level of the river is greatly raised by freshets it overflows its banks, and the water passes to the lakes by this slough. At seasons of low water, all communication between the river and lake is prevented by a bar at the mouth of the slough." [Williamson 1853, p.192].

Others have reported that water was exchanged between the two basins through subsurface flow. The Irrigation Congress, reporting on field work for canals in the

San Joaquin and Tulare Lake Basins, speculated that "the San Joaquin receives an important accession of volume from underground drainage — probably from the Tulare Lake drainage." [Anonym. 1873, p.8]. However, most accounts of groundwater in this area indicate that it was "stagnant" [Mendenhall et al. 1916], discharging at the surface. Additionally, groundwater contours of the Valley [e.g., Ingerson 1941; Mendenhall et al. 1916], indicate that groundwater predominantly moved downslope toward the valley trough, rather than along the axis of the valley. We were unable to locate any authoritative accounts of groundwater exchange along a north-south axis or any that allowed us to eliminate this potential exchange.

Tulare Lake Basin Water Balance

We also calculated a water balance around the valley floor of the Tulare Lake Basin, using the same procedure described previously for the entire Central Valley. The results of this water balance are presented in Table 8. All of the factors and assumptions used in the analysis are listed on the table in the column headed "source/assumptions."

We used different consumptive use factors in the Tulare Lake Basin than in the north because climatic and hydrologic conditions there are distinct. This area is "desert-like and barren....during the summer and autumn..." when it is reported to be "without green vegetation...and gives unobstructed passage to steady currents of air.." [Blake 1856, p.1]. Thus, we used consumptive use factors for grassland and saltbush that were 50 percent less than we used in areas to the north.

We also used a combined tule marsh/lake evaporation rate of 6 ac-ft/ac. During wet cycles, extensive freshwater lakes were formed, which in dry cycles were partially drained and their lower levels replaced by marshes [Forbes 1941, p.17]. Thus, the ratio of lake surface area to marsh was constantly changing under natural conditions. Therefore, we used a mean tule marsh/lake evaporation rate of 6 ac-

TABLE 8

TULARE LAKE BASIN WATER BALANCE FOR NATURAL CONDITIONS

Element in Water Balance	Long-term, Average Annual Water (millions of ac-ft/yr)	Source/Assumptions
Water Supply		
Rim Inflow	3.5	For period 1889-1929; DPW Bull. 29 (1931), Table 5
Precipitation on Valley Floor	4.5	Valley floor area (6,503 x 10^3 acres) times average precipitation (8.3 in.) from Schreiner (1987)
TOTAL SUPPLY	**8.0**	
Water Use		
Riparian Forest (Valley oak)	0.9	Forest area (515 x 10^3 acres) times evapotranspiration (1.7 ac-ft/ac) from Lewis (1968)
Prairie	2.0	Prairie area (4,027 x 10^3 acres) times evapotranspiration (0.5 ac-ft/ac) based on 50% of the mean (Table 7)
Saltbush	1.3	Saltbush area (1,298 x 10^3 acres) times evapotranspiration (1 ac-ft/ac) estimated as 50% of the average saltgrass use (Table 7)
Tule Marsh/Lake Evaporation	3.9	Total area (643 x 10^3 acres) times evapotranspiration (6 ac-ft/ac) from Table 6
TOTAL USE	**8.1**	
IMBALANCE	**-0.1**	

ft/ac. This is 40 percent greater than lake evaporation [Anderson and Idso 1987], which Forbes estimated to be 4.4 ft/yr [Forbes 1931, p. 541].

We found that for natural conditions, water use in the basin slightly exceeded in-basin supply by about 100,000 ac-ft/yr over the long-term. This suggests that the Tulare Lake Basin may have had an unidentified water supply, which we believe was surface and subsurface overflow from the San Joaquin Basin into the Tulare Lake Basin. Within the limits of error for this type of analysis, this suggests that the Tulare Lake Basin overflow did not contribute large quantities of water to San Francisco Bay. However, it is certainly possible that, during very wet years, a larger quantity of water could have been exchanged, depending upon the volume of water stored in the natural lakes just before the flood flows began. A conservative upper bound for this overflow is the total rim inflow for the basin or 3.5 million ac-ft/yr (Table 8). If the overflow were on the average this large, which we believe is physically impossible, it would not change any of the conclusions presented here.

RECOMMENDATIONS

The concepts and calculations presented here should be viewed as a first step in estimating what the natural inflows to San Francisco Bay may have been. Estimates such as these are difficult to make due to the absence of quantitative measurements, and considerable additional work is required to refine our first attempts. We recommend the following additional studies and analyses:

1) Water use by tule marshes and riparian forests that were indigenous to the Central Valley should be measured in field studies in preserved wetland areas.

2) The ecology and hydrology of freshwater marshes such as those that were common throughout the Central Valley have never been studied in a

comprehensive manner. Field studies in preserved wetlands should be conducted to determine, among other things, the source of water, the volume of water storage, species distribution and abundance, and the effect of floods and droughts on marsh productivity. The excellent research conducted in Europe and the USSR on mires, bogs, and swamps should be used as a guide [e.g., Ivanov 1981].

3) Daily salinity and tidal data have been collected at the Presidio, at the Golden Gate, since 1855. This information should be analyzed to confirm the concepts presented here. Historic changes in Delta outflow (Figure 1) should be reflected in tidal and salinity records at this site. Some of the tidal data have been reported elsewhere [Smith 1980], and we believe the increase in tidal height from 1860 to 1885 shown in these records reflects increased Delta outflows from the extensive harvesting of riparian forest and draining of swamps that occurred then [Meade and Emery 1971].

4) An extensive body of technical information exists in pre-1900 State and Federal reports, which were then published as appendices to congressional proceedings. Many of these have been abstracted and tabulated in bibliographies on the State [e.g., Cowan and Cowan 1933; Hasse 1908]. A thorough search and synthesis of this material may yield additional information that could further clarify the natural system.

5) Eye witness accounts can also provide valuable information. Many of the original journals and maps are archived in the Bancroft Library on the University of California's Berkeley campus. Additional diaries and journals of early explorers and settlers should be consulted to determine the response of the natural system to droughts and floods. Events of interest should be compiled and tabulated in a consistent format and classified by

year type (wet, dry) using the excellent climatological research that is available [e.g., Graumlich 1987; Lamb 1977; Lynch 1931].

6) Existing natural vegetation maps of California [Kuchler 1977; Roberts et al. 1977] should be revised using historic accounts as presented in journals, diaries, and early technical reports appended to congressional proceedings.

7) Our analyses have focused on the effect of changes in valley floor vegetation on Delta outflow. The influence of changes in upslope vegetation on freshwater inflow to the Bay should also be explored. Some important additional areas to investigate include timber harvesting in the Sierra and Coastal range forests, converting chaparral to grassland, and the accidental introduction of annual grasses into the prairie.

8) A reservoir operations study should be performed on the Central Valley and its ancient storage reservoirs - the natural flood basins and groundwater aquifers - to determine the monthly distribution of flows under natural conditions.

9) The surface area of the natural flood basins was much greater than the surface area of man-made reservoirs that replaced them. This means that under natural conditions, water surface evaporation was much greater than it is today. This was not considered in this work. It should be evaluated in future studies.

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Appendix B

Rebuttal to David R. Dawdy Exhibit 3 in Regard to Freshwater Inflow to San Francisco Bay under Natural Conditions

STATE WATER CONTRACTORS REBUTTAL TESTIMONY

REBUTTAL TO DAVID R. DAWDY EXHIBIT 3

IN REGARD TO

FRESHWATER INFLOW TO SAN FRANCISCO BAY

UNDER NATURAL CONDITIONS

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REBUTTAL TO DAVID R. DAWDY EXHIBIT 3
IN REGARD TO FRESHWATER INFLOW TO SAN FRANCISCO BAY UNDER NATURAL CONDITIONS

by

Phyllis Fox

State Water Contractor (SWC) Exhibit 262 estimated freshwater inflow to San Francisco Bay from the Delta under "natural" conditions. These analyses demonstrated that "natural" inflow was substantially less than DWR's "unimpaired" flows. The reason was that "unimpaired" flows do not include the high consumptive use of water by tule marshes and riparian forest that were present in the Central Valley under "natural" conditions. This evidence actually shows that the outflow to San Francisco Bay under "natural" conditions was probably less than it has been in recent times.

Other direct testimony (Dawdy 1987) and cross examination on November 23-24, 1987, identified some issues that merited further review and analysis. This document (SWC Exhibit 276) presents the results of those additional analyses. The conclusions drawn from this work are:

1. Extensive areas of tule swamp existed under "natural" conditions. These are documented by numerous eye-witness accounts. These accounts indicate that the tules were dense, that their growth was luxuriant, and that they grew in standing water or areas with a high water table. These swamps did not normally dry out or burn under "natural" conditions. The tule and related species are well adapted to flooding and can survive for long periods of time in deep water.

2. The land areas used in SWC Exhibit 262 do <u>not</u> overestimate "natural" tule swamp. The tule areas used in this work are "permanent swamp," and the dominant vegetation was the tule, predominately the bulrush Scirpus acutus. The tule swamp areas used in this work fall on the <u>low</u> side of the range obtained from official land surveys. Much lower estimates are typically <u>only</u> for Delta marshes while much higher estimates include seasonally flooded wetlands. The areas planimetered from Kuchler (1977) are confirmed by surveys that label the swamp area as "tule."

3. Consumptive use by native vegetation under "natural" conditions is probably <u>underestimated</u> rather than overestimated. The luxuriant growth of tules and the extensive network of sloughs in swampy areas favor higher consumptive use rates than those used here. Evapotranspiration from seasonally flooded areas that supported tules and other marsh vegetation was not included in SWC estimates. "Natural" grasslands comprised perennial species that grew luxuriantly and likely used more water than the annuals that quickly took over.

4. While some portions of the natural flood basins may have drained over the course of several months, the lower lying areas in the valley trough did not drain quickly. Many of them contained water year round and for several dry years in sequence.

5. The presence of freshwater in Suisun Bay does not mean that Delta outflow was higher than estimated "natural" outflows. Under "natural" conditions, much lower Delta outflows were able to move freshwater into Suisun Bay, or conversely, to keep salty water out of the Delta. The original Suisun Bay/Delta system was strongly stratified during low flow periods, and gravitational circulation controlled salinity intrusion into this area. Flows as low as 100 cfs could have moved freshwater to within 1 to 9 miles of Carquinez Straits. A substantial shoal blocked the entrance to the Sacramento River, and smaller shoals were present throughout the western Delta along both main river channels. These restricted the movement of salty Bay water into the Delta.

This rebuttal exhibit responds to issues raised by David R. Dawdy in Exhibit 3, An Investigation into the Feasibility of the Computation of Natural Inflows to Suisun Bay, and to additional points raised in cross examination of Phyllis Fox on November 23 and 24, 1987. The questions and claims, in the order in which they were presented, are listed below. The first seven points were raised by Dawdy (1987) and the last point was raised during cross examination. These questions and claims are addressed below in the order listed here:

1. Why compute natural Delta outflows?

2. The natural flood basins drained quickly to become savannas rather than retaining some water that was subsequently evapotranspired by tule marshes as claimed by SWC Exhibit 262.

3. The amount of tule acreage was smaller than claimed by SWC Exhibit 262.

4. Under natural conditions, only patches of tules were present, and hydraulic mining probably created the vast tule swamps reported by later visitors.

5. The tule swamps used less water because they dried out and burned during the period of peak water use.

6. Delta outflow must have been higher than stated because a number of early visitors reported freshwater in Suisun Bay.

7. The climate may have changed in the near past.

8. The tule swamps and riparian forests used less water than claimed in SWC Exhibit 262 because consumptive use factors were overestimated.

Before these points are addressed, it is important to define "natural" conditions. In SWC Exhibit 262 (Fox 1987), the term "natural" means prior to modification by European settlers. In other words, before about 1770. The calculations in SWC Exhibit 262 exclude the effects of colonization and settlement to the extent possible. Calculations are based on natural resources as they existed prior to 1770, using the climate of the period 1920 to 1983 (the period for which unimpaired flows were calculated). Much of the evidence presented by Dawdy (1987) is from the post-Gold Rush era, from 1848 forward.

In SWC Exhibit 262, eye-witness accounts after about 1850 were not used because major changes occurred during the Gold Rush. Material from the post-1850 period was carefully examined to assure that "natural" conditions as opposed to "altered" conditions were being described. Many of the errors in Dawdy's work relate to his failure to realize how rapidly the face of California was altered. Thus, important changes that occurred after about 1840 that would affect natural flow calculations are outlined here before the individual issues listed above are discussed.

The earliest settlements in the valley were in 1837, when Captain Sutter established New Helvetia at the mouth of the American River and Dr. John Marsh settled Los Medanos at the foot of Mt. Diablo. Many large Mexican land grants followed swiftly and by the end of 1846, 1.3 million acres had been granted in the Delta and along the Sacramento, San Joaquin, Feather, and Yuba rivers (Cowan 1977).

The great wave of immigration started about 1846. By 1848 Sutter reported 23,000 people living in the Sacramento Valley (Bancroft 1888, p.14), and gold was discovered on Sutter's property in 1848. In the first U.S. census of California in 1850, the State population was 92,600. Two years later in 1852 it had increased to 255,100 or by about 275 percent. Most of these people moved through the Central Valley to and from the Gold Mines. The population of the counties in the Central Valley itself increased from 21,500 in 1850 to 150,000 by 1880. During this same period, in just the Central Valley, cultivated land increased from about 3,000 acres in 1850 to over 2 million acres by 1880, a seven-hundred-fold increase. Similar increases were also experienced in the number of sheep, cattle, horses, and hogs that used the valley lands. Most of these increases occurred between 1860 and 1870, the period from which Dawdy takes his key references.

In addition to changes that occurred simply due to the huge influx of people -- primarily rapid changes in land use -- the natural resources were drastically altered. Riparian forests were harvested, tule marshes were drained and reclaimed. Mining and its associated infrastructure required water and lots of it. Streams were dammed, rivers were diverted from their normal channels, and the stream beds were mined. Massive quantities of mining debris were generated, sometimes damming up the rivers and creating colossal drainage problems. Other times, the debris was washed down into the valley during floods and was deposited in stream channels and in marshes.

Evidence used to substantiate "natural" conditions that is taken from the post-1846 period must be carefully inspected to assure that it truly represents "natural" conditions. Dawdy apparently did not do that, as much of his information includes influences of development.

1.0 WHY COMPUTE NATURAL DELTA OUTFLOWS?

Mr. Dawdy, on page 2, speculates that natural flows were calculated to provide a justification for not releasing flows "to maintain a minimum discharge and 'waste' water into the ocean." He states that "if the minimum flows into the Delta in particular were lower under natural conditions than they are now under developed conditions, then there should be no argument based on need of the environment to increase releases during the period of highest demand for irrigation water..."

This is not the reason that natural flows into the Delta were estimated. Natural flows were estimated because much testimony during the Hydrology Session used DWR's "unimpaired" flows (DWR Exhibit 26) as though they were "natural" flows, and witnesses further stated in direct testimony that "true natural" flows were likely larger than "unimpaired flows." Many exhibits dispense with the term "unimpaired," and call these flows "natural." Examples of such exhibits include EDF Exhibits 2 and 3 (Williams and Fishbain 1987), Tiburon Center Exhibit 1 (Rozengurt et al. 1987), and SWRCB Exhibit 3 (SWRCB 1987).

The DWR was very careful to define "unimpaired" flows, distinguishing them from true "natural" flows (DWR Exhibit 26, p. 1). DWR defines these terms in Exhibit 26: "The word natural connotes that the Central Valley landscape is in a prehistoric or virgin state. Unimpaired, on the other hand, implies only that certain items in the measured flows have been adjusted." (DWR, p.1) Specifically, the "unimpaired" flows assume that the river channels of the valley are in their present configuration. They neglect groundwater accretions to the river channels, consumptive use of riparian vegetation and water surfaces in swamps, and flood storage in the overflow basins.

Unimpaired and natural flows are not synonymous. True natural flows were much lower than unimpaired flows. The SWC entered rebuttal testimony on natural flows to clarify the distinction between "true natural" and "unimpaired" flows. Natural flows are those that would have occurred in a virgin, undisturbed state, before the Central Valley was altered by settlement. They assume natural channel configurations, land areas as they existed prior to settlement, and the climate of 1920-83. Natural flows are not estimates of what flows would have been in individual years, say in 1770 or 1850. The natural flows calculated in SWC Exhibit 262 are a long-term annual average for the climate of 1920-83 and the physical setting of an undeveloped period, i.e., prior to 1770 and up to perhaps 1846, but no later.

2.0 THE NATURAL FLOOD BASINS DID NOT DRAIN QUICKLY

Mr. Dawdy used simple hydraulic calculations to estimate how long it would take some of the flood basins where the tules grew to drain and how much water would be lost to evaporation and groundwater storage (Dawdy 1987, p.7-9). These calculations are not for "natural" conditions. These calculations are also only appropriate for the flood basins in the Sacramento Valley. The Delta, San Joaquin Basin, and Tulare Lake Basin functioned differently. The basin areas, storage capacities, slough capacities, and drainage rates used in these calculations do not agree with early engineering reports written when the flood basins were still in operation (Davidson et al. 1896; Grunsky 1928; Hall 1880; Price 1896).

Dawdy's calculations also do not agree with eye-witness accounts. They are not consistent with accounts that indicate that the swamps did not dry out (Sec. 5.1.2), that tules grew in standing water (Sec. 5.0.1), and that the flood basins contained some water throughout the year and even over several dry years (Sec. 2.1). Dawdy's calculations suggest that the basins completely drained much more quickly than they actually did and as a consequence, they underestimate the amount of evaporation and groundwater seepage that occurred.

There is not enough topographic and hydrographic data on the flood basins in their "natural," undisturbed configuration to perform the type of calculation attempted by Dawdy. This is the principal reason that the DWR has never attempted "natural" flow calculations. The first engineering studies on these basins were started in 1878, at the height of the Gold Rush era, well after rivers had been leveed, sloughs dammed, and mining debris had been deposited in the basins. Shoaling was a common problem, and rivers frequently changed their courses. Some of these changes are discussed in Section 4.0.

The details of the operation of these ancient flood basins are not crucial to the argument advanced in SWC Exhibit 262, namely that the basins attenuated flood peaks and were the home of tule swamps that evapotranspired water. Dawdy's hydraulic calculations are primarily useful to estimate monthly flows for a specified year(s). SWC Exhibits 353 and 262 did not attempt such an estimate due to the absence of reliable data. The drainage rate of the flood basins is of minor importance to the case presented because there is little doubt that the tules were there. Additionally, flood storage in these basins was <u>not</u> the only water supply for the swamps. The swamps also obtained water from springs that were recharged at the foothills; from groundwater stored in soils beneath the flood basins; from channel seepage; and from distributaries that drained water from the main river channels and groundwater aquifers.

2.1 <u>Historical Evidence That Flood Basins Did Not Drain Quickly</u>

Eye-witness accounts (Appx. A) and early engineering studies suggest that the flood basins did not completely drain until summer or over the course of several dry years. Water was stored in troughs and irregular depressions at the bottom of the basins. Since the sloughs, like the main river channels, were lined with natural levees, the water in these depressions was not able to drain back into the rivers via the sloughs.

Calculations made before the flood basins were artificially drained, which were intended to estimate "natural" outflows from the basins, indicate that significant amounts of water were still draining back into the main channels of the Sacramento River as late as June in all types of years and through July of average and wetter years:

	Four-River Index (ac-ft)	Drainage from Flood Basins (CDPW 1931) (ac-ft)	
		June	July
1907	33,704	319,950	360,110
1908	14,772	221,260	4,690
1909	30,681	359,340	136,290
1910	20,117	41,285	--
1911	26,381	516,200	262,255
1912	11,410	379,625	--
1913	12,847	160,000	--
1914	27,811	511,360	101,570
1915	23,857	989,825	67,780
1916	24,141	102,155	--
1917	17,260	267,170	--

Drainage from the Colusa, Sutter, and American Basins is included in these figures. This drainage was included in SWC Exhibit 353 and is the cause of the increase in "natural" Delta outflow in June compared to "unimpared" outflow. About 54 percent of the annual tule water use occurs between January and July, when by all accounts, the basins contained water and were still draining into the Sacramento River. Periodic submergence of tules present in these flood basins would not have significantly affected consumptive used, as dsicussed in Section 8.2.

The USDA described the tule basins of the Sacramento Valley in 1872, noting that "The surplus waters of the great river-floods also deluge these tracts, keeping them submerged during several months and maintaining a wet and swampy condition during the remainder of the year." (USDA 1872, p.184)

The Yolo County Surveyor, in his 1862 annual report, described the Colusa Basin that Dawdy considered on page 7. "Sycamore slough...is the natural but inefficient outlet to the tule water which comes partly from the mountains and partly from the overflow of the river. A great part of this water must await evaporation during the series of dry years." (CSG 1862, p.98)

Grunsky, William Ham. Hall's Assistant in charge of hydrographic surveys, attempted to qualitatively describe the operation of the flood basins under natural conditions. Of Sutter Basin, which Dawdy suggests largely drained in 2 months (Dawdy, p.6), Grunsky states: "Complete drainage of Sutter Basin as it was originally, was therefore a slow process ... Drainage .... was imperfect and water stood in some portions of the flood basin throughout the entire year." (Grunsky 1929, p.796).

Bryan, a geologist with the U.S. Geological Survey, described the operation of Yolo Basin very differently from Dawdy, who claims it passed flood waters in 10 hours and "drained to become a savannah." (Dawdy, p.8) Bryan noted that the Yolo Basin "contains some water even in the dry season as far north as the Southern Pacific causeway west of Sacramento and has a swamp vegetation of tule ... northward as far as the Cache Sink." (Bryan 1923, p.43)

2.2 Flood Basin Drainage Under Natural Conditions

Dawdy's calculations yield rapid drainage rates because the data on which they are based are not representative of natural conditions. The following sections discuss some of the important differences between "natural" conditions and those assumed by Dawdy (p.6-8).

2.2.1 Channel Roughness. Dawdy's calculations on page 6-8 assume that the flood basins can freely drain, the rate being established by the capacity of the sloughs. This is not correct and results in very fast drainage times, low evaporation, and low groundwater seepage. The flood basins and sloughs were filled with densely packed tules, which would have significantly reduced the flow rate of water moving through the basins. These tules would have increased the "roughness" and hence Manning's n, thus greatly reducing the rate at which the basins drained. This is a well known effect and has been described in literature on wetlands hydrology (e.g., Carter et al. 1978).

The sloughs were not open channels but were usually clogged with a thick growth of aquatic vegetation. Some sloughs were also blocked by tule mats, which were referred to as "floating islands" when they were torn loose by major flood events. Thus, the sloughs were very inefficient drainage channels, as the California Surveyor General reported (CSG 1862, p.98).

Sometimes these mats were "three or more feet in thickness, thirty to fifty feet across and from fifty to more than one hundred yards in length." (Latta 1977, p.506) The California Surveyor General (CSG 1862, p.44) investigated these "islands" after the 1862 flood and reported that "[t]hey were found to be an aggregation of strong fibrous grasses and roots, which had overgrown sloughs and small lakes, which frequently occur in the Swamp Lands, interweaving and increasing in thickness until sufficiently buoyant and strong to bear live stock, and even loaded wagons."

These blocks that formed in California sloughs are common in reed swamps the world over. For example, about 6 million acres of reed swamp are found in the headwaters of the Nile. The river channels there are "frequently blocked by masses of vegetable matter for months or even years at a time ... These masses can be quite large ... and a waterbuck ..." was reported traveling on one (Hurst 1957, p.118,119).

2.2.2 Sloughs Blocked by Sandbars. Drainage was further impeded by sandbars, which were very common in the Delta and in areas drained by sloughs. For example, Cache Slough, which drained Yolo Basin (Grunsky 1929, p. 797), was restricted by the Newton shoals. Engineer Price reported in 1896 that "It is evident the Newton shoals have existed ever since man has had any history of the river." (Price 1896, p.16)

2.2.3 Drainage Into San Joaquin. Much of the water that drained out of the flood basins did not directly contribute to Delta outflow. Some was spread out in flood plains in the San Joaquin delta/valley and some was consumptively used. The Sacramento River was rarely in flood at the same time as the San Joaquin (Hall 1880, Part II, p.51). Much of the flood flow, drainage from the flood basins, and even low flows were routed into the San Joaquin River through Georgiana and Threemile Sloughs, rather than into Suisun Bay. William Ham. Hall, in his book on Physical Data and Statistics of California (Hall 1886, p.406) wrote that "...at all stages of the river, there is an appreciable escape of Sacramento waters through the Georgiana and Three-mile sloughs, below Sacramento, into the San Joaquin."

This flow was gaged in the 1920's and found to average about 950 second-feet averaged over a period of about three months, but with extreme variations from no flow to 3700 second-feet. The percentage of the total flow passing Sacramento which went through Georgiana Slough was found to vary with the rate of flow in the Sacramento River, from a maximum of about 43 percent at 3000 cfs to a minimum of about 15 percent at 40,000 cfs or greater (CDPW 1931, p.37).

2.2.4 River Stage. The flood basins had no outlets except into the river and could only discharge water when the river stage was at or below the water elevation in the basins. The drainage of much of the Sacramento Valley (Butte, Sutter, Colusa basins) was controlled by the stage of the Sacramento River at Knight's Landing (Davidson et al., p.22-23; Grunsky 1929), which did not reach its seasonal low until the dry autumn months (Grunsky 1929, p.796) when many of the basins were still discharging some water.

As explained by Grunsky, who was an authority on drainage of these ancient flood basins, "[w]hen in times of general inundation, the water in this flood basin [Colusa] stands as high as the water in the river at Knight's Landing, it becomes closely connected with Sutter Basin by water across the west and east banks of Sacramento River, and the two inland seas are practically one, the stage of water in both depending upon the stage of the river at and below Knight's Landing" (Davidson 1896, p.22). He goes on to explain that Colusa Basin is drained by Lower Sycamore Slough, which "can discharge water from the basin into the river only when the basin water is highest, that is, in time of flood, or when in the course of the summer the river falls to a stage below the surface of the basin water....A rapidly falling river at a stage as high as...30.4 feet may produce a flow of about three thousand cubic feet per second in Lower Sycamore Slough, but this would not continue many days." (ibid, p.28)

If this description is compared with Dawdy's characterization of the Colusa Basin on page 7, it is evident that Dawdy's calculations are not realistic. He assumed the Colusa Basin drained independent of the stage in the Sacramento River. He calculates that the entire basin drained in two months at a constant rate of about 4,000 cfs. In fact, the rate was controlled by the depth of water in the basin and in the Sacramento River and decreased as the basin drained from a peak discharge of 3,000 cfs. Drainage probably occurred through the summer.

2.2.5 Incorrect Topography. Dawdy's calculations are based on elevations and topography reported on maps dating from 1868 and 1895, during the period when mining debris was present in channels, sloughs, and flood basins. Reclamation activities had also modified the channel systems. Therefore, the calculations do not represent natural conditions.

The areas and storage capacities of the flood basins that Dawdy used also do not agree with those recorded in early engineering reports. Dawdy's storage capacities for the flood basins are much lower than accepted values based on measurements during floods (Grunsky 1929):

	Storage Capacity (ac-ft)	
	Dawdy	Grunsky
Sutter Basin	404,600	918,300
Colusa Basin	477,500	1,033,000
Yolo Basin	300,000	1,148,000

Dawdy's calculations also only addressed about 10 percent of the flood plain or 250,000 acres out o a total of 2.2 million that were annually inundated.

3.0 THE AMOUNT OF TULE ACREAGE WAS NOT SMALLER THAN STATED

Dawdy (p.9,10) and cross examination of Fox on November 23 suggested that tule acreage was smaller than stated in SWC Exhibit 262 for the following reasons:

1. Kuchler's (1977) map reports the maximum extent of vegetation.

2. Kuchler's map overestimates tules in the Tulare Basin because it shows tules where lakes were formerly located.

3. Other estimates exist that report from 500,000 to 650,000 acres of tules.

4. Sources that do not specifically report "tule" include other types of land.

The information presented here indicates that SWC Exhibit 262 does not overestimate tule acreages. Kuchler's map was not the sole source of tule estimates. Areas planimetered from Kuchler were checked against early surveys and adjusted as required to more accurately reflect actual historical conditions. The tule area actually used in Exhibit 262 is on the low side of the range returned by field surveys. Some of these sources included surveys made during the dry parts of dry years and represent minimum acreages. Other sources are taken from periods when reclamation was in progress and the swamps had started to dry out and burn. The "natural" flow calculations are for the climate of 1920-83, which was wetter than much of the historical period used to verify Kuchler. Thus, these early historical estimates underestimate acreages for the period covered by SWC Exhibit 262. Finally, the tule acreages used are consistent with numerous eye-witness accounts of the extensive nature of the tule swamps (Appx. A).

3.1 How Many Acres of Tule Were There?

The tule acreages used in SWC Exhibit 262 are substantiated by numerous eye-witness accounts from the period 1772 to 1850 and by topographical surveys. Each source of information is discussed below.

Numerous estimates of tule acreages have been made, ranging from 250,000 acres (Jepson 1975, p.153) to 5,000,000 acres (CSG 1856, p.9). These extremes are not taken seriously in this work. Essentially all of these lands, except small tracts around San Francisco Bay and in Humboldt County, were in the Central Valley (Hilgard 1884). The wide range in reported acreages is due to two factors. First, there was a definition problem due to the terminology set forth in the Arkansas Act. Second, the areal extent of tules varied from year to year in response to relative wetness. Areal extent also decreased as the valley was settled. This work required the long-term average acreage prior to European settlement of the valley, but for a climate corresponding to that of 1920-83. The tule acreages actually used in SWC Exhibit 262 (p. A2-26) fall on the low of the range of estimates obtained from surveys.

All estimates identified at this writing are summarized in Table 1. SWC Exhibit 262 is based only on primary source material. Primary material is original estimates based on topographical surveys or engineering estimates from field studies. Other estimates, such as those reported in the press, promotional literature, and histories were not used in SWC Exhibit 262. Since the terms "tule lands," "swamp lands," "marsh," "swamp and overflowed land," and "overflowed lands" have been used indiscriminately and interchangeably in California, estimates that were not precisely defined and referenced back to original source material were rejected.

Eye-witness accounts of tules are summarized in Section 3.2. Each important primary source used in SWC Exhibit 262 is reviewed in Section 3.3. The low estimates summarized in Table 1, which were not used in SWC Exhibit 262, are discussed in Section 3.4.

3.2 Tule Lands Chronicled by Early Observers

Mr. Dawdy believes that "[p]rior to the coming of the Americans [the lower San Joaquin Delta] seemed to have scattered tracts of tules" and believes that siltation encouraged the spread of tules (Dawdy, p.19). This does not agree with historical records that pre-date the Gold Rush, nor with other contemporary writers who have interpreted the historical record. The tule lands were so common and of such interest to early settlers that most early maps show them (Appx. B; Landrum 1938; Hays 1854; Eddy 1854; Whitney 1874) and rare is the travel log that does not contain a reference to the tule.

Eye-witness accounts of tules identified and evaluated in this work are catalogued in Appendix A. These accounts clearly demonstrate that tule lands were extensive, that tule swamps were the only type of swamp present, that the tule was the dominant species in the swamps, that the swamps did not normally dry out or burn, and that the tules themselves were densely packed and very large. The extent of tules was also shown on the earliest maps of the Central Valley, from 1776 through the 1850s when the first maps based upon surveys were prepared. Some of these maps are reproduced in Appendix B. Most of these early maps cearly labeled the tules as "tules" or "tulares," while later maps used the standard cartographic symbol for marsh, droping the designation tule.

Many contemporary writers have also interpreted this material in a similar fashion. The historian, Vandor, in describing Fresno County around 1820, wrote that:

> "The unexplored interior, or that central portion that was at all known to the Californian, was named the Tulares, or the Tulare country, because of the immense tule swamps formed in the depression or slough between Tulare Lake and the great bend of the San Joaquin, and above it ....Around the lakes and sloughs for miles, along almost the full length of the San Joaquin and the lower half of the Sacramento and over a large territory of low ground about their mouths, extensive tule covered swamp lands formed...The tule swamps, apparently one immense tract to the eye, were at intervals visited by the Spaniards..in pursuit of deserting Indians, and horse and cattle thieves." (Vandor 1919, p.49)

In 1855, the County Surveyor of San Joaquin County, describing difficulties of surveying the tules in his county, wrote that it was impracticable to extend sectional lines from the plain as "it is almost one solid mass of tule, with frequent deep ponds and sloughs." (CSG 1856, p.240). A few years later, J. Hutchins, the well-known publisher of the California Magazine, wrote of a boat

Table 1. Estimates of Tule Swamp Acreages

PRIMARY SOURCES

Surveys

U.S. Swampland Surveys (Mandeville 1857)	This map shows U.S. surveys through 9/30/1857. It has no legend, but shows "swamp and overflowed" lands by the standard mapping symbol for marsh. The surveys were conducted in late summer/fall when flood waters had subsided and are taken as "permanent" swamp. Planimetering the map returns in the Central Valley 863,200 acres tributary to the Bay and 449,500 acres in Tulare Lake Basin. The map is included here as Fig. 1.
California Swampland Surveys (CSG 1850-1929; Eddy 1854)	These reports summarize "swamp and overflowed" lands surveyed and sold under Calif. reclamation laws. Surveys were conducted when the land was wet and include seasonally inundated land. Calif. ultimately received 2,192,506 acres of swampland grants from the U.S. These are located on the first official State map (Eddy 1854). Early estimates returned 2.6 (CSG 1852, p.12) to 5 (CSG 1856, p.9) million acres.
Board of Comm. on Irrig. (Alexander et al. 1874)	The U.S. established a Board under the War Dept. to investigate irrigation of the Central Valley. They conducted a reconaissance-level survey. Their report returned 1,225,000 acres of "overflowed or swamped land" (p.6) in the Central Valley, which are located on an accompanying map. This map was probably based on U.S. or Calif. surveys, though the source is not identified.
California Geol. Survey (Whitney 1874)	This geologic map of Calif shows about 1.2 million acres of land mapped with the standard swamp symbol. It includes no legend, but is based on U.S. surveys and thus likely reports "swamp and overflowed" land.
California State Engineer (Hall 1880, 1887,1888)	This office conducted extensive surveys in the valley (independent of the Arkansas Act) and prepared maps showing "swamp lands" and "bottom lands." Planimetering the 1887 map returns in the Central Valley 944,000 acres of swamp land tributary to the Bay and 711,000 acres in the Tulare Lake Basin.

Table 1. Continued.

Technical Summaries Based on Surveys

U.S. Dept. of Agriculture (USDA 1872)	Reports the area of "swamp or overflowed" lands at 2,000,000 to 5,000,000 acres, stating the Calif. Surveyor General returns 3,000,000 acres, of which 400,000 acres are "tide-lands" (p.181) and 200,000 acres are "fresh-water tide-lands." (p.183).
(Nesbit 1885)	The Calif Statistical Agent for the USDA reported 600,000 acres of "swamp and overflowed lands" in the Delta (p.195) and 1,000,000 acres of "fresh-water marshes along the Sacramento and San Joaquin Rivers" (p.197).
(USDA 1908)	This report summarizes "<u>unreclaimed</u> swamp and overflowed land" as of 1908 by land class. It returns 3,420,000 acres in Calif., of which 1,000,000 acres is "permanent swamp;" 1,000,000 acres is "wet grazing land;" and 1,420,000 acres is "periodically overflowed." (p.4) These totals exclude coastal tide lands (p.3). At this date, 323,000 acres had been reclaimed in the Delta (Thompson 1958, p.238).
U.S. Department of Interior (Hilgard 1884)	Estimated "tule lands" in each county for 1880 U.S. census. Reported 1,578,000 acres in the State, of which 1,543,000 acres or 98% was in the Central Valley. Of tule lands in the Central Valley, 1,178,000 acres were tributary to the Bay and 365,000 acres in the Tulare Lake Basin.
(Gilbert 1917)	Estimated extent of "marsh" prior to "encroachment by levees" was 108,000 acres in the Sacramento River delta and 234,000 acres in the San Joaquin River delta (p.78).
California State Engineer (Manson 1888)	Hall's Assistant summarized swamp and marsh acreages by type. His summary returns 203,660 acres of "salt marsh;" 1 million acres of "swamps of low outfall" on the lower San Joaquin and Sacramento river, 156,800 acres of "mountain swamp," and an indeterminate amount of "elevated swamp, having outfall" in the Tulare Lake Basin and elsewhere.

Table 1. Continued.

Vegetation Maps	
(Burcham 1957)	This is the first attempt at mapping "natural" vegetation in Calif. It is at a very coarse scale and the author considered it as "diagrammatic rather than precise.." (p.81). It does not map riparian forest and does not show many of the well-known tule swamps. It returns about 500,000 acres of tule.
(Kuchler 1977)	This is the only comprehensive attempt at mapping "natural" vegetation in Calif. It returns about 1.8 million acres of "tule marsh" in the Central Valley. Tule areas were reduced to agree with eye-witness accounts and surveys. The revised map (Fox 1987, Fig.3) returns 1.6 million acres of tules in the Central Valley.
SECONDARY SOURCES	
<u>Wetland Studies</u>	
(CDFG 1983)	This report summarizes contemporary estimates of various types of "wetlands." Wetlands ranged from 3.5 to 6 million acres (p.11) and included 500,000 acres of "permanent freshwater marshes" shown as "tule" on accompanying map; 381,000 acres of "coastal wetlands;" and 2,192,506 acres of "swamp and overflowed land." (p.11,Fig.1) [see note 1]
(Dennis and Marcus 1984)	This report compiles and summarizes contemporary estimates of natural wetlands made by various federal, state, and local agencies. It returns 4 million acres of "wetlands" in the Central Valley (p. v) and reports 500,000 acres of "tule marsh" using the source/map from CDFG (1983,Fig.1). [see note 1]
(USBR 1986)	This report compiles and summarizes contemporary estimates of natural wetlands, using different source material than the first two above-cited wetland studies (CDFG 1983; Dennis and Marcus 1984). This work is based on Smith (1985) and Gilmer et. al. (1982). It returns 4 to 5 million acres of "wetlands."

[1] The map in these reports that claim 500,000 acres of tules actually show 1,200,000 acres of tule. The source of the map showing tules and the estimate of tules written on the map are different and the authors did not reconcile the two sources. This is discussed in Section 3.4.2.

Table 1. Continued.

Histories	
(Hittell 1885)	Reports there are "several thousand square miles of so-called tule lands..about the heads of the bays, around lakes and ponds and along the lower parts of river courses.." (v.I, p.558). Greater than several thousand square miles is taken to mean greater than 1,280,000 acres.
(Bancroft 1890)	Reports 3,000,000 acres of "tule land" and "lands subject to overflow from salt water..." (p.22)
(Thompson 1958)	Reports 525,000 acres of tidal and river backswamps of tule in the Delta (p.21 51,52).
(Kahrl 1979)	Reports 500,000 acres of inland "freshwater marshes and swamps" (p.4), which from the description is taken to exclude the Delta. Reproduces Kuchler's Natural Vegetation Map (1977).
Popular Press/Promotional Literature	
(Hittel 1863)	Hittel's personal estimate of "tule-land" or "marshy land is 396,800 acres, of which 128,000 is on the Sacramento River, 64,000 on the San Joaquin River, 128,000 is north of Tulare Lake, and 76,800 acres is south of Tulare Lake (p.13).
(Cronise 1868)	Reports "tule lands" on a county-by-county basis, which total to about 660,000 acres (Dawdy 1987, p.10).
(Fabian 1869)	Reports 5,000,000 acres of "swamp and tule land," of which 30,000 is in Colusa county, 90,000 in Solano county, 200,000 in San Joaquin county, 20,000 in Fresno county, "thousands of acres of swamp land" are in Tulare county, and "a belt of tule" is in Sacramento county.
(Tide Land Reclamation Co 1869)	Reports "several million acres of swamp and overflowed lands in California...not to exceed 200,000 acres of...fresh water tide lands." (p.5)
Cronise (1870)	Reports "several million acres of swamp and overflowed lands, generally designated "tule," in California..not to exceed 200,000 acres of...fresh water tide lands." (p.47) In the San Joaquin Valley, he returns "1,000,000 acres of salt marsh and tule-lands..." (p.53).

trip down the San Joaquin, "An apparently interminable sea of tules extends nearly one hundred and fifty miles south, up the valley of the San Joaquin..." (Hutchings 1860, p.30).

Stockton was built in the midst of the tules and was originally called "Tuleburg" (Gudde 1960, p.305) and the Central Valley, the "Valley of Tules" (Tinkham 1880, p.62). Reflecting this heritage, the editor of the Stockton Times, in describing the Delta, wrote that:

> "The ordinary observer who travels over the San Joaquin River, as his eye surveys the vast expanse of tule or marsh land extending for miles on either bank, may receive the impression that it is unfit for agricultural purposes and uncultivable except for rice." (Gilbert 1879, p.322).

3.3 Primary References on Tule Acreages

Natural flow calculations in SWC Exhibit 262 were based on a total of 1,589,000 acres of tule swamp in the Central Valley, of which 946,000 acres were tributary to San Francisco Bay and 643,000 acres in the Tulare Lake Basin. These acreages were obtained by planimetering from Kuchler's 1977 Natural Vegetation Map, after adjusting it using the primary references cited in Table 1 and then checking the returned acreages against those from the surveys.

