CENTRAL VALLEY REGIONAL
WATER QUALITY CONTROL BOARD

Salt Tolerance of Crops in the Lower San Joaquin River (Merced ~~Stanislaus~~ to Stanislaus ~~Merced~~ River Reaches)

DRAFT REPORT

March 2010

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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Salt Tolerance of Crops in the Lower San Joaquin River (Merced ~~Stanislaus~~ to Stanislaus ~~Merced~~ River reaches)

Draft Report

June~~March~~ 2010

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Acknowledgements

Staff would like to acknowledge Dr. Glenn J. Hoffman, as this Report is built upon the technical foundation of his 2010 Report entitled “Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta”. Mark Gowdy of the State Water Resources Control Board Bay Delta Unit is thanked for his assistance with staff’s implementation of Dr. Hoffman’s approach. Staff also acknowledges information received from Jean Woods of the California Department of Water Resources that aided in crop and acreage analysis of the study area.

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1. Introduction

1.1. Location

This Report focuses on lands that are likely to use portions of the lower San Joaquin River (LSJR) between the Stanislaus River and the Merced River for irrigation of crops. For purposes of this Report, Staff made a coarse level assessment of the area likely to use irrigation water, which hereafter is called the "LSJR Irrigation Use Area". This area, shown in Figure 1.1, consists of lands likely receiving or having the potential to receive all or part of their irrigation water from the LSJR between the Stanislaus River and the Merced River. Those likely to use water for irrigation include individual water right holders and water agencies such as West Stanislaus Irrigation District (ID), ~~Turlock ID, Modesto ID,~~ Patterson ID and El Solyo Water District (WD).

Staff's purpose in developing the LSJR Irrigation Use Area was to provide a general sense of the areas that may use irrigation water rather than an exact determination of use. Staff feels that this coarse level of assessment is acceptable for the purposes of this Report, and caveats that it is not intended to confirm any party's existing or potential water rights.

The entire LSJR Irrigation Use Area consists of 68,458 acres. Of this, there are currently 52,541 acres used for irrigated agriculture according to Department of Water Resources (DWR) (DWR, 2009a). The non-irrigated lands in the LSJR Irrigation Use Area include urban areas, water courses, residential properties, open land, dairies and feedlots and farm homesteads. The LSJR Irrigated Use Area includes portions of San Joaquin, Stanislaus, and Merced counties. The reach of the LSJR from the Merced ~~Tuolumne~~ River to ~~Merced~~ Tuolumne River is 29 miles in length. It includes two commonly used monitoring sites; Crows Landing and Patterson. The major tributaries in this reach are the Merced River and the Tuolumne River on the east side while Del Puerto Creek and Orestimba Creek drain the west side. The LSJR from the Tuolumne River to the Stanislaus River is 8.4 miles in length and includes the Maze monitoring site.

1.2. Regulations

Water quality degradation of the San Joaquin River by salinity was recognized in the Central Valley Regional Water Quality Board's (Central Valley Water Board) 1975 Water Quality Control Plan for the Sacramento River Basin, Sacramento San Joaquin Delta Basin and the San Joaquin Basin (Central Valley Water Board, 1975). The LSJR was listed on the 1998 Clean Water Act (CWA) 303(d) list as impaired for both salt and boron (Central Valley Water Board, 1998). In 1999, the State Water Resources Control Board (State Water Board) adopted Water Rights Decision 1641. Among the directives of this decision was for the Central Valley Water Board to develop and adopt salinity objectives along with a program of implementation for the main stem of the LSJR upstream of Vernalis, CA.

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In 2004, the Central Valley Water Board adopted a Control Program for salt and boron dischargers into the LSJR which also called for setting of upstream salinity objectives. Phase I of the Control Program established an implementation program and a compliance schedule for salinity and boron objectives at Vernalis. Phase II entails a proposed Basin Plan Amendment (Amendment) containing site specific salinity and boron objectives and a program of implementation for the LSJR (Merced ~~Stanislaus~~ River to Stanislaus ~~Merced~~ River).

In regards to boron, the Central Valley Water Board adopted boron objectives that were approved by State Water Board in 1989, and are currently in effect based on state law. These objectives did not receive approval from US EPA, due to inconsistencies with the Clean Water Act Section 303. Thus the proposed Amendment will include an analysis of the latest technical information available for boron. This analysis will be conducted in a separate (future) draft Report.

Water quality objectives are required by law to provide reasonable protection for all designated beneficial uses of a water body. The LSJR has designated beneficial uses of municipal and domestic supply, agriculture (irrigation and stock watering), industry (process), recreation (contact, canoeing and rafting, other noncontact), freshwater habitat (warm), migration (warm, cold), spawning (warm) and wildlife habitat (Water Quality Control Plan~~Central Valley Water Board~~, 200~~7a~~9). Of the listed beneficial uses, Staff's initial review indicates that agriculture and municipal uses are likely to be the most sensitive to salinity and boron.

Central Valley Water Board staff is closely coordinating efforts to develop objectives for the LSJR with similar effort regarding the South Delta by State Water Board Division of Water Rights. This Report is built off of the technical approach completed by Dr. Glenn J. Hoffman under contract to State Water Board. In preparing this Report, Staff attempted to follow as closely as possible the technical and formatting approach used by Dr. Hoffman.

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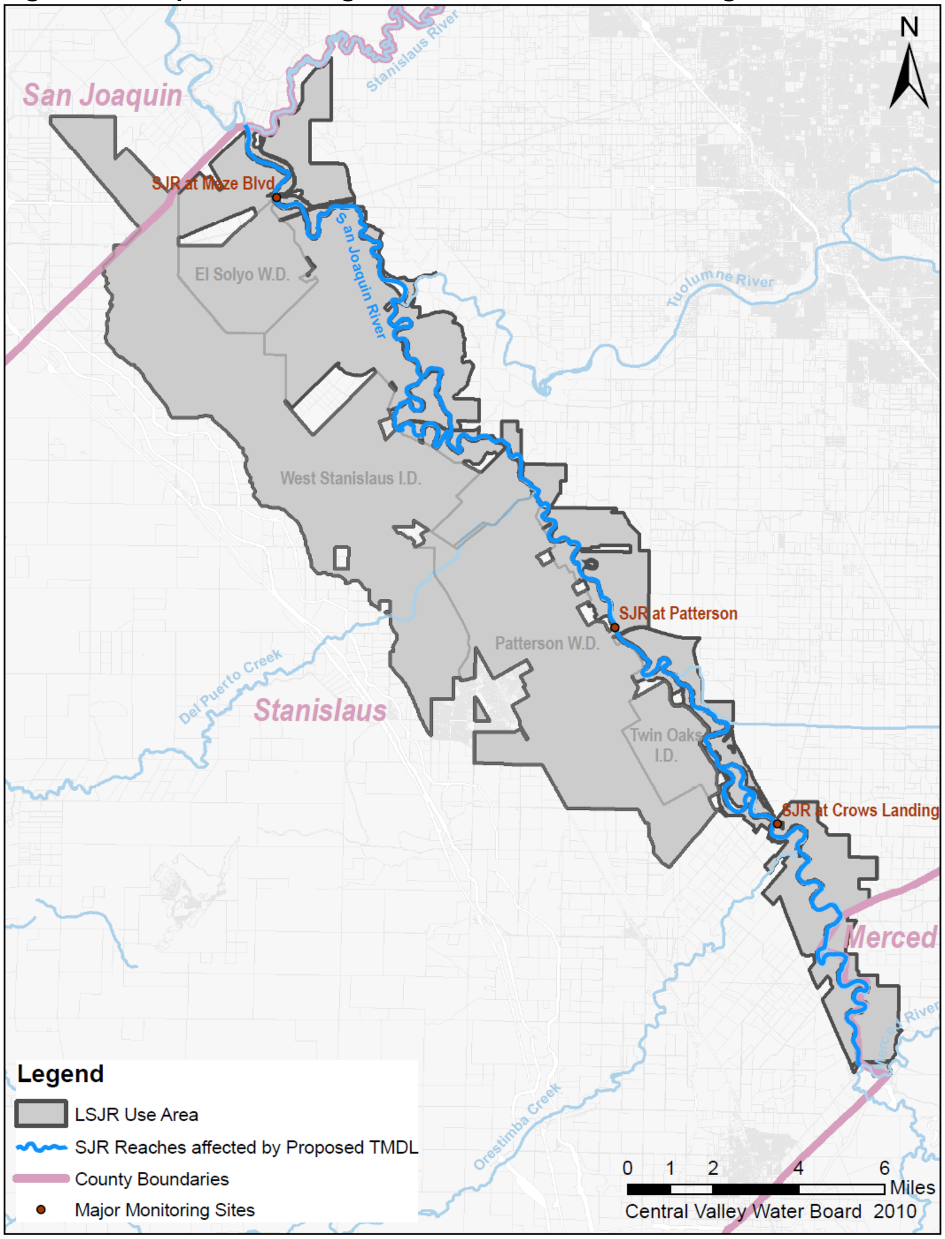
Figure 1.1. Map of LSJR Irrigation Use Area and monitoring stations



1.3. Purpose and Objectives

This Report is a first step in the process of developing the draft Amendment and is focused on salinity impacts to one specific beneficial use: agriculture (irrigation). Tailored to information available for the LSJR Irrigation Use Area, this Report uses the approach of Dr. Glenn J Hoffman (2010) in his Report *Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta*, which forms Appendix A of this Report. A detailed explanation of the purposes of Dr. Hoffman's work can be found in Appendix A Section 1.3.

This Report proposes protective salinity thresholds which were developed through a series of crop tolerance modeling studies on three crops grown in the LSJR: beans, which are the most salt sensitive, as well as alfalfa and almonds.

This Report evaluates and quantifies how the various factors influencing the use of saline water for irrigation apply to conditions in the LSJR Irrigation Use Area. The underlying objectives of this study are:

1) Compile existing data/information to determine salinity status of LSJR Irrigation Use Area. This information includes soil data with estimates of acreage; nature of salinity and drainage impairment; crop types and acreages including evapotranspiration data and estimate effectiveness of local rainfall in reducing the irrigation requirement.
2) Use a steady state soil salinity model to identify threshold salinity values in irrigation water that provide protection for the most salt sensitive crops grown in the LSJR Irrigation Use Area.
3) Present draft study findings under a range of conditions to Central Valley Salinity Alternatives for Long-Term Sustainability (CV- SALTS) stakeholders as part of the basin plan development process.

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2. Background information

2.1. General Salinity Information

A detailed review on general salinity is presented by Hoffman (2010) (Appendix A, Section 2.1). To provide a brief introduction, all natural waters contain soluble salts. Consequently, these salts may accumulate in soils through application of irrigation water for crop production. Soils also contain salts that vary in quantity and composition, depending on parent material, rainfall and other factors. The composition and concentration of salts determine the suitability of soils and waters for crop production. Water quality for crop production is normally judged based on three criteria: salinity, sodicity, and toxicity (Ayers and Westcot, 1985).

2.2. Sources and Quality of Irrigation Water in the LSJR Irrigation Use Area

Water conditions in the LSJR, between the Merced ~~Stanislaus~~ and Stanislaus ~~Merced~~ River confluences, are influenced by the inflow of the LSJR at its confluence with the Merced. Staff recognizes that there are other water sources used for irrigation in the LSJR Irrigation Use Area, but these sources were not considered in the analysis of results. Thus, for purposes of this Report, Staff assumed that the SJR was the sole source of water for field irrigation.

2.2.1. Salinity

The salinity of irrigation water, reported as electrical conductivity (EC) in units of μS/cm, is monitored at several locations in the LSJR Irrigation Use Area. The numerical values in units of microSiemens per centimeter (μS/cm) are 1000 times larger than the numerical values in units ~~of units~~ of deciSiemens per meter (dS/m). This Report will use dS/m as the salinity unit which is also consistent with literature on crop response to salinity. Using dS/m is also beneficial since it is numerically equal to millimho per centimeter (mmho/cm).
~~, an outdated unit of measure for electrical conductivity.~~

For information only, Figure 2.1 shows EC from 2000 to 2009 at the three stations monitored by the Central Valley Water Board's Surface Water Ambient Monitoring Program (SWAMP) along the San Joaquin River (SJR) (Central Valley Water Board, 2009). Specifically, the three stations are SJR at Crows Landing (station code: STC504), SJR at Patterson (station code: STC507) and SJR at Maze Blvd. (Highway 132) (station code: STC510). From Figure 2.1, Crows Landing and Patterson respectively have 28% and 26% higher EC than Maze. With reference to one of the sites, Figure 2.2 shows results for the middle site of the three monitoring stations, Patterson. The EC varied between 0.6 – 1.6 dS/m with a mean value of about 1.2 dS/m.

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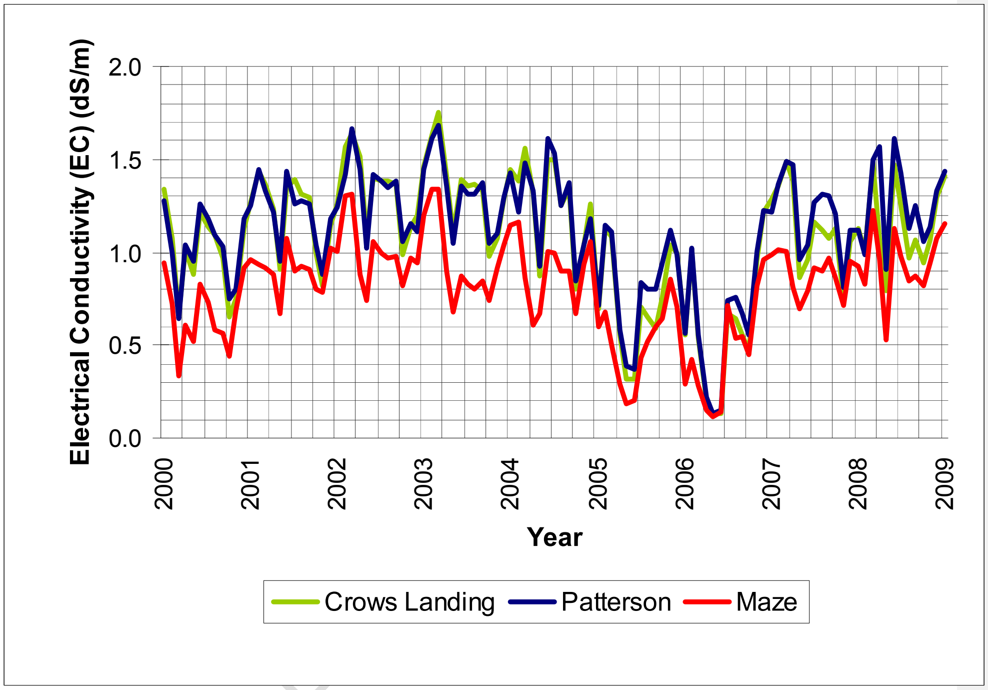
Figure 2.1. Monthly average of electrical conductivity (dS/m) for the three major monitoring stations in LSJR Irrigation Use Area from Jan. 2000 through Jan. 2009 (Central Valley Water Board, 2009).



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2.2.2. Sodicity

Soils with high levels of exchangeable sodium (Na) and low levels of total salts are called sodic soils.

As noted by Hoffman (2010):

> An important consideration in evaluating irrigation water quality is the potential for an excess concentration of sodium to occur in the soil leading to a deterioration of soil structure and reduction of permeability. When calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to have a granular structure that is easily tilled and readily permeable. High levels of salinity reduce swelling and aggregate breakdown (dispersion) and promote water penetration, whereas high proportions of sodium produce the opposite effect. Excess sodium becomes a concern when the rate of infiltration is reduced to the point that the crop cannot be adequately supplied with water or when the

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hydraulic conductivity of the soil profile is too low to provide adequate drainage.

~~Sodium, calcium, and magnesium most commonly form salts with chloride, sulfate, and bicarbonates in soils. Soil sodicity constitutes an excess of sodium ions, usually more than 10% over the other cations such as calcium and magnesium. High sodicity results in surface crusting, impermeability, sodium toxicity and micronutrient deficiencies. Further details on sodicity are reported by Hoffman (2010) (Appendix A, Section 2.2.2).~~

Table 2.0 shows water quality data on ~~soil sodicity and the corresponding~~ sodium adsorption ratio (SAR) which is an indicator of soil sodicity, for the SJR at three monitoring stations between 1985 and 2003 based on SWAMP monitoring (SWAMP, 2009). Sodic soils have an EC of less than 4 dS/m and a SAR greater than 13 in their saturation extract (USDA Handbook 60, 1954). From Table 2.0, the SAR values do not pose a sodicity concern in the LSJR Irrigation Use Area. The disparity in time period shown for Table 2.0, in comparison with Figure 2.1, is due to data availability.

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As provided by Hoffman (2010), the SAR is defined as:

$SAR = C_{Na} / (C_{Ca} + C_{Mg})^{1/2}$ (Eqn. 2.1)

Where C_{Na},C_{Ca},, and C_{Mg} are the respective concentrations in mol/m^3 of sodium, calcium, and magnesium ions in the soil solution. This equation is used to assess the sodium hazard of irrigation water. Both the salinity and the SAR of the applied water must be considered simultaneously when assessing the potential effects of water quality on soil water penetration. Sodic soils have an EC of less than 4 dS/m and a SAR greater than 13 in their saturation extract (USDA Handbook 60, 1954).

For example, from the water quality data for the SJR at Maze from 1985 to 2003 (62 samples) (Table 2), average ion concentrations were: Na = 3.6 mol/m^3; Ca = 1.5 mol/m^3; and Mg = 1.4 mol/m^3 (Central Valley Water Board, 2009). Inserting these values into Equation 2.1 gives a SAR of 2.11. This SAR is well below a value that would cause a sodicity problem (Maas and Grattan, 1999).

Table 2.0. Water Quality Data for three sites between 1985 and 2003 (Central Valley Water Board, 2009).

Site	No. of Samples	EC (dS m^{-1})	Sodium (mol m^{-3})	Calcium (mol m^{-3})	Magnesium (mol m^{-3})	SAR
Maze	62	0.78	3.6	1.5	1.4	2.11
Patterson	66	1.08	5.4	2.3	1.8	2.67
Crows Landing	80	1.02	5.4	2.3	1.9	2.63

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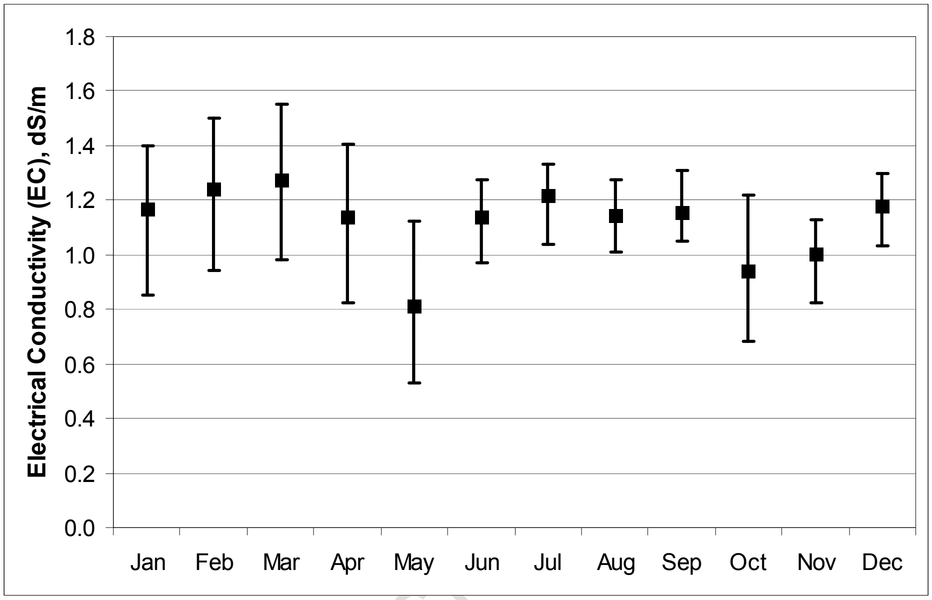
Figure 2.2 Median, high, and low electrical conductivity averaged by month as measured at LSJR at Patterson from Jan. 2000 through Jan. 2009 (Central Valley Water Board, 2009).



~~Table 2.0. Water Quality Data for three sites between 1985 and 2003 (Central Valley Water Board, 2009).~~

~~Site~~	~~No. of Samples~~	~~EC (dS m^{-1})~~	~~Sodium (mol m^{-3})~~	~~Calcium (mol m^{-3})~~	~~Magnesium (mol m^{-3})~~	~~SAR~~
~~Maze~~	~~62~~	~~0.78~~	~~3.6~~	~~1.5~~	~~1.4~~	~~2.11~~
~~Patterson~~	~~66~~	~~1.08~~	~~5.4~~	~~2.3~~	~~1.8~~	~~2.67~~
~~Crows Landing~~	~~80~~	~~1.02~~	~~5.4~~	~~2.3~~	~~1.9~~	~~2.63~~

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2.2.3. Toxicity

Hoffman (2010) discusses the potential toxic effects of certain specific solutes, such as sodium, chloride and boron. Hoffman used the suggested maximum concentrations provided by Pratt and Suarez (1990) to determine if significant concentrations of these trace elements were detected in the South Delta. Following the approach of Hoffman (2010), for information only, staff compared available data for the LSJR Irrigation Use Area to values given by Pratt and Suarez (1990). Staff reviewed SWAMP data, from 2001 to 2003, for a variety of trace elements including arsenic, cadmium, chromium, copper, lead, nickel, selenium, and zinc, none of which were detected at levels of concern. The maximum concentration of molybdenum detected was at the same level as the maximum threshold, however the average value was about half of the threshold value. Data for chloride and sodium was also evaluated, and is discussed in Section 3.7.2. Thus, staff concludes that generally these concentrations would not be expected to be a problem in the LSJR Irrigation Use Area.

In regards to boron, the LSJR is already recognized as impaired by boron on the current 2006 CWA 303(d) List (Central Valley Water Board, 2007b), thus an analysis of current boron levels is not conducted here. Due to lack of approval of existing boron objectives by US EPA, reconsideration of current boron technical information for protection of all beneficial uses will be completed. This will be done in a separate (future) draft Report which will become, along with this Report and others, part of the draft amendment.

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2.3. LSJR Irrigation Use Area Soils and Crops

2.3.1. Soils

The soils in the LSJR Irrigation Use Area were identified using information from surveys by the Natural Resource Conservation Service (NRCS) for Merced County, Stanislaus County and San Joaquin County, in 1992 (NRCS, 1992). Figure 2.4 was developed using the geographic information system (GIS) information from the NRCS Soil Survey Geographic (SSURGO) Database (NRCS, 2007a). The soils are grouped by different colors based on their surface soil texture. The associated NRCS soil units and some key soil properties are listed in Table 2.1 and grouped by the same general soil texture types.

The following two paragraphs present an overview of the geomorphic history and mineral description of the Central Valley soils presented in Table 2.1 for the LSJR Irrigation Use Area. Specific conditions at any point within the study area are a combination of the conditions described below. There could be wide variability from site to site.

According to NRCS (2007b), some soils in the LSJR Irrigation Use Area are formed predominantly from material weathered from sandstone, shale and other sedimentary rock much of which is calcareous. The sedimentary materials were deposited over millions of years from the erosion of surrounding mountains. Other soils are formed from alluvium with alluvial fan deposits that came from Coast Range materials while valley trough deposits came from a mixture of Sierra Nevada and Coast Range materials. The soils in the valley basin are formed in mixed alluvium that is dominantly granitic and was transported from the Sierra Nevada Mountains by the SJR. Streams flowing into the valley carried soil particles that settled out in order of their size. The largest particles settled out first, leaving the relatively light and permeable soils along the perimeter of the valley floor. The smallest particles were carried farther by the stream flows into the valley trough, where they formed tighter, less permeable soils. Over time, the valley trough was covered by large bodies of water (San Joaquin Valley Drainage Program, 1987).

Very fine soil particles in these water bodies settled to the bottom, forming less permeable clay layers. Such layers typically underlie areas with poor drainage at depths ranging from near land surface to about 40 feet or deeper if Corcoran clay is present. In such areas, ground water is typically present within 20 feet of land surface.

Soils derived from the marine sedimentary rocks of the Coast Range predominate in the west side of the LSJR in the Central valley. These typically contain relatively large amounts of water-soluble mineral salts which originated from their parent materials. The groundwater is highly mineralized and could extend down to a depth of about 300 feet to the groundwater reservoir (San

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Joaquin Valley Drainage Program, 1987). Figure 2.4 shows the location of various soil texture categories within the LSJR Irrigation Use Area. Figure 2.4 was created using ESRI ArcInfo 9.2 software in a California Teale Albers NAD 83 Projection using data from the NRCS-SSURGO Database (NRCS, 2007a).

Table 2.1 shows the textural categories and some physical properties of soils in the LSJR Irrigation Use Area. One of the properties shown is the soil hydrologic group which is ~~describes~~ based on physical factors that affect hydraulic properties of a soil. The Ksat is hydraulic conductivity under saturated soil conditions~~soil characteristics when soils are fully saturated~~. The soil hydrologic group is in turn dependent on soil type, infiltration rate, hydraulic conductivity, and water table depth. Group A is usually composed of sand or gravel and has very high infiltration rate, a very high hydraulic conductivity, and a very deep water table. On the other end, Group D is usually composed of clay and has a very low infiltration rate, a very low hydraulic conductivity, and a very shallow water table (NRCS, 2007b).

Figure 2.4 and Table 2.1 indicate that the soils in the LSJR Irrigation Use Area are predominantly clay loams, clays and silty clay loams with a few areas having patches of loams and silty loams. The analysis of groundwater depth was hampered by incomplete data since some LSJR Irrigation Use Area soil series do not have groundwater depth data in the NRCS-SSURGO database. From Table 2.1, both clays and clay loams constitute about 57% of the overall acreage of the LSJR Irrigation Use Area, most of which are distributed on the western side of the SJR (Figure 2.4). Among the clays, the most dominant soils are Capay, while for clay loams, Vernalis are the most dominant soils. The silty clay loam texture is dominated by El Solyo soils which are more prevalent downstream of the SJR at Patterson and have numerous patches distributed up to the Stanislaus and San Joaquin county boundary (Figure 2.4).

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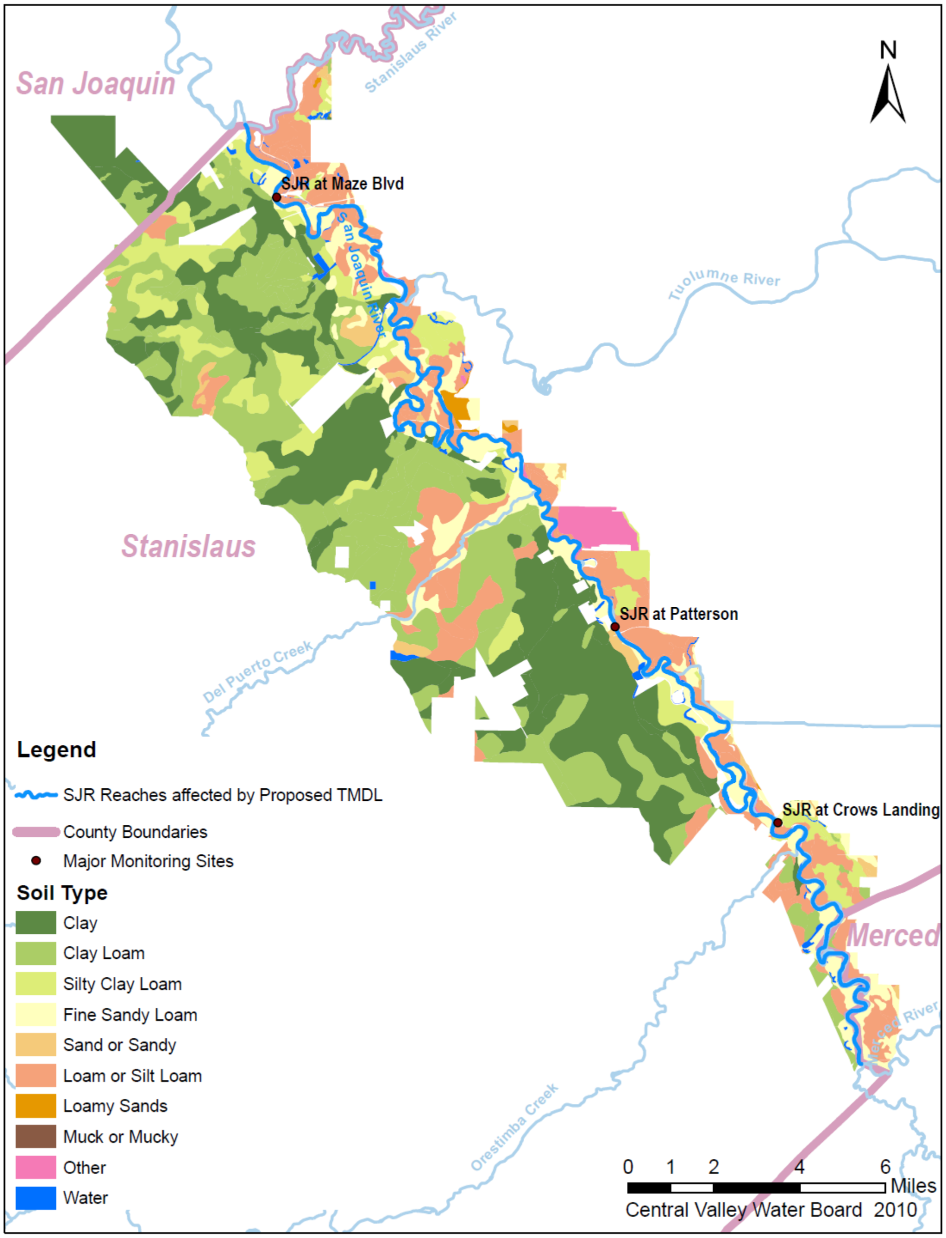
Figure 2.4. Map of soil textures in the LSJR Irrigation Use Area using GIS data from the NRCS-SSURGO database.



Note that this Report did not assess boron levels (See Section 6.1), which would have been presented as Figure 2.3. As a result, the above Figure was labeled 2.4 to allow for consistency with Hoffman (2010).

Table 2.1. Surface layer properties for soil units within the LSJR Irrigation Use Area from the NRCS-SSURGO database, including key soil properties and sorted by soil texture (with corresponding colors in Figure 2.4).

Texture Category	Soil Unit Number	Soil Unit Name	Ksat (in/hr)	Water Holding Capacity (in/in)	Depth to Ground Water (feet)	Hydrologic Group	Total Area (Acres)	Percentage of Total Area	Corresponding Color in Figure 2.3
Clay	100	Capay	0.13~~0.92~~	0.15		D	6836	9.96	
	101	Capay	0.13~~0.92~~	0.15	7.6	D	7552	11.00	
	102	Capay	0.13~~0.92~~	0.15		D	811	1.18	
	106	Capay	0.13~~0.92~~	0.15		D	567	0.83	
	118	Capay	0.13~~0.91~~	0.15		D	259	0.38	
	121	Capay	0.13~~0.91~~	0.15	12.8	D	1367	1.99	
	190	Clear Lake	0.13~~0.92~~	0.14	11.4	D	357	0.52	
	195	Clear Lake	0.13~~0.92~~	0.14	11.4	D	673	0.98	
	170	Dospalos	0.40~~2.82~~	0.13	10.2	D	706	1.03	
	RfA	Rossi	0.13~~0.91~~	0.12		D	7	0.01	
	RmA	Rossi	0.13~~0.91~~	0.12		D	0	0.00	
							19136	**27.87**	
Clay Loam	175	Dospalos	0.40~~2.82~~	0.13	10.2	D	1262	1.84	
	111	El Solyo	0.40~~2.82~~	0.19	7.6	C	1066	1.55	
	330	Pedcat	0.40~~2.82~~	0.13	10.8	D	313	0.46	
	RkA	Rossi	0.38~~2.7~~	0.15		D	111	0.16	
	130	Stomar	0.40~~2.82~~	0.17		C	2663	3.88	
	131	Stomar	0.40~~2.82~~	0.18	7.6	C	980	1.43	
	TdA	Temple	0.38~~2.7~~	0.18		C	41	0.06	
	120	Vernalis	0.40~~2.82~~	0.18		B	6498	9.47	
	123	Vernalis	0.40~~2.82~~	0.18	7.6	B	732	1.07	
	125	Vernalis	0.40~~2.82~~	0.18		B	629	0.92	
	126	Vernalis	0.40~~2.82~~	0.18		B	711	1.04	
	268	Vernalis	0.38~~2.7~~	0.18		B	358	0.52	
	140	Zacharias	0.40~~2.82~~	0.17		B	645	0.94	
	141	Zacharias	0.40~~2.82~~	0.17	7.6	B	1292	1.88	
	142	Zacharias	0.40~~2.82~~	0.13		B	1402	2.04	
	146	Zacharias	0.40~~2.82~~	0.17		B	574	0.84	
	147	Zacharias	0.40~~2.82~~	0.13		B	650	0.95	
							19928	**29.03**	
Silty Clay Loam	CoA	Columbia	0.38~~2.7~~	0.18		C	357	0.52	
	110	El Solyo	0.40~~2.82~~	0.19		C	3268	4.76	
	116	El Solyo	0.40~~2.82~~	0.19		C	398	0.58	
	160	Merritt	0.40~~2.82~~	0.18	12.7	B	635	0.92	
	165	Merritt	0.40~~2.82~~	0.18	12.7	B	735	1.07	
	197	Merritt			12.8		0	0.00	

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Table 2.1. Surface layer properties for soil units within the LSJR Irrigation Use Area from the NRCS-SSURGO database, including key soil properties and sorted by soil texture (with corresponding colors in Figure 2.4).

Texture Category	Soil Unit Number	Soil Unit Name	Ksat (in/hr)	Water Holding Capacity (in/in)	Depth to Ground Water (feet)	Hydrologic Group	Total Area (Acres)	Percentage of Total Area	Corresponding Color in Figure 2.3
	TeA	Temple	0.13~~0.91~~	0.13		C	230	0.33	
	TfA	Temple					166	0.24	
	TgA	Temple					91	0.13	
	ThA	Temple					435	0.63	
	TkA	Temple					617	0.90	
							6931	**10.10**	
Fine Sandy Loam	130	Columbia					0	0.00	
	132	Columbia	3.97~~28~~	0.11	10.2	C	3	0.00	
	150	Columbia	4.00~~28.23~~	0.13	10.2	C	158	0.23	
	151	Columbia	4.00~~28.23~~	0.13	10.2	C	388	0.57	
	153	Columbia	4.00~~28.23~~	0.11	10.2	C	1778	2.59	
	155	Columbia	4.00~~28.23~~	0.11	10.2	C	217	0.32	
	157	Columbia	4.00~~28.23~~	0.11	10.2	C	519	0.76	
	159	Columbia	4.00~~28.23~~	0.11	10.2	C	576	0.84	
	CcA	Columbia	3.97~~28~~	0.13		C	827	1.20	
	CdA	Columbia					42	0.06	
	CeA	Columbia	3.97~~28~~	0.15		C	386	0.56	
	180	Dello	4.00~~28.23~~	0.13	8.9	C	269	0.39	
	DmA	Dinuba	3.97~~28~~	0.12		C	42	0.06	
	DpA	Dinuba	1.28~~9~~	0.09		C	112	0.16	
	270	Elsalado	4.00~~28.23~~	0.14		B	965	1.41	
	FrA	Fresno	1.28~~9~~	0.09		D	4	0.01	
	FsA	Fresno	1.28~~9~~	0.09		D	92	0.13	
	GgA	Grangeville	3.97~~28~~	0.11		C	1	0.00	
	GmA	Grangeville	3.97~~28~~	0.16		C	2	0.00	
	HaA	Hanford					97	0.14	
	PcA	Pachappa	1.28~~9~~	0.13		D	4	0.01	
	PpA	Piper	1.28~~9~~	0.12		C	7	0.01	
	PuA	Piper	1.28~~9~~	0.08		C	27	0.04	
	TnA	Traver	1.28~~9~~	0.1		B	24	0.04	
	ToA	Traver					6	0.01	
	WaA	Waukena	0.38~~2.7~~	0.11		C	28	0.04	
	WaA	Waukena	1.28~~9~~	0.09		D	0	0.00	
	WbA	Waukena	0.38~~2.7~~	0.09		C	328	0.48	
	WbA	Waukena	1.28~~9~~	0.09		D	197	0.29	
	WcA	Waukena	0.38~~2.7~~	0.09		C	116	0.17	

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Table 2.1. Surface layer properties for soil units within the LSJR Irrigation Use Area from the NRCS-SSURGO database, including key soil properties and sorted by soil texture (with corresponding colors in Figure 2.4).

Texture Category	Soil Unit Number	Soil Unit Name	Ksat (in/hr)	Water Holding Capacity (in/in)	Depth to Ground Water (feet)	Hydrologic Group	Total Area (Acres)	Percentage of Total Area	Corresponding Color in Figure 2.3
							7215	**10.51**	
Sand or Sandy	CbA	Chualar	3.97~~28~~	0.12		B	6	0.01	
	210	Cortina	4.00~~28.23~~	0.11		B	252	0.37	
	DhB	Delhi	13.04~~92~~	0.07		A	5	0.01	
	DpA	Dinuba	3.97~~28~~	0.12		C	1	0.00	
	DrA	Dinuba	3.97~~28~~	0.12		C	56	0.08	
	DwA	Dinuba	1.28~~9~~	0.09		C	26	0.04	
	FtA	Fresno	1.28~~9~~	0.09		D	62	0.09	
	FuA	Fresno	1.28~~9~~	0.09		D	14	0.02	
	FvA	Fresno	1.28~~9~~	0.09		D	2	0.00	
	FxA	Fresno					34	0.05	
	GhA	Grangeville	3.97~~28~~	0.13		C	30	0.04	
	GkA	Grangeville	3.97~~28~~	0.11		C	0	0.00	
	HdA	Hanford	3.97~~28~~	0.12		B	14	0.02	
	HeA	Hanford	3.97~~28~~	0.13		B	0	0.00	
	TpA	Traver	1.28~~9~~	0.1		B	34	0.05	
	TsA	Traver	1.28~~9~~	0.1		B	4	0.01	
	200	Veritas	4.00~~28.23~~	0.14		B	525	0.77	
	WdA	Waukena	0.38~~2.7~~	0.11		C	47	0.07	
	WeA	Waukena	0.38~~2.7~~	0.09		C	0	0.00	
	WrA	Whitney	3.97~~28~~	0.12		C	4	0.01	
							1118	**1.63**	
Loam or Silt Loam	245	Bolfar	1.30~~9.17~~	0.14	10.2	D	380	0.55	
	246	Bolfar	1.30~~9.17~~	0.14	10.2	D	247	0.36	
	CbA	Columbia	1.28~~9~~	0.15		C	635	0.92	
	CeA	Columbia	1.28~~9~~	0.15		C	868	1.26	
	CfA	Columbia	1.28~~9~~	0.15		C	761	1.11	
	CgA	Columbia	1.28~~9~~	0.13		C	122	0.18	
	ChA	Columbia	1.28~~9~~	0.11		C	262	0.38	
	CkA	Columbia	1.28~~9~~	0.15		C	311	0.45	
	CmA	Columbia	1.28~~9~~	0.15		C	581	0.85	
	CpA	Columbia	1.28~~9~~	0.15		C	282	0.41	
	CsB	Columbia	1.28~~9~~	0.15		C	2123	3.09	
	271	Elsalado	1.30~~9.17~~	0.15		B	181	0.26	
	272	Elsalado	1.30~~9.17~~	0.15	12.7	B	5	0.01	
	274	Elsalado	1.30~~9.17~~	0.15		B	158	0.23	

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Table 2.1. Surface layer properties for soil units within the LSJR Irrigation Use Area from the NRCS-SSURGO database, including key soil properties and sorted by soil texture (with corresponding colors in Figure 2.4).

Texture Category	Soil Unit Number	Soil Unit Name	Ksat (in/hr)	Water Holding Capacity (in/in)	Depth to Ground Water (feet)	Hydrologic Group	Total Area (Acres)	Percentage of Total Area	Corresponding Color in Figure 2.3
	FrA	Fresno					3	0.00	
	GbA	Grangeville	1.28~~9~~	0.16		B	89	0.13	
	GcA	Grangeville					42	0.06	
	TbA	Temple	1.28~~9~~	0.15		C	222	0.32	
	TcA	Temple	1.28~~9~~	0.15		C	1077	1.57	
	TdA	Temple	1.28~~9~~	0.15		C	149	0.22	
	121	Vernalis	1.30~~9.17~~	0.16	7.6	B	169	0.25	
	122	Vernalis	1.30~~9.17~~	0.16		B	1678	2.44	
	127	Vernalis	1.30~~9.17~~	0.16		B	1469	2.14	
							11812	**17.21**	
Loamy Sands	DgA	Delhi	13.04~~92~~	0.08		A	223	0.33	
	HfA	Hilmar	13.04~~92~~	0.08		B	36	0.05	
	HkbA	Hilmar	13.04~~92~~	0.08		B	21	0.03	
	TuA	Tujunga	13.04~~92~~	0.08		A	1	0.00	
							282	**0.41**	
Mucky	n/a	n/a	n/a~~n/a~~	n/a	n/a	n/a	0	0.00	
Other	M-W	Miscellaneous water	n/a~~n/a~~	n/a	n/a	n/a	898	1.31	
	Rf	Riverwash	13.04~~92~~	0.04	n/a	D	48	0.07	
	Rr	Riverwash	13.04~~92~~	0.04	n/a	D	121	0.18	
							1067	**1.55**	
Water	128	Water	n/a~~n/a~~	n/a	n/a	n/a	447	0.65	
	284	Water	n/a~~n/a~~	n/a	n/a	n/a	3	0.00	
	W	Water	n/a~~n/a~~	n/a	n/a	n/a	540	0.79	
							990	**1.44**	
Unidentified	n/a	n/a	n/a~~n/a~~	n/a	n/a	n/a	174	0.25	
Grand Total							68654	100%	

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2.3.2. Crops

Following the approach of Hoffman (2010), staff compiled available information regarding crops grown in the LSJR Irrigation Use Area. The purpose of this information is to review past and current crops specifically in relation to their salt sensitivity, and subsequently use this information in deciding which crops to model as surrogates for other crops. A noticeable difference here from Hoffman (2010) is that much less cropping data is available for the LSJR Irrigation Use Area. Whereas the South Delta has four DWR surveys spanning 1976 to 2007, much less data is available for the counties here, as discussed below.

Land use survey GIS layers of the Merced, Stanislaus and San Joaquin counties, data from the DWR website (DWR, 2009a), were imported into ESRI ArcInfo 9.2 software and were in a California Teale Albers NAD 83 Projection. DWR takes turns in surveying land use and cover crop for each county once per decade; hence surveying periods vary among the GIS layers of the three counties. To resolve this difference, GIS layers were grouped and merged by their corresponding decade, one set of maps for the 1990s and another for the 2000s. The terms “1990s” and “2000s” are used in subsequent figures and tables when they were derived based on this grouping.

The 1990s layer includes the San Joaquin and Stanislaus layers from 1996 and the Merced layer from 1995. The 2000s layer includes the Stanislaus layer from 2004 and the Merced layer from 2002. There is currently no available GIS layer for the San Joaquin County in the 2000s.

Some crops in the DWR survey are double cropped and are assigned 100% for each crop that is planted in sequence (Table 2.3) (Woods, DWR, 2009; Personal Communication). For purposes of this Report, to achieve agreement and consistency with overall total acreage, crops that were cropped in sequence in the same field were both assigned 50% of the field acreage.

For intercropped fields, such as a young orchard intercropped with beans, DWR assigns 100% of the field acreage for the trees and 50% for the beans which is a 2:1 proportion. For this Report, the 2:1 proportion was split against 100% of the field acreage, yielding 66.67% for trees and 33.33% for beans. For mixed field and truck crops, DWR assigned a percentage to each planted crop in each field. The assigned percentage adds up to 100%; thus, no adjustment was necessary.

Tables 2.2 and 2.3 show irrigated crop acreage in the LSJR Irrigation Use Area. Following the same approach as Hoffman (2010), the crops are categorized by their tolerance to salinity based on findings of Maas and Hoffman (1977); Maas and Grattan (1999). The authors of these findings noted that the data should serve as a guide to relative tolerances among crops because absolute tolerances vary depending on climate, soil conditions and cultural practices.

