

Irrigation induced change in vegetation and evapotranspiration in the Central Valley of California

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Abstract

Landscape changes in the Central Valley of California, USA, have been dramatic over the past 100 years. Irrigated agriculture has replaced natural communities of California prairie, riparian forest, tule marsh, valley oak savannah, and San Joaquin saltbrush. This paper addresses the implication of vegetation change on evapotranspiration as a consequence of these changes. It was found that an increase in irrigated agriculture and a 60% reduction in the aerial extent of native vegetation has not produced significant changes in the moisture transfer to the atmosphere. The apparent reason for this result is that irrigated agriculture has substituted one actively transpiring surface for another and, therefore, has not significantly altered the transpiration **flux** of the landscape.

Introduction

Modern agricultural systems produce impressive quantities of food, but the resulting biotic environment is an artificial ecosystem in which the diversity of the natural vegetation has been replaced by a relatively small number of cultivated plants more vulnerable to climatic change than the naturally occurring plant species they replace (Oram 1985). Changes in the natural balance of the soil-vegetation-climate relationship induced by irrigated agriculture are less obvious than the vegetation alterations, but the changes in the radiation, heat, and moisture balances alter physical processes that link the earth's surface and the atmosphere (Fritschen and Nixon 1967; Miller 1977). The most obvious effect of irrigated agriculture on processes at the earth-atmosphere interface is that irrigation promotes the presence of an actively transpiring surface sustained by the constant availability of soil

moisture (Rutter 1975; Eagleson 1978b; McIlroy 1984).

Interest in the relationship between irrigated agriculture and regional moisture exchange processes is due in part to the sensitivity of agriculture to changing climate (Oram 1985) and in part to the projection that the global water demand for irrigation will nearly double by the year 2000 (SMIC Report 1971). The purpose of this paper is to examine the change in vegetation that has occurred in the Central Valley of California as a result of irrigated agriculture. The implications of the conversion of native vegetation to irrigated crops is assessed by comparing areal evapotranspiration for the natural landscape and the current irrigated landscape and the related changes in the spatial pattern of evapotranspiration.

The importance of agriculture to the soil-vegetation-climate system has been studied with respect to the destruction of tropical rainforests (Lock-

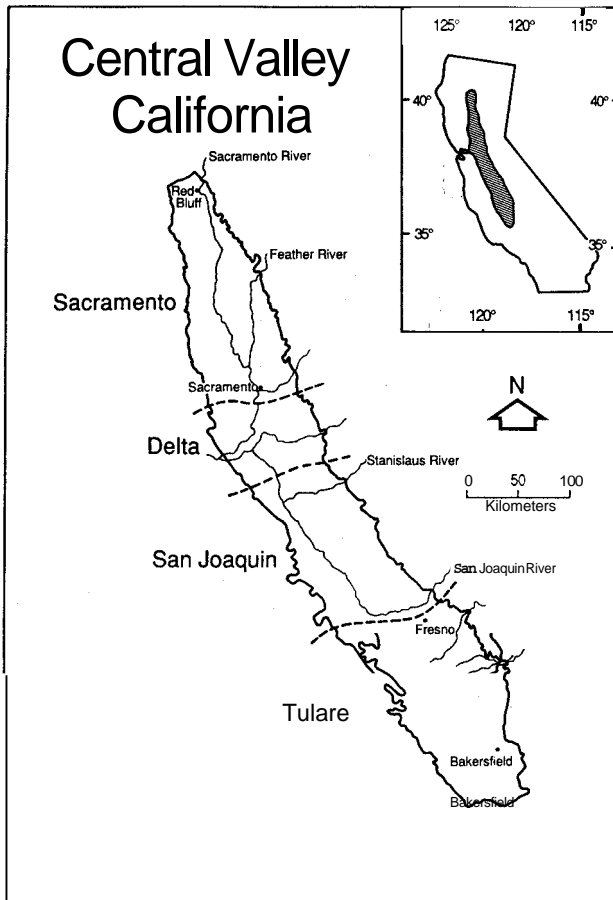


Fig. 1. The study area and subbasins.