SWC Exhibit 262 tule acreages fall the low side of the range of reliable estimates based on primary source material, principally federal and state surveys. SWC estimates also are equal to or lower than those variously reported by William Ham. Hall as "swamp lands" (Hall 1887, 1888) or "swamps of low outfall" (Manson 1888, p.88) and by Professor Hilgard for the U.S. Census as "tule lands" (Hilgard 1884).

The primary references (Table 1) return a minimum of 1.3 million acres of tule marsh. These minimum is taken from two sources. The federal surveys of "swamp and overflow" land reported 1,312,700 acres in the Central Valley, of which 863,000 acres were tributary to the Bay (Mandeville 1857). This value is considered to be a minimum because it is from incomplete federal surveys that conducted in the dry season during a period when the Sacramento River was reported not to have overflowed its banks (Gilbert 1879, p.57). Since annual overflows were normal and since these surveys were made during the driest part of the year, these are taken to be minimum permanent swamp. The second estimate of minimum tule acreages is taken from a USDA report that classified swamp and overflowed lands by degree of wetness (USDA 1908). The USDA in 1908 reported 1,000,000 acres of unreclaimed "permanent swamp." Since 323,000 acres of Delta tule marsh had been reclaimed by that date (CDPW 1931, p.158; Thompson 1958, p.238) plus an indeterminate amount of tule lands elsewhere (Hilgard 1884), the total "permanent swamp" was at least 1,323,000 acres. Because the only type of swamp or marsh ever reported in the Central Valley was "tule marsh," all of the "permanent swamp" is taken to be permanent tule marsh.

These primary sources also return a maximum "swamp and overflowed" land area of 2,192,506 acres, which is the amount of "swamp and overflowed" land that the U.S. ultimately granted to California under the 1850 Arkansas Act (Thompson 1958, p.186). The final U.S. grant figure, 2.2 million acres, is the sum of permanent tule swamp plus "overflowed" lands that were wet and unfit for cultivation throughout the growing season during at least three years out of five. These "overflowed" lands also supported marsh vegetation, but evapotranspiration from them was not included in SWC Exhibit 262. Professor Hilgard estimated that about 1.6 million acres of the lands granted to California were tule lands and that about 1.2 million acres of tule were in the Central Valley and tributary to the Bay (Table 2). Higher figures, 3 to 5 million, were reported in the early land survey reports (Table 1) and include seasonally flooded lands. These higher figures were not used in SWC Exhibit 262.

In summary, the range of reliable estimates of tules in the Central Valley based on primary source material is 1.3 [permanent swamp] to 2.2 million acres [permanent swamp plus seasonally overflowed]. SWC Exhibit is based on 1.6 million acres of tule swamp, which is the mid-point of this range and about equal to Hall's estimate of 1.7 million acres of "swamp" and Professor Hilgard's estimate of 1.5 million acres of "tules." No evaporation from the "overflowed" lands was included in SWC Exhibit 262.

The following subsections provide additional information on the primary source material.

3.3.1 Map Legends. Tules are clearly labeled on the early maps of the Central Valley. Some of these early maps that show the approximate extent of tules under "natural" conditions and that label these areas as "tules" are reproduced in Appendix B. However, later maps, after about 1849, were based on topographical surveys and were prepared by professional cartographers. These later maps often do not label vegetation types either on the map or in legends. Instead, they used standard cartographic sysmbols that were and are understood to represent marsh or swamp. A consistent symbol, typically closely spaced parallel lines [ ] or the standard marsh symbol [ ] (USGS 1913, p.214) is used on these later maps. This symbol was widely understood to represent "tule" or "swamp and overflowed" lands, which were used interchangeably in California (Sec. 3.3.4). This can usually be verified by reading accompanying reports.

3.3.2 First Surveys. The first surveys of the Central Valley were carried out by topographical engineers and hydrographers of the U.S. Army and the U.S. Navy (Farquhar 1932; Ringgold 1852; Wilkes 1845,1849). These surveys were typically reconnaissance in nature and only covered portions of the valley. Nevertheless, they serve to establish the extent of tules prior to the Gold Rush.

Charles Wilkes, U.S.N., commanded an extended U.S. exploring expedition between 1839 and 1842 to gather information on unknown territories to the west. He visited California in 1841 and explored and mapped San Francisco Bay, the Delta, and the lower Sacramento and San Joaquin rivers (Wilkes 1845, p.149-215; 1849). The map from this expedition is reproduced in Wilkes (1849) and the channel profile from his work is published in CDPW (Plate XXXV, 1931). The map has no legend but the standard marsh symbol indicates tules in the regions explored by the party. The geography of the valley shown on this map is inaccurate because they did not survey this region, while the geography of the Bay is quite accurate. This map reports the earliest soundings of the Bay and Delta.

The next surveys of note were carried out by Lietenant Derby, who was sent west to gather geologic and topographic information on California and to site a military outpost in the new State. He performed a reconnaissance-level survey, traversing the Sacramento Valley as far north as Butte Creek in September and October of 1849 (Farquhar 1932a), the Delta and San Joaquin Valley in July and August 1849 (Hollinsworth 1976), and the Tulare Valley in April and May 1850 as far north as the bend in the San Joaquin River (Farquhar 1932b).

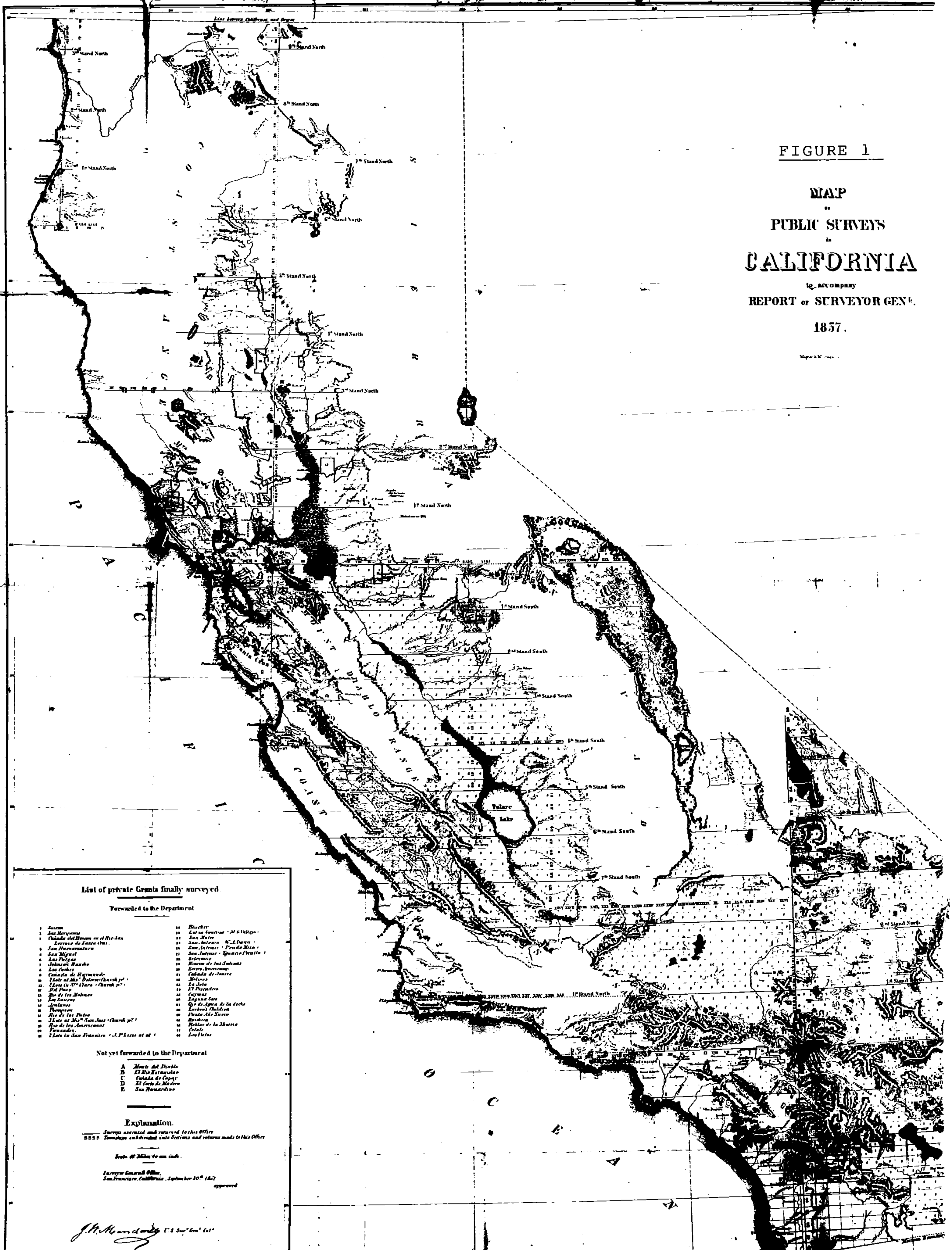
The surveys of the Sacramento Valley and Delta were made during the driest part of the year, during a drought period. They show tule, clearly labeled as such, in all of the places where it was subsequently more accurately defined by survey. These maps are notable because they show riparian forest. The extent of the tule is further clarified in the text that accompanies the maps. Derby's maps of the Sacramento and Tulare Basins are reproduced in Appendix B.

The final set of important, pre-Gold Rush surveys was made by Commander Cadwalader Ringgold, U.S. Navy. Ringgold participated in the Wilkes expedition and later returned to California, where he was commissioned to prepare a series of sailing charts of San Francisco Bay and the Delta region to facilitate the heavy upriver travel brought on by the start of the Gold Rush. A series of five sailing charts and a descriptive report were published by 1852 (Ringgold 1850-1852). These surveys were conducted in 1849 and 1850 using a system of triagulation and true azimuths; depth soundings were also taken throughout all embayments and sloughs. The surveys are regarded as accurate, being the first maps to correctly show embayments, rivers, sloughs, Delta islands, and vegetation. The maps indicate tule swamp and riparian forest by standard cartographic symbols. Swamp was shown along the northern and southern shores of Suisun Bay, throughout the entire Delta, and along the lower Sacramento and San Joaquin Rivers. The charts also show riparian forest along natural levees of Delta islands, which were reported by many early travelers.

3.3.3 Federal Surveys. The next official surveys of swamp lands in California were carried out by the U.S. Department of Interior in response to the Arkansas Act of 1850, which granted to the states all "swamp and overflowed" lands within their boundaries.

The U.S. Surveyor General for California summarized the results of the federal surveys in reports to the U.S. Congress (Reports of the Secretary of the Interior to Congress, Senate Executive Documents 1850-1900). Maps accompanied these reports starting in 1854 (Hays 1854) that delineated the surveys. An original of the 1857 map was planimetered for this work. This date was selected because earlier maps were not available and later maps were judged to potentially include influences from hydraulic mining and settlement of the valley. A copy of the 1857 map is shown in Figure 1. No legend is included on the map, but the accompanying report indicates that "swamp and overflowed" land was mapped (Mandeville 1857). This 1857 map reports 863,200 acres of swamp and overflowed land in the Central Valley tributary to San Francisco Bay and an additional 449,500 acres in the Tulare Basin. The swamp acreages from this map, which are based on incomplete surveys, are within 9 percent of those used in SWC Exhibit 262. These areas were assumed to represent "permanent swamp" or tules in this work, for the reasons outlined below.

FIGURE 1



MAP
OF
PUBLIC SURVEYS
IN
CALIFORNIA
to accompany
REPORT OF SURVEYOR GENL.
1857.
Tulare Lake
COAST RANGE
DIABLO RANGE
PACIFIC OCEAN
List of private Grants finally surveyed
Forwarded to the Department
San Miguel
Las Pulgas
Johnson Rancho
Del Paso
San Mateo
La Jota
Not yet forwarded to the Department
A Monte del Diablo
B El Rio Estanislao
C Cañada de Capay
D El Corte de Madera
E San Bernardino
Explanation.
Surveys executed and returned to this Office
Townships subdivided into Sections and returns made to this Office
Scale 12 Miles to an inch.
Surveyor General's Office,
San Francisco, California, September 30th 1857
approved
U.S. Sur. Genl. Cal.

The definition of "swamp and overflowed" lands under this Act is one of the factors that makes it difficult to accurately determine "tule" acreages. The Arkansas Act defined "swamp and overflowed lands" as those "made unfit..for cultivation." The U.S. General Land Office, in November 1850 in its general instructions to land offices, further clarified the types of lands that were covered (Butterfield 1850, p.8):

> "This Act clearly and unequivocally grants...those lands which, from being swampy or subject to overflow, are unfit for cultivation. In this class is included also all lands which, though dry part of the year, are subject to innundation at the planting, growing or harvesting season, so as to destroy the crop, and therefore are unfit for cultivation -- taking the average of the season for a reasonable number of years as the rule of determination."

The U.S. surveys were made in the dry season, in the late summer and fall (CSG 1857, p.14; 1862, p.10; 1856, p.211; Thompson 1958, p.189-190). This in part was due to the need to determine the character of the land as of September 28, 1850, the date of passage of the Act (Anonym 1861, p.17). These federal surveys were conducted after the flood basins had drained. Thus, the federal surveys are equivalent to "permanent" swamp or "tule," which was the only type of swamp in the State and do not include seasonally overflowed lands. The federal surveys underestimated acreages because they excluded lands that had been reclaimed prior to the survey (Thompson 1958, p.191).

These federal surveys were used to map swamp lands on a number of California maps. J.D. Whitney, the first State Geologist, prepared geological maps of California that showed swamp lands [also with no legend] (Whitney 1873, 1874). These maps were compiled from, among other sources, materials of the U.S. Surveyor General. The swamp lands shown on the State map accompanying Colonel Alexander's (Alexander et al. 1874) report on irrigation are almost identical as to location and areal extent to those on the Whitney maps and the U.S. Public survey maps, suggesting the U.S. surveys were also the source of Alexander's map. All of these maps return 1.2 to 1.3 million acres of swamp in the Central Valley.

3.3.4 California Surveys. Public demand for the purchase of "swamp and overflowed" land lands quickly exceeded the pace of the U.S. surveys. The State, therefore, allowed county surveyors to perform an advance survey for prospective buyers. The State processed the purchase applications and later U.S. surveys were conducted to affirm the land classification and provide the perfect title (Uzes 1977, p.133-134). The State surveys were reported by the California Surveyor-General to the State Legislature (CSG Reports, 1852-1926). The lands so surveyed were located on official State maps that were separately published, the first in 1854 (Eddy 1854). These maps were not planimetered in this work because the acreages were recorded in the annual reports.

Initially, California surveys reported higher acreages than U.S. surveys because the State surveys were made during wet periods and thus included overflowed lands that were dry in late September when most of the federal surveys were conducted. The U.S. Surveyor-General returned many of California's claims, and there was much conflict over what "swamp and overflowed land" was. Ultimately, these conflicts were resolved and California tightened up its definition of "swamp and overflowed land," in response to the Swamp Land Act of 1862. This new Act defined these lands in instructions to surveyors as:

"...made unfit for cultivation and is in fact unfit for cultivation and is in fact unfit for cultivation without 'necessary levees and drains to reclaim same;' that they are made such by reason of overflow of [name of river], in such a manner that no crop can be raised thereon, by reason of its overflowed and swamp condition, that they are not shallow lakes, or ponds, which may, by natural causes become dry; and that such was the character thereof on the 28th September, 1850, the day of passage of the grant." (Anonym. 1861, p.17).

The U.S. ultimately granted 2,192,506 acres of "swamp and overflowed" lands to California (Thompson 1958, p.186) in conformance with this definition. In contrast, only 1.6 million acres of tule swamp in the Central Valley (1 million acres tributary to the Bay) was used in this work.

Swamp and overflowed lands ultimately granted California were approximately equivalent to "permanent swamp" since they had to be wet and unfit for cultivation as of September 28, 1850 and since they required <u>both levees and drains</u> to reclaim. Some lands could dry out between the end of September and November when the rains start, but this would have had an insignificant impact on tule water use since 84 percent of such use occurs by the end of September.

In California, these "swamp and overflowed lands" became known as "Tule" or "tule lands" because they supported a dense growth of tule. The term tule, marsh, swamp, and swamp and overflowed lands were used interchangeably in California. Will Green, who wrote one of the authoritative histories of Colusa County and authored the first reclamation act in California, in describing the area around the Buttes, wrote that "[b]etween it and the Sacramento River, there is a great deal of tule...hence our swamps are called tule land." (Green 1857, p.57). Cronise indicated that "swamp and overflowed land [was] generally designated `tule,' in California." The Yolo County Surveyor in 1862 in describing swamp along the Sacramento River, designated the "flat and low swamp had to be leveed and drained to be reclaimed, while "overflowed land" only required levees. Contemporary authors have also reached the same conclusion. Burcham (1957, p.96), for example, states that the "marsh-grass community" was "referred to commonly as `tule lands.' "

The weight of evidence examined in this work suggests that "swamp" generally designated tule swamp, while "swamp and overflowed" lands may have included areas that were seasonally inundated. It is unclear whether "overflowed" lands also supported tules. Tules are able to rapidly colonize most areas, and it is likely that many of these seasonally flooded areas supported tule growth for at least part of each year since the flood basins were still draining in June and July of most years (CDPW 1931). SWC Exhibit 262 does not include evaporation or evapotranspiration from these seasonally overflowed lands (Sec.6.0).

3.3.5 <u>State Engineer Surveys.</u> The State Engineer's Office under William Ham. Hall also conducted surveys to ascertain the character of the land (Hall 1880, Part I). The results of this work were periodically summarized in annual reports to the Legislature. Comprehensive reports summarizing all of the field work directed by Hall in the Central Valley were in preparation when he resigned from office in 1888 amid much political controversy (Korr 1963, p.313). Although Hall attempted to retrieve his manuscript material and publish the reports pro bono, he was unsuccessful, and all that was ever published of these comprehensive surveys was the maps. The results of Hall's swampland surveys were summarized in a journal article by one of his assistants (Manson 1888). Two of the Hall maps (Hall 1887, 1888) and the Manson summary (Manson 1888) were used to validate tule lands obtained from Kuchler (1977).

The Hall maps were planimetered in this work to confirm tule swamp acreages obtained from Kuchler. The 1886 map includes a legend that clearly delineates "swamp land," "irrigated swamp land," and "bottom land." These maps indicate that the Central Valley contained 1,655,000 acres of "swamp land." Of this amount, 944,000 acres were tributary to the Bay and 711,000 acres were in the Tulare Basin. By comparison, SWC Exhibit 262 used 946,000 acres tributary to the Bay and 643,000 acres in Tulare Basin.

3.3.6 Kuchler's Natural Vegetation Map. Two maps of natural vegetation have been prepared of California. The first attempt was by Burcham (1957), who concluded that his map at best was "diagrammatic." (ibid., p.81). Later geographers have critized this map, stating that it was "seriously in error as far as the valley is concerned." (Thompson 1961, p.295) The scale was also too coarse to show most of the valley vegetation that was of interest in this study. Thus, the more comprehensive and accurate work of Kuchler (1977) was used. This map was published in full color at a scale of 1:1,000,000 in a widely used textbook, Terrestrial Vegetation of California (Barbour and Major 1977) and is reproduced in the California Water Atlas (Kahrl 1979, p.17). It was submitted in these Hearings in the Hydrology Session by the USBR as Exhibit 3A.

Kuchler's (1977) Map of the Natural Vegetation of California was used to estimate land areas used in SWC Exhibit 262. Grasslands were taken directly from Kuchler's map. However, some topographical errors with respect to tule swamps and riparian forests were identified, which were corrected. Kuchler's map shows tule swamps in areas that were either riparian forests or were usually flooded (Tulare Lake Basin). The first problem was corrected using surveys and other primary source material. The areas that Kuchler showed in the Tulare Basin that were actually lakes (Tulare, Kern, Buenavista Lakes) were not corrected because this region was not used in the Bay inflow calculations. Additionally, these lakes commonly fluctuated in volume from zero to 760 square miles, and tule acreages returned by surveys varied widely, making it difficult to estimate an average. Instead, consumptive use estimates were modified, as discussed in Section 8.1.

The Kuchler map was developed by using plant communities obtained from maps of contemporary vegetation. Topography, soils, climate, and other data were then used to reconstruct "natural" vegetation in those areas where it had been modified. Various drafts of the map were reviewed by numerous local experts and appropriate changes made (Kuchler 1987). The principals used to develop this map are outlined in Kuchler's textbook, Vegetation Mapping.

These types of procedures yield "potential" vegetation, hence tules are shown where seasonal lakes were located. They also can return "maximum" estimates of vegetation areas. These limitations were addressed in the present work by historical research. The locations of tule swamp and riparian forest shown on the Kuchler map were checked against early maps and eye-witness accounts and adjustment made as appropriate. The resulting acreages were then checked against surveys and other's estimates to verify that an average rather than an extreme value was obtained.

The Kuchler map was selected for several reasons. First, it is the only map of "natural" vegetation of California at a scale suitable for planimetering. Second, it includes all of the types of "natural" vegetation used to calculate "natural" outflow -- tule swamp, grasslands, and riparian forest. Third, it is internally consistent since all vegetation types are reported for the same set of conditions and were determined using similar methods. Thus, it avoids the problems of using three separate estimates from different sources that are based on different time periods, conditions, etc. Fourth, it was based on the climatic conditions of the present century, from about 1900 through 1977, the period used in the "natural" flow calculations.

3.3.7 Technical Summaries Based on Surveys. The U.S. Department of Agriculture (USDA), the U.S. Department of the Interior, and others published reports that summarized the results of public land surveys (Table 1). These reports were typically more explicit than the surveys themselves in defining the character of the land. These technical summaries clearly indicate that large tracts of "permanent swamp" existed in the Central Valley and that this permanent swamp was tule swamp. These technical summaries were used to verify the estimates obtained from Kuchler's map.

The most significant of these is the review of California lands written by Professor Hilgard for the 1880 census reports (Hilgard 1884). Hilgard was a pioneer in California agriculture. He is generally regarded as the father of modern soil science, he was the first director of the Agricultural Experiment Station at Berkeley, and he was a professor of agriculture at the University of California and at the University of Mississippi, among many other distinctions. His report for the 1880 U.S. census discusses the resources of each county in California, separately listing the area of tule lands in each. He also clearly defines tule lands as "..the name applied in California to all lands, whether littoral or inland, bearing as an important ingredient of its vegetation the tule or rush, which of course, varies in kind according to location near to or remote from saline tide-water...All these lands are, of course, subject to overflow, and need protection by levees." (Hilgard 1884, p.688)

The acreages of tule lands reported by Hilgard are summarized in Table 2. He reported a total of 1.6 million acres of tule lands in the State distributed as shown in Table 2. This estimate compares favorably with the estimate of 1.7 million acres obtained by planimetering Hall's maps and the estimate of 1.6 million obtained by planimetering Kuchler's (1977) maps. The tule acreages reported by these three sources for lands in the Central Valley tributary to the Bay also agree closely. However, areas in the Tulare Lake Basins differ, ranging from 365,000 (Hilgard 1884) to 711,000 acres (Hall 1887), no doubt due to the variable nature of tule lands in the Tulare Basin (Sec. 6.1).

The Manson (1888) report is also an important, authoritative reference source for tule acreages. Marsden Manson was one of William Ham. Hall's first Assistants, and he became a prominent Consulting Civil Engineer in California. His report is based on surveys made between 1878 and about 1886 by the State Engineer's Office before major reclamation projects had been attempted. Manson probably slightly underestimates "natural" swamplands because the surveys were made after the swamps had started to dry up. Damming of sloughs, leveeing of rivers, and hydraulic mining greatly reduced swamp water supplies and caused some swamps to dry up (Section 4.0).

Table 2. Summary of tule lands in the Central Valley as Reported by Cronise (1868), the California Surveyor General's Office, and Hilgard (1884).

COUNTY	ACRES OF TULE IN CENTRAL VALLEY			
	Cronise (1868) Tule Lands (1)	Early Estimate by County Surveyors (CSG 1855-1856) (2)	Based on Official Federal and State Surveys (CSG 1862) (2)	U.S.Census Tule Lands (Hilgard 1884) (1)
TRIBUTARY TO BAY				
San Joaquin	200,000	275,000	236,000	205,000
Sacramento	100,000[3]	130,000	162,000	157,000
Yolo	110,000[3]	80,000	182,000	160,000
Solano	90,000	90,000	100,000	131,000
Contra Costa[4]	75,000	150,000	150,000	16,000
Stanislaus	35,000[3]	35,000	NR	22,000[3]
Colusa	30,000[3]	192,000	99,000	90,000
Sutter	NR[5]	160,000	111,000	339,000[6]
Merced	NR	NR	NR	58,000[3]
Subtotal	640,000	1,112,000	1,040,000	1,178,000
TULARE LAKE BASIN				
Fresno	20,000	115,000	NR	160,000
Tulare	NR	NR	NR	19,000
Kern	NR	NR	NR	186,000
Subtotal	20,000	115,000	NR	365,000
OTHER PARTS OF STATE				
Alameda	2,000	NR	37,000	13,000
Sonoma	some	NR	21,000	some
Napa	some	some	12,000	22,000
Subtotal	2,000	-	70,000	35,000
TOTAL TULE LANDS	**662,000**	**1,227,000**	**1,110,000**	**1,578,000**

1 Reported as "tule lands."
2 Variously reported as "tule," "swamp," or "swamp or overflowed" lands. These terms were used interchangeably in California because the overflowed lands supported tules. Excludes salt marsh and high mountain swamps.
3 Calculated from estimates of length and width of tule lands presented in text.
4 A portion of this county is not in the Central Valley.
5 Not reported.
6 Includes some adobe.

Manson's article does not use the term "tule," describing "swamps" according to their drainage potential. It also does not use the nomenclature of the Arkansas Act, thus avoiding the definition problem discussed above. Manson distinguishes four types of swampland as follows: (1) salt marsh - 203,660 acres; (2) swamps of low outfall on the lower San Joaquin and Sacramento river and their tributaries - 1 million acres; (3) elevated swamps having outfall (Tulare, Colusa, and Butte Basins) - not given; and (4) mountain swamps - 156,800 acres.

The swamps of low outfall are here taken to be permanent tule swamps. The flood basins in these areas did not drain until low-water stages of the main rivers (Davidson et al. 1896) or were continuously supplied with water from tidal action and have been variously reported to contain standing water year round. Manson reports 1 million acres of these "swamps." This is comparable to estimates in SWC Exhibit 262 and is consistent with acreages obtained by planimetering the Hall maps, which report "swamp lands."

3.4 Secondary References on Tule Acreages

Lower estimates of tule lands than those used in SWC Exhibit 262 do exist, and they are predominately from secondary sources that are either nontechnical (i.e., newspapers, popular press, promotional literature, general histories written by nonhistorians) and/or are not referenced back to primary source material and/or are ambiguous (i.e., wetlands studies) due to a failure to define terms or specify locations.

The Dawdy rebuttal exhibit and cross examination used two of these secondary sources to justify tule acreages lower than used in SWC Exhibit 262. These two alternate sources are Cronise (1868), who reports about 660,000 acres of "tules," and a second source that estimates 500,000 acres of tule marsh. Each of these estimates is discussed below, and the reasons that they were eliminated from this work are outlined.

3.4.1 Cronise (1868). Mr. Dawdy uses a single source, Cronise (1868), to determine tule acreages (Dawdy, p. 10). Dawdy estimates there were 660,000 acres of tules (Dawdy, p. 10) using this sole source, compared with 946,000 acres used in SWC Exhibit 262. Dawdy uses this single estimate as a starting point for his subsequent arguments, claiming that natural acreages must have been lower than even 660,000 acres due to annual drying and burning of the tules. He further speculates that prior to the coming of the Americans, only "scattered tracts of tules" (Dawdy, p.19) existed and that additional overflow created when hydraulic mining debris filled channels encouraged "the spread of tules into areas not occupied by them under 'natural' conditions" (Dawdy, p.19).

This single source (Cronise 1868) is not sufficient to provide a reliable estimate in which confidence can be placed for the following reasons: (1) it was made late, around 1868, twenty years after the onset of the Gold Rush and associated development; (2) it does not cover all areas in the Central Valley that contained tule lands; (3) it does not agree with official state and federal surveys then extant; (4) it contains no references to authoritative sources then extant; and (5) it was one of many similar books designed to attract immigrants to California and therefore is "promotional" in nature.

Cronise was a farmer who lived in the San Joaquin Valley (Cronise 1870), not a trained historian or engineer. His book is not an authoritative and reliable source of data, containing no references or sources for the information presented. Bancroft, in compiling his monumental history of California, cited Cronise only once, and then to correct an error (Bancroft, 1885, v. ii, p.298). Cronise is not mentioned in biographical histories of the San Joaquin Valley. Professor Hilgard, who wrote an authoratative account of land use in California for the 1880 U.S. census used Cronise (1868) as a source for other land uses, but completely ignored Cronise's estimates of tule acreages (Hilgard 1884, p.656,745-783).

The information presented in Cronise on tule acreages does not agree with other authoritative sources from the same time. Notably, U.S. and California surveys were in progress when Cronise wrote, and the County Surveyor's offices contained current information on the extent of tule lands. These data were periodically summarized in annual reports to the State Surveyor General. Cronise's estimates do not agree with the information current when he wrote (CSG 1855-1870), and thus it is concluded that his estimates are based on his own travels, rather than surveys. He, for instance, does not mention tules in some counties -- Sutter, Merced, Tulare -- where they were common and widely reported in county histories and early travel literature.

<u>Not Representative of Natural Conditions.</u> Cronise's tule acreages are presumed to reflect acreages known to the author in 1867-68, as he states in his introduction that the book was "written within a year -- much of it within a few weeks of publication." (ibid, p. vi) At this early period, major changes had already occurred in the natural land and water resources in the Central Valley, contrary to Dawdy's assertion that this was "prior to any major drainage attempts" (Dawdy, p.10) and "before the advent of settlement of the Central Valley." (Dawdy,p.11)

The 1860s, when Cronise wrote, are well known for rapid growth, laissez-faire development, and destruction of many natural resources (Bancroft 1885). Dawdy suggets that tule acreages increased during this period due to increased flooding (Dawdy, p.9). Information reviewed in Section 4.0 indicates that tule lands probably decreased from 1850 to 1870 and beyond, rather than increasing. Cronise's 1868 figures undoubtedly <u>underestimate</u> "natural" tule acreages.

<u>Cronise Does Not Cover All Known Tule Lands</u>. Swamp lands were surveyed from 1852 through the turn of the century in California by both the U.S. Department of the Interior and the State of California (Section 3.3). The surveys were constantly being extended, modified and refined, and Cronise, who was a resident of the San Joaquin Valley, no doubt had incomplete information when he wrote in 1868.

Table 2 compares tule acreages reported by Cronise with those first estimated by county surveyors in 1855 and 1856, with the results of partial surveys reported in 1862, and with later estimates by Professor Hilgard. Both Cronise and Hilgard reported "tule lands" while the surveys variously reported "tules," "swamp," or "swamp and overflowed lands." These terms were used interchangeably in California because tules grew on all of these types of land (Sec. 3.3.4). Estimates prior to 1862 exclude effects due to mining debris, which only became important after the 1862 flood (Section 4.0) but are based on incomplete surveys and therefore are low. The later estimate (Hilgard 1884) includes the effects of mining debris, reclamation, harvesting of tules, and drying and burning, which were all common in the post settlement period (Sec. 4.4). Thus, the Hilgard estimates are also probably low.

This table demonstrates that Cronise's estimate was incomplete and was about a factor of two lower than official county surveyor figures reported before mining debris impacted the tules as well as subsequent reports on a county-by-county basis. Cronise does not report tules in Sutter, Merced, Tulare or Kern counties, where major tracts of tules had been consistently reported from the 1770s (Appx. A). The majority of the additional tule lands not reported by Cronise were in Sutter county and the Tulare Lake Basin (Fresno, Tulare, and Kern counties). The Sutter tule lands were reported as "tule" by the county surveyor in 1856 (CSG 1856, p.255) and also by Professor Hilgard (1884, p.747). Cronise also underestimates acreages for several counties.

Cronise himself revises upward his estimates in a second, similar report that he published in 1870 entitled The Agricultural and Other Resources of California. He states that "..there are several million acres of swamp and overflowed land, generally designated 'tule,' in California" (Cronise 1870, p.47), and he further located in the San Joaquin Valley "1,000,000 acres of salt marsh and tule lands..." (Cronise 1870, p.53).

3.4.2 Estimates of 500,000 Acres. There are several contemporary references that state that there were 500,000 acres of lands variously called "tule marsh," or "permanent freshwater marsh," or "freshwater marshes and swamps" (Burcham 1957, p.96; Kahrl 1979; CDFG 1983; Dennis and Marcus 1984). The basis of these figures was investigated, and the estimate was not used because it disagreed with more reliable survey and field studies or was revised in later, more comprehensive work. The basis for this opinion is discussed below. These estimates have been misused in a number of recent reports.

Origin of 500,000 Acre Tule Estimate. Most contemporary references to the 500,000 acres estimate appear to be based on the California Water Atlas (Kahrl 1979, p.4), which states:

> "Along the sheltered inland margins of bays, lagoons, and estuaries, salt and brackish water marshes provide fertile and productive habitats rich in nutrients which support grasses, pickelweed, mussels, clams, herons, egrets, and hosts of migrant waterfowl. Further inland where the land is relatively flat, freshwater marshes and swamps, which once covered an estimated 500,000 acres of California, provide habitats as well for ducks, marsh wrens, rails, swans, and geese."

The source of the 500,000 acre figure is not indicated in the Atlas and the location of the referenced marshes is not clear. Is the estimate for just the Delta, non-tidal marshes, or the entire State? The entire State seems quite unreasonable given the weight of evidence to the contrary in the primary sources (Table 1). A different chapter by a another author presents the Kuchler natural Vegetation Map, which shows 1 million acres of "freshwater marsh" in the Central Valley tributary to the Bay (Virgin Waterscape, p.17).

The most likely source of the 500,000 acres estimate in the Atlas among those cited (Kahrl 1979, p.113-115) is John Thompson's classic history on the Delta is the most likely source (Thompson 1958). This is the principal reference for historical, geographical, and other information on the Delta. Thompson, based on independent map measurements, estimated that "[a]pproximately 320,000 acres of the delta lay within the estimated mean pre-reclamation tidal basin. More than half of this swamp was inundated at high tide. Another 205,000 acres of the delta were subject to river flooding primarily, although extreme tides may have backed over some of the area...Areal distribution of the virgin tule coincided with the extent of pre-reclamation tidal or river backswamps." (ibid., p.52)

Thus, the estimate of 500,000 acres in the Atlas was probably intended to apply to Delta freshwater marshes. This estimate is consistent with primary source material (Table 1) that reports 342,000 (Gilbert 1917) to 600,000 acres (Nesbit 1885) of swamp in the Delta and is consistent with freshwater marsh shown also in the Atlas on page 17 (400,000 acres). It is also inconsistent with all primary source materials (Table 1), which report 1.3 [permanent swamp; USDA 1908 + Thompson 1958] to 2.2 million acres [swamp and overflowed land].

Misuse of the 500,000 Acre Estimate. Recent wetland studies have inappropriately used this 500,000 acre figure. An example of this misuse is shown in Figure 2. This figure is a map of the Central Valley that shows areas of "tule marsh lands" indicated by the standard marsh symbol. The legend on Figure 2 indicates that "tule marsh lands" are mapped and that 500,000 acres are shown. The tule areas are taken from "State Geological Survey of California 1874," which is a geologic map of California and Nevada prepared by J.D. Whitney, the first State Geologist (Whitney 1874). The Whitney map has no legend, and actually shows "swamp and overflowed land," not "tule marsh." The Whitney map and Figure 2 were planimetered in this work and show 1.2 million acres of "tule marsh," not 500,000 acres as marked on the map. In the text accompanying Figure 2, the 500,000 acres is referenced back to the Atlas (Kahrl 1979).

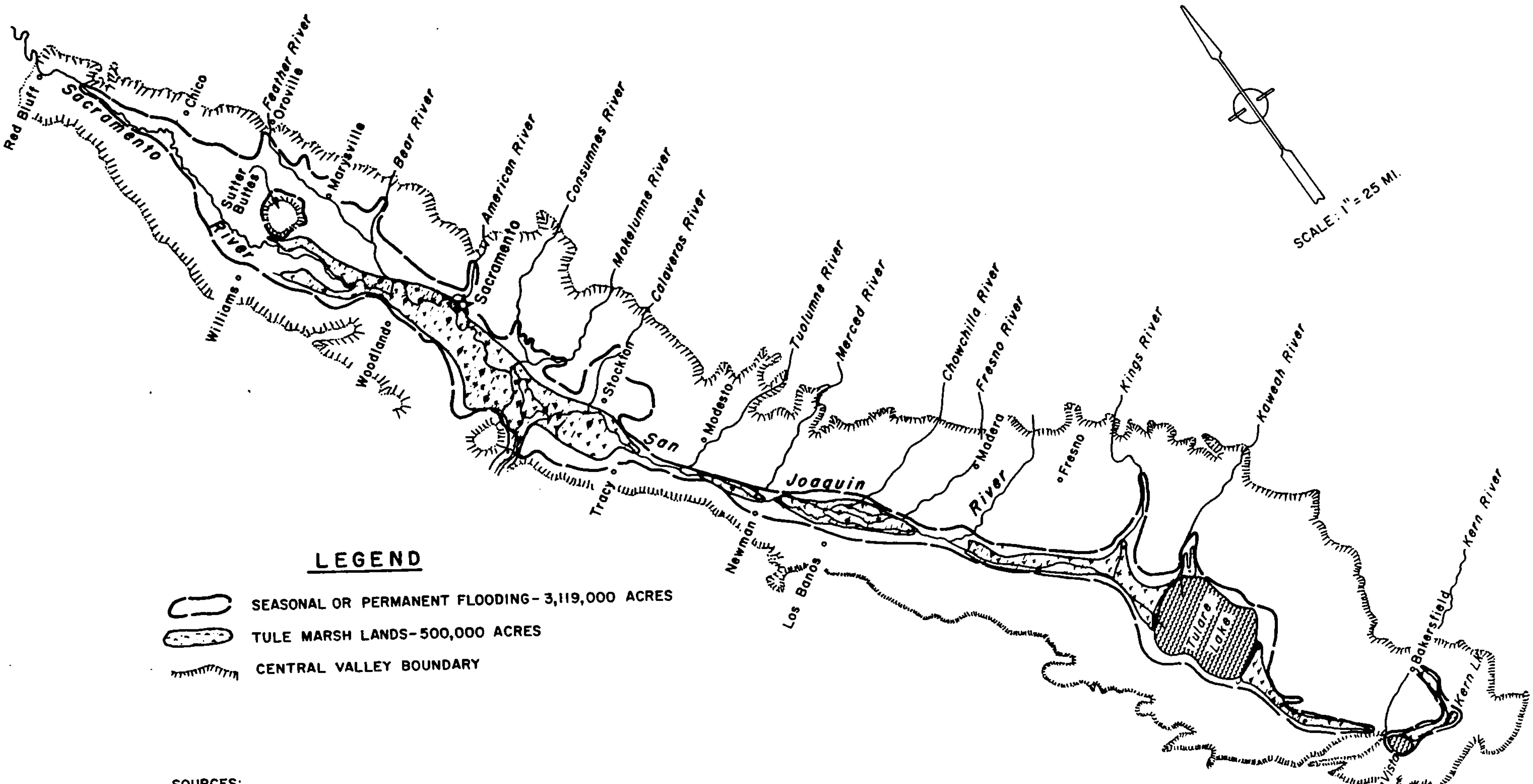
4.0 MINING DEBRIS DID NOT INCREASE TULE ACREAGES

Mr. Dawdy speculates on page 9 of his exhibit that "..debris caused the streams to overflow at relatively low discharges. This generated greater and more frequent flows in the overflow areas and generated more swamp lands. This encouraged the growth of tules. Therefore, the natural areas covered by tules probably was [sic] less than the 600,000 to 700,000 acres enumerated below." Mr. Dawdy further notes that "..during much of the period of historic observation of the growth of tules -- from 1860 to 1900 -- the debris was at its maximum extent in the channel."

This is not true because tule acreages used in SWC Exhibit 262 are substantiated by surveys that were conducted prior to the onset of channel siltation (Secs. 3.3.3, 3.3.4) and by numerous eye-witness accounts (Appx. A). Although mining debris filled many stream channels in the Sacramento Basin, it did not cause a significant increase in tule lands. The fate of tule lands during the Gold Rush depended on more complex factors than the silting of stream channels. Many other things occurred simultaneously with hydraulic mining. Some favored the growth of more tules while others reduced the growth of tules. The historical record suggests that the net effect of activities in the 1850 to 1870 period was to reduce tule acreages compared to natural conditions for the following reasons:

FIGURE 2

CENTRAL VALLEY MARSHES AND LANDS HISTORICALLY SUBJECT TO OVERFLOW



LEGEND

SEASONAL OR PERMANENT FLOODING - 3,119,000 ACRES

TULE MARSH LANDS - 500,000 ACRES

CENTRAL VALLEY BOUNDARY

SOURCES:

Overflow - Bulletins 26 and 29 DWR 1931

Marshlands - State Geological Survey of California 1874

1. Other activities were in progress at the same time that mining debris was generated that would tend to offset the effect of the debris on overflow of tule lands. Principal among these were leveeing the land, plugging of sloughs to keep the flood waters off the land, and diversion and use of water for mining that otherwise would have fed the swamps.

2. The mining debris not only filled the channels, but also the flood basins where the tules grew. More water brought with it debris, which was not necessarily advantageous for tules. This had two effects. First, the debris was sterile and did not support vegetative growth, causing tules and other vegetation to die back. Second, the debris raised the bed of the flood basins, reducing their storage capacity and enhancing drainage by raising the bed above the natural levees on the sloughs that drained off the flood peak.