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For crops where no salt tolerance was given such as unspecified pastures or miscellaneous grasses, generalized salt tolerance levels were assigned based on the most common salt tolerance level of crops in a given group. These crops are shown in *italics* in Table 2.2. All the unspecified crop categories except rice and grapes represent fallow fields with identifiable residue of certain crop types at the time of survey. The acreage for corn is for both human and animal (fodder) consumption while that for dry beans includes lima beans. Some of the mixed and native pastures are partially or not irrigated. The mixed truck crops represent fields planted with four or more types of truck crops while cells with a dash indicate an area that was not surveyed.

Data presented in Table 2.2 also indicates the relative importance of crops based on irrigated acreage. For example, almonds, dry beans and alfalfa, the crops modeled in this Report, occupy significant acreage in the LSJR Irrigation Use Area. Dry beans are the most salt sensitive crops grown on significant acreage.

Results from Table 2.2 show a general decline in irrigated acreage from the 1990s to the 2000s of about 7,000 acres. Despite this decline, the percentage of salt sensitive crops remained fairly stable between the 1990s and 2000s yet moderately sensitive crops declined by about 8%. There was an 8% increase in moderately tolerant crops in the 2000s (Table 2.3).

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Table 2.2. Summary of irrigated crop acreage in LSJR Irrigation Use Area for the 1990s and 2000s from DWR land use surveys

Crops	Salt Tolerance[1]	1990s	2000s
Fruits and Nuts			
Almonds	S	2091	4343
Apples	S	92	53
Apricots	S	4779	2776
Cherries	S	372	207
Eucalyptus	MT	6	-
Figs	MT	-	-
Grapefruit	S	-	-
Kiwis	S	-	-
Lemons	S	-	-
Olives	T	-	-
Oranges	S	-	-
Peaches/Nectarines	S	21	345
Pears	S	-	-
Pistachios	MS	16	31
Plums	MS	150	34
Prunes	MS	-	33
Walnuts	S	1902	2338
Misc. Deciduous Fruits & Nuts	*S*	-	44
Misc. Subtropical Fruits	*S*	-	-
Unspecified Deciduous Fruits & Nuts	*S*	-	-
Subtotal:		***9430***	***10204***
Field Crops			
Castor Beans	S	-	3019
Corn	MS	5592	318
Cotton	T	-	16
Dry Beans	S	12623	5893
Flax	MS	-	-
Safflower	MT	65	-
Sorghum	MT	-	-
Sudan	MT	69	613
Sugar Beets	T	-	-
Sunflowers	MT	-	-
Unspecified Field Crops	*MT*	1305	486
Subtotal:		***19653***	***10345***
Grain and Hay Crops			
Barley	T	-	-
Oats	T	-	-
Wheat	MT	-	33
Misc. & Mixed Grain/Hay	*MT*	-	110
Unspecified Grain/Hay Crops	*MT*	1923	5609
Subtotal:		***1923***	***5753***
Pasture			
Alfalfa	MS	8839	9398
Clover	MS	-	-
Induced High Water Table Native Pasture	*MS*	-	-
Mixed Pasture	*MS*	3444	3190
Native Pasture	*MS*	-	-
Turf Farms	*MT*	426	379
Misc. Grasses	*MS*	-	-
Unspecified Pasture	*MS*	-	-

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Table 2.2. Summary of irrigated crop acreage in LSJR Irrigation Use Area for the 1990s and 2000s from DWR land use surveys

Crops	Salt Tolerance[1]	1990s	2000s
Subtotal:		***12708***	***12967***
Truck, Nursery and Berry Crops			
Artichokes	MT	-	183
Asparagus	T	-	17
Broccoli	MS	-	122
Bush Berries	S	12	422
Cabbage	MS	-	606
Carrots	S	27	124
Cauliflower	MS	282	6
Celery	MS	-	7455
Cherries	S	-	277
Cole Crops	MS	51	-
Flowers/Nursery/Christmas Tree Farms	*S*	13	-
Green Beans	S	126	-
Lettuce	MS	29	-
Melons/Squash/Cucumbers	MS	2426	-
Mixed Truck Crops (four or more)	*MS*	95	-
Onions/Garlic	S	151	-
Pea	MS	-	-
Peppers	MS	452	-
Potatoes	MS	-	-
Spinach	MS	-	-
Strawberries	S	-	-
Sweet Potatoes	MS	-	-
Tomatoes	MS	9391	481
Misc. Truck Crops	*MS*	-	-
Unspecified Truck Crops	*MS*	-	604
Subtotal:		***13053***	***10297***
Rice			
Unspecified Rice	S	-	-
Vineyards			
Raisin Grapes	MS	-	-
Unspecified Grapes	MS	59	512
Subtotal:		***59***	***512***
Other			
Idle Field	Other	459	564
Subtotal Irrigated Crops:		**57287**	**50643**
Breakdown by Salt Tolerance:	**S**	22209	19841
	MS	30825	22790
	MT	3794	7414
	T	0	33
	Other	459	564
Other Land Uses/Covers:		***11171***	***15818***
Area without Data:		***0***	***0***
Total Area:		**68458**	**66460**

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Table 2.3. Percentage of total irrigated land in the LSJR Irrigation Use Area for each crop grown in the 1990s and 2000s from DWR land use surveys

Crops	Salt Tolerance[1]	1990s (%)	2000s (%)
Fruits and Nuts			
Almonds	S	3.65	8.58
Apples	S	0.16	0.11
Apricots	S	8.34	5.48
Cherries	S	0.65	0.41
Eucalyptus	MT	0.01	-
Figs	MT	-	-
Grapefruit	S	-	-
Kiwis	S	-	-
Lemons	S	-	-
Olives	T	-	-
Oranges	S	-	-
Peaches/Nectarines	S	0.04	0.68
Pears	S	-	-
Pistachios	MS	0.03	0.06
Plums	MS	0.26	0.07
Prunes	MS	-	0.07
Walnuts	S	3.32	4.62
Misc. Deciduous Fruits & Nuts	*S*	-	0.09
Misc. Subtropical Fruits	*S*	-	-
Unspecified Deciduous Fruits & Nuts	*S*	-	-
Subtotal:		***16.46***	***20.15***
Field Crops			
Castor Beans	S	-	5.96
Corn	MS	9.76	0.63
Cotton	T	-	0.03
Dry Beans	S	22.03	11.64
Flax	MS	-	-
Safflower	MT	0.11	-
Sorghum	MT	-	-
Sudan	MT	0.12	1.21
Sugar Beets	T	-	-
Sunflowers	MT	-	-
Unspecified Field Crops	*MT*	2.28	0.96
Subtotal:		***34.31***	***20.43***
Grain and Hay Crops			
Barley	T	-	-
Oats	T	-	-
Wheat	MT	-	0.07
Misc. & Mixed Grain/Hay	*MT*	-	0.22
Unspecified Grain/Hay Crops	*MT*	3.36	11.08
Subtotal:		***3.36***	***11.36***
Pasture			
Alfalfa	MS	15.43	18.56
Clover	MS	-	-
Induced High Water Table Native Pasture	*MS*	-	-
Mixed Pasture	*MS*	6.01	6.30
Native Pasture	*MS*	-	-
Turf Farms	*MT*	0.74	0.75
Misc. Grasses	*MS*	-	-

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Table 2.3. Percentage of total irrigated land in the LSJR Irrigation Use Area for each crop grown in the 1990s and 2000s from DWR land use surveys

Crops	Salt Tolerance[1]	1990s (%)	2000s (%)
Unspecified Pasture	*MS*	-	-
Subtotal:		***22.18***	***25.61***
Truck, Nursery and Berry Crops			
Artichokes	MT	-	0.36
Asparagus	T	-	0.03
Broccoli	MS	-	0.24
Bush Berries	S	0.02	0.83
Cabbage	MS	-	1.20
Carrots	S	0.05	0.25
Cauliflower	MS	0.49	0.01
Celery	MS	-	14.72
Cherries	S	-	0.55
Cole Crops	MS	0.09	-
Flowers/Nursery/Christmas Tree Farms	*S*	0.02	-
Green Beans	S	0.22	-
Lettuce	MS	0.05	-
Melons/Squash/Cucumbers	MS	4.23	-
Mixed Truck Crops (four or more)	*MS*	0.17	-
Onions/Garlic	S	0.26	-
Pea	MS	-	-
Peppers	MS	0.79	-
Potatoes	MS	-	-
Spinach	MS	-	-
Strawberries	S	-	-
Sweet Potatoes	MS	-	-
Tomatoes	MS	16.39	0.95
Misc. Truck Crops	*MS*	-	-
Unspecified Truck Crops	*MS*	-	1.19
Subtotal:		***22.79***	***20.33***
Rice			
Unspecified Rice	S	-	-
Vineyards			
Raisin Grapes	MS	-	-
Unspecified Grapes	MS	0.10	1.01
Subtotal:		***0.10***	***1.01***
Other			
Idle Field	Other	0.80	1.11
Subtotal Irrigated Crops:		**100.00**	**100.00**
Breakdown by Salt Tolerance:	**S**	38.77	39.18
	MS	53.81	45.00
	MT	6.62	14.64
	T	0.00	0.07
	Other	0.80	1.11

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Notes for Tables 2.2 and 2.3

1: Salt tolerance categories as follows:
S = Sensitive; MS = Moderately Sensitive; MT = Moderately Tolerant; T = Tolerant

3. Factors Affecting Crop Response to Salinity

3.1. Season-Long Crop Salt Tolerance

3.1.1. State of Knowledge

A review on the current knowledge of season-long crop salt tolerance is presented by Hoffman (2010) (Appendix A, Section 3.1.1). Only excerpts of this Section from Appendix A are presented here.

As discussed in Hoffman (2010):

For soil salinities exceeding the threshold of any given crop, relative yield (Y_r) can be estimated by:

$$Y_r = 100 - b(EC_e - a) \qquad \text{(Eqn. 3.1)}$$

Where:
a = the salinity threshold expressed in deciSiemens per meter;
b = the slope expressed in percentage per deciSiemens per meter;
EC_e = the mean electrical conductivity of a saturated-soil extract taken from the root zone.

An example of how this piecewise linear response function fits data can be seen in Figure 3.1 for data taken from a field experiment on corn in the Sacramento-San Joaquin Delta near Terminus, CA (Hoffman et al., 1983).

Crop salt tolerance has been established for a large number of crops in experimental plots, greenhouse studies, and field trials (Maas and Hoffman, 1977; and Maas and Grattan, 1999). Hoffman (2010) reported that salt tolerance coefficients, threshold (a) and slope (b) as presented in Equation 3.1 are widely used in steady state and transient models dealing with salinity control.

As discussed in Hoffman (2010):

Most of the data used to determine these two coefficients were obtained where crops were grown under conditions simulating recommended cultural and management practices for commercial production. Consequently, the coefficients indicate the relative tolerances of different crops grown under different conditions and not under some standardized set of conditions. Furthermore, the coefficients apply only where crops are exposed to fairly uniform salinities from the late seedling stage to maturity.

3.1.2 LSJR Irrigation Use Area Situation

The crop salt tolerance threshold and slope values of 10 most important crops grown in the LSJR Irrigation Use Area are shown in Table 3.1. These values are adapted from previous studies conducted by Maas and Hoffman (1977) and Maas and Grattan (1999). The methodology for crop selection of these 10 crops was based on an approach used by Hoffman (2010). This screening approach

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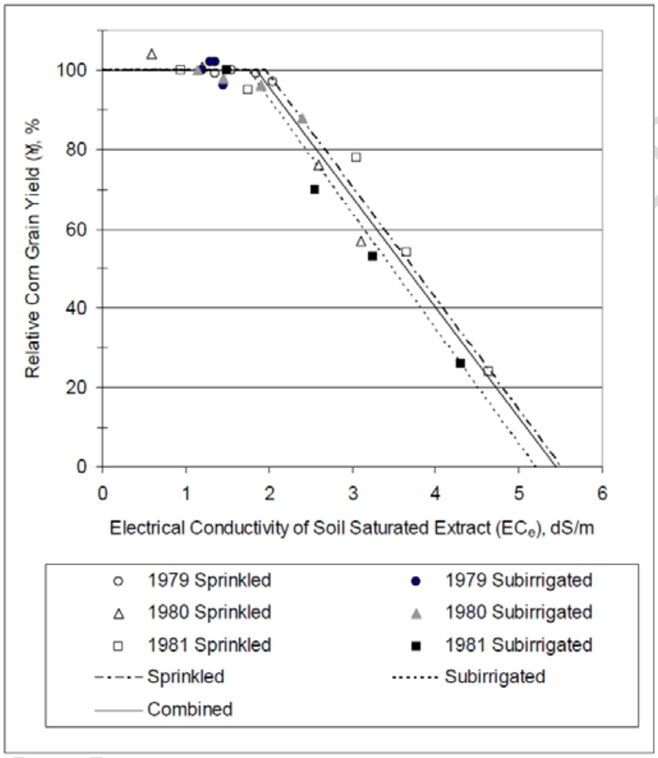
considered acreage for those crops that exceeded 1% of the irrigated area in the LSJR Irrigation Use Area as shown in Table 2.1 and 2.2.

Figure 3.1. Relative grain yield of corn grown in the Sacramento - San Joaquin River Delta as a function of soil salinity by sprinkled and subirrigated methods (Adapted from Hoffman, 2010).



As stated previously, one of the purposes of this study is to use the Hoffman (2010) steady state soil salinity model to identify threshold salinity values in irrigation water that provide protection for the most salt sensitive crops grown in the LSJR Irrigation Use Area. The first step in running this model is to determine which crop(s) should be modeled. As shown in Table 3.1, dry beans are the most salt sensitive crop grown in the LSJR Irrigation Use Area on significant acreage, and thus were selected as the primary crop to be modeled.

Staff review of the crops with 1% or more acreage in the LSJR Irrigation Use Area found that two other crops, almond and alfalfa, could be easily modeled since existing modules for these crops had been produced by Hoffman (2010). Furthermore, though these crops are not as sensitive to salinity as beans, they have different irrigation and/or growth patterns than dried beans. Thus, there is a possibility that modeling these crops may result in a lower threshold value than for the salt sensitive beans.

Almond is a perennial tree crop, that is managed as an orchard and could have cover crops grown on the orchard floor. For purposes of this Report, similar to Hoffman (2010), it was assumed that there was no cover crop. If a cover crop was grown in the almond orchard, the evapotranspiration for the cover crop would have to be added to that for almond to determine the irrigation requirements in the models. Almond has a relative salt tolerance of sensitive, tied in second place with grapes as the most sensitive of the crops listed following dry beans. Alfalfa is a perennial crop that goes through about six to seven cutting cycles, with each cycle lasting about 28-30 days (Hoffman, 2010). As a result, with all growth cycles considered, alfalfa has a longer growing season than beans. Further details on modeling assumptions of these three crops are provided in Chapter 5 of this Report.

Table 3.1. Crop salt tolerance coefficients for important crops in the LSJR Irrigation Use Area based on Maas and Hoffman (1977); Maas and Grattan, 1999.

Common Name	Botanical Name	Tolerance based on	Threshold* ECe, dS/m	Slope* % per dS/m	Relative Tolerance**
Alfalfa	*Medicago sativa*	Shoot (dry weight)	2.0	7.3	MS
Almond	*Prunus duclis*	Shoot growth	1.5	19	S
Apricot	*Prunus armeniaca*	Shoot growth	1.6	24	S
Bean (Dry)	*Phaseolus vulgaris*	Seed yield	1.0	19	S
Cabbage	*Brassica oleracea*	Head (fresh weight)	1.8	9.7	MS
Castor Bean	*Ricinus communis*	---	---	---	MS
Celery	*Apium graveolens*	Petiole (fresh weight)	1.8	6.2	MS
Grape	*Vitus vinifera*	Shoot growth	1.5	9.6	MS
Sudan Grass	*Sorghum sudanense*	Shoot (dry weight)	2.8	4.3	MT
Walnut	*Juglans*	Foliar injury	---	---	S

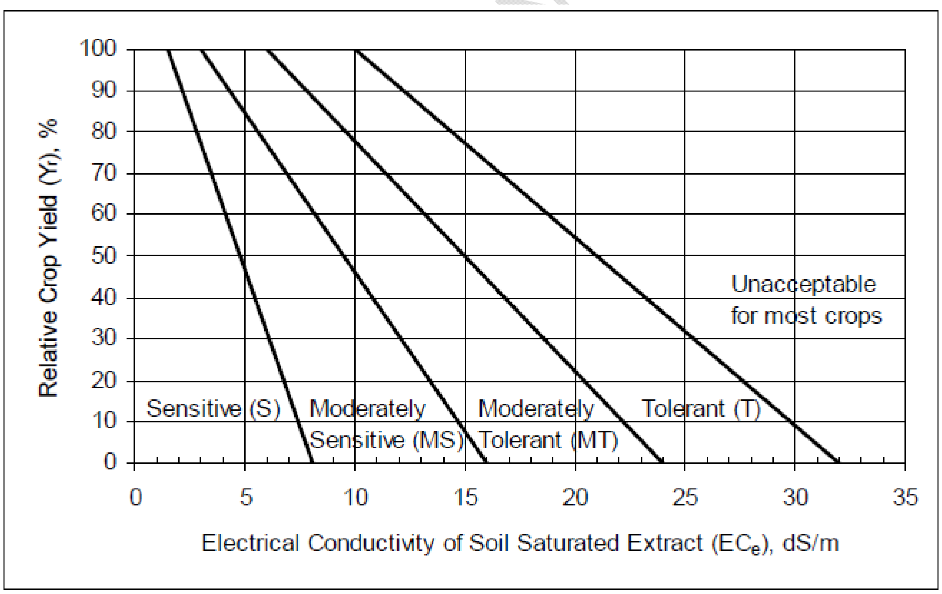
* Values of threshold = (a) and slope = (b) for Equation 3.1
** Relative salt tolerance ratings noted as (S) sensitive, (MS) moderately sensitive, (MT) moderately tolerant, and (T) tolerant, see Fig. 3.2.

The definition of relative crop tolerance ratings are given in Figure 3.2. Crop salt tolerance ranges for a sufficient number of crops in the LSJR Irrigation Use Area is known (Tables 2.2 and 2.3). As indicated previously, assigning of crop salt tolerances to various crops was based on Maas and Grattan (1999). Following the approach of Hoffman (2010), crops that have general categories in DWR crop surveys such as “Unspecified Field Crops”, “Miscellaneous Deciduous Fruits and Nuts", and "Mixed Pastures", crop salt tolerances were assigned with the most common salt tolerance among crops in the same category.

Figure 3.3 shows the percentage of crops grown in the LSJR based upon relative crop salt tolerance from DWR crop surveys conducted every 10 years. Of note are the decrease over time in the percentage of moderately salt sensitive crops and an increase in the percentage of moderately salt tolerant crops.

Crop tolerance maps and planted dry bean maps (Figures 3.4 and 3.5a) were developed ESRI ArcInfo 9.2 software and were in a California Teale Albers NAD 83 Projection. The goal of these figures was to identify crop salt tolerance and planted dry beans distribution across the LSJR Irrigation Use Area. Figure 3.4 illustrates the locations where crops are grown based upon salt tolerance from DWR crop surveys conducted in the 1990s and 2000s. Categories of increasing salt sensitivity were assigned varying colors as shown on the color ramp. Uncultivated areas are grey and areas without data in 2000s are black.

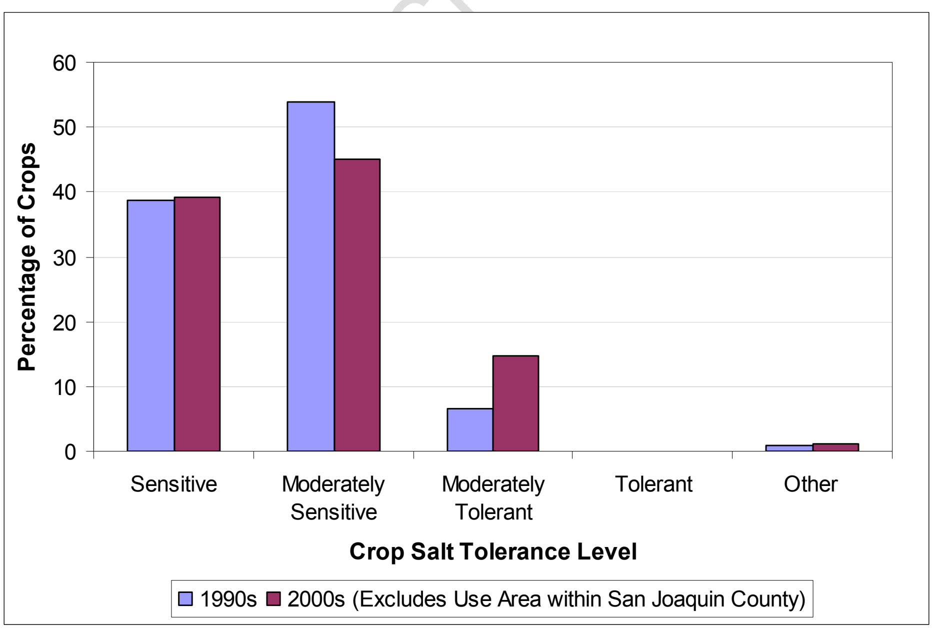
Figure 3.2. Classification of crop tolerance to salinity based on relative crop yield against electrical conductivity of saturated soil extract (EC_e) dS/m. (Adapted from Hoffman, 2010; Appendix A).



For the 1990s layer (Figure 3.4), the west side of the LSJR Irrigation Use Area displays a mosaic of predominantly sensitive to moderately sensitive crops. The periphery on each side of the San Joaquin River is characterized by native vegetation while the eastern side of the LSJR Irrigation Use Area is predominantly moderately sensitive crops. For the 2000s layer (Figure 3.4), the major differences from the 1990s layer is the increase in the “other” category which includes mixed crops or idle fields and the fact that there were no “mixed non agricultural land uses”. The area based on total acreage where moderately salt sensitive crops are grown has decreased with time from the 1990s to the 2000s by about 20% (Table 2.3).

Since the protective salinity threshold will be based on the most salt sensitive crop grown on significant acreage in the LSJR Irrigation Use Area, which is dry bean, it is instructive to evaluate how the acreage and location of dry bean has changed over the past decade. Figure 3.5a shows that although bean acreage appears to have decreased over time in the LSJR Irrigation Use Area, the location of bean fields remains widely spread out on the western side of the use area in recent years. Hoffman (2010) reported that the salt tolerance of bean is only based on five published reports of laboratory studies with only one experiment being conducted in soil in the South Delta area. In addition, these experiments were conducted more than 30 years ago and there are probably new and improved varieties now being grown that are representative of the area. These insights provide a relevant perspective for interpreting some of the results for the LSJR Irrigation Use Area.

Figure 3.3. Distribution of crops based on salt tolerance relative (as a percent) to total irrigated acres in the LSJR Irrigation Use Area in the 1990s and the 2000s (based on DWR land use surveys).



Based on Figs. 3.5a and 3.5b, during the 1990s, the distribution of dry beans was widely scattered throughout the LSJR Irrigation Use Area and had a greater acreage of ~~a higher percentage~~12,608 acres out of 57,287 total acres (22%) compared to the 2000s where acreage was 4643 acres out of 50,642 total acres (9%) (See Table 2.2). In the 2000s, there seemed to be a greater preference for planting dry beans in mixed crops (1249 acres) which accounts for an approximate difference of 2.454% above that in the 1990s (14 acres) (See Table 2.2). There is no indication that dry beans were planted on the east side of the LSJR Irrigation Use Area.

Hoffman (2010) assessed the original analysis performed by Maas and Hoffman (1977) and reviewed the experimental results used to establish the salt tolerance of bean (bean varieties were red kidney or wax). A total of nine experiments were analyzed. Of these nine, Maas and Hoffman (1977) used five. Results from the remaining four were not considered because the control (non-saline) treatment exceeded the salt tolerance threshold determined from the other five experiments or only pod weights were measured.

All the experimental data used to establish the salt tolerance of bean are shown in Figure 3.6. The relationship for bean salt tolerance published by Maas and Hoffman (1977) is also shown in Figure 3.6 for comparison with the experimental results. Hoffman (2010) recommended that a field experiment be conducted in the South Delta similar to the corn experiment near Terminus, CA (Hoffman et al., 1983).

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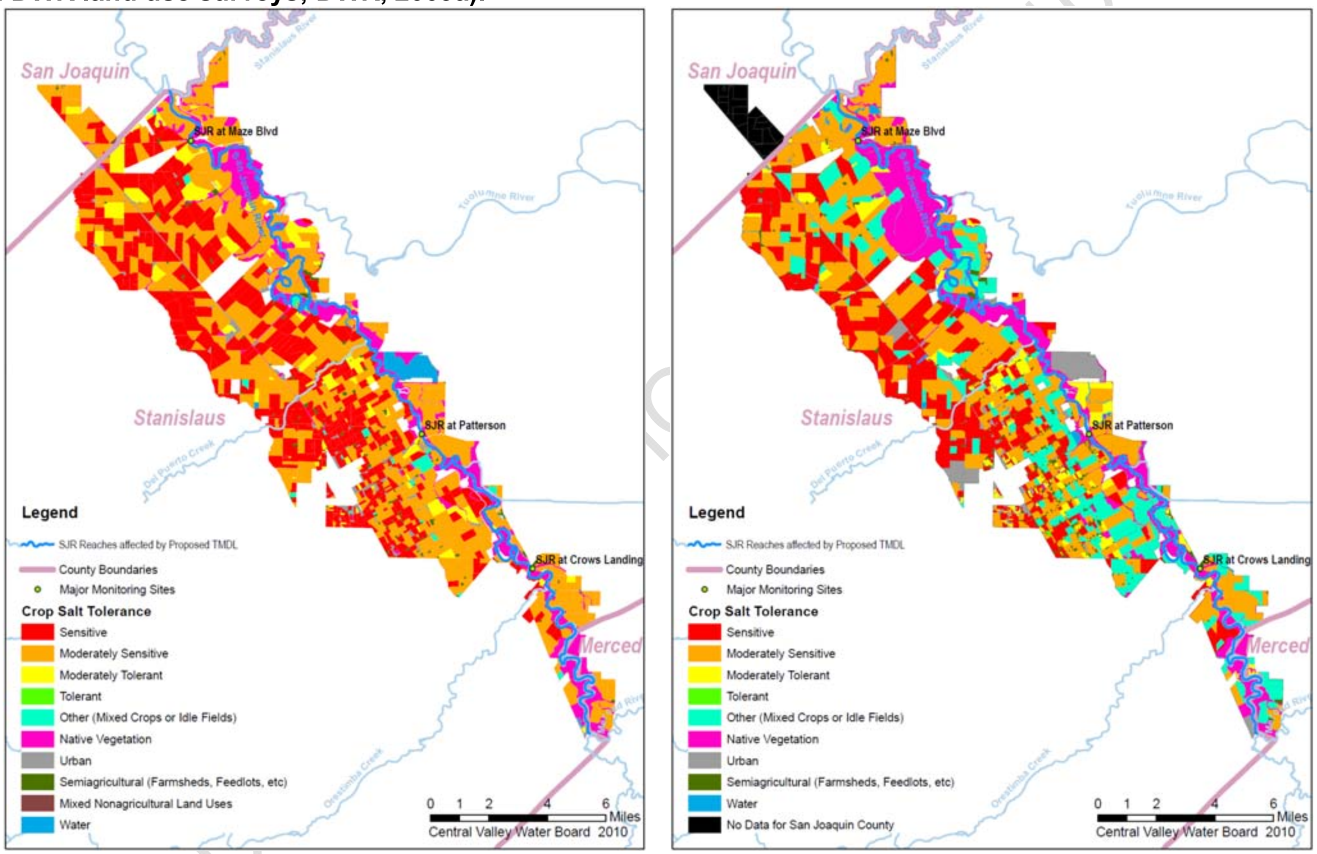
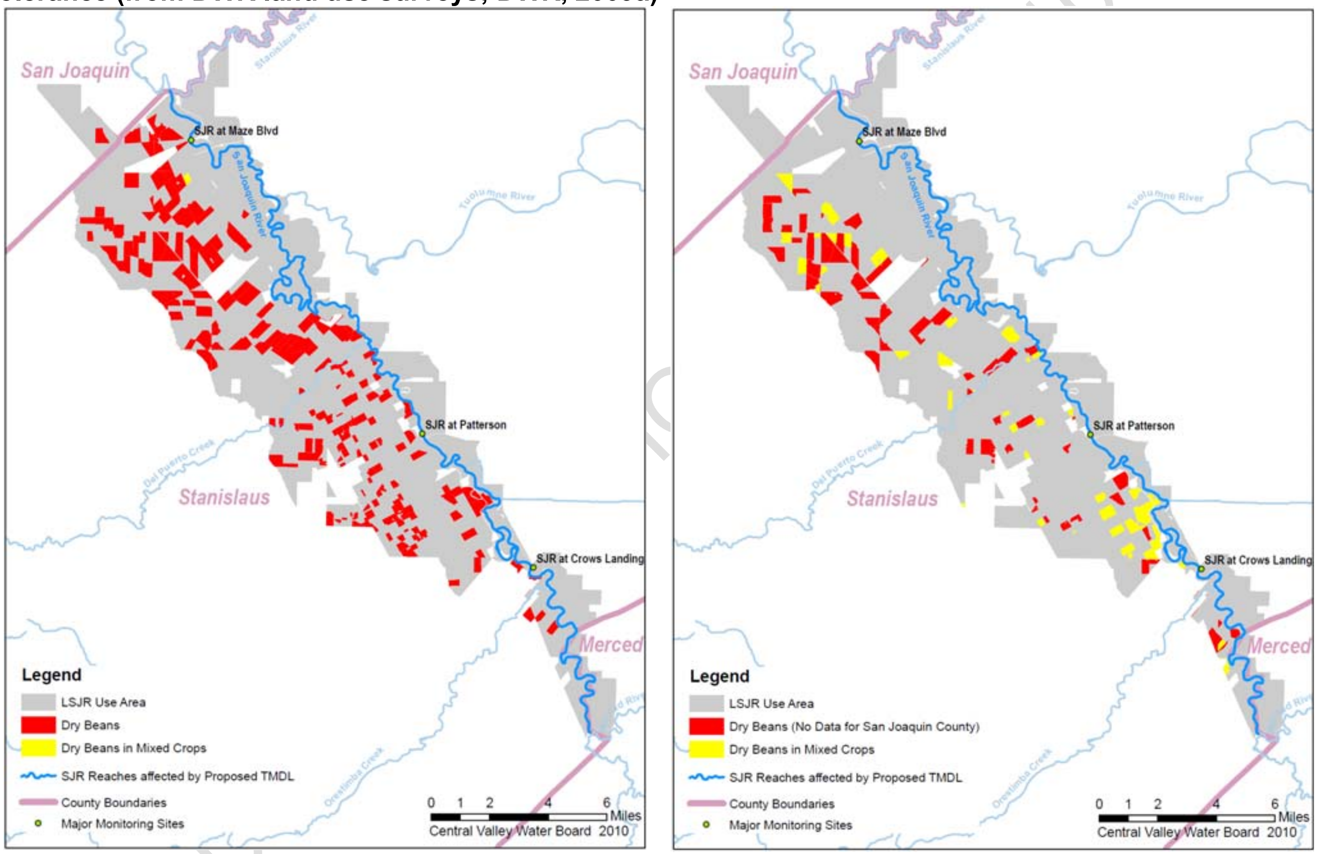
Figure 3.4. Distribution of crops in the LSJR Irrigation Use Area for the 1990s and 2000s based on salt tolerance (from DWR land use surveys; DWR, 2009a).



Crop Salt Tolerance in 1990s DWR Land Use Survey Crop Salt Tolerance in 2000s DWR Land Use Survey

Figure 3.5a. Distribution of dry beans grown in the LSJR Irrigation Use Area for the 1990s and 2000s based on salt tolerance (from DWR land use surveys; DWR, 2009a)



Planted beans in 1990s DWR Land Use Survey

Planted beans in 2000s DWR Land Use Survey

Figure 3.5b. Proportions of dry beans grown in the LSJR Irrigation Use Area for the 1990s and 2000s based on salt tolerance (from DWR land use surveys)

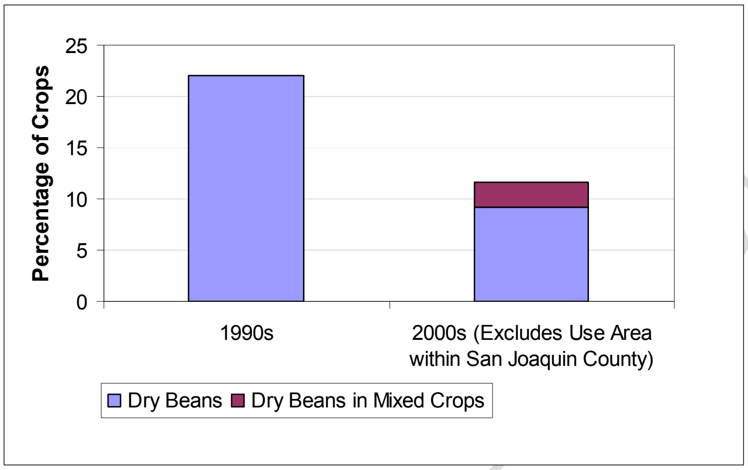
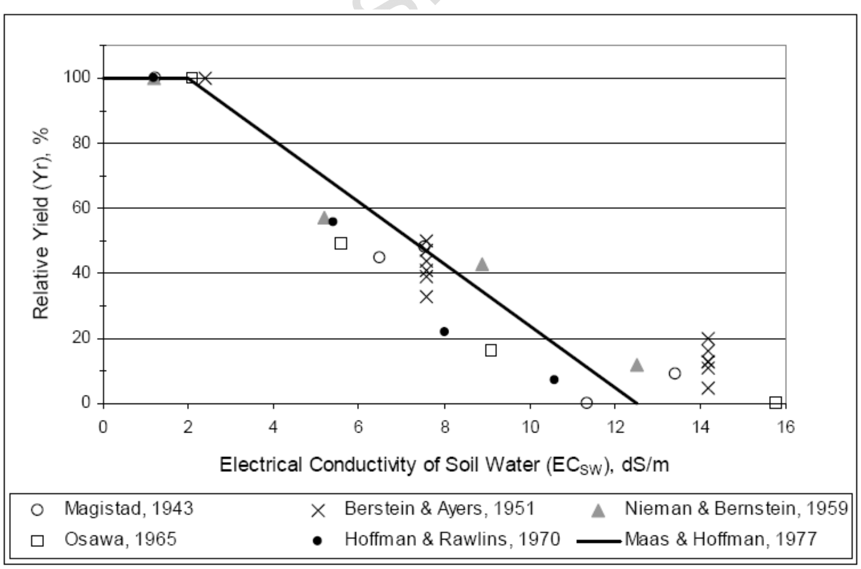


Figure 3.6. Original data from five experiments used to establish the salt tolerance of bean. (Adapted from Hoffman, 2010)



3.2. Crop Salt Tolerance at Various Growth Stages

3.2.1 State of Knowledge

A review on the state of knowledge for crop salt tolerance at various growth stages is given by Hoffman (2010) (Appendix A; Section 3.2.1).

3.2.2 LSJR Irrigation Use Area Situation

Staff is currently unaware of published experimental data related to crop salt tolerance at various growth stages collected in the LSJR Irrigation Use Area. Thus, staff relied on the existing information compiled by Hoffman (2010). Hoffman's review discussed experimental data published by Maas and Grieve (1994) related to crop salt tolerance.

Of the 10 crops important in the LSJR Irrigation Use Area, seedling emergence data from Mass and Grieve (1994) is available for two crops. The soil salinity level that reduced emergence by 10% is reported in Table 3.2. There was more than one reference reported for alfalfa; hence, the range of soil salinity that reduced emergence by 10% is given. In comparison to the tolerance values given in Table 3.1, Table 3.2 indicates that both alfalfa and bean have higher salt tolerance at emergence than for yield. As a result, since bean is a salt sensitive crop but had higher tolerance, salt tolerance at emergence may not be a concern especially if more tolerant cultivars are chosen.

Table 3.2. Level of soil salinity required to reduce emergence by 10% for crops important in the LSJR Irrigation Use Area (Maas and Grieve, 1994).

Common Name	Botanical Name	Electrical Conductivity of Soil Salinity (EC_e) that Reduced Emergence by 10%.
Alfalfa	Medicago sativa	2.5 to 9.5
Bean	Phaseolus vulgaris	5.5

Table 3.3 summarizes the effects of salinity at various stages of growth for several crops. This table shows the information currently available from various authors as indicated in the reference column and is included in Hoffman (2010). Hoffman's review of the published literature found an absence of information for crops important to the South Delta. Staff review of the crops important to LSJR Irrigation Use Area also found an absence of information for LSJR. Important crops with no information include beans and alfalfa. Although asparagus is grown on only a small number of acres in the LSJR Irrigation Use Area, Staff notes Hoffman's (2010) concerns regarding its apparent sensitivity in the first year of growth in an otherwise salt tolerant crop. Hoffman (2010) recommended that laboratory and/or field trials be conducted to establish the change in sensitivity to salt with growth stage on crops like bean and asparagus.

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Table 3.3. Salinity effects on crops at various stages of plant growth.

Crop	Salt Tolerance Threshold, EC_e (dS/m)				Reference
Asparagus	Germination 4.7	1st Growth 0.8	Fern 1.6	Spears 4.1	Francois, 1987
Corn, sweet	Germination 5.0	Emergence 4.6	Seedling 0.5	Yield 2.9	Maas et al., 1983
Corn, field	No salt affect on seedling density up to EC_e=8 dS/m				Hoffman et al., 1983
Corn (16 cultivars)	Germination 3.1 to 10	Seedling 0.2 to 1.2			Maas et al., 1983
Cowpea	Vegetation 0.8	Flowering 0.8	Pod-Filling 3.3		Maas & Poss, 1989b
Sorghum	Vegetation	Reproduction	Maturity		Maas et al., 1986
NK 265	3.3	10	10		
DTX	3.3	7.8	10		
Wheat	Vegetation 6.7	Reproduction 12	Maturity 12		Maas & Poss, 1989a
Wheat, Durum	Vegetation 3.6	Reproduction 5.0	Maturity 22		Maas & Poss, 1989a

Adapted from Hoffman (2010) (See Appendix A; Section 3.2.2)
All references cited in Table 3.3 can be found in the References section of Appendix A, Section 8.

3.3. Saline/Sodic Soils

3.3.1. State of Knowledge

Saline Soils
As noted by Hoffman (2010):

> A soil is classified as saline when salts have accumulated in the crop root zone to a concentration that causes a loss in crop yield. Yield reductions occur when salts accumulate in the root zone to an extent that the crop is unable to extract sufficient water from the salty soil solution, resulting in an osmotic (salt) stress. If water uptake is appreciably reduced, the plant slows its rate of growth and yield loss occurs. Salts that contribute to a salinity problem are water soluble and readily transported by water. A portion of the salts that accumulate from prior irrigations can be drained (leached) below the rooting depth if more irrigation or precipitation infiltrates the soil than is used by the crop or evaporates from the soil surface and barriers to drainage do not occur in the soil profile.

Sodic Soils
Physicochemical reactions in sodic soils cause slaking in soil aggregates and swelling and dispersion in clay minerals, leading to reduced permeability and poor tilth. Further details on saline and sodic soils are presented by Hoffman (2010) (Appendix A; Section 3.3.1).

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3.3.2. LSJR Irrigation Use Area Situation

The soil survey published by the NRCS in 1992 (NRCS, 1992) indicates that saline soils are predominantly located on the eastern side of the SJR. These traverse from parcels in close proximity to the Stanislaus River to the confluence of the Merced River with the SJR (Fig. 3.7a) in the LSJR Irrigation Use Area. Soil salinity in most areas classified as saline ranges from slightly saline to moderately saline. Soils in the LSJR Irrigation Use Area are most likely saline and/or sodic as a result of inherent parent material, poor drainage and other factors not necessarily related to quality of San Joaquin River water supply as indicated by small pockets of problem areas.

Table 3.4a lists each soil that was mapped as saline in 1992 in the LSJR Irrigation Use Area. The total area mapped as saline by the NRCS was about 8.84% of the total irrigated area in the 1990s. In the LSJR Irrigation Use Area, four isolated small areas classified as strongly saline. They are located around SJR at Maze, above and below the SJR at Patterson, close to the SJR at Crows Landing and close to the confluence of the Merced River with the SJR (Fig. 3.7a). The specific soils classified as strongly saline in this area are Fresno, Piper, Traver and Waukena. Their locations relative to the descriptions given above are presented in Figure 3.7b.

There are some sodic soils identified in the 1992 Soil Survey. Figure 3.7c shows the location of sodic soils in the LSJR Irrigation Use Area. Sodic soils are located on the eastern side of the SJR, close to the edges of the LSJR Irrigation Use Area. Some pockets of sodic soils are located near the confluence of the San Joaquin River with the Stanislaus River, north of the Maze Blvd Bridge; between Maze Blvd Bridge and Patterson; and in a stretch from Turlock Irrigation District Lateral #5 to the confluence of the SJR with the Merced River. Like the saline soils, the majority of sodic soils are located to the east of the SJR.

However, the calculation of the SAR for waters from the LSJR Irrigation Use Area given in Table 2.0 indicates that SAR values are well below the threshold value to cause a soil sodicity problem. ~~The sodic soils in the LSJR Irrigation Use Area make up about 2% of the total area and salt loads from these areas are not likely to cause significant changes to the overall watershed sodium concentration at the monitoring locations.~~

Based on the DWR crop surveys (DWR, 2009a) and the saline soils identified by the NRCS (1992), Figure 3.8 presents the distribution of crops in the LSJR Irrigation Use Area that are planted on saline soils. Very few (0.09%) salt sensitive crops were grown on the saline soils in the 1990s. In the 2000s, the percentage increased to about 3%. Conversely, salt sensitive crops grown in the entire LSJR Irrigation Use Area decreased from 39% in the 1990s to about 30% in the 2000s. There is an evident decline in the moderately sensitive crops from

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the 1990s to the 2000s both for the whole LSJR Irrigation Use Area as well as on the saline soils area.

Figure 3.7a. Location of saline soils in the LSJR using GIS data from the NRCS-SSURGO (legend shows soil map units from Table 3.4).