wood 1983; Henderson-Sellers and Gornitz 1984), the spread of desertification (Sagan *et al.* 1979; Potter *et al.* 1981; Henderson-Sellers and Wilson 1983; Gornitz 1985), and the effects of irrigation on precipitation (Schickedanz and Ackermann 1977; Barnston and Schickedanz 1984). In addition, current knowledge of the role of evapotranspiration in the earth's energy and moisture systems has stimulated interest in examining the extent of regional variability in the soil-vegetation-climate system resulting from the spread of irrigated agriculture (Eagleson 1978a; Shukla and Mintz 1982). Knowledge of evapotranspiration from pre-irrigation landscapes provides important benchmark data for assessing the magnitude of change resulting from altering the plant cover and increasing moisture availability by irrigation.

The study area

The semiarid Central Valley of California is an ideal location for examining irrigation related changes in vegetation and evapotranspiration. The Central Valley, composed of the Sacramento, Delta, San Joaquin, and Tulare subbasins, is a structural depression surrounded by mountains and filled by alluvium derived from the mountains (Fig. 1). It is approximately 640 km long, 48–112 km wide, and covers about 52,000 km². The valley's fertile soils and a dry summer subtropical climate support one of the greatest agricultural economies in the world. Four of the nation's top five agricultural counties, in terms of the value of crops sold, are in the southern half of the Central Valley (Williamson 1982), and the agricultural output of the Central Valley contributes significantly to California being ranked first in the nation in production of more than 20 farm commodities (Gardner *et al.* 1982).

Irrigation has been a major factor in California achieving a leading position in agricultural production. Even though California was the world's leading exporter of wheat in the late 1800s (Loomis 1983), dramatic increases in crop diversity were possible with the introduction of irrigation. By 1966, approximately 95% of the tonnage of agricultural products harvested in California was produced on irrigated land (Williamson 1982).

The first recorded irrigation by European settlers in California was at the San Diego Mission in 1770, but the first irrigation in the Central Valley did not occur until the early 1850s in the Sacramento subbasin and not until about 1870 in the San Joaquin subbasin (Harding 1960; Pisani 1984). Early in this century, irrigation expanded at an irregular rate due to technologic, economic, and climatic factors (Harding 1960; McGowan 1961; Pisani 1984) and much of the present irrigated agriculture evolved after World War II. A period of rapid expansion began in the 1950s when water was made available by the Central Valley Project developed by the U.S. Bureau of Reclamation and when the State Water Project constructed by the California Department of Water Resources became operational in 1967. Between 1959 and 1975, irrigated acreage increased

43% in the Central Valley and evapotranspiration by irrigated crops increased 32% (Williamson 1982).

Today, some 2.9 million ha of irrigated crops occupy about 57% of the Central Valley and account for over 75% of the irrigated acreage in California. No other single area in the state contains as much as 7% of the total irrigated acreage. As a proportion of the total area of the Central Valley, irrigation increases from north to south with the Tulare subbasin containing 1.37 million ha (Williamson 1982). Crops in the Central Valley receive about 32.3 km³ of applied water or over 77% of the irrigation water used statewide (Stewart 1975). Evapotranspiration of applied irrigation water from these crops is in excess of 18.7 km³ annually and 68% of this moisture flux occurs in the San Joaquin and Tulare subbasins (Williamson 1982).

Another irrigation related moisture transfer to the atmosphere is by evaporation from water storage and delivery facilities and drainage ponds. Unfortunately, estimates of evaporation from these free water surfaces are not available due to the difficulty in separating evaporation and seepage losses (Gardner et al. 1982). The native landscape of the Central Valley, however, contained extensive areas of rivers, ponds, marshes, and at least two large shallow lakes that supplied abundant moisture for evaporation (Harding 1960). Since much of the marsh land and the shallow lakes have disappeared from the landscape, it will be assumed that free water evaporation losses from the natural and the irrigated landscapes are approximately equal. This assumption permits a focus on the role of vegetation change in the moisture transfer process.

