

# **Survey of Irrigation Methods in California**

By Morteza Orang, Richard Snyder and Scott Matyac, DWR and UC Davis

# Survey of Irrigation Methods in California in 2001

Morteza N. Orang<sup>1</sup>, Richard L. Snyder<sup>2</sup>, J. Scott Matyac<sup>3</sup>

## Abstract

This report discusses a statewide survey of irrigation methods conducted in California during 2002. The purpose of the study was to collect information on irrigation methods to determine which methods were used by growers to irrigate their crops in 2001. Reliable information on irrigation methods is an important factor for planning future water demand by agriculture irrigation based on trends. To conduct the survey, one-page survey form was developed to collect irrigated land (acres) by crop and irrigation method. Then a questionnaire was mailed out to 10,000 of the estimated 80,000 growers in California by the California Department of Food and Agriculture. The results from comparing earlier studies with 2001 indicated that the amount of land irrigated by drip irrigation method has increased by about 33%, while the amount of land irrigated by surface methods has decreased by about 31%. The area planted to orchards and vineyards has increased, while that planted to field crops has declined. The largest increase in sprinkler use has been in vegetable crops, an increase of 19% since 1972. The 1991 and 2001 statewide surveys exclude rice acreage.

## Introduction

The application of water to soils for crop use is referred to as irrigation. Surface (gravity-driven surface irrigation), sprinkler, drip/micro, and sub-surface are types of irrigation methods that are used by growers to irrigate various crops in the state. The irrigation methods that growers use to apply water may affect the salt accumulation in the crop root zone (leaching), plant transpiration, soil evaporation, and runoff from soil surface. Irrigation performance is commonly measured by how much of applied water beneficially used for crop production. Irrigation (application) efficiency or consumed fraction is an index used to quantify the efficient use of water diverted to a field by an irrigation system and is defined as the ratio of that quantity of water stored in the root zone, which can be used in evapotranspiration to the amount of applied water as a percentage. Distribution uniformity (DU) is also an important element in irrigation water use efficiencies. DU is the measure of the uniformity of irrigation water distribution over a field. The most appropriate irrigation method for an area depends upon physical site conditions, the crops being grown, amount of water available, and management skill. The water management decisions strongly influence how uniform water can be applied through different irrigation methods to provide optimal soil water conditions for crop growth and marketable yields. The main objectives are to avoid water stress, achieve high yields and protect water quality. Water losses from irrigation vary with the type of irrigation method. In the absence of a reliable irrigation system, the water application is often non-uniform and is generally over applied, resulting in excess runoff and deep percolation below the root zone. If part of the

<sup>1</sup> Staff land and water use scientist, California Department of Water Resources – Division of Planning and Local Assistance, PO Box 942836, Sacramento, CA 94236-0001

<sup>2</sup> Biometeorologist, University of California, Atmospheric Science, Davis, CA 95616

<sup>3</sup> Senior land and water use scientist, California Department of Water Resources – Division of Planning and Local Assistance, PO Box 942836, Sacramento, CA 94236-0001

field is over irrigated, the crop roots near the soil surface will be exposed to water that has salinity near that of the irrigation water rather than an average root zone soil salinity value. As a result, crop yields are generally more affected by the irrigation water salinity level than by the soil water salinity in the lower part of the root zone. However, the use of a proper irrigation method that fits the crop, water, and site conditions will ensure that losses are held to a minimum and subsequently, will result in high irrigation efficiency and distribution uniformity.

Runoff and deep percolation generally are greater for gravity systems than for well managed sprinkler and drip/micro irrigation methods. The combined losses of deep percolation and runoff for poor managed gravity irrigation system will lower consumed fraction and subsequently, will pollute the surface water and groundwater supplies. Sprinkler and drip/micro systems reduce runoff or deep percolation compared to gravity irrigation, because these type systems provide complete control over the amount of water applied to the field. As a result, water is distributed more uniformly within the intended root zone. Generally, more water is used with gravity and sprinkler irrigation on an annual basis than with drip/micro. According to the “Report on Evaporation from Irrigated Agricultural Land in California” by Charles Burt of CalPoly, gravity and sprinkler irrigation tends to wet larger fractions of the soil surface (0.6-1.0, or 60%-100%, of the soil surface is wet during a typical irrigation) than drip/micro systems. In addition, it is often difficult to control the application depth of irrigation water because of uniformity and scheduling constraints. Drip/micro has typical wetted fractions ranging from almost 0, for subsurface drip, to 0.8, for some micro spray on tree crops. A typical range for trees in California is 0.3-0.6 for surface drip/micro. Drip/micro is also considered to have more flexibility for irrigation scheduling. Water resources project planning requires reliable estimates of crop and irrigation system combinations, which are important components in a variety of water budget analysis. To update California’s records on irrigation methods used within the state, a survey is conducted by the California Department of Water Resources about every 10 years. The gathered survey data is analyzed and compared with earlier surveys to study how irrigation methods are changing and to make projections of future changes for long-term planning.

The purpose of this report is twofold; (1) to demonstrate the reliability of the 2001 irrigation survey results on the number and type of irrigation systems used in California and (2) to present the results of our study comparing the earlier estimates to the 2001 estimates. Reliable information of current irrigation methods by various crops is extremely important for the California Department of Water Resources for planning its future water demand by agriculture irrigation based on trends. The absence of reliable information can severely limit its usefulness for long-term water planning purposes.