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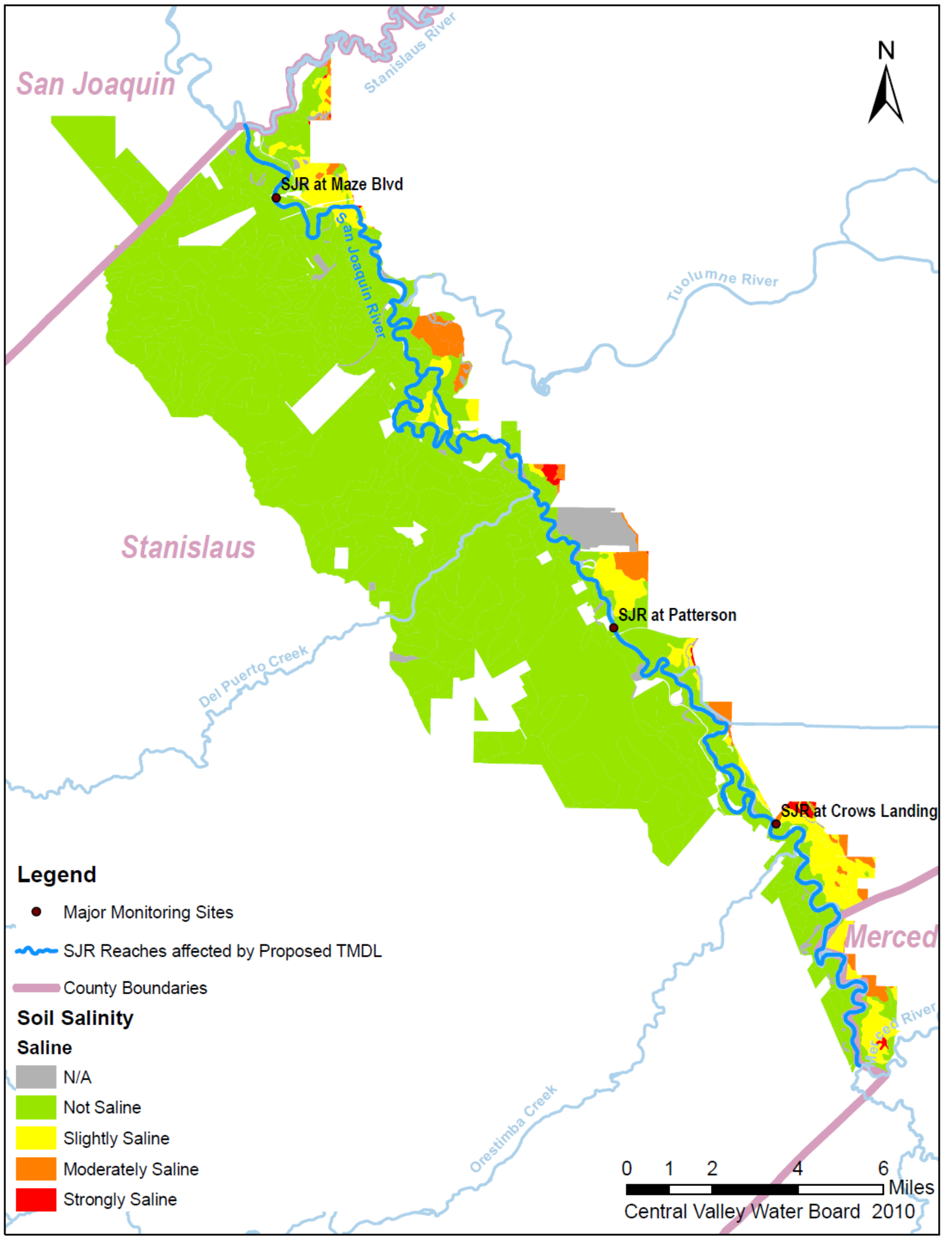
San Joaquin
Stanislaus
Merced
Stanislaus River
Tuolumne River
San Joaquin River
Del Puerto Creek
Orestimba Creek
Merced River
N
SJR at Maze Blvd
SJR at Patterson
SJR at Crows Landing
Legend
Major Monitoring Sites
SJR Reaches affected by Proposed TMDL
County Boundaries
Soil Salinity
Saline
N/A
Not Saline
Slightly Saline
Moderately Saline
Strongly Saline
0 1 2 4 6
Miles
Central Valley Water Board 2010

Figure 3.7b. Location of strongly saline soils in the LSJR using GIS data from the ~~Strongly saline soils as classified by~~ NRCS-SSURGO database.

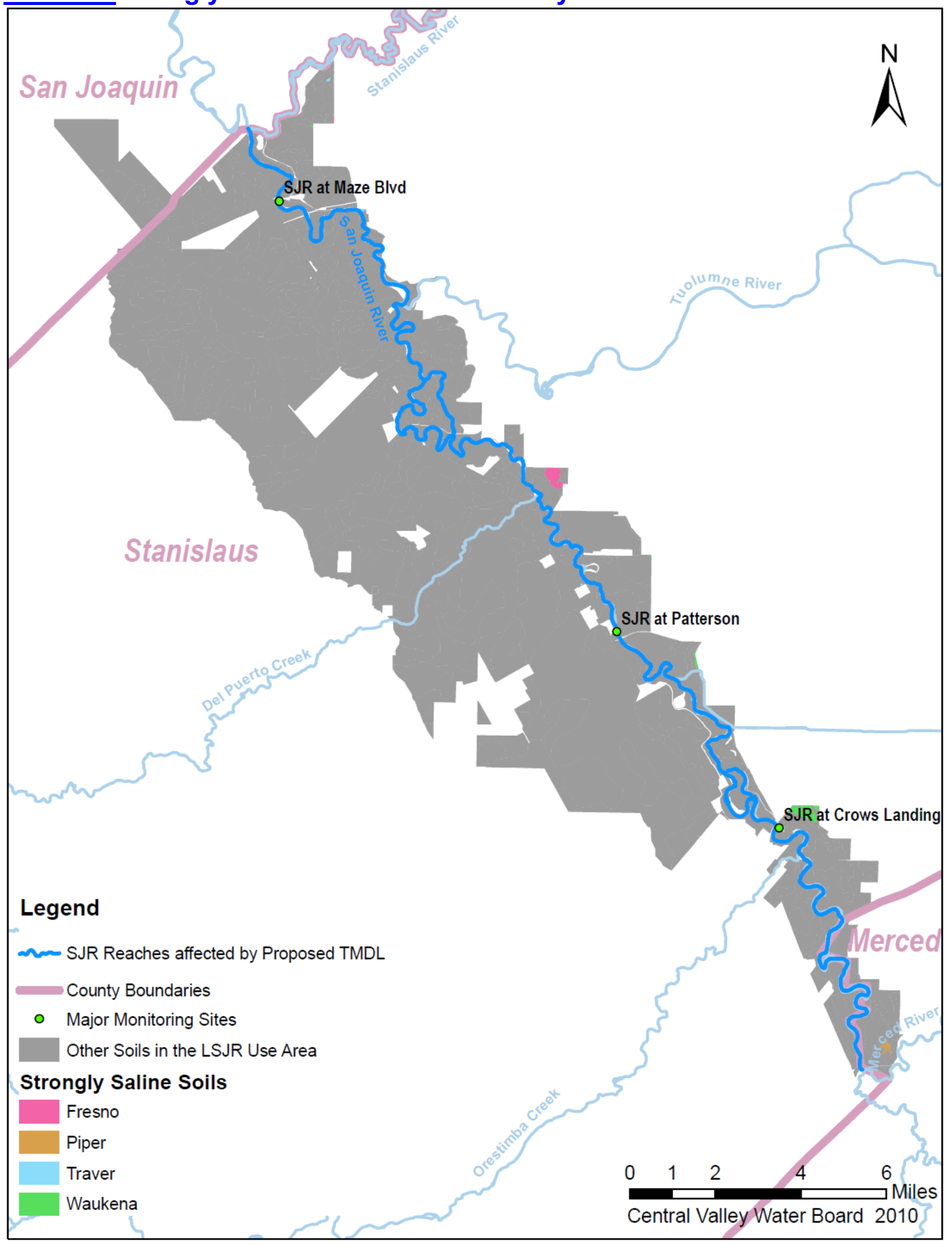

Table 3.4a. Saline soils according to the Soil Survey of Merced, Stanislaus and San Joaquin Counties in the LSJR Irrigation Use Area, California (NRCS, 1992).

Texture Category	Soil Unit Number	Soil Unit Name	Hydrologic Group	Salinity	Percentage
Clay Loam	TdA	Temple	C	Slightly Saline	0.06
Silty Clay Loam	CoA	Columbia	C	Slightly Saline	0.52
Silty Clay Loam	TeA	Temple	C	Slightly Saline	0.33
Silty Clay Loam	ThA	Temple		Slightly Saline	0.63
Fine Sandy Loam	DpA	Dinuba	C	Slightly Saline	0.16
Fine Sandy Loam	GgA	Grangeville	C	Slightly Saline	0.00
Fine Sandy Loam	PpA	Piper	C	Slightly Saline	0.01
Fine Sandy Loam	TnA	Traver	B	Slightly Saline	0.04
Fine Sandy Loam	WaA	Waukena	C	Slightly Saline	0.04
Fine Sandy Loam	WaA	Waukena	D	Slightly Saline	0.00
Sand or Sandy	CbA	Chualar	B	Slightly Saline	0.01
Sand or Sandy	DwA	Dinuba	C	Slightly Saline	0.04
Sand or Sandy	FtA	Fresno	D	Slightly Saline	0.09
Sand or Sandy	GkA	Grangeville	C	Slightly Saline	0.00
Sand or Sandy	TpA	Traver	B	Slightly Saline	0.05
Sand or Sandy	WdA	Waukena	C	Slightly Saline	0.07
Loam or Silt Loam	CbA	Columbia	C	Slightly Saline	0.92
Loam or Silt Loam	CgA	Columbia	C	Slightly Saline	0.18
Loam or Silt Loam	ChA	Columbia	C	Slightly Saline	0.38
Loam or Silt Loam	CmA	Columbia	C	Slightly Saline	0.85
Loam or Silt Loam	GcA	Grangeville		Slightly Saline	0.06
Loam or Silt Loam	TcA	Temple	C	Slightly Saline	1.57
Loamy Sands	HkbA	Hilmar	B	Slightly Saline	0.03
				Subtotal:	**6.05%**
Clay	RfA	Rossi	D	Moderately Saline	0.01
Clay	RmA	Rossi	D	Moderately Saline	0.00
Clay Loam	RkA	Rossi	D	Moderately Saline	0.16
Silty Clay Loam	TfA	Temple		Moderately Saline	0.24
Silty Clay Loam	TkA	Temple		Moderately Saline	0.90
Fine Sandy Loam	CdA	Columbia		Moderately Saline	0.06
Fine Sandy Loam	FrA	Fresno	D	Moderately Saline	0.01
Fine Sandy Loam	WbA	Waukena	C	Moderately Saline	0.48
Fine Sandy Loam	WbA	Waukena	D	Moderately Saline	0.29
Sand or Sandy	FuA	Fresno	D	Moderately Saline	0.02
Sand or Sandy	FxA	Fresno		Moderately Saline	0.05
Sand or Sandy	WeA	Waukena	C	Moderately Saline	0.00
Loam or Silt Loam	FrA	Fresno		Moderately Saline	0.00
Loam or Silt Loam	TdA	Temple	C	Moderately Saline	0.22
				Subtotal:	**2.43%**
Fine Sandy Loam	FsA	Fresno	D	Strongly Saline	0.13
Fine Sandy Loam	PuA	Piper	C	Strongly Saline	0.04
Fine Sandy Loam	ToA	Traver		Strongly Saline	0.01
Fine Sandy Loam	WcA	Waukena	C	Strongly Saline	0.17
Sand or Sandy	FvA	Fresno	D	Strongly Saline	0.00
Sand or Sandy	TsA	Traver	B	Strongly Saline	0.01
				Subtotal:	**0.36%**
Total Saline Soil					**8.84%**

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Table 3.4b. Sodic soils as classified by the NRCS-SSURGO database in the LSJR Irrigation Use Area (NRCS, 2007a).

Texture Category	Soil Unit Number	Soil Unit Name	Hydrologic Group	Sodicity	Percentage
Clay	RfA	Rossi	D	Sodic	0.01
Clay	RmA	Rossi	D	Sodic	0.00
Clay Loam	RkA	Rossi	D	Sodic	0.16
Fine Sandy Loam	DpA	Dinuba	C	Sodic	0.16
Fine Sandy Loam	FrA	Fresno	D	Sodic	0.01
Fine Sandy Loam	FsA	Fresno	D	Sodic	0.13
Fine Sandy Loam	GgA	Grangeville	C	Sodic	0.00
Fine Sandy Loam	PpA	Piper	C	Sodic	0.01
Fine Sandy Loam	PuA	Piper	C	Sodic	0.04
Fine Sandy Loam	TnA	Traver	B	Sodic	0.04
Fine Sandy Loam	ToA	Traver		Sodic	0.01
Fine Sandy Loam	WaA	Waukena	C	Sodic	0.04
Fine Sandy Loam	WaA	Waukena	D	Sodic	0.00
Fine Sandy Loam	WbA	Waukena	C	Sodic	0.48
Fine Sandy Loam	WbA	Waukena	D	Sodic	0.29
Fine Sandy Loam	WcA	Waukena	C	Sodic	0.17
Sand or Sandy	CbA	Chualar	B	Sodic	0.01
Sand or Sandy	DwA	Dinuba	C	Sodic	0.04
Sand or Sandy	FtA	Fresno	D	Sodic	0.09
Sand or Sandy	FuA	Fresno	D	Sodic	0.02
Sand or Sandy	FvA	Fresno	D	Sodic	0.00
Sand or Sandy	FxA	Fresno		Sodic	0.05
Sand or Sandy	GkA	Grangeville	C	Sodic	0.00
Sand or Sandy	TpA	Traver	B	Sodic	0.05
Sand or Sandy	TsA	Traver	B	Sodic	0.01
Sand or Sandy	WdA	Waukena	C	Sodic	0.07
Sand or Sandy	WeA	Waukena	C	Sodic	0.00
Loam or Silt Loam	ChA	Columbia	C	Sodic	0.38
Loam or Silt Loam	FrA	Fresno		Sodic	0.00
Loam or Silt Loam	GcA	Grangeville		Sodic	0.06
Loamy Sands	HkbA	Hilmar	B	Sodic	0.03
Total Sodic Soil					**2.36%**

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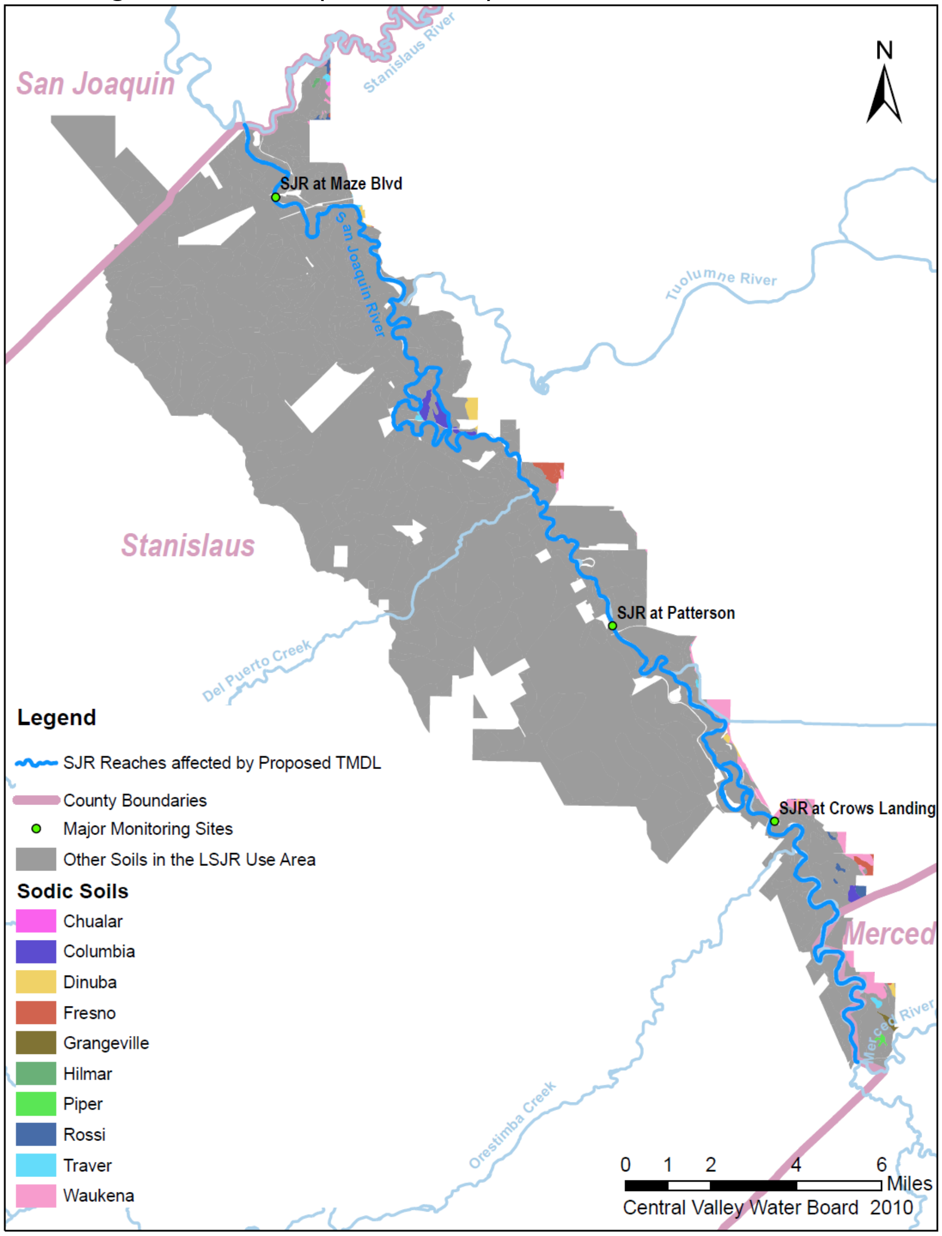
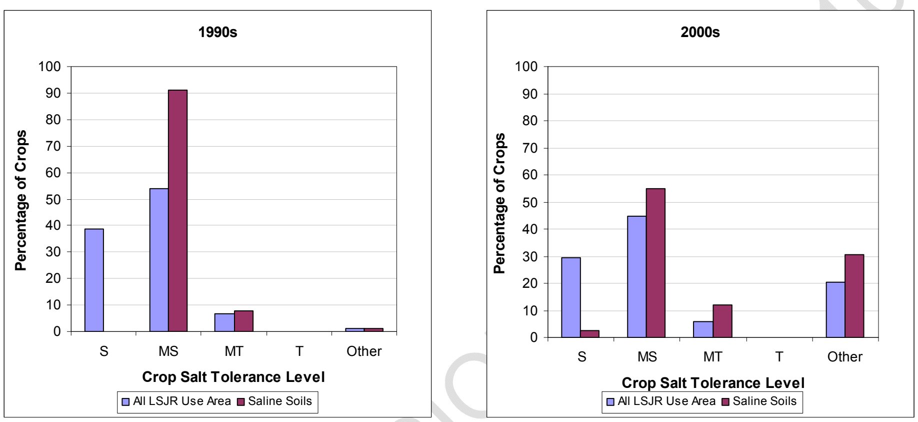
Figure 3.7c. Sodic soils as classified by the NRCS-SSURGO database in the LSJR Irrigation Use Area (NRCS, 2007a).



As shown in Figure 3.8, moderately salt sensitive and more tolerant crops are more abundantly grown in the saline areas than elsewhere within the LSJR Irrigation Use Area. In general, salt tolerant crops are absent or not grown in the use area.

Figure 3.8. Distribution of crops based on salt tolerance relative (as a percent) to: a) total irrigated crops grown on saline soils and b) total irrigated crops grown in the LSJR Irrigation Use Area for 1990s and 2000s (based on DWR land use surveys).



* 0.3% crops without soil data not represented here.

* 3.1% crops without soil data not represented here.

3.4. Bypass Flow in Shrink-Swell Soils

3.4.1 State of Knowledge

A review on the state of knowledge of bypass flow in shrink-swell soils is presented by Hoffman (2010) (Appendix A; Section 3.4.1).

3.4.2 LSJR Irrigation Use Area Situation

According to the NRCS Soil Survey (1992; 2002), there are 33 soil series in the LSJR Irrigation Use Area that have the potential to shrink and swell as the soil dries and subsequently rewets. These soil series are listed in Table 3.5 along with the percentage of the LSJR Irrigation Use Area they represent. Figure 3.9a shows the location of these soils within the LSJR. The color reference to identify each soil series is given in Table 3.5.

Staff is currently unaware of published studies done on shrink-swell soils in the LSJR Irrigation Use Area. Thus, previous work conducted by Corwin et al. (2007) on Imperial Valley shrink-swell soils will be used as a representation for the LSJR Irrigation Use Area and is quoted from Hoffman (2010):

> In their lysimeter study, bypass flow occurred through surface cracks during irrigations until the cracks were swollen then closed. After crack closure, preferential flow was substantially reduced and subsequently dominated by the flow through pores that were scattered throughout the profile. The simulations from this study revealed that when less than 40% of the applied water bypassed the surface soils, salinity was less than the crop salt tolerance threshold for each crop in the rotation, even though the simulations were conducted with irrigation water from the Colorado River (EC_i =1.23 dS/m). The yield of alfalfa was only reduced by 1.5% during the first season. Corwin and colleagues concluded that the levels and distribution of soil salinity would not be significantly affected by bypass flow up to 40%. Although the extent of bypass flow in the Imperial Valley has not been established, Corwin et al., (in press) concluded that crop yields would not be reduced by bypass flow.

About 70% of the LSJR Irrigation Use Area contains soils with a shrink-swell potential. This compares to 47% of the South Delta (Hoffman, 2010) and 60% of the Imperial Valley soils (Corwin, 2007). The slightly higher amount of shrink-swell potential soils in the LSJR Irrigation Use Area may be of concern, though it is possible that there was overestimation of the potential to shrink-swell based on classification of soils by the NRCS (1992). For example, if a Capay soil (series) was classified as having a high potential to shrink-swell by NRCS (1992) soil survey, all areas in the LSJR Irrigation Use Area with Capay soil were categorized as having a high shrink-swell potential. Staff therefore assumes that the level of severity of the shrink-swell potential is probably similar to that of Imperial Valley soils. As stated previously, Corwin and colleagues concluded that shrink-swell soils should not pose a yield problem in the Imperial Valley. Without any evidence to the contrary for the LSJR Irrigation Use Area, it is probably safe to assume that shrink-swell soils should not cause bypass flow in the LSJR to the extent that they would cause salt management problems.

Figure 3.9a shows the classification for various levels of shrink-swell potential of soils within the LSJR Irrigation Use Area while Figure 3.9b further shows those locations with soils that have high shrink-swell potential in the LSJR Irrigation Use Area. Soils with high shrink-swell potential are mainly located on the western side of the SJR in the LSJR Irrigation Use Area. Most of these soils are clays which comprise the bulk of irrigated croplands in the LSJR Irrigation Use Area. Soils on the eastern side of the SJR generally showed a low shrink-swell potential. Some areas, including a significant portion of soils in the eastern side of the SJR did not have their shrink-swell potential identified due to the lack of corresponding soil information.

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Table 3.5. Soil series in the LSJR Irrigation Use Area that have the potential to shrink and swell (NRCS Soil Survey, 1992), with color identification used

Texture Category	Soil Unit Number	Soil Unit Name	Ksat (in/hr)	Water Holding Capacity (in/in)	Depth to Ground Water (feet)	Hydrologic Group	Shink-Swell Potential	% of the LSJR
Clay Loam	330	Pedcat	0.402.82	0.13	10.8	D	Moderate	0.46
Clay Loam	120	Vernalis	0.402.82	0.18		B	Moderate	9.47
Clay Loam	123	Vernalis	0.402.82	0.18	7.6	B	Moderate	1.07
Clay Loam	125	Vernalis	0.402.82	0.18		B	Moderate	0.92
Clay Loam	126	Vernalis	0.402.82	0.18		B	Moderate	1.04
Clay Loam	268	Vernalis	0.382.7	0.18		B	Moderate	0.52
Clay Loam	140	Zacharias	0.402.82	0.17		B	Moderate	0.94
Clay Loam	141	Zacharias	0.402.82	0.17	7.6	B	Moderate	1.88
Clay Loam	142	Zacharias	0.402.82	0.13		B	Moderate	2.04
Clay Loam	146	Zacharias	0.402.82	0.17		B	Moderate	0.84
Clay Loam	147	Zacharias	0.402.82	0.13		B	Moderate	0.95
Silty Clay Loam	160	Merritt	0.402.82	0.18	12.7	B	Moderate	0.92
Silty Clay Loam	165	Merritt	0.402.82	0.18	12.7	B	Moderate	1.07
Loam or Silt Loam	245	Bolfar	1.309.17	0.14	10.2	D	Moderate	0.55
Loam or Silt Loam	246	Bolfar	1.309.17	0.14	10.2	D	Moderate	0.36
Loam or Silt Loam	121	Vernalis	1.309.17	0.16	7.6	B	Moderate	0.25
Loam or Silt Loam	122	Vernalis	1.309.17	0.16		B	Moderate	2.44
Loam or Silt Loam	127	Vernalis	1.309.17	0.16		B	Moderate	2.14
			-				Subtotal:	27.84
Clay	100	Capay	0.130.92	0.15		D	High	9.96
Clay	101	Capay	0.130.92	0.15	7.6	D	High	11.00
Clay	102	Capay	0.130.92	0.15		D	High	1.18
Clay	106	Capay	0.130.92	0.15		D	High	0.83
Clay	118	Capay	0.130.91	0.15		D	High	0.38
Clay	121	Capay	0.130.91	0.15	12.8	D	High	1.99
Clay	190	Clear Lake	0.130.92	0.14	11.4	D	High	0.52
Clay	195	Clear Lake	0.130.92	0.14	11.4	D	High	0.98
Clay	170	Dospalos	0.402.82	0.13	10.2	D	High	1.03
Clay Loam	175	Dospalos	0.402.82	0.13	10.2	D	High	1.84
Clay Loam	111	El Solyo	0.402.82	0.19	7.6	C	High	1.55
Clay Loam	130	Stomar	0.402.82	0.17		C	High	3.88
Clay Loam	131	Stomar	0.402.82	0.18	7.6	C	High	1.43
Silty Clay Loam	110	El Solyo	0.402.82	0.19		C	High	4.76
Silty Clay Loam	116	El Solyo	0.402.82	0.19		C	High	0.58
							Subtotal:	41.90
Total Soil with Moderate or High Shrink-Swell Potential								**69.75**
Soil with no Shrink-Swell Potential classification due to lack of information (not listed here)								**8.42**

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in Figure 3.9a.

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Figure 3.9a. Location of NRCS-SURRGO soil map units with shrink-swell potential in the LSJR Irrigation Use Area (as listed in Table 3.5).

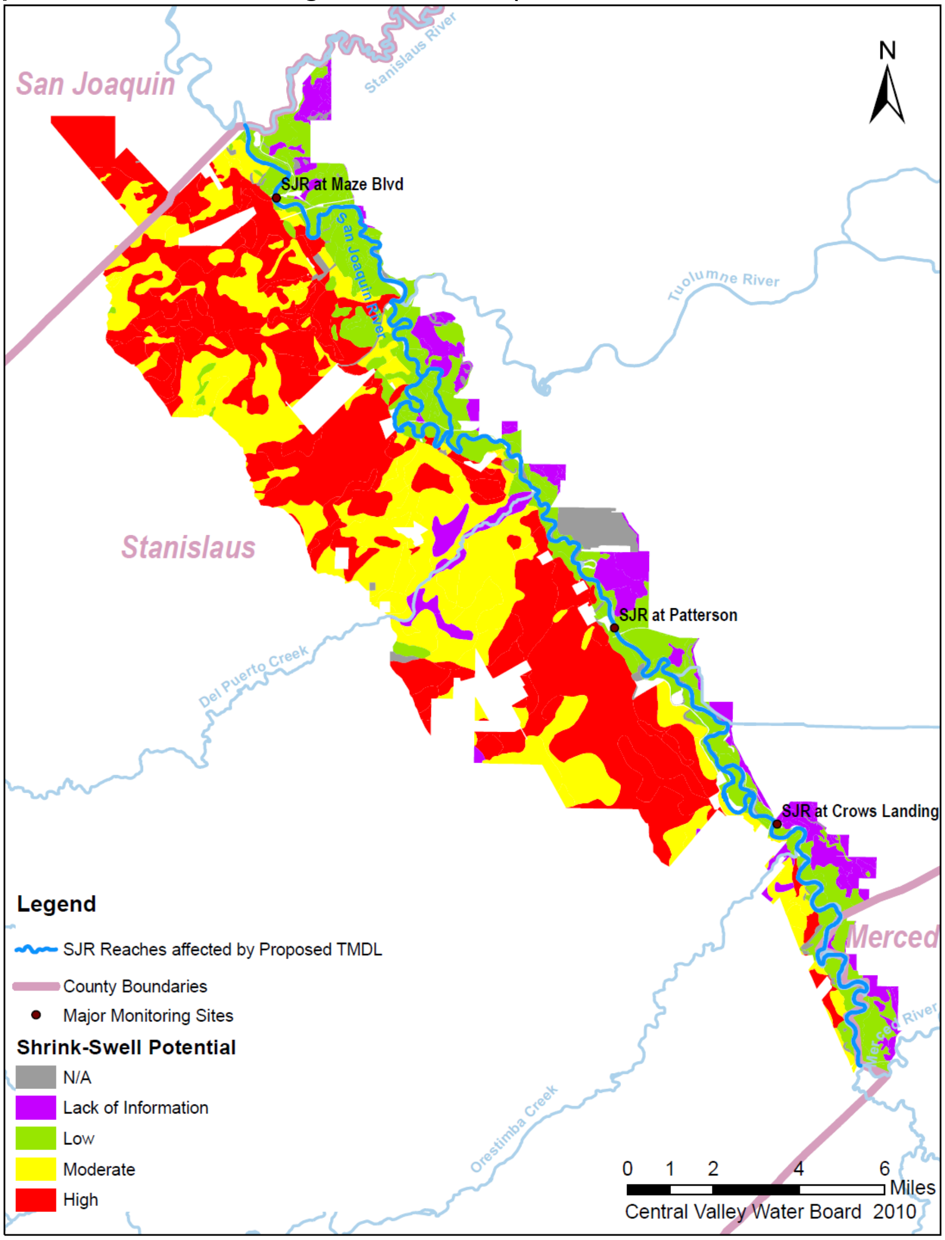
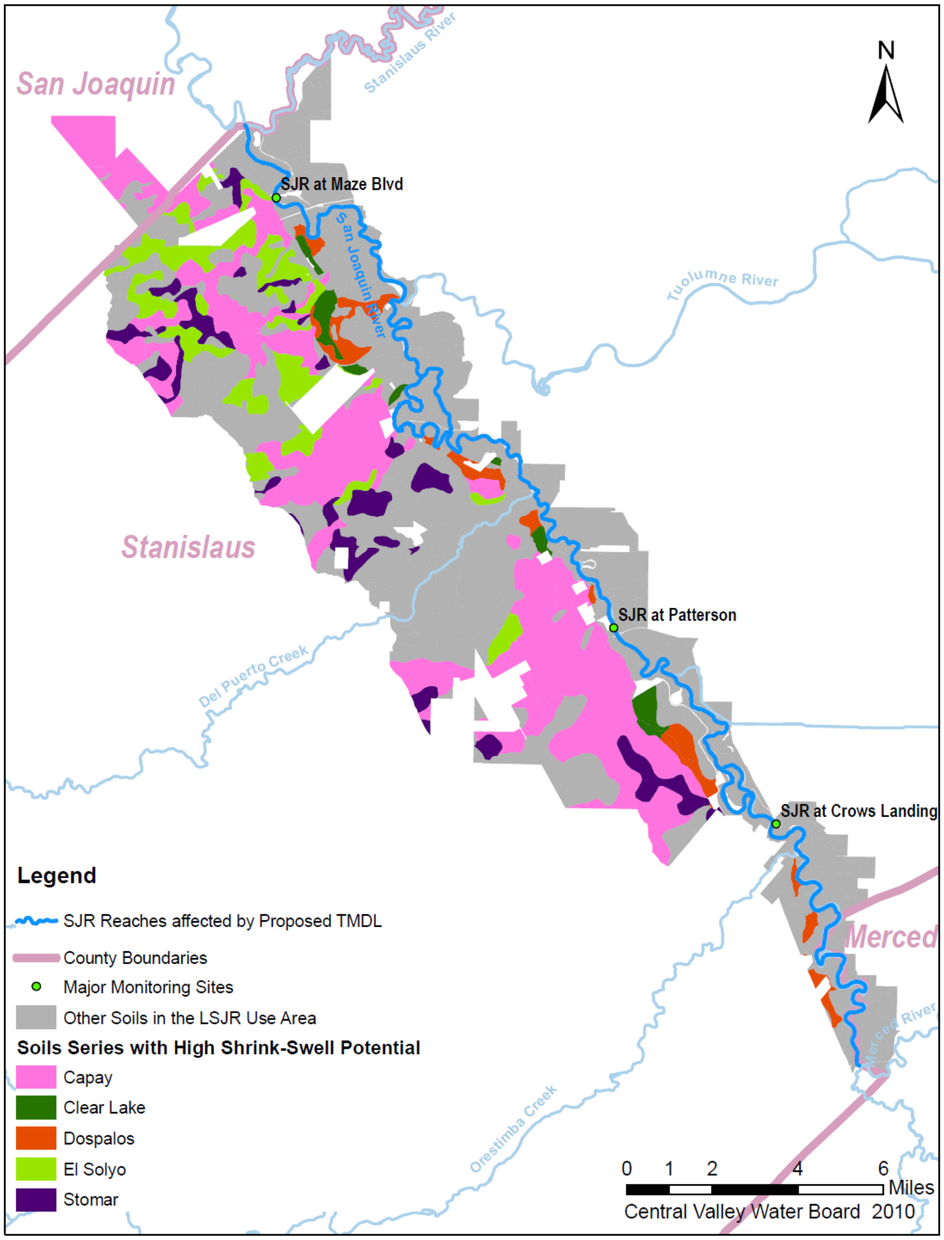


Figure 3.9b. Location of NRCS-SURRGO soil map units with high shrink-swell potential in the LSJR Irrigation Use Area (as listed in Table 3.5).



3.5. Effective Rainfall

3.5.1 State of Knowledge

Rainfall can be an important source of irrigation water in California. The amount of rain actually used by crops, known as effective rainfall or effective precipitation, is largely influenced by the climate, plant and soil characteristics. A detailed review on the state of knowledge of Effective Rainfall is given by Hoffman (2010) (Appendix A; Section 3.5.1).

Excerpts of Hoffman (2010) are presented below:

> A field measurement program was conducted by DWR (MacGillivray and Jones, 1989) to validate the techniques used in estimating the effectiveness of winter rains. The study was designed to determine the broad relationships between monthly rainfall in the winter and the portion stored in the soil and available for crop use during the following growing season. Total monthly rainfall and the corresponding change in soil water content were measured during the winter at about 10 sites in the Central Valley of California. The 4-year study, started in 1983, drew several important conclusions. First, the relationship between total rainfall and change in soil water content is remarkably similar for November, December, January, and February. The relationship is:
> **Change in stored soil water = -0.54 + 0.94 x (rainfall amount) (Eqn. 3.2)**
>
> Second, soil water content increases linearly with increased monthly rainfall for each of the four months. Third, soil surface evaporation is relatively constant, at 0.6 to 0.8 inches per month. The DWR Report also concluded that in October, when the soil is initially dry, both the amount of stored soil water and the amount of evaporation from the soil surface increases with increasing amounts of total monthly rain. The relationship for October is:
> **Change in stored soil water = -0.06 + 0.64 x (rainfall amount) (Eqn. 3.3)**
>
> In contrast, for March, when initial soil water content is generally high and evaporative demand is also high, surface evaporation rates are twice those for the four winter months and the amount of rain going to stored soil water is correspondingly low. The relationship for March is:
> **Change in stored soil water = -1.07+ 0.84 x (rainfall amount) (Eqn. 3.4)**

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3.5.2 LSJR Irrigation Use Area Situation

As provided in Hoffman (2010), the average annual rainfall for locations along the 400-mile axis of the Central Valley of California is shown in Figure 3.10 (MacGillivray and Jones, 1989). The rainfall gradient along the axis of the Valley is remarkably uniform. During any given year, however, rainfall can vary significantly from these long-term averages.

Table 3.6 from MacGillivray and Jones (1989) summarizes the disposition of average annual rainfall for several zones in the Central Valley of California. The eight zones depicted in their table cover the distance from Red Bluff to Bakersfield. As was done by Hoffman (2010) for the South Delta, Staff prepared Table 3.6 showing the three zones near the LSJR Irrigation Use Area. Zone 4 is north of Stockton. Stockton is located about 20 miles north of the northern boundary of the LSJR Irrigation Use Area. Zone 5 is south of Modesto. Modesto is located about 9.5 miles east of the LSJR Irrigation Use Area eastern boundary. Zone 6 is north of Bakersfield. Bakersfield is about 175 miles south of the LSJR Irrigation Use Area southern boundary. The LSJR Irrigation Use Area values in Table 3.6 are the best estimate of the effective rainfall that was found in the literature based on field measurements.

Figure 3.10. Annual precipitation totals along a longitudinal transect of the Central Valley of California (MacGillivray and Jones, 1989).

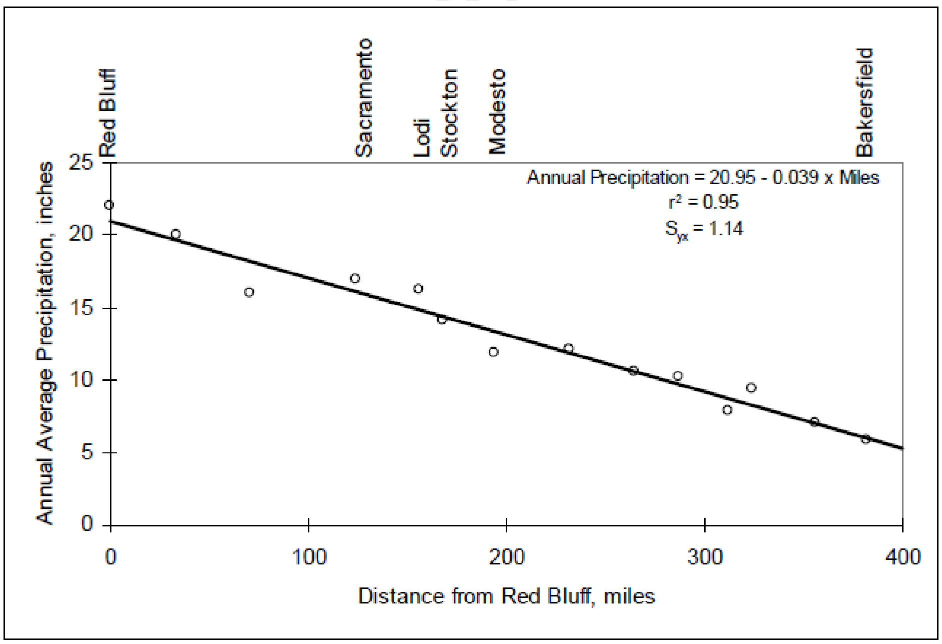

Table 3.6. Disposition of average rainfall for various zones including the LSJR Irrigation Use Area (MacGillivray and Jones, 1989).

Zone	Average Annual Rainfall (in.)	Effective Rainfall			Surface Evaporation (in.)	Deep Percolation (in.)
		Growing Season (in.)	Non-Growing Season (in.)	Total (in.)		
LSJR Irrigation Use Area	17.4	1.4	10.4	11.8	5.6	0.0
4 (North of Stockton)	15.0	1.3	7.5	8.8	5.5	0.7
5 (South of Modesto)	12.5	1.1	6.3	7.4	5.1	0.0
6 (North of Bakersfield)	10.0	0.9	4.4	5.3	4.7	0.0

Table 3.6 assumed average rainfall amounts, frequency, intensity; no surface runoff; deep, medium-textured soil with water storage capacity of 1.5 inches/foot; bare soil surface during winter; crop planted in early April and harvested in late September; and 5-foot rooting depth. The average annual rainfall for the LSJR Irrigation Use Area was calculated by averaging precipitation records reported over a 57-year period for the three monitoring stations (Crows Landing, Patterson and Maze) and the partitioned values of rainfall were calculated from the steady state model.

As noted in Section 3.5.1, an average evaporation rate from the soil surface has a range of 0.6-0.8 and can be assumed to be 0.7 inches per month. This value is used in the steady state models reported in Section 5 for the LSJR Irrigation Use Area.

Hoffman (2010) noted that:

> Precipitation during the non-growing season (P_{NG}) can be beneficial to the overall soil water balance by contributing water for soil surface evaporation (E_S) during the non-growing season which also contributes an additional amount of water stored in the crop root zone. However, if P_{NG} is excessive it could cause surface runoff and if P_{NG} is minimal a depletion of stored soil water may occur.

As an example, for bean with the May 1st planting date, assuming that surface evaporation is 5.6 in. (0.7 in./month during 8 month non-growing season) then P_{NG} of at least 5.6 in. would be consumed by surface evaporation (E_S). If P_{NG} were below 5.6 in. then water would be taken from stored water or surface evaporation would be reduced.

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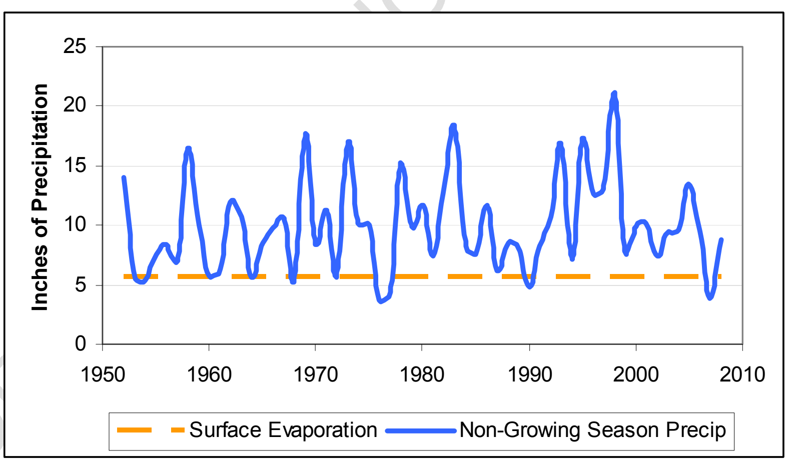
Figure 3.11 shows the 57-year record of P_{NG} and E_S. In only 3 years is P_{NG} not large enough to satisfy the E_S of 5.6 in. For the other 54 years, there is enough P_{NG} to reduce the irrigation requirement by more than 4 inches each year.

As Hoffman (2010) found was the case for the South Delta, though surface runoff in the LSJR Irrigation Use Area is a potential factor in reducing effective rainfall, there is probably low surface runoff from rain due to a number of reasons. First, rainfall in the LSJR Irrigation Use Area is normally of low to moderate intensity yet rainfall records only consist of daily amounts and do not report intensity as a means of verification. Second, irrigated fields in the LSJR Irrigation Use Area are leveled with a slope typically of about 0.2% (San Joaquin Valley Drainage Program, 1987) to enhance irrigation management. This low slope is not conducive to runoff. The third factor is crop residue after harvest, cultivations throughout the year, and harvesting equipment traffic are all deterrents to surface runoff. Thus, without definitive measurements to the contrary, surface runoff is assumed not to significantly reduce effective rainfall in the LSJR Irrigation Use Area.

Figure 3.11. Comparison of bean non-growing season precipitation (P_{NG}) with estimate of surface evaporation (E_s); for the May 1st planting date and using precipitation data from NCDC station no. 6168, Newman C (near Crows Landing and Patterson) for water years 1952 through 2008.



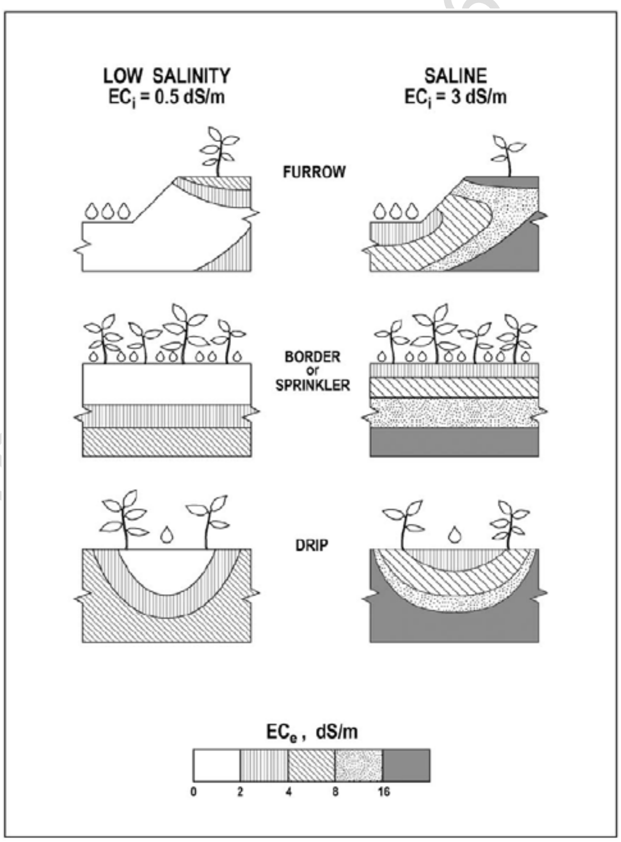
3.6. Irrigation Methods

3.6.1 State of Knowledge

A review on the state of knowledge on irrigation methods is presented by Hoffman (2010) (Appendix A, Section 3.6.1).