4.1 Surveys that Predate Channel Siltation

One way to substantiate that the tule acreages used in SWC Exhibit 262 do not include effects from increased overflow due to hydraulic mining debris is to determine when increased overflows occurred from this cause and then to inspect surveys that predate this period. The first effects of mining debris were felt following the 1862 flood. Surveys prior to this date are consistent with the estimates of tule lands used in SWC Exhibit 262.

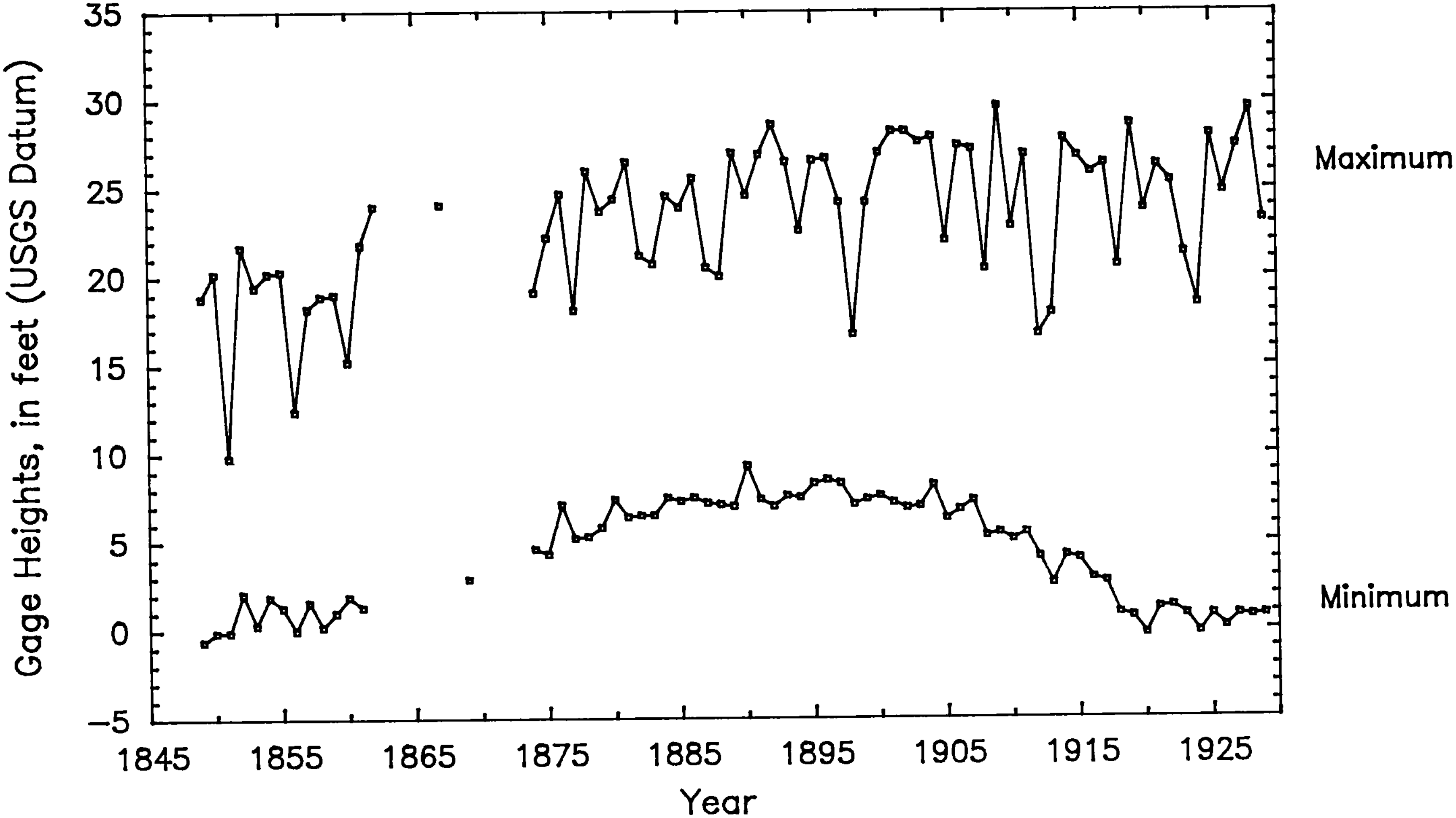
Hydraulic mining primarily was used in the Yuba, Feather, Bear, and American River Basins. Minor operations in the headwaters of the Cosumnes, Mokelumne, etc. did not affect downstream areas (Gilbert 1917; CDPW 1931). Annual minimum and maximum river stage records of the Sacramento River at Sacramento provide a good measure of the effect of the debris on overflow. Daily stage records were kept at Sacramento for most years since 1849. These were summarized by the California Department of Public Works (CDPW 1931, p.157) through 1929 and are plotted on Figure 3. This figure shows that the river stage does not significantly increase until after 1862. The great flood of 1862 triggered mud and land slides and initiated the era of channel siltation. This also agrees with the historical accounts, as summarized by Kelley (1959).

Based on this evidence, authentic surveys that predate the 1862 flood should reflect tule acreages prior to increased overflows from channel siltation. Federal surveys made through 1857 (Fig. 1) returned a total of 1.3 million acres of "swamp and overflowed lands" approximately equivalent to "permanent swamp" (Sec. 3.3.3). By the close of 1862, the California Surveyor General had surveyed 1.5 million acres of "Swamp Land" and 56,000 acres had been sold (CSG 1862, p.11). Of this total, 1 million acres were in the Central Valley in the drainage of San Francisco Bay. By 1890, the widely accepted estimate of tule swamp land in the Central Valley north of the bend in San Joaquin River was still 1 million acres (Manson 1888, p.4; Hall 1888; Hilgard 1884). One million acres was used in SWC Exhibit 262.

Estimates made prior to 1862 tend to underestimate "natural tule acreages because surveys were still incomplete. Gold mining had already started to affect swamp water supply by clogging east-side tributaries with debris dams that slowly moved downstream. Some of the waters contributing to swamps were dammed and used in mining. Additionally, this was a dry period, and the

FIGURE 3

ANNUAL MINIMUM AND MAXIMUM RIVER STAGES
OF SACRAMENTO RIVER AT SACRAMENTO
1849–1929



Sacramento River did not overflow its banks from 1853 to 1862 (Gilbert 1879, p.57).

4.2 Tules Reported Prior to Gold Rush

The tule acreages claimed in SWC Exhibit 262 are also substantiated by numerous eye witness accounts from 1772 through 1848. These early eye-witness accounts clearly demonstrate the extensive nature of the "natural" tule swamps. This early evidence (1770-1848) is more voluminous and more compelling than the later evidence (1860-1900) cited by Dawdy. Evidence of the extent of tule swamps prior to the Gold Rush is catalogued in Appendix A, which abstracts key quotes.

The earlier evidence of tule swamps is more abundant than later evidence for two reasons. The Spaniards were forced to explore and venture into these swamps because thieves, escapees from the missions, and other outlaws took refuge in them. The Spaniards were also the first explorers in the area and initially tried to travel through the swamps. Later travelers benefited from knowledge of these early forays and took routes that led them around this difficult terrain. In fact, early wagon trails and other roads followed the edges of the plains, above the swampy area, explaining the frequent accounts of plains in some of the later travel literature cited by Dawdy.

4.3 Did Increased Overflow Significantly Increase Tule Lands?

Early county histories, California Surveyor General reports, State Engineer Reports on the debris issue, and early newspapers were reviewed to locate reports of increased tule lands during the post 1850 period. No reports of increased tule lands or tule colonization of debris-impacted lands were encountered. However, increased overflows brought with them mining debris, which was deposited in the flood basins, burying vegetation under anywhere from a few inches to a few feet of sterile rock, sands, and gravel. This new surficial material was rapidly colonized by willows and cottonwoods, but apparently not by tules. The mining debris was not a suitable growth medium for tules and other emergent aquatic vegetation. These plants have extensive root systems, typically rhizomes, which extract most of their nutrients from near-surface sediments (Barko and Smart 1978, p.109). Since the mining debris lacked these essential nutrients, tules and similar vegetation did not grow well on it.

Significant increases in tule lands would probably have been reported. Since ranches and farms bordered the tule swamps on both sides -- in the plains and along the river banks -- an increase in tule acreage would have infringed on nearby landholders and would have been reported, contested, and generally discussed in the press and technical literature. It was not. Additionally, two independent parties surveyed these swamp lands, the State and the U.S. government. A significant difference in surveys, due to such a novel cause, would have been reported. There were differences in the surveys, to be certain, but not due to expanding tule lands.

Hydraulic mining washed large quantities of rock, gravel, and sand from cliff faces onto lands bordering the Sacramento, Yuba, and Feather Rivers. Gilbert estimated that 1555 million cubic yards of mining debris had been generated by hydraulic mining from 1849 to 1909 (Gilbert 1917, p.43). Most of it was deposited in stream channels, where it increased the severity of overflows. However, about one-quarter of it, or some 294 million cubic yards, was deposited on inundated lands and tidal marshes by 1914 (ibid, p.50). This sediment destroyed much of the land that it subsequently covered by uprooting and smothering vegetation and by replacing the rich alluvial soils with sterile gravels and sands. Hall (1880) estimated that about 43,000 acres of land had been destroyed by this cause. Bancroft (1890, p.21) reported that "[i]n the lower half [of the Sacramento Valley] the river bottoms, on the eastside are widely covered with mining debris, termed slickens, which have converted once fertile tracts into sterile wastes..."

Brewer, a botanist, noted in August 1862 a spot at the mouth of the American River at Sacramento that had been 50 feet deep in 1849, which in 1862 supported "a luxuriant growth of young willows on the mud bank that occupies the spot." (Farquhar 1949, p.295) Professor Hilgard, in writing for the U.S. Census Reports, recorded that river lands, "formerly the richest in the county, are now so covered with this debris, or slickens, as to be "only a swamp of willows, cottonwood, and vines; a waste where bars of white sand and pools of slimy water glisten through the saplings. At high water the thick and muddy waters of the river are spread out over a wide region of level country, sometimes a mile or even three miles wide, once the richest farming lands of the region, but now deserted, leveed in, and covered with mountain mud, sand, and pebbles." (Hilgard 1884, p.89) [Much of this prime farming land was reclaimed tule swamp.]

In an article on duck hunting in the San Francisco Bulletin (Feb. 27, 1878), it was noted that "[t]he debris from the hydraulic mines....are carried down into the waters of Butte Creek and ....deposited over the tules in depth from an inch to many feet. It adheres tenaciously, and can be removed only as it slowly dissolves or melts away." William Ham Hall, in his first official survey of the Sacramento Valley, noted in his personal diary on May 1, 1878, that the waters draining out of "..Sycamore Slough...are charged with a dark adobe colored mud."

The Stanislaus County Supervisor reported in December 1862, following the great flood of that year, that "the flood left large deposits on the land of a light sandy character, unfit to sustain vegetable life. The flood appears, in most cases, to have swept off the soil and original deposits to the depth of from five to twenty feet, and as the water subsided, to have deposited sand and loose gravel of various depths." (CSG 1862, p.102). The San Joaquin County Surveyor made a similar report, indicating land was buried under "from six inches to four feet.." (CSG 1862, p.101). This flood was reported to have been so severe that it uprooted tules and carried them into San Francisco Bay, with snakes tenaciously hanging on (McClure 1927, p.109).

The <u>California Culturist</u> reported in September 1860 that "[t]he tule lands...on the eastern side of the rivers [in the Sacramento valley]...receive an annual deposit of slum, brought down by the rivers, which pour in upon them the sedimentary earths set loose from a thousand hill-sides in the mining districts, and are in rapid transition from muck-beds to alluvial bottoms.." (Anonym. 1860, p. 109-112).

What effect did this debris have on the tules? The overall effect of mining debris -- increased flooding and deposition of debris on the marshes -- cannot be ascertained with certainty. Massive siltation of the marshes would certainly have altered their productivity and very likely destroyed some. Marsh vegetation grows luxuriantly on clayey soils, but its growth is stunted on sandy soils (Migahid 1947; Barko and Smart 1978). Thus, it is likely that the debris deposited in the swamps reduced evapotranspiration. Tules probably would not have recolonized the areas covered by the debris, nor would they have colonized any new lands created by the debris because the debris was sterile, lacking nutrients and humus material esstential for growth (Hilgard 1884, p.22). Plants like tules, which have shallow, extensive root systems and little absorptive surface exposed to the water, obtain their nutrients almost exclusively from the near-surface sediments (Barko and Smart 1978), which in the case of mining debris, would be sterile. The literature suggets that willows were the principal plant that colonized the slickens.

4.4 Activities that Offset Effect of Mining Debris

Other activities took place during the Gold Rush that tended to offset any effect from increased bank overflows. Some of these activities probably reduced swamp areas. Rivers were variously diverted from their banks or dammed and the waters used in mining. Sloughs were plugged and levees were thrown up along most rivers. Debris choked tributaries to the main channels as well as distributaries. Finally, settlers increasingly used the tule swamps in their livelihood. Each of these points is discussed below.

4.4.1 Swamp Water Supply Diverted for Mining. Initially, gold was recovered directly from stream beds -- at first by dry washing, then by panning and finally by river bed mining and massive washing with cradles and sluices. These latter practices severely altered the natural hydrologic regime and deprived swamps of an important water supply. Entire rivers were diverted from their channels and sent from mine to mine for washing. Audubon, for example, noted in his celebrated journal on March 20, 1850, "..At night many men are here engaged in digging canals to drain the bed of the river at low water." (Audubon 1906, p.221).

When placer deposits were exhausted, hydraulicking was invented near Nevada City in 1853, reaching its zenith in the 1860s. Great streams of water under pressure were directed against hill sides to loosen the gravel and debris harboring the gold, followed by large-scale washing operations. One of the great needs of this new industry was water (Kelley 1959, p.28; Harding 1960, p.61-70; Bowman 1874). The first water projects in California -- dams and canals -- were conceived and built by hydraulic mining interest. Most of this activity occurred in the Sacramento Basin, the mining debris problem south of the American River being minor by comparison (CDPW 1931, p.154; Gilbert 1917, p.43).

The east-side tributaries were dammed and diverted. The first ditch was built in 1850. By March 1850, 24 dams were being built across tributaries of the Tuolumne River (Stockton Times, March 23, 1850). By 1868, 325 separate canals were in operation (Johnson 1950, p.193). By about 1880, these delivered from 300,000 (Harding 1960, p.65) to over 750,000 acre-feet/year (Hall 1880, p.24, Part III) of water for mining. This water formerly was an important supply for swamps along the trough of the Valley.

Swamp water supply was also interrupted by mining debris that choked mountain streams tributary to the main rivers. Mining debris generated prior to the great flood of 1862 was dumped into slow-moving upland creeks where most of the tailings remained until carried downstream by great floods. As hydraulic mining became increasingly sophisticated and expanded, the mining companies began dumping debris directly into the canyons. Drainage then became a major problem, and this debris completely impeded the flow of many streams that otherwise would have fed the swamps. The great flood of 1862 finally washed much of this debris out of the hills into the valleys, where it was deposited in the channels and flood basins (Kelley 1959, p.57-58).

4.4.2 Rivers Were Leveed at an Early Date. The earliest settlers in the Valley occupied the high natural levees along the rivers and built low levees to keep annual flood waters from just overtopping the natural levees and running across their lands (Green 1950, p.58). They also built dams across the mouths of small sloughs (McGowan 1961, p.286). Since these overflow waters would have otherwise entered the tule basins, which were immediately behind the farmed lands, this deprived the tule swamps at an early date of an important water supply, causing some of them to dry up between major floods, whereas under natural conditions, they were annually innundated.

An agricultural periodical, the California Culturist, in 1860 reported that (Flint, 1860, p.109-112):

> "The tule lands west of the Sacramento river...are covered in the winter and spring from the waters of Putah, Cache, and other creeks....Formerly the Sacramento river contributed to the result, but farms being opened all along its banks, the small sloughs, which at high water discharged a portion of the surplus into the tule, have been closed up, so that none of its waters now go upon the tule...."

The Surveyor-General of California in his 1862 Annual Report to the Legislature reported similarly:

> "Along the banks of the Sacramento private enterprise is constructing considerable embankments. The effect, in every instance which has come under my notice, of keeping the water away from those tracts of Swamp Land which border on the tide waters of San Pablo or Suisun Bays, or near the mouths of the rivers dischaging into them, has been ....a rapid dying out of the samphire and tule, which are the natural growth of these Swamp Lands, and a spontaneous growth of clover..." (CSG 1862, p.12).

Many miles of levees were built along the main river channels in the Central Valley between 1850 and 1870, when the first major "reclamation" projects were attempted. These are chronicled in early newspapers and county histories, and an excellent review on reclamation in the Delta is provided by Thompson (1958, Appendix B). Some of the highlights are presented here to demonstrate that the natural hydrologic system was already significantly modified in the 1850s and 1860s, sufficient to deprive the tule lands of an important water supply.

Unsuccessful argonauts in large numbers settled the river banks in the early 1850's. The Stockton Times reported on February 26, 1851 that:

> "Within the past six months, large numbers of persons from the mines...have left the placers and settled down upon the banks of the San Joaquin...In this manner, much of the richly wooded tracts of land, on the margins of Calaveras, Stanislaus, Tualumne [sic] and Merced, and of their tributary creeks have been occupied.

In the neighborhood of Stockton it is almost impossible to find an acre of land which is either not fenced in or claimed by some person engaged in agriculture within a circle of ten miles around Stockton...."

During the 1850s, "the lower Sacramento's east bank became a solid string of farms ..." The first levee was built in 1850 on the tip of Grand Island (Dillon 1982, p.89). The German prince, Paul Wilhelm, described the levees around the City of Sacramento in September 1850 (Butscher 1978, p.43). By 1853, low "shoestring" levees gave partial protection to Merritt, upper Tyler, northern Grand, and Andrus islands (Dillon 1982, p.90). In the South Delta, the banks of the San Joaquin, Mokelumne, Calaveras, and Stanislaus rivers were occupied by 1852 and levees followed.

The City of Stockton, originally known as Tuleburg, was built on low land in a region formerly occupied by tules (Bowan 1943, Land Grant Case Map ND339). Levees were constructed from Stockton's earliest days (chartered in 1850) and are amply described in early editions of the Stockton Times. In the Stockton area, tule lands were being reclaimed in 1853, and in 1854 there were 40,000 acres of them in cultivation (Tinkham 1880, p.372). Irregular, discontinuous ridges were shoveled up to protect Roberts and Union islands by 1857, and the San Joaquin's east bank south of French Camp in 1861 (Dillon 1982, p.90). Reclamation of Union Island started in 1852, of Staten Island in 1854, and just after 1862, 50 miles of levee and 75 flood-gates were built in this area (Gilbert 1879a, p.133).

By the close of 1872, about 70,000 acres of freshwater tide lands in the Delta had been enclosed by levees and furnished with self-acting tide gates. Among the districts reclaimed by this date were Sherman Island, Twitchell Island, Bouldin Island, Mandeville Island, Grand Island, and a large portion of the right bank of the San Joaquin. Brannan Island, Andros Island, and a large tract along the left bank of the Sacramento River were nearly completed (USDA 1872, p.186-187).

In Yolo County, the first levee was built on Merritt Island in 1852 (Russell 1940, p.144), its reclamation district was organized in 1862, and its levees completed in 1876 (ibid., p.91). Between 1854 and 1862, 5 miles of levee were built along the Sacramento River in Yolo county (Gilbert 1879b, p.56). By the 1860s, 15,000 acres of tule land had been reclaimed in the Sacramento Valley and some 92,000 acres in the 1870s (McGowan 1961, p.285). By November 1, 1867, during the time Cronise was writing, the State had sold about 1.3 million acres of "swamp land" (CSG 1867, p.36) and by 1874, 257,100 acres of this land had been reclaimed (CSG 1874, p.17). Reclamation did not start until 1862 in Sutter county (Chamberlain and Wells 1879) nor until 1867 in Colusa county (Green 1950, p.58).

These facts and figures demonstrate that significant leveeing and reclamation of swamp lands took place between 1850 and the 1870s. These levees kept water out of the swamps, causing them to dry up. This would have reduced the area of tule land after the Gold Rush and particularly in 1868 when Cronise wrote, compared to "natural" conditions.

4.4.3 Stock Use of Tule Land. The tule swamps (and prairies) were extensively used by livestock -- sheep, mules, wild horses, and hogs -- particularly during droughts when no other pasture was available. This significantly altered the appearance of the plains and tule swamps at a very early date, probably in part leading to descriptions of "desolate," devoid of vegetation," and "dried out." Bidwell, one of the first settlers in the Sacramento Valley, noted a great change in the appearance of the plains from 1841 to 1843 "due to horses, cattle, and sheep." (Rogers 1891, p.45) Brackenridge, assistant naturalist on the Wilkes expedition (Maloney 1945), wrote on October 24, 1841, of the San Joaquin Valley that "..no plant of any consequence was seen -- every green particle of vegetation (but trees) being browsed down by the numerous herds of cattle everywhere to be found in California." (ibid., p.333)

Sheep, mules, wild horses, and hogs made extensive use of the tule swamps from at least 1852 through the great flood of 1862 and again from 1863 through the great flood of 1868. The livestock grazed on and trampled the swamp vegetation, stockmen harvested swamp grasses nestled among the tules, and hogs rooted out and ate the tule roots. Thus, during the period Dawdy claims the tule swamps were increasing in area due to increased flooding, other activities tended to decrease these lands.

These uses are significant because the post Gold-Rush era saw an explosive increase in the numbers of stock that were raised in the Central Valley (DeBow 1854, p.202; CSG 1859; CSG 1870):

	Number in Central Valley		
	1850	1859	1870
Sheep	2,100	194,700	710,000
Cattle	17,700	186,800	146,200
Hogs	1,000	81,700	162,600

Prior to American settlement of the Central Valley, extensive herds of wild horses and cattle roamed the prairies, using the tules in times of drought. The horses originated from the old Spanish missions, and their numbers increased greatly after about 1830, when the missions began to decay (Gudde 1958, p.121). Most early observers from this period forward record the huge herds of these wild stock, particularly in the San Joaquin Valley.

In Fremont's two expeditions through the San Joaquin Valley, numerous sittings of these wild horses are recorded, suggesting they were quite plentiful (Fremont 1852, 1887; Fremont and Emory 1846). Fremont remarked in April 1844 while travelling along the San Joaquin River south of the Merced River, that "..the prairies along the left bank are alive with immense droves of wild horses," and again a few days later, near the bend in the San Joaquin River, 1852, p.361-362). The Mexicans also established large cattle ranches throughout the Valley, the first one being granted in 1836 (Smith 1932, p.68; Cowan 1977). Most of the prime land along the rivers was ranched by 1845 (Cowan 1956; Bowman 1943,1958). Fences were not used, and these cattle roamed freely, using the tule marshes for feed in dry seasons.

Burcham (1957, p.97) reported that the tule swamps, since "they remain green throughout most of the dry season and are succulent when other natural feed has dried up....are grazed extensively during late summer and fall, and are particularly important as sources of forage during drought periods." Cronise (1868, p. 357) also chronicles a related use. He notes that the coarse wiry, heavy swamp grass among the "watery tule lands" was harvested. "The year 1864 was one of famine to cattle in this State...and the usual feeding grounds were barren. Some enterprising men cut fifty thousand tons of this coarse grass in that year, and it proved the salvation of a large number of cattle."

Will Green, the "Father of Irrigation" in California (Green 1950) and the author of the Green Act, the first reclamation law in California, wrote of the area around Sycamore Slough in Colusa County in 1857 that "there is a great quantity of overflowed land; and some tule, out back of the farms, on which the cattle of these Islanders can feed during the dry season."

Brewer, in April 1863, at the start of an extended drought, reported cattle and horses living on rushes. In the vicinity of Fresno City, near the present town of San Joaquin, at the northern-most end of the vast tract of swamp that extended south to Tulare Lake, Brewer noted: "It (Fresno City) is surrounded by swamps, now covered with rushes, the green of which was cheering to the eye after the desolation through which we had passed. These swamps extend southeast to Tulare Lake....our animals had to content themselves with eating the coarse rushes...The cattle and horses that live on this look well." (Farquhar 1949, p.379) A year later in June 1864, the drought still raging, Brewer records a similar scene in the same area: "For the first ten miles the ground was entirely bare, but then we came on green plains, green with fine rushes....The ground is wetter and cattle can live on the rushes and grass. We now came on thousands of them that have retreated to this feed and have gnawed it almost into the earth." (ibid, p.510).

J.H. Rhorer, in describing the tule lands of the Sacramento Valley in Yolo and Colusa counties in 1872, noted that "[o]n account of the luxuriant growth of grass on them, these lands have been pasture for many years of large herds of cattle and sheep, whose trampling has cleared a large part of it of all tule growth...." (Rhorer 1872, p.). This is confirmed by the Yolo County Surveyor who reported in December of 1862 that "Previous to 1861, the tule lands were the almost sole pasture of the immense herds of cattle then in the county; and they had, within the knowledge of residents, receded from earlier limits to the extent of more than a mile." (CSG 1862, p.98)

Apparently, this use of tule lands was so common that Rhorer coined the phrase "tule stock-raiser," clearly explaining that in the dry season, the only thing that remained green was the tule land and that was where the stock was. He wrote: "During the dry season...the lands of California (except the Tules...) are necessarily subject to droughts...and all vegetation dries up...During such seasons until recently immense herds were saved by being driven upon the Tule lands then belonging to the State." (ibid, p.15). This use apparently declined as the State sold the lands and they were reclaimed (ibid, p.15)

Swine were also apparently raised in the tule swamps. Bancroft reported that "[t]he raising of swine is restricted by dry pasture...nevertheless, there are favorable localities, especially in the tule regions of San Joaquin and Sacramento." (Bancroft 1890, p.61). Hittel (1863), in another work similar to Cronise's, recorded a similar story. "Swine ...do not thrive upon the dry pastures...It is probable that in a few years great numbers...will be bred in the tules, the roots of which they like to eat." (ibid, p.233)

Finally, eye-witness accounts of hog raising in the tules are common. T.J. Mayfield, in reminescences of the San Joaquin Valley in the 19th century, recounted that "My Daddy and Gordon put their hogs on Tulare lake to feed on tule roots and mussels. After the hogs had fattened at the lake, they were taken to the Sierra foothills..." (Latta 1929). And Tinkham, in his history of Stanislaus County noted that the "razor-backs...were never fed, but were turned out to roam at will and root hog or die. They fed on tules...and such stuff as they found in the river bottoms." (Tinkham 1921, p.51)

4.4.4 <u>Other Uses of Tules.</u> Settlers also used the tule lands for other purposes. These other uses were minor and were probably about equal in magnitude to Indian use of tules immediately prior to settlement of the Valley by Europeans. The peat soils were mined on a small scale and used as fuel (Bancroft 1890, p.77). The tule root was harvested and shipped to San Francisco where it was consumed by the Chinese. Two tons of tule root, for example, were shipped from Colusa to San Francisco on January 18, 1875 (Rogers 1891, p.143). Early settlers also used the tule to thatch roofs and to ferry belongings and stock across rivers (Tinkham 1880, p.69,316; Leale 1939, p.65; Sutter 1932, p.8; Yates 1971, p.16; Kantor 1964, p.19). These types of uses were similar to those by the native Indian populations who had previously used the tule. A number of game animals including the tule elk (Roosevelt et al. 1902; McCullough 1971; Neasham 1973), wild boar, beavers and ducks, among others, were common inhabitants of the tule swamps. These were vigorously hunted from 1850 to 1870, when most of this game disappeared (McCullough 1970; Neasham 1973).

5.0 TULES DID NOT DRT AND BURN

Mr. Dawdy maintains that tules dried out each year and burned (Dawdy, p.10). His principal evidence is again Cronise (1868, p.314-315) who states that "Late in the season...large sections of these lands (tules) becoming dry on the surface -- the dense body of rushes, the growth of former years, having meantime wilted and dried up, the latter often take fire, and burning with terrific fierceness for days in succession, many thousand acres are burned over and stripped of both the dead and living tules. In all the counties containing large tracts of tule lands, these fires are common, generally occurring in the fall and winter..." Dawdy supports Cronise's statement with a similar summary by a contemporary historian and four eye-witness accounts of fires (Dawdy, p.11-12).

There is no doubt that some overflowed lands dried out from year to year and that the quantity that did dry varied with the wetness. SWC Exhibit 262 attempted to estimate "permanent swamp," or that portion of the overflowed lands, which, under average conditions, would not dry out. The sources consulted in this work were summarized in Section 3.3. The only extant estimate of "permanent swamp" was made by the USDA (1908). They reported the following breakdown of "swamp and overflowed" lands in California that were unreclaimed in 1908:

Permanent swamp	1,000,000 acres
Wet grazing land	1,000,000 acres
Periodically overflowed	1,420,000 acres
TOTAL SWAMP AND OVERFLOWED LAND	3,420,000 acres

The USDA defined "permanent swamp" as "lands which are permanently wet and are never fit for cultivation, even during the most favorable years..." (USDA 1908). In 1908, 323,000 acres of tidally inundated lands lands in the Delta had been reclaimed (Thompson 1958, p.238), bringing the total area of permanent swamp to 1.3 million acres. Lands outside of the Delta had also been reclaimed at this date, but the acreages are unknown. This USDA estimate of permanent swamp is consistent with the 1.5 million acres of tule swamp used in SWC Exhibit 262. This demonstrates that the tule swamps claimed here did not dry out.

Before the drying issue is addressed further, tule life history is briefly discussed to help clarify some points that have led to misunderstanding.

5.0.1 Tule Life History. The term "tule" is the general name applied in California to all lands bearing as an important ingredient of its vegetation the tule or rush, which varies in kind according to location. The common tule or bulrush, Scirpus acutus, was the dominant species (Atwater and Belknap 1980; Jepson 1893; Burcham 1957; Kuchler 1977). Other species were present, including cattails (Typha spp.), reeds, spike-rushes (Eloechans spp.), and sedges (Carex spp.). The comments included in this section pertain primarily to Scirpus spp., but also are true in a general way for these other plants.

The tule or Scirpus spp. is shown in Figure 4. This tall, dark-green bulrush dominated the freshwater marshes in the Central Valley. They grow from shallow rhizomes (Fig. 4), which are not affected by long periods of inundation as they are ventilated by spongy tissue called aerenchyma (Braendle and Crawford 1987). They are often among the earliest rooted macrophytes to invade a flooded area and are found in depths up to 5 feet (Dabbs 1961).

Under "natural" conditions in the Central Valley, they were "always found in ground more or less covered by water" (Hittell 1885, p.558; Roosevelt 1908, p.168). They occurred in dense, expansive tracts, grew to heights of eight to twenty feet, and were 1 to 2 inches in diameter (Cone 1876, p.111; Hittel 1866, p.107; Hittell 1885, p.558; Preston 1981, p.22; Gibbs 1866, p.107; Farnham 1849, p.328; Roosevelt 1908, p.168; Fremont 1852, p.363). Central Valley tules as described in Appendix A were much larger than tules from other areas (Correll and Correll 1972, p.360; Mason 1957, p.323), which typically only grow to 6 feet.

Cone reported that "These tules grow so luxuriantly and thickly on the rich, swampy land that neither man nor beast can make a way through them; they must be trodden down and made into a sort of pontoon bridge and walked over." (Cone 1876, p.111). President Roosevelt reported that "The tule...some fifteen feet long, growing from shallow water, and so dense that half a dozen stalks to the square foot, an inch to an inch and a half in diameter, are common. Back of

Figure 4. Tules showing rhizomes at base. . Gray Lodge, California
'87

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*

this, on dryer ground, are cattails and flag, very rank and tall..." (Roosevelt 1908, p.168)

Tules are perennials (Mason 1957, p.323), which means that they can live throughout several years before they dye back. However, like other perennials, they have a distinct annual cycle. Their period of maximum growth and water use is April through October, when 84 percent of their water use occurs (Figure 5). New foliage grows in spring and dies in autumn so that a mature stand will usually contain dead foliage remaining from previous years. In the late fall and early winter, the tule enters a dormancy period; water use drops radically and the deep green stalks of summer become "ghostly pale" in winter. This life cycle was described by Mary Austin, a well-known naturalist who wrote at the turn of the century:

> "The reeds, called tules, are ghostly pale in winter, in summer deep poisonous-looking green, the waters thick and brown, the reed beds breaking into dingy pools, clumps of rotting willows, narrow winding water lanes and sinking paths. The reeds grow inconceivably thick in places, standing manhigh above the water; cattle, no, not any fish nor fowl can penetrate them..." (Austin 1903, pp.240-241)

Thus, tule marshes in late summer and fall would be expected to contain some old tule growth. Dried remains from annuals that die back each year would also be present. The presence of this dried vegetation does not necessarily mean that the marsh had dried out due to a lack of water.

It is likely that some of the observations of "dried" marshes in the post-Gold Rush period were misinterpretations. An untrained observer could easily lump all types of vegetation into the catch all "tule" and record a dry marsh or "corn field" when in fact only certain plants were dry. This is demonstrated by Figure 6, which is a photograph taken at Gray Lodge, near the Sutter Buttes, on October 12, 1987. The green reeds in the midground are tules. Notice the appearance of "corn fields" in the distance. Water is clearly not limiting. How would a farmer from the east, as many of the argonauts were, untrained in botany and unfamiliar with the California landscape, record this scene? Perhaps as a dried out marsh.

5.1 Did the Tule Swamps Dry Out?

This question was addressed by cataloguing eye-witness accounts of tules from 1772 through 1870. This information is presented in Appendix A and indicates the following:

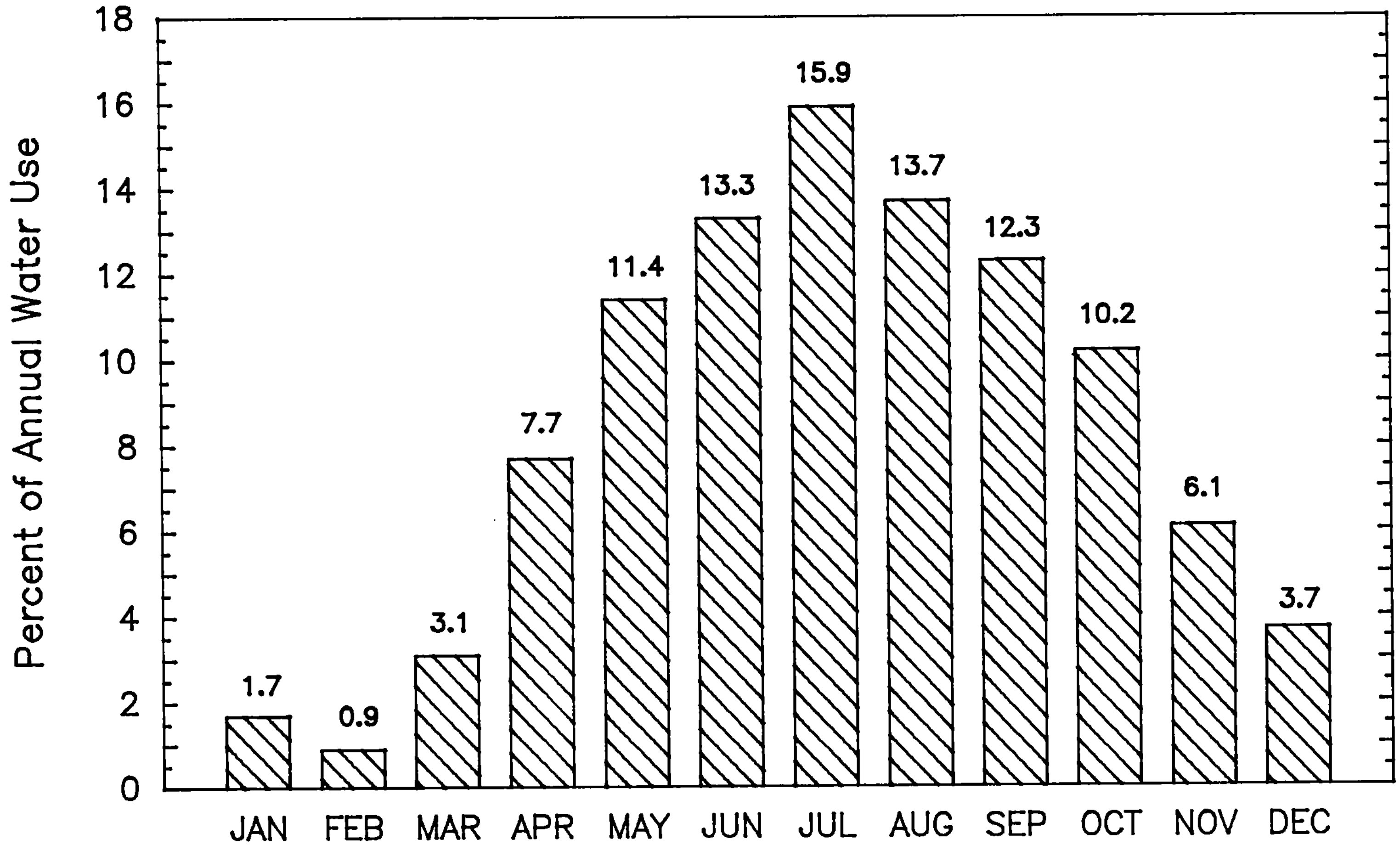
1. Drying of tules was rare under "natural" conditions. In nearly 100 years of eye-witness accounts, there are only two records of dried tules.

2. Drying was more common in the post-Gold-Rush era, after 1848, in areas that had been settled, because sloughs were dammed and the lands leveed, cutting off the swamps' water supplies.

3. In undisturbed areas, the tule swamps remained green and were extensively used by stock during extended droughts, when all else was barren and dry.

FIGURE 5

SEASONAL TULE WATER USE



Reference: DPW 1931, p. 69

5.1.1 Evidence of Drying. The eye-witness accounts in Appendix A indicate that there are only two report of dry conditions in the swamps. Both are in the southwestern Delta. The first such report was made by the great diarist, Pedro Font, in April 1776 near the present site of Byron Hot Springs (Bolton 1931b, p.407-409). The second report was by a Kentucky journalist, Edwin Bryant, in September 1846. Each of these is discussed below, followed by a review of the evidence that supports the position that drying was not common before settlement of the valley.

Father Pedro Font. The first recorded evidence of dried tules was by Father Font in April of 1776. Font reported that "We traveled more than three leagues...going with some difficulty in the midst of the tulares, which for a good stretch were dry, soft, mellow ground, covered with dry slime and with a dust which the wind raised from the ashes of the burned tule...." (Bolton 1931a, p.407). It is not clear whether just the ground or the surrounding vegetation was dry. A fire would have dried out the ground, and this may be a fire account, not an account of dried tules, particularly since earlier the great "green" tulares had been described from a hillside (Bolton 1931, p. 378).

According to Bolton, they were eastward of the town of Byron (ibid., p.407) on the outermost edge of the Delta. Tules are not claimed in this area in SWC Exhibit 262 (Fox, Fig. 3). They are also not shown in this area in most of the early maps (e.g., Hall 1888; Appx B). Thus, it is concluded that this was a marginal area that supported tules during wet periods and was subject to drying at other times.

Edwin Bryant. The second eye-witness account of dried tules is by Bryant in September 1846. Dawdy correctly quoted the relevant material in his rebuttal (Dawdy, p.19). Bryant was travelling around the southwestern edge of the Delta (Dawdy incorrectly states he traveled through the Delta on p.19) headed for Dr. Marsh's ranch at the foot of Mt. Diablo. Bryant probably took the old Livermore Road around the outskirts of the southwestern Delta. From an unidentified vantage point in the plains on the western side of the San Joaquin, Bryant notes that "At a distance, the tule of these marshes presents the appearance of immense fields of ripened corn. The marshes are now nearly dry....and...we crossed several of them without difficulty."

Several factors are important in interpreting this account. First, Bryant is travelling around the southwestern edge of the Delta. Thus, the dry area is along the edge or boundary of the marsh. Since he was on horseback on the level plain, rather than on a hill, he could not have seen far into the dense tule. Second, it is important to note that Bryant traveled among tules the preceeding day and did not report that they were dry or brown. Since he does not comment on their condition, one may infer that they were "normal." This suggests that only one localized region was dry.

The region where Bryant made his comment was the first part of the Delta to be settled. When Bryant was there in 1846, about 100,000 acres along his path were already devoted to Mexican cattle ranches. Grants in this area had been made as early as 1836, and some of these lands had been cultivated and inhabited on for a decade before Bryant's arrival. The history and location of these grants are discussed in Smith (1932, pp.68-93), Bowman (1943, 1958), and Cowan (1956). Therefore, it is difficult to determine whether the drying was "natural" or whether it was due to alterations in the natural system brought about by the ranches. Sloughs that would have supplied the marshes with water may have been plugged, and the stock likely made extensive use of the tules (Section 4.4.3).

5.1.2 Evidence the Swamps Did Not Dry. There are three major types of evidence that support the position that tule swamps did not dry out. The first is negative evidence or the absence of reports that the swamps dried out. The second is positive evidence, or eye-witness accounts that describe the marshes as verdant during droughts when the surrounding plains are brown. The third is the wide-spread use of tule swamps by stock during dry periods and extended droughts.

Negative Evidence. Eye-witness accounts of tules are catalogued in Appendix A. This material overwhelmingly supports both the large areal extent of the tule swamps and the fact that they did not dry. These accounts cover the period 1772 through 1868, they include material from all types of climatic conditions - winter, summer, fall, and spring as well as severe drought, normal years, and wet years. They also cover all areas claimed to support tules (Fox 1987, Plate I). There is nothing in this material that would suggest that tules dried on a regular basis.