Native vegetation and the pre-agricultural landscape

In the Central Valley, the pre-agricultural landscape was a composite of soils and vegetation related to the semiarid conditions of the valley floor and landscape features related to runoff from the more humid environment in the Sierra Nevada to the east. Consequently, the natural landscape in the Central Valley contained two major river systems,

an expanse of perennially flooded land that remained inundated for much of the year, tributary streams that drained to the valley floor through sloughs and marshes rather than connecting directly with major stream channels, and an island-dotted structural basin known as the Sacramento-San Joaquin Delta (McGowan 1961; Thompson 1961). The floor of the Central Valley was a composite of open water, swamps and marshes, alkali sinks, riparian forest, and grassland (Kuchler 1977; Major 1977). In 1880, over 800,000 ha were classified as swamp and overflow lands and most of this land required extensive drainage before irrigated agriculture could be introduced (Harding 1960).

Due to seasonal variations in the amount of land flooded and differences in land classification definitions in the early records, it is difficult to determine precisely the areal characteristics of various vegetation types. However, Kuchler's (1977) map of major vegetation types in California provides the basis for a conservative estimate of the areal extent of native vegetation in the Central Valley (Table 1). Evapotranspiration by native vegetation is estimated using available data for representative stations and area weighting of these estimates quantifies the total moisture flux to the atmosphere.

Tule marsh covered approximately 15% of the pre-agricultural landscape of the Central Valley (Kuchler 1977). Tules (*Scirpus acutus*) and cattails (*Typha lactifolia*) which grow to heights of 180–300 cm (Young and Blaney 1942) are the dominant plants in this vegetation type. Dense formations of these hydrophytes were found on marsh and overflow lands along the Sacramento and San Joaquin rivers. The largest areas of tule marsh, however, occupied the perennially wet portions of the Delta and Tulare subbasins (Table 1).

Tules and cattails grow with their roots in water or in very wet soils and consume greater quantities of water than other plants (Linacre 1976). As much as 90 cm of their cylindrical stems may be under water. Techniques for measuring and estimating water use by vegetation that grows in water or in very wet soil have been described by Young and Blaney (1942), Blaney (1961), and Linacre (1976). Based on consumptive use data from tanks set in natural swamp areas in the Delta, the estimated

Table 1. Estimated area and evapotranspiration for native vegetation in the Central Valley and subbasins.

Vegetation type	Sacramento		Delta		San Joaquin		Tulare		Central Valley	
	Pre-ag. ^c	Present ^d	Pre-ag.	Present	Pre-ag.	Present	Pre-ag.	Present	Pre-ag.	Present
California prairie: Area ^a	1,029	550	489	311	655	282	975	321	3,148	1,464
California prairie: ET ^b	2,928	1,564	1,404	889	1,873	803	2,775	917	8,980	4,173
Tule marsh: Area	147	43	235	112	117	23	261	51	760	229
Tule marsh: ET	3,675	1,080	5,843	2,787	2,936	565	6,483	1,263	18,937	5,695
San Joaquin saltbrush: Area	0	0	0	0	58	18	496	126	554	144
San Joaquin saltbrush: ET	0	0	0	0	91	28	750	191	841	219
Riparian forest: Area	200	83	64	40	90	0	24	0	378	132
Riparian forest: ET	3,265	1,384	1,057	650	1,478	151	408	0	6,208	2,185
Valley oak savanna: Area	0	0	0	0	0	0	204	26	204	26
Valley oak savanna: ET	0	0	0	0	0	0	1,238	161	1,238	161
Total: Area	1,376	676	788	463	920	332	1,960	524	5,044	1,995
Total: ET	9,868	4,028	8,304	4,326	6,378	1,547	11,654	2,532	36,204	12,433

^a Units are 1,000 ha. ^b Evapotranspiration; units are hm³. ^c Pre-agricultural area planimeted from Kuchler 1977. ^d Present area calculated from Williamson 1982.

transpiration of tules in the Central Valley is about 2642 mm of water annually and the transpiration of cattails is about 2286 mm annually (Young and Blaney 1942).