Figure 3.12 illustrates the salt distribution under different irrigation methods with non-saline and saline irrigation water as presented by Hoffman (2010). Note that the salt concentration near the top of the seedbed for furrow irrigation is higher than that in the seedbed wall and that in the furrow trough. The sketches in this figure assumed an idealized condition. Soil salinity patterns may diverge from what is depicted under actual soil, plant, and management conditions.

Figure 3.12. Influence of irrigation water quality and the irrigation method on the pattern of soil salinity.



(Adapted from Hoffman, 2010)

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3.6.2 LSJR Irrigation Use Area Situation

Based on information provided by DWR land use surveys (DWR, 2009a), Table 3.7 presents the breakdown or distribution of the various irrigation methods used in the LSJR Irrigation Use Area. Irrigation by gravity is the dominant irrigation method which includes basin, border strip and furrow irrigation. Micro-irrigation is the second most used method which includes high precision and drip irrigation systems. Sprinklers are the least used method.

The proportion of these irrigation systems are known to change as the growers change from one crop to another responding to changing economic demands. Most of the hay and pasture crops are irrigated by borders while wheat and barley are irrigated mainly by basinfurrow. Most of the vegetables including tomatoes are irrigated mainly by furrow and a smaller percentage by both sprinkler and micro-irrigation. Tree crops are mainly irrigated by gravity through surface flooding while grape vines are mainly irrigated by micro-irrigation with smaller percentages by gravity and sprinkler systems.

Crops grown with furrow irrigation are likely more susceptible to salt damage due to build up at the top of the bed (Figure 3.12). Much of the LSJR Irrigation Use Area is irrigated with furrow as shown in Table 3.7.

Table 3.7. Irrigation methods in the LSJR Irrigation Use Area based upon crop surveys and estimates by DWR[1] (as percent of total irrigated crop area).

Crop Type	Crop Area (Acres)	Crop Area (%)	Irrigation Method[2]				
			Gravity (%)	Drip/Micro (%)	Sprinkler (%)	Unknown (%)	Unirrigated (%)
Fruit and Nuts & Vineyards	10879	20.7	4.6	11.4	4.4	0.3	0.1
Field Crops & Truck Crops (except crops included in the categories below)	13778	26.2	19.3	0.0	0.8	6.1	0.0
Tomatoes & Asparagus	8518	16.2	14.4	0.1	0.2	1.6	0.0
Alfalfa & Pasture	12968	24.7	23.0	0.0	1.5	0.0	0.2
Grain & Hay	5833	11.1	6.0	0.0	0.0	4.3	0.8
Idle	564	1.1	0.0	0.0	0.1	1.0	0.0
Totals:	52541	100.0	67.3	11.5	7.0	13.2	1.0

1. DWR county land use surveys for: 1996 (San Joaquin), 2002 (Merced) and 2004 (Stanislaus).
2. Gravity (irrigation) includes basin, border strip, and furrow irrigation;
drip/micro (irrigation) includes buried drip, surface drip, and other types of micro-irrigation;
sprinkler includes all types of sprinklers except micro-sprinklers;

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Table 3.7 also provides the total percentage of irrigated area by each irrigation method. About 67% of the LSJR Irrigation Use Area is irrigated by gravity, 12% by drip/micro-irrigation, 7% by sprinkler, and about 1% of the crops not irrigated. About 13% of the acreage has unknown irrigation methods. As previously discussed in Section 3.1.2 regarding the three crops selected for this study, in the LSJR Irrigation Use Area about 98% of dry beans are furrow irrigated. Almonds are predominantly irrigated by micro sprinkler, which accounts for about 54% and another 35% of almonds are irrigated by surface drip and permanent sprinkler. About 96% of alfalfa is irrigated by border strip irrigation (DWR, 2009a).

Personal communication with Jean Woods of DWR (2009) helped clarify that the irrigation method is recorded based upon readily available information in the field during the surveys. Thus, for cases with unknown irrigation methods, fields may not have revealed sufficient evidence for surveyors to identify the irrigation system especially if the surveys are conducted after the harvest period. Jean Woods further noted that sometimes farmers only record the dominant irrigation method used in a mixed cropping system. For purposes of this Report, in order to avoid double counting the irrigated acreage, cases where mixed irrigation methods were used such as in a mixed cropping system, e.g. if sprinkler irrigation used to grow beans and then drip irrigation to grow tomatoes on the same piece of land in succession, the irrigation system was given a corresponding weight that add up to 100%.

3.7. Sprinkling with Saline Water

3.7.1 State of Knowledge

A review on the state of knowledge of sprinkling with saline water is presented by Hoffman (2010) (Appendix A; Section 3.7.1).

3.7.2 LSJR Irrigation Use Area Situation

Crops that are sprinkler irrigated may be damaged if levels of sodium and or chlorine in the irrigation water are too high. With reference to Table 3.7, the crops that are predominantly irrigated by sprinklers are fruit tree crops, nut tree crops and vines. From January 2001 until June 2003, the concentration of chloride in the SJR at Crows Landing, Patterson, and Maze never exceeded 5 mol/m^3 and averaged about 1.3 mol/m^3 (SWAMP, 2009). Over the same time period, the average concentration of sodium was about 3.3 mol/m^3. During the winter months of January to April from 2001 to 2003, the average concentration of sodium was about 3.6 mol/m^3. Table 3.8 shows the relative susceptibility of crops to foliar injury from saline sprinkling waters (Maas and Grattan, 1999). From table 3.8, fruit tree crops such as almond are susceptible to foliar injury while crops such as cotton and sugar beet are more tolerant. With reference to sodium and chloride results for the LSJR Irrigation Use Area discussed above, if these values are compared to the relative susceptibility thresholds shown in

Table 3.8, staff concludes that generally these concentrations would not be expected to be a problem in the LSJR Irrigation Use Area.

Since trees and vines are not irrigated during the winter, it is not likely that sprinkling will result in yield loss based on the types of irrigation methods (Table 3.7) and the chloride and sodium concentrations reported above in the SJR.

Table 3.8. Relative susceptibility of crops to foliar injury from saline sprinkling waters (Maas and Grattan, 1999). (Adapted from Hoffman, 2010)

Na or Cl concentration causing foliar injury, mol/m^3*			
<5	**5-10**	**10-20**	**>20**
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugar beet
Plum	Tomato	Cucumber	Sunflower
		Safflower	
		Sesame	
		Sorghum	

**To convert mol/m_3 to mg/L or ppm divide Cl concentration by 0.02821 and Na concentration by 0.04350. The conversion from mg/L to EC is EC = mg/L / 640.*

As noted by Hoffman (2010), data presented in Table 3.8 are to be used as general guidelines for daytime sprinkling. Foliar injury is also influenced by cultural and environmental conditions.

3.8. Irrigation Efficiency and Uniformity

3.8.1 State of Knowledge

A review on the state of knowledge of irrigation efficiency and uniformity is presented by Hoffman (2010) (Appendix A; Section 3.8.1).

3.8.2 LSJR Irrigation Use Area Situation

From the estimates reported in Table 3.7 and average values for irrigation efficiency (Hoffman, 2010; Heermann and Solomon, 2007) (78% for border, 70% for furrow, 75% for sprinkler, and 87% for micro-irrigation), it is reasonable to assume that the average irrigation efficiency for the LSJR Irrigation Use Area may be about 75%. As mentioned previously, because bean is the most salt sensitive crop and is furrow irrigated, an irrigation efficiency of 70% may be a reasonable estimate. As stated by Hoffman (2010), if desired, a range or irrigation efficiencies could be assumed to determine the impact on the water quality standard.

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The uniformity of irrigation applications is probably relatively low because of the variability of soil types within a given field and the inherent problems of applying water uniformly with surface irrigation systems. Staff reiterates the approach of Hoffman (2010) in that no attempt is made here to quantify non-uniformity in the LSJR Irrigation use Area.

3.9. Crop Water Uptake Distribution

3.9.1 State of Knowledge

A review on the state of knowledge of crop water uptake distribution is presented by Hoffman (2010) (Appendix A; Section 3.8.1).

3.9.2 LSJR Irrigation Use Area Situation

Staff is unaware of studies conducted in the LSJR Irrigation Use Area to estimate crop water uptake patterns. Thus, both the exponential and the 40-30-20-10 distribution patterns are used in the steady state model developed for the LSJR Irrigation Use Area in Sections 4 and 5 of this Report. This follows the approach of Hoffman (2010).

3.10. Climate

3.10.1 State of Knowledge

A review on the state of knowledge of climatic impacts on plant response to salinity are presented by Hoffman (2010) (Appendix A; Section 3.10).

3.10.2 LSJR Irrigation Use Area Situation

The vast majority of experiments that were used to establish crop salt tolerance have been conducted at the United States (U.S) Salinity Laboratory in Riverside, California. Following the approach of Hoffman (2010), the average monthly temperature and relative humidity (RH) in Riverside, California are compared with average monthly values at Patterson and Modesto, California, which are located in or near the LSJR Irrigation Use Area as shown in Figure 3.14c. Data for these comparisons were obtained from the California Irrigation Management Information System (CIMIS). The Modesto A station is in close proximity (2½ miles) with Maze monitoring site (which represents the LSJR Stanislaus to Tuolumne River). Maximum and minimum daily temperatures and RH reported in Figures 3.13 (a and b) and 3.14 (a and b) are from November 1987 through November 2009 which is the record of available data.

Figure 3.13a shows that the average maximum temperature by month is slightly higher in Riverside (by 4 °F) for all months than the stations in the LSJR Irrigation Use Area except for May and June when it is higher by about 2 °F at Patterson than Riverside. As a result, it should be noted that during May and June, crop salinity stress is potentially greater in Patterson than in Riverside. This would likely have a considerable effect on early stage growth of bean. However, little is known about salt tolerance of bean throughout the growing season.

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TSimilarly, the average minimum temperature is higher in Riverside than Patterson (by 4 °F) and higher in Riverside than Modesto (by 8 °F) than the LSJR for every month (Figure 3.13b). Figure 3.14 (a and b) shows the comparison between average daily minimum and maximum RH for Patterson and Modesto compared to Riverside. The RH is always lower in Riverside than in Modesto but was higher in Riverside for May, June and July (Figure 3.14 a and b). The maximum RH was lower in Riverside by 8% than Patterson and lower by 22% in Riverside than in Modesto. The minimum RH was lower in Riverside by 8% than Patterson, and lower by 15% in Riverside than in Modesto with the exception of May, June and July.

Thus, on average, plants likely experience higher evaporative demands in Riverside than in the LSJR Irrigation Use Area. Under otherwise identical conditions, plants in Riverside experience slightly higher salt stress than plants in the LSJR Irrigation Use Area. These slight climatic differences would result in a slightly smaller reduction in crop yields than the published salt tolerance responses in the LSJR Irrigation Use Area. Thus, using the crop salt tolerance values modeled in this study should be slightly more conservative with respect to climatic conditions since crop tolerance to salinity may be slightly higher in the LSJR Irrigation Use Area than the published results from experiments conducted in Riverside.

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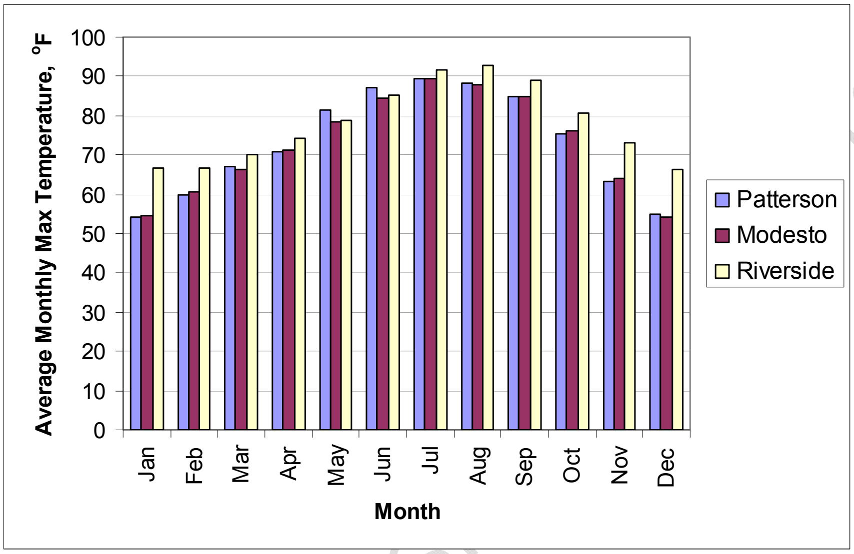
Figure 3.13. Average over the year of a) monthly maximum temperature and b) monthly minimum temperature as measured at Patterson (CIMIS #161), Modesto (CIMIS #71) and Riverside (CIMIS #44) between November 1987 and November 2009.

a) Average over the year of monthly maximum temperature.



b) Average over the year of monthly minimum temperature.

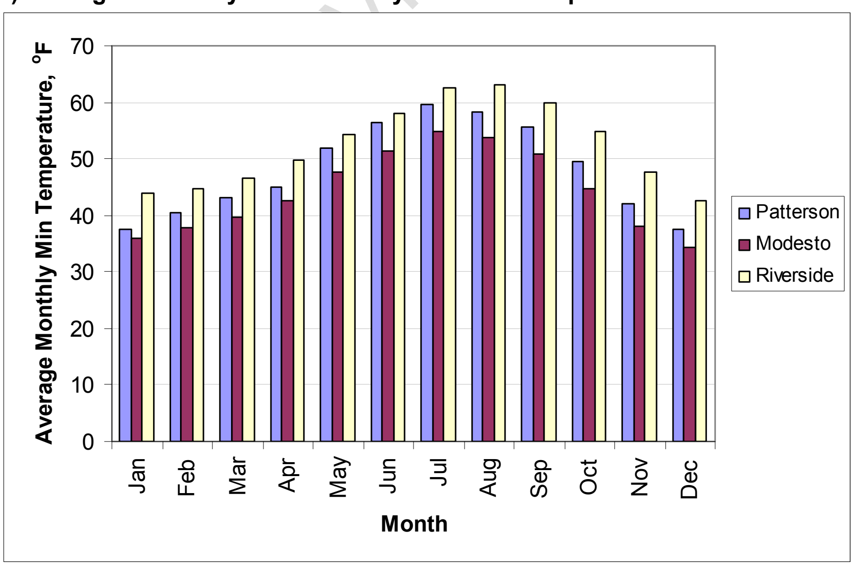
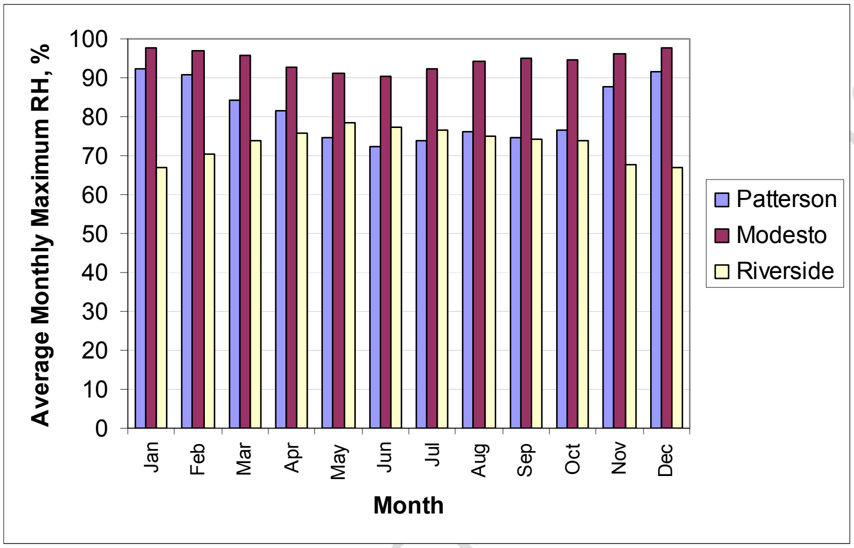


Figure 3.14. Average over the year of a) monthly maximum relative humidity and b) monthly minimum relative humidity as measured at Patterson (CIMIS #161), Modesto (CIMIS #71) and Riverside (CIMIS #44) between November 1987 and November 2009.

a) Average over the year of monthly maximum relative humidity (RH).



b) Average over the year of monthly minimum relative humidity (RH).

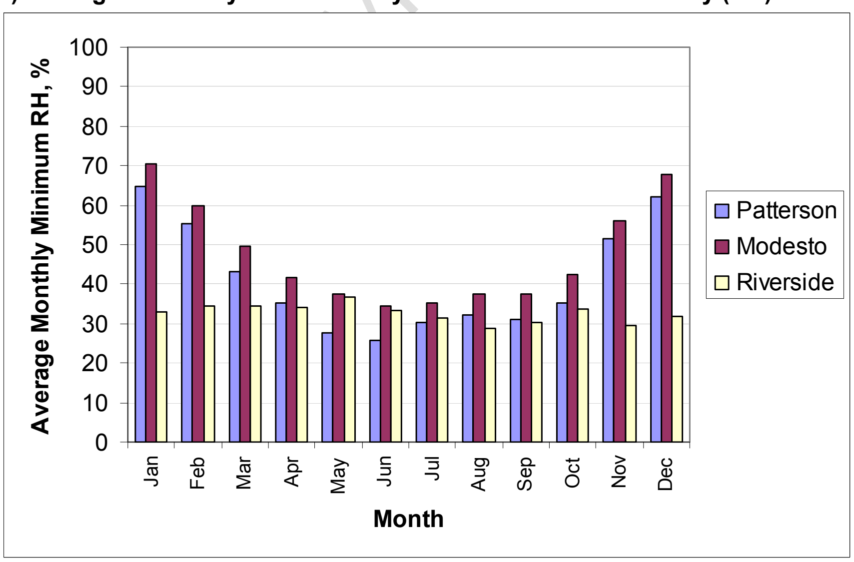
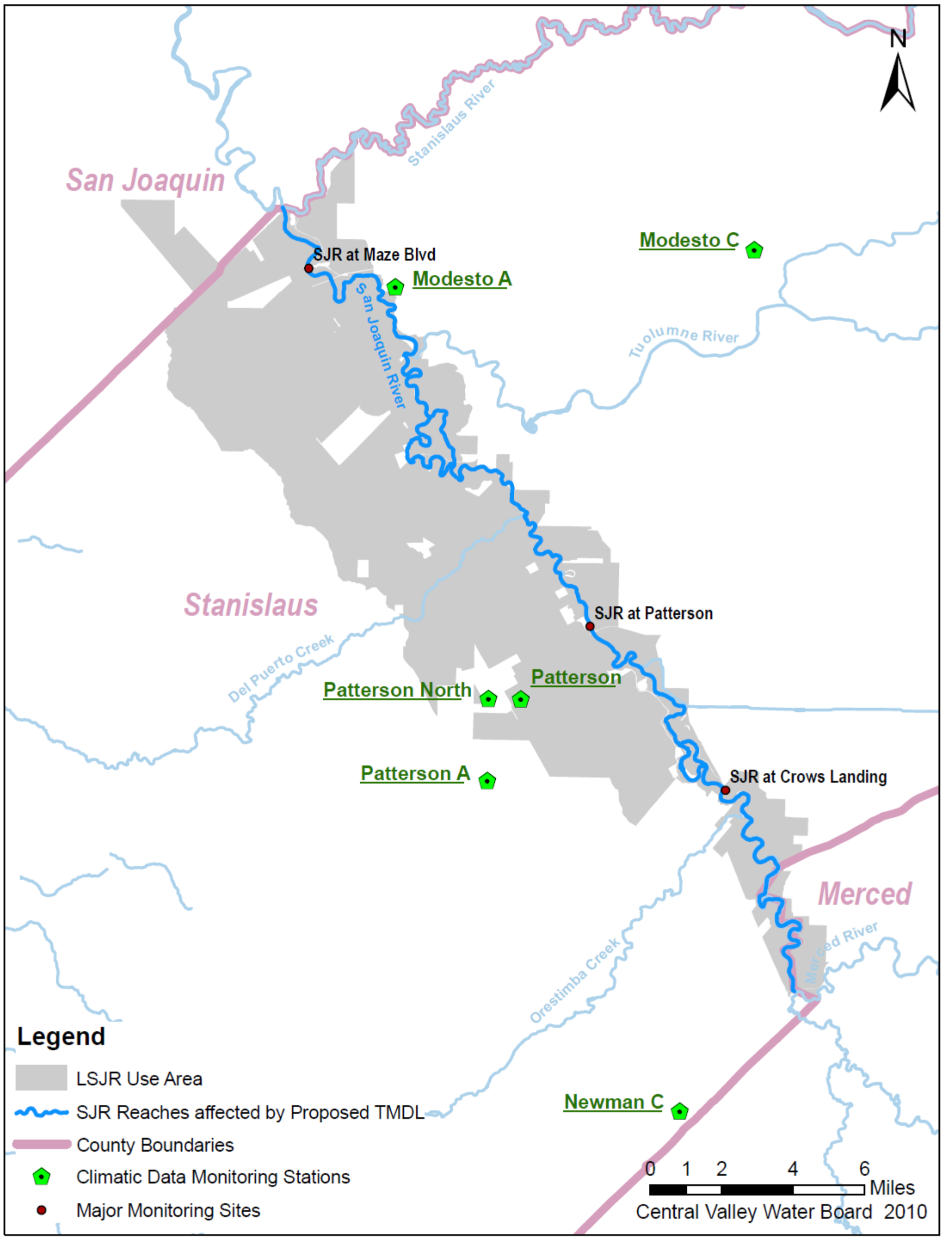


Figure 3.14c. Location map for climatic stations near the three monitoring stations in the LSJR.



3.11. Salt Precipitation or Dissolution

3.11.1 State of Knowledge

A review on the state of knowledge of salt precipitation or dissolution by irrigation water is presented by Hoffman (2010) (Appendix A; Section 3.11.1).

3.11.2 LSJR Irrigation Use Area Situation

Hoffman (2010) reviewed salt precipitation and dissolution based on consultation with two independent sources by personal communication (Suarez in 2008 and Oster in 2009) (Figure 3.15). These sources assessed precipitation and dissolution based on the the WATSUIT model which was developed by the USDA salinity lab and is public domain available at http://www.ars.usda.gov/services/software/download.htm?softwareid=107. Sis unavailable to Staff and neither is Staff is also un-aware of salt precipitation and dissolution a similar analysis previously conducted in the LSJR Irrigation Use Area. As a result, for the LSJR Irrigation Use Area, Staff relied upon the analysis of Hoffman (2010) for the SJR at Mossdale (approximately 8 miles downstream of the northern boundary of the LSJR Irrigation Use Area), because of its relative proximity and the lack of known previous data for this use area.

Excerpts of Hoffman (2010) are presented below:

> Based upon the salt constituents of the water from the San Joaquin River at Mossdale, CA from 2000 to 2003 and from 2005 to 2007 (Dahlgren, 2008), the relationship between the leaching fraction and whether salt would precipitate or be dissolved was calculated (Figure 3.15). The salt constituent data were analyzed by Dr. Don Suarez, Director of the U. S. Salinity Laboratory in Riverside, CA, and he determined the relationship shown in Figure 3.15 using the WATSUIT model for drainage water salinity.
>
> The results show that because the water is low in gypsum, carbonates, and silicate minerals at leaching fractions higher than 0.10 the water draining from the root zone would contain salt dissolved from the soil profile and at leaching fractions lower than 0.10 salt would precipitate in the soil. This means that if the leaching fraction for the South Delta is based upon the ratio EC_i/EC_d the leaching fraction would be slightly lower than it really is because some of the salts in the drainage water would be from dissolution of salts in the soil.
>
> I also asked Dr. Jim Oster, emeritus professor from the University of California, Riverside, to analyze the same data set. He also used the WATSUIT model but based his analysis on the average root zone salinity rather than drainage water salinity. The results are also shown in Figure 3.15. The results by Oster predict that salts would tend to dissolve from the soil profile at all leaching fractions.

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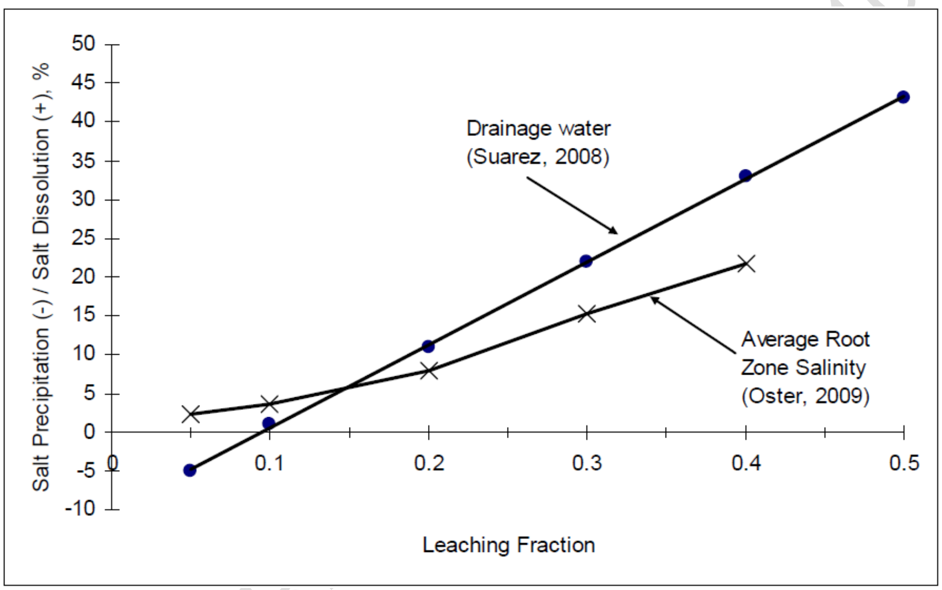
Both analyses indicate that at a leaching fraction of 0.15, salinity would be increased about 5%. Considering all of the other factors that influence crop response to salinity, the effect of salt precipitation/dissolution would be minimal at leaching fractions near 0.15.

Figure 3.15. The relationship between leaching fraction and salt precipitation or dissolution in the soil when using water from the San Joaquin River (Adapted from Hoffman, 2010).



3.12. Shallow Groundwater

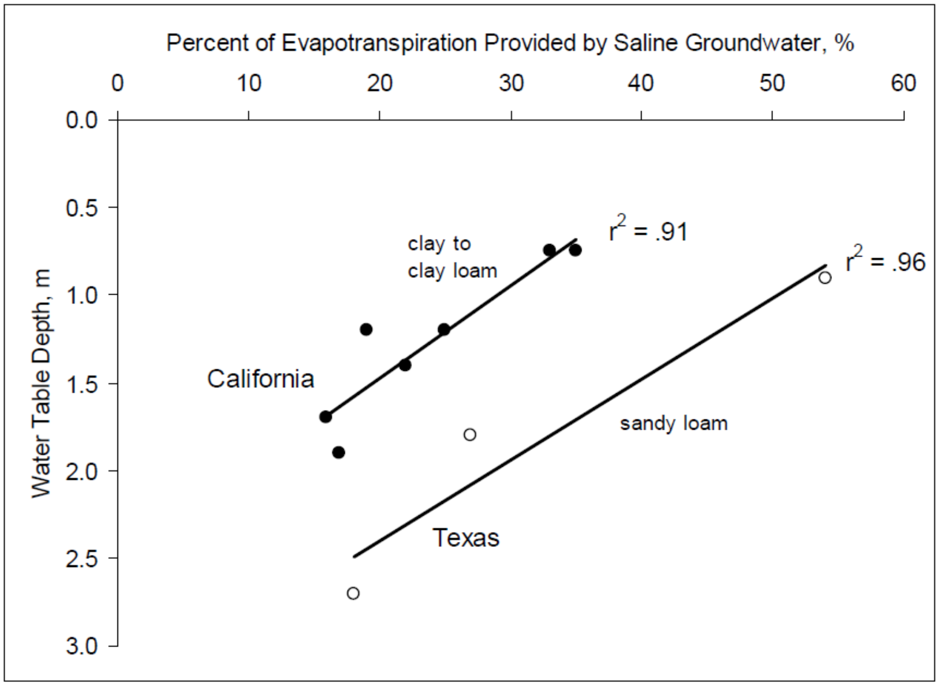
3.12.1 State of Knowledge

Hoffman (2010) reviewed some relationships between crop water use with the depth and salt content of groundwater. Figure 3.16 shows the relationship between groundwater usage for cotton and water table depth in clay and clay loam soils from field experiments on the west side of the San Joaquin Valley, CA. A review on the state of knowledge of use of shallow groundwater is presented by Hoffman (2010) (Appendix A; Section 3.12).

3.12.2 LSJR Irrigation Use Area Situation

Well level data from DWR was used to find water table depth in the LSJR Irrigation Use Area (DWR, 2009b). These results are shown in Table 3.9 and represented by the varying colors and circle sizes in Figure 3.17 categorized according to the water table depth.

Figure 3.16. Contribution of shallow, saline groundwater to the evapotranspiration of cotton as a function of depth to the water table and soil type (Adapted from Hoffman, 2010).



The depth to the water table ranges from about 7 feet – 111 feet with an average of 40 feet for the LSJR Irrigation Use Area over the past 20 years as shown in Table 3.9. Hoffman (2010) noted that a depth of 5 feet will minimize upward flow of water from the water table. About 85% of the wells in the LSJR Irrigation Use Area (Figure 3.17) have a water table depth greater than 10 feet. Considering that a significant portion of the use area has an average depth of about 40 feet, there are limited chances that crops would extract groundwater in these settings. A possible exception to this would be deeper rooted crops such as alfalfa and cotton. More salt sensitive crops in the LSJR Irrigation Use Area such as beans are shallow rooters. The shallowest well depths (ranging from 7 to 10 ft) are concentrated in the lower western side of the LSJR Irrigation Use Area. As noted in Figure 3.18, subsurface tile drains have been installed in the LSJR Irrigation Use Area, the presence of these tile drains may indicate that any problems with shallow groundwater have already been rectified (Hoffman, 2010).

Table 3.9. Groundwater well level data for post-1990 data (DWR, 2009b).

State Well No.	Identifier on Fig. 3.17	Years of Data	Average Depth (ft.) per DWR Well Level Data
03S06E36N001M	36-36N	1990 to 1998	12.5
04S06E02Q001M	46-02Q	1990 to 1998	36.3
04S06E12N001M	46-12M	1990 to 1998	27.1
04S06E24L001M	46-24L	1990 to 1998	82.8
04S07E06M002M	47-06M-2	1990 to 1998	20.0
04S07E19J002M	47-19J-2	1990 to 1998	52.5
04S07E27M001M	47-27M	1990 to 1998	31.0
04S07E35D001M	47-35D	1990 to 1998	29.4
05S07E09J001M	57-09J	1990 to 2009	111.2
05S07E13K002M	57-13K-2	1990 to 1995	71.1
05S07E14D001M	57-14D	1990 to 2009	85.9
05S07E23B001M	57-23B	1990 to 1998	85.5
05S07E23F001M	57-23F	1990 to 1992	103.3
05S07E24H001M	57-24H	1990 to 2009	54.7
05S08E06E001M	58-06E	1990 to 2009	34.4
05S08E17J001M	58-17J	1990 to 1991	11.4
05S08E17N001M	58-17N	1990 o 1993	24.6
05S08E31E001M	58-31E	1990 to 1995	36.7
05S08E32K001M	58-32K	1990 to 2004	9.1
06S08E01J001M	68-01J	1990 to 2009	12.7
06S08E03R001M	68-03R	1990 to 2008	6.9
06S08E11G001M	68-11G	2004 to 2008	9.6
06S09E20F001M	69-20F	2004 to 2008	13.5
06S09E29B001M	69-29B	2004 to 2008	14.1
07S09E04H001M	79-04H	2004 to 2007	12.2

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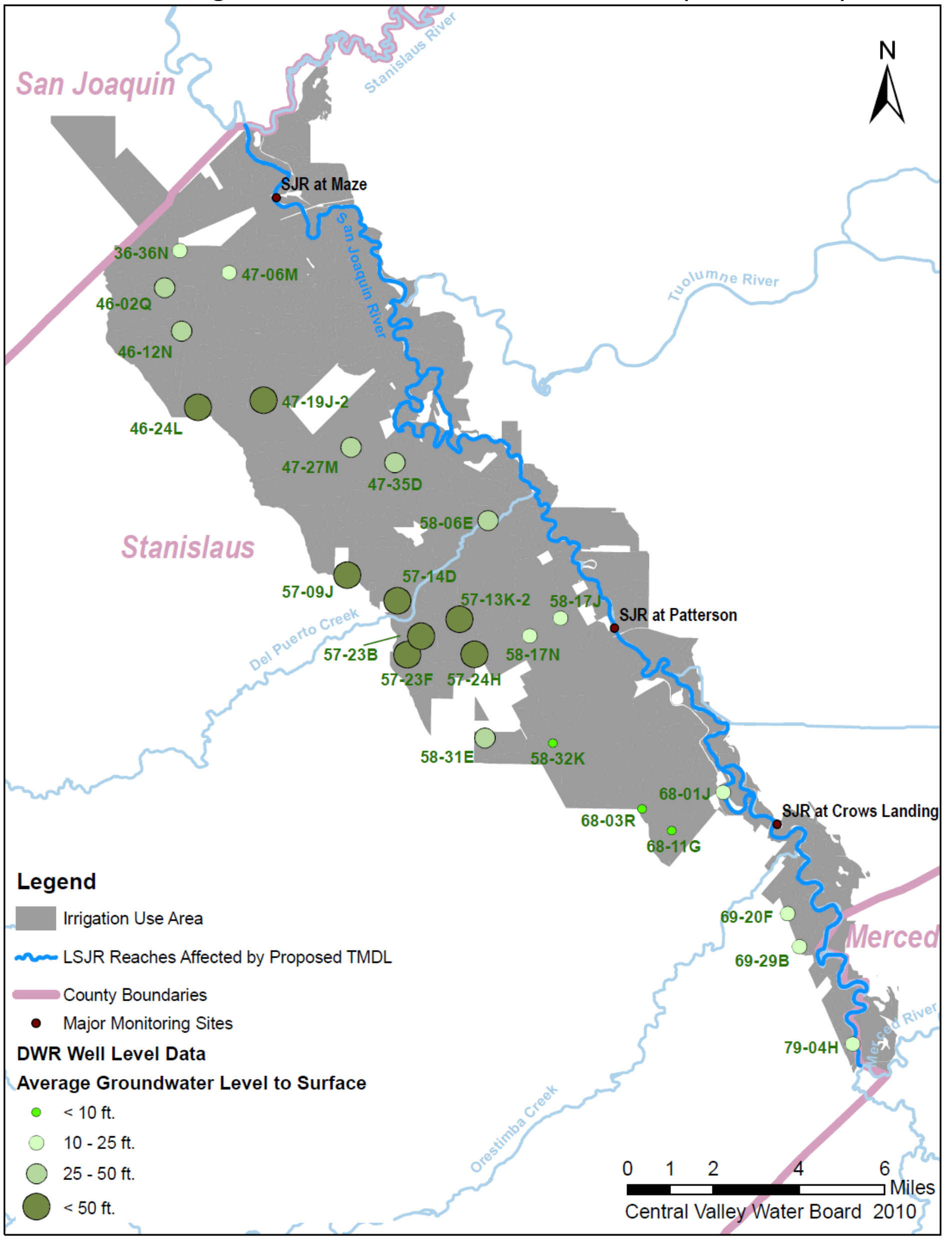
Figure 3.17. Depth to the water table in the LSJR Irrigation Use Area from location of DWR groundwater wells listed in Table 3.9. (DWR, 2009b)



3.13. Leaching Fraction

3.13.1 State of Knowledge

The information provides some underlying concepts used in the steady state models reported in Section 4 and further provides literature that supports model assumptions listed in Section 5 of this Report. This section directly reports information as presented in Appendix A; Section 3.13.1 by Hoffman (2010):

> The amount of applied water needed to satisfy the water requirement of crops can be estimated from the water and salt balances in the crop root zone. The major inputs of water into the root zone are irrigation, rainfall, and upward flow from the groundwater. The major outputs of water from the root zone are evaporation, transpiration, and drainage. Under steady state conditions, the change in the amount of water and salt stored in the root zone is essentially zero. If the total water inflow is less than losses from evaporation plus transpiration, water is extracted from soil storage and drainage is reduced, with time, the difference between inflows and outflows becomes zero. In the absence of net downward flow beyond the root zone, salt accumulates, crop growth is suppressed, and transpiration is reduced.
>
> In the presence of a shallow water table, deficiencies in the irrigation and rainfall amounts may be offset by the upward flow from the groundwater. Upward flow will carry salts into the root zone. If upward flow continues and sufficient leaching does not occur, soil salinity ultimately reduces crop growth and water consumption. Over the long term, a net downward flow of water is required to control salination and sustain crop productivity.
>
> Conditions controlling the water inflow and outflow into and out of the root zone rarely prevail long enough for a true steady state to exist. However, it is instructive to consider a simple form of the steady state equation to understand the relationship between drainage and salinity. Assuming that the upward movement of salt is negligible, the quantities of dissolved salts from soil minerals plus salt added as fertilizer or amendments is essentially equal to the sum of precipitated salts plus salt removed in the harvested crop. When the change in salt storage is zero under steady state conditions, the leaching fraction (L) can be written as:
>
> $$L = D_d / D_a = C_a / C_d = EC_a / EC_d \qquad \textbf{(Eqn. 3.5)}$$
>
> Where D refers to depth of water, C is salt concentration, and EC is the electrical conductivity and the subscripts d and a designate drainage and applied water (irrigation plus rainfall). This equation applies only to salt constituents that remained dissolved.

The minimum leaching fraction that a crop can endure without yield reduction is termed the leaching requirement, L_r, which can be expressed as follows:

$$L_r = D_d^* / D_a = C_a / C_d^* = EC_a / EC_d^* \qquad \textbf{(Eqn. 3.6)}$$

The notation in Equation 3.6 is the same as in Equation 3.5 except the superscript (*) distinguishes “required” from “actual” values.

3.13.2 LSJR Irrigation Use Area Situation

The leaching fraction in the LSJR Irrigation Use Area is difficult to estimate because measurements of soil salinity or drainage water salinity are not measured routinely. However, consistent EC measurements for multiple subsurface drains installed in the LSJR Irrigation Use Area were made over a brief period of time.

Chilcott et al., (1988) sampled tile drain discharge in the LSJR basin which includes the LSJR Irrigation Use Area. Only drains located within the LSJR Irrigation Use Area (Zone D from their Report) are discussed here (Figure 3.18). The majority of the drains are approximately 4 miles upslope of the SJR. Twenty discharge sites within this zone were sampled in April and June, 1986 and July, 1987. Though samples were analyzed for various properties including minerals and trace elements; only EC measurements are reported in Table 3.10. These data are relatively consistent during the two years sampled with EC values from different drains ranging from 0.7 to 4.5 dS/m with an overall average of 2.2 dS/m. The drains are located in clay to clay loam soils and are in or near the soils mapped as saline (compare with Figures 3.7a and 3.17).

The data presented in Table 3.10 allow for an estimate of the leaching fraction to be computed using Equation 3.5. However, there will be inherent uncertainty in these estimates due to lack of more detailed data for the irrigation source water. For the purposes of this analysis, estimated leaching fractions were computed using three different EC values of the applied irrigation water; 0.50, 0.59, and 0.70 dS/m. 0.59 dS/m represents the average electrical conductivity in the LSJR, measured at Crows Landing, Patterson, and Maze monitoring station, during the 1986 and 1987 sampling period. As an example, from Table 3.10, the average estimated leaching fraction, with measured EC_i = 0.59 dS/m, for the fields drained by the systems reported would be 0.32. The minimum and maximum estimated leaching fractions in the LSJR Irrigation Use Area for measured EC_i = 0.59 dS/m was 0.13 and 0.84 respectively. Estimated leaching fractions were also computed assuming EC_i of 0.50 dS/m and 0.70 dS/m to represent upper and lower brackets with measured EC_i averages. Calculated leaching fractions in the South Delta by Hoffman, 2010 are similar to those calculated in the LSJR Irrigation Use Area. Hoffman (2010) noted that regardless of the applied water quality, the leaching fractions are relatively high and indicative of surface irrigation systems managed to prevent crop water stress.

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Figure 3.18. Location of subsurface tile drains sampled in the LSJR Irrigation Use Area (Chilcott et al., 1988).