Positive Evidence. There are several accounts in the record that state the swamps did not dry out or that contrast the dry, brown, scorched condition of the plain with the "green" tule swamps. The Spaniards were aware at an early date that the swamps did not dry out. Anza, who led many expeditions into the tulares, reported in 1776 that "...two soldiers who belong to this country assured me now that...the tulares...even in dry season they have found unfordable." (Bolton 1930, p.147)

The most vivid of these accounts is that recorded by William H. Brewer during the extended 1863-64 drought. Bancroft, the noted California historian, reported that the period following the 1862 flood through 1864 was the most disastrous drought in the State (Bancroft 1890, p.15) when "crops failed over vast areas, and cattle died of starvation and were slaughtered by the hundred thousand..." Brewer was a trained botanist and his diary describes his travels with the first geological survey of California under Whitney. Travelling south in the San Joaquin Valley on April 8, 1863:

> "The country had been growing more and more desolate....we rode over a plain of absolute desolation. The vegetation that had grown up last year, the wet year, was dead, and this year none has started. Sometimes no living thing cheered the eye, nothing in sight alive for miles. Fresno City...is surrounded by swamps, now covered with rushes, the green of which was cheering to the eye after the desolation through which we passed. These swamps extend southeast to Tulare Lake.." (Farquhar 1949, p.379)

Brewer reports a similar scene a year later in June 1864 when it was even drier (ibid., p.510). He also clearly states that the marshes have water when the plains are dry in a description from October 1861: "The San Joaquin plain...desolate...without water during nine or ten months of the year, and practically a desert. The soil is fertile enough, but destitute of water, save the marshes near the river and near the Tulare Lake." (ibid., p.202-203)

Rhorer, in describing the tule lands of the Sacramento Valley in Yolo and Colusa counties, noted in 1872 that "During the dry season, continuing about eight months, in which there is no rain, the lands of California (except the Tules and a few irrigated valleys of small extent) are necessarily subject to droughts...and all vegetation dries up, so that no green thing can be seen...During such seasons, until recently, immense herds were saved by being driven upon the Tule lands then belonging to the State." (Rhorer 1872, p.15)

Finally, Jepson, the noted California botanist, in describing marshes in the lower Sacramento Valley (Jepson 1893, p.240) notes that "As the traveler passes late in the year from the sun-scorched plains to the riparian region, the change in the physiognomy of the country is decided and impressive. Even in September and October the river country is as fresh and green as the landscape in April on the plains of the Sacramento..."

Stock Use of Tules. Stock -- cattle, sheep, horses, mules, hogs -- used the tules for pasture, particularly during droughts when these were the only green areas. This usage was so common that herders were known as "tule stock men." The evidence supporting this point was presented in Section 4.4.3.

5.2 Did the Tules Burn?

To address this question, three types of information were examined -- possible causes of fire (Section 5.2.1), the historical record (Section 5.2.2), and soil surveys (Section 5.2.3). The results of each evaluation is discussed in the following subsections. The conclusions from this work are as follows:

1. Fires in tules were not common until the Central Valley was settled on the eve of the Gold Rush (1847). After that time, they were set by hunters to drive game from the dense tule swamps, by farmers to clear the lands, and accidentally, as swarms of gold seekers moved through the Delta en route to the mines.

2. A single tule fire is reported by early explorers and travelers between 1772 through December 1847. After that date, they become increasingly common.

3. Soil surveys suggest that a small 11,000-acre area in the southwestern Delta was subject to severe burning perhaps as long as 1000 years ago. Grassland fires, on the other hand, were common and were recorded from the earliest times. Periodic burning of 11,000 acres of tules would have had a negligible effect on long-term average annual Delta outflow.

5.2.1 Why Did Tule Fires Occur? Tule fires are commonly reported in travel diaries, early histories, and newspapers from 1847 through 1880. Dawdy only cites two actual records of these fires, Cronise's (1868) and Brewer's. However, they were common, and many others have been reported (Hutchings 1860, p.30-31; Stockton Times, November 23, 1850; Sutter 1939, p.97,112; Ca. Farmer, v.2, n.16, p.122, 1854).

They were apparently spectacular and thus extensively covered in the popular press. In one typical report, Hutchings (1860, p.30-31) records a trip up the San Joaquin River through the Delta noting:

"An apparently interminable sea of tules extends nearly one hundred and fifty miles south, up the valley of the San Joaquin; and when these are on fire, as they not unfrequently are, during the fall and early winter months, the broad sheet of licking and leaping flames, and the vast volumes of smoke that rise, and eddy, and surge, hither and thither, present a scene of fearful grandeur at night, that is suggestive of some earthly pandemonium."

This description was accompanied by an engraving of the scene, which has been reproduced in a contemporary work on the Delta (Bohm 1969, frontis.). Surely, if these fires occurred during earlier periods, they would have been recorded.

Tule fires occurred in late fall and winter, typically after the first rains had come and typically in November or December (e.g., Cronise 1868; Ca. Farmer, v.2,n.16, p.122, 1854), the period of minimum tule water use (Fig. 5). The time when these fires occur is important in unravelling their cause. As the editor of the State Journal remarked in October of 1854, "How is it that the great tule fires are after the rains rather than before them?" (ibid.)

A fire requires ignition -- and there are only two possibilities, lightning and man. Lightning can be eliminated as the principal cause because, in California, it occurs most frequently in the summer months from June to October, but less frequently earlier and later (Komarek 1968, p.16). Additionally, lightning strikes are rare in the Valley, tending to occur at higher elevation (ibid., p.20). Indian fires can also be eliminated because these occurred from July to October (Baumhoff 1978, p.21), depending upon the crop of itnerest. This eliminates "natural" causes as possible sources, explaining why pre-settlement eye-witness accounts do not report tule fires (Appendix A).

Since tule fires were not randomly distributed throughout the year, and a human agent was implicated, activities that occur in late fall and early winter that would involve burning were investigated. The results of these historical researches are summarized in the next section.

5.2.2 What Evidence Of Tule Fires Is There In The Historical Record? Eye-witness accounts of the Valley under natural conditions (Appx. A) and early newspapers, county and city histories, agricultural and mining literature, and California Indian ethnology were reviewed to identify possible human causes of tule fires. This review indicates that tule fires were rare under natural conditions and common following settlement of the Valley, as were fires of all types (Barrett 1935). Tule fires after the white man settled the Valley were intentionally set by hunters and farmers and accidentally caused by many others who travelled through the valley to and from the mines.

Only a single tule fire is reported in the diaries and journals of early visitors from 1772 through 1847. The first post-settlement fire is recorded in Sutter's diary at New Helvetia in late 1847 (Sutter 1939), and they became increasingly common after that date. These tule fires were quite spectacular (Section 5.3.1), and they would have been recorded if they had been common. The single fire during this pre-settlement period was recorded by Father Font (Bolton 1931, p.407) eastward of Byron Hot Springs. They "...traveled with some difficulty in the midst of the tulares, which for a good stretch were dry, soft, mellow ground, covered with dry slime and with a dust which the wind raised from the ashes of the burned tules..."

The site described by Font was near an Indian village (ibid, p.382), and one contemporary writer (Barrett 1935, p.13) attributed this fire to Indians. However, noted California Indian ethnologists do not report that Indians burned the tules (e.g., Kroeber 1953; Heizer and Whipple 1971; Heizer 1978). Eye witness accounts of the valley prior to settlement by the white man also do not record Indian tule fires (Appendix A). If the 1776 tule fire was set by Indians, it was probably accidental and not a common occurrence.

What remains? Activities of man that occur in late fall and early winter, typically November and December that involve the use of fire. A search of the literature identified four -- reclamation practices, hunting, sheep herding, and the return of the miners to the gold mines. Mining required water, and the mines were often shut down in the dry summer period, resuming operation with the first rains. However, before these post-settlement causes of tule fires are reviewed, pre-settlement Indian burning practices are briefly discussed. The Indians used controlled burning in hunting and food gathering, and these practices were reviewed to determine if the Indians set tule fires. The conclusion from this review is that Indians did not set tule fires during the pre-settlement period. They did, however, set fire to the tules in the post settlement period to flush out game.

Indian Burning Practices. The California Indian used controlled burning in the prairies and forests (Lewis 1973; Burcham 1957,1960; Clar 1959; Heady 1972; Sterling 1906; Knowles 1953; Barrett 1935; Sampson 1944, p.18-20; Kroeber 1953). They used fire to flush wildlife from underbrush, to uncover acorns in the grass, to clear small areas for tobacco, to foster seed-bearing annual grasses, to capture and roast grasshoppers and other insects, and to harvest acorns (and perhaps promote oak orchards). These practices are reviewed in Baumhoff (1978, p.22-24) and in Lewis (1973). These fires were widely reported by early explorers, travelers, and settlers in the Central Valley (Appx. A). None of these sources reported Indian tule fires.

The prevalent view of the authorities is that California Indians burned small areas located near the coast or inland streams, that these fires did not have a significant impact on grasslands and forests, and that extensive areas burned infrequently. The principal effects of these fires on native vegetation were: (1) to select for groves of valley and interior oaks on the plains, which have thick bark that is resistant to fire (Jepson 1910, p.11); (2) to increase the production of shrubs and herbaceous plants in the chaparral (Baumhoff 1978, p.23); and (3) to maximize the production of grasses in the prairie (Jepson 1910, p.22; Lewis 1973). Indian burning occurred either in spring or fall, but most typically after the seed harvest, which may have been any time from July to October (Baumhoff 1978, p.22; Preston 1981, p.36). This was before the period when the tule fires were reported and after the period when the Font fire was recorded. Thus, Indians do not appear to have set tule fires under "natural" conditions, prior to settlement of the valley.

However, as the valley was settled, the Indians were forced to modify their earlier food preferences and hunting habits, which were replaced by new practices introduced by the white man. Fishery stock was greatly reduced by mining debris and early modifications to streams. Prairies were overrun by cattle, wild horses, and sheep (Sec. 4.4.3). Oak groves were harvested for lumber and fuel. Plentiful game was greatly reduced in number by the hide and tallow trade and later by market hunters (Stine 1980). By the Gold Rush, game that previously roamed the plains had been driven into the tule swamps for protection (McCullough 1971; Roosevelt 1908; Neasham 1973). Since the tule swamps were dense and difficult to penetrate, hunters, including the Indians, used fire to flush the animals from the reeds. Thus, late accounts, after the Gold Rush, report that Indians used fire to hunt elk in the swamps (e.g., Dillon 1982, p.27). This cause of tule fires is discussed below in the section, "Hunting."

Reclamation Practices. The tules were burned during fall, the period when tule fires are reported to have occurred, to remove tules from land that was to be farmed. The tule lands were reclaimed by constructing a levee around the area to exclude floods and tidal overflow. In the fall of the year following levee construction, the tules dry up, die, and are burned. Drainage ditches are then installed, and the sod turned over to a depth of about 2 feet with plows designed to cut the tule roots (Tide Land Reclamation Company 1869; Anonym 1870/71; Nordhoff 1874, p.130; Gilbert 1879; Lapham and Mackie 1905; Cosby 1941; Weir 1950).

These reclamation practices are widely described in the press and local histories that predate 1880, and they were used in the Delta as early as 1850. The Courier de San Francisco reported that "As soon as these levees are completed...the tules which cover the whole land, dry up, and are destroyed...by means of fire" (Courier, July 27, 1869). The term "drying out" was commonly used by farmers from this era to mean "ready to burn" (Anonym 1870/71). Thus, it is likely that these reclamation fires probably accounted for many of the spectacular fires that were widely reported.

Hunting. Fires were also widely used to flush game out of the tules, which were often too dense to penetrate (Appx. A). Waterfowl was a prime target of these hunters, and the open season was from October 15th to March 15th. The arrival of the geese, in fact, was used by early settlers as an indication that the weather was about to change (Taylor 1959, p.70). The onset of the hunting season was marked by tule fires, which were often set by the hunters.

This cause of tule fires was documented by George Tinkham, a well known historian of the San Joaquin Valley. Tinkham wrote in his History of San Joaquin County in 1923 that:

> "The tule or peat land became, during the winter season, the feeding place of thousands of ducks and geese that flew from the north at the first approach of the Arctic winters. Then everybody that could fire a shotgun went hunting.....One of the most beautiful sights annually occurring in the fall of the year was the burning of miles and miles of tules. They were set on fire by the hunters to clear the land and drive out the game, making it easier to locate a flock of ducks or geese ...These annual fires continued perhaps twice or three times a year until along in the eighties." (Tinkham 1923, p.35-36)

Other hunters sought the tule elk, which took refuge in the tule marshes to escape the ravages of the early settlers (Roosevelt 1908, p.168; McCullough 1971; Stine 1980). They were mercilessly hunted for the hide and tallow trade in the early 1800s and after 1848 by market hunters (ibid., p.20-21). The last elk was allegedly shot around 1870 in Suisun Bay marshes (ibid., p.24). Fire was commonly used to flush elk from the tules. The Stockton Weekly Independent reported in September 1872 that "The tall tules gave a weird and rustling sound. Occasionally an opening would be found which had been burned off by Indians to get at the elk, which frequented them in large numbers..." (Anonym 1872, p.5). These hunting practices of the Indians were not reported until long after settlement and were learned from the white man. Prior to settlement of the valley, the Indian made minor use of the elk, and did not use fire in hunting them (McCullough 1971, p.17-18; Kroeber 1953; Heizer 1978).

It is also likely that some of the hunting-related tule fires were accidental, set by waddings from muzzle-loader shot guns (Barrett 1935, p.57).

Accidents and Other Causes. Most fires are caused by accidents. Fire statistics for the State for 1909 indicate that 80 percent of all fires with known causes were accidental -- campers and engines being the primary cause (Ca Board Forestry 1912, p.4). Other accidental causes of fires, widely reported in the press from 1850 to about 1880 include sparks from locomotives and steamers, clearing logs from paths, smoking, incendiary, wood choppers, and hunters (Barrett 1935).

The argonauts were notorious for setting fires as a form of amusement on the tedious journey to Sacramento and Stockton (Thompson 1958, p.55; Hittell 1897, p.5). Buffum, in one of the celebrated accounts of the gold mines, reported of his trip to the mines, "We continued our progress up the river (Sacramento) occassionally stopping and amusing ourselves by firing the woods on either side, and watching the broad flames as they spread and crackled through the underbrush." (Buffum 1850, p.50) Many other fires were accidentally set in the course of the long up-rivers trips.

Shepherds were notorious for burning the range as they moved their sheep out in late fall. In dry years, they herded their stock into the marshes and the sierras. At the onset of winter, they would move their animals out, burning everything in their path. It is likely that the herders also burned the tule when they moved the sheep to high ground before the floods (Barrett 1935).

Finally, fires were in constant use to smoke out mosquitoes, which were described by all of the early settlers (Fremont and Emory 1846, p.17). These mosquitoes bred in the marshes. Grimshaw, one of the early pioneers, recalls "The only way of getting through the night was to build a fire which could make as much smoke as possible..." to keep away the "clouds of mosquitoes" (Kantor 1964, p.21). Many of these fires probably spread into the tules.

5.2.3 Soil Surveys. If extensive tule burning occurred under "natural" conditions, it would be recorded in soil profiles as "ash" or "carbonaceous residue," or "char." Soil surveys for the Central Valley were checked to determine if there was any evidence of burning (Nelson et al. 1915; Lapham and Mackie 1905; Holmes et al. 1913; Cosby 1941).

In the Sacramento Valley tules grew in peat and muck, Columbia silt loams and Sacramento clays. There is no evidence in the soil survey of the Sacramento Valley (Holmes et al. 1913) of burning in any of these soil types.

In the Delta, tules grew on virtually all surveyed soil types. Most of the organic soils show some evidence of having been burned, but this is due to reclamation and farming as explained in the soil survey. However, one locality, in the southwestern Delta, suffered severely from burning and was separately mapped as "Egbert muck, burned phase." (Cosby 1941, p.22). In this area, "a thin layer of almost pure ash separates the surface material from the subsoil, which rests on the mineral substratum..." (ibid, p.22). This burned material comprises some 11,000 acres or 3.6 percent of the soil mapped in the Delta (ibid., p.16). This burned soil was also reported in an earlier survey of the San Joaquin Valley (Nelson et al. 1915, p.2710).

In the San Joaquin Valley, tules grew in peat and muck, Stockton and Fresno undifferentiated soils, Hanford fine silty loams, Merced clay loams, Stockton adobe soils, Hanford loams, and Sacramento clay loams. Evidence of burning is reported only in the latter, which occurs in the island region southwest of Stockton. The burned area typically occurred at a depth of about 12 to 30 inches and was about one foot deep. About 61,000 acres of this soil were reported (Nelson et al. 1915, p.2610). This is the same area occupied by the burned Egbert muck. The San Joaquin Valley survey was a reconnaisance-level survey, and the subsequent Delta soil survey represents a refinement. Thus, these two reports of burned peat are from the same area and are for the same burned soil.

The period when this burning occurred and its effect on evapotranspiration can be estimated from these soil surveys and recent studies of Delta marshes. Atwater (1980, p.99) has reported that the formation rate of peat soils in the south-central Delta was about 1 - 2 mm/yr. Since the burned zone occurs about 12 to 30 inches beneath the surface, it was probably deposited anywhere from 150 to 750 years ago.

If 61,000 acres of tules burned annually, it could reduce the tule evapotranspiration estimates in SWC Exhibit 262 by up to 69,000 acre-feet/year. This is less than 1 percent of the total estimated tule water use (7,095,000 acre-feet/year), which is insignificant. (The soil survey indicates that a much smaller area, about 11,000 acres, is all that burned.)

This was calculated by assuming an annual fire at the end of October that reduced the evapotranspiration from 61,000 acres of tules to zero for the period November through the end March, when it is assumed that the tules resume using water. About 15 percent of the annual tule evapotranspiration occurs from November to March (Fig. 5). If tules in this area used water at an average rate of 7.5 acre-feet/year, about 69,000 acre-feet of water would not be evapotranspired (61,000 ac x 0.15 x 7.5). The fire itself would evaporate large quantities of water from surrounding water surfaces (e.g., sloughs). Water would also be drawn by capillary action to the land surface from whence it would be evaporated.

6.0 SALINITY AND CURRENT DATA

Mr. Dawdy argues that freshwater in Suisun Bay is "evidence of considerable flow from the Sacramento and San Joaquin Rivers into the San Francisco Bay at the time of observation." (Dawdy 1987, p.19) He states that this is evidence that Delta outflow could not be zero in "late August, September, or October" as indicated in rebuttal testimony Exhibit 353 (Case A). Dawdy's hypothesis is not true. Freshwater in Suisun Bay does not mean that Case A is invalid nor that natural outflows were larger than claimed in SWC Exhibit 262. First, freshwater in Suisun Bay on a given day of the historical record does not mean that the long-term average monthly flow cannot be zero nor that the average annual outflow is larger than reported in SWC Exhibit 262. SWC Exhibits 262 and 353 present estimates of long-term, average flows for the climate of 1920-83. The actual flow (or salinity conditions) in any given year could certainly have deviated by large amount from the average due to the naturally high variability in the climate and hydrology of California. Second, the hydrography (tidal prism, depths, channel configuration, tidal flow, etc.) was entirely different under "natural" conditions than at present. Thus, one cannot interpret observations of freshwater 200 years ago using today's framework, as Dawdy has done (i.e., just because a high outflow today would be required to deliver freshwater at, say Chipps Island, does not mean that a similarly high outflow would have been required with a different channel configuration, water depth, etc.).

The information reviewed here and discussed below indicates that freshwater was typically encountered from August to October somewhere between Chipps Island and Collinsville or Antioch. Under today's conditions, it would take a minimum of about 11,000 cfs for freshwater (salinity of 500 ppm) to reach Collinsville (Fox 1987a). However, under "natural" conditions, shoals and sandbars were present at the mouths of the rivers and for a significant distance upstream of the mouths, into the Delta. Many areas in Suisun Bay and upstream were also much shallower than they are today. This would have reduced tidal diffusion (i.e., the advance of salinity) into this region. This means that much lower Delta outflows could have delivered freshwater to the eastern boundary of Suisun Bay at the mouth of the rivers.

The basis for this interpretation is presented in Section 7.1 and misrepresentations in Dawdy's material are outlined in Section 7.2.

6.1 Current and Salinity Observations Under Natural Conditions

Eye-witness accounts of the occurrence of salinity/freshwater and current were compiled from early diaries. This information is presented in Appendix A, Part II. Observations made during the low-flow period addressed by Dawdy (p.19) are summarized in Table 3. Observations made during the spring high flow period are not relevant to Dawdy's case and are not tabulated. However, the same concepts discussed here for the low-flow case would apply.

The information in Table 3 is difficult to interpret. First, the exact location of the observer, particularly in the early Spanish material, is usually uncertain. Second, the terms used to describe freshness and current -- "sweet," "fresh," "brackish," "perfectly limpid," "still" -- are qualitative. Most of the salinity observations are made by professional sailors who spend a considerable amount of time at sea where the water is not potable and the salinity is 33,000 ppm. Sweet relative to sea water could range from as little as 100 ppm up to 2,000 ppm or more. Third, Delta outflow and tidal phase (flood, ebb, spring, neap) at the time of observation are not known. Thus, only a qualitative interpretation of these records is possible.

Observations in the Salinity Column (Table 3) record three reports of freshwater in Suisun Bay (Canizares, Abella) and three reports of salinity intrusion into the western Delta (Belcher, Wilkes, Bryant). Freshwater was found at the mouths of the rivers, typically between Chipps Island and Antioch

Table 3. Salinity and Current Observations in the Suisun Bay/Delta Region During August - October Under "Natural" Conditions. Summarized From Appendix A, Part II.

Date of Observation Observer (Year Type) [1]	Location of Observation	Salinity	Currents
August 1775 (wet) Canizares	Mouth of rivers, near west end of Sherman Is.	Sweet water	NR[2]
September 1776 (avg) Canizares	Chipps Is. upstream to Collinsville & Antioch	Sweet water	NR
October 1808 (dry) Moraga	Sacramento R. at Butte City	NR	Scarcely any current
October 1810 (avg) Father Viader	San Joaquin R. at mouth of Merced R.	NR	Very slow
October 1811 (avg) Abella	From western end of Suisun Bay to mouth of rivers	Water gradually becomes sweet as they traversed south shore of Suisun Bay.	Current is brought to standstill from Rio Vista to points downstream.
October 1837 (dry) Comm. Belcher	Sacramento R. at Rio Vista	Perfectly sweet[3]	Almost still water
August 1841 (wet) Comm. Wilkes	Threemile Sl. north of Emmaton	Brackish[3]	NR
September 1846 (avg) Bryant	Sacramento R. near mouth of American R. (near Sutter's Fort)	Fresh	Perfectly limpid
October 1846 (avg) Bryant	Upstream from Rio Vista on Sacramento R.[4]	Fresh and sweet[3]	Perfectly limpid

1 Type of year (wet, dry, avg) synthesized from climatic data reported in Lynch (1931); Graumlich (1987); and Lamb (1977), records for London and Philadelphia.
2 Not reported.
3 These observations are probably of salinity intrusion into the Delta.
4 Location based on presence of riparian vegetation along levees. Accounts by various observers indicate that oaks and a heavy undergrowth of vines, as described by Bryant, begins on ascending the Sacramento River, no more than a mile or two below Rio Vista (Cook 1960, p.287).

or Collinsville, during the August to October period of average to wet years. Abella suggests that a salinity gradient was present in late October of 1811 across Suisun Bay. However, he does not indicate how many measurements he may have taken; if only two were made, at the eastern and western ends, this would not establish a gradient. The observations of salinity intrusion into the Delta (one report north of Emmaton and two near Rio Visa) confirm the "natural" Delta outflows estimated in SWC Exhibits 262 and 353. Freshwater at the eastern end of Suisun Bay is consistent with "natural" outflows, as demonstrated below.

Given present channel configurations, etc., it would take in excess of about 11,000 cfs to deliver freshwater to this region (Fox 1987a). However, under "natural" conditions, the topography of Suisun Bay/Delta was quite a bit different, and much lower flows would have moved freshwater into this region. This was probably due to two factors. First, mixing was apparently minimal during low-flow periods, and gravitational circulation probably controlled salinity intrusion into the Delta. Second, extensive areas of shoals and sandbars were present at the mouths of the rivers and upstream into the Delta. These blocked the movement of salty bottom currents into the Delta. The effect of each of these factors on freshwater movement into Suisun Bay is discussed below.

6.1.1 Gravitational Circulation. Observations in the Currents Column of Table 3 indicate that currents during the August to October period were uniformly reported as close to zero. They were described as "limpid," "almost still water," and "very slow." Suisun Bay, the mouths of the rivers, and upstream points, as high as Butte City on the Sacramento, were described as having no observable currents. Although these are only qualitative statements, they certainly indicate that tidal and riverine flow rates were low rather than high. This was probably in part due to the retarding effect of aquatic vegetation in Delta and Suisun Bay marshes (CDPW 1931, p.161). The dense growth of tules and other aquatic vegetation would have retarded tidal flow into and out of the Delta compared to the highly channelized system that exists today. Shallower water depths in a number of regions would also have reduced tidal diffusion.

Since observable currents, waves, or other manifestations of turbulence and mixing in the system are not recorded in these early reports, it is concluded that Suisun Bay was probably strongly stratified under "natural" conditions during the low flow period. Gravitational circulation would probably have been the most important salinity intrusion mechanism. In contrast, the present system is partially mixed, and gravitational circulation is responsible for only about 30 percent of the salinity intrusion into Suisun Bay/Delta (Fischer and Dudley 1976).

If gravitational circulation were the dominant mechanism of salinity intrusion under natural conditions, Delta outflows as low as 100 cfs could have delivered a lense of freshwater water throughout the eastern half of Suisun Bay. This conclusion is based on calculations using Fischer's relationship for the length of salinity intrusion (L) given by:

$$L = \left[\frac{h^7 c^5 E^3 g^{1/2}}{U_f U_t^5}\right]^{1/4} \times 3.7 \qquad (1)$$

in which L = length of salinity intrusion; c = Chezy coefficient, E = dimensionless density difference between ocean and freshwater = 0.025, U_t = Q_f/A, Q_f = freshwater flow rate; A = cross-sectional area; U_t = peak ebb flow tidal velocity.

If this equation is solved for a Delta outflow of 100 cfs, mean depths of 15 to 30 feet, cross-sectional areas of 45,000 to 275,000 square feet, and an ebb tide velocity of 3.5 feet/sec, it yields a salinity intrusion of about 1 to 9 miles. In other words, an outflow of 100 cfs could move freshwater to within 1 to 9 miles of the mouth of Carquinez Straits near Benecia for a condition of gravitational flow when Suisun Bay is strongly stratified. This would locate freshwater west of Chipps Island in the vicinity of the eastern end of Ryer Island. This is entirely consistent with observations recorded by the early explorers (Table 3).

6.1.2 Shoals. Under "natural" conditions, shoals were present at the mouths of the rivers. These shoals were described by early Spanish explorers (Appx A, Part I, Canizares) and were subsequently surveyed and mapped by Ringgold in 1850 (Fig. 6). Ringgold remarked that "[a]t the main confluence of the rivers, a group of islets is formed, together with a very extensive shoal, which, from its location at the mouths of the rivers, as well as from its shape, I have called 'Tongue Shoal.' Doubtless the islets and this shoal have been formed by the meeting of the currents of the rivers at and near Point Sacramento [on northern tip of Sherman Island]." (Ringgold 1852, p.28) These shoals are also described in many of the early accounts of upriver boat trips because of the navigation hazards they presented; boats commonly ran aground on the shoals and so remained for days in succession until high tides freed them.

Tongue Shoal at the mouth of the Sacramento River was nearly 3000 feet long and blocked most of the main channel (Fig. 6). Shallow, 300-foot wide channels with depths of 12 to 15 feet were present on either side of this shoal. A similar though less extensive shoal, Fraser Shoal, was also present at the mouth of the San Joaquin River (Fig. 6). Tongue Shoal has been removed. Fraser Shoal remains, but channels along either side have been deepened and widened. These shoals restricted the movement into the Delta of salty ocean water by upstream bottom currents. These shoals functioned much like weirs or so-called "hydraulic restraining channels" that have been proposed to prevent salt water intrusion into estuaries. Since they restrained the movement of salty water bottom, the shoals would have allowed freshwater to move out of the Delta in a surface lense on the ebb tide at very low outflows.

6.1.3 Channel Capacity. Channel capacity, especially water depth, has an influence on both of the factors discussed above. When channels are enlarged by either making them wider or deeper or both, the tidal flow is increased and salinity can intrude farther into an area (e.g., Richards and Granat 1986; CDPW 1931). Originally, the Sacramento and San Joaquin Rivers were not large enough to carry normal flood waters (Hall 1880) and annually flooded the Valley. As the flood flows were restrained by levees and other hydraulic works, it was necessary to enlarge the Sacramento River to carry the increased flows. Main channels were also deepened for navigation. Some of the principal changes that have occurred include: (1) widening the lower Sacramento River from Collinsville to above Rio Vista; (2) Sacramento River deep water ship channel; (3) Stockton deep water channel; (4) Suisun Bay deep water channel; and (5) dredging at diverse sites to maintain deep water.

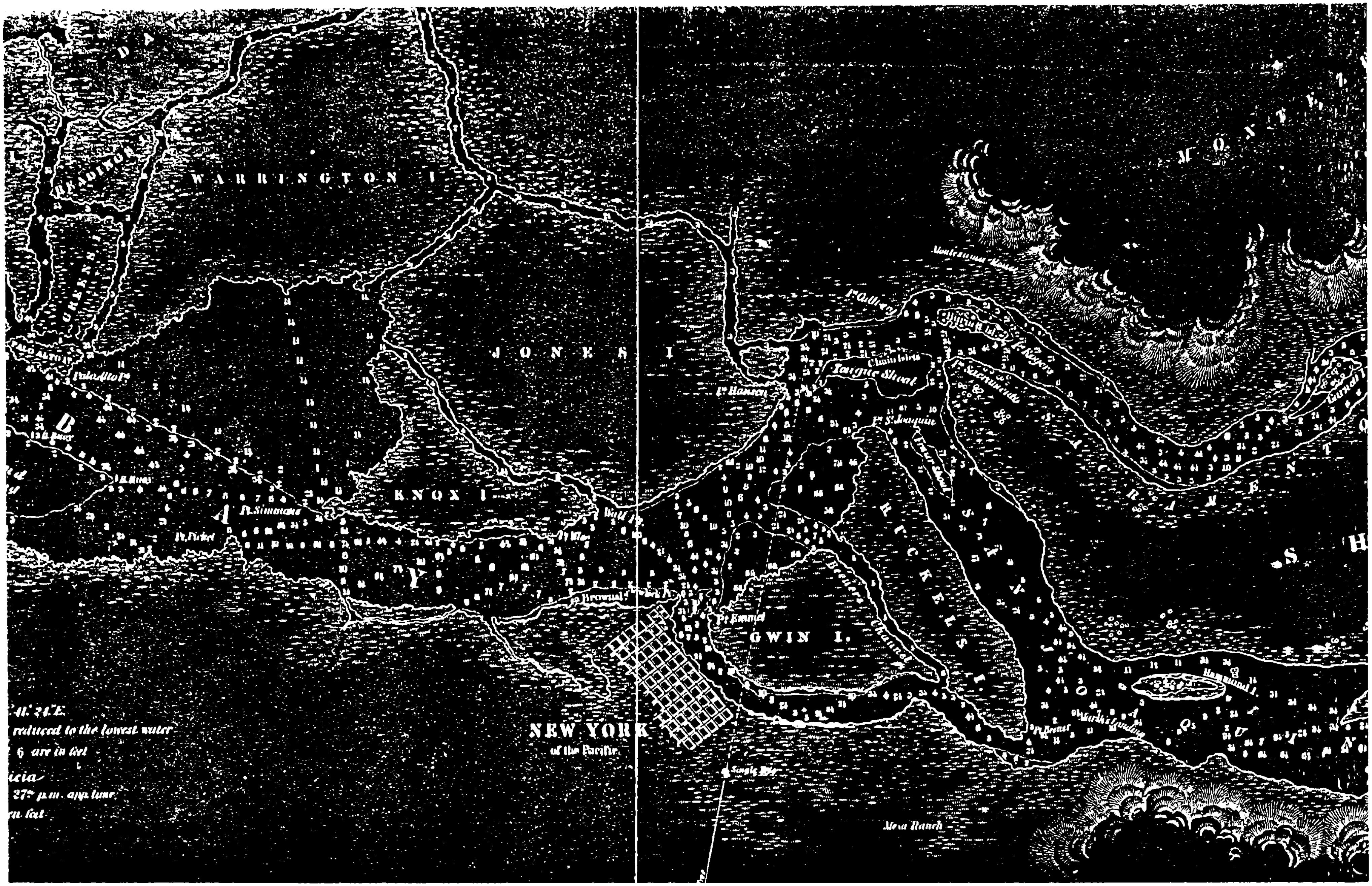


FIGURE 6. A portion of Commander Ringgold's sailing chart of Suisun Bay in 1850 (Ringgold 1850). Water depths are in fathoms (1 fathom = 6 feet) at low water. The town of New York is close to the present town of Pittsburg, and Knox Island is now known as Chipps Island. Notice Tongue Shoal at the mouth of the Sacramento River and the marsh pattern indicating tule swamp.

These changes in channel depth allow greater salt water intrusion for the same outflow conditions. The effect of the Sacramento River channel enlargement, for example, is discussed in Bulletin 27 (CDPW 1931, p.216).

6.2 Errors in the Dawdy Analysis

Dawdy claims that SWC Exhibit 353, Case A, cannot be valid because freshwater was reported historically "in Suisun Bay" (p.19). Dawdy has overstated his case by locating observers in Suisun Bay who were actually elsewhere. Two of his pieces of evidence are actually reports of salinity intrusion into the Delta while the third is a report of freshwater at the eastern edge of Suisun Bay, not in Suisun Bay. Two other reports of freshwater in March and April during high outflow periods are provided, but these are not relevant to the discussion of freshwater in Suisun Bay during August to October.

Dawdy cites three observations of freshwater during the period of August to September: Canizares in 1775, Belcher in 1837, and Bryant in 1846. None of these reports record freshwater in Suisun Bay. Two of the reports actually were made in the Delta and are reports of salinity intrusion into the Delta while the third one was made at the mouth of the rivers, probably around the western end of Sherman island. Each of this misrepresentations is briefly reviewed.

Dawdy's first piece of evidence is the 1775 Ayala expedition (Dawdy, p.20). The authority that Dawdy cites (Bolton 1926, p.42), a noted California historian who translated many of the early Spanish diaries, footnotes the location where freshwater was reported as where the rivers discharge, at "the head of Suisun Bay." Dawdy does not provide this clarification, and instead states "there was freshwater in Suisun Bay during late September 1775." Translations of this material by other historians also locate the place where freshwater was found as the mouths of the rivers (Eldredge 1909, p.67; Galvin 1971, p.97). Although the precise location where freshwater was found is unknown, it was probably around the western end of Sherman island. Another point of interest is that these observations were not made in late September as claimed by Dawdy but in late August (Ayala's diary in Galvin 1971, p.84-85).

Dawdy's next observation of "sweet water in Suisun Bay" (Dawdy, p.20) was made by Captain Belcher in October 1837 (Pierce and Winslow 1969, p.46). Belcher was actually on the Sacramento River near Rio Vista when he first found freshwater. This site was 56 miles from Yerba Buena [San Francisco], reported in the text as about 20 miles above the first anchorage, which was 36 miles from Yerba Buena (ibid., p.35-46). Dawdy apparently assumed the site was 20 miles from Yerba Buena (San Francisco), which would have located Belcher in Carquinez Straits. Thus, rather than being a report of freshwater in Suisun Bay, this is actually the first record of salinity intrusion into the Delta under "natural" conditions.

Dawdy's third report of freshwater in Suisun Bay was made by Bryant in October 1846 (Bryant 1985, p.343-344). The exact location where Bryant first reports freshwater can be estimated from his description of riparian vegetation at the site. Bryant states that "[t]he banks of the river, and several large islands which we passed during the day, are timbered with sycamore, oak, and a variety of smaller trees and shrubbery. Numerous grape-vines, climbing over the trees...give to the forest a tangled appearance." (Bryant 1936, p.343) According to the historian, Cook, under "natural" conditions, this type of vegetation began on the Sacramento River near the foot of Grand Island and continued thence up the river (Cook 1960, p.287). Hence, Bryant was upstream of Rio Vista, well into the Delta, not at the "upstream end of Suisun Bay" as suggested by Dawdy (p.21). Again, this is a record of salinity intrusion into the Delta.

7.0 CLIMATE

Mr Dawdy, on page 22, makes the point that it is important to use the actual climate that goes with "natural" flows. This, in fact, is what was done in SWC Exhibit 262. "Natural" flows were calculated for the period 1921 - 1983, using the climate for that period. Clearly, the information that one would need to calculate natural flows at some point in the distant past is not available.

Dawdy (p.22) also cites tree-ring evidence to demonstrate that the climate was different in the past than it is at present. The Fritts precipitation record reconstructed from tree-ring data (Fritts and Gordon 1980) does not appear to be an accurate representation of rainfall in California. It, for example, shows an extended drought from 1760 through about 1830 that is not substantiated in the historical record. It also does not reproduce annual floods and droughts prior to about 1850. It disagrees with weather patterns estimated from early mission records (Lynch 1931) and with other, more recent tree-ring reconstructions (Graumlich 1987). This is partially because the work was based on trees from a very large region, and few trees actually located in California were included. The regression model used to relate tree-ring data to rainfall also only explained about 22 percent of the variance, an unacceptably low value for prediction.

8.0 CONSUMPTIVE USE VALUES ARE NOT TOO HIGH

Cross examination of Fox on November 23 and 24, 1987, attempted to demonstrate that consumptive use values used to estimate "natural" Delta outflows in SWC Exhibit 262 were too high for the following reasons:

1. Consumptive use values used in the Tulare Lake Basin were adjusted downward, while those used elsewhere were not adjusted. The suggestion was that the other consumptive values were, therefore, too high.

2. Kuchler's map shows tule swamp in the area formerly occupied by Tulare Lake. Since tules do not grow under 20 feet of water, the map must overestimate tule swamps.

3. Tule marsh consumptive use is too high because the factors were extrapolated from other areas where evapotranspiration would be higher without adjusting for climatic differences; other plants were present in the swamps that used lesser amounts of water; the swamps were not "dense" and thus used less water; depth to water table was not considered; and a factor of 1.4 was used to estimate consumptive use from pan evaporation when a factor of 0.95 should have been used.

The first two points are addressed below in Section 8.1, Tulare Basin Water Balance. The third point and other related issues are addressed in Section 8.2, Consumptive Use Estimates.

8.1 Tulare Basin Water Balance

A water balance was used in SWC Exhibit 262 to evaluate the magnitude of the Tulare Lake Basin overflow into the San Joaquin River. Exhibit 262 used DWR estimates, which are based on historical measurements (Fox 1987, p.A2-37 - A2-43). However, there is substantial evidence that formerly, the San Joaquin River drained into the Tulare Lake Basin and not into the Bay. Blake, a geologist who explored and surveyed this region for the Pacific Railroad (Williamson 1856, p.193), concluded that the greater part of the Tulare Basin was covered with a broad lake and that the San Joaquin River drained into this lake. Deposition of sediment by the San Joaquin, however, raised the level at the end of the valley near the San Joaquin, shutting off communication with the river and causing the lakes in the Tulare Basin to dry up. There are also eye-witness accounts of flow from the San Joaquin River into Tulare Lake (reviewed in Fox 1987, p.A2-39).

The conclusion from the Tulare Basin water balance analysis was that the San Joaquin certainly could have flowed into the Tulare Basin and that DWR's estimate of the overflow (which goes in the other direction) was likely an overestimate of the "natural" overflow. Nevertheless, the DWR estimate was used retained in SWC Exhibit 262 to provide a conservative estimate of "natural" Delta outflow. Thus, the Tulare Lake Basin water balance and the various factors used in it were not used to estimate "natural" Delta outflow. All of the assumptions are clearly listed in Table 8, page A2-42 of SWC Exhibit 262. The basis for each assumption is briefly reviewed here.

The Tulare Lake Basin is distinct from areas to the north (Sacramento Basin, the Delta, and San Joaquin Basin). The topography, climate, hydrography, and vegetation are very different from northern areas. These differences dictate that different assumptions be used in water balances.

Vegetation in the Tulare Basin is different from that in northern regions, reflecting differences in soils, climate, and water supply. The northern riparian forests are dominated by the cottonwood (Kuchler 1977, p.20), which uses 5.2 - 7.7 ac-ft/ac of water (Fox 1987, Table 5). The Tulare riparian forests are dominated by the valley oak (Kuchler 1977, p.22; Preston 1981, p.21-22), which uses only about 1.7 ac-ft/ac. Thus, different consumptive use rates in these two regions for riparian forest habitat is justified.

Different prairie consumptive use values were used in the two regions to accommodate differences in precipitation. The prairie in the Tule Basin comprises saltbush as a major component, plus other grasses. Saltbush is rare to the north. The prairie consumptive use values used in the Tulare Basin were 50 percent lower than those used to the north. The factor of 50 percent was estimated from precipitation data and field consumptive use studies. Since the principal water supply for the prairie was rainfall, precipitation ratios in the two areas were evaluated. The mean precipitation in the Tulare Basin (8.3 inches; Fox, Table 8) is about 50 percent of the mean precipitation of the northern region (15.6 inches; Fox, Table 4). Ratios of field consumptive use for alfalfa during 1959 and 1960 were also evaluated. Alfalfa evapotranspires about 50 percent less water in the Tulare Basin [1959 = 23.8 inches; 1960 = 18.7 inches] than in the Sacramento Valley [1959 = 45.6 inches; 1960 = 34.0 inches] (DWR 1963, p.42-48).