## Methodology

Approximately every 10 years one-page irrigation survey forms are mailed out to many growers throughout California to conduct a statewide survey to update California’s records on irrigation methods. A statewide survey of current irrigation methods was conducted during 2002 to determine which irrigation methods were used in California during 2001. The 1991 was chosen as the base year to keep a 10-year period between this survey and the previous study done during 1972. Earlier surveys of irrigation methods had been conducted by Ian Stewart in 1972 and by Robert Hagan with California Department of Water Resources in 1980. In these studies, irrigated crop acreage was estimated by UC Cooperative Extension specialists and county farm advisors in each county. The 1991 and 2001 studies were conducted by mailing questionnaires to growers who were randomly selected from a list of growers. A list

of 58,000 of the estimated 80,000 growers in California from the California Department of Food and Agriculture (CDFA) was used to determine the mailing list. All rice-only growers were excluded from the list. Since valid data on the rice acreage for any given year is available and the irrigation method is flooding, collecting this information was unnecessary. Non-irrigated farms and large livestock ranches were also excluded from the survey. Growers were asked to state the main county in which they farmed and the acreages they had planted during 2001 to each of 20 possible crops by irrigation method within that county. Number and types of crops used in 2001 survey are slightly different from those used in 1979, 1980, and 1991. The 2001 survey of irrigation methods included a 20-crop category as opposed to 13-crop category used in 1991 survey. A list of crops used in 1972, 1980, 1991, and 2001 surveys are shown in Table 1. Note that the 1991 and 2001 surveys did not include rice, whereas 1979 and 1980 studies did include rice acreage (Table 1). Survey forms were mailed by the California Department of Food and Agriculture to an estimated 10,000 growers in 58 counties and there was a 35% useable return rate. A sample of the 2002 survey form is shown in Figure 1.

**Table 1. Crop types used in 1972, 1980, 1991, and 2001**

2001 Crop Group	1991 Crop Group	1980 Crop Group	1972 Crop Group
Alfalfa	Alfalfa	Alfalfa	Alfalfa
Grain	Small Grains	Grain	Small Grains, Misc. Hay
Corn	Corn	Corn	Corn
Cotton	Cotton	Cotton	Cotton
Other Field Crops, Dry Beans, Safflower,	Other Field Crops	Miscellaneous Field	Other Field Crops
Pasture, Turf grass and Landscape	Pasture	Pasture	Pasture
Almond & Pistachio, Other Deciduous	Deciduous Fruits and Nut Trees	Deciduous Fruits And Nut Trees	Peaches & Nectar./Prunes/ Almonds/Walnuts
Subtropical Trees	Subtropical	Subtropical	Citrus & Avocado/Other Orchard
Sugar Beets	Sugar Beets	Sugar Beets	Sugar Beets
Tomato (fresh), Tomato (process)	Processing Tomatoes	Tomatoes	Tomatoes
Other Truck Crops, Onion & Garlic, Potato, Cucurbit	Vegetables (Truck Crops)	Miscellaneous Truck	Beans, All Types/Potatoes/ Lettuce/Other Veg. Crops
Vineyard	Grapes And Bush Berries	Vineyard	Grapes
		Rice	Rice

**Figure 1. A sample of the irrigation survey form to gather irrigated acreages by crop and by irrigation method in 2001**

ACERAGE IRRIGATED BY CROP AND BY IRRIGATION METHODS IN 2001

What is the name of the main county where you farm? \_\_\_\_\_ Please fill in the **number of acres** of each crop irrigated by each method in **2001** (include only those acres in the main county where you farm).  
 In the shaded cell, below the number of acres, enter the **main water source** for that irrigation system and crop: **S = surface water, G=ground water, or B = both**

CROP (not including rice)	SUBSURFACE DRAIN PIPE OR DITCH (NOT DRIP)	IRRIGATION METHOD															
		SURFACE				SURFACE-SPRINKLER		SPRINKLER						DRIP			
		WILD FLOOD	BORDER	BASIN	FURROW	FURROW SIDE- ROLL	FURROW HAND- MOVE	PERMANENT	HAND- MOVE	LINEAR- MOVE	SIDE- ROLL	MICRO- MINI	HOSE- PULL	CENTER- PIVOT	ABOVE GROUND	BURIED DRIP	
CORN	Acres																
	Source																
COTTON	Acres																
	Source																
DRY BEANS	Acres																
	Source																
GRAINS (1)	Acres																
	Source																
SAFFLOWER	Acres																
	Source																
SUGAR BEETS	Acres																
	Source																
OTHER FIELD CROPS (2)	Acres																
	Source																
ALFALFA	Acres																
	Source																
PASTURE (3)	Acres																
	Source																
CUCURBITS (4)	Acres																
	Source																
ONION & GARLIC	Acres																
	Source																
POTATO	Acres																
	Source																
TOMATO (FRESH)	Acres																
	Source																
TOMATOES (PROCESSING)	Acres																
	Source																
OTHER TRUCK CROPS (5)	Acres																
	Source																
ALMOND & PISTACHIO	Acres																
	Source																
OTHER DECIDUOUS (6)	Acres																
	Source																
SUBTROPICAL TREES (7)	Acres																
	Source																
TURFGRASS & LANDSCAPE	Acres																
	Source																
VINEYARD	Acres																
	Source																

<sup>1</sup>wheat, oats, barley, etc; <sup>2</sup>sorghum, sunflower, sudangrass, etc; <sup>3</sup>excluding grass hay; <sup>4</sup>melons, squash, cucumbers, etc; <sup>5</sup>carrots, celery, cauliflower, broccoli, strawberries, asparagus, etc; <sup>6</sup>apples, peaches, prunes, pears, etc; <sup>7</sup>olives, avocados, citrus, dates, etc.

Table 2 includes the individual and total irrigated land in acres by each 20 crops and by each 16 different irrigation methods in California during 2001 irrigation survey. The total irrigated land from 1991 and 2001 surveys are 539,875 and 509,400 acres, respectively. The variation between 1991 and 2001 surveys is only 5.6%. This indicates an insignificant difference in irrigated land between the 1991 and 2001 surveys. The sample of 509,400 irrigated acres in the state was used to determine which irrigation methods growers used to irrigate their crops in 2001. The sample represents nearly 5.6% of the irrigated land in the state surveyed.