Riparian forest, composed of medium tall to tall broad-leaved deciduous trees, occupied natural river levees and accounted for approximately 8% of the total area of the Central Valley (Table 1). The composition of the native riparian forests is uncertain (Griffin 1977), but Thompson (1961) provides an excellent review of historical accounts and Kuchler (1977) suggests that cottonwood (*Populus fremontii*) was the dominant species. Over one-half of the native riparian forest was in the Sacramento subbasin along five major drainage systems while the Tulare subbasin contained just two relatively small areas of riparian forest.

Riparian vegetation obtains moisture from groundwater or from water percolating out of the stream bed; consequently, riparian vegetation seldom experience moisture stress and probably consume the equivalent of evaporation from a free water surface (Young and Blaney 1942). For the Sacramento River portion of the Central Valley, where most of the riparian forest occurred, evaporation averages about 1623 mm annually (MacGillivray 1975).

The native vegetation in the Central Valley included two mesophytic vegetation types, the Cali-

fornia prairie and the valley oak savanna (Kuchler 1977). The pristine California prairie accounted for the largest area of pre-agricultural vegetation in the region (Table 1). It covered about 63% of the Central Valley and was over four times larger in area than the tule marsh which was the next largest vegetation type. The California prairie, composed of perennial bunch grass (*Stipa pulchra*) dominants and numerous annual species, occurred on well-drained land ranging in elevation from sea level to approximately 1200m throughout the Central Valley (Heady 1977).

The Sacramento and Tulare subbasins each accounted for approximately one-third of the total area of California prairie in the Central Valley (Table 1), but the distribution of the prairie was different in these two settings. In the Sacramento subbasin, topography and the location of the Sacramento River restricted the grassland on the west side of the valley to a relatively narrow band except in the extreme northern end of the region. The broader Tulare subbasin was characterized by a more equal distribution of grassland on both sides of the valley.

Evapotranspiration from mesophytic plants is easier to measure than evapotranspiration for hydrophytes and riparian vegetation because the drying soil environment that supports mesophytes presents fewer instrument problems (Miller 1977).

Also, estimates of consumptive use by plants in drying ecosystems are obtained readily using one of the numerous techniques available for estimating evapotranspiration of plants utilizing stored soil moisture (Jensen 1973). Although consumptive use by native vegetation on drying soil varies within a given vegetation type in response to local climate, soil, and drainage differences (Miller 1977), data for a representative site provide a reasonable basis for estimating the areal moisture flux.

Representative evapotranspiration from mesophytic vegetation is lower than evapotranspiration for hydrophytes and riparian vegetation by as much as a factor of eight (Table 1). The significantly lower evapotranspiration flux for these plants is the product of differences in plant physiology (Linacre 1976) and the reduced availability of moisture to plants during the dry summer months. Annual evapotranspiration from the valley grassland is estimated to be 282 mm since it occurred in areas where precipitation was moderately limiting (Major 1977).

The other mesophytic vegetation type, valley oak savanna, covered 204,000 ha and accounted for the smallest area of native vegetation in the Central Valley (Table 1). This vegetation type is characterized by valley oak (*Quercus lobata*) growing in groups or singly and towering above an underlying California prairie cover. It occurred along the east side of the Tulare subbasin south of Fresno in the vicinity of the Kings and Kaweah rivers (Kuchler 1977). Moisture available to the grasses is limited to soil moisture storage, but the oaks are able to exploit moisture drawn from groundwater (Griffin 1977). The evapotranspiration for this mesophytic vegetation is estimated to be 600 mm which combines the limited moisture available to the grasses and the unlimited moisture available to the scattered oaks (MacGillivray 1975).

San Joaquin saltbrush is the fifth major native vegetation type in the Central Valley (Table 1). This xerophytic vegetation commonly occupied poorly drained alkali soils in the arid southern and western portions of the Tulare subbasin and a comparatively small area of the central San Joaquin subbasin. San Joaquin saltbrush (*Atriplex polycarpa*) is the dominant in a broad-leaved evergreen and/or

deciduous shrub community composed of alkali-tolerant species (Heady 1977).