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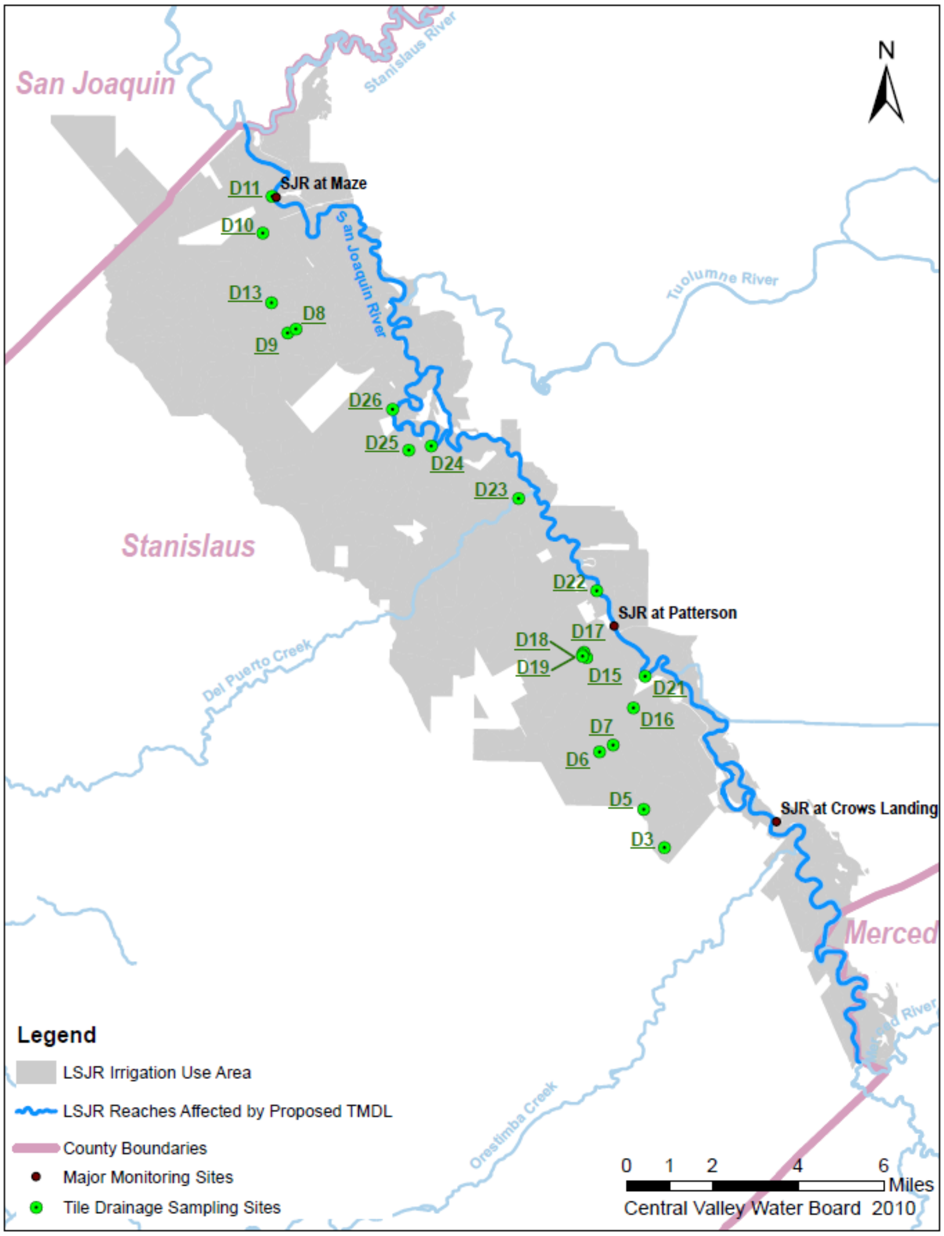
San Joaquin
Stanislaus River
N
SJR at Maze
D11
D10
San Joaquin River
D13
D8
D9
Tuolumne River
D26
D25
D24
D23
Stanislaus
D22
SJR at Patterson
D18
D17
D19
D15
D21
Del Puerto Creek
D16
D7
D6
SJR at Crows Landing
D5
D3
Merced
Legend
LSJR Irrigation Use Area
LSJR Reaches Affected by Proposed TMDL
County Boundaries
Major Monitoring Sites
Tile Drainage Sampling Sites
Orestimba Creek
0 1 2 4 6
Miles
Central Valley Water Board 2010

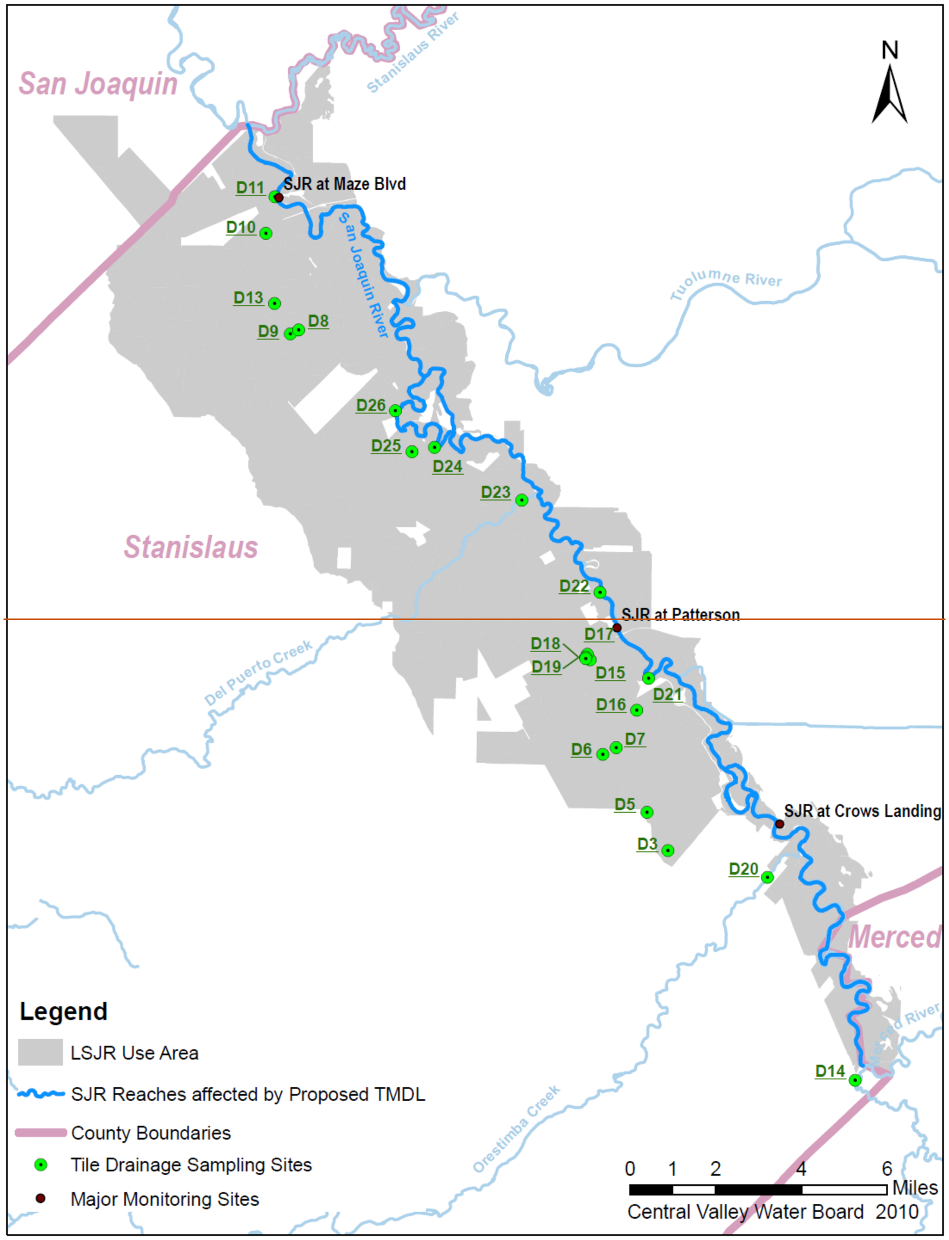
San Joaquin
Stanislaus River
N
D11
SJR at Maze Blvd
D10
San Joaquin River
Tuolumne River
D13
D8
D9
D26
D25
D24
D23
Stanislaus
D22
SJR at Patterson
D17
D18
D19
D15
Del Puerto Creek
D21
D16
D7
D6
D5
SJR at Crows Landing
D3
D20
Merced
D14
Legend
LSJR Use Area
SJR Reaches affected by Proposed TMDL
County Boundaries
Tile Drainage Sampling Sites
Major Monitoring Sites
Orestimba Creek
0 1 2 4 6
Miles
Central Valley Water Board 2010

Table 3.10. Average electrical conductivity (EC) and calculated leaching fraction (L) from 20 sites in the LSJR Irrigation Use Area, with measured EC of applied water as 0.59 dS/m for subsurface tile drains during 1986 and 1987 (Chilcott et al., 1988).

Drain Location Description/Coordinates	Number of Samples	EC (dS/m)	L assuming EC_i=0.50 dS/m	L measured EC_i=0.59 dS/m	L assuming EC_i=0.70 dS/m
D3. Perry and Fialho Tile Drain Sump	3	3.2	0.16	0.18	0.22
D5. George Silva Tile Drain Sump	2	2.4	0.21	0.25	0.30
D6. Apricot Avenue Drain	2	2.6	0.19	0.23	0.27
D7. *(37.457009,-121.081266)*	2	2.3	0.22	0.26	0.30
D8. Tosta Tile Drain	2	2.3	0.22	0.26	0.30
D9. Chunn Tile Drain	2	2.0	0.25	0.29	0.34
D10. Thoming Tile Drain	3	2.4	0.21	0.25	0.29
D11. Blewett Drain or El Solyo Water District Main Drain	1	2.5	0.20	0.24	0.28
D13. Hospital Creek Collector Tile Drain	2	1.4	0.35	0.41	0.49
D15. *(37.484436,-121.093293)*	2	1.5	0.34	0.40	0.48
D16. Pomelo Avenue Drain	2	1.6	0.31	0.37	0.44
D17. *(37.489238,-121.09052)*	2	2.3	0.22	0.26	0.31
D18. South Tile Drain at Patterson Water District Lift Canal	1	2.7	0.19	0.22	0.26
D19. North Tile Drain at Patterson Water District Lift Canal	2	1.4	0.36	0.43	0.51
D21. Ramona Lake Main Drain Outfall (RD 1602 Main Drain)	2	1.4	0.37	0.44	0.52
D22. Olive Avenue Drain	2	3.9	0.13	0.15	0.18
D23. Del Puerto Creek	2	1.9	0.26	0.31	0.37
D24. Del Mar Drain	2	0.7	0.69	0.82	0.97
D25. Westley Wasteway at Cox Road	2	4.5	0.11	0.13	0.16
D26. Minnie Road Drain	2	1.3	0.39	0.46	0.55
Number of Drains Sampled in Use area: 20					
	Average:	2.22	0.27	0.32	0.38
	Median:	2.30	0.22	0.26	0.30
	Minimum:	0.70	0.11	0.13	0.16
	Maximum:	4.50	0.71	0.84	1.00

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4. Steady State vs. Transient Models for Soil Salinity

4.1. Steady State Models

This Section introduces some scientific background information related to the use of the steady state model used for the LSJR Irrigation Use Area. In order to maintain consistency with nomenclature of the model variables used by Hoffman (2010), the indented text in this section represents direct quotations from Hoffman (2010) (See Appendix A; Section 4.1), as follows:

> Steady state analyses are less complex than transient-state analyses. The common assumption is that with time, a transient system will converge into a steady state case and provide justification for steady state analyses if crop, weather, and irrigation management remain constant over long periods of time.
>
> These models are typically applied over a period of a year or a number of years, assuming the storage of soil water and salt does not change over the period of time in question; thus, steady state is assumed. All of the steady state models considered here have been directed at solving for the leaching requirement. The leaching requirement (Lr) is the smallest fraction of applied water (irrigation plus rainfall) that must drain below the crop root zone to prevent any loss in crop productivity from an excess of soluble salts. The amount of leaching necessary to satisfy the Lr depends primarily upon the salinity of the applied water and the salt tolerance of the crop. As the leaching fraction decreases, the salt concentration of the soil solution increases as crop roots extract nearly pure soil water leaving most of the salts behind. ~~If the salt concentration in the soil exceeds the crop's salt tolerance threshold level (Table 3.1), leaching is required to restore full crop productivity.~~
>
> If the salt concentration in the soil exceeds the crop's salt tolerance threshold level (Table 3.1), leaching is required to restore full crop productivity. Depending on the degree of salinity control required, leaching may occur continuously or intermittently at intervals of a few months to a few years. If leaching is insufficient, losses will become severe and reclamation will be required before crops can be grown economically.
>
> All steady state and transient models are based upon mass balance of water and salt. Thus for a unit surface area of a soil profile over a given time interval, inflow depths of irrigation (D_i) and effective precipitation (P_e) minus outflows of crop evapotranspiration (ET_c) and drainage (D_d) must equal changes in soil water storage (ΔD_s). For steady state conditions:
> $$\Delta D_s = D_i + P_e - ET_c - D_d = 0. \qquad \textbf{(Eqn. 4.1)}$$

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The amount of salt leaving the soil by evapotranspiration and that applied in precipitation are negligible. Thus, the change in mass of salt stored per unit area within the root zone (ΔM_s) is given by:

$\Delta M_s = (C_i \times D_i) - (C_d \times D_d) = 0$. **(Eqn. 4.2)**

The salt concentration in the irrigation water is noted as C_i and the salt concentration in the drain water is represented by C_d. Under steady state conditions ΔD_s and ΔM_s are zero. Therefore, the leaching fraction (L) at steady state, defined as the ratio of water leaving the root zone as drainage to that applied, $D_a = D_i + P_e$, or the ratio of salt applied to salt drained, can be expressed as was given in Equation 3.5. The leaching requirement (L_r) can be expressed as presented in Equation 3.6.

Steady state models have been proposed to relate EC_{d^*} to some readily available value of soil salinity that is indicative of the crop's leaching requirement. Bernstein (1964) assumed EC_{d^*} to be the electrical conductivity of the soil saturation extract (EC_e) at which yield in salt tolerance experiments was reduced by 50% (EC_{e50} in Figure 4.1). Bernstein and Francois (1973b) and van Schilfgaarde et al. (1974) contended that the value of EC_{d^*} could be increased to the EC of soil water at which roots can no longer extract water. Assuming the soil water content in the field to be half of the water content of a saturated soil sample, the value of EC_{d^*} was proposed to be twice EC_e extrapolated to zero yield from salt tolerance data ($2EC_{e0}$ in Figure 4.1). Concurrently, Rhoades (1974) proposed that EC_{d^*} could be estimated from ECd* = 5ECet – EC_i in which EC_{et} is the salt tolerance threshold ($5EC_{et} - EC_i$ in Table 4.1). A fourth model, proposed by Rhoades and Merrill (1976) and Rhoades (1982), differentiates between infrequent and high-frequency irrigations. The model calculates soil salinity based upon a 40-30-20-10 soil water extraction pattern by successively deeper quarter-fractions of the root zone. The average soil salinity for conventional (infrequent) irrigations is taken as the linear average of the quarter-fraction values. This is the model utilized by Ayers and Westcot (1976 and 1985). For high frequency irrigation, Rhoades assumed soil salinity is weighted by crop water-uptake.

Hoffman and van Genuchten (1983) determined the crop water-uptake weighted salinity by solving the continuity equation for one dimensional vertical flow of water through the soil assuming an exponential soil water uptake function (Exponential in Table 4.1). Their equation given as the crop water-uptake weighted salt concentration of the saturated extract (C) is given by:

$C/C_a = 1/L + [\delta/(Z \times L)] \times \ln [L + (1 - L) \times \exp^{(-Z/\delta)}]$ **(Eqn. 4.3)**

Where C_a is the salt concentration of the applied water, L is the leaching fraction, Z is the depth of the crop root zone, and δ is an empirical constant set to 0.2*Z.

The resultant mean root zone salinity (C) for any given L was reduced by the mean root zone salinity at an L of 0.5 because salt tolerance experiments were conducted at leaching fractions near to 0.5. The amount of soil salinity at a crop's salt tolerance threshold does not have to be leached. This correction results in a reasonable relationship between any given crop's salt tolerance threshold, determined at an L of about 0.5, and the salinity of the applied water as a function of L_r. The L_r based on the Hoffman and van Genuchten model can be determined from Figure 4.2 for any given EC of the applied water and the crop's salt tolerance threshold.

Figure 4.1. Three of the salt tolerance variables used in various steady state models illustrated for tomatoes. (Adapted from Hoffman, 2010).

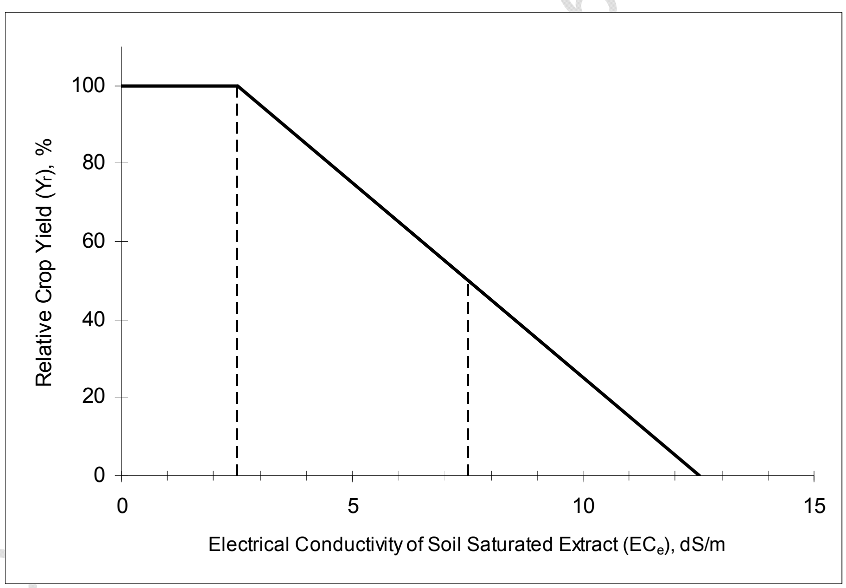

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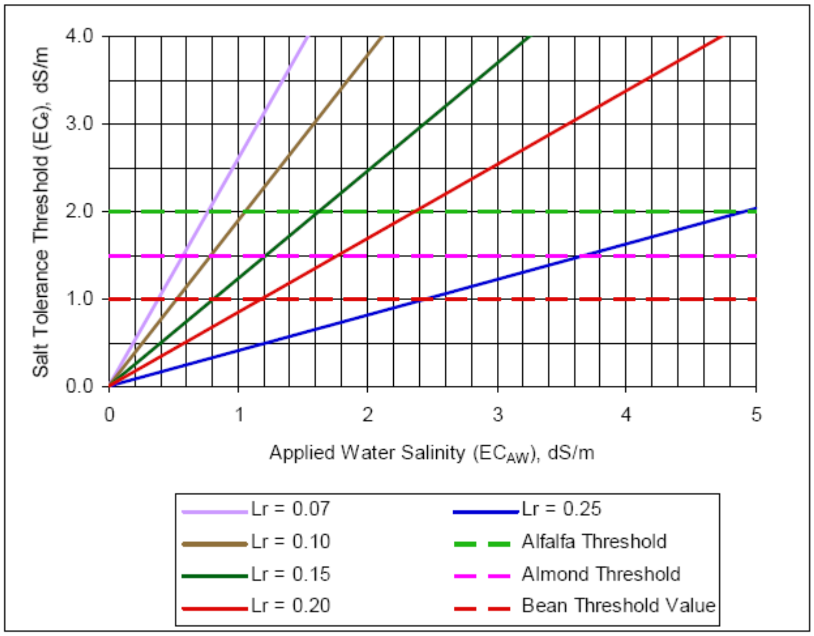
Figure 4.2. Graphical solution (using exponential plant water uptake model) for crop salt tolerance threshold (EC_e) as a function of applied water salinity (EC_{AW}) for different leaching requirements (Hoffman and Van Genuchten, 1983).



4.2. Transient Models

In regards to transient models, Hoffman (2010) noted that:

> Transient models on the other hand are designed to account for the time dependent variables encountered in the field. Some of these variables include switching crops with different salt tolerances, variable irrigation water salinity, rainfall, multiple years of drought, timing and amount of irrigation, multiple soil layers, crop ET and initial soil salinity conditions.

Hoffman (2010) presents further theory on various transient models that have been developed to manage the complexity associated with irrigation water where salinity is a hazard (Appendix A; Section 4.2).

4.3. Comparison of Leaching Requirement Models

Hoffman (2010) provided a review on leaching requirement models, as follows:

> Hoffman (1985) compared four steady state models namely the Grattan model, Corwin model, Simunek model and Letey model with results from seven independent experiments conducted to measure the leaching requirement of 14 crops with irrigation waters to different salt concentrations. The seven experiments included Bower, Ogata, and Tucker (1969 and 1970) who studied alfalfa, tall fescue, and sudan grass. Hoffman and colleagues experimented on barley, cowpea, and celery (Hoffman and Jobes, 1983); oat, tomato, and cauliflower (Jobes, Hoffman, and Wood, 1981); and wheat, sorghum, and lettuce (Hoffman, et al., 1979). Bernstein and Francois (1973b) studied alfalfa and Lonkerd, Donovan, and Williams (1976, unpublished report) experimented on wheat and lettuce. Comparisons between measured and predicted leaching requirements by these five steady state models are presented in Table 4.1.
>
> The EC_{e50} model consistently over estimated the L_r while the $2EC_{e0}$ model consistently under estimated. The $5EC_{et}$-EC_i model gave reasonable estimates at low leaching requirements, but over estimated severely at high leaching requirements. The exponential model correlated best with measured values of L_r but under estimated high measured values of the L_r.
>
> One of the main conclusions of Letey and Feng (2007) was that steady state analyses generally over predict the negative consequences of irrigating with saline waters. In other words, the L_r is lower than that predicted by steady state models. Letey (2007) made a comparison among steady state models and concluded that the highest L_r was calculated with linear averaged soil salt concentrations, intermediate L_r values occurred with the $5EC_{et}$-EC_i model, and the lowest L_r was found with the water-uptake weighted soil salt concentrations, the exponential model. This is confirmation that if a steady model is to be used to evaluate a water quality standard, the exponential model is the closest to the results from a transient model like the ENVIRO-GRO transient model proposed by Letey (2007).

Further details on this comparison are presented by Hoffman (2010) (Appendix A; Section 4.3).

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Table 4.1. Comparisons of leaching requirement (L_r) predicted by five steady state models with experimentally measured leaching requirements for 14 crops with various saline irrigation waters (Hoffman, 1985).

Crop	Data		L_r Prediction Using				
	L_r	EC_i	EC_{e50}	$2EC_{e0}$	$5EC_{et}$-EC_i	40-30-20-10	Exp.
CEREALS							
Barley	0.10	2.2	0.12	0.04	0.06	0.01	0.05
Oat	0.10	2.2	0.18	0.06	0.11	0.04	0.09
Sorghum	0.08	2.2	0.22	0.08	0.07	0.01	0.06
Wheat	0.07	1.4	0.11	0.03	0.05	0.03	0.04
Wheat	0.08	2.2	0.17	0.05	0.08	0.01	0.07
VEGETABLES							
Cauliflower	0.17	2.2	0.31	0.09	0.25	0.22	0.18
Celery	0.14	2.2	0.22	0.06	0.32	0.34	0.20
Cowpea	0.16	2.2	0.24	0.08	0.10	0.03	0.09
Lettuce	0.26	2.2	0.43	0.12	0.51	0.72	0.24
Lettuce	0.22	1.4	0.27	0.08	0.27	0.36	0.18
Tomato	0.21	2.2	0.29	0.09	0.21	0.16	0.16
FORAGES							
Alfalfa	0.20	2.0	0.18	0.05	0.15	0.16	0.13
Alfalfa	0.32	4.0	0.36	0.11	0.36	0.52	0.22
Alfalfa	0.06	1.0	0.11	0.03	0.11	0.09	0.09
Alfalfa	0.15	2.0	0.23	0.06	0.25	0.31	0.17
Barley	0.13	2.2	0.17	0.05	0.08	0.02	0.07
Cowpea	0.17	2.2	0.31	0.09	0.38	0.45	0.22
Fescue	0.10	2.0	0.17	0.05	0.17	0.17	0.13
Fescue	0.25	4.0	0.25	0.07	0.40	0.58	0.23
Oat	0.17	2.2	0.31	0.0	0.25	0.22	0.18
Sudan Grass	0.16	2.0	0.14	0.04	0.19	0.17	0.13
Sudan Grass	0.31	4.0	0.28	0.08	0.49	0.58	0.23

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5. Steady State Modeling for LSJR Irrigation Use Area

5.1. Model Description

5.1.1 Steady State Assumptions

As previously discussed, this Report follows the approach of Hoffman (2010). Staff utilized the model provided by Hoffman (2010) and input specific climatic data for the LSJR Irrigation Use Area. The model begins with the steady state equations presented in Section 4.1. At steady state, the inputs of irrigation (I) and precipitation (P) must equal crop evapotranspiration (ET_c) plus drainage (D) (see Equation 4.1 presented as depths of water). Furthermore, the amount of salt entering the crop root zone must equal the amount leaving (refer to Equation 4.2). The time frame chosen for the model is a yearly time frame and the inputs and outputs are annual amounts (water year, October 1st through September 30th). Being a steady state model, variation in soil water storage and salt mass are assumed not to change from one year to the next.

As discussed by Hoffman (2010), the steady state models are one-dimensional, vertical direction only, and do not account for soil permeability. The steady state models assume no crop water stress and that fertility is adequate and insects and diseases are avoided. The dissolution of salts from the root zone (5% of the salts leaving the bottom of the root zone from Section 3.11) is not considered in the steady state model. Also the model is not capable of determining intra-seasonal salinity or double or inter-row cropping.

5.1.2 Cropping Assumptions

As discussed in detail in Section 3.1.2, three crops were modeled based on screening approach that considered salt sensitivity, crop acreage that exceeded 1% of the irrigated acreage in the LSJR Irrigation Use Area, and model availability based on work done by Hoffman (2010). The crops modeled were dry bean, which is the most salt sensitive, as well as almond and alfalfa.

As noted by Hoffman (2010):

> The salt tolerance threshold for bean is an EC_e of 1.0 dS/m (refer to Table 3.1). In the model, the salinity of the soil water (EC_{sw}) is used. Thus, for ease in comparison, the threshold value for bean is an EC_{sw} of 2.0 dS/m. This assumes the relationship $EC_{sw} = 2 \times EC_e$. The salt tolerance threshold for alfalfa is an EC_e of 2.0 dS/m or an EC_{sw} of 4.0 dS/m. For almond the threshold is an EC_e of 1.5 dS/m or an EC_{sw} of 3.0 dS/m.
>
> Based upon the publication of Goldhamer and Snyder (1989), dry beans in the San Joaquin Valley are planted from April 1 until as late as mid-June and harvested as early as the end of July (as shown in Figure 5.3) until the end of September. Bean was modeled for three planting dates shown

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in the Goldhamer and Snyder report: April 1, May 1, and June 16. For ease in model calculations, it is assumed that there is no double cropping and that the soil surface is bare from harvest until planting. As noted by Hoffman (2010), the model could be used to evaluate bean followed by a second crop or a multi-year crop rotation, if desired.

The model was also run for a mature crop of alfalfa assuming seven cuttings per year. Seven is probably the most harvests possible, depending upon weather and possible management decisions only six cuttings may be made. Assuming seven harvests, produces a conservative estimate of EC_{sw} due to the additional irrigation water required to satisfy one more harvest during the growing season.

Based upon the publication of Goldhamer and Snyder (1989), assuming an already established stand, alfalfa in the San Joaquin Valley of California has a growth cycle from 12 February and likely harvested before the 13 March. Alfalfa goes through a cyclical pattern of (about 28-30 days) sprouting and cutting as shown in Figure 5.4. For modeling, it was assumed that alfalfa completely covers the ground (Hoffman, 2010).

A mature almond orchard was also modeled. Based upon the publication of Goldhamer and Snyder (1989), almonds in the Central Valley of California start leafing out likely about 15 February and are harvested around 10 November (Figure 5.5). Thus the non-growing season was considered as November 10 to February 15 with the assumption that there was no cover crop in the almond orchard.

5.1.3 Crop Evapotranspiration

Excerpts of this Section that were directly quoted from Hoffman (2010) are shown as indented, as follows:

Crop water requirements are normally expressed as the rate of evapotranspiration (ET_c). The level of ET_c is related to the evaporative demand of the air above the crop canopy. The evaporative demand can be expressed as the reference evapotranspiration (ET_o) which predicts the effect of climate on the level of crop evapotranspiration of an extended surface of a 4 to 6 inch-tall cool season grass, actively growing, completely shading the ground, and not short of water.

One of the more simple and accurate equations to estimate ET_o is the Hargreaves equation (Hargreaves and Allen, 2003). The equation can be written as:

$$\mathbf{ET_o = 0.0023 \times R_a \times (TC + 17.8) \times TR^{0.50}} \qquad \textbf{(Eqn. 5.1)}$$

Where R_a is the extraterrestrial radiation, TR is the difference between the mean maximum and minimum daily temperatures in degrees Celsius, and

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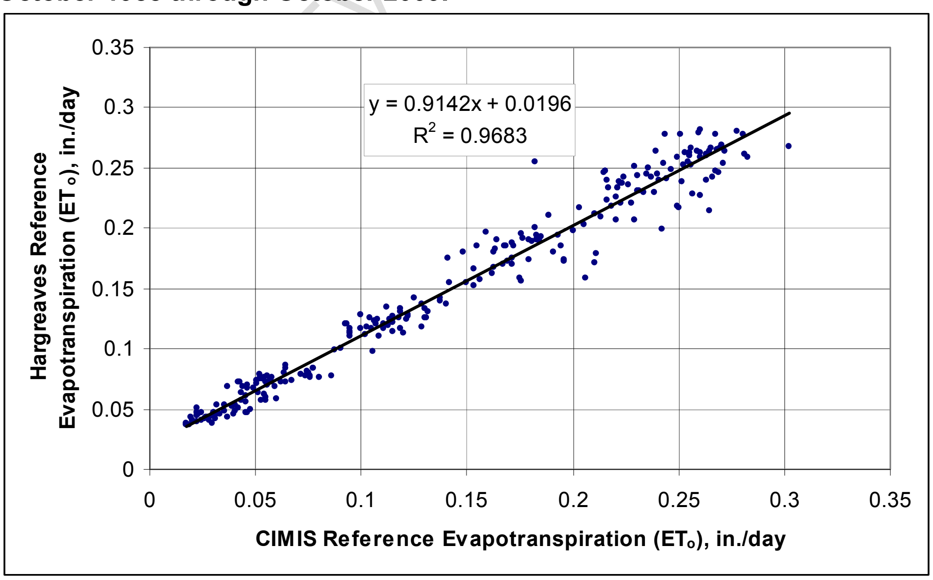
TC is the average of the maximum and minimum daily temperature in degrees Celsius.

The Penman-Montheith equation is generally considered the most comprehensive and accurate equation to estimate ET_o. However, the CIMIS station # 71 has shorter historical records compared to the 57 years of temperature and precipitation data at the NCDC Modesto C station. The longer historical record is used in our steady state analysis; thus, the Hargreaves equation was employed in the model for the years 1952 to 2008.

Values of ET_o are calculated with the Hargreaves equation using temperature data from Modesto A (CIMIS #71). Modesto A is backed up by Modesto C, NCDC #5738 which is in close proximity with the Maze monitoring station (Stanislaus River to Tuolumne River reach). This is then compared with ET_o calculated by the Penman-Montheith equation based upon data collected at the CIMIS station #71 near Maze. The data presented in Figure 5.1 show good agreement between the Hargreaves and the Penman-Montheith equations with an R^2 value of 0.97. This comparison validates the use of the Hargreaves equation. Data from Patterson A, Patterson, Patterson North and Newman serve as backups for each other in the NCDC database and data from these stations were used for SJR at Patterson and SJR at Crows Landing monitoring sites (Merced River to Tuolumne River reach) (Figure 5.2).

Figure 5.1. Monthly reference evapotranspiration (ET_O) calculated with the Hargreaves equation plotted against CIMIS ET_O calculations with the Penman- Monteith equation; using Modesto A CIMIS #71 climate data from October 1988 through October 2009.



Further excerpts quoted from Hoffman (2010) are shown as indented, as follows:

> The evapotranspiration of a crop (ET_c) can be estimated by multiplying the ET_o value by a crop coefficient (K_c) that accounts for the difference between the crop and cool season grass. A crop coefficient actually varies from day to day depending on many factors, but it is mainly a function of crop growth and development. Thus, K_c values change as foliage develops and as the crop ages. Crop growth and development rates change somewhat from year to year, but the crop coefficient corresponding to a particular growth stage is assumed to be constant from season to season. Daily variations in ET_c reflect changes in ET_o in response to evaporative demand. The equation to calculate crop evapotranspiration is:
>
> $$ET_c = K_c \times ET_o. \qquad \textbf{(Eqn. 5.2)}$$
>
> The crop coefficient is typically divided into four growth periods as shown in Figure 5.3 for bean (Goldhamer and Snyder, 1989). The four growth periods for annual crops are initial growth, rapid growth, midseason, and late season. Growth is reflected by the percentage of the ground surface shaded by the crop at midday. For annual crops, the K_c dates correspond to: A, planting; B, 10% ground shading; C, 75% or peak ground shading; D, leaf aging effects on transpiration; and E, end of season. Figure 5.3 shows the K_c values for bean with a planting date of April 1 and the dates when each growth stage changes.

The crop coefficients for alfalfa are presented in Figure 5.4 assuming seven harvests. Note in Figure 5.4 that on the day that alfalfa is cut K_c drops from 1.2 to 0.4 and after a few days increases rapidly to 1.2 as the crop grows. Cuttings are typically made every 28 to 30 days after the first spring cutting.

The crop coefficients for almond are plotted in Figure 5.5. The non-growing season for almond was taken as November 10 until February 15 as reported by Goldhamer and Snyder (1989). It was assumed that there was no cover crop. If a cover crop was grown in the almond orchard, ET_c for the cover crop would have to be added to ET_c for almond to determine the irrigation requirements in the models.

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Figure 5.2. Location map for climatic stations near the three monitoring stations in the LSJR.

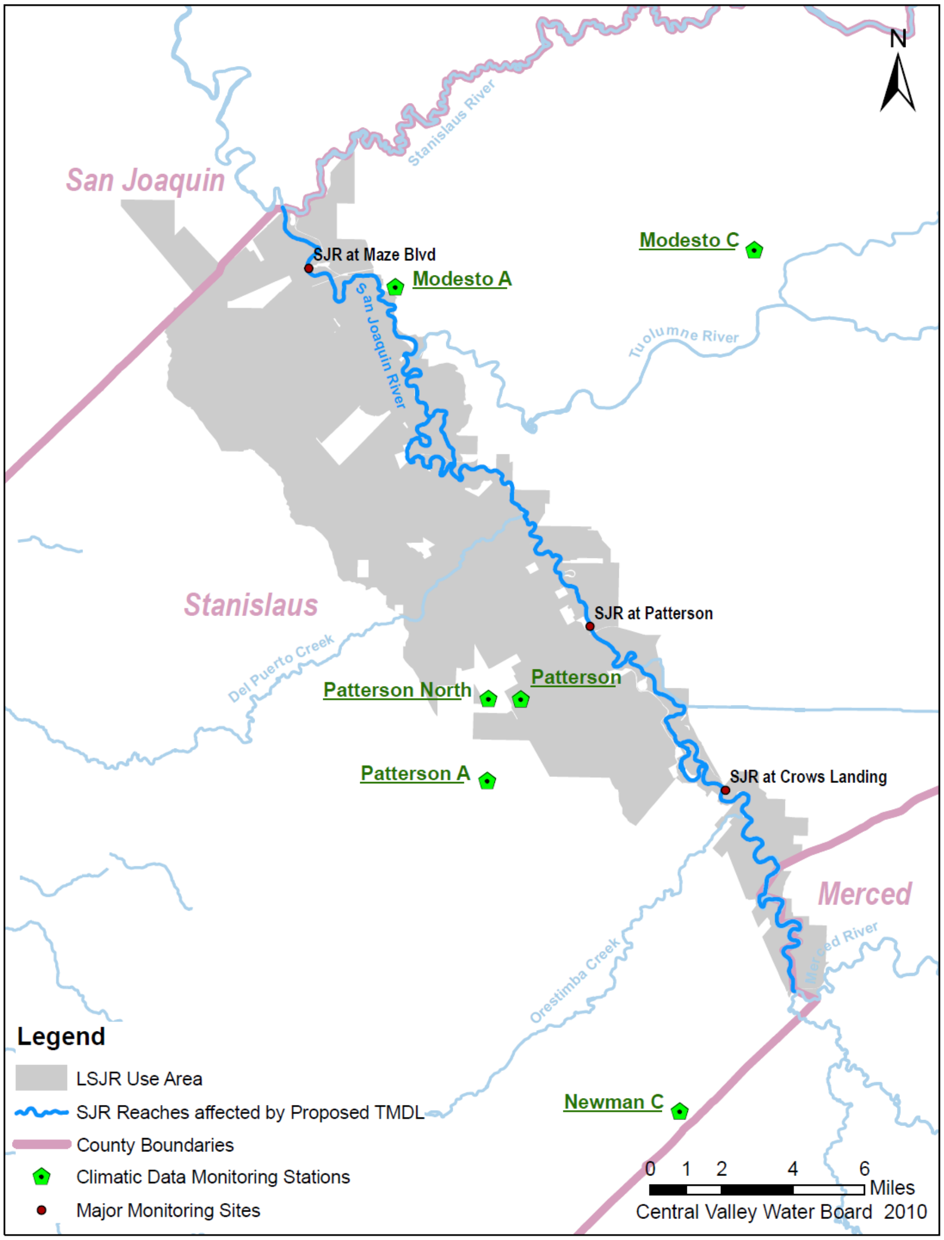


Figure 5.3. Crop coefficients (Kc) for different growth and development periods of bean with April 1st planting date (Goldhamer and Snyder, 1989) used in steady state modeling. (Adapted from Hoffman, 2010).

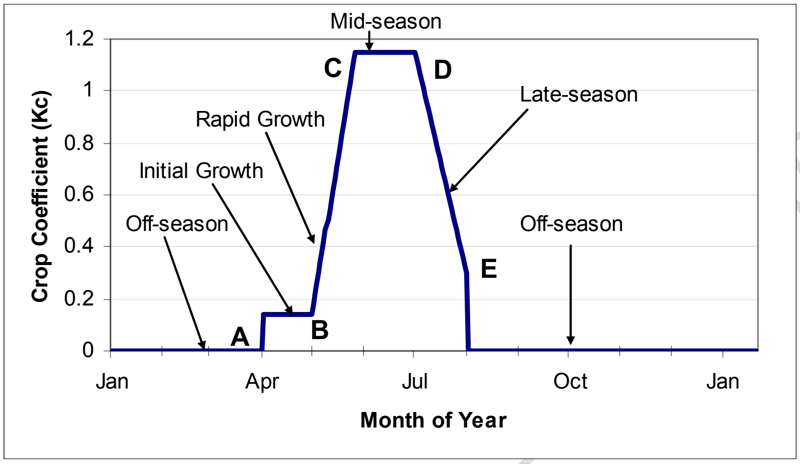


Figure 5.4. Crop coefficients (K_c) for different growth and development periods assuming 7 cuttings per year of alfalfa (adapted from Goldhamer and Snyder, 1989 and South Delta Water Agency input) used in steady state modeling. (Adapted from Hoffman, 2010).

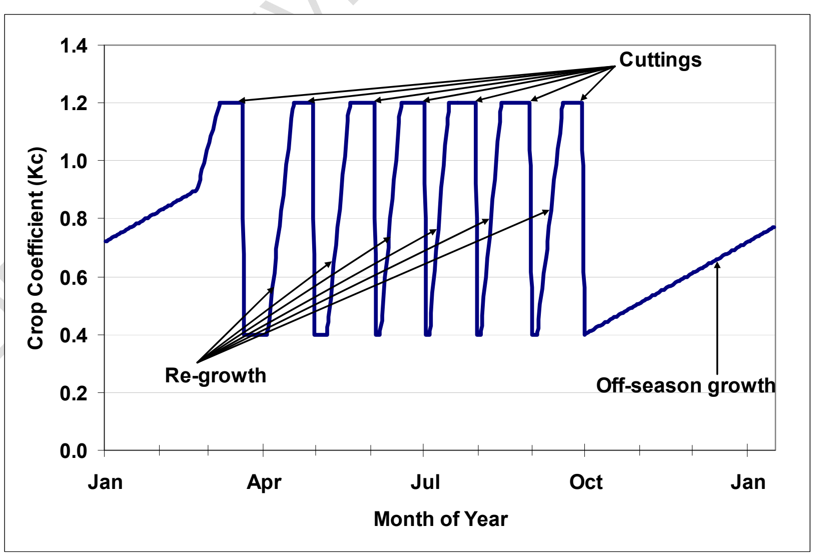
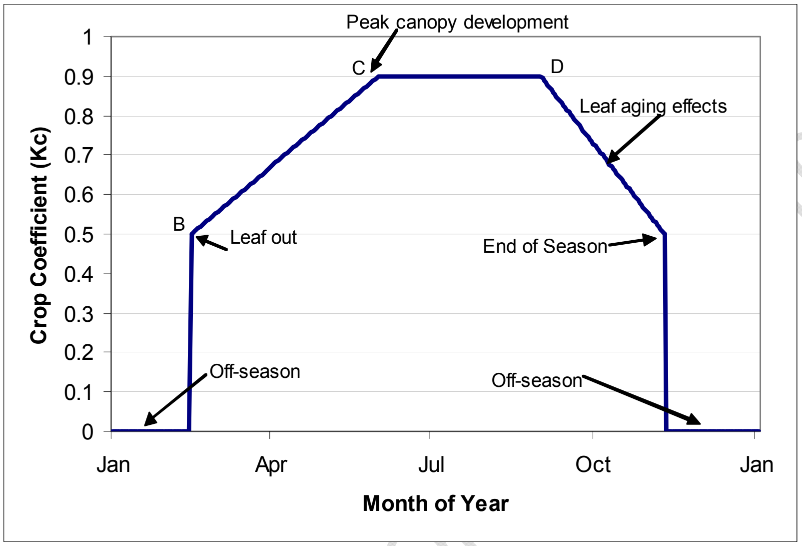


Figure 5.5. Crop coefficients (K_c) for the different growth periods of almond (Goldhamer and Snyder, 1989) used in steady state modeling. (Adapted from Hoffman, 2010).



5.1.4 Precipitation

To maximize the time period for the model, precipitation records were taken from the NCDC stations shown in Figure 5.2. Precipitation records are presented by water years (October of previous year through September of the stated water year) from 1952 through 2008. Following the approach of Hoffman (2010), the precipitation amounts were divided between the amount during the growing season from April 1 to August 1 (P_{GS}) and the remainder of the year as non-growing (P_{NG}) for bean. It was assumed that all precipitation occurring during the growing season was consumed by evapotranspiration. The reasons for this assumption are given in Section 3.5.2. For example, for Crows Landing and Patterson, the amount of precipitation during the growing season (P_{GS}) never exceeded 4.0 inches and the median was only 0.2 inches over the 57 years of precipitation record. Thus, if some runoff occurred it would likely be insignificant.

During the non-growing season, the rate of surface evaporation (E_s) was taken as 0.7 inches per month as previously discussed in Section 3.5.2. For bean with a 4-month growing season, surface evaporation (E_S) would total 5.6 inches for the 8 months of the year without a crop. On a yearly basis, the evapotranspiration for bean was added to the 5.6 inches of E_s to obtain one of the outputs from the root zone. The values for ET_C, P_{GS}, and P_T are plotted in Figure 5.6 for water years 1952 to 2008. The effective precipitation (P_{EFF}) is P_{GS} + (P_{NG} - E_S). P_{GS} is taken as contributing to ET_C and P_{NG} is reduced annually by E_S or 5.6 inches per year.

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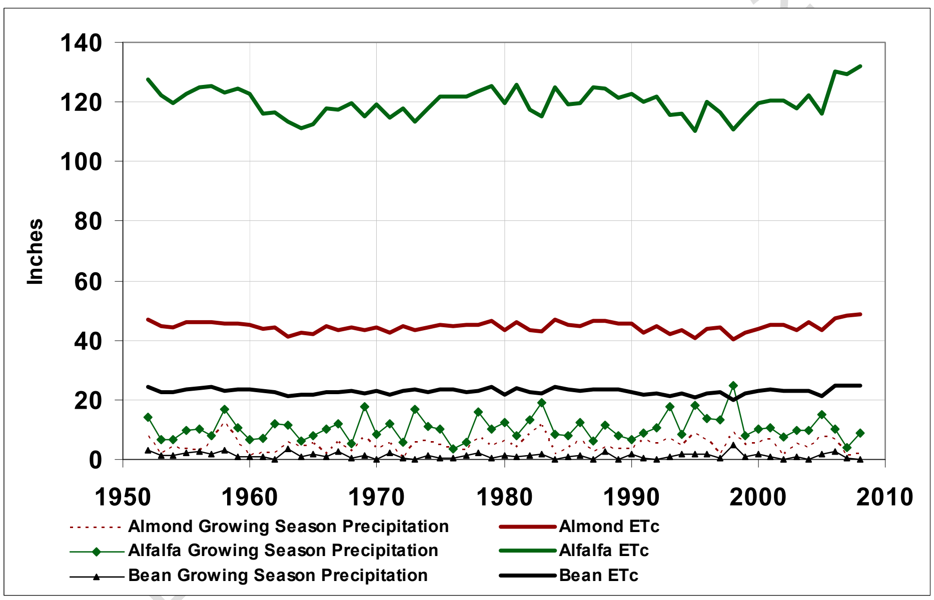
As reported in Table 5.2, in only 3 years of the 57 years of record was P_{EFF} negative (1976, 1977 and 2007) which means that stored water had to be used to satisfy E_S. Surface runoff was assumed to be zero for the reasons stated in Section 3.5.2. Thus, all of the precipitation and irrigation is assumed to infiltrate the soil surface and be available for surface evaporation, crop evapotranspiration, or leaching.

Figure 5.6. Comparison of crop evapotranspiration (ET_C) estimate for bean, alfalfa, and almond against total precipitation during the corresponding growing season (P_{GS}) with precipitation data from NCDC station no. 5738, Modesto C for water years 1952 through 2008. Note that P_{GS} for alfalfa is equal to total precipitation for the year.



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5.1.5. Steady State Models

Hoffman (2010) discussed two crop water uptake distributions that are used to calculate average soil salinity (Appendix A; Sections 3.9 and 4.1). One distribution assumes a 40-30-20-10 uptake distribution by quarter fractions of the root zone and the other assumes an exponential uptake distribution. These patterns are described in detail in Section 3.9 of Appendix A. Although the exponential pattern has better agreement with experimental results (Hoffman, 2010), both distributions are used in the steady state modeling in this Report because Staff opted to replicate the same distributions used in the analysis of Hoffman (2010). For the purpose of reporting results of the modeling, Staff followed Hoffman's recommendation and presents only the results of exponential modeling in Table 6.1.

The equations used in the model to calculate the average soil water salinity (EC_{sw}) for both water uptake distributions are given in Table 5.1. Both equations use irrigation water salinity (EC_i) when precipitation is ignored and salinity of applied water (EC_{AW}) when rainfall is considered.

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Table 5.1. Definition of input variables and equations for the steady state model.