**Table 2. - Statewide irrigated land (acres) by crop and irrigation method in 2001**

Irrigation Method	Corn	Cotton	Dry Beans	Grains	Safflower	Sugar beet	Other Field Crops	Alfalfa	Pasture
SUBSURFACE	4,183.00	381.00	0.00	583.00	315.00	0.00	24.00	1,545.00	1,505.00
WILD FLOOD	1,842.50	0.00	20.00	1,926.30	258.60	0.00	200.50	1,278.50	11,118.7
BORDER	4,672.00	700.00	69.00	17,505.00	247.00	0.00	3,425.00	48,076.50	10,255.4
BASIN	65.00	0.00	120.00	70.00	85.00	0.00	0.00	225.00	242.00
FURROW	23,092.50	32,456.00	1,119.00	3,360.00	650.00	1,708.00	2,923.00	5,310.00	849.00
SIDE-ROLL	0.00	2,000.00	0.00	72.00	0.00	0.00	0.00	0.00	1,120.00
HAND- MOVE	341.00	100.00	385.00	148.00	0.00	0.00	0.00	468.50	321.00
PERMANENT	50.00	652.00	0.00	80.00	0.00	0.00	15.00	47.00	859.00
HAND-MOVE	2.00	1,265.00	895.00	1,403.00	600.00	0.00	555.00	2,419.00	2,537.50
LINEAR-MOVE	0.00	0.00	0.00	50.00	0.00	0.00	5.00	2,345.00	2,025.00
SIDE-ROLL	0.00	0.00	0.00	715.00	0.00	0.00	292.00	4,323.00	580.00
MICRO-MINI	0.00	0.00	0.00	0.00	0.00	0.00	6.50	0.00	0.00
HOSE-PULL	0.00	0.00	0.00	30.00	0.00	0.00	0.00	40.00	202.50
CENTER - PIVOT	220.00	0.00	400.00	505.00	0.00	0.00	125.00	2,844.00	223.80
ABOVE GROUND	2.00	0.00	0.00	5.00	0.00	0.00	122.00	0.00	0.00
BURIED DRIP	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00

**Table 2. - Statewide irrigated land (acres) by crop and irrigation method in 2001 (continued)**

Irrigation Method	Onion & Garlic	Potato	Other Deciduous	Subtropical Trees	Turf grass & landscape	Vineyard	Tomato (fresh)	Tomato (processed)	Other Truck Crops
SUBSURFACE	0.00	0.00	156.80	358.00	2.00	151.50	0.00	0.00	0.00
WILD FLOOD	0.00	0.00	1,309.05	169.40	0.00	182.00	0.00	0.00	0.00
BORDER	0.00	0.00	4,537.48	215.50	5.00	759.00	0.00	0.00	0.00
BASIN	0.00	0.00	586.50	1,103.30	0.00	551.50	0.00	0.00	29.00
FURROW	303.50	37.50	6,041.57	2,288.33	1.00	15,093.82	1,825.50	3,809.00	5,609.00
SIDE-ROLL	0.00	0.00	57.00	112.00	0.00	64.50	307.00	493.00	0.00
HAND- MOVE	585.00	0.00	37.25	102.00	0.00	120.00	2,017.50	863.00	6,987.00
PERMANENT	826.17	41.17	7,974.44	3,626.80	43.00	6,749.00	2.00	0.00	273.60
HAND-MOVE	319.00	2,731.00	2,488.08	368.20	206.14	262.00	0.00	2,299.00	12,880.00
LINEAR-MOVE	0.00	0.00	80.00	5.00	0.00	0.00	0.00	0.00	10.00
SIDE-ROLL	0.00	0.00	80.00	464.00	600.00	0.00	0.00	0.00	0.00
MICRO-MINI	0.00	0.00	5,504.60	25,388.34	25.00	1,045.20	0.00	0.00	245.00
HOSE-PULL	0.00	0.00	773.00	422.59	25.00	0.00	0.00	0.00	105.00
CENTER - PIVOT	0.00	0.00	100.00	57.00	0.00	30.00	0.00	0.00	12.00
ABOVE GROUND	1.25	230.63	6,979.50	4,378.57	74.00	52,866.52	402.31	75.00	6,498.00
BURIED DRIP	0.00	0.00	566.50	604.00	1.00	2,602.50	2,216.00	74.00	2,300.00

Percentage of statewide acreage reported for each crop was then calculated by each irrigation method. Table 3 illustrates the percentages of irrigated land by each of 20 crops and by four irrigation methods in 2001.

**Table 3. Percentages of irrigated land area by crop and irrigation method in California in 2001**

	Crop	Gravity	Sprinkler	Drip/Micro	Other
1	Corn	87.1	0.8	0.0	12.1
2	Cotton	93.9	5.1	0.0	1.0
3	Dry beans	56.9	43.1	0.0	0.0
3	Grains	87.3	10.5	0.0	2.2
4	Safflower	57.6	27.8	0.0	14.6
5	Sugar beet	99.9	0.0	0.1	0.0
6	Other Field crops	85.1	12.9	1.7	0.3
7	Alfalfa	80.3	17.4	0.0	2.2
8	Pasture	75.1	20.2	0.0	4.7
9	Cucurbit	45.3	23.6	31.1	0.0
10	Onion & Garlic	43.7	56.3	0.1	0.0
11	Potato	1.2	91.2	7.6	0.0
12	Tomato (fresh)	61.3	0.0	38.7	0.0
13	Tomato (process)	67.8	30.2	2.0	0.0
14	Other Truck Crops	36.1	38.0	25.9	0.0
15	Almond & Pistachio	19.2	11.3	69.3	0.2
16	Other Deciduous	33.7	30.8	35.0	0.4
17	Subtropical Trees	10.1	12.5	76.6	0.9
18	Turfgrass & landscape	0.6	89.0	10.2	0.2
19	Vineyard	20.8	8.7	70.2	0.2
20	Total	49.4	15.6	33.1	1.8

Tables 4 and 5 show the irrigated land area by each of 13 crops and by each 16 different irrigation methods in California during 1991 and 2001, respectively.