Different tule marsh consumptive use values were used in the two regions to accommodate differences in the water supply and hydrography. In the northern basins, a range of 6 to 9 ac-ft/ac was used while in the Tulare Basin, 6 ac-ft/ac was used. The lower value was selected for the Tulare Basin for two reasons: (1) it was water-supply limited and (2) the marsh-to-lake surface area varied dramatically from year to year.

First, rim inflows are the principal water supply for the marshes. Some of the water recharges groundwater aquifers that feed the marshes, some of it overflows channel banks and into the marshes, and some of it seeps out of the channels later in the year. In the Tulare Basin, there is much more land and much less water than in the northern regions. This is reflected in the rim inflow to valley floor area ratio. This ratio is 0.6 ac-ft of inflow per acre of land (0.6 ac-ft/ac) in the Tulare Basin and 3.6 ac-ft/ac in the northern basins. This means that there is four times more water per acre of land in the northern basins than the Tulare Basin. Clearly, given these mean water-supply-to-land ratios, the Tulare Basin would be water short in many years compared to northern regions. The bottom of the tule water use range was, accordingly, selected.

The second reason a lower consumptive use figure was selected is because the area of Tulare Lake fluctuated dramatically from year to year in response to the degree of wetness. Historically, the lake is known to have fluctuated between extremes -- from completely evaporated to 760 square miles (Preston 1981, p.18; CDPW 1931a, p.76). Since the surrounding swamp areas fluctuated according to the elevation of water in the adjoining lakes, Grunsky reported that "[i]t is impossible to give their [swamp] acreages." (Grunsky 1888, p.89). This is the reason that Kuchler's tule marsh areas in the Tulare Basin were not modified to show the lake. Instead, the varying swamp-to-lake surface area was considered by modifying consumptive use values.

The varying size of the lake was considered by weighting the consumptive use values for a free water surface and for tule marsh, while holding the total swamp area returned by Kuchler constant. When the lake was large, water use would be at the lower rate of 4 to 5 ac-ft/ac (free-water surface evaporation). Since from none up to 75 percent of the land area that Kuchler (1977) shows as tule marsh in the Tulare Basin could have been free-water surface, the weighted use would be about 6 ac-ft/ac.

In summary, these same adjustments should <u>not</u> be used in northern basins because: (1) their vegetation was different; (2) their precipitation was about a factor of two higher; (3) the permanent swamp in the northern areas was not water-supply limited; and (4) the valley tributaries to the north did not drain into a lake whose level controlled the extent of marshes.

8.2 <u>Consumptive Use Estimates</u>

Estimates of the amount of water used by "natural" vegetation in SWC Exhibit 262 are conservative and probably <u>underestimate</u> vegetative water use for the following reasons:

1. Most of the areas where tules grew were criss-crossed by a complex maze of sloughs. Tules and other swamp vegetation that grow along exposed edges of sloughs evapotranspire water two to three times faster than tules in dense swamps (Young and Blaney 1942; Blaney 1961, p.39; Anderson and Idso 1987,

p.1041), and rates of up to 20 ac-ft/ac have been recorded. Exhibit 262 ignored this effect, which could increase consumptive use in areas such as the Delta by 10 to 20 percent compared to rates actually assumed in Exhibit 262. This would reduce "natural" Delta outflows below those reported in SWC Exhibit 262. The same concept is valid for riparian forests, which occurred in long strips along river banks. Evapotranspiration along this outer edge would have been larger than elsewhere in the forest.

2. The tules and other vegetation in the Central Valley were large and luxuriant (e.g., Jepson 1893; numerous citations in Appx. A). Tules, for example, typically grew to 12 to 15 feet and sometimes to 20 feet, while tules in other areas are typically 5 to 6 feet tall. Deciduous trees in the riparian forests were also larger than normal, and their great size was frequently remarked upon by early visitors. This suggests that water and nutrients were plentiful and that growth was not seasonal (i.e., as opposed to for only part of the year due to drying) or limited by water supply. Tall vegetation also evapotranspires more water than short vegetation due to atmospheric turbulence (Anderson and Idso 1987; Penman 1948). The tank studies used to estimate consumptive use were conducted on normal tules and some of them reported that growth was stunted. Thus, consumptive use rates taken from tank studies probably underestimate "natural" consumptive use in the Central Valley.

3. This work did not include any evaporation/evapotranspiration from seasonally flooded land or seasonal marshes. These lands probably supported some aquatic vegetation for part of the year. The data summarized in Table 1 suggest there were 1.5 to 3.5 million acres of these lands that could have evapotranspired from 1 to 5 million acre-feet of water that was not included in Exhibit 262.

4. The "natural" grasslands comprised perennials (Burcham 1957) that used more water than the annuals that replaced them. These grasses were luxuriant and often grew to 3 to 5 feet (Rogers 1891, p.45; Jepson 1910, p.11). SWC Exhibit 262 used consumptive use figures corresponding to water-limited annuals rather than luxuriant perennials.

The magnitude of water losses from evapotranspiration estimated in SWC Exhibit 262 is consistent with those reported for reed swamps from other parts of the world. About 50 percent of the flow of the Nile River is evapotranspired by reed swamps in the Sudan (Hurst and Phillips 1938; Hurst 1957). Nearly 75 years of study of these swamps has demonstrated that large reed swamps, up to 2 million acres in extent, along several rivers (e.g., Bahr el Ghazal, Bahr el Jebel, etc.) use 6 to 8 ac-ft/ac of water (Hurst and Phillips 1938; Chan and Eagleson 1980).

The objections to the consumptive use estimates raised in cross-examination are minor compared to the conservatism built into the estimates. The objections involve minor adjustments that are within the limits of error of estimated outflows. The estimated "natural" Delta outflow varies over a factor of two, from 7.8 to 18.9 million ac-ft. Minor adjustments will not significantly affect these estimates or the principal conclusion, namely that "natural" Delta outflow was much lower than formerly believed. Each of those points, listed at the beginning of this section, is briefly addressed here.

Water Table Depth. Depth to water table is usually not considered when estimating the consumptive use of aquatic vegetation such as tules because they typically only grow where there is standing water. They also evapotranspire at the potential rate (Anderson and Idso 1987). The fact that the tules were large and luxuriant is strong evidence that the tule swamps had an abundant water supply. The absence of accounts of dried out swamps prior to 1846 (Appendix A) is also strong evidence that the tules had an adequate water supply. Additionally, the tule acreages used here are for "permanent" swamp (Sec. 3.3) under average conditions for the period 1920-83. Thus, water table is not an issue because "permanent" swamp normally had an adequate water supply. (Annual fluctuations were not relevant to this work because long-term, average annual natural Delta outflows were calculated).

None of the studies reviewed here (Fox 1987, p.A2-33) report or even discuss the need to consider water table depth in tule marshes. This is probably because the tule does not commonly occur in water-limited areas where water table is a concern. The water-table evidence offered by Mr. Sanger in cross-examination was for saltgrass (Blaney 1955, p.818). This is a desert grass that grows in salt marshes around San Francisco Bay (Robinson 1958, p.56). It is not common in freshwater marshes. It is customary to consider water table depth for these types of plants because they typically occur in water-limited environments.

Other Swamp Plants. The predominant swamp plant reported in all of the early eye-witness accounts was tules (Appx. A). Tule generally meant any of several tall plants that may have included reeds, cattails, rushes, and sedges. Recent studies on Delta marshes (Atwater 1980) also indicate that the tule was and is the dominant species. All of these plants evapotranspire at about the same rate as tules (Young and Blaney 1942, p.127,128; Hurst and Phillips 1931). The edges of tule swamps were also reported to contain coarse grasses, which would evapotranspire at a lower rate since they are shorter. However, their areal extent was too low to affect the overall tule swamp consumptive use rate. Stout (1929) estimated that in 1929, the entire Delta, including cattails, tules, and similar aquatic growth (Stout 1928) used 9.6 ac-ft/ac water, consistent with the range of 6 to 9 ac-ft/ac used here.

Extrapolation from Other Areas. The tule swamp consumptive use range used in this work was not extrapolated from values measured in other areas. The range was taken from values measured in the Delta [7 to 13 ac-ft/ac] (Fox 1987, Table 6). The consumptive use values for other areas also reported in Fox (Table 6, p.A2-33) were presented for informational purposes only, to confirm the local values. This range was then further verified by estimating consumptive use from pan evaporation using the ratio of tule to pan evaporation published by Young (1938) and Young and Blaney (1942). This ratio typically ranges from 0.5 to 1.9, and averages about 1.4. The average was used here.

Effect of Innundation on Tules. Scirpus spp., which dominated the "natural" tule swamp plant community, and other similar plants (e.g., Typha spp.), are unusually resistant to flooding. This may be one of the main reasons that the tule dominated Central Valley marshes. Thus, it is unlikely that periodic flooding during the winter and spring or even standing water on a year-round basis would have reduced evapotranspiration or areal extent.

The rhizomes of tules and cattails can tolerate long periods (over 3 months) of complete submergence, particularly in spring when carbohydrate reserves are large (Braendle and Crawford 1987, p. 399). The rhizomes are of interest because most plant roots extract oxygen from soil air for respiration. Once soil is flooded, the soil oxygen is exhausted. Tules and other similar plants have an adaptation (i.e., spongy tissue called aerenchyma) that allows them to transport oxygen from the atmosphere through their shoots to the roots, overcoming a long-term anaerobic condition.

Tules and cattails also prefer flooded areas. Barrett and Seaman (1980), in a study of weed flora of Central Valley rice fields, found that Typhaceae (e.g., Typha latifolia) and Cyperaceae (e.g., Scirpus acutus) preferred the flooded rice fields and ditches to drier areas. Dabbs, in a study of Scirpus species in freshwater marshes, found that the mean depth of water in which Scirpus acutus, the common tule of the Central Valley, was found growing was 3.6 feet and that it was frequently found at depths up to 5 feet. Several experiments with this species demonstrated that it preferentially colonized the deeper areas. Studies with cattails have also demonstrated that they preferentially grow in deeper water, up to about 7 feet (Hutchinson 1975, p.412).

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APPENDIX A

EYE-WITNESS ACCOUNTS OF THE CENTRAL VALLEY

1772 to 1876

by

Alison S. Britton

Part I of this Appendix presents observations by early explorers of California's interior valleys (from Fages in 1772 to Cone in the 1870s), amply documenting the existence of immense tracts of tule-covered wetlands, long since diminished by drainage and reclamation works. Part II furnishes comments on currents and salinity, in an attempt to determine the nature of Delta outflow under "natural" conditions before reclamation, flood control, and water development. Only eye-witness accounts are included. Later histories, hearsay, and opinions not based on observation are excluded.

An attempt has been made to be as comprehensive as possible for the period prior to about 1840. However, after that date, the available material is much more voluminous. Thus, only a selection from these later diaries and publications is included. Most of the references used (a list is appended) may be found in the Bancroft Library at the University of California, Berkeley campus.

Each cited reference was read in full, and material pertaining to tule swamps, salinity, and currents was abstracted and quoted. This material is presented herein in approximate date order, starting with the first observation in 1772. A separate entry is provided for each date (month,year) or location of an observation. Each entry is accompanied by: (1) name of observer and date of observation; (2) location of observation; (3) quote or summary thereof; square brackets are used to indicate changes in the original text made by the present author; and (4) reference where the quote may be found, which is included at the end of this appendix. The geographic locations where the observations are made are often unknown and can only be approximated. The location specified by the translator or editor of the reference is given when available.

The information contained herein is qualitative. Locations are imprecise. Descriptive terms such as "sweet," "fresh," and "limpid" mean very different things, depending upon the frame of reference of the observer. Distances cited in leagues are qualitative at best because they depend upon the type of terrain traversed. Freshwater to a sailor may be very different than freshwater to someone accustomed to drinking Hetch-Hetchy water. Delta outflow and prevailing weather at the time of observation are usually not known with certainty.

The observations recorded here should be considered relative to prevaling climatic conditions. Early weather conditions in California have been determined from records kept at the missions (Lynch 1931). These are summarized here. The first explorations of Suisun Bay and the Delta were conducted between 1772 and 1776. This was a time of plentiful rainfall in California, except for a short period. The records show that floods occurred in 1771-72, 1775-76, and 1779-80. Thus, the earliest expeditions, during which freshwater was reported in Suisun Bay (e.g., Crespi, Anza, Canizares), were conducted during a wet period. A period of rainfall shortage began in 1781 and lasted through 1809 with minor interruptions. The drought was statewide, and it was reported at all missions. Many expeditions were conducted during this dry period, uniformly reporting extensive tracts of tules. None of them report freshwater in Suisun Bay.

The statewide drought was followed by a period of excess rainfall that lasted for eleven years from 1810 to 1821. Floods were reported in 1810-11, 1814-15, and 1816-17. The intensity of rainfall during this period has been compared with that of 1889 to 1893. Freshwater is again reported in Suisun Bay in October 1811 (Abella). This wet period was followed by an extreme drought that lasted from 1821 until 1832 and was interrupted only by a large flood in 1825. Extensive tule tracts are still reported during this drought.

The period from 1832 to 1842 experienced normal to subnormal rainfall, interrupted by intervals of heavy rainfall and floods in 1833-34, 1839-40, and 1841-42. Two occurrences of salinity intrusion into the Delta are reported during this period (Belcher, Wilkes). Following the flood of 1841-42, a period of subnormal rainfall ensued, lasting for 41 years until 1883 but interrupted by occasional floods in 1849-50, 1851-52, 1852-53, 1859-60, 1861-62, 1866-67, 1873-74, and 1875-76. These floods were quite moderate, except the flood of 1861-62, which was the most severe since the founding of the missions in 1769. The third observation of salinity intrusion into the Delta is reported during this long dry period (Bryant).

There is much variation in place and river names in the early reports and maps, dependent on whether the observer used the Spanish, English, or Indian nomenclature. Set forth below are some of the common variations:

Rio de San Francisco: The Spanish term for the entire body of water emptying into the Delta (Sacramento and San Joaquin Rivers), generally used only in the earliest accounts.

Jesu Maria: Spanish term for what is now known as the Sacramento River.

Sacramento: Spanish term for what is now known as the Feather River.

Rio de la Pasion: Now known as the Mokelumne River (sometimes spelled Moqueles), but sometimes identified as the Cosumnes River.

Tache Lake: Name sometimes used for Tulare Lake, taken from the Indian tribe (known as Tachi, Sin Tache, Tadji or Dachi) in the vicinity. The lake is sometimes referred to as Tontache (although this usually designates the southern portion of the lake bed), Thuohuala or Bubal. The lake no longer exists.

Kaweah River: Previously known as the San Gabriel, Frances, or Ee-dek River.

Rio de las Llagas: Spanish term for the American River.

San Pedro River: Now known as Tule River.

Puerto Dulce: Spanish term for Suisun Bay. Sometimes referred to as Junta de los quatro Evangelistas.

Bahia Redondo: Spanish term for San Pablo Bay. Sometimes referred to as Bahia de N.S. de Guadalupe.

In addition, other Spanish terms frequently encountered include:

Braza: Spanish measurement of approximately one fathom (5-1/2 feet).

Legua: League; varies with type of terrain; the distance travelled by a horse or man in about an hour; for boat travel, a league is a very unreliable measure of distance and at best is equal to about an hour of time; often cited as about 2-2/3 statute miles.

Tule: Spanish term for "reed" or "bulrush." Large areas of tule marsh are commonly referred to as "tulares." Other terms encountered include "rushes," "flags," or "rank vegetation."

Vara: Spanish measurement of approximately one yard (33 inches).

PART I - TULES

OBSERVER, DATE: Fages/Crespi, 1772 (April)
LOCATION: Looking east from Pittsburg-Antioch area toward Delta
DESCRIPTION: Diary entry: "[T]his plain probably must exceed one hundred and twenty leagues in length and is in places twenty, fifteen, or fewer, leagues wide. In its entirety it is a labyrinth of lakes and tulares."
REFERENCE, PAGE: Treutlein, 355; Bolton (1931), 213

OBSERVER, DATE: Juncosa, 1775
LOCATION: Southern San Joaquin Valley
DESCRIPTION: "[P]erhaps you will find traces of the animals from the various times the soldiers have crossed from the valley to San Luis when they have gone in search of some deserters who were among the immense tulares which are about on the parallel of San Luis."
REFERENCE, PAGE: Bolton (1931), 217

OBSERVER, DATE: de Canizares, 1775 (August)
LOCATION: Suisun Bay, at mouth of the Delta
DESCRIPTION: "The rivers come, one from the east-northeast . . . the other, which has many branches, comes from the northeast through tulares and swamps in very low land, the channels not over two brazas with sandy bars at their mouths, where I found in sounding the water not more than a half braza."
REFERENCE, PAGE: Eldredge/Molera, 67-68 (de Canizares, D.J., Report of the Pilot Don Jose de Canizares to Commander Don Juan de Ayala, September 7th, 1775, Angel Island); also Galvin, 97

OBSERVER, DATE: Anza, 1776
LOCATION: Area of Carquinez Strait, proceeding east-northeast
DESCRIPTION: April 3rd: "[W]e went about half a league to the northeast over some hills, from which we saw the three arms of the river noted by those who first discovered it, but whereas they mention only three islands we have seen seven low ones . . . . [A]lthough we wished to go directly to [the river] this was not possible because many marshes intervened."
LOCATION: San Ricardo, near site of Antioch Bridge
DESCRIPTION: April 3rd: "[W]e have been led to doubt whether this is a river, or a lake formed by the water of the tulares, so famous in these establishments, which are found to the north and east of the missions of San Luis and San Antonio, and extending toward this place." April 4th: "To get around [the marshes] I made such efforts as were possible, both on foot and on horseback, but the water and marshes alike prevented our going to the east-northeast . . . . [W]e traveled [east-southeast] about five leagues . . . [a]nd as we beheld more water and more marshes in all the immense plain which we saw to the east and to the north, the two soldiers who belong to this country assured me now that this water comes from the tulares which run in those directions and are distant twenty-five or thirty leagues from the missions of San Luis and San Antonio, and which even in dry season they have found unfordable."
REFERENCE, PAGE: Bolton (1930), 143-146

OBSERVER, DATE: Font, 1776 (April)
LOCATION: Small hill southeast of Antioch, looking into the Central Valley
DESCRIPTION: "[A] confusion of water, tulares, some trees near the sierra to the south, and a level plain of immeasurable extent . . . . This is the plain through which the sea of fresh water extends, not continuously but in places leaving great areas uncovered or with little water, forming those great green tulares that begin near the mission of San Luis. According to their direction and to this account they must be more than a hundred leagues long to this place, not counting the distance which they may extend above, for we are unable to see their terminus, and in width they must be some twenty-five or thirty leagues. I surmised that these tulares must run to the vicinity of the port of Bodega, and that the green field which Captain Don Juan de la Quadra saw to the east of his port must have been tulares like these which we saw here, or that they might even have been the same ones, extending as far as that place."
REFERENCE: Bolton (1931b), 386-389

OBSERVER, DATE: Font, 1776 (April)
LOCATION: En route from Antioch to Knightsen via Oakley; then travelling parallel to Old River, to Bethany in San Joaquin county
DESCRIPTION: "We traveled a short distance to the east, intending to follow the water, either along the banks, or in sight of it. But very soon our way was cut off by the tulares and mires, which forced us to change our direction, and separated us from the water so far that we did not see it again except from a distance and from the top of the sierra . . . . With the intention of seeing if the tulares would afford us a free passage we turned northeast and traveled this way for about another league, but shortly the tulares prevented us from continuing in that direction. Then we began to wind about, now to the southeast and now to the east-southeast, without being able to make any headway toward the Sierra Nevada, but rather getting farther away from it . . . . Once we came to a path with the tracks of a man, which seemed to lead toward a small village which we saw within the tules. But . . . we soon came to a mire through which the animals could not pass . . . . We now realized the difficulty and saw that it was impossible to penetrate the tule marsh. The soldiers here told us that it was so dangerous to travel in the tulares that when they went to catch the deserters among them, one deserter who saw himself about to be captured, in order to get away jumped precipitately into one of those mires, trusting perhaps that he might be able to swim, but was swallowed up and unable to get out, and as it was impossible to aid him, he remained there drowned and buried in the mud."
REFERENCE, PAGE: Bolton (1931b), 405-407

OBSERVER, DATE: Font, 1776 (April)
LOCATION: East of Byron Hot Springs
DESCRIPTION: "[W]e traveled more than three leagues . . . going with some difficulty in the midst of the tulares, which for a good stretch were dry, soft, mellow ground, covered with dry slime and with a dust which the wind raised from the ashes of the burned tule, so biting that it made our eyes smart severely . . . . We now saw that the mass of fresh water which extends through those tulares has its floods, and that when it rises it extends far beyond the land we were traversing, which was full of shells of snails and turtles and of silt produced by the water when it extends through there . . . . We now saw that it was impossible to cross the plain or to approach the Sierra Nevada . . . since the tulares at each step took us farther from the sierra, for it was seen that what was called a river had become to us a lake . . . . From all accounts it is clear that these tulares are the same as those near the mission of San Luis, and that they continue clear to there . . . . Here, we are without grass or firewood because there is none, and without water because the marshes and the vast mires of the tulares prevent us from reaching it."
REFERENCE, PAGE: Bolton (1931b), 407-409

OBSERVER, DATE: Father Pangua, 1794
LOCATION: Describing area from Mission San Gabriel to Soledad
DESCRIPTION: Indians take refuge from soldiers in the tules, which are "lakes full of plants."
REFERENCE, PAGE: Cutter, 48

OBSERVER, DATE: Hermenegildo Sal, 1796
LOCATION: Sacramento Valley area
DESCRIPTION: "[A]ll the countryside abounds with fresh grass, tule swamps, and lakes where deer breed."
REFERENCE, PAGE: Cook (1960), 242 (Report of Hermenegildo Sal, San Francisco, January 31, 1796; Cal. Arch., Prov. St. Pap., XIV:14-16)

OBSERVER, DATE: Zalvidea, 1806 (July)
LOCATION: Area of Buena Vista Lake
DESCRIPTION: "The shore of the lake is completely covered with a great deal of tule."
REFERENCE, PAGE: Cook (1960), 245 (Report of an expedition to the interior by Father Jose Maria de Zalvidea, from 19 July to 14 August of 1806; Santa Barbara Arch., IV:49-68)

OBSERVER, DATE: Moraga expedition (reported by Munoz), 1806 (September)
LOCATION: San Joaquin River, Santa Rita area
DESCRIPTION: September 23rd: "There are also great tule swamps in all this region and much black willow along the stream." September 24th: "On all sides [of two stream beds] tremendous tule swamps present themselves, which can be very miry in wet years." September 27th: "[W]e crossed the river and . . . pushed through about a league of very high, thick tules, in the midst of which could be seen a few clearings well covered with grass."
REFERENCE, PAGE: Cook (1960), 248 (Diary of Father Pedro Munoz, Santa Barbara Arch. IV:1-47)

OBSERVER, DATE: Moraga, 1808 (September)
LOCATION: San Joaquin River, vicinity of Laguna del Blanco
DESCRIPTION: September 27th: "[The corporal] found [the ford in the river], but on the opposite side he was confronted by a very large tular and could not continue." Rio de las Llagas, October 14th: "I sent the corporal downstream with four men . . . . He couldn't reach its mouth because of the abundance of tules."
REFERENCE, PAGE: Moraga, 14, 22

OBSERVER, DATE: Viader, 1810 (August)
LOCATION: San Joaquin River (northern San Joaquin Valley), proceeding south
DESCRIPTION: August 19th: "[A]fter having gone about ten leagues over bad ground and along the edge of the tule swamps we arrived at a lake in the middle of an oak grove where we could neither get to the river nor turn back." August 20th: "We . . . traveled some distance from the river on account of the swamps." August 23rd: "Today, after three and one-half leagues in the same direction and without being able to get near the river on account of the sloughs, flooded land, and swamps, we had to rest on an open plain . . . . Everything we crossed today is low ground, tule swamps and ponds . . . ."
LOCATION: Proceeding south from Merced/Tuolumne Rivers, via Orestimba Creek.
DESCRIPTION: August 24th: "[T]hinking that we were opposite Soledad [Mission] and that the tule swamps and low, flooded territory continued as far as the vicinity of San Miguel, we decided to turn back."
REFERENCE, PAGE: Cook (1960), 258-259 (Father Jose Viader, San Juan Bautista, August 28, 1810)

OBSERVER, DATE: Viader (Moraga expedition), 1810 (October)
LOCATION: Area of San Joaquin and Merced Rivers
DESCRIPTION: October 24th: Trying to reach banks of Tuolumne, "on account of so many sloughs, swamps and ponds we turned back . . . We arrived at another river, the Merced . . . Here is much wood on both banks of the river: oak, live oak, cottonwood, cypress, willow, etc. . . . it was clear that the spring floods cover a great deal of these lands . . ." October 25th: "From here southward there are no more trees, only tules and more tules."
REFERENCE, PAGE: Cook (1960), 260 (Father Jose Viader, Santa Clara Mission, October 28, 1810)

OBSERVER, DATE: Abella, 1811 (October)
LOCATION: Travelling by boat from San Francisco Bay through Delta, up west branch of San Joaquin River
DESCRIPTION: October 17th: "There are various [Delta] islands covered with tule rushes and thickets. At fourteen leagues the rivers begin to form, with tule on the banks. It is sheer swamp, which prevents any landing on firm ground." October 18th: "Everything is tule swamp on each side . . . . the banks are covered with nothing but tule, and so high that one sees nothing but sky, water, and tule . . . There is land but it is flooded." October 19th: "The river keeps on in the same way with its windings, covered with tules . . . ." October 21st: "We . . . stopped at a high spot which had a number of oak trees but was entirely surrounded by tule swamps . . . . [F]rom horseback in the tules, one cannot see well . . . ." October 22nd: "All the tule swamp is impassable . . . . The other [river] . . . runs in the middle of the tule swamps, and in that region nothing can be accomplished unless it be salmon fishing and beaver [trapping] . . . ." October 24th: "The previous night we slept in the tule swamps and the water reached our blankets at the turn of the tide. The whole area is this way for several leagues."
REFERENCE, PAGE: Cook (1960), 261-263 (Arguello, Diario de un registro de los rios grandes, October 15-31)

OBSERVER, DATE: Cabot, 1814 (early October)
LOCATION: Tulare Lake, southeastern area
DESCRIPTION: Lake so extensive that nothing but water and tules could be seen.
REFERENCE, PAGE: Cutter, 205

OBSERVER, DATE: Ortega, 1815 (November)
LOCATION: Kings River area
DESCRIPTION: "In the darkness of the night, along the river and in the tule swamps and thickets it was impossible to catch [the Indians]."
REFERENCE, PAGE: Cook (1960), 267 (Juan Ortega's Diary)

OBSERVER, DATE: Jose Dolores Pico, 1815 (November)
LOCATION: San Joaquin Valley, northwest of Kings River
DESCRIPTION: "We followed our course, coming finally to sleep at a lake at the edge of the tule swamp."
REFERENCE, PAGE: Cook (1960), 269 (Jose Dolores Pico's Diary)

OBSERVER, DATE: Various observers, 1815 (September to November)
LOCATION: San Joaquin Valley, general area of Tulare Lake
DESCRIPTION: To escape punitive expeditions of Spaniards, Indians hid in tule marshes.
REFERENCE, PAGE: Cutter, 208-226

OBSERVER, DATE: Martinez, 1816 (May)
LOCATION: Southern San Joaquin Valley
DESCRIPTION: "This big river [San Joaquin] ends as such in Buenavista Lake or loses itself in ponds and swamps . . . . I was here three days, sending my Indians on sorties through the tule swamps."
REFERENCE, PAGE: Cook (1960), 271 (Fr. Luis Antonio Martinez to Prefect Sarria, San Luis Obispo, May 29, 1816, Alexander S. Taylor Papers, Archbishop's Office, San Francisco, Doc. 489)

OBSERVER, DATE: Arguello, 1817 (April)
LOCATION: Main channel of Sacramento River
DESCRIPTION: Notes terrain favorable to hostile Indians, "because of the very dense thickets and the immense tule swamps, all submerged and covered with water, which have extended as far as we have come."
LOCATION: San Joaquin River, in channel connecting with Sacramento River
DESCRIPTION: "We could not get out of the boat because everywhere was a swamp."
REFERENCE: Cook (1960), 276-279 (Letter of L.A. Arguello to Governor Pablo Vicente de Sola, San Francisco, May 26, 1817)

OBSERVER, DATE: Duran, 1817 (May)
LOCATION: Sacramento River (Duran unsure as to which channel)
DESCRIPTION: May 14th: "We landed on a small island of tule which at high tide was covered with water . . . ." May 20th: "One may come to this place by land in the dry season, to judge by appearances, because, although one sees tule-patches in the vicinity, it seems that in October everything must be dry, for there is no water except the floods from the river." May 23rd: "During the night we passed on our right the village of the Nototemnes . . . they used to live almost in the center of the tule region." May 24th, at the mouth of the San Joaquin River: "[I]n all that part which we have travelled there is nothing but tule, without a tree under which the navigator may find shade, nor a stick of firewood . . . whereas the Sacramento, when it is not flooded, has dry land on both banks covered with poplar groves . . . ."
REFERENCE, PAGE: Chapman, 333-349

OBSERVER, DATE: Estudillo, 1819 (October-November)
LOCATION: San Joaquin Valley
DESCRIPTION: From summit of hill looking east into San Joaquin Valley, October 22nd: "[A] great plain of tulares. The view from south to north is beautiful, for its end can not be seen with its lakes, swamps, and groves of trees." Leaving Tontache rancheria, October 30th: "We took routes to the east, northwest and south because of the many arroyos, tule-filled lakes, and sloughs of muddy water which there are in this great Roblar." Kings River area, November 4th: "With much trouble we passed four sloughs full of water and tules, and so sticky that finally Ygnacio Sola's horse could not get out, and he and his munitions got wet all over. The swamp which I crossed today is very miry, having crossed four times today a slough full of mud and water in the same swamp." Heading north along San Joaquin River, November 7th: "The journey made today has been 12 leagues through the middle of marshes, tulares, willow thickets, and sloughs."
REFERENCE, PAGE: Gayton, 69-81

OBSERVER, DATE: Amador, 1820
LOCATION: Village of the Cosumnes
DESCRIPTION: "We killed 8 or 10 of the natives. The rest went for a big tule swamp and escaped."
REFERENCE, PAGE: Cook (1962), 196 (Jose Maria Amador: Memorias sobre la Historia de California, p. 15)

OBSERVER, DATE: Arguello, 1824
LOCATION: Southern (?) San Joaquin Valley
DESCRIPTION: "[T]he local terrain . . . consists of a swamp, or tule marsh, boggy and impenetrable to our cavalry . . . [The Indians'] favorite food consists of fish, plant growth, tule roots and various fresh water shell fish such as clams, which these lakes and swamps produce in great abundance . . ."
REFERENCE, PAGE: Cook (1962), 154 (Letter from Arguello to Minister of War and Navy, dated June 11, 1824, at Monterey)

OBSERVER, DATE: de la Portilla, 1824 (June)
LOCATION: Tulare Valley
DESCRIPTION: "I established the camp at the edge of the marsh, while the horses grazed on the green tule in the vicinity."
REFERENCE, PAGE: Cook (1962), 155 (Pablo de la Portilla: Report of the expedition to the tulares in pursuit of the rebel mission Indians, Santa Barbara, June 27, 1824, Calif. Arch. [Dept. State Papers, t. I] 27:41-45)

OBSERVER, DATE: Pico, 1826 (January)
LOCATION: Area of Kings and San Joaquin Rivers
DESCRIPTION: January 1st: "I followed my route to the east and penetrated into the interior of the tule swamps to the point where we were to remain and meet [the two guides]. But we were unsuccessful, because the night was dark and there were several sloughs across which no passage could be found." January 14th: "The soldiers brought me word of finding the tracks of horses, but the latter went into a muddy swamp, filled with brush and tules. Thereupon I . . . found there was no possibility of catching the horses." January 19th: "We followed the same direction and traveled about 9 leagues until we got into the tule swamps near the village of the Taches." January 20th: "I tried as best I could to get to an island in Lake Bubal but it was impossible to do it because the stream which we had to cross was exceedingly deep, and there were many swamps impassable for the horses." January 22nd: "[W]e arrived where [the village of Bubal] was located in an isolated spot in the interior of the tule swamps. This village must be almost a league from the lake shore . . . ."
REFERENCE, PAGE: Cook (1962), 181-184 (Report composed by Sergeant Jose Dolores Pico, of the expedition which he made as arranged by Citizen and Commander Jose Estudillo, and carried out from December 27, 1825 to January 31, 1826)

OBSERVER, DATE: Rodriguez, 1828 (April-May)
LOCATION: Area of Buena Vista Lake
DESCRIPTION: April 24th: "The party . . . bogged down in some very miry tule swamps." May 2nd: "I set out for the San Joaquin River, which I found much more flooded, and when I went through the tule swamps, with much water and deep mud, several loads fell off."
REFERENCE: Cook (1962), 184-185 (Sebastian Rodgriguez: Diario)

OBSERVER, DATE: Work, 1833 (March-June)
LOCATION: Cache Creek area, en route to San Francisco
DESCRIPTION: March 11th: "[The] road we meant to pursue out in the plain is impassable for the camp on account of lakes and swamps. Where we are encamped is on a small running stream, yet the water bad, of a brackish taste. The road today in places very soft and swampy, not long since it would have been difficult to pass." March 16th: "The road in many places still very soft, and down along the big river is still a chain of lakes."
LOCATION: Suisun Bay
DESCRIPTION: March 28th: "[H]ere the bay is destitute of wood, it has the resemblance of a swamp overgrown with bulrushes and intersected in almost every direction with channels of different sizes and except the want of wood apparently very well adapted for beaver, the people say that beaver are to be found among the rushes."
LOCATION: Vicinity of French Camp Creek
DESCRIPTION: June 26th: "The country a little way to the Westward of us is a continuation of swampy lakes of bulrushes all under water . . . ."
REFERENCE, PAGE: Maloney, 35-39, 61

OBSERVER, DATE: Unknown, 1837 (August)
LOCATION: Central Valley, possibly region of Mokelumne River
DESCRIPTION: Regarding a fugitive Indian: "Up to his neck in water, running around in the swamps, he sank and did not reappear. It was believed that he drowned among the tule roots . . . ."
REFERENCE, PAGE: Cook (1962), 190 (Letter from J.deJ. Vallejo to M.G. Vallejo, dated August 21, 1837, at San Jose)

OBSERVER, DATE: Wilkes, 1841 (August)
LOCATION: Sacramento River Delta
DESCRIPTION: "The Tula [sic] marshes, which are overflowed by the river above, are very extensive, and are said to be the resort of a vast number of beavers . . . ."
LOCATION: Sacramento River in vicinity of American River
DESCRIPTION: "The banks of the [?] river are bordered with marshes, which extend for miles back. This kind of country continues up both the Sacramento and San Joachim, and is the proper Tula district of which so much has been said, and so many errors propagated. Here the tule (Scirpus lacustris) grows in great luxuriance . . . . The tula or bulrush was still found in great quantities, growing on the banks. The Indians use its roots as food, either raw, or mixed with the grass seed, which forms the principle article of their food. This root is likewise eaten by the grisly bear."
REFERENCE, PAGE: Wilkes, 177, 182-183

OBSERVER, DATE: Phelps, 1841 (July)
LOCATION: Proceeding up Sacramento River from Delta
DESCRIPTION: "All the distance [about 20 miles] the banks were low and covered with rush flags or Tules as they are called here."
LOCATION: Area of Sutter's Fort
DESCRIPTION: "The scene of our [hunting] operations was in a long strip of high flags [tule reeds] which commenced near the mouth of the Feather River and extended itself in a belt of about 2 or 300 yards in width and 15 or 20 miles in length running nearly parallel to the Sacramento River at about 1/4 of a mile from the bank, its inner edge at a short distance from the thick woods which border it. This is a favorite resort of the Elk who find rich feed among the flags . . . ."
REFERENCE, PAGE: Briton/Cooper/Busch, 191, 202-203

OBSERVER, DATE: Fremont, 1844 (April)
LOCATION: San Joaquin River, south of Merced River
DESCRIPTION: April 5th: "Over the bordering plain were interspersed spots of prairie among fields of tule (bulrushes), which in this country are called tulares, and little ponds." April 6th: "Columns of smoke were visible in the direction of the Tule Lakes to the southward -- probably kindled in the tulares by the Indians, as signals that there were strangers in the valley."
REFERENCE, PAGE: Fremont (1887), 358

OBSERVER, DATE: Bryant, 1846 (September-October)
LOCATION: Southern Mokelumne River, en route to San Joaquin River
DESCRIPTION: September 15th: "Large tracts of land are evidently subject to annual inundations. About noon we reached a small lake surrounded by tule . . . . Passing through large tracts of tule we reached the San Joaquin river at dark . . . ." September 16th: "We passed during the afternoon several tule marshes, with which the plain of the San Joaquin is dotted. At a distance, the tule of these marshes presents the appearance of immense fields of ripened corn. The marshes are now nearly dry, and to shorten our journey we crossed several of them without difficulty. A month earlier, this would not have been practicable."
LOCATION: Delta of Sacramento and San Joaquin Rivers
DESCRIPTION: October 24th: "These sloughs [of the rivers] wind through an immense timbered swamp, and constitute a terraqueous labyrinth of such intricacy, that unskilful and inexperienced navigators have been lost for many days in it, and some, I have been told, have perished, never finding their way out."
REFERENCE, PAGE: Bryant, 301-302, 343

OBSERVER, DATE: Farnham, 1840-1847
LOCATION: San Joaquin Valley
DESCRIPTION: "There are very many swamps or marshes here filled with tules, a large rush, ten or twelve feet high, and from one to two inches in diameter, having a bulbous and branched root, eight or ten inches long, and six or eight in diameter . . . . On the western side of the mouth of the San Joaquim [sic], there is a vast tract of marshy land, and some hundreds of low islands in the Upper Bay, which are saturated by the tides . . . . [T]his low surface . . . yields an immense growth of rushes."
REFERENCE, PAGE: Farnham, 328-329

OBSERVER, DATE: Sutter, 1847 (November 27)
LOCATION: West side of Sacramento River near mouth of American River (New Helvetia or Sutter's Fort).
DESCRIPTION: "The Tular on the left bank of the Sacramento in fire."
OBSERVER, DATE: Sutter, 1848 (January 29)
DESCRIPTION: "A pleasant day, great fire in the Tule on the other side."
REFERENCE, PAGE: Sutter, 97,112

OBSERVER, DATE: Fremont, c. 1847
LOCATION: Area of Tulare Lake
DESCRIPTION: "This [river] is the principal affluent to the Tulare lake, (the bullrush lake,) a strip of water, about 70 miles long, surrounded by lowlands, rankly overgrown with bullrushes, and receiving all the rivers in the southern end of the valley."
REFERENCE, PAGE: Fremont, 17

OBSERVER, DATE: Carson, 1846-1852
LOCATION: San Joaquin Valley
DESCRIPTION: "The Mariposa, Chowchilla and Fresno Rivers may be classed with the Calaveras, being running streams during the rainy season and spring only. These streams do not enter directly into the San Joaquin, but their united waters form the immense tule marsh between the bend of the San Joaquin and the mouth of the Merced; the water thus collected enters in the San Joaquin at many different points during high water . . . . The Mariposa . . . continues its course towards the marsh but the waters of them sink to such a degree, that the branches can be stepped across where they enter the tule marsh."
LOCATION: Slough connecting Tulare Lake and San Joaquin River
DESCRIPTION: "The tules at the lower end of the lake are some fifteen miles in width; the water of the lake oozes out through this for miles, and then, owing to the height of the lake above the slough, the water begins to gather into small sloughs; and these, running to a common centre, form near the other edge of the tules the lake slough. Where the slough leaves the tules, there is a fall of near five feet, and the water runs rapidly for a distance of nearly a mile. The writer made three attempts to enter the lake in a whale boat, but did not succeed in getting over three miles into the tules, owing to the slough spreading into hundreds of small branches, too narrow and swift to get a boat through."
REFERENCE, PAGE: Carson, 85, 92-93

OBSERVER, DATE: Anonymous, 1848
LOCATION: Proceeding up the San Joaquin River to Stockton
DESCRIPTION: "The tall tules gave a weird and rustling sound. Occasionally an opening would be found which had been burned off by Indians to get at the elk, which frequented them in large numbers. We often caught sight of them as they would trot off with their heads erect into the dense growth of standing tule . . . . The next night we tied up in close proximity to one of the great tule fires, the light of which I had seen reflected from the clouds while in San Francisco. At that time of the year the waters had become comparatively dry, and the tules, with other vegetation, made a brilliant flame, lighting up the country for miles around -- everything had to flee before it; great numbers of owls were hovering around watching for some luckless bird or small animal which they might devour."
REFERENCE, PAGE: Anonymous, 5

OBSERVER, DATE: Hittell, 1848
LOCATION: Sacramento River
DESCRIPTION: "[T]hose who sailed up and down the Sacramento River below Sacramento could see all along on both sides of the stream, instead of cultivated orchards, gardens and farms as now, very little but brushy borders and grassy wastes, covered with droves of elks. The earliest gold-miners, who went up the river from San Francisco in 1848, used to amuse themselves at times by setting fire to the dry brush and watch the broad flames as they swept and crackled along in the direction of the breeze."
REFERENCE, PAGE: Hittell, 865