Input Variables

L= leaching fraction (input assumption)
EC_i= irrigation water salinity (input assumption)
P_T= total annual precipitation
P_{NG}= total precipitation during the non-growing season (Dates determined by Goldhamer & Snyder, 1989)
E_S= total off-season surface evaporation (0.7 in/mo. from end of previous to beginning of stated water year's growing season)
P_{GS}= total precipitation during the growing season (Dates determined by Goldhamer & Snyder, 1989)
P_{EFF}= total effective precipitation where $P_{EFF} = P_{GS} + (P_{NG} - E_S)$
ET_C= total crop evapotranspiration as calculated per Goldhamer & Snyder, 1989 (total of growing season stated water year)

Steady state Equations (without consideration of precipitation)

For a particular water year:
I_1= irrigation required to satisfy assumed leaching fraction given total ET_C (excluding precipitation): $I_1 = ET_c/(1-L)$

$$EC_{SWa-1} = \left[EC_i + \frac{EC_i * I_1}{I_1-(0.4*ET_c)} + \frac{EC_i * I_1}{I_1-(0.7*ET_c)} + \frac{EC_i * I_1}{I_1-(0.9*ET_c)} + \frac{EC_i * I_1}{I_1-ET_c)}\right] \div 5$$

$$EC_{SWb-1} = \left[\left(\frac{1}{L}\right) + \left(\frac{0.2}{L}\right) * \ln[L+(1-L)*\exp(-5)-1.7254]\right] * EC_i$$

Steady state Equations (including consideration of precipitation)

For a particular water year:
I_2= amount of irrigation required to maintain L (accounting for precipitation): $I_2 = [ET_c/(1-L)] - P_{EFF}$
EC_{AW} = salinity of applied water (combined P_{EFF}+ I_2): $EC_{AW} = I_2 \times EC_i /(P_{EFF} + I_2)$.

$$EC_{SWa-2} = \left[EC_{AW} + \frac{EC_{AW} * (I_2+P_{EFF})}{(I_2+P_{EFF})-(0.4*ET_c)} + \frac{EC_{AW} * (I_2+P_{EFF})}{(I_2+P_{EFF})-(0.7*ET_c)} + \frac{EC_{AW} * (I_2+P_{EFF})}{(I_2+P_{EFF})-(0.9*ET_c)} + \frac{EC_{AW} * (I_2+P_{EFF})}{(I_2+P_{EFF})-ET_c)}\right] \div 5$$

$$EC_{SWb-2} = \left[\left(\frac{1}{L}\right) + \left(\frac{0.2}{L}\right) * \ln[L+(1-L)*\exp(-5)-1.7254]\right] * EC_{AW}$$

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5.2. Model Results

This section presents the results of running the Hoffman (2010) steady state model for the LSJR Irrigation Use Area. To duplicate the approach of Hoffman (2010), two uptake water distribution functions, 40-30-20-10 and exponential were used to determine protective salinity thresholds for beans, alfalfa and almond. Three sites were used within the LSJR Irrigation Use Area: Crows Landing and Patterson (which represent the Merced ~~Tuolumne~~ River to Tuolumne ~~Merced~~ River reach) and Maze (which represents the Stanislaus River to Tuolumne River reach). The main climatic variables used for these three sites for the Hoffman (2010) steady state model were temperature and precipitation.

5.2.1. Bean

Table 5.2 presents an example of calculated irrigation amounts and soil water salinity values for 57 water years if bean is planted on May 1 in Crows Landing and Patterson. Values are presented for both water uptake distributions (the 40-30-20-10 uptake and exponential uptake) with and without precipitation. The example includes model input variables of EC_i = 1.0 dS/m and L= 0.15. The input values for precipitation including total, growing season and non-growing season precipitation, off season evaporation, and crop evapotranspiration for the 57 water years are also given in Table 5.2. The model was run over a range of EC_i values from 0.5 to 2.0 dS/m, with L= 0.15, 0.20, and 0.25.

Results from the exponential model for Crows Landing and Patterson are summarized in Table 5.3 for the three possible planting dates and corresponding crop coefficients for the San Joaquin Valley as given by Goldhamer and Snyder (1989). The median annual rainfall for both Crows Landing and Patterson is 10.6 inches while the median annual rainfall of Maze is 10.9 inches. The median values for soil salinity are presented as a comparison with the salt tolerance threshold for bean (2.0 dS/m).

Staff followed the methodology of Hoffman (2010) for choice of leaching fractions used in the steady state model. Hoffman (2010) used three leaching fractions (0.15, 0.20 and 0.25) for modeling beans. The use of the same leaching fractions is appropriate because of the many similarities between the South Delta and LSJR Irrigation Use Area. For example, furrow irrigation is the predominant irrigation method for beans in both areas (as presented in Section 5.2). There are also similar calculated leaching fractions based on subsurface tile drain data (Section 3.13). The rationale provided by Hoffman (2010) for not modeling below a leaching fraction of 0.15 for bean was based upon leaching fractions that were calculated from tile drainage discharges in the South Delta.

Results from Table 5.3 reveal that at an EC_i of 0.7 or 1.0 dS/m, the planting date has minimal impact on the median soil salinity values. As expected, higher leaching fractions resulted in lower soil salinity values. With the exception of an

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EC_i of 1.0 and L of 0.15 for the May 1st planting date, no other median values exceeded the salt tolerance threshold for bean of 2.0 dS/m.

Figure 5.7 shows the impact of rainfall on the average soil salinity for an EC_i of 0.7 dS/m for both the 40-30-20-10 model and the exponential model for leaching fractions of 0.15, 0.20, and 0.25. All trends indicate that an increase in precipitation decreases soil salinity. For both Crows Landing and Patterson, considering the 40-30-20-10 model (Figure 5.7a1), at L=0.15, the soil salinity may exceed the salt tolerance threshold with potential yield losses of about 2% (Equation 3.1) if rainfall dropped to the 5th percentile. For Maze considering the 40-30-20-10 model (Figure 5.7a2), at L=0.15, potential yield losses would be about 1% if rainfall dropped to the 5th percentile. Conversely, at higher leaching fractions of 0.20 and 0.25 for the 40-30-20-10 model, no yield losses would occur even if annual rainfall was below the 5th percentile for all three sites (Figure 5.7a).

For the exponential model distribution in Figure 5.7b, regardless of the amount of annual rainfall, the bean threshold is not exceeded for all leaching fractions even if annual rainfall was below the 5th percentile for all three sites. Thus, it is unlikely to have a reduction in bean yield if EC_i is 0.7 dS/m.

Figure 5.8a shows the modeling results if the EC_i is increased to 1.0 dS/m. In this scenario, bean yield losses occur even when precipitation is higher than the median value for the 40-30-20-10 model except for the 0.25 leaching fraction. For Crows Landing and Patterson (Figure 5.8a1) and Maze (Figure 5.8a2), for the 40-30-20-10 model at the median precipitation, there is a potential for yield loss for leaching fractions 0.15 and 0.20 respectively. Higher yield losses would occur if the rain decreased to the 5th percentile mark.

In contrast, the exponential model predicts no yield loss for leaching fractions above 0.20 (Figure 5.8b). At a leaching fraction of 0.15, yield losses would start to occur if rainfall decreases to below the median.

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Table 5.2. Output from steady state models both 1) without precipitation and 2) including precipitation data from NCDC station no. 6168, Newman C (for Patterson and Crows Landing) and evapotranspiration coefficients from Goldhamer and Synder (1989) for beans with May 1st planting date.

Input Variables: EC_i = 1.0; L = 0.15

ET_C = crop evapotranspiration
E_S = off-season surface evaporation
P_{GS} = precipitation during growing season
P_T = total annual (infiltrating) precipitation

Model Output

1) Without precipitation
L= Leaching fraction
EC_i = Irrigation water salinity
I_1 = Irrigation requirement
EC_{SWa-1} = Average soil water EC

2) With precipitation
I_2 = Irrigation required for L_2
EC_{AW-2} = salinity of applied water
EC_{SWa-2} = Soil water salinity (40-30-20-10)
EC_{SWb-2} = Soil water salinity (Exponential)

Water Year	P_T (in.)	P_{NG} (in.)	E_S (in.)	P_{GS} (in.)	P_{EFF} (in.)	ET_C (in.)	I_1 (in.)	EC_{SWa-1} (dS/m)	EC_{SWb-1} (dS/m)	I_2 (in.)	EC_{AW-2} (dS/m)	EC_{SWa-2} (dS/m)	EC_{SWb-2} (dS/m)
1952	16.9	16.9	6.0	0.0	10.9	23.5	27.6	3.18	2.46	16.67	0.60	1.92	1.49
1953	6.8	6.8	5.9	0.0	0.8	22.3	26.3	3.18	2.46	25.43	0.97	3.08	2.38
1954	6.5	6.5	5.9	0.0	0.6	22.3	26.3	3.18	2.46	25.70	0.98	3.11	2.41
1955	9.8	9.0	5.9	0.8	3.8	22.9	26.9	3.18	2.46	23.14	0.86	2.73	2.11
1956	10.9	10.1	6.0	0.8	4.9	23.3	27.4	3.18	2.46	22.52	0.82	2.61	2.02
1957	8.7	7.8	5.9	0.9	2.7	23.9	28.1	3.18	2.46	25.33	0.90	2.87	2.22
1958	19.7	18.6	5.9	1.1	13.8	22.8	26.8	3.18	2.46	13.08	0.49	1.55	1.20
1959	10.8	10.8	5.9	0.0	4.9	23.2	27.3	3.18	2.46	22.43	0.82	2.61	2.02
1960	6.6	6.6	6.0	0.0	0.6	23.3	27.5	3.18	2.46	26.80	0.98	3.11	2.40
1961	7.1	6.6	5.9	0.6	1.2	23.1	27.2	3.18	2.46	26.03	0.96	3.04	2.36
1962	12.0	12.0	5.9	0.0	6.1	22.3	26.2	3.18	2.46	20.12	0.77	2.44	1.89
1963	14.0	13.8	5.9	0.2	8.1	21.2	25.0	3.18	2.46	16.89	0.68	2.15	1.67
1964	6.5	5.9	6.0	0.6	0.5	21.4	25.1	3.18	2.46	24.63	0.98	3.12	2.41
1965	10.3	9.9	5.9	0.4	4.3	21.2	24.9	3.18	2.46	20.60	0.83	2.63	2.03
1966	10.6	10.2	5.9	0.4	4.6	22.1	26.0	3.18	2.46	21.32	0.82	2.61	2.02
1967	13.5	13.2	5.9	0.3	7.5	22.5	26.4	3.18	2.46	18.88	0.71	2.27	1.76
1968	6.1	6.0	6.0	0.0	0.1	22.6	26.6	3.18	2.46	26.52	1.00	3.17	2.45
1969	18.8	18.8	5.9	0.0	12.9	21.6	25.4	3.18	2.46	12.48	0.49	1.56	1.21
1970	8.6	8.6	5.9	0.1	2.7	22.5	26.5	3.18	2.46	23.75	0.90	2.86	2.21
1971	13.4	12.7	5.9	0.6	7.4	21.8	25.7	3.18	2.46	18.26	0.71	2.26	1.75
1972	6.2	6.2	6.0	0.0	0.2	22.6	26.6	3.18	2.46	26.37	0.99	3.16	2.44
1973	17.0	17.0	5.9	0.0	11.1	22.7	26.7	3.18	2.46	15.61	0.59	1.86	1.44
1974	11.5	10.8	5.9	0.7	5.6	22.2	26.1	3.18	2.46	20.49	0.79	2.50	1.93
1975	10.7	10.7	5.9	0.0	4.8	23.0	27.1	3.18	2.46	22.31	0.82	2.62	2.03
1976	4.3	4.3	6.0	0.0	-1.7	22.5	26.5	3.18	2.46	28.16	1.06	3.38	2.62
1977	5.7	5.2	5.9	0.5	-0.3	22.7	26.7	3.18	2.46	27.00	1.01	3.21	2.49
1978	17.3	17.2	5.9	0.0	11.3	23.0	27.1	3.18	2.46	15.77	0.58	1.85	1.43
1979	10.4	10.2	5.9	0.2	4.4	23.5	27.7	3.18	2.46	23.26	0.84	2.67	2.07
1980	13.0	12.5	6.0	0.6	7.1	21.9	25.8	3.18	2.46	18.71	0.73	2.31	1.79
1981	8.2	7.8	5.9	0.4	2.3	23.3	27.5	3.18	2.46	25.16	0.92	2.91	2.26
1982	14.8	14.7	5.9	0.1	8.9	22.0	25.9	3.18	2.46	17.04	0.66	2.09	1.62
1983	19.8	19.4	5.9	0.4	13.8	22.0	25.9	3.18	2.46	12.07	0.47	1.48	1.15
1984	8.4	8.4	6.0	0.0	2.5	23.8	28.0	3.18	2.46	25.53	0.91	2.90	2.25
1985	8.2	7.8	5.9	0.4	2.3	22.9	26.9	3.18	2.46	24.65	0.92	2.91	2.25
1986	12.9	12.3	5.9	0.7	7.0	22.8	26.8	3.18	2.46	19.86	0.74	2.36	1.82
1987	6.3	6.3	5.9	0.0	0.4	22.6	26.6	3.18	2.46	26.20	0.99	3.14	2.43
1988	11.0	10.3	6.0	0.8	5.1	22.8	26.8	3.18	2.46	21.76	0.81	2.58	2.00
1989	8.2	8.2	5.9	0.0	2.2	23.2	27.3	3.18	2.46	25.05	0.92	2.92	2.26
1990	6.5	4.9	5.9	1.6	0.6	22.6	26.6	3.18	2.46	26.00	0.98	3.11	2.41
1991	8.8	8.6	5.9	0.2	2.8	21.3	25.0	3.18	2.46	22.18	0.89	2.82	2.18
1992	10.8	10.7	6.0	0.1	4.8	21.6	25.4	3.18	2.46	20.59	0.81	2.58	1.99
1993	17.8	17.1	5.9	0.8	11.9	21.1	24.8	3.18	2.46	12.91	0.52	1.66	1.28
1994	8.9	8.0	5.9	1.0	3.0	21.9	25.8	3.18	2.46	22.78	0.88	2.81	2.18
1995	18.7	18.2	5.9	0.5	12.8	20.7	24.3	3.18	2.46	11.56	0.47	1.51	1.17
1996	14.2	12.9	6.0	1.3	8.2	22.2	26.1	3.18	2.46	17.88	0.69	2.18	1.69
1997	13.6	13.4	5.9	0.2	7.7	21.8	25.7	3.18	2.46	17.98	0.70	2.23	1.73
1998	26.0	22.1	5.9	4.0	20.1	20.4	24.0	3.18	2.46	3.93	0.16	0.52	0.40
1999	8.7	8.7	5.9	0.1	2.8	21.5	25.3	3.18	2.46	22.55	0.89	2.83	2.19
2000	11.5	11.2	6.0	0.3	5.5	22.4	26.3	3.18	2.46	20.77	0.79	2.51	1.94
2001	11.1	11.1	5.9	0.0	5.2	22.7	26.7	3.18	2.46	21.50	0.81	2.56	1.98
2002	7.6	7.6	5.9	0.1	1.7	22.3	26.3	3.18	2.46	24.62	0.94	2.98	2.31
2003	10.5	10.1	5.9	0.4	4.5	22.0	25.9	3.18	2.46	21.42	0.83	2.63	2.03
2004	9.8	9.6	6.0	0.2	3.8	22.5	26.5	3.18	2.46	22.65	0.86	2.72	2.11
2005	15.3	14.3	5.9	1.0	9.4	21.3	25.0	3.18	2.46	15.66	0.63	1.99	1.54
2006	12.1	11.3	5.9	0.8	6.2	24.7	29.1	3.18	2.46	22.92	0.79	2.51	1.94
2007	4.3	4.3	5.9	0.0	-1.6	23.7	27.9	3.18	2.46	29.51	1.06	3.36	2.60
2008	8.8	8.8	6.0	0.0	2.8	24.0	28.3	3.18	2.46	25.49	0.90	2.87	2.22
Median:	**10.6**	**10.2**	**5.9**	**0.2**	**4.6**	**22.5**	**26.5**	**3.18**	**2.46**	**22.31**	**0.82**	**2.62**	**2.03**
Max:	**26.0**	**22.1**	**6.0**	**4.0**	**20.1**	**24.7**	**29.1**	**3.2**	**2.5**	**29.5**	**1.1**	**3.4**	**2.6**
Min:	**4.3**	**4.3**	**5.9**	**0.0**	**-1.7**	**20.4**	**24.0**	**3.2**	**2.5**	**3.9**	**0.2**	**0.5**	**0.4**

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Table 5.3. Comparison of growth stage coefficients and dates for the three plantings of dry beans presented in Goldhamer and Snyder (1989) and corresponding exponential model output (median EC_{SWb-2}) at L = 0.15, 0.20, and 0.25 with EC_i = 0.7 and 1.0 dS/m.

April 1st Planting Date

Growth Stage	Crop Coefficient (Kc)	Dates
Initial Growth	0.14	April 1 to 30
Rapid Growth	0.14 to 0.15	April 30 to May 25
Mid-Season	1.15	May 25 to June 29
Late-Season	1.15 to 0.30	June 29 to July 31
		121 Days Total

Median EC_{swb-2}

Crows Landing & Patterson	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.4	0.98	0.69
EC_i =1.0 dS/m	2	1.4	0.99
Maze	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.36	0.95	0.67
EC_i =1.0 dS/m	1.94	1.35	0.96

May 1st Planting Date

Growth Stage	Crop Coefficient (Kc)	Dates
Initial Growth	0.14	May 1 to 18
Rapid Growth	0.14 to 1.12	May 18 to June 8
Mid-Season	1.12	June 8 to July 12
Late-Season	1.12 to 0.35	July 12 to August 15
		106 Days Total

Median EC_{swb-2}

Crows Landing & Patterson	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.41	0.99	0.7
EC_i =1.0 dS/m	2.02	1.41	0.99
Maze	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.37	0.96	0.68
EC_i =1.0 dS/m	1.96	1.37	0.97

June 16th Planting Date

Growth Stage	Crop Coefficient (Kc)	Dates
Initial Growth	0.13	June 16 to July 1
Rapid Growth	0.13 to 1.07	July 1 to July 26
Mid-Season	1.07	July 26 to Sept. 2
Late-Season	1.07 to 0.20	Sept. 2 to Sept. 30
		106 Days Total

Median EC_{swb-2}

Crows Landing & Patterson	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.36	0.95	0.68
EC_i =1.0 dS/m	1.95	1.36	0.96
Maze	L=0.15	L=0.20	L=0.25
EC_i =0.7 dS/m	1.33	0.93	0.66
EC_i =1.0 dS/m	1.9	1.33	0.95

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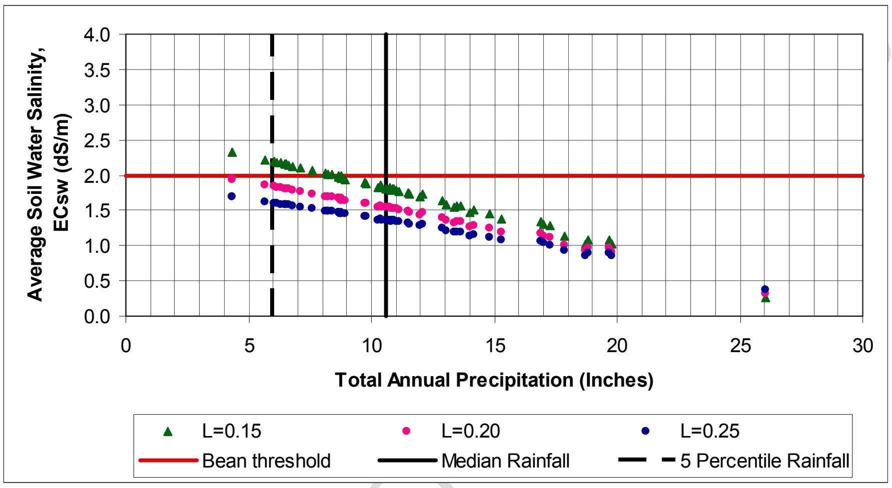
Figure 5.7a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for bean with leaching fractions ranging from 0.15 to 0.25 and irrigation water (EC_i) = 0.7 dS/m using the 40-30-20-10 crop water uptake function with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

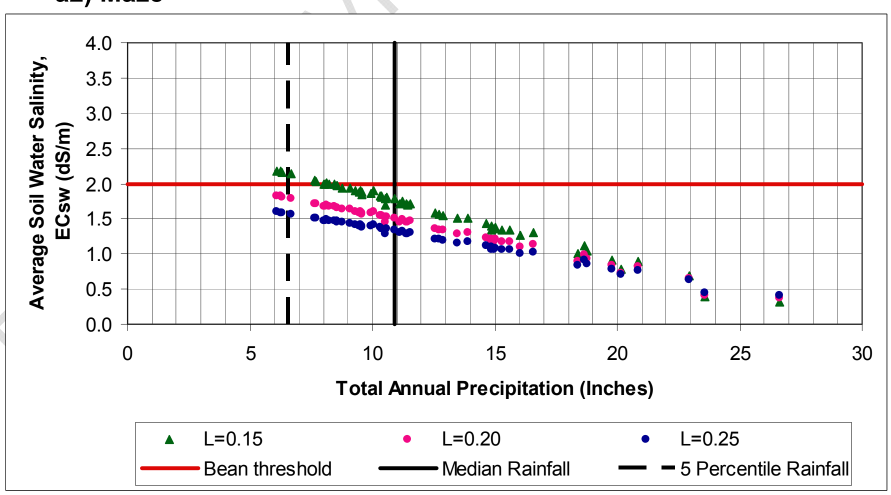
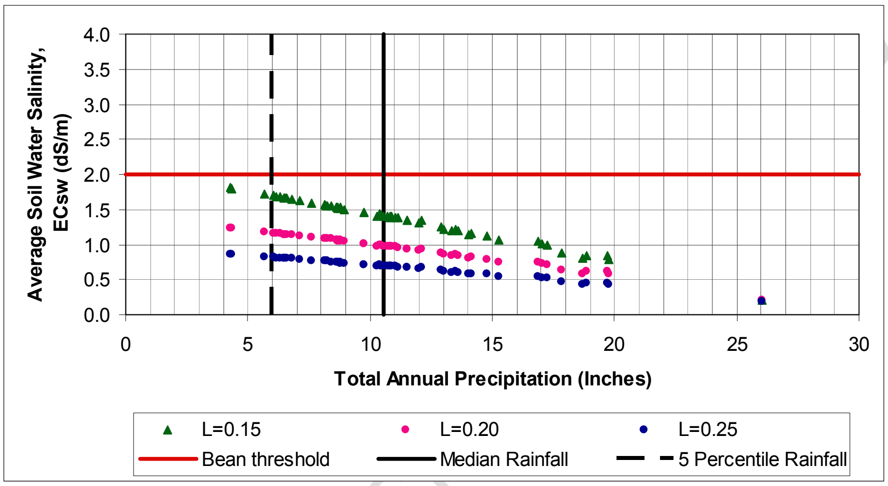
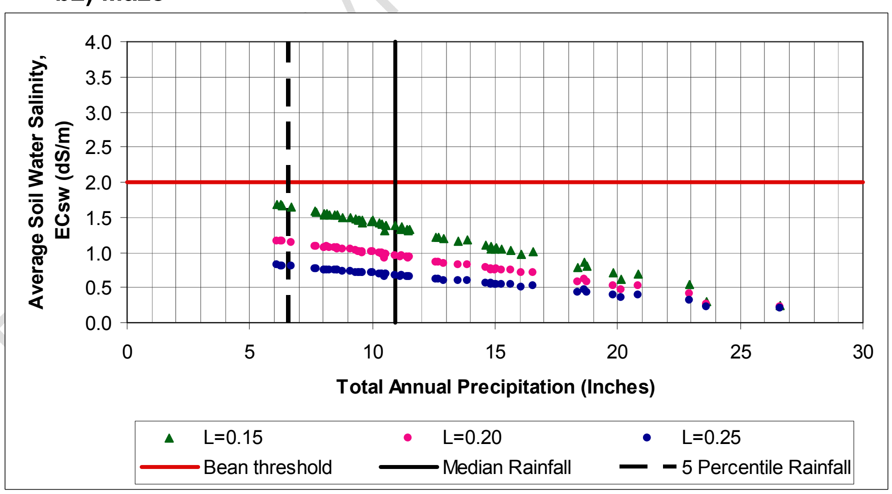


Figure 5.7b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for bean with leaching fractions ranging from 0.15 to 0.25 and irrigation water (EC_i) = 0.7 dS/m using both the exponential crop water uptake function* with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

The results for median and minimum precipitation values are shown in Figure 5.9 with relative bean yield as a function of irrigation water salinity. The dashed lines assume minimum precipitation and the solid lines are for median precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008. For all three sites, the average of the threshold point for L=0.15 (Figure 5.9a) and L=0.20 (Figure 5.9b) with the 40-30-20-10 model with minimum precipitation shows that an EC_i of about 0.65 dS/m could be used without bean yield loss. This result is in close agreement with the analysis of Ayers and Westcott (1976) which assumed no precipitation and found an EC_i of 0.70 dS/m. If median precipitation is considered with the 40-30-20-10 model, EC_i increases to 0.80 dS/m at L=0.15 (Figure 5.9a) and to 0.90 dS/m for an L=0.2 (Figure 5.9 b).

As shown in Figure 5.9a, if minimum precipitation is considered with the exponential model, a leaching fraction of 0.15 yields an EC_i of 0.85 dS/m without bean yield loss. If median precipitation is considered at a leaching fraction of 0.15, EC_i at the bean threshold is 1.0 dS/m. As portrayed in Figure 5.9b, if the exponential model is used, the EC_i could potentially be increased for leaching fractions above 0.15. This results in an EC_i at the bean threshold of 1.4 dS/m for Crows Landing and Patterson and 1.5 dS/m for Maze.

Figure 5.10a presents the relative crop yield for bean with L=0.15 at EC_i = 0.7 and 1.0 dS/m against total annual rainfall using both the 40-30-20-10 and exponential crop water uptake models. This is useful for visualizing how the relative yield is distributed around the 5th percentile and median values of annual precipitation. As shown in Figure 5.10a, for the 40-30-20-10 model, at an EC_i of 0.7 dS/m, yield losses would only occur if rainfall was below 8.5 inches. As salinity increases to an EC_i of 1.0 dS/m, yield losses occur even if the rainfall was above the median value. For the exponential model, at an EC_i of 0.7 dS/m, results indicate that no reduction in bean yield would occur regardless of precipitation (Figure 5.10b). A yield reduction of about 5% would occur if precipitation dropped below the median value for an EC_i = 1.0 dS/m (Figure 5.10 b).

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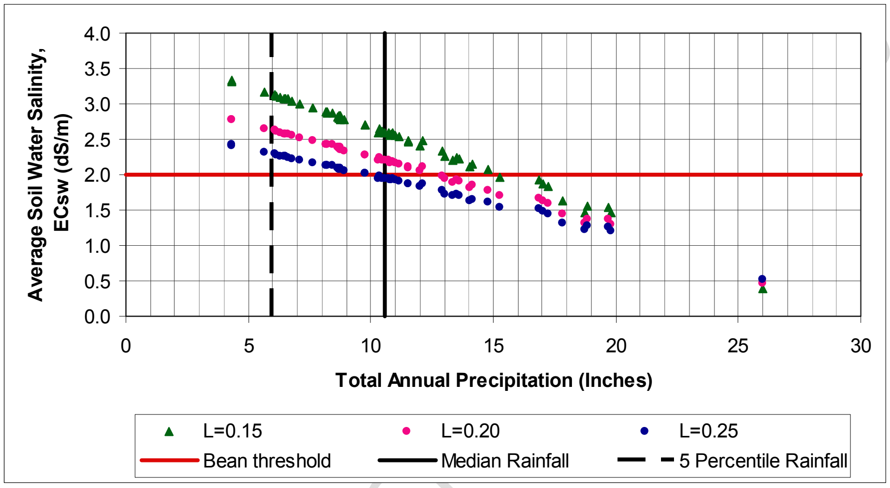
Figure 5.8a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for bean with leaching fractions ranging from 0.15 to 0.25 and irrigation water (EC_i) = 1.0 dS/m using the 40-30-20-10 crop water uptake function with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

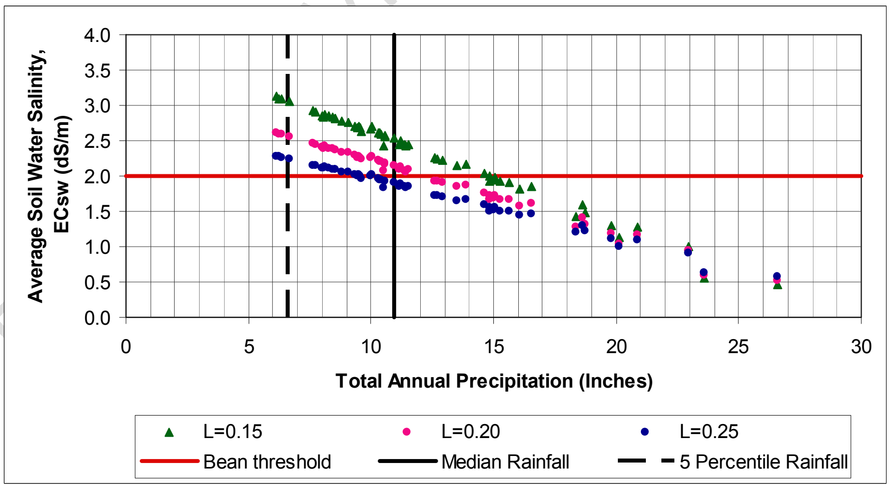
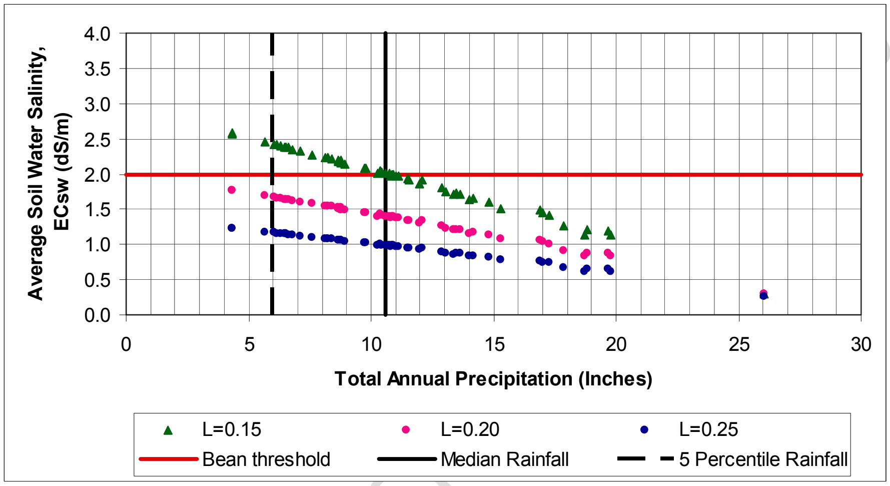
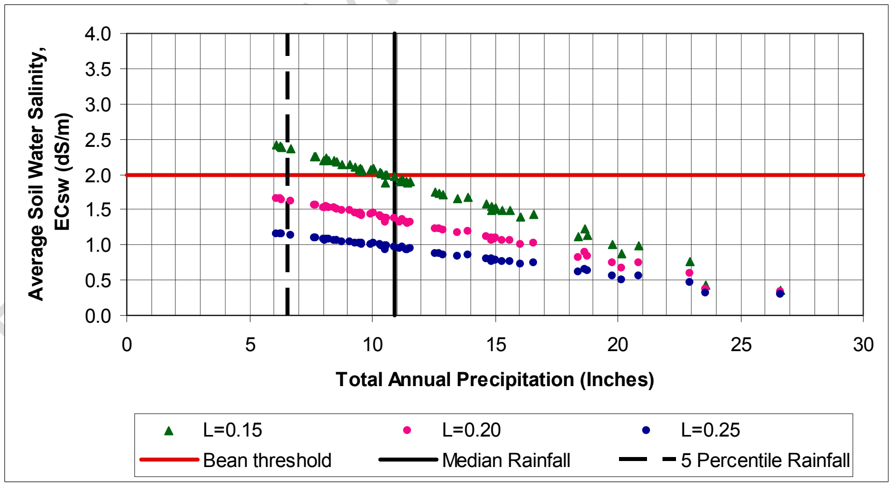


Figure 5.8b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for bean with leaching fractions ranging from 0.15 to 0.25 and irrigation water (EC_i) = 1.0 dS/m using the exponential crop water uptake function* with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



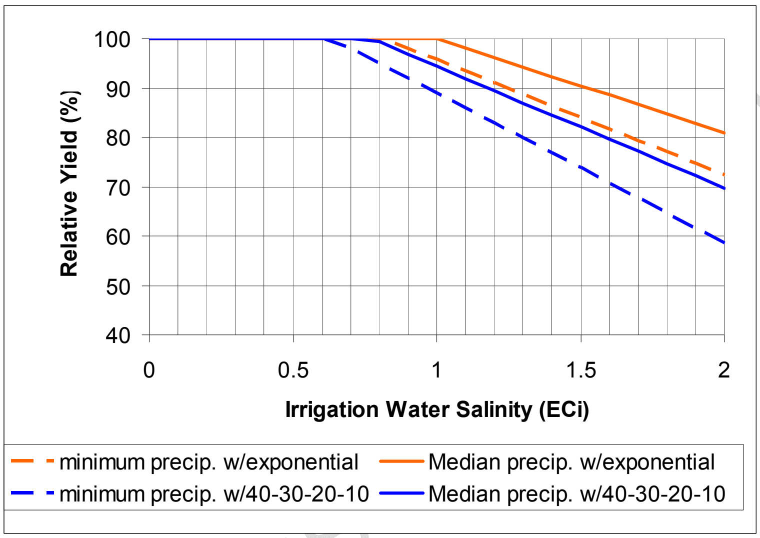
b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

Figure 5.9a. Relative bean yield (percent) as a function of irrigation water salinity (EC_i) with L = 0.15 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

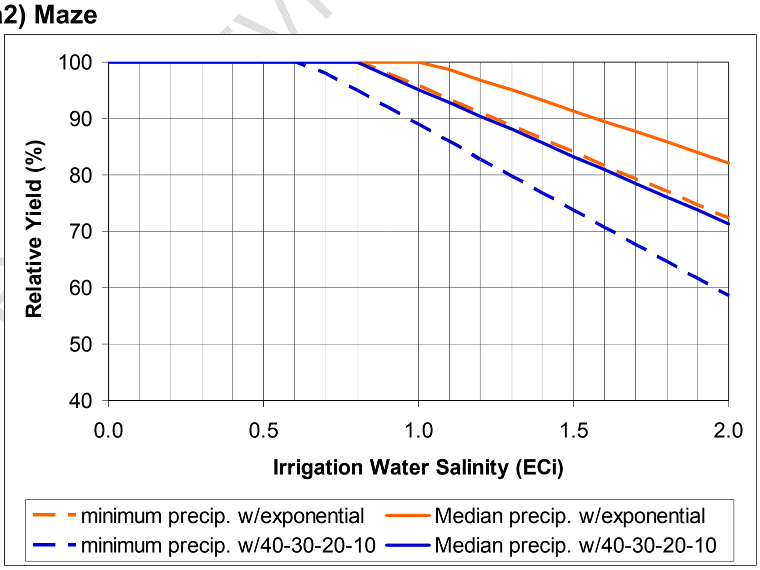
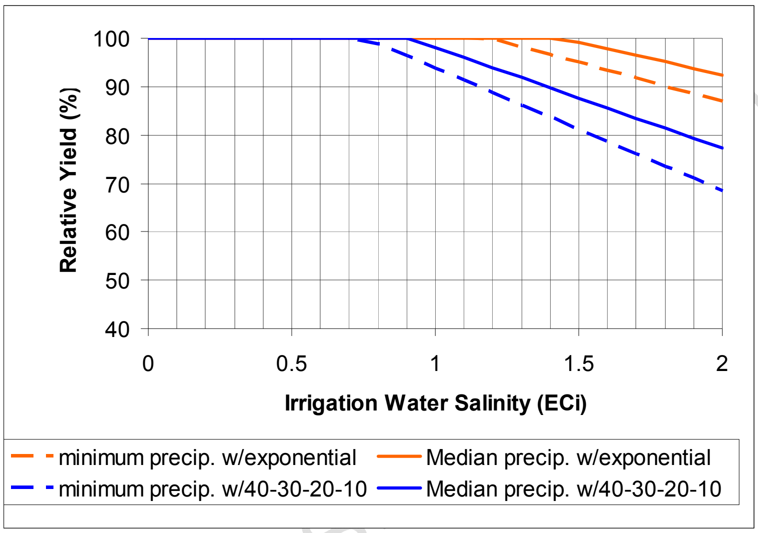


Figure 5.9b. Relative bean yield (percent) as a function of irrigation water salinity (EC_i) with L = 0.20 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze

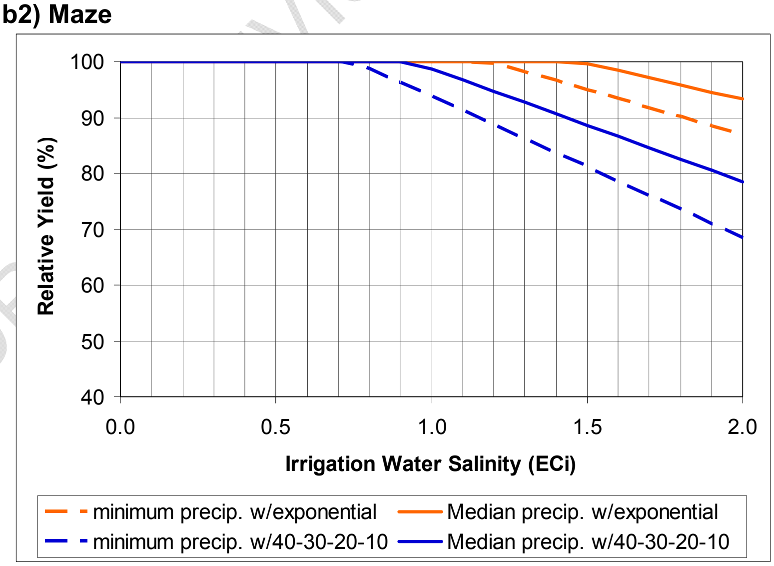
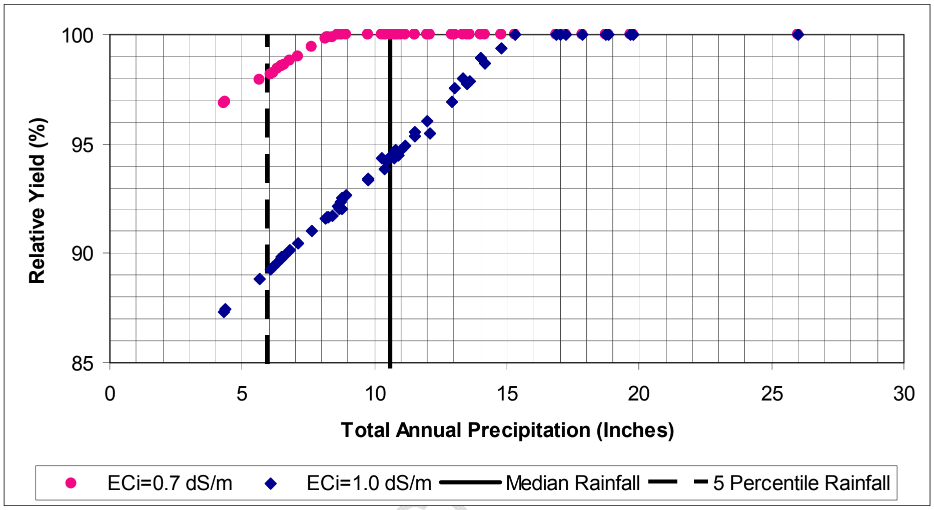


Figure 5.10a. Relative crop yield (%) for bean with L = 0.15 at EC_i = 0.7 and 1.0 dS/m vs. total annual rainfall using the 40-30-20-10 crop water uptake function (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

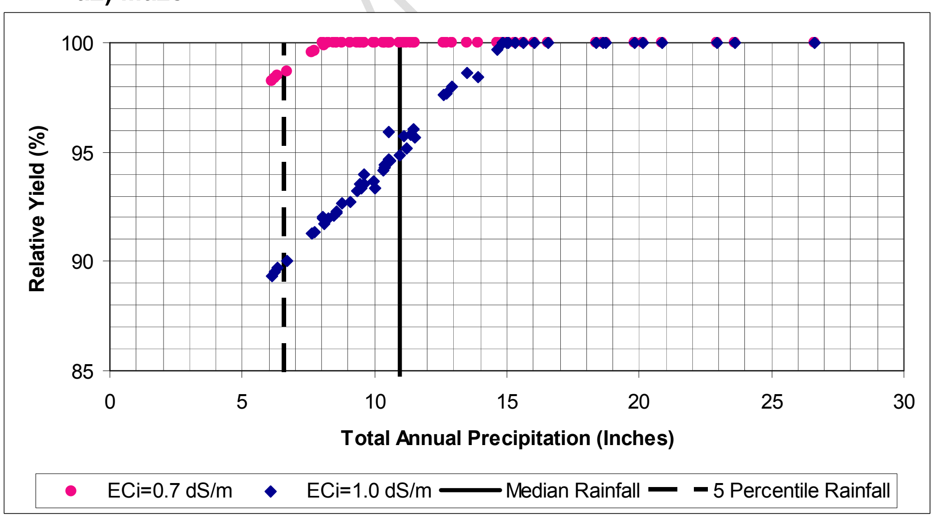
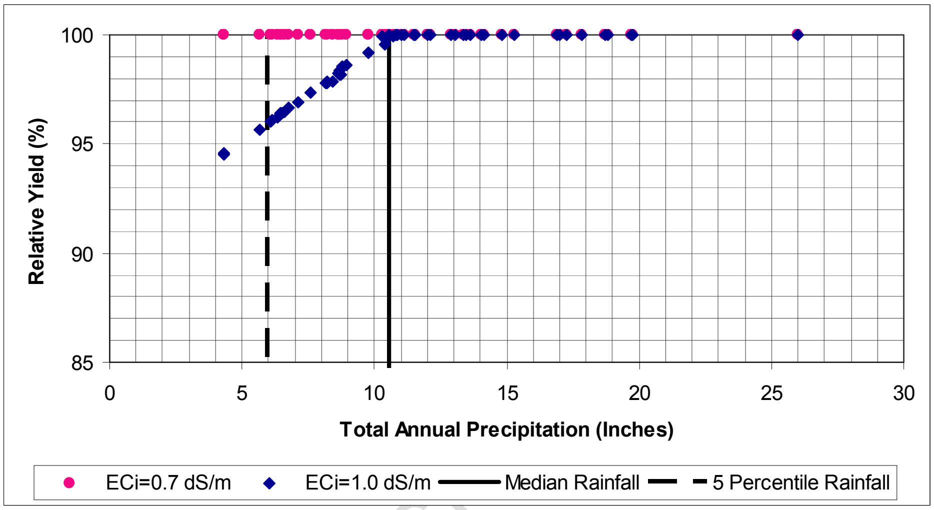
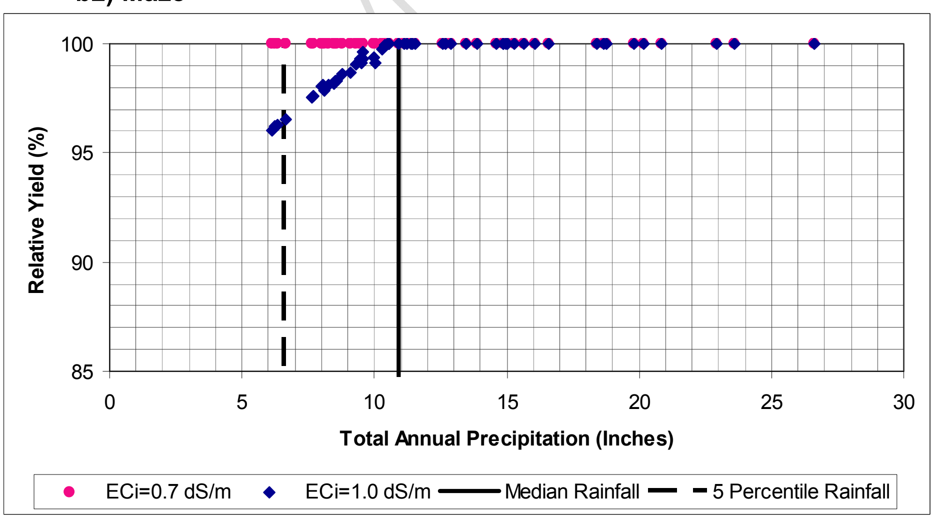


Figure 5.10. Relative crop yield (%) for bean with L = 0.15 at EC_i = 0.7 and 1.0 dS/m vs. total annual rainfall using the exponential crop water uptake function* (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

5.2.2. Alfalfa

Alfalfa is a moderately salt sensitive perennial crop that was also modeled for the LSJR Irrigation Use Area as discussed in Section 3.1.2 of this Report. Table 5.4 presents an example of calculated irrigation amounts and soil water salinity values for 57 water years if alfalfa goes through seven cutting cycles at Crows Landing and Patterson. Values are presented for both water uptake distributions (the 40-30-20-10 uptake and exponential uptake) with and without precipitation. The example includes model input variables of EC_i = 1.0 dS/m and L=0.10. The input values for precipitation including total, growing season and non-growing season precipitation, off season evaporation, and crop evapotranspiration for the 57 water years are also given in Table 5.4. The model was run over a range of EC_i values from 0.5 to 2.0 dS/m, with leaching fractions of 0.07, 0.10, 0.15 and 0.20. In Table 5.4, the total precipitation is taken as effective rainfall and ET_c is calculated using the crop coefficients shown in Figure 5.4.