**Table 4. Statewide irrigated land (acres) by crop and irrigation method in 1991**

Irrigation Methods	ALF	SGR	CRN	CTN	OTH	PAS	DEC	SUB	SBT	TOM	VEG	VIN	Total
Wild flood	4,616	1,265	563	0	1,815	9,282	4,288	259	0	0	309	1,299	23,697
Border	49,793	22,662	4,587	13,360	9,025	9,364	20,869	249	178	336	538	3,021	133,983
Basin	566	452	35	0	1,944	165	981	558	0	0	151	781	5,632
Furrow	4,362	8,717	11,313	40,451	8,983	2,626	12,911	3,238	8,630	13,318	13,135	17,409	145,093
Furrow and wheel line	0	168	44	400	353	0	417	0	781	1,650	2,141	469	6,424
Furrow and hand move	0	1,929	1,359	11,784	721	158	1,077	235	1,420	16,934	10,260	477	46,354
Solid set sprinkler	44	0	0	469	689	504	28,546	3,460	116	74	8,141	6,210	48,254
Hand move sprinkler	3,162	1,855	0	3,848	412	1,998	8,028	291	1,566	1,492	3,604	277	26,533
Linear move sprinkler	0	99	0	0	0	44	121	40	0	0	2,438	0	2,742
Wheel line sprinkler	2,974	2,035	0	0	1,089	175	7	242	0	689	0	0	7,212
Micro and mini sprinkler	299	0	0	0	42	0	9,327	25,416	0	0	2	37	35,123
Hose pull sprinkler	516	0	0	0	0	170	2,388	2,065	0	0	0	89	5,229
Other sprinkler methods	1,998	299	0	249	133	274	442	170	0	0	0	0	3,567
Surface drip	25	0	0	0	22	0	8,687	2,947	0	0	2,719	21,610	36,010
Buried drip	0	0	0	161	168	0	3,762	143	0	299	4,182	299	9,013
Drip and sprinkler	0	0	0	0	0	0	1,210	22	0	0	499	153	1,885
Subsurface total	650	165	161	0	121	1,630	257	0	0	0	0	141	3,125
<b>Total</b>	<b>69,004</b>	<b>39,646</b>	<b>18,061</b>	<b>70,724</b>	<b>25,520</b>	<b>26,392</b>	<b>103,318</b>	<b>39,337</b>	<b>12,691</b>	<b>34,792</b>	<b>48,121</b>	<b>52,270</b>	<b>539,875</b>

**Table 5. Statewide irrigated land (acres) by crop and irrigation method in 2001**

Irrigation	ALF	SGR	CRN	CTN	OTH	PAS	DEC	SUB	SBT	TOM	VEG
SUBSURFACE	1,545	583	4,183	381	339	1,505	316	358	0	0	0
WILD FLOOD	1,279	1,926	1,843	0	479	11,119	2,941	169	0	0	37
BORDER	48,077	17,505	4,672	700	3,741	10,255	14,506	216	0	0	84
BASIN	225	70	65	0	205	242	1,836	1,103	0	0	149
FURROW	5,310	3,360	23,093	32,456	4,692	849	6,552	2,288	1,708	5,635	7,343
SIDE-ROLL	0	72	0	2,000	0	1,120	212	112	0	800	0
HAND- MOVE	469	148	341	100	385	321	1,847	102	0	2,881	8,097
PERMANENT	47	80	50	652	15	859	15,883	3,627	0	2	1,147
HAND-MOVE	2,419	1,403	2	1,265	2,050	2,538	3,308	368	0	2,299	17,02
LINEAR-MOVE	2,345	50	0	0	5	2,025	80	5	0	0	10
SIDE-ROLL	4,323	715	0	0	292	580	89	464	0	0	25
MICRO-MINI	0	0	0	0	7	0	40,019	25,388	0	0	245
HOSE-PULL	40	30	0	0	0	203	1,047	423	0	0	105
CENTER - PIVOT	2,844	505	220	0	525	224	100	57	0	0	412
ABOVE GROUND	0	5	2	0	122	0	25,874	4,379	0	477	6,779
BURIED DRIP	0	0	0	0	0	0	2,447	604	2	2,290	2,556
Total	68,922	26,452	34,470	37,554	12,857	31,839	117,056	39,663	1,710	14,383	44,01

## Irrigation Methods

Irrigation methods are separated into four groups, surface (gravity), sprinkler, drip/micro, and sub-surface. These types of irrigation methods are used by growers to irrigate their crops in the state.

### Sub-Surface Irrigation

In sub-surface irrigation, underground pipe or open ditches are blocked to back up water and force it into a crop root zone.

### Surface Irrigation

Surface irrigation includes wild flood, border, basin, furrow irrigation without sprinklers, wheel line sprinklers followed by furrow irrigation, and hand move sprinklers followed by furrow irrigation. Acres that are irrigated with both sprinklers and furrows are included under the surface irrigation column.

### Sprinkler Irrigation

Sprinkler methods include solid set, hand move, linear move, wheel line, hose pull, and other types including center pivot, gun-type, etc.

### Drip/Micro-Sprinkler Irrigation

Drip/micro-sprinkler irrigation includes surface and buried and micro- or mini-sprinklers.

The method used to separate irrigation methods into four groups in 2001 is slightly different from those used in 1991 study. Micro- or mini sprinklers are combined with surface and buried drip in 2001, while they were listed as sprinklers in 1991 study. To be consistent with 2001 estimates, micro sprinklers in 1991 were separated into surface and buried drip as done in 2001. Table 6 and 7 show the breakdown of irrigated land in percentage by each of 13 crops and four irrigation methods during 1991 and 2001.

**Table 6. Percentage of irrigated land planted by crop and irrigation method in 1991**

Irrigation Method	ALF	SGR	CRN	CTN	OTH	PAS	DEC	SUB	SBT	TOM
Gravity	86.0	88.8	99.1	93.3	89.5	81.8	39.2	11.5	86.7	92.7
Sprinkler	12.6	10.8	0.0	6.5	9.1	12.0	38.3	15.9	13.3	6.5
Low Volume	0.5	0.0	0.0	0.2	0.9	0.0	22.2	72.5	0.0	0.9
Subsurface	0.9	0.4	0.9	0.0	0.5	6.2	0.2	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

**Table 6. Percentage of irrigated land planted by crop and irrigation method in 1991 (continued)**

Irrigation Method	VEG	VIN	Total
Gravity	55.1	44.9	66.9
Sprinkler	29.5	12.6	17.3
Low Volume	15.4	42.3	15.2
Subsurface	0.0	0.3	0.6
Total	100.0	100.0	100.0

**Table 7. Percentage of irrigated land planted by crop and irrigation method in 2001**

Irrigation Method	SUB	SBT	TOM	VEG	VIN	ALF	SGR	CRN	CTN	OTH	PAS	DEC	Total
Gravity	10.1	99.9	64.8	35.7	20.8	80.3	87.3	87.1	93.9	73.9	75.1	23.8	49.6
Sprinkler	12.5	0.0	16.0	42.5	8.7	17.4	10.5	0.8	5.1	22.5	20.2	17.5	15.7
Low Volume	76.6	0.1	19.2	21.8	70.2	0.0	0.0	0.0	0.0	1.0	0.0	58.4	32.9
Subsurface	0.9	0.0	0.0	0.0	0.2	2.2	2.2	12.1	1.0	2.6	4.7	0.3	1.8
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

To compare the earlier estimates with those of 2001, it was also necessary to aggregate the 1991 and 2001 crops into four crop groups. The breakdown of irrigated land in percentage by four crop groups and four irrigation methods during 1991 and 2001 are shown in Tables 8 and 9, respectively.