OBSERVER, DATE: Lyman, 1848 (June)
LOCATION: Entering San Joaquin plain from area of Livermore
DESCRIPTION: June 8th: "Two or 3 miles on entered the plain of the San Joaquin. Passing up stream several miles over an almost barren and heated plain we came to the Tulares now overflowed with water, skirted these some miles . . . halted to dine & rest at a slough or deep channel setting out from the river."
REFERENCE, PAGE: Teggart, 261

OBSERVER, DATE: Johnson, 1849
LOCATION: Sacramento Valley
DESCRIPTION: "[W]e saw on either hand immense tulare marshes stretching as far as the eye could see. These marshes abound in the valley of the Sacramento, often covering fifty miles in circumference. The tule is a kind of rush, but grows higher and thicker than our common rush, and at this season of the year, "green grow the rashes O," throughout the whole of the extensive plains bordering on these rivers. In the Autumn before the rains, or in Spring before growing up again, they are frequently set in a blaze from the camp fires of the Indians or others, causing most extensive and long-continued conflagrations. The flames from one of these illumined the sky all the previous night, forming an immense volume of fire by night, and of smoke by day . . . . Gazing toward the coast range . . . we beheld . . . the river with a green, waving border of new-grown tule."
REFERENCE, PAGE: Taylor, 110-111

OBSERVER, DATE: Taylor, 1849 (September?)
LOCATION: Area of Livermore Pass, looking east into San Joaquin Valley
DESCRIPTION: "At least a hundred miles of [the plain's] surface were visible, and the hazy air, made more dense by the smoke of the burning tule marshes, alone prevented us from seeing the snowy outline of the Sierra Nevada." At a ferry on the San Joaquin River: "[W]e launched into another plain, crossed in all directions by tule swamps, and made towards a dim shore of timber twelve miles distant."
REFERENCE, PAGE: Taylor, 73, 75

OBSERVER, DATE: Grimshaw, c. 1849
LOCATION: Steamboat [Merritt's] Slough
DESCRIPTION: "At night the tule west of the Sacramento would sometimes be burning and the elk & deer running affrighted before the fire would make a rumbling like distant thunder."
REFERENCE, PAGE: Kantor, 11

OBSERVER, DATE: Derby, 1849 (September)
LOCATION: Sacramento Valley
DESCRIPTION: September 22nd, junction of American and Sacramento Rivers: "A small field of tule commences with the Dry creek, extending nearly to the Sacramento. Upon the commencement of the rainy season the soil upon this plain greedily absorbs the water, and in a few days becomes a thick, tenacious quagmire, which it is difficult, not to say dangerous, to attempt crossing, even with pack-animals. The tule at this time is preferable for crossing, as its thickly-interlaced roots, until thoroughly saturated with water, continue elastic, affording for some days a safe passage to terra firma."
REFERENCE, PAGE: Farquhar (1932a), 108

OBSERVER, DATE: Derby, 1849 (October)
LOCATION: Sacramento Valley
DESCRIPTION: October 24th: "Near its mouth [Butte Creek] widens to about 600 feet, the ground in the vicinity being marshy and covered with tule, and the banks difficult of access on account of the density of the alders and grapevines with which they are lined . . . . The 'tule' swamps do not extend far above 'Butte Creek;' there are but two or three isolated marshes of this description on the west bank of the Sacramento and Feather rivers and their branches." October 31st: "The whole country between [Putah and Cache Creeks] is liable to overflow, and is very dangerous to attempt travelling after a heavy rain. The 'Tule' swamp, upon the western bank of the Sacramento, extending to the vicinity of 'Butte' Creek, and occurring occasionally above, is from three to six miles in width, and is impassable for six months out of the year."
REFERENCE, PAGE: Farquhar 1932a, 115-118

OBSERVER, DATE: J.W. Audubon, undated (1849-1850)
LOCATION: San Joaquin River, Tulare Valley
DESCRIPTION: "Following down the San Joaquin southwest and west, we came to the river of the lakes . . . but were so impeded in our progress by the bull-rushes that we turned aside . . . . This is the locality from which, I suppose, the valley takes its name, 'tulare' meaning 'rush', this plant taking here the place of all others."
LOCATION: Area of Sutter's Fort
DESCRIPTION: "The swampy neighborhood, bad atmosphere, and malarial conditions must render this section of the country unhealthy of a great degree for half the year; for as autumn comes on the daily supply of freshly-melted snow-water from the mountains will no longer purify the lagoons and bayous of the vicinity."
REFERENCE, PAGE: J.W. Audubon, 184, 234

OBSERVER, DATE: Lyman, 1850 (May)
LOCATION: Vicinity of Suisun Bay and mouth of San Joaquin River
DESCRIPTION: May 5th: "Running [survey] lines up the river & Ulpino creek, wet & swampy. Immense rush marshes extending out of sight towards the N.W."
REFERENCE, PAGE: Teggart, 293

OBSERVER, DATE: Ringgold, 1849-1850
LOCATION: West Fork of Sacramento River
DESCRIPTION: "On the west, the waters terminate and waste themselves in swamps and mud flats."
REFERENCE, PAGE: Ringgold, 39

OBSERVER, DATE: Derby, 1850 (April-May)
LOCATION: Tulare Valley
DESCRIPTION: April 30th: "We were unable to get close to the water [of Tulare Lake], in consequence of the tule which environed it, extending into the lake from two hundred yards to one-fourth of a mile, as far as the eye could reach. With a glass I could distinguish the timber at the north and the tule at the south ends of the lake, the length of which I estimated at about twenty miles, but we could not distinctly make out the opposite or eastern shore." May 3rd: "This . . . [southern Tulare Lake bed] is little more than a very extensive swamp, covering the plain for fifteen miles in a southerly direction, and is about ten in width. It is filled with sloughs and small tule lakes, and is of course impassable except with the assistance of boats or rafts. The gradual receding of the water is distinctly marked by the ridges of decayed tule upon its shore, and I was informed, and see no reason to disbelieve, that ten years ago it was nearly as extensive sheet of water as the northern lake, having been gradually drained by the connecting sloughs, and its bed filled by the encroachments of the tule." May 7th: "[T]he banks [of the San Pedro River] are swampy near the lake, and for a long distance in the plain, the tule running up to within five miles of the hills." May 9th: "Three large sloughs also make out from [Kern River] near its mouth and form an extensive swamp in the plain upon the north bank of [Buena Vista] lake . . . . Like the other bodies of water in the valley it is nearly surrounded with tule . . . ." May 18th: "[Kings River] forms five sloughs like the Frances, but they are much wider, and the country between them is swampy and difficult of access." May 20th: "The whole country for forty miles in extent in a southerly direction by ten in width, between the San Joaquin river and the Tache lake, is, during the rainy season and the succeeding months until the middle of July, a vast swamp everywhere intersected by sloughs, which are deep, miry and dangerous."
REFERENCE, PAGE: Farquhar (1932b), 252-261

OBSERVER, DATE: Gibbes, 1850 (May)
LOCATION: Upper San Joaquin River
DESCRIPTION: "[I have] been engaged for some months in exploring the different channels and sloughs . . . which spread through the vast tule flats for thirty miles above the mouth . . . . I could see timber on the river . . . but could find no communication through, until we ran the boat over the tule (which was overflown) . . . . [W]e also saw . . . several grisly bears and numerous herds of elk . . . [that] when alarmed rush into the tule, where the plunging of such herds of large animals makes a tremendous roar that can be heard for some distance . . . . [T]he banks would have to be leveed, which . . . would not answer as a general thing to confine in the channel the immense body of water that now spreads over the tule . . . . As near as I can judge, the tule land in the upper part of this tract is from 2 to 5 feet lower than the banks of the river, and when the water is high most of the small slues [sic] afford fine water power. I have seen the water in some of them a foot lower than the river, and rushing in like a mill stream; these discharge into small lakes or spread out in the tule, and are drained off by the slues, below which, although they may look large enough for a river . . . only headed in the tule, having a depth of 2 or 3 fathoms nearly to the head, and I have seen several boats in the wrong river or slues, coming up to Stockton."
REFERENCE,PAGE: Gibbes

OBSERVER: G. Gibbs, 1851 (August)
LOCATION: Clear Lake and Putah Creek
DESCRIPTION: On August 17, "...striking the lake, our trail ran through the tule marshes which border its western side to camp." Describing the tule that Indian canoes are made from, "Their canoes, or rather rafts, are made of bundles of the tule plant, a gigantic bulrush, with a round, smooth stem, growing in marshy grounds to the height of ten or twelve feet." On August 19, describing Clear Lake, "Its waters empty by an outlet into Cache creek; a stream which heads in a high peak to the northward, and runs, towards the Sacramento, losing itself in a tule swamp nearly opposite the mouth of the Feather river." Describing Putah Creek, "...Putos creek or the Rio Dolores...heads to the south-west and runs nearly parallel to Cache creek towards the Sacramento, loosing itself, like the former, in a swamp, except during the rainy season." Describing Clear Lake, "....with the lake and its green margin of tule in front..."
REFERENCE: Gibbs, 106-109

OBSERVER, DATE: Williamson, 1853 (July)
LOCATION: San Joaquin Valley, area of Elkhorn to Grayson's ferry
DESCRIPTION: "I mounted to the summits of several of the hills. On nearly alll sides there seemed to be no limit to their succession; one rounded outline was seen beyond another far into the distance, and all were of the same brown or yellow hue, without a green tree or shrub. But looking eastward, towards the San Joaquin, a far different view was presented. There lay outstretched the broad and green Tulares -- great swamps or lowlands overgrown with rushes and threaded by the sinuous channels and sloughs of the river . . . The lower portion of the San Joaquin river is bordered by numerous sloughs, and winds about through low marshy ground, covered with rushes and willows. Such portions of these marshes as are only temporarily overflowed, during the winter months, support a growth of coarse grass and other plants . . . The number and intricacy of the winding sloughs and channels that traverse this wide area of low marshy land is worthy of notice . . . . The whole included area may be regarded as the alluvium of the Sacramento and San Joaquin rivers, and as an extensive interior delta."
REFERENCE, PAGE: Williamson, Part II, 10

OBSERVER, DATE: Williamson, 1853 (July)
LOCATION: Tulare Valley
DESCRIPTION: "The banks of [Tulare Lake] and of [Kern and Buena Vista Lakes] are low and marshy, and in most places are covered with a dense growth of rank grass and tule. This forms a wide green margin about a portion of the principal lake, and the growth is so luxuriant and the ground so soft that it is almost impossible to reach the water. The width of this belt of green tule is variable . . . in some places it is over three miles . . . It is like our large bulrushes in its form, but grows to an enormous size, attaining a height of from 8 to 15 feet, and sometimes a diameter of three-quarters of an inch. This plant occupies the ground to the exclusion of other forms of vegetation; there are no shrubs or trees to overshadow it, and it constitutes a remarkable feature of the vegetable physiognomy of California."
REFERENCE, PAGE: Williamson, Part II, 191-192

OBSERVER, DATE: Kip, 1854 (February)
LOCATION: San Joaquin River, en route to Stockton
DESCRIPTION: "I found the scenery the same as that of the Sacramento River, -- broad meadows covered with tules, and the river winding tortuorusly . . . . The whole scenery below Stockton -- meadows covered with rank, luxurious vegetation -- reminded me vividly of the Pontine Marshes. Formerly, they were tenanted by herds of elk, which were often lassoed by the native vaqueros, but the increasing population has driven them farther into the recesses of the country . . . . [I]nnumerable large gray squirrels and flocks of water fowl find their hiding places in the weeds and tall reeds."
LOCATION: San Joaquin River, returning from Stockton
DESCRIPTION: "[A]s long as I remained on deck, the scenery around was lighted up by fires. The dry tules which cover the marshes are thus burned over every season. Any accident which starts the fire -- the carelessness of a party camping out, or even the sparks from a passing steamer, begins a conflagration which spreads over a wide extent of the country."
REFERENCE, PAGE: Kip, 115-119

OBSERVER, DATE: Hutchings, 1850's (published 1860)
LOCATION: San Joaquin Valley
DESCRIPTION: "An apparently interminable sea of tules extends nearly one hundred and fifty miles south, up the valley of the San Joaquin; and when these are on fire, as they not unfrequently are, during the fall and early winter months, the broad sheet of licking and leaping flame, and the vast volumes of smoke that rise, and eddy, and surge, hither and thither, present a scene of fearful grandeur at night, that is suggestive of some earthly pandemonium."
REFERENCE, PAGE: Hutchings, 30-31

OBSERVER, DATE: Flint, 1860
LOCATION: Sacramento and San Joaquin Valleys
DESCRIPTION: "The tule lands in the district where the rivers disgorge into the bay, are subject to tidal overflows, and the annual floods have no great effect on them . . . . [T]he tule lands west of the Sacramento river . . . are covered in the winter and spring from the waters of Putah, Cache, and other creeks coming in from the coast range . . . . Formerly the Sacramento river contributed to the result, but farms being opened all along its banks, the small sloughs, which at high water discharged a portion of the surplus into the tule, have been closed up, so that none of its waters now go upon the tule, as is evident from the clear condition of the water in the tule, the Sacramento river being highly discolored the entire year from the effects of mining . . . . [T]he tule lands . . . on the eastern side of the rivers . . . receive an annual deposit of slum, brought down by the rivers, which pour in upon them the sedimentary earths set loose from a thousand hill-sides in the mining districts, and are in a rapid transition from muck-beds to alluvial bottoms . . . . [F]or this [reclamation], two kinds of [cultivated] grasses, red-top and blue joint, are especially adapted, as each, aided by the sedimentary deposit, rapidly supplants the tule."
REFERENCE, PAGE: Flint, 109-112

OBSERVER, DATE: Brewer, 1861 (October)
LOCATION: San Joaquin Valley
DESCRIPTION: "The San Joaquin . . . plain lies between the Mount Diablo Range and the Sierra Nevada -- a great plain here, as much as forty to fifty miles broad, desolate, without trees save along the river, without water during nine or ten months of the year, and practically a desert. The soil is fertile enough, but destitute of water, save the marshes near the river and near the Tulare Lake. The marshy region is unhealthy and infested with mosquitoes in incredible numbers and of unparalleled ferocity."
REFERENCE, PAGE: Brewer, 202-203

OBSERVER, DATE: Brewer, 1861 (November)
LOCATION: Area of Sebastopol, looking toward Delta
DESCRIPTION: "The swamps bordering all the rivers, bays, or lakes are covered with a tall rush, ten or twelve feet high, called 'tule' . . . which dries up where it joins arable land. On the plain below camp, fire was in the tules and in the stubble grounds at several places every night, and in the night air the sight was most grand -- great sheets of flame, extending over acres, now a broad lurid sheet, then a line of fire sweeping across stubble fields. The glare of the fire, reflected from the pillar of smoke which rose from each spot -- a pillar of fire it seemed -- was magnificent. Every evening we would go out and sit on a fence on the ridge and watch this beautiful sight, some nights finer than others."
REFERENCE, PAGE: Brewer, 219-220

OBSERVER, DATE: Brewer, 1862 (July)
LOCATION: Area of Suisun Bay
DESCRIPTION: "North of the marsh that skirts the bay for some miles is a very rich agricultural region, teeming with grain."
REFERENCE, PAGE: Brewer, 293

OBSERVER, DATE: Brewer, 1863 (April)
LOCATION: Fresno City
DESCRIPTION: "[Fresno City] is surrounded by swamps, now covered with rushes, the green of which was cheering to the eye . . . . These swamps extend southeast to Tulare Lake . . . . [O]ur animals had to content themselves with eating the coarse rushes that grew on the edges of the swamp. The cattle and horses that live on this look well."
REFERENCE, PAGE: Brewer, 379

OBSERVER, DATE: Leale, c. 1867
LOCATION: Sacramento River area
DESCRIPTION: "All the river farms were bank land. The back land, which is now entirely cultivated, was then all tule and small lakes."
REFERENCE, PAGE: Leale, 37

OBSERVER, DATE: Leale, 1876
LOCATION: Mokelumne River
DESCRIPTION: "Navigation was pretty bad in the fall of the year for the reason that there was much burning of peat land which caused dense smoke."
REFERENCE, PAGE: Leale, 65

OBSERVER, DATE: Cone, 1870's (published 1876)
LOCATION: San Joaquin Valley
DESCRIPTION: ""[T]here are . . . three millions of acres from which the water is to be drained before it can be used for agricultural purposes. This land consists in part of marsh land contiguous to the bay and its estuaries, and in part of tule lands which border the San Joaquin and Sacramento rivers, and extend through a considerable part of both valleys, forming a strip varying in width at a greater or lesser distance from the river . . . . [T]here is another class of lands which is peculiarly a California possession. These are the tule lands, so called from the only product of the soil -- the tule . . . . The tule is a species of bulrush, and judging from the size it must be the great father of all the bulrushes. It grows from six to ten feet high; occasionally one more enterprising than its compeers attaining the altitude of ten feet. The tule is straight as an arrow, and without joints or leaves or any appendage except upon the very summit, which is crowned with a head not unlike that upon the sorghum, only upon a reduced scale. These tules grow so luxuriantly and thickly on the rich, swampy land that neither man nor beast can make a way through them; they must be trodden down and made into a sort of pontoon bridge and walked over. During the fall or early winter they are often burned. The fires made by the burning tule can be seen miles away, looking not unlike the fires on the prairies, except that the volume of smoke is greater and of a more tartarean color . . . . There is a belt of these tule lands reaching all the way from Kern Lake to the Upper Sacramento. These, like the swamp lands, are wonderfully productive when reclaimed."
REFERENCE, PAGE: Cone, 110-112

PART II - CURRENTS AND SALINITY

OBSERVER, DATE: Crespi, 1772 (March)
LOCATION: Carquinez Strait
DESCRIPTION: March 29th: "The bed of the estuary is very deep and its shores precipitous; on its banks we did not see so much as a bush; and the water was so still that it seemed to have no current . . . . After following the course of this estuary for six leagues, we observed that the water had a current towards the round bay, and that it made some foam, which, we observed, lasted but a short space."
REFERENCE, PAGE: Bolton (1926), 343-344; Galvin, 111-112

OBSERVER, DATE: Crespi, 1772 (March)
LOCATION: Carquinez Straits to mouth of Delta
DESCRIPTION: The following are reported in a legend to a map: In Carquinez Straits, "...currents were observable and a tide-rip in the water. About ten leagues further northward from that bay [San Pablo], in the course of the day's travel on March 29th, the water of the inlet [location uncertain, but probably somewhere in Suisun Bay] was tested and was quite fresh." Near the mouth of the rivers, "Here the channel of the inlet, divided in two branches a good quarter of a league wide, formed an island. We were then in 39 13' north latitude and at the furthest point reached. The water was without currents, as if held in a still pool; it appeared to be very deep; and, as tested, was fresh and very palatable."
REFERENCE, PAGE: Galvin, 123

OBSERVER, DATE: de Canizares, 1775 (August)
LOCATION: Bahia Redondo (San Pablo Bay)
DESCRIPTION: "After a careful examination of its shore, I did not find any fresh water or any signs of it."
LOCATION: Suisun Bay
DESCRIPTION: "[Carquinez Straits] enters another bay with a depth of thirteen brazas, diminishing to four where some rivers empty and take the saltiness of the water which there becomes sweet, the same as in a lake."
REFERENCE, PAGE: Eldredge/Molera, 66-67; Galvin, 96-97

OBSERVER, DATE: de Canizares, 1776-1781(?)
LOCATION: Chipps Island to Antioch/Collinsville
DESCRIPTION: This map is dated 1781. It may be based on a map drawn by Canizares after the September 1776 expedition to the Delta (Wagner,179). However, notations on the map archived in Madrid suggest it may reflect conditions during a later expedition. The map shows Chipps, Van Sickle, Hammond, Browns, Winter, and Sherman Islands and locates freshwater by a keyed legend. The first five listed islands are labeled: "low islands in fresh water." A point upstream from Antioch in the main channel of the San Joaquin is labeled: "fresh water among beds of bulrushes."
REFERENCE: Wagner, 179-180; Galvin, 104

OBSERVER, DATE: Font, 1776 (April)
LOCATION: Suisun Bay
DESCRIPTION: "As soon as we arrived at the shore of the water we began to doubt that it was a river, because we did not see that it had any current, nor did the water have any more movement than that which we observed at the mouth of the port of San Francisco, where we noted a very gentle and inconspicuous motion, caused no doubt by the tide . . . . [T]hese banks are without any signs of floods . . . . This [Suisun Bay] is . . . a gulf of fresh water . . . . By the way [the Indians] anchored [their boat] I was confirmed in the suspicion or opinion which I had already formed that the water had no current toward the bay . . . . I estimated that the water would be some nine or ten varas deep, noting at the same time that it is very quiet and placid . . . . [The Indians] went to the other side of the water with great ease, steadiness and rapidity, and only in the middle did we see that they used their oars a little. Now, they landed on the opposite side a good distance above the place from which they had set out on this side; whereas it appears the contrary would have been the case if the water had a current, for it is natural that if the water ran toward the bay, even though they should row they would come out on the other side below the place whence they set out on this side."
LOCATION: Carquinez Strait
DESCRIPTION: "I tasted the water [of Carquinez Strait] and found it salty although not so salty as that of the sea outside."
LOCATION: Vicinity of Antioch Bridge (banks of San Joaquin River)
DESCRIPTION: "As soon as we halted we went to see the water and to taste it, finding it very clear, fresh, sweet, and good . . . . We saw that it had a slight movement caused by the wind, and that it beat upon the shore or beach with gentle waves, but we did not see any current whatever. In order to find out whether or not it had any, the commander took a fair-sized log which ended in a knob and threw it in the water with all the force he could muster. In a short time we saw that instead of floating downstream, the water with its little waves returned it to the shore, and I may note that, according to what we saw afterward, the tide was falling at this time. On the beach there was no driftwood from the foods nor any debris except a little dry tule. About an hour passed and we returned to see the water, and we noted that a good strip of beach had become uncovered and that the water had fallen about two feet, judging from the uncovered trunks of some trees on the shore which formerly we had seen submerged. From this we inferred that the water had its ebb and flow like the sea, and that at this time the tide was falling."
REFERENCE, PAGE: Bolton (1931b), 369-397

OBSERVER, DATE: Anza, 1776 (April)
LOCATION: A hill east of Antioch
DESCRIPTION: April 3rd: "[The Indians] were on the banks of the river, whose water we tasted, and it was now very fresh, but we noted that it was changeable . . . . [W]e noticed . . . that the river we had thought would turn to the east, continued to the east-northeast, and that from here upstream it appeared to us to be more like a large lake than a river. This impression was supported by the fact that up to now we had not seen the current which was reported on the first journey, and that the water appeared to have an ebb and flow, and also by the fact that we had not found any flotsam, and that the surf continued."
LOCATION: San Ricardo, near site of Antioch Bridge
DESCRIPTION: April 3rd: "As soon as we halted we went to the bank of the river, and threw logs into it, the largest possible, and instead of carrying them away the river returned them to the place where we were. We still noted a surf in the river. And having set up stakes at the edge of the waves we observed that from half-past five in the afternoon until a quarter past ten, sixteen and one-half yards of beach were uncovered, and that the water fell three and a quarter yards."
REFERENCE, PAGE: Bolton (1930), 144-145

OBSERVER, DATE: Moraga, 1808 (October)
LOCATION: Feather River
DESCRIPTION: "They have measured this river at 169 varas across, and uniformly from one shore to the other a vara and a half deep . . . . According to indications, it can be seen that in times of freshets or floods the overflow of the river extends 1-1/2 leagues eastward and about 1 league to the northwest."
LOCATION: Sacramento River, Butte City area
DESCRIPTION: October 11th: "[The river] must be from 25 to 30 varas wide and very deep; there is scarcely any current, and both sides of the river have steep banks."
REFERENCE, PAGE: Moraga, 18-19, 21

OBSERVER, DATE: Viader, 1810 (August)
LOCATION: San Joaquin River, after proceeding east from Walnut Creek
DESCRIPTION: August 18th: "At seven leagues we came to the San Joaquin River, or, as it is called the River of the Tulares. It is about a quarter of a league wide, and apparently very deep. It is reached by the tides of the sea."
REFERENCE, PAGE: Cook (1960), 258 (Father Jose Viader, San Juan Bautista, August 28, 1810)

OBSERVER, DATE: Viader (Moraga expedition), 1810 (October)
LOCATION: Area of San Joaquin and Merced Rivers
DESCRIPTION: October 25th: "The Merced River, it seems to me, cannot be dammed, not only because the soil is pure sand, but because it is now confined between very close banks. I can say the same of the other stream, the San Joaquin, and furthermore the bottom is so level that the current is very slow, even though the water is deep."
REFERENCE, PAGE: Cook (1960), 260 (Father Jose Viader, Santa Clara Mission, October 28, 1810)

OBSERVER, DATE: Abella, 1811 (October)
LOCATION: Travelling by boat from San Francisco Bay through Delta, up San Joaquin River, down Sacramento River, thence returning to San Francisco
DESCRIPTION: Passing through Suisun Bay, October 17th: "Gradually from here the water becomes sweet." October 26th, entering the Sacramento River through Steamboat Slough, found double amount of water, "seven varas deep and 400 wide. From here downward [the river] seems like an arm of the ocean, for the land becomes lower and at the meeting point of the sea and the other river the current is brought to a standstill." October 29th (returning to San Francisco): "We . . . arrived at Carquinez Strait by sunrise. The section we traversed this morning is a large bay [Suisun], and before arriving at the Strait the water is already salty."
REFERENCE, PAGE: Cook (1960), 261-265 (Abella, Diario de un registro de los rios grandes, October 15-31)

OBSERVER, DATE: Duran, 1817 (May)
LOCATION: Sacramento River, junction of three channels
DESCRIPTION: May 17th: "[W]e took the said branch to the north . . . . In the whole day we went by four leagues, because the river carries a considerable current. Our course . . . has been northwest, north, and northeast." May 18th: "[W]e set out toward the northeast following the same river. We went a league (which cost us much labor to go, on account of the great strength of the current), and came upon the main stream of the Sacramento which runs from north to south."
LOCATION: Sacramento River (Duran unsure as to which channel)
DESCRIPTION: May 24th (mouth of San Joaquin River): "It is necessary to pass [the mouth] at high tide, because there is a sand-bar, and the launches are blocked by it. There is this difference between the Sacramento and the San Joaquin; the latter carries less volume of water, although in some places it is wider . . . ."
REFERENCE, PAGE: Chapman, 339, 349

OBSERVER, DATE: Duran (reported by Arguello, Diario), 1817 (May)
LOCATION: Travelling by boat up Delta
DESCRIPTION: From San Francisco Bay into Delta, ease of navigation due to high water in sloughs and river systems. Upon reaching main channel of Sacramento River, increasingly difficult navigation due to sailing and rowing against current. Turned back in vicinity of Freeport. Attempting to enter Georgianna Slough, many logs and branches in water -- normally impassable, but navigable only because of high water at this time.
REFERENCE, PAGE: Cutter, 190-196

OBSERVER, DATE: von Kotzebue, 1824 (November)
LOCATION: Pescadores [old channel of San Joaquin?] River
DESCRIPTION: "[W]e continued our voyage up the stream; but it was ebb-tide, and both currents united allowed us to make but little progress . . . . The river flowing as before, from the north, was here a mile broad, and deep enough for the largest ships . . . . On the following morning . . . favoured by wind and tide, [we] sailed swiftly forward in a direction almost due north. The aspect of the river now frequently changed: its breadth varied from one to two and three miles."
LOCATION: Ascending the Sacramento River
DESCRIPTION: "The river now took a northwesterly direction. Its breadth was from two hundred fifty to three hundred fathoms, independently of numerous branches on the east side . . . . The power of the current impeded our progress . . . . Our pilot assured us that at this season the quantity of rain that falls, so much swells the river and strengthens the currents, as to make it impossible to contend with the continually increasing force of the stream."
REFERENCE, PAGE: von Kotzebue, 140, 145-146

OBSERVER, DATE: Coulter, c. 1835
LOCATION: Tulare Valley
DESCRIPTION: "The Tule Lakes are now known not to exceed 100 miles in total length . . . and notwithstanding their many tributaries from the eastward, they discharge, during a considerable portion of the year, very little, if any, water into San Francisco. It is only immediately after the rainy season, which is usually ended in February, and during the thaw of the snow on the high range of hills between the lakes and the great sand plain, that there is any considerable discharge of water from them in this direction."
REFERENCE, PAGE: Coulter, 60

OBSERVER, DATE: Belcher, 1837 (October)
LOCATION: Sacramento River near Rio Vista
DESCRIPTION: "All the trees and roots on the banks aford unequivocal proofs of the power of the flood-streams, the mud line on a tree we measured exhibiting a rise ten feet above the present level, and that of a recent date. At the period of our examination the river was probably at its lowest, and much less than I had anticipated in regard to strength, being at times almost still water."
REFERENCE, PAGE: Pierce/Winslow, 41
DESCRIPTION: "About twenty miles above the <u>Starling</u>'s anchorage we found the water perfectly sweet." [Note: The ship had been anchored in Yerba Buena Bay, then taken thirty-six miles from there up the Delta into the Sacramento River, and left anchored in sufficiently deep water. Therefore, fresh water was found fifty-six miles from its original anchorage or near Rio Vista. Thus, this is a report of salinity intrusion into the Delta.]
REFERENCE, PAGE: Pierce/Winslow, 46

REFERENCE,PAGE: Sutter, 9
OBSERVER, DATE: Sutter, December 1839
LOCATION: Sacramento River
DESCRIPTION: "At the time the Communication with the Bay was very long and dangerous, particularly in open Boats; it is a great wonder that we got not swamped a many times...Once it took me (in December 1839) 16 days to go down to Yerbabuena and to return. I went down again on the 22d xber 39 to Yerbabuena and on account of the inclemency of the Weather and the strong current in the River I need a whole month (17 days coming up)..." [During a great flood.]

OBSERVER, DATE: Phelps, 1841 (July)
LOCATION: San Pablo Bay
DESCRIPTION: "[We] entered the bay of St Pedro with a strong current in our favour . . . ."
LOCATION: Sailing up Sacramento River, passing mouth of San Joaquin River
DESCRIPTION: July 27th: "The tide and wind still favouring us . . . we continued on for about 20 miles." July 28th: "and on the flood tide beginning to make at 5AM, we commenced rowing and sailing up river . . . . The width of the river from 200 yards to a third of a mile." Returning to the Bay, August 6th: "We beat down to the Straits of the Carquines, here meeting the tide of flood."
REFERENCE, PAGE: Briton/Cooper/Busch, 190-192, 214

OBSERVER, DATE: Wilkes, 1841 (August)
LOCATION: Threemile Slough north of Emmaton
DESCRIPTION: "The party . . . proceeded up the stream for the distance of three miles, where they encamped, without water, that of the river being still brackish."
LOCATION: Sacramento River at New Helvetia (Sutter's Fort near Sacramento)
DESCRIPTION: "At this place the Sacramento is eight hundred feet wide, and this may be termed the head of its navigation during the dry season, or the stage of low water."
LOCATION: Travelling down Sacramento River toward Butte Creek
DESCRIPTION: "At the place where the survey ended, the river was two hundred feet wide, its banks being twenty feet above the river; but it was evident that its perpendicular rise exceeded this, as there was every appearance of its overflowing them; and, according to the testimony of the Indians, the whole country was annually inundated. On the afternoon of the 31st of AUgust, the party turned to go down the stream, and with the aid of the current made rapid progress."
REFERENCE, PAGE: Wilkes, 177, 178, 189

OBSERVER, DATE: Phelps, 1842 (March)
DESCRIPTION: Sailing up the Sacramento River
DESCRIPTION: "The current very strong against us, but by keeping close to the shore [we] were enabled to make tolerable progress.....raining hard."
REFERENCE, PAGE: Busch, 275

OBSERVER, DATE: Fremont, 1844 (April)
LOCATION: San Joaquin River, in vicinity of Merced river
DESCRIPTION: April 3rd: "Today we touched several times the San Joaquin River -- here a fine-looking, tranquil stream, with a slight current, and apparently deep . . . . [I]ts average width appeared to be about eighty yards." Continuing south along the San Joaquin, April 4th: "We reached the river again at the mouth of a large slough, which we were unable to ford, and made a circuit of several miles around . . . . The river is about a hundred yards in breadth, branching into sloughs, and interspersed with islands. At this time it appears sufficiently deep for a small steamer, but its navigation would be broken by shallows at low water."
REFERENCE, PAGE: Fremont (1887), 357-358

OBSERVER, DATE: Duvall, 1846 (June)
LOCATION: Travelling up Sacramento River to New Helvetia
DESCRIPTION: June 12th: "Continued our course up the river . . . the men being exhausted from pulling against a four knot current . . . . All day, the river had been very torturous -- here the banks are rather higher (about twenty feet) one hundred yards wide -- the current very rapid."
REFERENCE, PAGE: Rogers, 15-16

OBSERVER, DATE: Bryant, 1846 (late October)
LOCATION: Sacramento River 1 to 2 miles below Rio Vista
DESCRIPTION: "The islands of the Sacramento are all low, and subject to overflow in the spring of the year . . . . The water, at this season, is perfectly limpid, and although the tide ebbs and flows more than a hundred miles above the mouth of the river, it is fresh and sweet . . . . A more beautiful and placid stream of water I never saw....At twelve o'clock at night, the ebb tide being so strong that we found ourselves drifting backwards..."
REFERENCE, PAGE: Bryant, 343-344

OBSERVER, DATE: Bryant, 1846 (September)
LOCATION: Sacramento River near Sutter's Fort (Sacramento)
DESCRIPTION: "The Sacramento river, at this point, is a stream nearly half a mile in width. The tide rises and falls some two or three feet. The water is perfectly limpid and fresh."
REFERENCE, PAGE: Bryant, 271

OBSERVER, DATE: Fremont, c. 1847
LOCATION: San Joaquin Valley
DESCRIPTION: "Only the larger streams, which are fifty to one hundred and fifty yards wide, and drain the upper parts of the mountains, pass entirely across the valley, forming the Tulare lakes and the San Joaquin river, which, in the rainy season, make a continuous stream from the head of the valley to the bay . . . . In June, 1847, the Joaquin was no where fordable, being several hundred yards broad as high up as the Aux-um-ne river, even with its banks, and scattered in sloughs all over its lower bottoms . . . . All the large tributaries, the Aux-um-ne, To-wal-um-ne, Stanislaus, and Mo-kel-um-ne . . . were pouring down a deep volume of water from the mountains, one to two hundred yards wide."
REFERENCE, PAGE: Fremont, 14, 19

OBSERVER, DATE: Derby, 1849 (September)
LOCATION: Junction of American and Sacramento Rivers
DESCRIPTION: September 22nd: "At the time of our crossing the water was quite low, varying from eighteen inches to two and a half feet in depth; but at the commencement of the rainy season it swells rapidly -- three days of heavy rain being sufficient to raise it from four to six feet . . . ."
REFERENCE, PAGE: Farquhar (1932a), 108

OBSERVER, DATE: Derby, 1850 (May)
LOCATION: Tule River, near Tulare Lake
DESCRIPTION: May 7th: "At this time the stream was about one hundred yards wide, from twelve to twenty feet deep, and very rapid, which last is a general characteristic of all the streams to the east of the lake."
LOCATION: Kern River
DESCRIPTION: May 9th: "[W]e arrived . . . upon the north bank of the Kern river, a very broad and deep stream with a current of six miles an hour, which, rising high up in the Sierra Nevada, discharges itself by two mouths into Buena Vista lake near its northern extremity."
LOCATION: Kings River
DESCRIPTION: May 18th: "The Kings river is the largest stream in the valley, at this time about three hundred yards wide, with a rapid current and the water cold as ice."
LOCATION: Attempting to reach slough connecting Tulare Lake with San Joaquin River
DESCRIPTION: "We were engaged on the 21st, 22d, and 23d [of May] in getting through the mire, crossing no less than eight distinct sloughs, one of which we were obliged to raft over, before arriving at the Sanjon. In all of these sloughs a strong current was running southwest, or from the San Joaquin river to the lake . . . . The 'Sanjon de San Jose' is a large and deep slough about forty miles in length, connecting the waters of the Tache lake with the San Joaquin river . . . . At this time it was about two hundred and forty feet in width, and with an extremely slow current setting towards the river."
REFERENCE, PAGE: Farquhar (1932b), 254-260

OBSERVER, DATE: Ringgold, 1849-1850
LOCATION: Rivers of the Delta
DESCRIPTION: "During the winter months, the navigation of the rivers by sailing craft is attended, with more difficulty and delay, than at other seasons. The freshets considerably augment the currents, rendering a resort to kedging and warping often necessary, while the winds are light and irregular."
REFERENCE, PAGE: Ringgold, 41

OBSERVER, DATE: Williamson, 1853 (July)
LOCATION: San Joaquin River, Grayson's Ferry downstream from mouth of Tuolumne River
DESCRIPTION: "At the time we crossed the river the water was not at its lowest stage, the stream being still swollen by the melting of the snow on the peaks of the Sierra Nevada. A large portion of the bottom-land of the river was therefore submerged, and the stream was much broader than is usual in the dry season. The current was swift and strong . . . ."
LOCATION: San Joaquin River at Tulare Lake
DESCRIPTION: "At these periods of high water, the lakes sometimes communicate with the San Joaquin River by a slough or channel at the northern extremity of the Tulare Lake. This slough is like a canal, and is very deep near the San Joaquin, but eight or ten miles from this river it divides up into numerous channels, which become intricate and ramified as they enter the lake. It is said that when the level of the river is greatly raised by freshets it overflows its banks, and the water passes to the lakes by this slough. At seasons of low water, all communication between the river and lake is prevented by a bar at the mouth of the slough . . . . It is very possible that the principal part of [the water of the San Joaquin] was formerly delivered to the lakes."
REFERENCE, PAGE: Williamson, Part II, 11, 192-193

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Appendix C

Additional Evidence in Regards to Freshwater Inflow to San Francisco Bay under Natural Conditions

STATE WATER CONTRACTOR'S REBUTTAL TESTIMONY

ADDITIONAL EVIDENCE IN REGARD TO

FRESHWATER INFLOW TO SAN FRANCISCO BAY

UNDER NATURAL CONDITIONS

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Additional Evidence in Regards to Freshwater Inflow

by

Phyllis Fox

State Water Contractor (SWC) Exhibit 262 estimated freshwater inflow to San Francisco Bay from the Delta under "natural" conditions. These analyses demonstrated that "natural" inflow was substantially less than DWR's "unimpaired" flows. The reason for this is that "unimpaired" flows do not include the high consumptive use of water by tule marshes and riparian forests that were present in the Central Valley under "natural" conditions. This evidence actually shows that the outflow to San Francisco Bay under "natural" conditions was probably less than it has been in recent times.

This document presents evidence that collaborates the estimates of Delta outflow presented in SWC Exhibit 262. It also presents rebuttal to David R. Dawdy's direct testimony on December 9, 1987, and clarifies issues raised during the cross examination of Phyllis Fox on November 23, 1987. The conclusions from the information presented herein are:

1. Eye-witness accounts of salinity intrusion into Suisun Bay and the Delta from 1796 through the 1870's suggest that summer/fall Delta outflows were often a factor of two to five lower than unimpaired flows.

2. Shell remains from 425 Indian middens around San Francisco Bay indicate that the Bay is not substantially saltier today than under "natural" conditions.

3. Fish remains from Indian middens in the Central Valley indicate that the fishery under "natural" conditions was dominated by species characteristic of slow-water environments (e.g., sloughs, lakes, seasonally flooded areas), rather than main river channels with strong currents (i.e., present highly channelized system).

4. The "natural" vegetation in Suisun Marsh is not substantially different from that present today and was dominated by salt-tolerant plants characteristic of salt and brackish marshes, rather than of freshwater marshes. Tules were not reported west of Montezuma Slough. Thus, salinity in Suisun Bay is not substantially different today than it was under natural conditions.

5. Eye-witness accounts support the distribution and extent of tule marshes and riparian forests claimed in SWC Exhibit 262.

6. Ferry-boat captains have recorded significant changes in tides at the Presidio as the upper basins were drained.

7. The consumptive use factors used in SWC Exhibit 262 are consistent with eye-witness accounts of native vegetation, which was reported to grow luxuriantly and densely to sizes over twice that found elsewhere. Climatic adjustments to consumptive use factors extrapolated from Southern California are not required because climatic variables are similar.

1.0 COLLABORATIVE EVIDENCE

If Delta outflow were significantly larger under "natural" conditions than it is today, the Bay should have been fresher. This would have been reflected in benthic fauna and native vegetation from around the Bay. Significant changes in outflow also would have been noticed by river-boat captains who regularly traveled from San Francisco up the major rivers. Eye-witness accounts and archaeological reports were examined for evidence of these types of changes. This information is presented here.

1.1 Salinity Intrusion

Early eye-witness accounts record salinity intrusion far upstream into Delta channels. This information suggests that under "natural" conditions, summer/fall Delta outflows were considerably lower than "unimpaired" outflow and also lower than they are at present.

1.1.1 San Joaquin River Delta

The first notable account of salinity intrusion into the San Joaquin River Delta was made by Hermenegildo Sal, who was an army officer. He commanded an expedition in January 1796 into the Stockton area. The mission records indicate that a state-wide drought was in progress during this period (Lynch 1931). Sal left no personal diary, but he did write a letter to the Governor summarizing his expedition. The letter, dated January 31, 1796, reported that Sal found salt water at high tide in Old River north of Tracy, in Middle River at the southern end of Roberts Island, in the main stem of the San Joaquin River southwest of French Camp, and in the Calaveras River near Stockton (Cook 1960, p.241-242).