As previously shown in this Report (see Table 2.2), alfalfa is classified as a moderately sensitive crop to salinity. From Figure 3.4, moderately sensitive crops predominantly occupy areas with clays and clay loam soils. Therefore, it is reasonable to state that alfalfa is frequently grown on clay soils which have a low infiltration rates. In addition, alfalfa has a high water requirement with an annual evapotranspiration of about 53 inches (see Table 5.4). Thus, it can be difficult to meet the high demand for evapotranspiration plus some additional water for leaching. To investigate this scenario, leaching fractions of 0.07 and 0.10 were modeled in addition to leaching fractions of 0.15 and 0.20. Hoffman (2010) cited these same reasons for using these leaching fractions for the South Delta with alfalfa. Staff opted to duplicate Hoffman (2010) methodology for alfalfa (with leaching fractions 0.07, 0.1, 0.15 and 0.20) based on similar site specific soil and hydrological conditions as explained above.

Similar to Figures 5.7 and 5.8 for bean, Figures 5.11 and 5.12 show the impact of annual rainfall on soil salinity. Figures 5.11a and b show how the response of soil salinity to different leaching fractions (0.07 to 0.20) as a function of annual rainfall for both models assuming an EC_i of 1.0 dS/m. Soil salinity remains below the threshold for alfalfa for both models except at a leaching fraction of 0.07 when annual rainfall is below the median (Figures 5.11a and b).

Figures 5.12a and b are similar to Figures 5.11a and b except the EC_i is increased to 1.2 dS/m for Figure 5.12a and b. Both models predict alfalfa yield loss at the lowest leaching fraction (0.07) for several years except for years when precipitation was above the median value. Some yield loss is likely as predicted by the model at leaching fraction of 0.10 for the drier years.

Similar to Figures 5.9 and 5.10 for bean, Figures 5.13 and 5.14 show the relative yield of alfalfa as a function of irrigation water salinity (EC_i) and total annual precipitation (P_T), respectively. Note that the yield impact curve calculated using the 40-30-20-10 and exponential water uptake functions at all sites are nearly

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identical at the 0.10 leaching fraction (Figure 5.13a). In general, the two water uptake functions generate similar results at lower leaching fractions, and gradually divergent results as the leaching fraction increases (Figure 5.13b). Model results shown in Figure 5.13 for median precipitation indicate that at a leaching fraction of 0.10, both models predict a loss in alfalfa yield beginning at an EC_i of 1.2 dS/m at all sites. However, if the leaching fraction is increased to 0.15 (Figure 5.13b), no yield loss occurs until EC_i exceeds 2 dS/m for the exponential model.

Based on these model predictions and results presented in Figure 5.14, no alfalfa yield loss would occur if the leaching fraction is 0.10 or higher regardless of annual rainfall amounts for an EC_i of 1.0 dS/m (Figure 5.14a). If an EC_i of 1.2 dS/m is assumed with a leaching fraction of 0.10 (Figures 5.14b), no yield loss would occur at all sites if rainfall was above the median value. Predicted yield for the driest year would be about 98% using the 40-30-20-10 model and about 99% using the exponential model at all sites (Figures 5.14b).

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Table 5.4. Output from the steady state models both 1) without precipitation and 2) including precipitation (all equations defined in Table 5.2) with precipitation data from NCDC station no. 6168, Newman C and Alfalfa evapotranspiration coefficients from Goldhamer and Synder (1989).

Input Variables

EC_i = 1.0 **L = 0.10**

ET_C = crop evapotranspiration
E_S = off-season surface evaporation
P_{GS} = precipitation during growing season
P_T = total annual (infiltrating) precipitation

Model Output

1) Without precipitation
L= Leaching fraction
EC_i = Irrigation water salinity
I_1 = Irrigation requirement
EC_{SWa-1} = Average soil water EC

2) With precipitation
I_2 = Irrigation required for L_2
EC_{AW-2} = salinity of applied water
EC_{SWa-2} = Soil water salinity (40-30-20-10)
EC_{SWb-2} = Soil water salinity (Exponential)

Water Year	P_T	P_{NG}	E_S	P_{GS}	P_{EFF}	ET_C	I_1	EC_{SWa-1}	EC_{SWb-1}	I_2	EC_{AW-2}	EC_{SWa-2}	EC_{SWb-2}
	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(dS/m)	(dS/m)	(in.)	(dS/m)	(dS/m)	(dS/m)
1952	16.9	0.0	0.0	16.9	16.9	55.6	61.8	4.11	3.79	44.94	0.73	2.98	2.75
1953	6.8	0.0	0.0	6.8	6.8	53.1	59.0	4.11	3.79	52.22	0.89	3.63	3.35
1954	6.5	0.0	0.0	6.5	6.5	52.8	58.6	4.11	3.79	52.11	0.89	3.65	3.37
1955	9.8	0.0	0.0	9.8	9.8	54.1	60.1	4.11	3.79	50.36	0.84	3.44	3.17
1956	10.9	0.0	0.0	10.9	10.9	55.0	61.1	4.11	3.79	50.17	0.82	3.37	3.11
1957	8.7	0.0	0.0	8.7	8.7	54.8	60.9	4.11	3.79	52.20	0.86	3.52	3.25
1958	19.7	0.0	0.0	19.7	19.7	54.2	60.3	4.11	3.79	40.58	0.67	2.76	2.55
1959	10.8	0.0	0.0	10.8	10.8	54.4	60.5	4.11	3.79	49.61	0.82	3.37	3.11
1960	6.6	0.0	0.0	6.6	6.6	53.3	59.3	4.11	3.79	52.64	0.89	3.65	3.36
1961	7.1	0.0	0.0	7.1	7.1	52.2	58.0	4.11	3.79	50.85	0.88	3.60	3.32
1962	12.0	0.0	0.0	12.0	12.0	51.7	57.5	4.11	3.79	45.47	0.79	3.25	3.00
1963	14.0	0.0	0.0	14.0	14.0	49.4	54.9	4.11	3.79	40.91	0.74	3.06	2.82
1964	6.5	0.0	0.0	6.5	6.5	50.9	56.6	4.11	3.79	50.12	0.89	3.64	3.35
1965	10.3	0.0	0.0	10.3	10.3	49.7	55.2	4.11	3.79	44.94	0.81	3.34	3.08
1966	10.6	0.0	0.0	10.6	10.6	52.9	58.7	4.11	3.79	48.17	0.82	3.37	3.11
1967	13.5	0.0	0.0	13.5	13.5	51.0	56.7	4.11	3.79	43.20	0.76	3.13	2.89
1968	6.1	0.0	0.0	6.1	6.1	52.4	58.3	4.11	3.79	52.22	0.90	3.68	3.39
1969	18.8	0.0	0.0	18.8	18.8	51.0	56.7	4.11	3.79	37.88	0.67	2.74	2.53
1970	8.6	0.0	0.0	8.6	8.6	52.9	58.8	4.11	3.79	50.12	0.85	3.50	3.23
1971	13.4	0.0	0.0	13.4	13.4	50.5	56.1	4.11	3.79	42.72	0.76	3.13	2.88
1972	6.2	0.0	0.0	6.2	6.2	52.6	58.5	4.11	3.79	52.31	0.89	3.67	3.39
1973	17.0	0.0	0.0	17.0	17.0	51.2	56.9	4.11	3.79	39.91	0.70	2.88	2.66
1974	11.5	0.0	0.0	11.5	11.5	52.5	58.3	4.11	3.79	46.82	0.80	3.29	3.04
1975	10.7	0.0	0.0	10.7	10.7	53.0	58.9	4.11	3.79	48.15	0.82	3.36	3.10
1976	4.3	0.0	0.0	4.3	4.3	53.7	59.6	4.11	3.79	55.33	0.93	3.81	3.51
1977	5.7	0.0	0.0	5.7	5.7	53.9	59.9	4.11	3.79	54.20	0.91	3.72	3.43
1978	17.3	0.0	0.0	17.3	17.3	53.5	59.4	4.11	3.79	42.17	0.71	2.91	2.69
1979	10.4	0.0	0.0	10.4	10.4	54.7	60.8	4.11	3.79	50.38	0.83	3.40	3.14
1980	13.0	0.0	0.0	13.0	13.0	51.8	57.5	4.11	3.79	44.48	0.77	3.18	2.93
1981	8.2	0.0	0.0	8.2	8.2	54.8	60.8	4.11	3.79	52.61	0.86	3.55	3.27
1982	14.8	0.0	0.0	14.8	14.8	51.6	57.3	4.11	3.79	42.50	0.74	3.04	2.81
1983	19.8	0.0	0.0	19.8	19.8	50.3	55.9	4.11	3.79	36.12	0.65	2.65	2.45
1984	8.4	0.0	0.0	8.4	8.4	55.6	61.8	4.11	3.79	53.35	0.86	3.55	3.27
1985	8.2	0.0	0.0	8.2	8.2	53.5	59.5	4.11	3.79	51.25	0.86	3.54	3.26
1986	12.9	0.0	0.0	12.9	12.9	52.9	58.7	4.11	3.79	45.83	0.78	3.20	2.96
1987	6.3	0.0	0.0	6.3	6.3	54.9	61.0	4.11	3.79	54.73	0.90	3.68	3.40
1988	11.0	-1.1	0.0	12.1	11.0	55.4	61.5	4.11	3.79	50.51	0.82	3.37	3.11
1989	8.2	0.0	0.0	8.2	8.2	54.1	60.1	4.11	3.79	51.91	0.86	3.55	3.27
1990	6.5	0.0	0.0	6.5	6.5	53.8	59.8	4.11	3.79	53.31	0.89	3.66	3.38
1991	8.8	0.0	0.0	8.8	8.8	51.2	56.8	4.11	3.79	48.07	0.85	3.47	3.20
1992	10.8	0.0	0.0	10.8	10.8	52.9	58.8	4.11	3.79	48.01	0.82	3.35	3.09
1993	17.8	0.0	0.0	17.8	17.8	50.5	56.1	4.11	3.79	38.28	0.68	2.80	2.58
1994	8.9	0.0	0.0	8.9	8.9	51.8	57.5	4.11	3.79	48.57	0.84	3.47	3.20
1995	18.7	0.0	0.0	18.7	18.7	48.4	53.7	4.11	3.79	35.01	0.65	2.68	2.47
1996	14.2	0.0	0.0	14.2	14.2	51.4	57.2	4.11	3.79	43.01	0.75	3.09	2.85
1997	13.6	0.0	0.0	13.6	13.6	52.2	58.0	4.11	3.79	44.42	0.77	3.14	2.90
1998	26.0	0.0	0.0	26.0	26.0	48.2	53.6	4.11	3.79	27.56	0.51	2.11	1.95
1999	8.7	0.0	0.0	8.7	8.7	50.9	56.6	4.11	3.79	47.87	0.85	3.47	3.20
2000	11.5	0.0	0.0	11.5	11.5	52.7	58.5	4.11	3.79	47.01	0.80	3.30	3.04
2001	11.1	0.0	0.0	11.1	11.1	53.6	59.5	4.11	3.79	48.36	0.81	3.34	3.08
2002	7.6	0.0	0.0	7.6	7.6	53.2	59.1	4.11	3.79	51.50	0.87	3.58	3.30
2003	10.5	0.0	0.0	10.5	10.5	52.1	57.9	4.11	3.79	47.45	0.82	3.36	3.10
2004	9.8	0.0	0.0	9.8	9.8	54.2	60.3	4.11	3.79	50.50	0.84	3.44	3.17
2005	15.3	0.0	0.0	15.3	15.3	51.7	57.5	4.11	3.79	42.17	0.73	3.01	2.78
2006	12.1	0.0	0.0	12.1	12.1	56.2	62.5	4.11	3.79	50.38	0.81	3.31	3.05
2007	4.3	0.0	0.0	4.3	4.3	57.7	64.1	4.11	3.79	59.76	0.93	3.83	3.53
2008	8.8	0.0	0.0	8.8	8.8	58.1	64.6	4.11	3.79	55.82	0.86	3.55	3.27
Median:	**10.6**	**0.0**	**0.0**	**10.6**	**10.6**	**52.9**	**58.7**	4.11	**3.79**	**48.36**	**0.82**	3.37	3.11
Max:	26.0	0.0	0.0	26.0	26.0	58.1	64.6	4.11	3.79	59.76	0.93	3.83	3.53
Min:	4.3	-1.1	0.0	4.3	4.3	48.2	53.6	4.11	3.79	27.56	0.51	2.11	1.95

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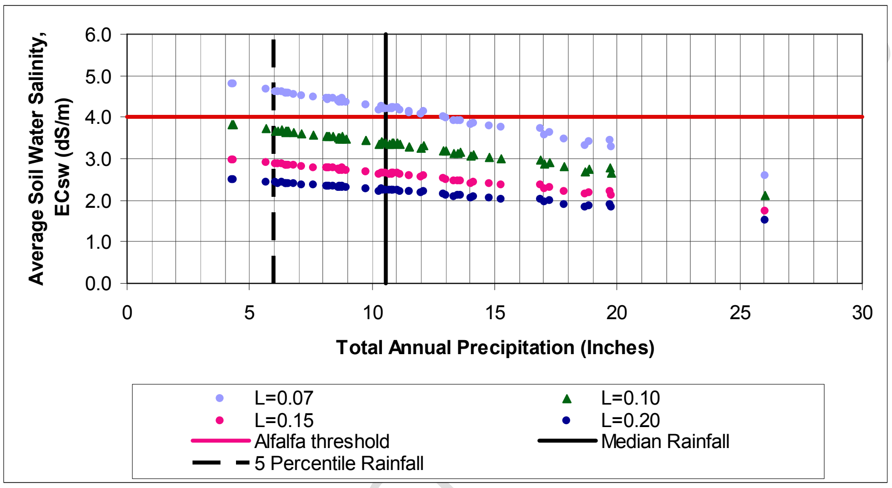
Figure 5.11a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (EC_i) = 1.0 dS/m using the 40-30-20-10 crop water uptake function from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

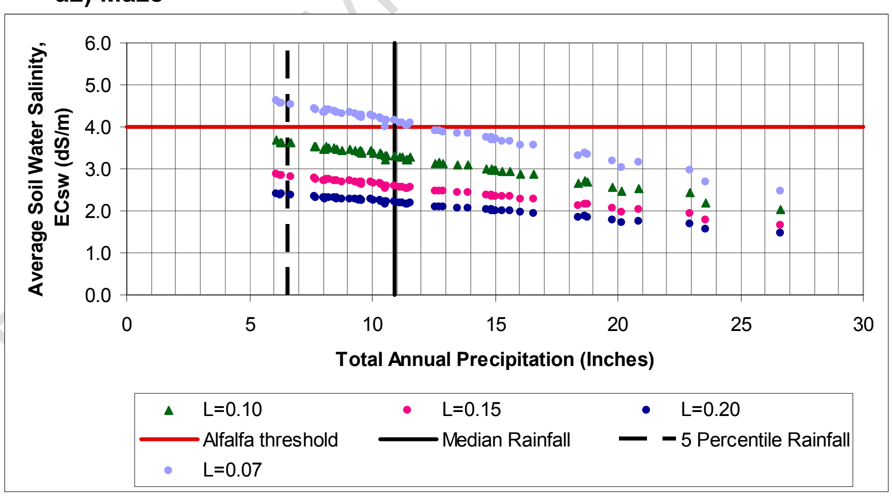
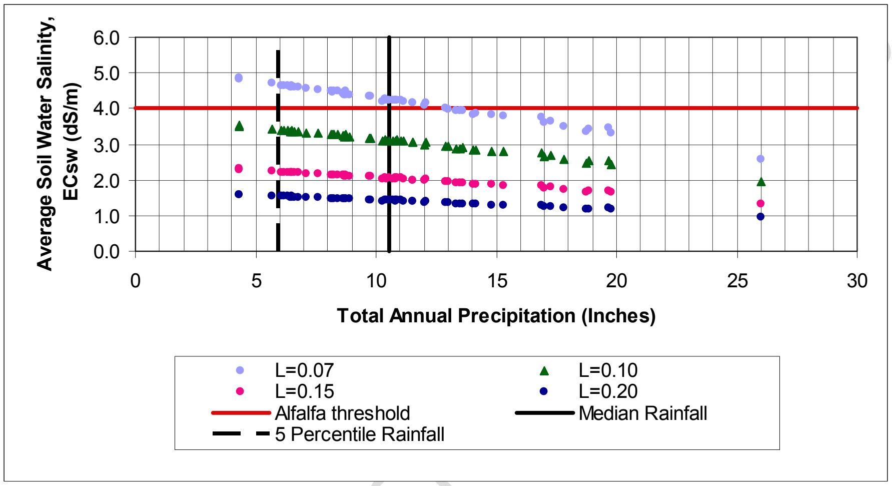
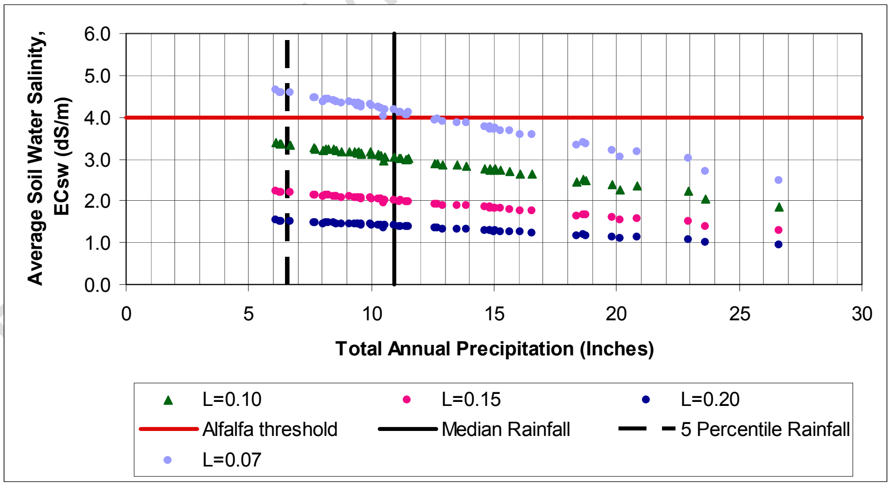


Figure 5.11b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (EC_i) = 1.0 dS/m using the exponential crop water uptake function* from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



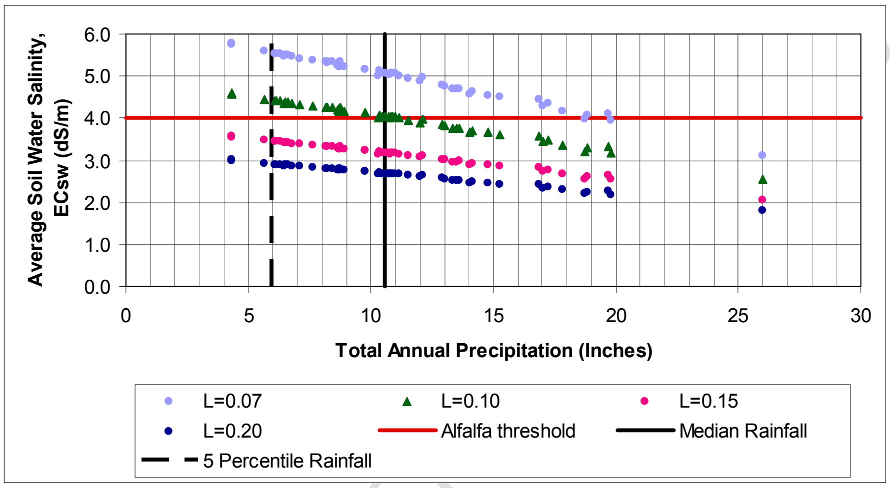
b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

Figure 5.12a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (EC_i) = 1.2 dS/m using the 40-30-20-10 crop water uptake function from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

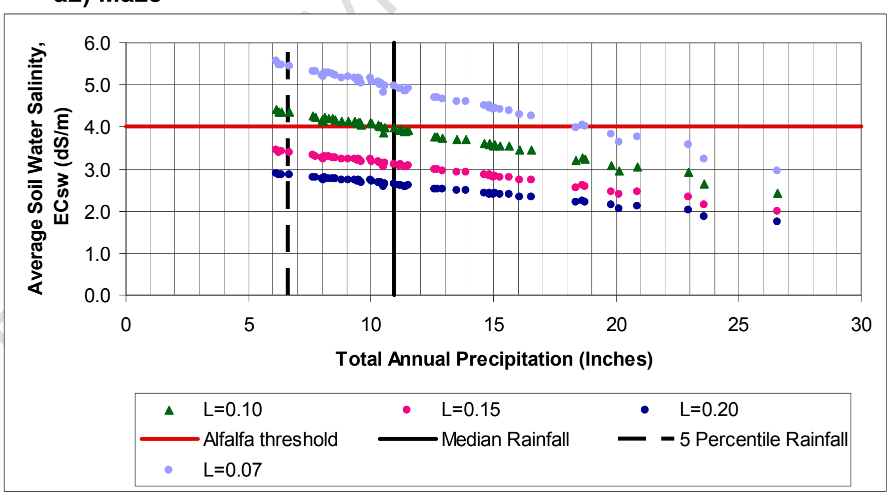
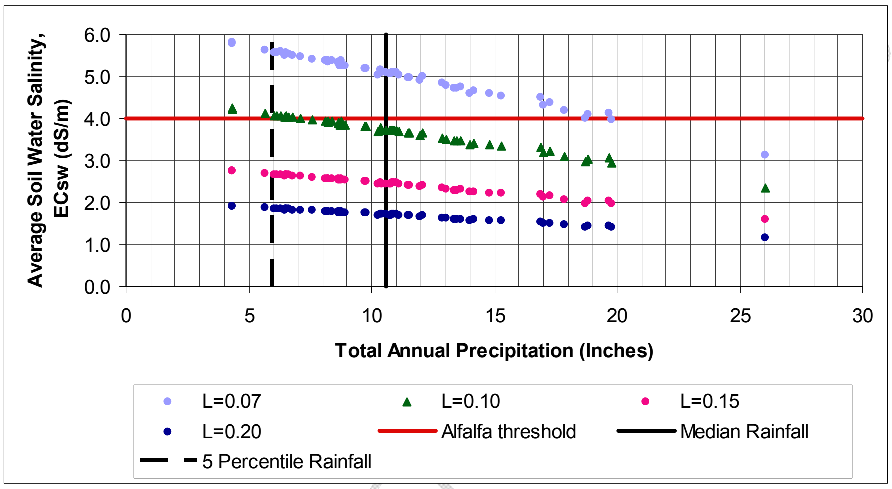
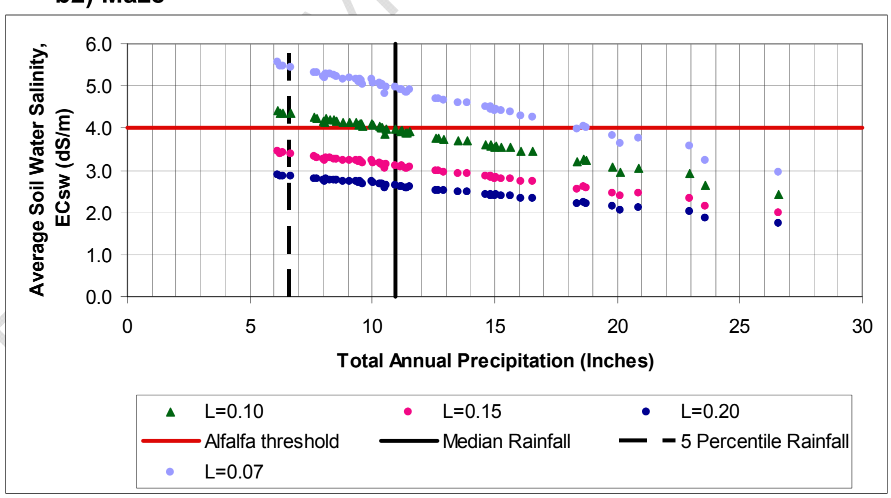


Figure 5.12b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (EC_i) = 1.2 dS/m using the exponential crop water uptake function* from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



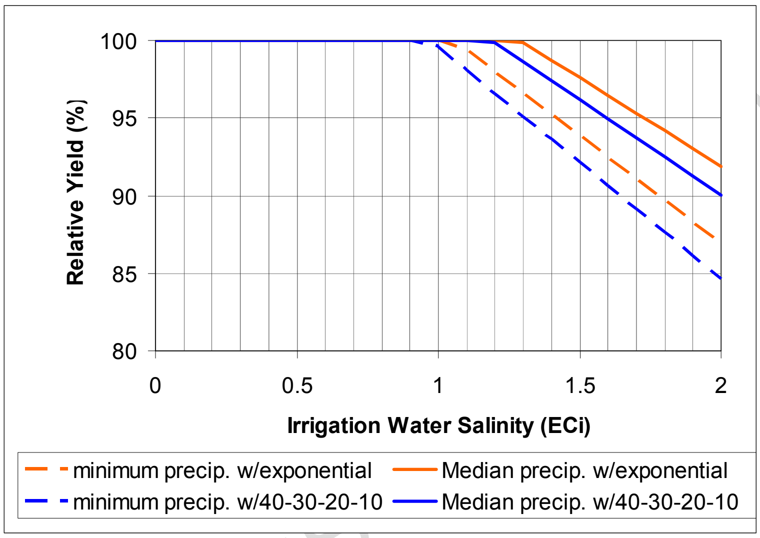
b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

Figure 5.13a. Relative alfalfa yield (percent) as a function of irrigation water salinity (EC_i) with L=0.10 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

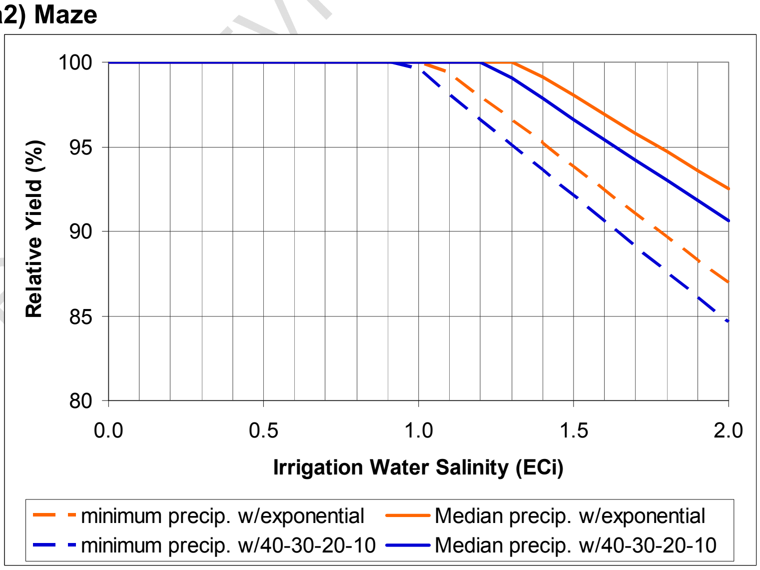
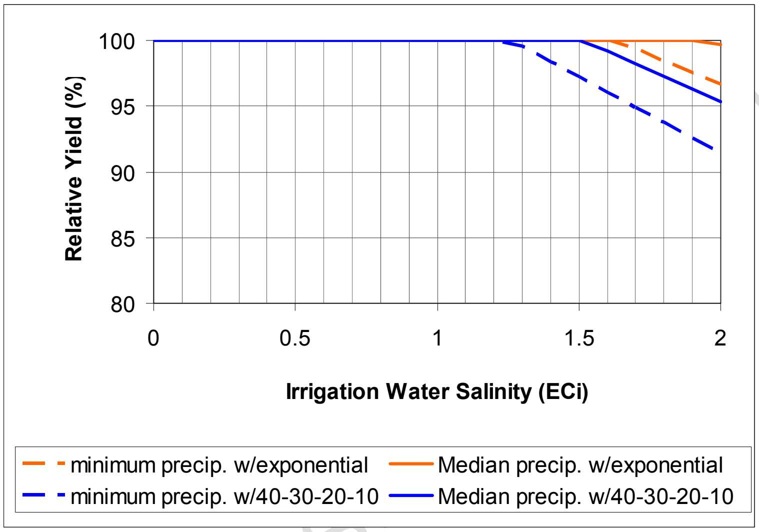


Figure 5.13b. Relative alfalfa yield (percent) as a function of irrigation water salinity (EC_i) with L=0.15 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze

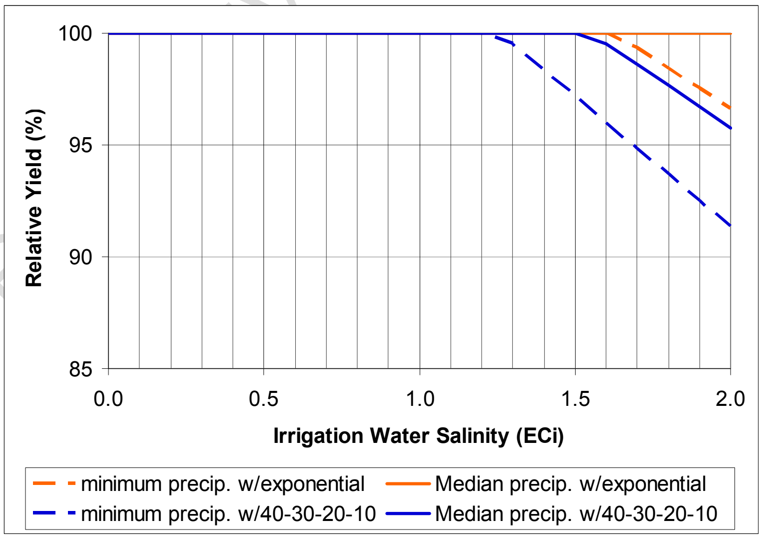
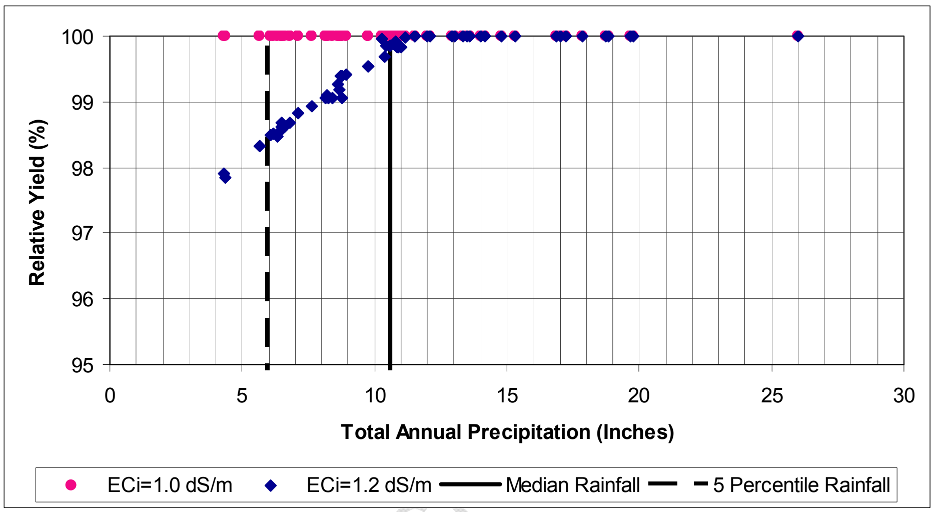


Figure 5.14a. Relative crop yield (%) for alfalfa with L = 0.10 at EC_i = 1.0 and 1.2 dS/m vs. total annual rainfall using the 40-30-20-10 crop water uptake function (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

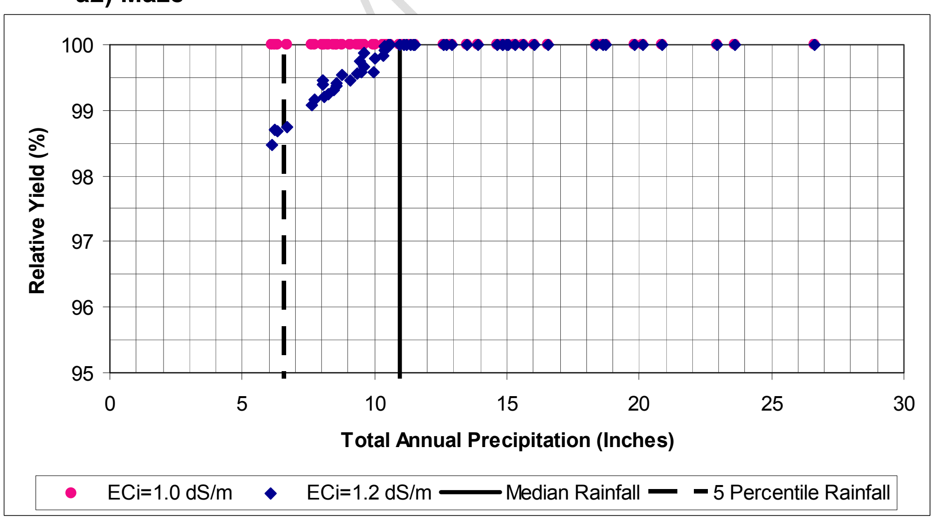
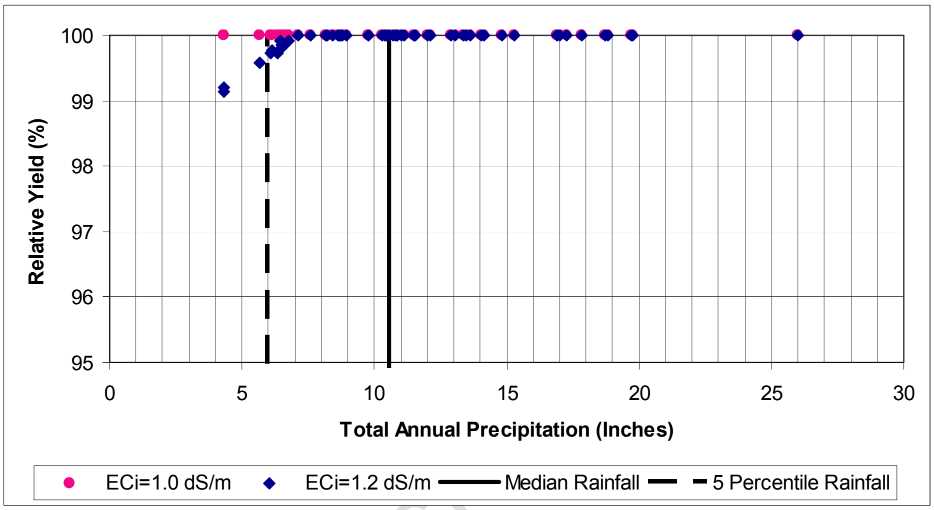
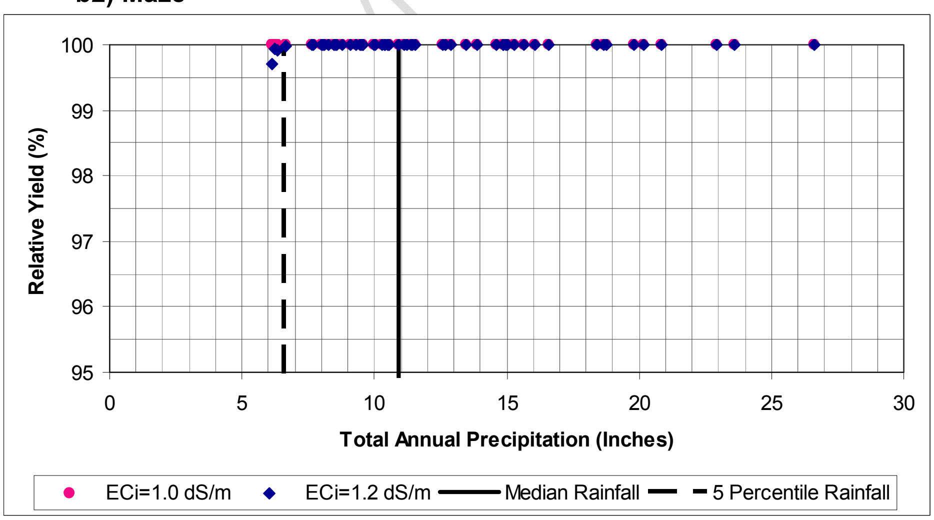


Figure 5.14b. Relative crop yield (%) for alfalfa with L = 0.10 at EC_i = 1.0 and 1.2 dS/m vs. total annual rainfall using the exponential crop water uptake function* (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

5.2.3. Almond

Almond is a salt sensitive perennial crop that was also modeled for the LSJR Irrigation Use Area as discussed in Section 3.1.2 of this Report. Figure 5.5 shows the crop coefficients that were used to calculate ET_c as reported by Goldhamer and Snyder (1989). The non-growing season for almond was considered as November 10 to February 15 as reported by Goldhamer and Snyder (1989). Table 5.5 presents an example of calculated irrigation amounts and soil water salinity values for 57 water years at Maze for almond leaf out (See Figure 5.5) on 15 February as reported by Goldhamer and Snyder (1989). Values are presented for both water uptake distributions (the 40-30-20-10 uptake and exponential uptake) with and without precipitation. The example includes model input variables of EC_i = 1.0 dS/m and L= 0.15. The input values for precipitation including total, growing season and non-growing season precipitation, off season evaporation, and crop evapotranspiration for the 57 water years are also given in Table 5.5. The model was run over a range of EC_i values from 0.5 to 2.0 dS/m, with 0.10, 0.15 and 0.20.

In DWR crop surveys, almond are classified in the category of trees and vines. In the LSJR Irrigation Use Area, trees and vines are predominantly irrigated by drip/micro-sprinklers (11% of total of all irrigated crop area) as shown in Table 3.7. Similarly, in the South Delta, trees and vines are predominantly irrigated by drip/micro-sprinklers (48%). Thus, Staff followed the approach of Hoffman (2010) for choice of the three leaching fractions for almond (0.10, 0.15 and 0.20) with the assumption that similar almond irrigation methods exist between the South Delta and the LSJR Irrigation Use Area.

Figures 5.15a and b, show the variation of average soil salinity with total annual precipitation for an applied water salinity (EC_i) of 0.70 dS/m at all sites. Both models show that soil salinity remains below the almond threshold value with no predicted decline in yield for all the leaching fractions regardless of the precipitation, even at the lowest rainfall amount at the 5^{th} percentile for all sites.

Figure 5.16 shows the variation of soil salinity with rainfall if the EC_i increases to 1.0 dS/m. For both Crows Landing and Patterson (Figure 5.16a1) at a leaching fraction of 0.10 dS/m with the 40-30-20-10 model, soil salinity remains below the almond threshold up to an annual rainfall about 13.5 inches, below which yield declines would occur. For Maze (Figure 5.16a), at a leaching fraction of 0.10 dS/m, soil salinity remains below the almond threshold up to an annual rainfall about 12 inches, below which yield declines would occur. The 40-30-20-10 model shows that all sites at leaching fractions of 0.15 and 0.20 have soil salinity values below the almond threshold with no yield loses predicted even below the 5^{th} percentile rainfall.

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Figure 5.16b shows results for the exponential model for an EC_i of 1.0 dS/m. Almond yield losses at a leaching fraction of 0.10 only occur when total rainfall declines below the median value while no yield loses are predicted at leaching fractions of 0.15 and 0.20 regardless of the rainfall amount at all three sites.

Figure 5.17 shows the variation of almond yield as a function of irrigation water salinity for median and minimum amounts of annual rainfall. At a leaching fraction of 0.10, for Crows Landing and Patterson, both models predict a yield threshold at an EC_i of 0.9 dS/m (Figure 5.17a1) while for Maze, the exponential model predicted a yield threshold at an EC_i of 1.0 dS/m and the 40-30-20-10 model predicted a yield threshold at an EC_i of 0.9 dS/m (Figure 5.17a2).

If the leaching fraction is increased to 0.15 as shown in Figure 5.17b, for Crows Landing and Patterson, the exponential model predicts a yield threshold at an EC_i of 1.4 dS/m while the 40-30-20-10 models predicts a yield threshold at 1.3 dS/m (Figure 5.17b1). For Maze, the exponential model predicted a yield threshold at an EC_i of 1.5 dS/m and 1.1 dS/m for the 40-30-20-10 model (Figure 5.17b2).

Yield losses for almond as a function of annual precipitation for both models are presented in Figure 5.18 with L = 0.10. For example, for both Crows Landing and Patterson, assuming an EC_i of 1.0 dS/m, a yield loss of about 9% is predicted for the driest year by the 40-30-20-10 model (Figure 5.18a1) while for the exponential model, a yield loss of 6% is predicted for the driest year (Figure 5.18b1). Thus, employing the exponential model, an EC_i of 1.0 dS/m would protect almond from yield loss with a leaching fraction of 0.10 provided annual rainfall remained above the median value and yield losses would be about 6% if rainfall dropped to the 5^{th} percentile. An EC_i of 0.7 dS/m would prevent yield loss for both the 40-30-20-10 and exponential models at all sites regardless of the rainfall amount (Figure 5.18a and b).