**Table 8. Percentages of irrigated land by four crop categories and irrigation methods in 1991**

Irrigation Method	Field	Vegetable	Orchard	Vineyard	All Crops
Gravity	89.3	70.9	31.6	44.9	66.9
Sprinkler	9.4	19.8	32.1	12.6	17.3
Low Volume	0.3	9.3	36.1	42.3	15.2
Subsurface	1.0	0.0	0.2	0.3	0.6
Total	100.0	100.0	100.0	100.0	100.0

**Table 9. Percentages of irrigated land by four crop categories and irrigation methods in 2001**

Irrigation Method	Field	Vegetable	Orchard	Vineyard	All Crops
Gravity	83.6	42.9	20.3	20.8	49.6
Sprinkler	12.3	36.0	16.2	8.7	15.7
Low Volume	0.1	21.1	63.0	70.2	32.9
Subsurface	4.0	0.0	0.4	0.2	1.8
Total	100.0	100.0	100.0	100.0	100.0

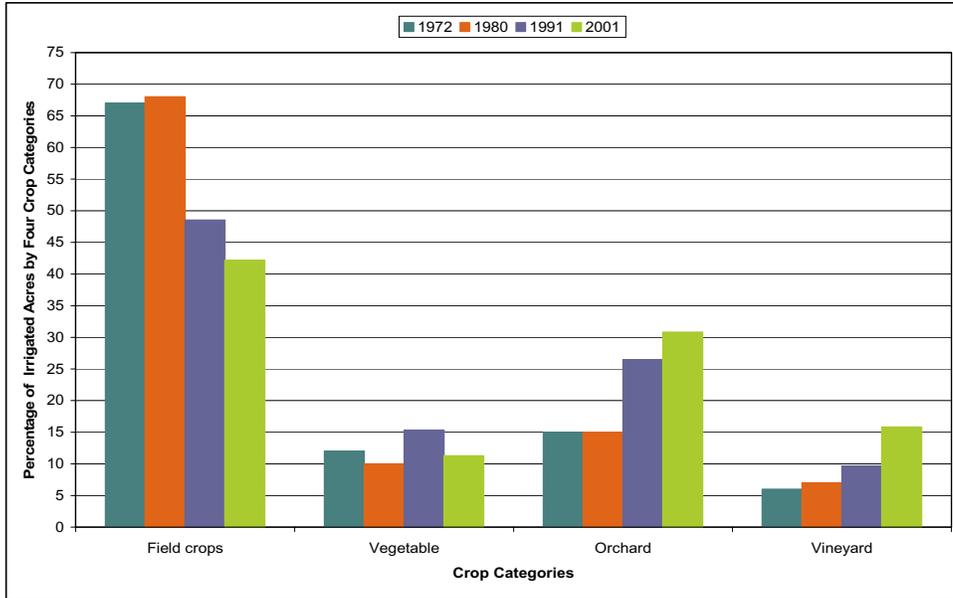
## Results and Discussion

A comparison of early studies with those conducted in 2001 indicated that irrigated land planted to vineyards and orchards has increased, while the percentage of land planted by field crops has decreased. Table 10 and figure 2 illustrate the estimated irrigated land in percentage by four crop categories in California since 1972 and how the percentage of acreages planted by various crop categories has changed from 1972 to 2001.

**Table 10. Percentage of irrigated acreages by four crop categories in 1972, 1980, 1991, and 2001**

Year	Field crops (%)	Vegetable (%)	Orchard (%)	Vineyard (%)	Total (%)
2001	42	11	31	16	100
1991	49	15	26	10	100
1980	68	10	15	7	100
1972	67	12	15	6	100

**Figure 2. Percentages of irrigated land planted by four crop categories in California between 1972 and 2001.**



As it is evident from the table and figure, the percentage of land area planted to orchard has increased from about 15% to 31% and acreages planted by vineyard has increased from about 6% to 16%, while the amount of land planted by field crops has decreased from about 67% to 42% since 1972.

To validate the information of the irrigation survey conducted in 2001, we compared 2001 estimates to the 1972, 1980, and 1991 estimates to see if a shift toward drip/micro irrigation method is a positive trend for orchards and vineyards. To increase the benefits from more precise water application to soils for crop use, it is expected to see a shift from sprinkler and gravity irrigation toward drip/micro by growers. Drip/micro irrigation allows growers to distribute water more uniformly within the intended root zone than sprinkler and gravity irrigation.