Estimating evapotranspiration for xerophytic plants is accomplished using techniques similar to those available for estimating water use by mesophytes (Jensen 1973). In most cases, annual precipitation closely approximates the water available to xerophytic plants. A representative value for evapotranspiration by San Joaquin saltbrush is 150 mm annually due to the limited precipitation in the southern portion of the Central Valley (Major 1977). Evapotranspiration by the tule marsh vegetation is more than 16 times greater than the rate of moisture loss from San Joaquin saltbrush.

The estimated area of native vegetation derived by planimetry of the Kuchler (1977) vegetation map and the estimates of consumptive water use by these vegetation types provide a basis for estimating the moisture flux to the atmosphere from the native vegetation. Area weighting the representative evapotranspiration data indicates that 36,200 hm³ is a conservative estimate of the total annual moisture flux to the atmosphere by native vegetation prior to irrigation (Table 1). Over one-half of the total volume of water transferred to the atmosphere was contributed by the heavily transpiring tule marsh vegetation even though this vegetation type covered only 15% of the area. The large expanse of mesophytic California prairie accounted for another 25% of the total evapotranspiration flux.

Although the tule marsh was the dominant source of evapotranspiration for the Delta and Tulare subbasins, its contribution to total evapotranspiration was slightly less in the San Joaquin subbasin and lower still in the Sacramento subbasin (Table 1). The larger areas of riparian forest and California prairie in the Sacramento and San Joaquin subbasins compensated for the higher rate of evapotranspiration by the tule marsh. Each of these native vegetation types contributed nearly equal amounts of annual evapotranspiration in the Sacramento subbasin.

The landscape with irrigation

The influence of irrigated agriculture on the Cen-

tral Valley landscape can be observed almost everywhere. More than one-half of the contemporary landscape, or approximately **29,000 km²**, is occupied by irrigated crops. Another *5,000 km²* in the Central Valley is cropland not employing irrigation (McCorkle and Nuckton **1983**). This agricultural land was previously forests, marsh and overflow land, grasslands, and alkali flats (Harding **1960**; Thompson **1961**).

The greatest expanse of surviving native vegetation is in the Sacramento subbasin and the smallest area is in the San Joaquin subbasin (Table 1). The greatest conversion of land from native vegetation to irrigated agriculture has occurred in the Tulare subbasin where native vegetation has been reduced to about **27%** of its pre-agricultural area.

California prairie continues to be the most expansive native vegetation throughout the Central Valley even though its area has been reduced to about **46%** of its original coverage (Table 1). The present-day prairie occurs as a ring around the Central Valley that increases in size from south to north. The largest area of this grassland vegetation is in the Sacramento subbasin where it occupies many of its original locations and some areas that have reverted to grasslands following the removal of riparian forests (Heady **1977**).

The substantial area of tule marsh remaining in the Central Valley belies the impact that irrigated agriculture has had on the distribution of this native vegetation. Nearly one-half of the present-day area of tule marsh is in the Delta Subbasin (Table 1). Agriculture in the western section of the Delta occurs on leveed islands that are below sea level and surrounded by marshes containing large expanses of tules and cattails (Zinke and Delwiche **1983**). In the other subbasins, much of the marsh and overflow lands that supported the tule marsh has been largely drained and the native plants replaced by irrigated crops (Harding **1960**). This particular land conversion is especially apparent in the San Joaquin and Tulare subbasins where the tule marsh has been reduced to less than **20%** of its original area.

Riparian forest is the third most widely occurring native vegetation type in the contemporary Central Valley even though it represented the second smallest area of pre-agricultural vegetation (Table 1).

The distribution of the present riparian forest is more limited, however, because nearly all of this vegetation type has disappeared in the San Joaquin and Tulare subbasins. Almost two-thirds of the contemporary riparian forest is in the northern and eastern Sacramento subbasin where topography and soils make land less attractive for irrigated agriculture. Nevertheless, the riparian forest in the Sacramento subbasin has been reduced to a fraction of its original extent (Thompson **1961**).

San Joaquin saltbrush has been replaced by irrigated crops on all but the most alkaline soils in the arid southern end of the Central Valley. Today, saltbrush occupies about one-fourth the area of its pre-agricultural habitat, but nearly **90%** of the saltbrush is in the Tulare subbasin (Table 1). The relatively flat valley floor in the San Joaquin and Tulare subbasins occupied by San Joaquin saltbrush was easily converted to agriculture as soon as irrigation water became available. The irrigated acreage in these subbasins today accounts for more than one-half of the irrigated land in California (McCorkle and Nuckton **1983**).