This boundary is similar to the limit of salinity intrusion (1000 ppm chloride) into the Delta during the 1931 drought (DWR Exhibit 60). Salt water intruded farther into the Delta in 1931 than at any other time in recorded history. Delta outflow during the 1931 drought was negative, and ranged from -88,000 to -186,000 ac-ft/mo (DWR Exhibit 27g). Thus, during droughts under "natural" conditions, salt water penetrated far upstream into Delta channels much as it did prior to upstream water development. These conditions do not occur today because flows are released from upstream reservoirs to control salinity intrusion into the Delta.

Eye-witness testimony presented in the Antioch trial and summarized by the California Department of Public Works (CDPW 1931b, p.47) indicates that salt water intruded up the San Joaquin beyond Three Mile Slough in the early 1870s. The California Department of Public Works (CDPW) reported that:

> There appears to be no doubt that the water in the San Joaquin River at Antioch became brackish or salty and unfit for domestic consumption during a part of the late summer or early fall months of most years and certainly during dry years, as far back as the sixties and seventies. It is stated that, because of these conditions, many of the residents had cisterns which they filled with fresh clear water immediately after the freshets in June, so that they would have fresh water for use in the later summer and fall months when the water supply became brackish and unfit for drinking, washing and occasionally even garden irrigation. One witness in the trial of the Antioch suit who resided on Twitchell Island testified that the water became brackish and unfit for drinking for certain periods during the early seventies as far up the San Joaquin River as Larsen Landing on Twitchell Island, or above Three Mile Slough."

If 2,000 ppm dissolved solids (about 1,000 ppm chlorides) is taken as the upper limit of potability (Public Health Service 1962, p.33), this would correspond to a Delta outflow of about 3,000 cfs or 180,000 ac-ft/mo during the July to October period. This flow was taken from the graph relating salinity and Delta outflow presented in DWR Bulletin 76 (CDWR 1962, Plate 15). This is considerably lower than the unimpaired flow for this period, which ranges from 357,000 to 970,000 ac-ft/mo (DWR Exhibit 26, p.37).

1.1.2 Sacramento River

Three early accounts of salinity intrusion into the Sacramento River Delta have been recorded. These were summarized and discussed in SWC Exhibit 276 (Fox 1987b, p. 41-43). Two of them do not report fresh water until the vicinity of Rio Vista (Belcher and Bryant). The third one reports brackish water that was not potable in Three Mile Slough in August 1841. This later report would correspond to a Delta outflow of about 2,000 cfs or 120,000 ac-ft/mo.

1.1.3 Suisun Bay

The California Department of Public Works (CDPW) summarized historic salinity conditions in upper Suisun Bay from eye-witness accounts of the early settlers on the marshlands adjacent to Suisun Bay. They reported (CDPW 1931b, p.47-48):

> It is stated that the first levees for the reclamation of these marshlands were started in the early seventies and the salinity conditions in the channels adjacent to these lands were well known by the individuals who developed and utilized these lands. The annual invasion and retreat of saline waters in upper Suisun Bay were observed from the earliest time of this development. Only in a few years of extremely heavy precipitation and run-off of the Sacramento and San Joaquin Rivers did the water remain fresh in the upper part of Suisun Bay during any considerable period of the year.

> Shortly after 1900 it is reported that a tract of land on the southeasterly portion of Grizzly Island was reclaimed by the construction of drains and the leaching out of the salts by diversion of water from Montezuma Slough at a point about three miles below its confluence with the Sacramento River. The leaching operations were conducted over a period of about five or six years whenever fresh water was available in Montezuma Slough. In order to determine whether the water was fresh enough for this purpose samples of the water were taken and analyzed for saline content. It was usually found that fresh water was available in Montezuma Slough at the point of diversion up to about the first of July or not later than the first of August, at which time the salinity of the water became too great to be used effectively for leaching operations. The water remained saline usually until about November or December when the first winter stream freshets occurred.

This material agrees with similar evidence from Indian shellmounds and early reports of vegetation growing in the area and suggests that under "natural" conditions, Suisun Bay was at least as salty and perhaps saltier than it is at present.

1.2 Indian Middens

Shell remains from Indian middens provide an indication of the salinity regime in the Bay under "natural" conditions because benthic species distribution is largely determined by salinity (Packard 1918; Nichols 1979, p.415). Archaeologists that have studied these mounds have concluded that "[i]t may be taken as almost axiomatic that the species in a mound reflect the molluscan fauna of the vicinity, and hence the environment during the period of growth of the mound." (Gifford 1916, p.7)

Shell remains from 425 shellmounds (Fig. 1) around San Francisco Bay (Uhle 1909; Nelson 1909, 1910, 1971; Gifford 1916) suggest that the Bay is not substantially saltier today than it was under "natural" conditions and that Suisun Bay may be fresher today than originally. The shell species reported from these middens are summarized in Table 1. The same species were found

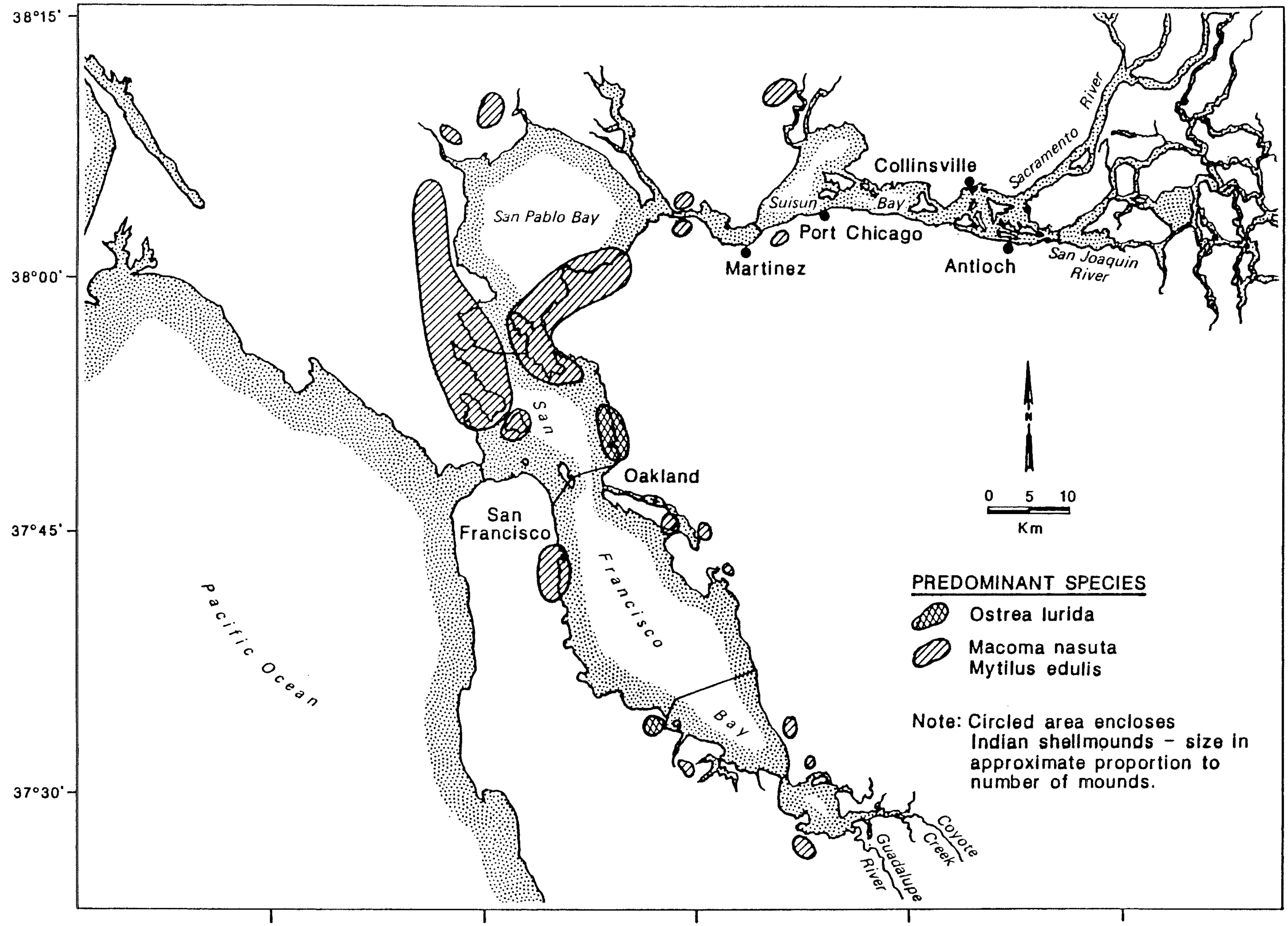

Figure 1
MAP SHOWING THE LOCATION OF
INDIAN SHELLMOUNDS (Nelson 1909)

Table 1. Mollusks Reported in 425 Shellmounds from Around San Francisco Bay (Nelson 1909,1910,1971; Gifford 1916; Uhle 1909).

NAME		COMMENT
DOMINANT SPECIES		
Bent-Nose Clam	Macoma nasuta	Most common species in mounds and in Bay prior to about 1900 (Skinner 1962). Predominates in upper strata of mounds. Very hardy and resistant to adverse conditions (Bonnot 1940). Has been replaced by Mya arenaria over part of its range (Fischer 1916).
Common Bay Mussel	Mytilus edilus	Common in Bay shellmounds. Most abundant in lower strata (Nelson 1909). Some believe it was introduced from Europe (Skinner 1962). Still common in Bay today.
Native Bay Oyster	Ostrea lurida	Common in mounds at Pt. Isabel, West Berkeley, Alameda, and San Mateo.
SPARSELY REPRESENTED		
<u>Sheltered Bays</u>		
Heart Cockle	Clinocardium corbis (Cardium corbis)	May have been overfished.
Rinkled Purple	Thais lamellosa (Purpura crispata)	
Soft-Shelled Clam	Mya arenaria	Now common throughout Bay (Hopkins 1986). Originally introduced with spat from Atlantic Coast (Fisher 1916).
Common Little-Neck Clam	Protothaca staminea (Tapes staminea)	
Horne Shell	Cerithidea californica	Small univalve, common in South Bay mounds. Inhabits salt marshes where it is found in shallow pools.
Unknown	Phytia myosotis	Small univalve common in South Bay mounds. Inhabits salt marshes where it occurs on the underside of driftwood.
<u>Wind-Swept Open Coast</u>		
Sea Mussel	Mytilus californianus	These may have been caught on coast and/or used as utensils.
Abalone	Haliotis rufescens	
Plate Limpit	Acmaea scutum (Acmaea patina)	

throughout the entire depth of the mounds, representing 500 to 3,000 years of accumulation. This data suggests a "continuity throughout shellmound times of the conditions as they were at the coming of the white man." (Gifford 1916, p.7) All of these species are marine or estuarine species that are not commonly found where the bottom salinity is fresher than 5 to 10 ppt; none of them are freshwater species.

The dominant species in all of the mounds (except Point Isabel, West Berkeley, Alameda, and San Mateo, where Ostrea lurida dominated) were the bent-nose clam, Macoma nasuta, and the common Bay mussel, Mytilus edilus (Nelson 1909, 1971; Gifford 1916). These are the only species that have persisted since the middens began to accumulate, and they are still abundant in the Bay today.

The bent-nose clam and the common Bay mussel were also dominant in mounds along Carquinez Straits and in the western portion of Suisun Bay. Today, these species are generally restricted to the more saline regions of the Bay seaward of Carquinez Strait (Hopkins 1986). Under present conditions, these types of species only invade Suisun Bay during drought conditions (Nichols 1985). This suggests that Suisun Bay and environs may have been saltier under "natural" conditions than at present. This is consistent with eye-witness accounts of salinity in Suisun Bay (Sec. 1.1) and of "natural" vegetation in Suisun Marsh (Sec. 1.3)

Fish remains from middens in the Central Valley (Schulz and Simons 1973; Schulz 1979) indicate that the majority of the species were inhabitants of slow-water environments, including sloughs, lakes and seasonally flooded grasslands, rather than main rivers with strong currents. Some 93 percent of the fish remains at a site in southern Colusa County were from a slow-water environment while 86 percent from a site in the northern Delta also were. Typical species from these sites include the Sacramento perch, hitch, and thicktail chub, which are now either extinct or uncommon.

The "natural" system in the Central Valley included extensive areas of freshwater marshes, small lakes, and sloughs. The fish species found in Indian middens substantiate the many eye-witness accounts of these features of the environment.

1.3 Vegetation

The early eye-witness accounts and historical records indicate that Suisun Bay tidal marshes were dominated by salt-tolerant plants characteristic of California salt and brackish marshes, rather than of freshwater marshes. The plants present under natural conditions are still present today. Since the regional distribution of principal tidal marsh plants appears to be controlled by water salinity (Atwater and Hedel 1977, p.2), Suisun Bay was at least as salty under "natural" conditions as it is today.

The western boundary of tule growth under natural conditions suggest that Suisun Bay may have been saltier than it is today. Early maps (1776 - 1850) indicate that tules were only present east of Montezuma Slough at the head of the estuary, nearest to the source of freshwater. This boundary is about the same as the eastward limit of salinity intrusion recorded by early settlers in the area (Sec. 1.1.3). Several of these early maps are included in SWC Exhibit 276 (Figs. B-1 - B-3). Others include the 1776 Canizares map (front cover Science, v.231 1986; Cook 1957), the 1781 Canizares map (Galvin 1971; Watson 1934), and the 1849 Riley map (Riley 1849).

This distribution for tules is similar to that reported in recent historic times (CDWP 1931a, Plate IV; CDWR 1984), except tules now occur further to the west, suggesting Suisun Marsh may be fresher today than it was formerly. It is also notable that none of the eye-witness accounts (SWC Exhibit 276, Appx. A) remark on tules in Suisun Marsh. This is probably because they were not "unusual" enough to remark upon. Tules in inland marshes, on the other hand, were frequently reported as large, typically 10 to 15 feet tall, and very dense. Tules do not grow as luxuriantly in salty water as in fresh (e.g., Lee 1931, p.271).

Tules prefer freshwater and grow most abundantly and luxuriantly in freshwater (Lee 1931, p.271; Deschenes and Serodes 1985; Pearcy and Ustin 1984). Too much salt inhibits growth, as evidenced by the decrease in size and abundance of tules west of the Delta during the drought of 1976-77 (Atwater et al. 1979). The absence of significant tule growth in the western portion of Suisun Marsh under "natural" conditions is further evidence that salt water commonly intruded a significant distance into Suisun Marsh. This was actually observed in the early 1870s by the first settlers in the area (Sec. 1.1.3). It also agrees with molluscan remains found in Indian middens in Suisun Bay (Sec. 1.2).

The California Department of Public Works evaluated the native vegetation present in Suisun Marsh in conjunction with studies of the then-proposed salt barrier project (CDPW 1931a, p.96). The conclusion from these evaluations was:

> The old time residents of the marsh areas state that the original native vegetation on these lands consisted of various aquatic plants (tules, cat-tails, sedges and wire grass), salt grass, pickle weed, and some red top [Agrostis alba, a creeping grass] and clover on high lands bordering the sloughs. The aquatic plants generally grew where water was normally present continuously, whereas the salt grass grew on the higher ground not usually flooded and the pickle weed in isolated pockets lacking drainage. Salt grass was the predominating growth over most of the marsh area.

These observations generally agree with eye-witness accounts and archaeological evidence. The California Surveyor-General, for example, reported in his 1862 Annual Report to the Legislature that "samphire [pickleweed] and tule" were present in Suisun Marsh. Indians in the Delta and around Suisun

Marsh used locally available saltgrass (Distichlis spicata) as their principal source of salt (Kroeber 1941; Heizer 1958). The salt was extracted by roasting the grass.

These plant distributions are not significantly different from those present in the Marsh today. Mall (1969, p.11) reported that three plant species occupy just over 50 percent of the Marsh. Saltgrass was the dominant species, covering about 26 percent of the Marsh, followed by pickleweed (19%), and alkali bulrush (6%). Twelve other plants individually covered from 1 to 5 percent of the Marsh, including cattail, rushes, fat-hen, brass buttons, wire grass, and others (ibid., p.10). Redtop and clover are not common today, probably having been replaced by introduced annuals such as wild oats.

1.4 Tidal Records

Changes in riverine flow are known to affect the tides (Meade and Emery 1971). Daily tidal data have been collected at the Presidio, at the Golden Gate, since 1855 (Smith 1980; NOAA 1983). This data shows an increase in tidal height from 1860 to 1885 that may reflect increases in Delta outflow from harvesting of riparian and other forests that occurred during this period.

River-boat captains that traveled from San Francisco up the Sacramento and San Joaquin Rivers have also recorded the changes in tides that accompanied upstream development. Captain John Leale piloted steamers through tule rushes and dense Bay fogs from the 1860s through 1877. In 1877, he began a 36-year captain's watch on the bridge of the transbay ferryboat fleet and is attributed with more than a million miles of transbay travel.

Captain Leal, in his memoirs, records some revealing observations with respect to the tides (Leale 1939, p.123-124):

> It also may seem strange to say that the tides at the ferry landing at San Francisco (and in fact on the city front generally) are not so strong as in former years. The reason is, that the by-passes on the Sacramento River -- such as the cut from Rio Vista to the lower end of Horseshoe Bend -- do not allow the winter water to accumulate in the Delta regions. All the water from the river-floods goes through Raccoon Straits or around Angel Island Point out the Golden Gate to the Sea. As the young flood tide "makes," the river water presses it out to the city shore, and as the flood strengthens, it forces the river water toward the city, then in time -- for a short while -- the flood joins forces with the river water and this is called the bore.

2.0 ADDITIONAL REBUTTAL

This section presents additional rebuttal of David R. Dawdy's Exhibit 3, David R. Dawdy's direct testimony on December 9, 1987, and of issues raised during cross-examination of Phyllis Fox on November 23-24, 1987.

2.1 Dawdy's Cross Section of the Central Valley

In direct testimony on December 9, 1987, Mr. Dawdy redrew[1] the "Cross Section of the Central Valley Showing Principal Geomorphic Features and Natural Vegetation" from SWC Exhibit 262, Figure 2. This figure, of course, was simply diagrammatic and was clearly labeled as "not to scale."

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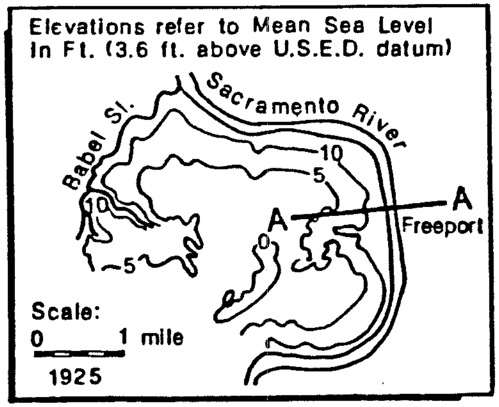
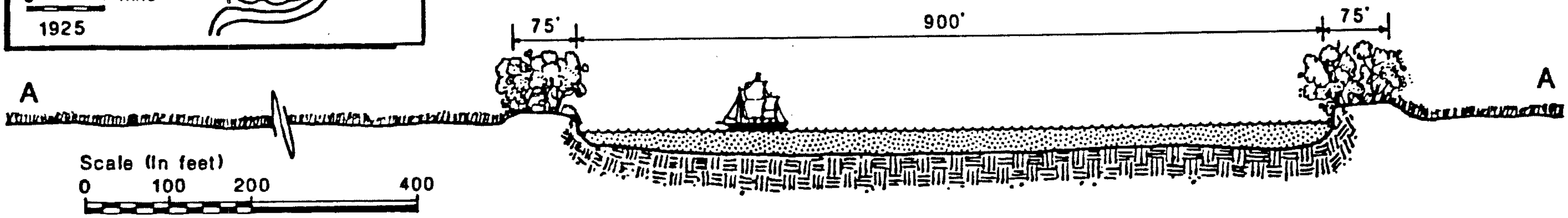
[1] Mr. Dawdy prepared his sketch from elevations in his Exhibit 3, page 8. It should be noted that Dawdy's elevations in his Exhibit 3, page 8, were erroneously reported to two separate datums. The slough and Sacramento River elevations use the U.S.E.D. datum and the adjacent land elevations use the sea level datum. This has been corrected here on Figure 2. (The U.S.E.D. datum is 3.6 feet below mean sea level.)

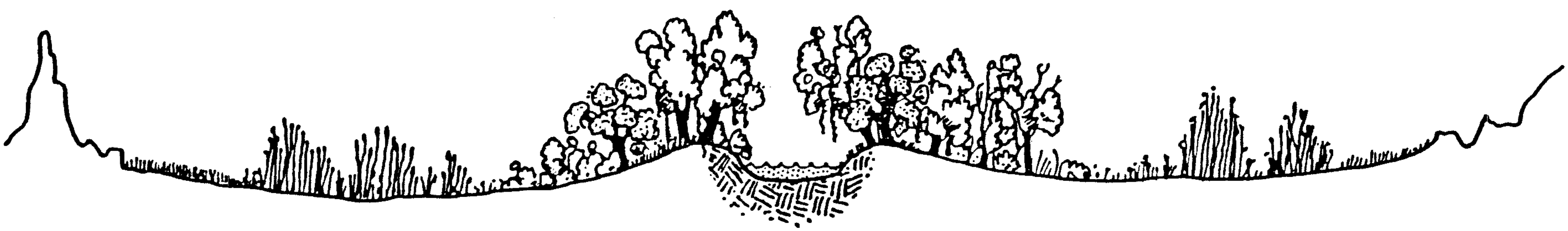


NOTES:

1. Sacramento River channel bottom in 1841 was -20 ft. U.S.E.D. and in 1929, at -18 ft. U.S.E.D. The 1841 elevation is used here (CDPW 1931, Plate 35).
2. Water depth at low water in 1850 was 25-30 ft., channel width was 900 ft., and natural levee width was about 75 ft. (Ringgold 1850; Calif. Comm. of Pub. Wks., 1895).
3. Natural levee height along left bank was +18 ft. U.S.E.D. and along right bank +20 ft. U.S.E.D. (McClure 1925).
4. Vegetation heights taken from Jepson (1910, 1975). Riparian trees assumed to be 40 to 70 feet tall and tule marsh vegetation up to 15 feet tall.



TYPICAL CROSS SECTION OF CENTRAL VALLEY
TO SCALE



TYPICAL CROSS SECTION OF CENTRAL VALLEY
NOT TO SCALE (SWC Exhibit 262, Fig. 2)

Figure 2

Mr. Dawdy's sketch was only to scale in the vertical and greatly distorted the horizontal dimension. Thus, the subject figure is redrawn to scale in both dimensions in Figure 2 to clarify the record. The cross section shown in Figure 2 is at Freeport on the Sacramento River. As one moves up or downstream, the relative proportions of river, levee, and flood basin change. At the mouth of the Sacramento River, levees and riparian forests are absent and tules grow along the river flood plain. Levees and riparian forest first appear above Three Mile Slough and first become notable in the vicinity of Rio Vista. As one moves upstream from that point, the levees get higher and wider. Above Sacramento, the levees are 25 to 30 feet above low water, and they may extend several miles beyond the river.

2.2 Dawdy's Eye Witness Accounts

Mr. Dawdy used nine eye witness accounts to attempt to challenge the extent and composition of natural vegetation claimed in SWC Exhibit 262 (Fox 1987a, Fig. 3). Dawdy's Exhibit 3, page 11, states that "All early travelers did not note tules everywhere. They were more likely to remark on the extensive savannas in the Delta." From this point through page 19 Dawdy quotes from historical accounts to demonstrate that plains and forests, not tules, were present in the Delta and the Central Valley. Mr. Dawdy, in his direct testimony on December 9, 1987, read some of these quotes and further located them on a map (Dawdy Exhibit 4), suggesting early travelers did not record the type of vegetation claimed in SWC Exhibit 262.

The material quoted by Dawdy is misleading, and it does not demonstrate that tules and riparian forests were not present where indicated in SWC Exhibit 262 for the following reasons:

1. The early material cannot be accurately located on a map as attempted by Dawdy. The Spanish league, which Dawdy used to locate observers, is the distance a packed mule or a horse carrying a rider, would travel at a walk in one hour, and varied according to terrain (e.g., Latta 1977, p.33). Dawdy did not consider this variance in his estimates. In the early accounts, before about 1840, geographical names are either nonexistent or very ambiguous. The same name was often used for different sites (e.g., Sacramento was used for both the Sacramento and Feather Rivers) or different names were used for the same place, depending upon the nationality of the observer (e.g., the Sacramento River was variously called the San Francisco, Bonaventura, etc.).

2. Dawdy selectively extracts material supporting plains and forests and does not report material on tules from the same sources (e.g., Moraga 1776, Phelps 1841).

3. Dawdy has incorrectly located some of his observers; the traveler or explorer is simply not in the location Dawdy states.

4. Dawdy fails to point out that travelers only see countryside along the path taken. A traveler in the plains would not report tules. Likewise, a boat trip up the Sacramento River at low water would not record tules; the water level is below the top of the natural levees, which were heavily fringed with riparian forests. The early trails through the Central Valley were across the plains due to the difficulty of traveling through the swamps and heavily wooded stream banks.

4. Not everyone records everything he sees. On expeditions where several parties keep diaries, it is not unusual to find only one out of the lot that records tules (e.g., compare the diaries in Galvin 1971); many explorers focused on the Indians or the day-to-day labors of the expedition.

5. Dawdy has only consulted nine out of several hundred possible diaries and journals. Additional eye-witness accounts, omitted by Dawdy, are presented in SWC Exhibit 276 (tules) and in Appendix A to this exhibit (riparian forests).

6. Many of the early Spanish expeditions were organized to locate suitable sites for missions and presidios. The diaries from these expeditions discuss conditions necessary for a settlement, e.g., existence of water, areas that can be cultivated, presence of timber that can be used in building, to the exclusion of all else. Thus, the 1808 Moraga expedition, for example, discusses pines in the sierras because they are good timber and ignores riparian tree growth, because it not suitable for building.

7. The nationalistic and other biases of the observers must be recognized when working with eye-witness accounts. It was, for example, more common for Spanish-speaking visitors to record tules than English speakers. The Spaniards had previously encountered similar swamps in Mexico. Tule, in fact, is the Aztec word for reed. Americans crossing the frontier from the midwest had probably never seen a reed swamp, and if they had, they would not call it "tule." These visitors usually recorded tules as "rank vegetation," "tall grass," or "flags."

Each historical account that Dawdy cites is reviewed here. Relevant material that was omitted is supplied. Geographical and historical errors of fact are corrected.

2.2.1 Moraga 1776

Dawdy states in Exhibit 3, page 11, that "...the first Spanish explorers described the immense plains and herds of animals in the Delta." This is incorrect, and Dawdy's material does not support it. Dawdy's first observer is Jose Joaquin Moraga who took an overland route from the Presidio south into the San Joaquin Valley. This is not an eye witness account, and it was transcribed by Father Palou from the explorers after they had returned. It is very brief and contains very little descriptive material.

The Moraga land expedition was to rendevouz at the mouth of Carquinez Straits with a second expedition that traveled by water. The land expedition that Dawdy quotes from never reached the Delta and returned without making contact with the water expedition. Bolton, the historian who translated the diary, stated that he did not know where in the San Joaquin Valley the land expedition had gone.

Bolton was a well-known University of California historian who translated many early documents on the colonization of California (e.g., diaries of the Anza expeditions, of Font, of Crespi, Palou's History), and he traveled over most of the territory covered by the material he translated. Bolton did not know where the Moraga land expedition went, yet Mr. Dawdy states they were in the Delta and locates their river crossing at A on his Exhibit 4. The river expedition, however, did reach the Delta and did report tules. Dawdy does not mention the tules reported by the river expedition.

The material that Dawdy quotes from in the last two paragraphs on his page 11 (Dawdy Exhibit 3) is from Bolton's Vol. IV, Chapter XX, pp. 127-131. The quoted passage is from the second Anza expedition, organized to found, among other things, the Presidio at San Francisco. What Dawdy fails to mention is that his quote describes the San Joaquin Valley, which was an immense plain. Dawdy incorrectly states his quote applied to the Delta (Dawdy, page 11), even though the text he quoted from clearly indicated that the description applied to the San Joaquin Valley.

The land expedition that Dawdy quotes from went southeast from San Francisco, rounded the Bay, and crossed the mountains into the San Joaquin Valley. The route taken by the expedition is given on Bolton's page 128, and Dawdy's quote is from Bolton's page 130. Bolton footnoted the location of the passage quoted by Dawdy to indicate that Moraga "must have ascended the valley past the site of Modesto." Moraga never reached the Delta, and all of the material quoted by Dawdy applies to the Livermore and San Joaquin valleys.

The location of this expedition was further clarified in a later work by Bolton. Bolton republished this material four years later, verbatim, in a book entitled Anza's California Expeditions (1930). The relevant passages are in Vol. III, pp. 395-399. This version is annotated and contains several explanatory footnotes. In this version, Bolton indicates he did not know where the Moraga expedition had been. Bolton states on page 398, referring to the material quoted by Dawdy, "....His route is uncertain. The pass nearest to the south end of San Francisco Bay is Mission Pass, which should have taken him to Livermore Valley, but where he emerged into the San Joaquin is not clear...."

The acknowledged authority on this diary does not know where Moraga was and Dawdy is certain that he was in the Delta and that he crossed the San Joaquin at A on his Exhibit 4!

The September 1776 expedition cited by Dawdy did not reach the Delta. However, the water party did reach the Delta and did record tules. The river party did not leave behind a diary, but did prepare an excellent map of the Bay that shows the location of tules and freshwater at high and low tides. This map was published on the front cover of Science (v. 231, February 7, 1987) and was submitted as Bay Institute Exhibit 28 (The Modification of an Estuary). The map has also been published in other books (e.g., Galvin 1971). The legends on this map indicate that "tulares" were present on all of the islands shown in Suisun Bay as well as along the north and south shores of Suisun Bay and along the Sacramento and San Joaquin Rivers. The legend shows that the expedition reached a point in the San Joaquin River midway along Sherman Island, where progress was blocked by the tulares. This map is also discussed by Wagner (1937, p.179-180). The existence of tules in the Delta in 1772, 1775, and earlier in 1776 is confirmed by quotes from other expeditions. These quotes are presented in SWC Exhibit 276, pages A-4 - A-5.

2.2.2 Moraga 1808

Dawdy's second observer is Ensign Gabriel Moraga, who in September and October of 1808 traversed the Central Valley from the Merced River to north of Sutter Buttes (Dawdy, p.12). Dawdy used this account in his Exhibit 3 and his direct testimony to suggest that oaks and patches of tules were present in the Valley. Dawdy neglects to include or mention a map that accompanied the Moraga report that shows his trail. This map is reproduced here as Figure 3. It shows that Moraga was not where Dawdy states and that he only infrequently reports tules because he took a path that went around the swamps,

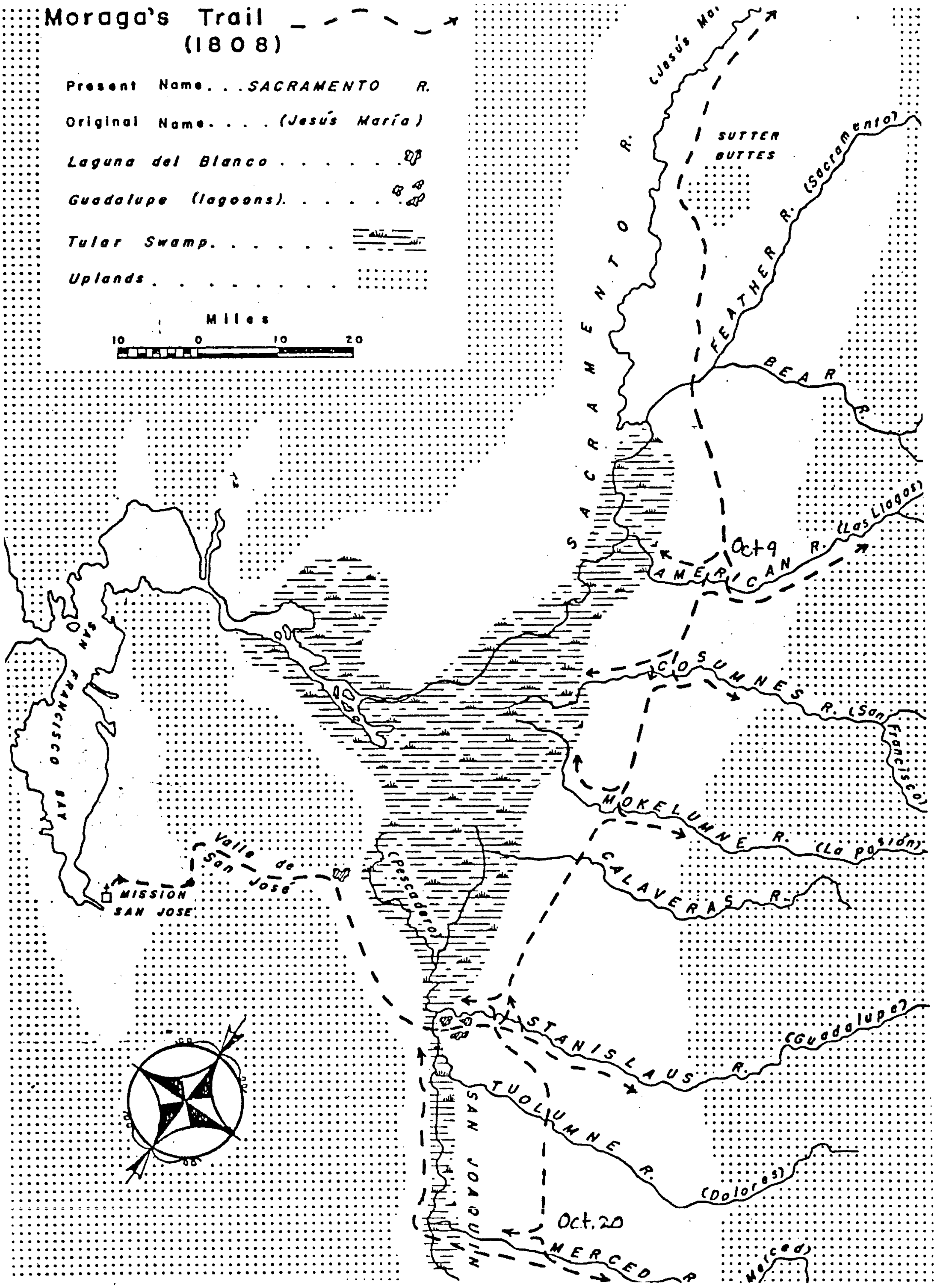


Figure 3. Moraga's Trail Through the Central Valley (Moraga 1808)

some ten miles above them. Moraga only reports tules when he moves down the rivers to explore.

Dawdy read in direct testimony on December 9, 1987, the first 14 lines of page 12, Exhibit 3 (Dawdy 1987,p.12) and located the site recorded as B1 on Exhibit 4 in the heart of the Delta near Stockton. Dawdy remarked that this was the first record of a tular, even though the observer had traveled through the Delta in regions shown as tule in SWC Exhibit 262. In fact, a complete reading of the text, the notes, and the accompanying map (Fig. 3), indicates that Moraga was traveling along the western edge of the Delta where no tule is claimed in SWC Exhibit 262.

Dawdy next quotes Moraga on October 9, 1808 (Dawdy, p.12): "Today we broke camp and moved to the river discovered yesterday, which we named the Sacramento. They have measured this river at 169 varas across (420 feet wide), and uniformly from one shore to the other a vara and a half (4 plus feet) deep...I sent three men to ford the river, and having found a ford, they crossed." Dawdy then uses these measurements to calculate the channel cross-section and states that at a velocity of 1 ft/sec, the flow would equal average unimpaired flow. He further states that since the soliders had to search for a ford, the velocity must have been twice as fast.

This analysis is misleading and incorrect. First, the Sacramento River referred to in the text is actually the Feather River, which is footnoted by the translator (Cutter 1957, p.33). This is important because the banks of the Feather River where Moraga was located (Fig. 3) are steep. They had to search for a ford, not because the currents were swift, as stated by Dawdy, but because the banks were steep. Two days later, on October 11, Moraga reports that the Sacrament River, above the mouth of the Feather River, had "scarcely any current."

The flow in a channel with a cross-sectional area of 1700 sq ft and a velocity of 1 ft/sec is 1700 cfs. If this were constant during the month of October, the flow would be about 104,000 ac-ft/mo. The average unimpaired Delta outflow for October (DWR Exhibit 26, p.37) is 496,000 ac-ft/mo, a factor of five lower, <u>not about equal to</u> as Dawdy states. Much of this water (flow of the Feather River) would be consumptively used by Delta tule marshes and riparian vegetation along the Sacramento River before it reached the Bay.

The last portion of the Moraga material that Dawdy cites is from October 20, 1808, in which Moraga reports a willow grove where the Merced River enters the San Joaquin River. Dawdy located this as B2 on his Exhibit 4. Dawdy omitted the material from October 19, in which Moraga reports "willow, ash and oak" along the Merced River. Dawdy implied in his testimony on December 9 that the 1 - 2 mile strip of riparian vegetation shown in SWC Exhibit 262, Figure 3 was excessive. This type of judgment cannot be made from Moraga's simple statement that a willow grove was encountered. Moraga reports no dimensions. The text contains no descriptive material that supports a judgment of forest width. This is a second-hand account, recorded by Palou, and Moraga's descriptions focus on aspects of the terrain essential to a settlement, rather than a general description of the terrain.

2.2.3 <u>1811 Sanchez Expedition</u>

In Dawdy's Exhibit 3, page 12, next to the last paragraph, Dawdy records a trip in October 1811 by Sergeant Jose Antonio Sanchez through the Delta in which are reported "low-lying river lands and a great plain, covered with wild herds, that seemed to stretch endlessly into the distance." Dawdy's source is Julian Dana's <u>The Sacramento, River of Gold</u>, published in 1939. Dana was a journalist, not a historian. This book is not a scholarly work but a natural history directed at the layperson and contains no references or source material. Dawdy's quote was correctly taken from Dana's page 37.

Dana is simply wrong. The Sanchez expedition provided some of the very best documentary evidence extant on tule marshes. This expedition did not report low lying river lands and a great plain. It reported dense, extensive tule swamps throughout the Delta and riparian vegetation on natural levees. The relevant material is quoted in SWC Exhibit 276, page A-8 (Abella).

Sanchez was the commander of the expedition and Father Abella the diarist (Bancroft 1886, p.321-322). Abella wrote a diary documenting the trip entitled "Diaro de un registro de los rios grandes." Bancroft was the first historian to use this material, and he translated the diary in substance in a footnote on pages 321-322 of volume ii of his well-known work, A History of California. This history was widely available when Dana wrote in 1939. This diary has also been translated in full by Cook (1960, p.261-263).

These translations tell a very different story than Dana's brief summary. On October 18, 1811, travelling from Suisun Bay to Brown or Kimball Island in the Delta, along the southern shore, Abella reported that they moved through "islands, tules, and swamps..." On October 18, they wandered through sloughs, including Three Mile Slough, and into the Sacramento River, eventually sailing southward down the San Joaquin with "nothing in sight but water and tule and sky." From October 19 to 22, they moved "through the tules southward and eastward to the Pescadero Rancheria..." (near the southern end of Union Island). No plains are described in the Delta (quotes are from Bancroft 1886). The only plains are in the Sacramento Valley, reached by travelling north across Carquinez Straits.

2.2.4 Belcher and Kotzebue Expeditions

These commanders sailed from San Francisco up the Sacramento River in 1837 and 1824. These are river expedition, and most of the observations are from the vantage point of shipboard or from the natural levees, which in many places are several miles wide (Fig. 2). This should be kept in mind when attempting to interpret the material, which is particularly difficult as locations along the river are not usually given. These expeditions provide excellent documentation of the extent and nature of riparian forests claimed in SWC Exhibit 262, and some of it is repeated here in Appendix A.

Dawdy no doubt has cited this material because it does not report tules and it reports beyond the riparian forest, "a vast plain almost without an inequality covered with the richest pasture and interspersed with parklike groups of trees..." and "the country is one immense flat...." (Dawdy, p.13). However, this does not mean that there are no tules or that everything beyond the riparian forest is plains. The expeditions are river expeditions that presumably periodically anchored and explored the shores. However, if they did so, none of the accounts indicate where they went. They could have, for example, explored the plains north of Carquinez Straits or south of Suisun Bay.

2.2.5 1841 Phelps Expedition

Phelps, in 1841, sailed from San Francisco up the Sacramento River to the vicinity of Sutter's Fort, near the mouth of the American River. This is also a river expedition, and most of the observations reported by it are from the vantage point of shipboard or from the natural levees, which in many places are several miles wide (Fig. 2). However, Phelps also traveled overland, reporting tules. Dawdy omits that part of the narrative.

Phelps reported a tule swamp between the Feather and American Rivers. Dawdy omits this, quoting material on either side of it that supports plains.

On July 30, 1841 (Busch 1983, p.202), Phelps reports: "The scene of our operations was in a long strip of high flags (tule reeds) which commenced near the mouth of the Feather River and extended itself in a belt of about 2 or 300 yards in width and 15 or 20 miles in length running nearly parallel to the Sacramento River at about 1/4 of a mile from the bank, its inner edge at a short distance from the thick woods which border it." This strip of tule is shown in SWC Exhibit 262, Figure 3.

2.2.6 1846 Bryant

Bryant was a journalist from Kentucky who traveled in California in 1846 and 1847. Dawdy quotes most of the relevant material in his Exhibit 3, page 18-19 and on page 20-21. Dawdy also located four of Bryant's descriptions on a map (Dawdy Exhibit 4) in his direct testimony on December 9, 1987 (marked F1-F4). Locations F1-F3 are wrong. Bryant does not state where he is, and Dawdy apparently has assumed that he was travelling along the eastern edge of the Delta. Bryant was probably traveling some 20 miles east of the Delta, along a well-known wagon trail.