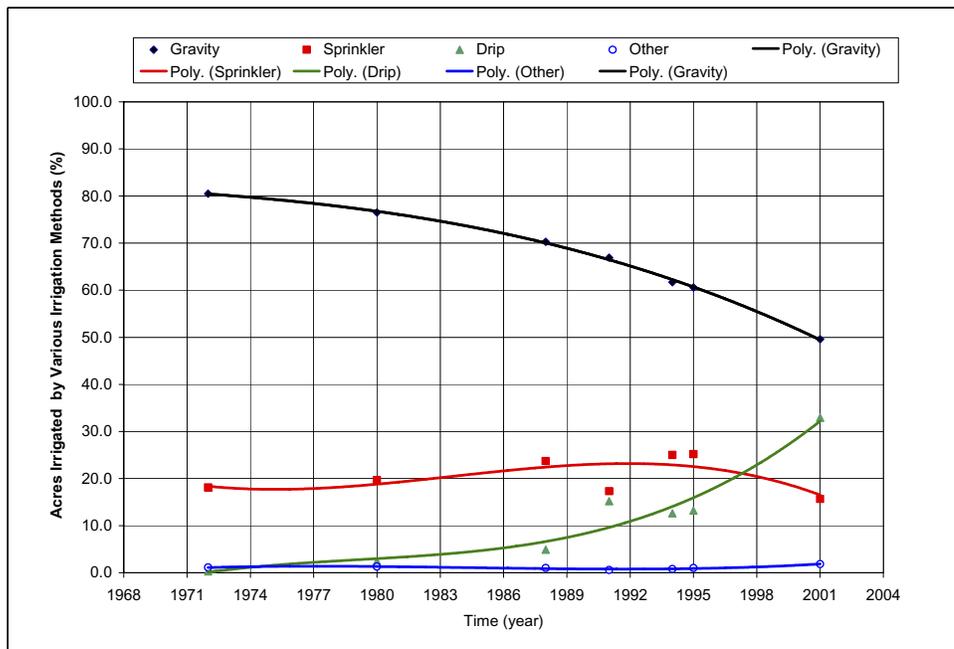
Table 11 shows the percentage of irrigated land by irrigation methods for 1972, 1980, 1991, and 2001. We used the information in Table 11 to see if there is a consistent trend in shifting irrigation methods from gravity to drip/micro between 1972 and 2001. The results confirm the trend of decreased acreage in gravity and the increased acreage in drip/micro irrigation from 1972 to 2001. The comparison demonstrates that the amount of land irrigated by gravity irrigation has declined from 80.5% in 1972 to about 49.6% in 2001, while the amount of land irrigated by micro/drip irrigation has increased from 0.3% to 32.9% over the period of the data sets. Although different methodologies were used to conduct these studies, results show a very consistent trend in the use of specific irrigation methods when plotted on a time series graph (Figure 3).

**Table 11. Percentage of irrigated land by different irrigation systems for 1972, 1980, 1988, 1991, 1994, 1995, and 2001 survey results in California**

Irrigation Method	1972	1980	1988	1991	1994	1995	2001
Gravity	80.5	76.5	70.3	66.9	61.7	60.6	49.6
Sprinkler	18.1	19.7	23.7	17.3	25.0	25.2	15.7
Drip	0.3	2.4	4.9	15.2	12.6	13.2	32.9
Other	1.1	1.3	1.0	0.6	0.8	1.0	1.8
Total	100	100	100	100	100	100	100.0

Since the 1972 and 1980 surveys were mainly based on farm advisors estimates rather than direct grower responses, there was no information available on data variability to determine changes in the use of irrigation methods. Using data from the seven surveys, non-linear trendlines of the percentage of land versus time were determined to evaluate changes in the usage of the irrigation methods from 1972 to 2001. Figure 3 shows the percentage of irrigated land by irrigation methods versus time and it shows trends in irrigation methods based on the information collected from variety of sources (e.g., decreasing use of gravity irrigation and increasing use of drip/micro irrigation). The results of this analysis confirm that the irrigation method survey conducted during 2001 is valid and reliable for long-range water planning in California.

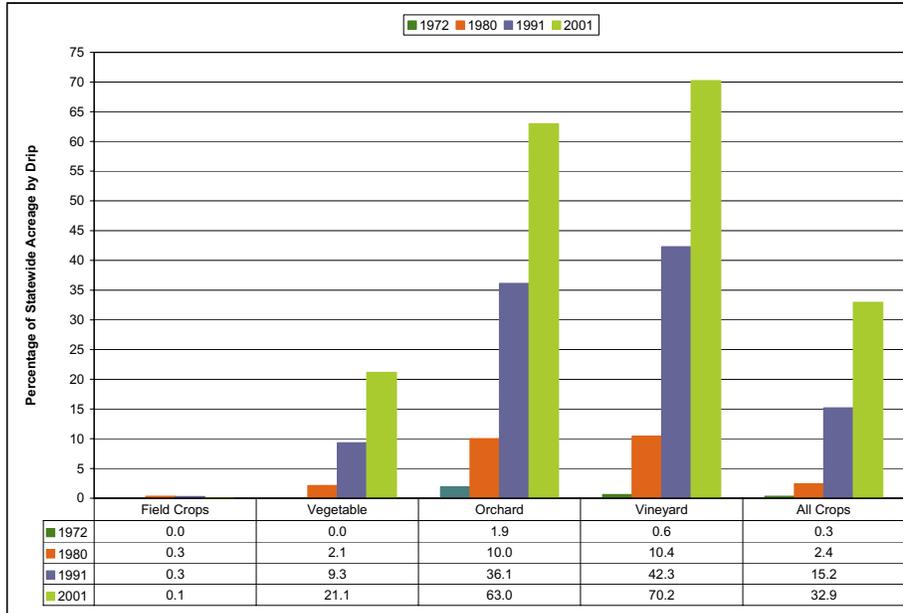
**Figure 3. Comparison of irrigated land by different irrigation method in percentage within the state**