Irrigated agriculture has nearly eliminated the valley oak savanna from its native areas in the Tulare subbasin (Table 1). Although valley oak savanna accounted for the smallest area of the five native vegetation types in the Central Valley, it has experienced the greatest relative reduction in area. Approximately **87%** of the total area of valley oak savanna has been converted to irrigated agriculture. The remaining valley oak groves are found on alluvial fans on the east side of the valley where groundwater is available at moderate depth (Zinke and Delwiche **1983**).

The irrigated crops which replaced the native vegetation in the Central Valley comprise a highly diversified and flexible agricultural production system which contains many specialty crops (Loomis **1983**). Field crops occupy **41%** of the irrigated area, **27%** supports alfalfa and pasture, tree and vine crops account for about **22%** of the acreage, and vegetable crops are grown on about 8% of the irrigated land (Table 2). The mix of crops grown in each subbasin is determined primarily by variations in climate, soil, and water resources in the Central Valley, but it is a response to market conditions also

Table 2. Area and evapotranspiration for present selected land uses in the Central Valley subbasins.

Land use	Sacramento			Delta		
	Area ^a (1,000 ha)	Annual unit evapotranspiration ^b (mm)	Total annual evapotranspiration ^b (hm ³)	Area ^a (1,000 ha)	Annual unit evapotranspiration ^b (mm)	Total annual evapotranspiration (hm ³)
Alfalfa	53	1,222	656	36	1,095	398
Cotton	0	– ^c	0	0	– ^c	0
Deciduous orchard	92	1,057	987	33	1,006	336
Field crops	110	820	910	82	757	626
Other vegetables	17	711	123	36	757	272
Pasture (irrigated)	153	1,250	1,937	60	1,130	689
Rice	126	1,349	1,714	4	1,229	46
Subtropical orchard	2	859	14	0	– ^c	0
Sugar beets	31	1,001	310	22	1,011	228
Tomatoes	26	965	260	21	851	179
Vineyards	2	930	17	18	818	145
Total for crops	612	– ^c	6,928	312	– ^c	2,919
Native vegetation	616	770 ^d	5,260	463	924 ^d	4,326
Urban	88 ^e	625	553	13 ^e	565	76
Total	1,376		12,741	788		7,321

Land use	San Joaquin			Tulare		
	Area ^a (1,000 ha)	Annual unit evapotranspiration ^b (mm)	Total annual evapotranspiration ^b (hm ³)	Area ^a (1,000 ha)	Annual unit evapotranspiration ^b (mm)	Total annual evapotranspiration (hm ³)
Alfalfa	99	1,207	1,212	186	1,207	2,274
Cotton	36	953	352	328	965	3,200
Deciduous orchard	96	1,021	995	86	955	828
Field crops	86	747	650	299	749	2,263
Other vegetables	38	511	222	181	566	1,049
Pasture (irrigated)	116	1,245	1,460	56	1,247	708
Rice	11	1,313	141	1	1,303	17
Subtropical orchard	2	810	15	60	805	493
Sugar beets	9	975	92	31	864	274
Tomatoes	11	899	97	11	820	93
Vineyards	42	843	355	132	833	1,111
Total for crops	546	– ^c	5,591	1,371	– ^c	12,301
Native vegetation	332	461 ^d	1,547	524	477 ^d	2,532
Urban	42 ^e	622	264	65 ^e	624	411
Total	920		7,402	1,960		15,244

^a Source: Stewart 1975. ^b Source: Kodani 1979. ^c Not applicable. ^d Area weighted average. ^e Source: U.S. Census.

(McCorkle and Nuckton 1983).

In the Sacramento subbasin, the largest areas of irrigated cropland are in pasture, rice, and field crops (Table 2). These three crops account for about 64% of the irrigated acreage. In contrast, subtropical orchards and vineyards represent less than 1% of the irrigated land.