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Table 5.5. Output from the steady state models both 1) without precipitation and 2) including precipitation (all equations defined in Table 5.2) with precipitation data from NCDC Modesto C Station #5738 and almond evapotranspiration coefficients from Goldhamer and Synder (1989)

Input Variables							Model Output						
	EC_i = 1.0			L= 0.15									
			ET_C = crop evapotranspiration E_S = off-season surface evaporation P_{GS} = precipitation during growing season P_T = total annual (infiltrating) precipitation				**1) Without precipitation** L= Leaching fraction EC_i = Irrigation water salinity I_1 = Irrigation requirement EC_{SWa-1} = Average soil water EC			**2) With precipitation** I_2 = Irrigation required for L_2 EC_{AW-2} = salinity of applied water EC_{SWa-2} = Soil water salinity (40-30-20-10) EC_{SWb-2} = Soil water salinity (Exponential)			
Water Year	P_T	P_{NG}	E_S	P_{GS}	P_{EFF}	ET_C	I_1	EC_{SWa-1}	EC_{SWb-1}	I_2	EC_{AW-2}	EC_{SWa-2}	EC_{SWb-2}
	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(dS/m)	(dS/m)	(in.)	(dS/m)	(dS/m)	(dS/m)
1952	16.1	9.6	2.2	6.5	13.9	40.9	48.1	3.18	2.46	34.3	0.71	2.27	1.75
1953	9.6	6.2	2.2	3.4	7.4	40.0	47.1	3.18	2.46	39.7	0.84	2.68	2.08
1954	7.7	3.3	2.2	4.5	5.5	41.2	48.4	3.18	2.46	42.9	0.89	2.82	2.18
1955	12.9	8.1	2.2	4.8	10.7	41.0	48.2	3.18	2.46	37.5	0.78	2.48	1.92
1956	15.6	11.8	2.2	3.9	13.4	41.8	49.2	3.18	2.46	35.7	0.73	2.31	1.79
1957	8.6	2.6	2.2	6.0	6.3	41.7	49.0	3.18	2.46	42.7	0.87	2.77	2.14
1958	22.9	8.4	2.2	14.6	20.7	42.3	49.7	3.18	2.46	29.0	0.58	1.86	1.44
1959	10.0	4.7	2.2	5.3	7.8	45.3	53.3	3.18	2.46	45.5	0.85	2.72	2.10
1960	6.1	4.6	2.2	1.5	3.9	45.1	53.1	3.18	2.46	49.2	0.93	2.95	2.28
1961	8.5	5.1	2.2	3.4	6.2	43.0	50.6	3.18	2.46	44.3	0.88	2.79	2.16
1962	11.5	8.6	2.2	2.9	9.3	43.5	51.2	3.18	2.46	41.9	0.82	2.60	2.01
1963	12.7	6.3	2.2	6.4	10.5	40.7	47.9	3.18	2.46	37.4	0.78	2.48	1.92
1964	7.6	3.6	2.2	4.1	5.4	41.8	49.2	3.18	2.46	43.8	0.89	2.83	2.19
1965	11.5	5.6	2.2	5.9	9.2	40.7	47.9	3.18	2.46	38.7	0.81	2.57	1.99
1966	9.3	7.7	2.2	1.6	7.1	43.6	51.3	3.18	2.46	44.2	0.86	2.74	2.12
1967	14.6	7.8	2.2	6.9	12.4	41.7	49.1	3.18	2.46	36.7	0.75	2.38	1.84
1968	8.6	3.9	2.2	4.6	6.4	42.4	49.8	3.18	2.46	43.5	0.87	2.78	2.15
1969	18.8	10.5	2.2	8.2	16.5	41.9	49.3	3.18	2.46	32.7	0.66	2.11	1.64
1970	10.4	6.0	2.2	4.4	8.2	42.6	50.1	3.18	2.46	41.9	0.84	2.66	2.06
1971	12.6	6.8	2.2	5.8	10.4	40.7	47.9	3.18	2.46	37.5	0.78	2.49	1.93
1972	6.7	5.5	2.2	1.2	4.5	43.1	50.7	3.18	2.46	46.2	0.91	2.90	2.24
1973	16.6	9.6	2.2	6.9	14.3	42.0	49.5	3.18	2.46	35.1	0.71	2.26	1.75
1974	15.0	6.6	2.2	8.4	12.8	41.6	48.9	3.18	2.46	36.1	0.74	2.35	1.82
1975	11.4	5.5	2.2	5.9	9.2	40.7	47.9	3.18	2.46	38.7	0.81	2.57	1.99
1976	6.3	1.7	2.2	4.6	4.0	40.5	47.6	3.18	2.46	43.6	0.92	2.91	2.25
1977	6.3	2.8	2.2	3.5	4.1	41.6	48.9	3.18	2.46	44.8	0.92	2.91	2.26
1978	20.9	10.6	2.2	10.3	18.7	42.0	49.4	3.18	2.46	30.7	0.62	1.98	1.53
1979	10.9	6.2	2.2	4.7	8.7	43.3	51.0	3.18	2.46	42.2	0.83	2.64	2.04
1980	14.9	7.6	2.2	7.3	12.6	40.3	47.4	3.18	2.46	34.7	0.73	2.33	1.81
1981	9.1	5.1	2.2	4.0	6.9	43.8	51.5	3.18	2.46	44.7	0.87	2.76	2.13
1982	19.8	7.3	2.2	12.5	17.6	40.3	47.5	3.18	2.46	29.9	0.63	2.00	1.55
1983	26.6	11.9	2.2	14.7	24.4	40.0	47.0	3.18	2.46	22.6	0.48	1.53	1.18
1984	10.3	7.0	2.2	3.4	8.1	43.7	51.4	3.18	2.46	43.3	0.84	2.68	2.07
1985	11.2	4.9	2.2	6.4	9.0	42.5	50.1	3.18	2.46	41.1	0.82	2.61	2.02
1986	18.6	8.5	2.2	10.2	16.4	42.2	49.6	3.18	2.46	33.2	0.67	2.13	1.65
1987	8.3	4.8	2.2	3.5	6.1	43.0	50.5	3.18	2.46	44.5	0.88	2.80	2.17
1988	9.6	5.6	2.2	4.0	7.4	42.8	50.4	3.18	2.46	43.0	0.85	2.72	2.10
1989	8.8	4.7	2.2	4.1	6.6	41.2	48.4	3.18	2.46	41.9	0.86	2.75	2.13
1990	8.0	3.3	2.2	4.7	5.8	39.7	46.7	3.18	2.46	40.9	0.88	2.79	2.16
1991	8.1	2.0	2.2	6.1	5.8	38.6	45.4	3.18	2.46	39.6	0.87	2.77	2.15
1992	11.1	7.1	2.2	4.0	8.9	41.6	49.0	3.18	2.46	40.1	0.82	2.60	2.01
1993	18.4	11.1	2.2	7.3	16.1	39.5	46.5	3.18	2.46	30.3	0.65	2.08	1.61
1994	9.4	3.7	2.2	5.8	7.2	40.8	48.0	3.18	2.46	40.7	0.85	2.70	2.09
1995	20.2	9.5	2.2	10.6	17.9	38.4	45.1	3.18	2.46	27.2	0.60	1.92	1.48
1996	15.3	8.4	2.2	6.9	13.1	41.6	48.9	3.18	2.46	35.8	0.73	2.33	1.80
1997	13.5	11.8	2.2	1.7	11.3	41.1	48.3	3.18	2.46	37.1	0.77	2.44	1.89
1998	23.6	14.8	2.2	8.8	21.4	38.5	45.3	3.18	2.46	23.9	0.53	1.68	1.30
1999	10.5	5.7	2.2	4.8	8.3	36.2	42.6	3.18	2.46	34.3	0.80	2.56	1.98
2000	14.9	6.0	2.2	8.8	12.7	41.6	48.9	3.18	2.46	36.3	0.74	2.36	1.83
2001	10.4	4.0	2.2	6.4	8.1	42.3	49.7	3.18	2.46	41.6	0.84	2.66	2.06
2002	10.6	8.1	2.2	2.4	8.4	42.0	49.5	3.18	2.46	41.1	0.83	2.64	2.05
2003	10.6	4.8	2.2	5.8	8.4	41.3	48.6	3.18	2.46	40.3	0.83	2.63	2.04
2004	10.0	5.1	2.2	4.9	7.8	44.4	52.2	3.18	2.46	44.4	0.85	2.71	2.09
2005	15.0	6.9	2.2	8.1	12.8	40.5	47.6	3.18	2.46	34.9	0.73	2.33	1.80
2006	13.9	6.0	2.2	7.9	11.7	41.9	49.2	3.18	2.46	37.6	0.76	2.43	1.88
2007	8.1	4.3	2.2	3.9	5.9	42.7	50.3	3.18	2.46	44.4	0.88	2.81	2.17
2008	9.5	7.5	2.2	2.0	7.3	43.6	51.3	3.18	2.46	44.0	0.86	2.73	2.11
Median:	10.9	6.2	2.2	5.3	8.7	41.7	49.0	3.18	2.46	40.1	0.82	2.61	2.02
Max:	**26.0**	**22.1**	**6.0**	**4.0**	**20.1**	**24.7**	**29.1**	**3.2**	**2.5**	**29.5**	**1.1**	**3.4**	**2.6**
Min:	**4.3**	**4.3**	**5.9**	**0.0**	**-1.7**	**20.4**	**24.0**	**3.2**	**2.5**	**3.9**	**0.2**	**0.5**	**0.4**

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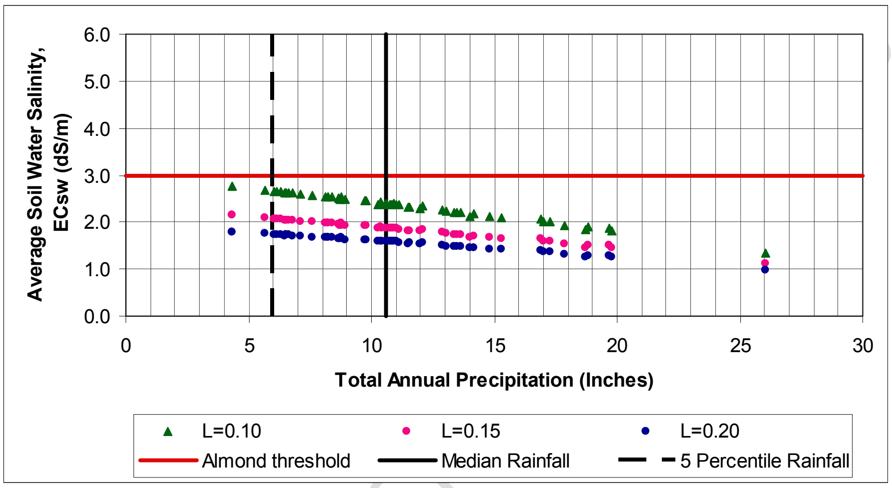
Figure 5.15a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for Almond with leaching fractions ranging from 0.15 to 0.20 and irrigation water (EC_i) = 0.7 dS/m using the 40-30-20-10 crop water uptake function with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

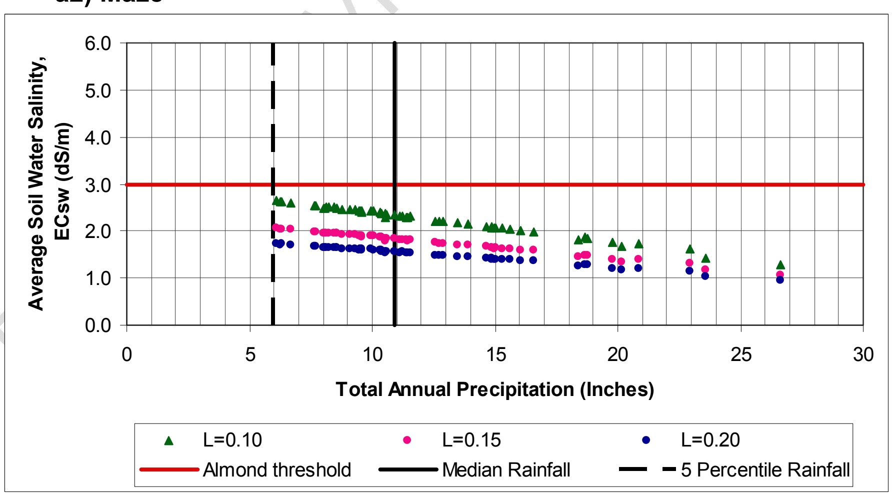
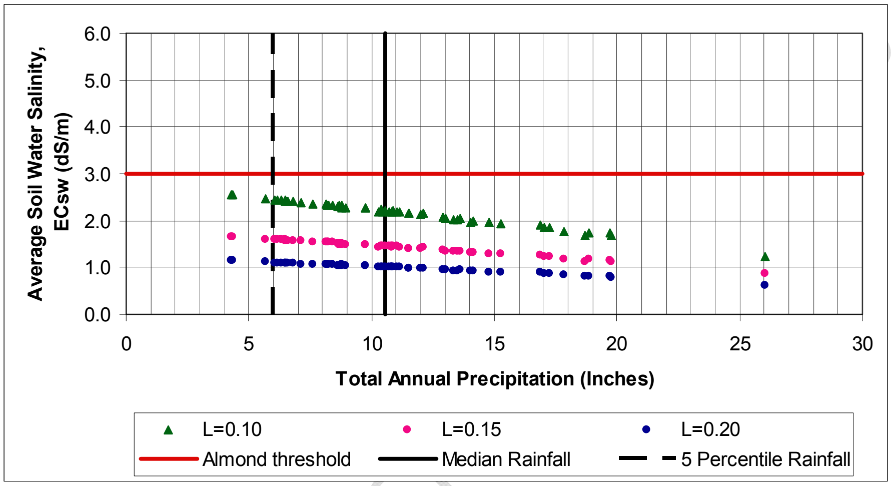
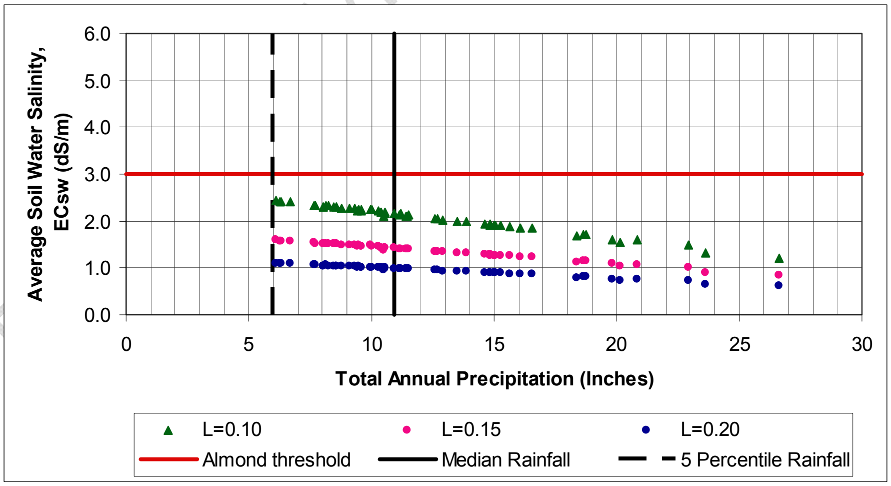


Figure 5.15b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for Almond with leaching fractions ranging from 0.15 to 0.20 and irrigation water (EC_i) = 0.7 dS/m using the exponential crop water uptake function* with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



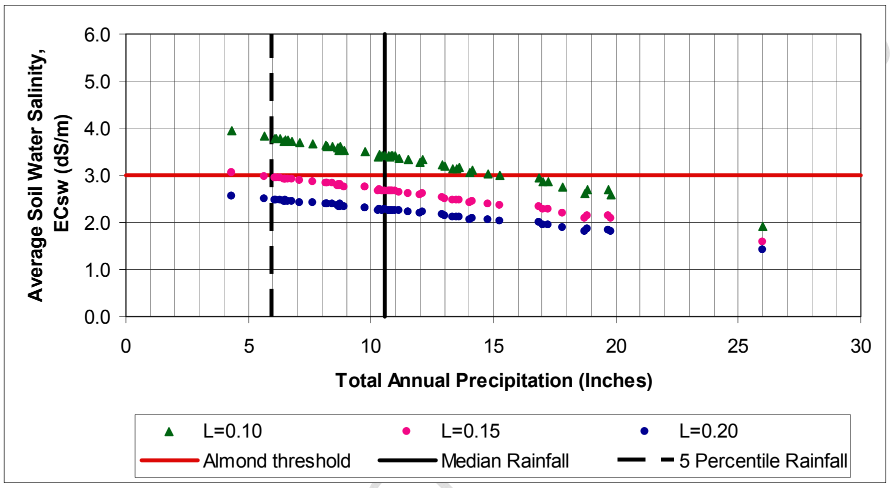
b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

Figure 5.16a. Average soil water salinity (EC_{sw}) vs. total annual rainfall for almond with leaching fractions ranging from 0.10 to 0.20 and irrigation water (EC_i) = 1.0 dS/m using the 40-30-20-10 crop water uptake function with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

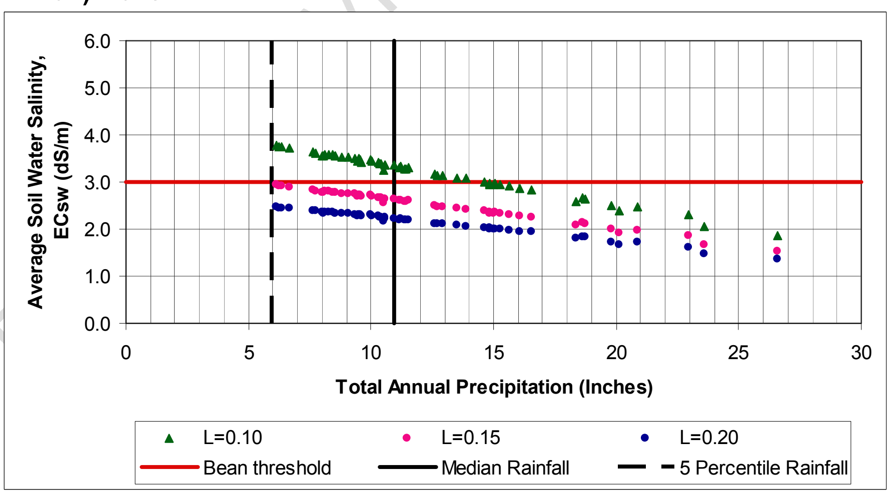
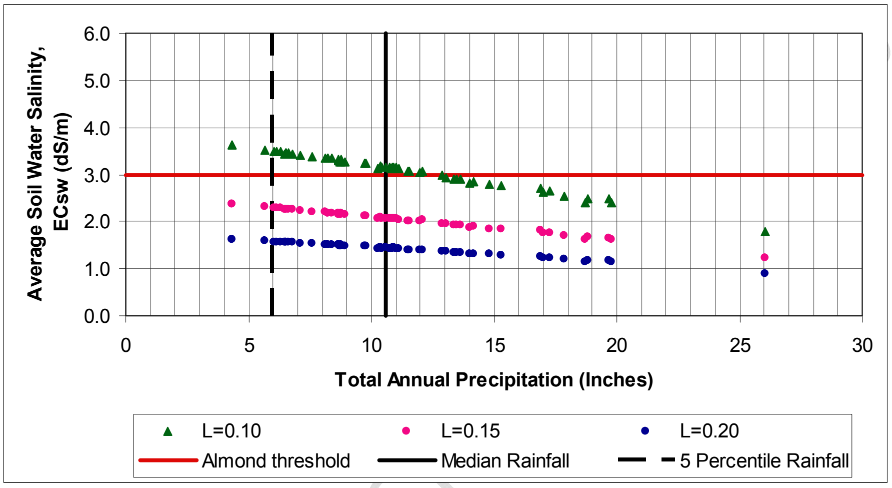
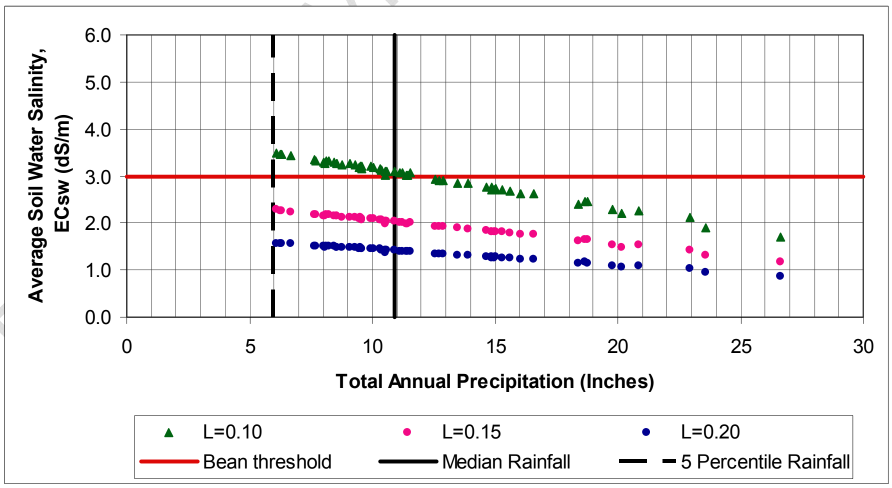


Figure 5.16b. Average soil water salinity (EC_{sw}) vs. total annual rainfall for almond with leaching fractions ranging from 0.10 to 0.20 and irrigation water (EC_i) = 1.0 dS/m using the exponential crop water uptake function* with precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

b1) Crows Landing and Patterson



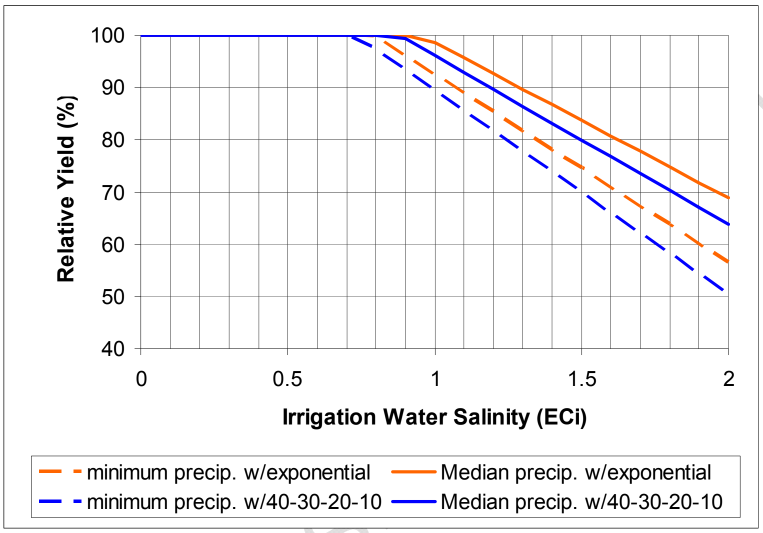
b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

Figure 5.17a. Relative Almond yield (percent) as a function of irrigation water salinity (EC_i) with L=0.10 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

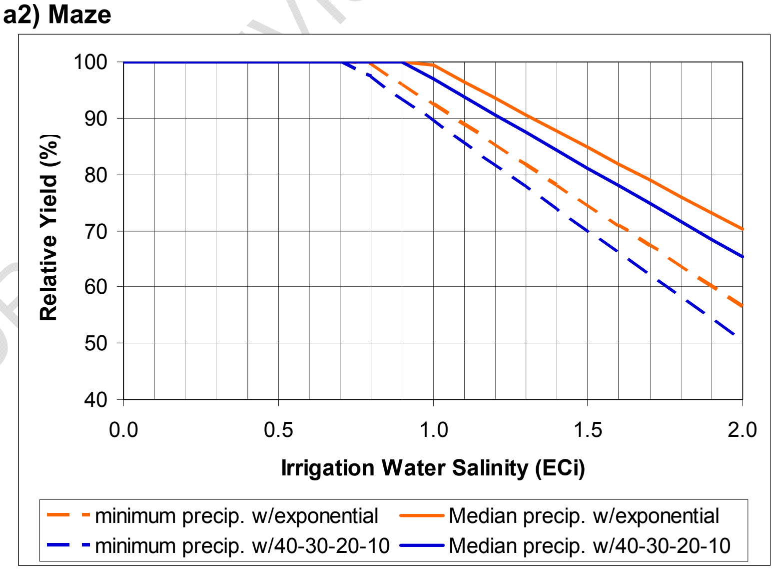
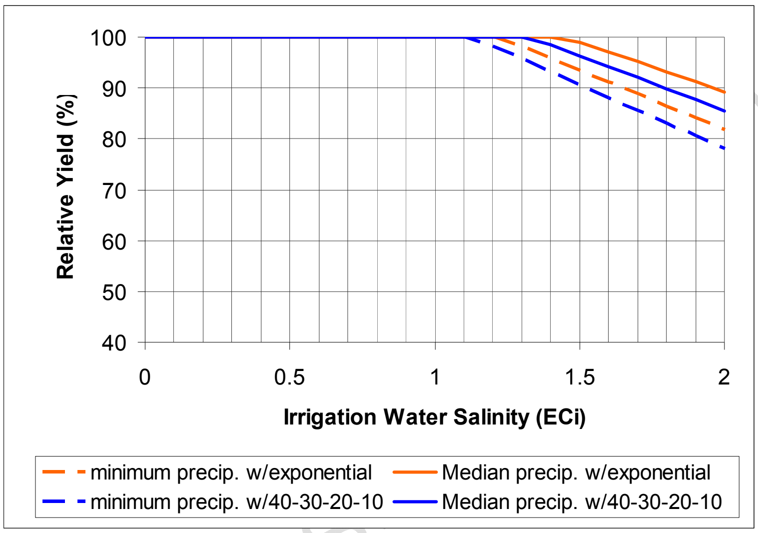


Figure 5.17b. Relative Almond yield (percent) as a function of irrigation water salinity (EC_i) with L=0.15 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze

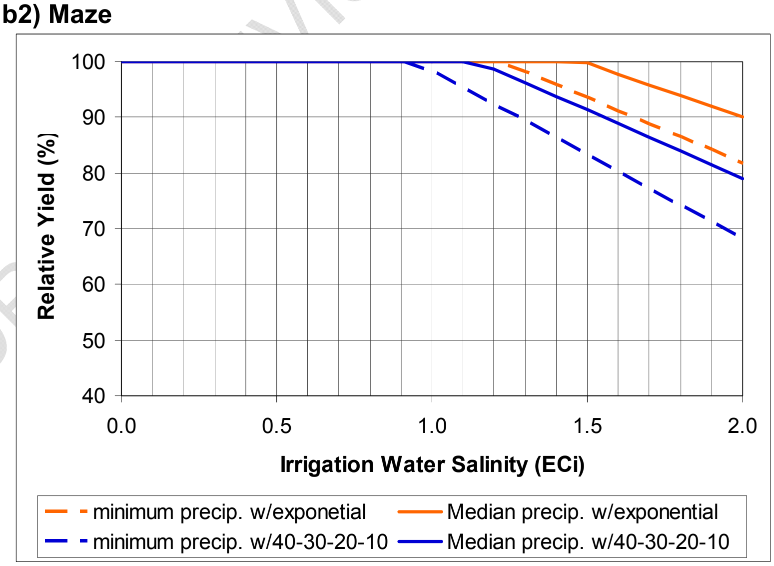
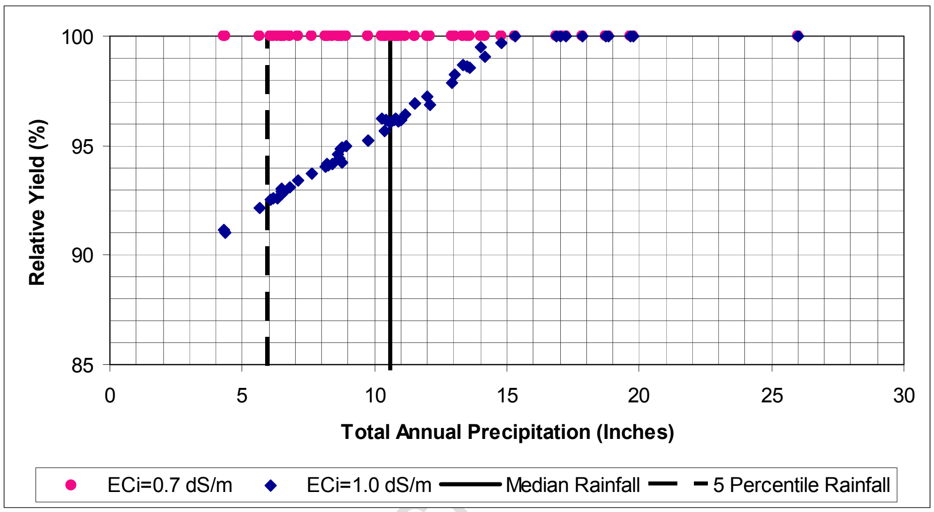


Figure 5.18a. Relative crop yield (%) for almond with L = 0.10 at EC_i = 0.7 and 1.0 dS/m vs. total annual rainfall using the 40-30-20-10 crop water uptake function (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

a1) Crows Landing and Patterson



a2) Maze

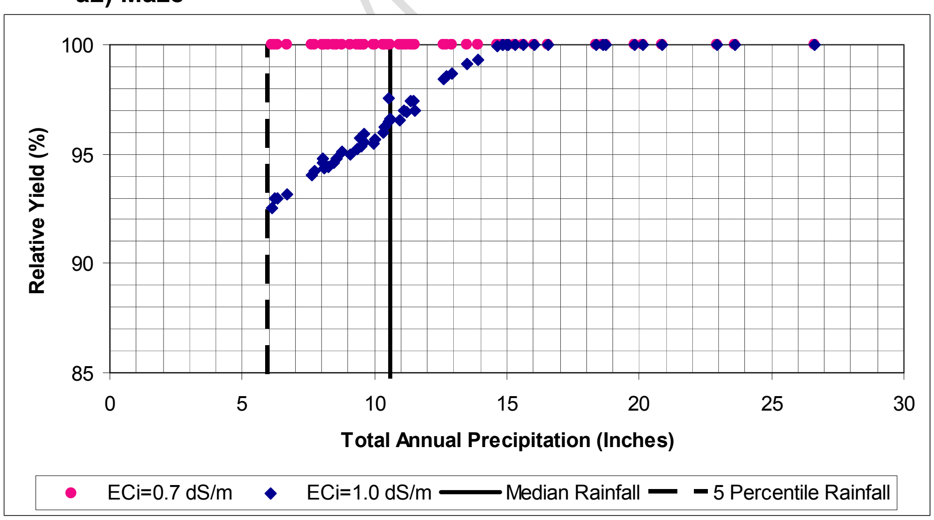
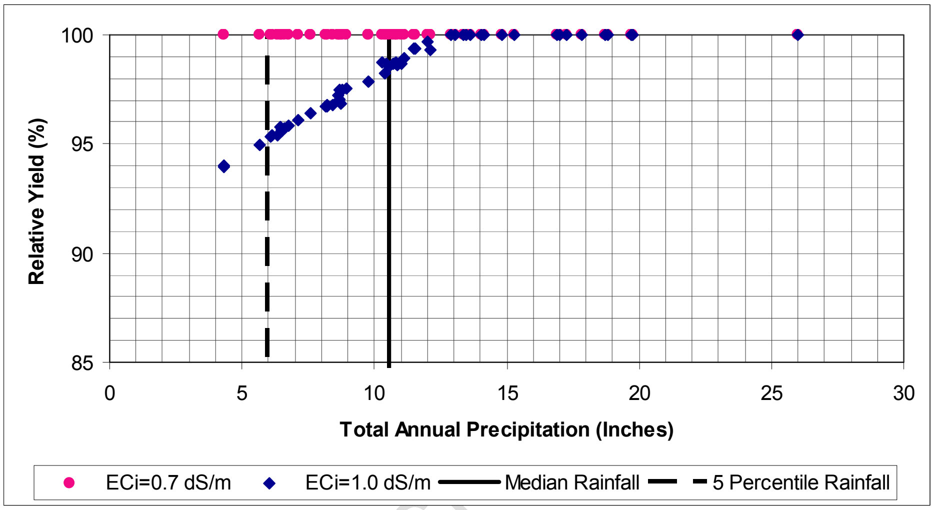
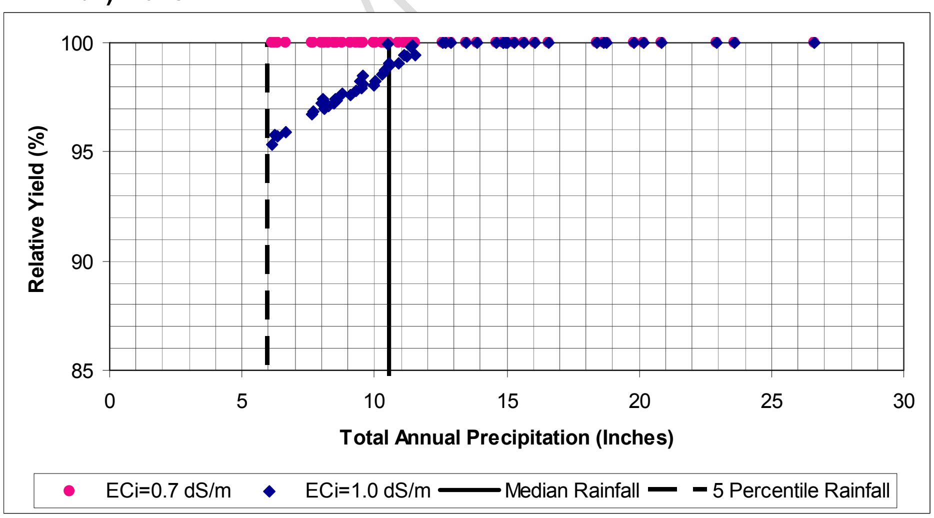


Figure 5.18b. Relative crop yield (%) for almond with L = 0.10 at EC_i = 0.7 and 1.0 dS/m vs. total annual rainfall using the exponential crop water uptake function* (precipitation from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

b1) Crows Landing and Patterson



b2) Maze



** As discussed in Section 4.1, the average soil water salinity was reduced by the soil salinity at 50% leaching for the exponential model.*

6. Summary and Conclusions

As indicated in various Sections of this study, the purpose of this Report is to apply the methodology of Hoffman (2010) using information specific to the LSJR Irrigation Use Area. This Report references Hoffman (2010) regarding the general state of knowledge on information related to crop salt tolerance. Following the Hoffman (2010) approach, Staff also compiled existing information on the LSJR Irrigation Use Area including irrigation water quality, soil types and location of saline and shrink/swell soils, crop surveys, salt tolerance of crops, effective rainfall, irrigation methods and their irrigation efficiency and uniformity, crop water uptake distribution, climate, salt precipitation/dissolution in soil, shallow groundwater, and leaching fraction.

The Report then discusses Hoffman's (2010) review of various published steady state and transient models. Staff ran the steady state soil salinity model developed by Hoffman (2010) with data specific to the LSJR Irrigation Use Area. The model was run with two water uptake distribution functions: the exponential uptake distribution and the 40-30-20-10 distribution. The Report draws site-specific conclusions from the steady state model results.

6.1. Factors Influencing Use of Protective Crop Salinity Thresholds

For information only, staff reviewed electrical conductivity data in the LSJR from 1985 to 2008 (measured at Crows Landing, Patterson and Maze) and found that it ranged from 0.3 to 1.6 dS/m and averaged about 0.96 dS/m. The salt constituent analyses of water samples from the LSJR revealed little concern for sodicity and toxicity in the irrigation water. Boron was not evaluated here as the review and update (as appropriate) of boron water quality objectives is already part of the Amendment scope and will be evaluated in a future report.

Review of the NRCS-SSURGO database (NRCS, 2007a) and Soil Survey (NRCS, 1992) indicates that clay and clay loam soils are the dominant textures and are scattered on the western side of the SJR in the LSJR Irrigation Use Area. Saline soils constitute about 9% of the LSJR Irrigation Use Area while sodic soils constitute about 2.4%. The NRCS soil survey also identified a number of soils with shrink-swell potential. These shrink-swell soils occupy nearly 70% of the LSJR Irrigation Use Area. A study conducted on soils in the Imperial Valley of similar texture showed that when water infiltrated the cracks, the soils swelled and prevented preferential flow. This suggests that bypass flow of applied water in these shrink-swell soils may not cause a salinity management problem.

Data taken from DWR Crop Surveys over the past two decades indicate that tree and vine crops have increased from 17% to 21% of the irrigated land in the LSJR Irrigation Use Area. Grain and hay crop also increased from 3% to 11%, and pasture from 22% to 26%. Conversely, field crops decreased from 34% to 20%

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and truck crops from 23% to 20%. Of the ten crops being grown on more than 1% of the total acreage within the LSJR Irrigation Use Area, as identified in the crop surveys, the more salt sensitive crops are almond, apricot, bean, and walnut. Among them, bean is the most sensitive with a salt tolerance threshold of EC_e =1.0 dS/m.

The 2007 DWR crop survey shows that about 67% of the LSJR Irrigation Use Area is irrigated by border, basin, and furrow irrigation, which have an average irrigation efficiency ranging from 70% to 78% (Hoffman, 2010; Heermann and Solomon, 2007). About 7% is irrigated by sprinklers (75% efficiency) and/or micro-irrigation (87% efficiency). The irrigation method on about 13% of the irrigated land was not identified and 1% of the cropped area was not irrigated. Thus, the overall irrigation efficiency in the LSJR Irrigation Use Area likely averages about 75%. The minimal use of sprinkler irrigation in the LSJR Irrigation Use Area (7%; see Table 3.7) presents little concern for foliar damage.

Based on DWR data, water table depth in the LSJR Irrigation Use Area appears to average at about 40 feet with some areas having a groundwater depth of up to 111 feet. At these depths, any significant water uptake by crop roots may be restricted to deep-rooted and more salt tolerant crops such as cotton and alfalfa.

Estimates of leaching fractions ranging from 0.13 to 0.84 in the LSJR Irrigation Use Area were computed based upon salinity measurements of subsurface tile drainage and SJR water samples taken at various locations in the LSJR Irrigation Use Area during the 1986 and 1987 sampling period. These estimates are dependent upon the salinity of applied water and tile drainage discharge, thus carry a low degree of certainty due to the lack of information regarding source of water present in the subsurface drainage.

6.2. Using Models to Develop Protective Salinity Thresholds

Hoffman (2010) evaluated a number of steady state and transient models that have been developed to calculate the leaching requirement which can also be used to estimate protective salinity thresholds for crops. The distribution of crop water uptake through the root zone is one of the most important inputs to most steady state and transient models.

As this Report is based upon Hoffman (2010), Staff note Hoffman's justification in using steady state soil salinity models, based on the rationale that they are simpler and require less data than transient models. The assumption is that a transient system will converge into a steady state case and provide justification for steady state analyses if crop, weather, and irrigation management remain unchanged over long periods of time.

Following Hoffman (2010), two water uptake distribution functions were utilized in this study for steady state modeling; the 40-30-20-10 water uptake and the exponential water uptake. Hoffman (2010) recommended the exponential water

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uptake distribution over the 40-30-20-10 water distribution in steady state modeling because the exponential distribution agrees more closely with transient model results than the 40-30-20-10 distribution. As a result, discussion of model results in the summary that follows was exclusively based on predictions using the exponential water uptake distribution.

6.2.1 Summary of Selected Steady State Model Results

Table 6.1 presents a selection of protective salinity thresholds specific to the use of the LSJR (between the Merced ~~Stanislaus~~ and Stanislaus ~~Merced~~ Rivers) for irrigation supply. The thresholds were determined using LSJR Irrigation Use Area specific information and the technical approach of Hoffman (2010). These salinity thresholds were determined by ascertaining the point at which irrigation water salinity starts to cause a decrease in relative crop yield which would imply that the crop salinity threshold would be exceeded.

Section 5 of this Report discusses model results for a wider range of leaching fractions than shown in Table 6.1. The selection of results shown in Table 6.1 is not intended to restrict the use of any of the other results shown in Section 5. The results are also limited to those produced using the exponential water uptake distributions, as Hoffman (2010) expressed preference for in Section 6.1 of his Report (Appendix A). Beans were modeled as well as alfalfa and almond, as explained in Section 3.1.2. Beans were found to be the most salt sensitive crop of significant acreage in the LSJR Irrigation Use Area. As shown in Table 6.1, almond and alfalfa salinity thresholds were higher than bean, thus use of bean salinity threshold would implicitly be protective of other crops grown in the LSJR Irrigation Use Area.

Actual selection of a salinity threshold(s) protective of the agriculture (irrigation) beneficial use will involve a number of policy considerations including:

Selection of the most salt sensitive crop in the Use Area.
Selection of the most sensitive crop to salinity has an impact on the salinity threshold. Staff identified bean as the most salt sensitive crop in the LSJR Irrigation Use Area. Beans were selected based on the approach of Hoffman (2010). Staff identified the ten crops with acreage that exceed 1% of the irrigated area. Of theses ten crops, bean was the most salt sensitive. If another methodology is used to select the crops to be considered, it is possible that a different most sensitive crop could be identified.

Leaching fraction
The leaching fraction selected will have an impact on salinity threshold. In Table 6.1, staff displayed a selection of the leaching fractions considered in Section 5. The amount of leaching needed is dependant on the amount of excess salinity in the soil. In the absence of leaching, salts can accumulate and crop growth may be suppressed.

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Precipitation
Consideration of precipitation has an impact on the salinity threshold. Table 6.1 shows results for both median and minimum effective precipitation. The results shown in Table 6.1 are for the 57 year record (1951 to 2008) available for the LSJR Irrigation Use Area. As noted by Hoffman (2010), rainfall can be an important source of irrigation water in California. The amount of rain actually used by crops, known as effective rainfall or effective precipitation, is largely influenced by the climate, plant and soil characteristics.

Water uptake distribution type
The type water uptake distribution used in the steady state model will affect the salinity threshold. The two water uptake distributions considered in this modeling include the 40-30-20-10 model and the exponential model. It should be noted that results in Table 6.1 are predictions from one distribution type: the exponential water uptake which was recommended by Hoffman (2010). Further details on protective salinity thresholds for the 40-30-20-10 distribution are shown in Section 5 for all three crops: bean, almond and alfalfa.

Yield
The salinity thresholds shown in Table 6.1 are protective of 100% yield, determined by the point at which irrigation water salinity starts to cause a decrease in relative crop yield. Alternatively, it is possible to consider options other than 100% yield protection. Results presented in Section 5 show crop yield reductions when the salinity threshold(s) are exceeded.

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Table 6.1. Lower San Joaquin River site specific salinity thresholds protective of use of irrigation water (agriculture), modeled using approach of Hoffman (2010), with the exponential water uptake distribution function, when median and minimum precipitation are considered.

Monitoring Site/LSJR Reach	Effective Precipitation Considered	Leaching Fraction (L)	Salinity Thresholds (EC_i) dS/m
BEAN (Most Salt Sensitive Crop in LSJR Irrigation Use Area)			
Crows Landing and Patterson (LSJR Merced ~~Tuolumne~~ River to Tuolumne ~~Merced~~ River)	Median	**0.15**	**1.0**
	Minimum	**0.15**	**0.8**
	Median	**0.20**	**1.4**
	Minimum	**0.20**	**1.2**
Maze (LSJR Tuolumne ~~Stanislaus~~ River to Stanislaus ~~Tuolumne~~ River)	Median	**0.15**	**1.0**
	Minimum	**0.15**	**0.8**
	Median	**0.20**	**1.5**
	Minimum	**0.20**	**1.2**
ALMOND			
Crows Landing and Patterson (LSJR Merced ~~Tuolumne~~ River to Tuolumne ~~Merced~~ River)	Median	0.15	1.4
	Minimum	0.15	1.2
Maze (LSJR Tuolumne ~~Stanislaus~~ River to Stanislaus ~~Tuolumne~~ River)	Median	0.15	1.5
	Minimum	0.15	1.2
ALFALFA			
Crows Landing and Patterson (LSJR Merced ~~Tuolumne~~ River to Tuolumne ~~Merced~~ River)	Median	0.10	1.3
	Minimum	0.10	1.0
	Median	0.15	1.9
	Minimum	0.15	1.6
Maze (LSJR Tuolumne ~~Stanislaus~~ River to Stanislaus ~~Tuolumne~~ River)	Median	0.10	1.3
	Minimum	0.10	1.0
	Median	0.15	>2
	Minimum	0.15	1.6

7. Next Steps

Hoffman (2010) made a number of recommendations regarding the use and interpretation of his work as part of the development of water quality objectives for the Southern Delta. Hoffman (2010) identified three key subjects where further information would benefit the process of developing water quality objectives for salinity: 1) updated field studies of salt tolerance for relevant cultivars of dry beans that include changes in salinity tolerances over the entire lifecycle of the crop, 2) further investigation of existing transient soil salinity models to determine their applicability to the objective development process, and 3) more accurate determination of actual leaching fractions in irrigated agriculture in the study area. Staff concur these areas are worthy of future study, but also acknowledge the need to develop salinity water quality objectives in the LSJR in a timely manner, based on available science.

For the South Delta, Hoffman (2010) also recommended the analysis of existing boron concentrations in the project area and a determination of whether a boron water quality objective is warranted for the protection of the agricultural beneficial use. The scope of Amendment currently being prepared for the LSJR (Merced ~~Stanislaus~~ to Stanislaus ~~Merced~~ Rivers) includes review and update (as necessary) of the existing objectives.

Application of the Hoffman (2010) steady state soil salinity model presented in this Report is only one component of an ongoing effort to develop and adopt site specific salinity water quality objectives in the LSJR between the Merced ~~Stanislaus~~ and Stanislaus ~~Merced~~ Rivers. This Report addresses only the protection of one beneficial use agriculture (irrigation) of the many listed in the Basin Plan for the LSJR (Water Quality Control Plan, 2009~~Central Valley Water Board, 2007a~~). Protection of each of the beneficial uses must be evaluated as part of the development of site specific water quality objectives. Additional steps in developing a draft basin plan amendment include, but are not limited to, determination of an appropriate averaging period for the potential objectives, consideration of Porter-Cologne Section 13241 factors, economics and CEQA analysis and development of a program of implementation. After all these elements have been completed, a draft basin plan amendment and accompanying staff report can be released for public review and consideration for adoption by the Central Valley Water Board.

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8. References

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Appendix A: Final Report by Dr. Glenn Hoffman: Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta

The Final Report by Dr. Glenn Hoffman:
***Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta* is presented as Appendix A below.**

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