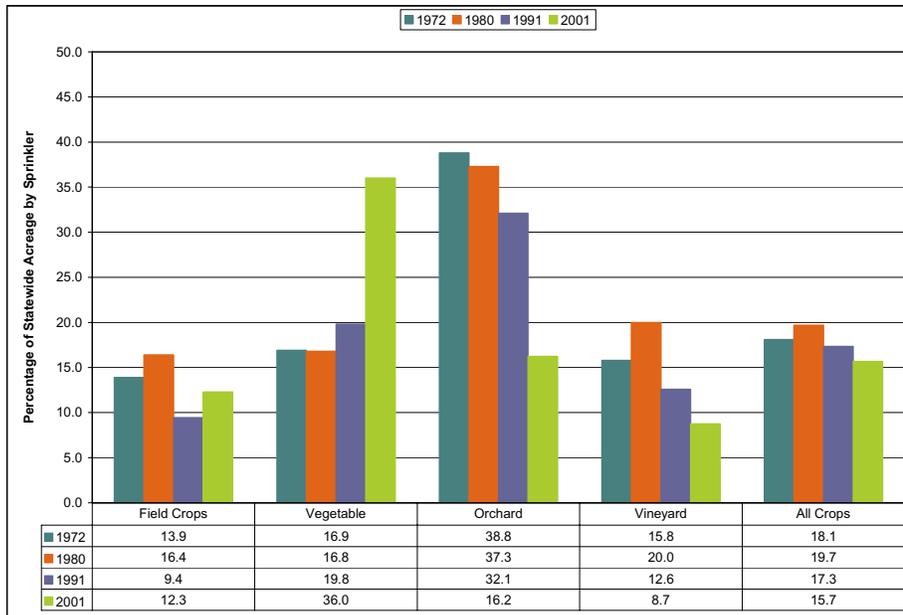
While there has been a slight decrease in acreage irrigated with sprinklers, there has been a shift towards more irrigated acreage with drip/micro irrigation in 2001. The decrease in sprinkler irrigation method in 2001 was mainly due to changes in orchard and vineyards irrigation technology, shifting from sprinklers to drip/micro irrigation. For vineyards and orchards, the amount of land irrigated by gravity and sprinkler irrigation has declined, while the amount of land irrigated by drip/micro irrigation has increased. Figures 4-6 display the changes in irrigation method by four crop categories for 1972, 1980, 1991, and 2001 surveys. In the analysis of the 2001 survey, it was observed that gravity-driven surface irrigation methods were used to irrigate 83.5% of the field crops with an additional 12.4% irrigated by sprinkler methods. For the orchard crops, 63% were irrigated by drip irrigation methods and 20.3% irrigated using surface methods. Most of the vegetable crops were irrigated by gravity methods (42%) and 36% were irrigated by sprinkler methods. The majority of the vineyard crop land was irrigated by drip irrigation (70%) whereas 21% was irrigated by surface irrigation methods. The largest change in irrigation methods from 1972 to 2001 was the increase in drip irrigation, particularly in vineyard and orchard crops (Figure 4). In 1972, 0.6% of the vineyard crops and 1.9% of the orchard crops were under drip irrigation. In 2001, 70.2% of the vineyards and 63% of the orchards were irrigated with drip irrigation methods, an increase of 69.9% for vineyards and 61.1% for orchards. The increase in drip irrigation in vineyards corresponds with declines in both surface (down 62.6%) and sprinkler (down 7.1%) methods from 1972 to 2001. Drip irrigation also increased 21% in vegetable and 1.8% in orchard crops as well. For all crops combined, drip irrigation increased from 0.3% in 1972 to 15.2% in 1991 to 32.9% in 2001. Figure 4 illustrates the increase in drip irrigation in vegetable, orchard, and grape crops.

There has been a large increase in sprinkler irrigation with vegetable crops. Sprinkler irrigation increased from 16.9% in 1972 to 36.2% in 2001, while sprinkler use in most crops appeared to have declined slightly from 1972 to 2001. It declined dramatically in orchards from 59.3% in 1972 to 20.3% in 2001, a decrease of 39%. The large increase in sprinkler use in vegetables corresponds with declines in surface methods from 1991 to 2001, a decrease of 39.7%. Sprinkler irrigation increased 26.4% in vegetables since 1991. For all crops combined, sprinkler use decreased from 18.1% in 1972 to 17.3% in 1991 to a low of 15.7% in 2001 (Fig. 5). It is important to note that the reduction in sprinklers in 2001 was due to a shift from sprinklers to drip because of changes in orchard and grapevine irrigation practices.

**Figure 4. Comparison of irrigated land by micro/drip irrigation by various crops from 1972, 1980, 1991, and 2001**

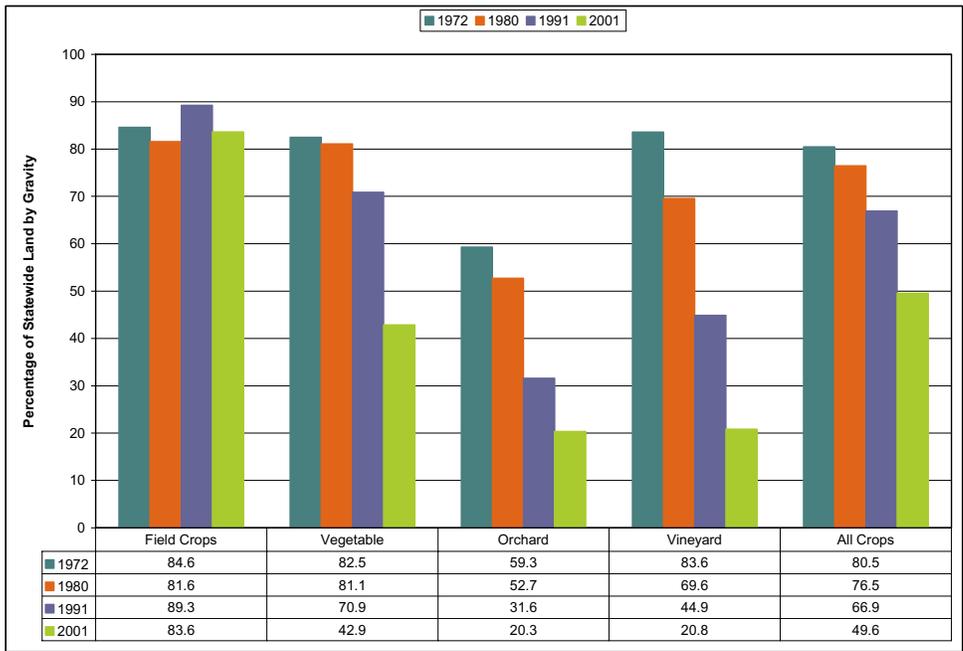


**Figure 5. Comparison of irrigated land by high-pressure sprinkler irrigation by various crops from 1972, 1980, 1991, and 2001**



The results from comparing the surveys conducted in 1972, 1980, 1991, and 2001, show that surface irrigation has declined for all crops from 80.5% in 1972 to 49.6% in 2001 (Figure 6). There has been a dramatic decrease particularly in vineyards. In 1972, approximately 82.5% of the land area planted to vegetables, 59.3% planted to orchards, and 83.6% planted to vineyards were under surface irrigation methods. In 2001, 42.8% of the vegetables, 20.3% of the orchards, and 20.8% vineyards were irrigated with surface irrigation methods. The study shows a decrease of 39.7% for vegetables, 39% for orchards, and 62.8% for vineyards.