Field crops and pasture are the two largest irrigated crop acreages in the Delta subbasin (Table 2). Except for the small acreage in rice, the crop areas are much more balanced in the Delta subbasin than in any of the other three subbasins.

Irrigated pasture is the largest crop area in the San Joaquin subbasin, but it accounts for just over 20% of the total irrigated area (Table 2). Cotton and vineyards play a more prominent role here than in the two northern subbasins.

The four largest areas of individual crops in the Tulare subbasin are all greater in size than the largest crop area in the other three subbasins. Cotton accounts for the largest area, but it is followed closely by field crops (Table 2). Vineyards are the fifth largest crop in the Tulare subbasin, but they are larger than any other crop area in the Central Valley except for irrigated pasture in the Sacramento subbasin.

Annual evapotranspiration varies with the crop and with climatic controls in the region. Evapotranspiration of some crops is higher in the San Joaquin and Tulare subbasins than in the Sacramento subbasin due to greater energy loadings and higher temperatures in the southern subbasins. Annual water requirements are typically 25–50 mm less in the Delta due to the cool ocean breeze which enters the valley through this region (Kodani 1979). However, within each subbasin the variation in evapotranspiration and in climatic indices that are indicators of evapotranspiration are small in both time and space and the error added by areal extension of point data is less than 5% (Williamson 1982).

Crop evapotranspiration occurs from March through October with a peak in July. Almost all of the applied water demand occurs from April through October but the winter season ground cover consumes some water (Kodani 1979). The annual total evapotranspiration for crops in the

Central Valley is estimated to be about 27,700 hm³ (Table 2).

Irrigated pasture produces the largest evapotranspiration flux of 4,794 hm³ followed closely by alfalfa and field crops. These three sources combined account for 50% of the total annual evapotranspiration from irrigated crops in the Central Valley. However, each subbasin contains a slightly different mix of crops which accounts for the maximum evapotranspiration flux. These differences represent variations in climate and cropping patterns within the Central Valley. Irrigated pasture and rice are the leading sources of evapotranspiration in the Sacramento subbasin, while the major sources of evapotranspiration in the Delta subbasin are irrigated pasture and field crops (Table 2). In the San Joaquin subbasin, irrigated pasture and alfalfa produce more evapotranspiration than other crops by a factor of 10. Cotton, alfalfa, and field crops are the principle sources of evapotranspiration in the Tulare subbasin.

Total annual evapotranspiration from the irrigated landscape is estimated to be 42,700 hm³ (Table 2). Two-thirds of this moisture flux, or approximately 27,700 hm³, is derived from irrigated crops and, since urban areas contribute relatively little moisture, most of the remaining evapotranspiration is contributed by the surviving native vegetation.

Comparison of the pre-agricultural and contemporary landscapes

The introduction of irrigated agriculture in the Central Valley has resulted in several distinct changes in the vegetation component of the landscape. Perhaps the most apparent result of irrigation is the expanse of green plants across the valley floor throughout the spring and summer. The irrigated crops contrast markedly with much of the native vegetation, especially the California prairie, which turns brown by late spring. Also, the area occupied by trees in the Central Valley has been reduced appreciably.

Although the Central Valley is often perceived as a single landscape unit, the impact of irrigated agri-

culture on native vegetation displays distinct spatial variability within the Central Valley. In general, native vegetation has been replaced less extensively in the northern section of the valley than in the southern portion. The present landscape in the Sacramento subbasin has the largest area of native vegetation and the Delta subbasin has the third largest area (Table 1). Although the Tulare subbasin has the largest total land area, its present area of native vegetation is only 60,000 ha larger than the areal expanse of native vegetation in the Delta subbasin. The smallest area of native vegetation in the contemporary landscape is in the San Joaquin subbasin.

The smallest reduction in native vegetation has occurred in the Delta subbasin where about 41% of the land has been converted to irrigated agriculture. This does not suggest, however, that irrigated agriculture has not altered the landscape in this subbasin. A significant component of the change in native vegetation has been a 52% reduction in tule marsh (Table 1) which has resulted from the creation of islands protected by levees. The cultivated land on the leveed islands was previously covered by water for most or all of the year.