In 1846, about 20,000 people lived in the valley, and well-traveled wagon roads led to many locations. One of the better known such roads was the one that led south from Sutter's Fort to the town of San Joaquin, on the west bank of the San Joaquin River upstream from the mouth of the Stanislaus. This is the route that Bryant probably took from Sutter's Fort, where he started his journey. This road was located about 20 miles east of the Delta tule swamps and is shown on most early maps. See, for example, Figures B-3 and B-4 in SWC Exhibit 276. The vegetation along this wagon trail as described by Bryant is consistent with that claimed in SWC Exhibit 262, Figure 3.

2.3 Consumptive Use Factors

Considerable discussion on consumptive use factors occurred during cross examination on November 23-24, 1987. Some of the issues raised were addressed in SWC Exhibit 276 (p.45-50), before the Reporter's Transcript was available. This section presents additional discussion of issues raised during cross examination, based on the Reporter's Transcript, Vol. L and LI.

2.3.1 Consumptive Use of Willows in the Delta

In the Transcripts, Vol. L (November 23, 1987), p. 208, Line 11-23, Mr. Sanger suggests that the consumptive use value for willows from DPW 1931 cited in SWC Exhibit 262, Table 5, was from a study made in the Delta. This issue was raised because this was the lowest reported value for willow consumptive use (2.9 ac-ft/ac), and it was not used to calculate riparian forest evapotranspiration. It was not used because the cited reference did not state where the measurements were made (CDPW 1931b, p.69).

The source of the willow measurements has now been located. The consumptive use factors for tules and willows cited in SWC Exhibit 262 (p.A2-30, A2-33) were calculated by Charles H. Lee and first published in DWR Bulletin No. 28 (Lee 1931, p.270-307). The willow consumptive use value was calculated from measurements of pounds of water per pound of dry leaf matter for several varieties of deciduous trees at the Austrian Forest Experiment Station at Mariabrumm, Austria, from 1878 to 1880. The trees studied did not even include willow. Lee used rather elaborate procedures to attempt to convert these transpiration factors to consumptive use values representative of the Delta. However, the methods used in the Austrian studies are of "doubtful value" (Meinzer 1942, p.291), and the extrapolations made by Lee are excessive.

2.3.2 Climatic Adjustment to Consumptive Use Factors

The Transcripts, Vol. L (November 23, 1987), p. 208, Line 24 through p. 211, Line 23, contain considerable discussion on whether consumptive use factors measured in Southern California should be adjusted when applied to the Central Valley. This issue was clarified with respect to tules in SWC Exhibit 276 (p.49). In the case of tules, a climatic adjustment is not required because the range used (6 to 9 ac-ft/ac) was taken from actual measurements made in the Delta. The tule consumptive range was not extrapolated from Southern California. The rest of this section discusses the adjustment of riparian forest consumptive use values extrapolated from Southern California.

Consumptive use depends upon climatic and vegetative factors, both of which should be considered in extrapolating values from one area to another. The climatic factors are similar in the two regions while the vegetative factors suggest that Southern California values should be increased when applied to the Central Valley under "natural" conditions. No adjustment was made in an effort to be conservative. The basis for this conclusion is presented here.

The important climatic factors are temperature, relative humidity, wind speed, number of daylight hours, and length of growing season. Most of the empirical formulae used to estimate evapotranspiration (et) do not consider all of these factors; those formulae that attempt a complete integration require extensive meteorological data that is rarely available. Thus, SWC Exhibit 262 used pan evaporation data to evaluate whether a climatic adjustment was required when extrapolating Southern California et values to the Central Valley. Pan evaporation integrates all of the climatic factors that influence evapotranspiration, rather than considering just one or two, as does the Blaney-Criddle (temperature, total daytime hours) and other formulae.

Most evapotranspiration studies also record pan evaporation data at the experimental site. These measurements were compared with pan evaporation data reported by the California Department of Water Resources (CDWR 1979, p.27) at Davis in the Central Valley. Pan evaporation for the same period at each site was used. Davis was selected for the comparison because it is the only evaporation station in the Central Valley that has records that cover the period of evapotranspiration studies, from the 1930s through the recent past. This station is also in the middle of the geographic range covered by SWC Exhibit 262.

Table 2 summarizes the results of this comparison for all riparian forest evapotranspiration measurements made in California. This table expands Table 5, SWC Exhibit 262 (p. A2-30). Out-of-state measurements have been eliminated due to vegetative differences. Some of the originally reported et values were for periods of less than a year; these have been extrapolated to a 12-month basis. Additional descriptive material has been added to clarify the nature and type of vegetation.

The pan evaporation column compares the evaporation at the experimental site with that measured at Davis for the same period. This column demonstrates that the evaporation at Davis is typically <u>within 10 percent</u> of the evaporation at most experimental sites in Southern California. At the Santa Ana sites, evaporation is 2 to 7 percent higher than at Davis, indicating a slight downward adjustment when extrapolating to the Central Valley. At San Luis Rey and San Dimas, the evaporation is 7 to 30 percent lower than at Davis, indicating a slight upward adjustment when extrapolating to the Central Valley. Since the typical range of 2 to 7 percent is small and within the limits of error of the estimate, no climatic adjustment was made to any of the Southern California et values (i.e., a 7 percent increase in 6 ac-ft/ac is still 6 ac-ft/ac when rounded).

Table 2. Water Use by Common Riparian Vegetation in the Central Valley. Modified from Fox (1987a, Table 5, p.A2-30).

LOCATION	TYPE OF VEGETATION	SIZE/DENSITY/OTHER Experimental Site	SIZE/DENSITY/OTHER Central Valley	PAN EVAPORATION Site (ac-ft/ac)	PAN EVAPORATION Davis (ac-ft/ac)	MEASURED ET (ac-ft/ac)	REFERENCE
FIELD STUDIES							
Lower Reach Coldwater Canyon Upper Santa Ana River in San Bernardino Mtns.	82% alder, 8% sycamore, 4% Bay, 3% willow, some maple, oak. Understory of grapevine, blackberry.	87% of trees had a diameter less than 1.2 ft. 380 trees/ac	alders 1 to 2-2/3 ft in diameter.	NR	4.6	6.9[1]	Blaney (1933, p.88-121)
Upper Reach Coldwater Canyon Upper Santa Ana River in San Bernardino Mtns.	48% alder, 26% Bay, 9% maple, 7% willow, 6% sycamore, some oak, cedar, spruce, etc. Same understory.	94% of trees had a diameter of less than 1.2 ft. 456 trees/ac	alders 1 to 2-2/3 ft in diameter.	NR	4.6	5.4[1]	Blaney (1933, p.88-121)
Temescal Creek, southeast of Corona	willows, tules and other unspecified vegetation	dense	NR	NR	NA	9.5[2]	Blaney et al. (1930, p. 65-74
Santa Ana River between Riverside Narrows and Prado	38% of area was heavy tree cover comprising willows, alders, cottonwood, sycamore; 19% was grass, 20% brush, 6% tule swamp.	not stated, but likely similar to Coldwater Canyon	NA	6.4	6.0	4.2	Troxell (1933, p.147-172)
Placer Co., CA 10 mi northeast of Lincoln	Typical foothill oak savanna comprising interior live oak, blue oak, and black oak. Understory is poison oak and groundcover is annual grasses.	Tree density ranges from 150 to 500 per acre.	Quercus lobata, a much larger, moisture-loving species dominates.	NA	NA	1.6-2.2	Lewis and Burgy (1964)
TANK STUDIES							
Santa Ana, CA	Isolated clump of red willow	7 ft tall	20-50 ft tall	5.5	5.4	4.4	Blaney (1933, p.67)
San Luis Rey River, CA	Mixture of cottonwood and willows.	NR	NA	5.1	5.5	5.2-8.1 [3]	Muckel and Blaney (1945, p.5
San Dimas Forest, 35 mi northeast of Los Angeles	Scrub oak (Quercus dumosa)	NR	Quercus lobata dominates	3.8	5.0	1.5-2.1	Patric (1961)

1 Evapotranspiration reported for period of May to October 1932 and converted to a 12 months basis by dividing by 0.77.
2 Evapotranspiration reported for May 1929 and converted to a 12-month basis by dividing of 0.11.
3 Range depends on depth to groundwater, which varied from 3 to 4 feet.
4 Abrevations used herein include: NR = not reported; NA = not applicable; ET = evapotranspiration.

Vegetative factors should also be considered when extrapolating et values. Vegetative factors include plant species, thickness of foliage canopy, density of cover (percent of land shaded by foliage), size of vegetation, depth to water table, and available supply of water. Methods do not presently exist to extrapolate et for one set of vegetative factors to another, and formulae integrating these various concepts have never been developed.

This complex problem was approached in this work by comparing tree sizes and densities in Central Valley riparian forests as recorded by early explorers and botanists with those used in the experimental studies. The eye witness accounts (Appx. A) indicate that the riparian forests were dense and thickly wooded and that the trees were large and even "immense." The cottonwoods and willows were often reported to grow down the banks to the water's edge. The early botanists also remarked on the luxuriant growth and large size of the vegetation. Jepson, one of California's great botanists, remarked of the lower Sacramento Valley: "On account of the water-soaked condition of the soil...plant life in this region is endowed with all the requisites for the most robust growth...Certain species that grow in drier regions .... in favored situations...here double their common stature, twice or even three times over." (Jepson 1893, p.241)

Tank studies used to measure evapotranspiration of trees, on the other hand, use young trees, which are smaller and use less water than mature trees. In all cases for which comparison can be made (the data are sparse), Central Valley trees were larger. For example, the tank studies of willow in Santa Ana were made on individuals 7 feet tall while the typical willow in the Central Valley was 20 to 50 feet tall (Jepson 1910). Many Central Valley willows and cottonwoods grew along the edges of streams, where their evapotranspiration rates would be much higher than individuals within a large stand of trees. Similarly, the alders studied in Coldwater Canyon were small compared to those found in the

Central Valley. None of the Southern California sites are described as luxuriant or in the terms recorded by the early explorers.

The oak studies provide another relevant example of vegetative factors that can influence evapotranspiration. The valley oak, Quercus lobata, is the principal oak found in riparian forests in the Central Valley. It is the largest of the western oaks, reaching heights of over 100 feet (Jepson 1910, p.206). It favors moist soil and hot valleys (ibid., p.205) and has a well developed root system which reaches the water table. The et of this species has apparently never been measured, but xylem sap tension measurements indicate that it uses more water than other oak species that grow in drier areas (Griffin 1973).

Other oaks that occur in the Central Valley (blue oak, black oak, interior live oak) are smaller, occur in dry sites, may have a shallow root system and special adaptations (e.g., shedding of leaves) that allow them to survive droughts (Jepson 1910; Griffin 1973). These oaks typically use 1.5 to 2.2 ac-ft/ac of water (Lewis and Burgy 1964). It would be unreasonable to extrapolate these low et values to the valley oak, which grows in much wetter areas and is considerably larger.

These types of considerations suggest that more water would have been used in the Central Valley than in Southern California by similar types of vegetation. This in part is simply due to the fact that more water was available. This was addressed in SWC Exhibit 262 by selecting the higher et value when a range of evapotranspiration factors was reported.

APPENDIX A

EYE WITNESS ACCOUNTS OF RIPARIAN FOREST IN THE CENTRAL VALLEY

1776 to 1862

Alison S. Britton

Under "natural" conditions, the levees and flood plains of perennial and ephemeral streams of the Central Valley supported a luxuriant growth of vegetation, sometimes several miles wide (Thompson 1961). The vegetation bordering these streams is usually referred to as "riparian forest." These forests can comprise four phases -- the open flood plain, the gravel bar thicket, the riparian forest, and the valley oak forest (Conard et al. 1977). The original extent of this vegetation has been mapped by Kuchler (1977) and Roberts et al. (1977). Its original extent has also been estimated by several investigators, including Smith (1977), Katibah (1983), and USBR (1986). These various estimates indicate that 1 to 1.6 million acres of riparian forest were originally present in the Central Valley. None of these studies or estimates address the four phases of the riparian forest.

The types of trees present in the Central Valley riparian forests were catalogued and described by Willis Jepson in his well-known Silva. Jepson's list of trees is presented in Table A-1 together with the typical habitat of each. This table demonstrates that the majority of the trees found in the Central Valley inhabit stream banks and moist areas along perennial and ephemeral streams. Even though specific data are lacking on some of them, it is believed that all of these may be classified as phreatophytes (plants that habitually obtain their water supply from groundwater).

Kuchler (1977, p.20) states that these riparian forests comprised "medium tall to tall, broad-leaved deciduous forest with lianas" and were dominated by the common cottonwood (Populus fremontii). Kuchler clearly distinguishes this type of forest from the "valley oak savanna," which is dominated by the valley oak (Quercus lobata) and comprises widely spaced and stately oaks with insignificant undergrowth. Kuchler's riparian forest and valley oak savanna are often adjacent or near neighbors and where the oak savanna merges with the riparian forest, tree density increases. Kuchler's riparian forest only occurs north of the bend in the San Joaquin River and his "valley oak savanna" only occurs south of this point, predominately in the Tulare Lake Basin.

Conard et al. (1977) reports that a valley oak phase of the riparian forest existed on high terrace deposits and above cut banks along the outside of meanders. Kuchler (1977) and others did not map to a scale that would could show this type of detail (scale: 1:1,000,000). Most of the valley oak forests on the higher terrace deposits were not included in the riparian forest addressed in this work, and they were grouped with grasslands. Conard et al. (1977, p.49) reported that the valley oak woodland phase is dominated almost exclusively by valley oak (73%). Common associates include sycamore, willows, box elder, Oregon ash, and black walnut. Tree density was reported as 50 per acre.

Table A-1. Census of Native Trees in the Central Valley (Jepson 1909,1910).

TREE	HABITAT
WILLOW FAMILY	
Yellow Willow (Salix lasiandra)	Grows along the Sacramento and San Joaquin Rivers and their tributaries, and fringes most Coast Range streams and creeks where the water flow is not intermittent. Grows to 20 to 45 ft.
Red Willow (Salix laevigata)	Grows along living streams or occasionally along summer-dry arroyos in regions of high winter precipitation. Grows to 20 to 50 ft.
Black Willow (Salix nigra)	Inhabits river banks in the Sacramento and San Joaquin valleys and follows desert rivers through southeastern California. Has a more extensive range than other tree in the U.S. Grows to 20 to 45 ft.
Arroyo Willow (Salix lasiolepis)	Grows on banks of living streams in valley and canons, and also follows the winter flood-streams into the foothills where it is the common and often only willow of summer-dry arroyos. Grows to 10 to 18 ft.
Common Cottonwood (Populus Fremonti)	Inhabits stream beds and moist delta in the valleys, rarely entering dry foothills except along living streams. Most abundant in the San Joaquin Valley. Dependent upon an abundant water supply and a dry climate. Grows to 40 to 90 ft.
WALNUT FAMILY	
California Walnut (Juglans californica)	Inhabits mountain slopes, stream beds or gravelly washes. Grows along banks of lower Sacramento. Grows to 50 to 75 ft. in the Central Valley.
BIRCH FAMILY	
White Alder (Alnus rhombifolia)	Borders rivers and perennial stream in the Coast Ranges, Sacramento and San Joaquin valleys and in the Sierra Nevada, usually forming continuous files of trees along water courses. Grows to 30 to 80 ft.
OAK FAMILY	
Valley Oak (Quercus lobata)	A strictly California tree all but confined to the Sacramento and San Joaquin valleys and the valleys of the Sierra foothills and Coast Ranges. It favors both moist soil and hot valleys and attains its greatest development in the deep moist loam of alluvial or delta valleys. So frequently an inhabitant of delta lands it is called "Water Oak" or "Swamp Oak." Typically 40 to 75 ft. tall, but grows to 100 to 150 ft in delta areas.

TREE	HABITAT
OAK FAMILY (Continued) Interior Live Oak (Quercus Wislizenii)	Grows in the Sierra foothills, mostly in ravines and canons but often in gravelly soil or on the driest slopes. It follows the water-courses down into the Central Valley where it was abundant along the banks of creeks and in river bottoms or prairie uplands. It also grows along streams on the western side of the Sacramento Valley and extends southward to Suisun Valley. Grows to 30 to 75 ft. high.
PLANE-TREE FAMILY Western Sycamore (Platanus racemosa)	Inhabits the beds and alluvial benches of creeks and streams in the valleys and often follows canon bottoms into mountains. It grows in the valley of the Sacramento on the banks of the Sacramento River and its main arms, marches along the San Joaquin and ascends its upper eastern tributaries into the foothills. It reaches its greatest development as a tenant of river beds in low valleys. Typically 40 to 90 ft. high.
MAPLE FAMILY Big-leaf Maple (Acer macrophyllum)	Inhabits the banks of rivers and perennial creeks in valleys, and mostly the north and east slopes of mountains, choosing moist swales or the neighborhood of springs. Sometimes called "Water Maple." It is nowhere in its range a common tree. Grows to 30 to 65 ft.
Box Exder (Acer Negundo var. californicum)	Inhabits banks or bottoms of constant streams in the Coast Ranges and alluvial banks of the Sacramento and San Joaquin rivers. Trees in a locality are usually few and scattered. Grows to 20 to 50 ft.
ASH FAMILY Oregon Ash (Fraxinus oregona)	Borders streams in valleys and mountain canons. Distributed throughout the North Coast Ranges, Sacramento and San Joaquin valleys. Grows to 30 to 80 ft.
HONEYSUCKLE FAMILY Blue Elderberry (Sambucus glauca)	Grows in open woods, canons or moist flats of the lower hill country or middle altitudes along stream banks in the valleys (Jepson 1975, p.965). Typically grows to 15 to 28 ft.

Very few measurements of the composition of riparian forests or the tree density in them are available. Conard et al. (1977) studied several sites along the Sacramento River. They reported that cottonwood (44%) dominates the riparian forest of lower terrace deposits and stabilized gravel bars along the Sacramento River. Common associates are valley oak (7%), willows (20%), Oregon ash (19%), western sycamore (7%), box elder (1.5%), and button-willow (1.5%). Tree density was reported as 102 per acre.

The composition and extent of riparian forest under natural conditions is difficult to determine with certainty because it was rapidly used by early settlers, particularly during the Gold Rush. The riparian forests were the first lands to be settled because they were higher and less subject to flooding. Steamships transporting miners and supplies upriver were heavy users of local wood fuel. The wood was also used to a lesser extent for building. When Cronise wrote in 1868 (Cronise 1868), most of the riparian forest was already gone. The riparian forests as chronicled by Cronise in 1868 and by Hilgard in 1880 are summarized in Table A-2. The qualitative extent of alteration of these forests around these dates can be determined by comparing this tabulation with the eye-witness accounts presented below.

Observations of riparian forest by early explorers of the Central Valley are summarized in this appendix. Some of this material has also been reported and interpreted by Thompson (1961, 1977). Only eye-witness accounts are included. Later histories, hearsay, and opinions not based on observation are excluded. An attempt has been made to be as comprehensive as possible for the period prior to about 1840. However, after that date, the literature does not reflect "natural" conditions due to the rapid harvesting of these forests. Most of the references used (a list is appended at the end of this document) may be found in the Bancroft Library at the University of California, Berkeley campus.

Some of the early explorers also mapped riparian vegetation. Several of these maps were included in SWC Exhibit 276 (Fox 1987b). Derby located riparian forest in the Sacramento Valley (Figure B-4) in 1849, Nugen located forest in the Tulare Valley and along the lower San Joaquin River in 1853 (Figure B-6), and Gibbes located riparian forest along the San Joaquin to the mouth of the Tuolumne River in 1850 (Figure B-7). Ringgold (1850) also showed riparian vegetation on his navigation chart of the lower Sacramento River. None of these maps indicate tree type and none are based on surveys; they merely show which streams were lined with trees.

The accounts summarized here indicate that the main rivers with year-round flow were lined with a dense arboreous fringe consisting of cottonwood, willow, box elder, ash, and oak. The valley oak typically occurred in groves back from the main river banks (Conard's valley oak phase) or intermixed with other trees along the main river bank. Other types of oaks -- the blue oak, black oak and interior live oak -- occurred in the plains between the main rivers, and along dry arroyos and ephemeral streams. These woodland and dry-land oaks were not classified as "riparian forest" in this work and were treated as grasslands. The lower Sacramento River Delta, from around Rio Vista upstream, also contained a narrow band of riparian vegetation along the natural levees. The first occurrence of this vegetation has been widely used by historians to locate explorers (e.g., Cook 1960). This vegetation also was not classified as "riparian forest" in this work and was subtracted from the Delta tule lands.

Table A-2. Riparian Forest on a County-by-County Basis as Reported by Hilgard (1884) and Cronise (1868).

COUNTY	RIPARIAN FOREST[1]
Tehama	Along Sacramento River and other streams: narrow strip of cottonwood and sycamore (H,101; C,289).
Butte[2]	Riparian forest not mentioned.
Colusa	Along Butte Creek and Sacramento River: cottonwood, sycamore, and ash (H,88). River banks cultivated in 1868; originally narrow belts of sycamore and cottonwood (C,297).
Yuba	River banks were farmed until mining debris covered them with slickens; cottonwoods, willows, and vines grow in slickens (H,89). Originally timbered along lower portions (C,300).
Sutter	Along Feather and Sacramento Rivers: cottonwood and sycamore (H,89). Cronise agrees, but calls the strip of riparian vegetation "narrow" (C,298).
Yolo	Along Sacramento River, Cache, and Putah Creeks: cottonwood, sycamore, and willow (H,90; C,303).
Solano	River banks are all cultivated; does not mention native vegetation (H,91; C,305).
San Joaquin	Along San Joaquin and lower Stanislaus Rivers: cottonwood, willows, and sycamore. Along Mokelumne River: willows, sycamores, and oaks (H,93). Most of water courses are lined with a narrow fringe of oak (C,315).
Sacramento	River banks are cultivated; native vegetation along Sacramento River: cottonwood and sycamore (H,92). Along banks of streams: oaks, sycamore, and cottonwood. Originally, the riprian growth was so broad and dense that navigation by sail vessels was difficult (C,309).
Stanislaus	Along Stanislaus River: luxuriant growth of grape-vines among the oaks. Along other major streams: narrow belts of cottonwood and oak (H,94). A few scattered oaks along the larger streams (C,319).

COUNTY	RIPARIAN FOREST[1]
Merced	Along Merced and San Joaquin Rivers: oak (H,95). Cronise does not mention riparian vegetation.
Fresno[3]	Along San Joaquin River: cottonwood, sycamore, willow, and large oaks (H,96). Fresno means white oak in Spanish, and the Fresno River was so named because it was originally lined with white oak (C,322). Along San Joaquin River: sycamore, cottonwood, willow, and oak, the latter predominating (C,324).

1 The references cited here are indicated as follows: the letter C stands for Cronise (1868) and the letter H for Hilgard (1884); the number following the letter is the page number the information is found on.

2 When Hilgard wrote, the present Glenn County was part of Butte County. Glen County was formed in 1891 (Coy 1973, p.107).

3 When Hilgard wrote, the present Madera County was part of Fresno County. Madera County was formed in 1893 (Coy 1973, p.157).

Most of these historical accounts give no indication of the actual depth of the riparian forest. Belcher in 1837 reported a bank of oaks about 300 yards deep north of Rio Vista. John Work, the trapper, in 1832, wrote, probably referring to French Camp Creek east of the Delta: "the plain is overflowed and we had to encamp at the skirt of the woods about two miles from the river." (Maloney 1945). Derby's report of 1849 (Farquhar 1932) noted a 2-mile-wide belt of woods on both sides of the lower Feather River. The map accompanying the report (included in SWC Exhibit 276, Fig. B-4) shows riparian forest some 2 to 5 miles in width bordering the entire mapped portion of the river system from the vicinity of Clarksburg in the south to Glenn in the north. The widths shown on this and other early maps are certainly not accurate as they are not based on surveys (Thompson 1961, 1977).

Many of the riparian forest accounts are difficult to interpret because travelers vary widely in their knowledge of botany. Some travelers are apparently only familiar with oak and report it everywhere to the exclusion of all else. This is certainly because the oak is one of the commonest trees, and some 500 species occur throughout the world. Additionally, the valley oak is spectacular, it is the largest of the western oaks, and it often grows to over 100 feet (Jepson 1910, p.206). However, many of the other trees present in the valley, such as the sycamore, are comparatively uncommon elsewhere and thus are only cited by the better informed observers. Some travelers even report trees that do not occur in California or clearly indicate that they do not know what trees they are observing (e.g., see Lienhard, 1846-50 in following accounts).

For these reasons, the available material was carefully screened to eliminate inaccurate or biased accounts. Many of the following types of accounts were not reported: (a) accounts of generic timber or forest in which tree types were not identified; (b) accounts of trees that were not present in California; (c) accounts of oak everywhere to the exclusion of all else; (d) inaccurate descriptions of well-traveled sites that had been accurately and extensively documented by others (e.g., Sacramento River near Rio Vista).

EYE-WITNESS ACCOUNTS OF RIPARIAN FORESTS

OBSERVER, DATE: Sal, 1796
LOCATION: Mokelumne River
DESCRIPTION: "[T]he Rio de la Pasion [is] populated with ash, alder, and other trees, and with a very deep channel."
REFERENCE, PAGE: Cook I, 242 (Report of Hermenegildo Sal, San Francisco, January 31, 1796, Cal. Arch., Prov. St. Pap., XIV: 14-16)

OBSERVER, DATE: Munoz (Moraga expedition), 1806 (September-October)
LOCATION: Merced River
DESCRIPTION: "[T]he entire river bottom possesses fine lands, well covered with grass and populated with oak trees . . . . The borders of this river carry much willow, ash, poplar, and shrubbery."
LOCATION: Area of Stanislaus River
DESCRIPTION: "The banks are covered with an infinity of wild grapevines, a little torote, and an abundance of ash trees."
LOCATION: Mokelumne River
DESCRIPTION: "[The river] has also much ash, willow, torote, and wild vines."
LOCATION: Area of Mariposa and Chowchilla Creeks
DESCRIPTION: "[We] . . . encountered a line of oaks and willows which contain the bed of a large stream [Mariposa Creek] . . . . [Chowchilla River] has grass, willows, oaks, and ash."
REFERENCE, PAGE: Cook I, 249-253 (Diary of Father Pedro Munoz, Santa Barbara Arch. IV:1-47)

OBSERVER, DATE: Moraga, 1810 (October)
LOCATION: Merced River
DESCRIPTION: "The little timber that exists is willow, ash and oak; for only in the sierra did we see pinon pine."
LOCATION: Merced River at junction with San Joaquin River
DESCRIPTION: "There are some beautiful willow groves, but also there is the disadvantage that not one stone can be found."
REFERENCE, PAGE: Moraga, 23-24

OBSERVER, DATE: Viader, 1810 (October)
LOCATION: San Joaquin River, proceeding southeast from Delta
DESCRIPTION: "[We] went up the river, southeasterly through oak groves, willow thickets, ponds, and lands flooded during the freshets."
LOCATION: Merced River, near junction with San Joaquin River
DESCRIPTION: "Here is much wood on both banks of the river: oak, live oak, cottonwood, cypress, willow, etc."
REFERENCE, PAGE: Cook I, 259-260 (Report of Father Jose Viader, From 19 to 27 October, 1810)

OBSERVER, DATE: Abella, 1811 (October)
LOCATION: Lower Sacramento River
DESCRIPTION: "Each branch [of the river] is covered with trees on both banks, of various kinds and very large."
REFERENCE, PAGE: Cook I, 264 (Abella, Diario de un registro de los rios grandes, October 15-31, 1811)

OBSERVER, DATE: Estudillo, 1819
LOCATION: San Joaquin River, proceeding toward Merced River
DESCRIPTION: "[The Indian] pointed out on the other shore of the river a great willow thicket and tular . . . . I had to cross by swimming and maneuvering about with considerable trouble because of the obstacles, the great density of trees, willows and zarxamora on both sides . . . . All the San Joaquin River and the arroyo of Santa Rita is studded with groves of a very large species of willow."
REFERENCE, PAGE: Gayton, 83

OBSERVER, DATE: von Kotzebue, 1824
LOCATION: Sacramento Valley
DESCRIPTION: "Between [the Sierra Nevada] and the [Sacramento] river the country is low, flat, thickly wooded, and crossed by an infinite number of streams, which divide the whole of it into islands."
REFERENCE, PAGE: von Kotzebue, 142

OBSERVER, DATE: Not given, 1829
LOCATION: Area of Stanislaus River
DESCRIPTION: "The village was located in the middle of a willow thicket. These bushes, interlaced one with the other by the great quantity of runners and stems of grapevines, made the area inaccessible even to the rays of the sun, not to speak of affording entry for fighting."
REFERENCE, PAGE: Cook II, 170 (A.M. Osio, Historia de California, 126-138)

OBSERVER, DATE: Work, 1832
LOCATION: Sacramento Valley below Red Bluff
DESCRIPTION: "All the way along the river here there is a belt of woods principally oak which is surrounded by a plain with tufts of wood here & there which extend to the foot of the mountain, where the hills are again wooded."
LOCATION: Lower Butte Creek
DESCRIPTION: "Where we are encamped is near the mountain, the bank of the river is well wooded with oak and other trees . . . ."
REFERENCE, PAGE: Maloney (1945a), 18, 33

OBSERVER, DATE: Belcher, 1837
LOCATION: Lower Sacramento River
DESCRIPTION: "The marshy land now gave way to firm ground, preserving its level in a most remarkable manner, succeeded by banks well wooded with oak, planes, ash, willow, chestnut, walnut, poplar, and brushwood. Wild grapes in great abundance overhung the lower trees, clustering to the river, at times completely overpowering the trees on which they climbed . . . . Our course lay between banks . . . . These were, for the most part, belted with willow, ash, oak, or plane (platanus occidentalis) [sycamore], which latter, of immense size, overhung the stream, without apparently a sufficient hold in the soil to support them, so much had the force of the stream denuded their roots. Within, and at the very verge of the banks, oaks of immense size were plentiful. These appeared to form a bank on each side, about three hundred yards in depth, and within (on the immense park-like extent, which we generally explored when landing for positions) they were seen to be disposed in clumps, which served to relieve the eye, wandering over what might otherwise be described as one level plain or sea of grass . . . . The ash is excellent, but does not attain any great size . . . . Our friend the plane, however, will not be eclipsed. The timber of this tree is solid, and does not swim; when green it seasons well, and I found it made good gunwales and timbers for light boats. Laurels, varieties of oak, sumach, pine, &c., we noticed . . . ."
REFERENCE, PAGE: Pierce/Winslow, 38-46

OBSERVER, DATE: Wilkes, 1841
LOCATION: Sacramento River, above its junction with Feather River
DESCRIPTION: "The trees that line the banks consist of cotton-wood, &c. Single oaks, with short grass beneath them, are scattered over the plain . . . . At the encamping-place was a grove of poplars of large size, some of which were seventy feet high, and two and a half feet in diameter . . . . As they proceeded up the river, the country continued of the same character, the level being only interrupted by the line of trees that bordered the river. These consist of oaks and sycamores."
LOCATION: Sacramento River above Sutter Buttes
DESCRIPTION: "The trees on the shores [of the Sacramento River] had now become quite thick, and grew with great luxuriance; so much so, that were the sight confined to the river banks, it might be supposed that the country was one continued forest, instead of an open prairie."
REFERENCE, PAGE: Wilkes, 183-184, 187

OBSERVER, DATE: Cordua, 1842
LOCATION: Area of Marysville
DESCRIPTION: "The whole estate was a valley with hardly any trees. There were only a few beautiful oaks. The banks of the river were lined with oaks, alders, willows and sycamores; here and there were arbors of wild grapes."
REFERENCE, PAGE: Gudde (1933), 284

OBSERVER, DATE: Phelps, 1841 (July)
LOCATION: Sacramento River, en route to New Helvetia
DESCRIPTION: "The immense size of the trees, the dense thickness of the unpenetrated forests in some places, and the level plains with here and there a bunch of scrub oaks without underbrush in others, together with a profusion of wild flowers such as roses, sun flowers, holly hocks and many unknown ones . . . was charming to the senses. The forests consist mostly of sycamore, a variety of oak, but mostly the white, ash & some wallnut."
REFERENCE, PAGE: Briton/Cooper/Busch, 193

OBSERVER, DATE: Brackenridge, 1841 (October)
LOCATION: Sacramento River, proceeding to Feather River
DESCRIPTION: October 11th: "[C]amped on the banks of the Sacramento, where we found a species of Platanus [sycamore] of very graceful growth." October 13th: "We found the valley on the South side of the River flatter and the soil richer, and most of the good land was covered with stately Oaks of two different species [valley oak and interior live-oak]. I calculated 20 good trees to the acre . . . . Plants observed: Dipsacus sp. - banks of river - Platanus, Willows & Ash line the banks of the river." October 22nd: "A number of evergreen species of Oak made there appearance today along the banks of a small river called the Moqueles . . . ."
REFERENCE, PAGE: Maloney (1945b), 329-332

OBSERVER, DATE: Fremont, 1844 (April)
LOCATION: San Joaquin River, below Merced River, proceeding south
DESCRIPTION: "Here the country appears very flat; oak-trees have entirely disappeared, and are replaced by a large willow nearly equal in size . . . . [T]he river was deep, and nearly on a level with the surrounding country; its banks raised like a levee, and fringed with willows . . . . After having traveled fifteen miles along the river we made an early halt under the shade of sycamore-trees . . . . Late in the afternoon we discovered timber, which was found to be groves of oak-trees on a dry arroyo . . . . Riding on through the timber . . . we found abundant water in small ponds . . . bordered with bog-rushes (Juncus effusus) and a tall rush (Scirpus lacustris) twelve feet high, and surrounded near the margin with willow-trees in bloom; among them one which resembled Salix myricoides. The oak of the groves was the same already mentioned, with small leaves, in form like those of the white oak, and forming, with the evergreen oak, the characteristic trees of the valley . . . . [C]rossing a number of dry and timbered arroyos, we traveled until late through open oak groves, and encamped among a collection of streams. These were running among rushes and willows . . . ."
REFERENCE, PAGE: Fremont (1887), 358-360

OBSERVER, DATE: Fremont, 1846 (March-April)
LOCATION: Sacramento Valley
DESCRIPTION: March 30th: "[W]e encamped on Deer creek, another of those beautiful tributaries to the Sacramento. It has the usual broad and fertile bottom lands common to these streams, wooded with groves of oak and a large sycamore, (platanus occidentalis,) . . . peculiar to California." April 5th: "[W]e resumed our journey northward, and encamped on a little creek, near the Sacramento . . . . It is . . . wooded with groves of oak, and along the creek are sycamore, ash, cottonwood and willow." April 7th: "We encamped, at an elevation of about 1,000 feet above the sea, on a large stream called Cottonwood creek, wooded on the bottoms with oaks, and with cottonwoods along the beds, which are sandy and gravely."
REFERENCE, PAGE: Fremont (1848), 21-23

OBSERVER, DATE: Bryant, 1846
LOCATION: Sacramento River
DESCRIPTION: "[The Sacramento River] is fringed with timber, chiefly oak and sycamore. Grape-vines and a variety of shrubbery ornament its banks, and give a most charming effect when sailing on its placid and limpid current."
LOCATION: Northern San Joaquin River
DESCRIPTION: "Oak and small willows are the principal growth of wood skirting the river."
LOCATION: Dr. Marsh's ranch
DESCRIPTION: "[T]he San Joaquin, at a distance of about ten miles, is belted by a dense forest of oak, sycamore, and smaller timber and shrubbery."
LOCATION: Delta of the Sacramento River
DESCRIPTION: "The banks of the river, and several large islands which we passed during the day, are timbered with sycamore, oak, and a variety of smaller trees and shrubbery."
REFERENCE, PAGE: Bryant, 271, 301, 305, 343

OBSERVER, DATE: Grimshaw, 1848
LOCATION: Steamboat Slough
DESCRIPTION: "In passing through the narrow Steamboat Slough (then called Merritt's) the branches of the large Sycamore trees growing at the rivers edge met and formed an almost continuous arch overhead. From the Slough up, the trunks and branches of the trees protruded from the bank far out over the river on each side . . . . Before the grand rush in 1849 these obstructions were mostly removed . . . ."
REFERENCE, PAGE: Kantor, 11

OBSERVER, DATE: Derby, 1849
LOCATION: Sacramento Valley
DESCRIPTION: "The timber on the banks of the San Joaquin, Tuolumne, and Stanislaus rivers is composed almost entirely of the holly-leafed oak, a species of white oak, willow, and sycamore."
LOCATION: American River
DESCRIPTION: "On crossing the American, we passed through a fine grove of oaks which borders the stream throughout its entire extent . . . ."
LOCATION: Feather River
DESCRIPTION: "The [Feather River] . . . is lined on either bank with majestic sycamores, in a fine grove of which, upon the west bank, is situated Captain Sutter's farmhouse . . . . Its banks are thickly wooded, for some two miles in depth, throughout its entire extent, with the holly and long-acorn oaks, sycamores, beech [apparently a misattribution -- possibly cottonwood], ash, and alder trees."
LOCATION: Yuba River
DESCRIPTION: "Near [the mouth of the Yuba River] it widens to about 600 feet, the ground in the vicinity being marshy and covered with tule, and the banks difficult of access on account of the density of the alders and grape-vines with which they are lined. There are many clusters of beautiful trees -- oaks, sycamores, and ash -- upon its banks, but it is not thickly wooded, as is the case with the Sacramento and Feather rivers and their branches."
LOCATION: Bear Creek
DESCRIPTION: "[Its banks are] thickly wooded toward its mouth, mostly with scrub-oak, buck-eye, and alder."
REFERENCE, PAGE: Farquhar (1932a), 103, 108-117

OBSERVER, DATE: Lienhard, 1846-1850
LOCATION: Lower Sacramento River
DESCRIPTION: "Along both banks trees were visible; they appeared to be either California oaks, poplars, cottonwoods, sycamores, willows or ash."
REFERENCE, PAGE: Wilbur, 38

OBSERVER, DATE: Ringgold, 1849-1850
LOCATION: Lower Sacramento River
DESCRIPTION: "The banks increase in altitude, gradually, after leaving the mouth of the river, and groves of sycamore and oaks are soon reached . . . ."
REFERENCE, PAGE: Ringgold, 28

OBSERVER, DATE: J.W. Audubon, 1849-1850
LOCATION: Area of French Camp
DESCRIPTION: "The road from Stanislaus over broad prairies of poor sandy soil extends for miles until nearing the edge of the line of beautiful old oaks that fringe French Creek and its swamps . . . ."
REFERENCE, PAGE: Audubon, 227

OBSERVER, DATE: Williamson, 1853
LOCATION: San Joaquin Valley
DESCRIPTION: "[The Tuolumne] river, as indeed are all the rivers flowing into the San Joaquin and the lakes, is fringed with trees. In the summer and autumn, when the water is low, these trees are 20 and 30 feet above the river . . . . The whole of this [Kaweah River] delta is covered with a luxuriant growth of oak."
REFERENCE, PAGE: Williamson, Vol. V, Part I, 12-13

OBSERVER, DATE: Williamson, 1855 (?)
LOCATION: Sacramento Valley
DESCRIPTION: "Of trees, there are none, except such as grow in narrow lines along the streams. These belts of timber are of varying breadth, from a mile or more, or wide-spreading magnificent oaks . . . to a meager border of willows, poplar, or sycamore, hung with festoons of grape along the water's edge."
REFERENCE, PAGE: Williamson Vol. VI (Geological Report), 20-21
DESCRIPTION: "The forest trees, which, in the [Sacramento] valley, are confined to the banks of the streams, are chiefly oaks, sycamores, and cottonwoods. . . . [The Sacramento River] is bordered by a dense growth of willows, sycamores and oaks."
REFERENCE, PAGE: Williamson Vol. VI (General Report), 26, 38
DESCRIPTION: "The banks of the streams are lined with belts, of greater or less width, of timber, which are composed chiefly of the long-acorned oak, here exhibiting a size and beauty of form not surpassed, if equaled, by the oaks of any other part of the world. Along the water's edge, the sycamore, the cottonwood and two species of salix [willow] are overgrown by grape vines and form a screen, by which the view of the river is frequently shut out from the traveler upon its banks. At the north end of the valley, along the river, and on the hills which border it, are found many plants not met with below. Of the trees, Q. Hindsii, Q. Garryana, and Q. Agrifolia, the 'nut pine,' and cottonwood, were the most common . . . . [The sycamore] is growing on the banks of the Feather river, a few miles above its mouth, and situated on the alluvial bottom but some 40 feet above the stream, and a little separated from the belt of timber -- principally sycamore -- which line its banks. This tree had a diameter of trunk of over 6 feet, an altitude of about 100 feet, and a spread of branches nearly equal to its height, constituting one of the noblest specimens of vegetation I have ever seen . . . . We found [sycamore] bordering the Sacramento river and its tributaries in all parts of the Sacramento valley, but did not meet it further north."
REFERENCE, PAGE: Williamson Vol. VI (Botanical Report), 14-15, 34

OBSERVER, DATE: Brewer, 1862 (August)
LOCATION: Sacramento River, area of Red Bluff
DESCRIPTION: "[G]enerally we saw only the river and its banks, which were more or less covered with trees -- willows, cottonwoods, oaks, and sycamores -- with wild grapevines trailing from them."
REFERENCE, PAGE: Brewer, 296 (Farquhar (1949), 296?)

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