**Figure 6. Comparison of irrigated land by gravity-driven surface irrigation by various crops from 1972, 1980, 1991, and 2001**



The reductions in surface methods are due to the reductions in field crop acreages. The percentage of land area planted to orchard has increased from about 15% to 31% and acreages planted by vineyard has increased from about 6% to 16%, while the amount of land planted by fields crops has decreased from about 67% to 42% since 1972.

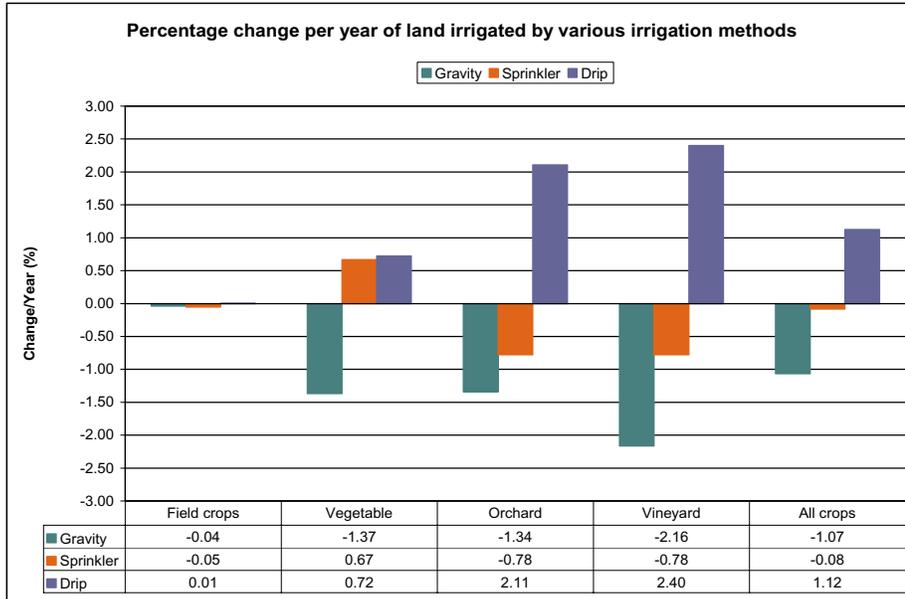
Table 12 displays percentage change per year of percentage of acreages irrigated by gravity, sprinkler, and drip methods for four crop categories between 1972 and 2001. There has been a large increase in drip irrigation, particularly in vineyards. The table below shows that the drip irrigation in vineyards has increased at an average rate of 2.4% per year over the period of the data sets (Table 12 and Figure 7).

**Table 12. Percentage change per year of percentage of land area irrigated by various irrigation methods by four crop categories assuming a linear change between 1972 and 2001.**

Crops	Irrigation Method	Change per Year (%)
Field crops	Gravity	-0.04
	Sprinkler	-0.05
	Drip	0.01
Vegetable	Gravity	-1.37
	Sprinkler	0.67
	Drip	0.72
Orchard	Gravity	-1.34
	Sprinkler	-0.78
	Drip	2.11
Vineyard	Gravity	-2.16
	Sprinkler	-0.78
	Drip	2.40
All crops	Gravity	-1.07
	Sprinkler	-0.08
	Drip	1.12

There was a small increase in the use of the drip irrigation for vineyards between 1972 and 1980, an increase of 9.8%. But a dramatic increase in drip irrigation was observed between 1980 and 2001, an increase of 59.8%. The rate of increase calculated between 1980 and 2001 is about 3% per year. The increase in drip irrigation is mostly due to a 2.16% per year decrease in surface irrigation and 0.75 % decrease in sprinkler to vineyards. The uses of drip irrigation in orchards and vegetable crops have also increased at about 2.1% and 1.1% per year, respectively. For all crops, drip irrigation increased at about 1.1% per year during the period of record. For vegetable crops, drip irrigation increased at a rate of 0.72% per year. Although use of sprinkler irrigation in most crops declined slightly from 1972 to 2001, it increased at about 0.67% per year for vegetable crops (Table 12 and Figure 7). For vineyard and orchard crops, surface irrigation has declined approximately 2.16% and 1.3% per year from 1972 to 2001, respectively. For vegetables and all crops, surface irrigation declined at about 1.37% and 1.07% per year, respectively. There have been no changes in irrigation methods for field crops. Results indicate that field crops are still mainly irrigated by surface irrigation methods and the land area planted to field crops is reduced by small percentage.

**Figure 7. Percentage change per year of land irrigated by various irrigation methods versus years from 1972 by crop categories**



### Conclusions

The results of 2001 survey demonstrate consistent trends in crop acreages as well as the irrigation methods used in the various crops based on the information collected from variety of sources. A decrease in use of surface irrigation and an increase in use of drip/micro irrigation have been observed. The largest increase in drip irrigation use occurred in orchards and vineyards. The largest increase in sprinkler use was in vegetable crops. The results of this survey seem to be consistent with the information collected from other sources on trends in crop acreage and irrigation methods.

### References

Burt, C.M., Mutziger, R.J., Allen, R.G., Howell, T.A. (2004). "Evaporation Research – A Review and Interpretation." Unpublished CalPoly report.

Edinger-Marshal, S., and Letey, J. (1996). "Irrigation shifts toward sprinklers, drip and microsprinklers." California Agriculture, Volume 51, Number 3: 38-40.

Hagan, R. M., and Wagner, R. J. (1983). Irrigation methods in California: an update. California Dept. of Water Resour. Div. of Plng., Sacramento, Calif.

Snyder, R. L., Plas, M. A., Grieshop, J. I. (1996). "Irrigation Methods Used in California: Grower Survey" *ASCE J. of Irrig. & Drain. Engr.* 122(4): 259-262.

Stewart, J. I. (1975). "Irrigation in California: a report to the State Water Resources Control Board." *Standard Agreement No. 2-2-65 between State Board and Univ. of California*, California Water Resour. Control Board, Sacramento, Calif.