The Tulare subbasin represents the most severe change in vegetation resulting from the introduction of irrigated agriculture. Only about 27% of the subbasin area is still inhabited by native vegetation (Table 1). Irrigated crops occupy all of the land that was once riparian forest and all but a small percentage of the valley oak savanna habitat. Tule marsh in the Tulare subbasin has been reduced to about one-fifth of its previous area, and San Joaquin saltbrush occupies an area one-fourth its pre-agricultural extent.

Changing the vegetation structure of the Central Valley has altered the transfer of moisture to the atmosphere, but there are several surprising facets to the change in evapotranspiration. In the pre-agricultural landscape, the largest evapotranspiration flux was provided by the Tulare subbasin and was supported largely by the expanse of tule marsh (Table 1). The arid conditions in this subbasin make such a large volume of evapotranspiration unexpected. It was made possible by runoff draining into the valley from the east which sustained the

tule marsh habitat.

In the present landscape, evapotranspiration from native vegetation in the Tulare subbasin is little more than 20% of the pre-agricultural volume. This is the smallest percentage among the four subbasins. However, irrigated crops in the Tulare subbasin more than compensate for the reduced evapotranspiration by native vegetation. Evapotranspiration from irrigated crops (Table 2) is greater than the evapotranspiration by native vegetation in the pre-agricultural landscape, and the total evapotranspiration from the current landscape exceeds the volume of pre-agricultural evapotranspiration by about 3,600 hm³.

The change in evapotranspiration in the Delta subbasin is notable also. In this case, evapotranspiration for the irrigated landscape is less than evapotranspiration for the pre-agricultural landscape by about 1,000 hm³ (Table 1). This is the result of tule marsh and riparian forest being replaced by irrigated crops which use less water than the native vegetation. It is a highly uncommon occurrence for irrigated crops to result in a reduced evapotranspiration flux.

For the entire Central Valley, annual evapotranspiration from the irrigated landscape is about 6,500 hm³ greater than the moisture flux from the pre-agricultural landscape. Distributed evenly over the entire basin, this amounts to 0.35 mm per day for the entire year or 0.7 mm per day if the difference is assumed to occur during a six-month growing season. In either case, these are relatively small magnitudes compared to the amount of precipitable water already present in maritime air masses advected into the valley (Lott 1976). If the irrigation contribution is lumped into a six-month growing season from April to September, the additional water vapor represents about a 10% increase in all months except April when it is equivalent to an 18% increase.

Conclusions

Irrigated agriculture has increased markedly in the Central Valley since the turn of the century. As a consequence, the area of native vegetation has been

reduced by about 60% and all five of the major native vegetation types have been affected. The extent to which the area of each native vegetation type has been altered most varies among the subbasins.

Riparian forest has been eliminated in the Tulare subbasin while the California prairie in the Delta subbasin has been reduced the least. Throughout the Central Valley, a greater percentage of the California prairie remains today than any of the other native vegetation types. Still, the area of prairie converted to irrigated agriculture in each of the subbasins is larger than the reduction in area for any of the other four native vegetation types.

Expressing the area of each native vegetation type in the present landscape as a percentage of the area in the pre-agricultural landscape provides a convenient method for expressing the relative change in each subbasin. On this basis, the greatest vegetation change in the Sacramento and Delta subbasins has been in the tule marsh habitat while the riparian forest habitat was reduced the most in the San Joaquin and Tulare subbasins.

The change from native vegetation to irrigated agriculture in the Central Valley has not produced a significant increase in moisture transfer to the atmosphere. Irrigation is estimated to have increased the total volume of evapotranspiration about 18% only. At the same time, the spatial distribution of evapotranspiration in the Central Valley has not been altered appreciably. The apparent reason for the surprisingly small change in evapotranspiration in the Central Valley is that initiation of irrigated agriculture involved substitution of one actively transpiring surface for another and not the introduction of an enhanced evapotranspiration flux. Consequently, the altered moisture flow to the atmosphere usually associated with irrigation is significantly smaller in magnitude in the Central Valley.

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