VOLUME III

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III.1 Current and Projected Groundwater Use in the San Joaquin Valley

A. Overview

The framework for balancing competing objectives discussed in Section I.3 indicates a need to compare the actual impacts of interventions to improve groundwater quality, by considering impacts that are positive and negative from the perspective of various parties. That is, rather than proceeding from the assumption that the optimal policy is one that protects every beneficial use in every location, it is of interest to consider how water is actually used, now and in the future as a basis for assessing the real incremental impacts of water quality interventions. The land use and water consumption forecasts presented here are used to calculate the benefits of groundwater quality regulation based on actual and future use in the Representative Area analysis in subsequent sections and on the groundwater modeling presented in the other volume of this report. This synthesis plays an important role in our analysis and can play a similar role in other planning projects that the Regional Board may wish to undertake.

B. Background

Somewhat surprisingly, there is no single document that compiles available information on groundwater demand in the San Joaquin Valley. Bulletin 160, for example, has some information on projected use of groundwater, but is at a fairly high level of generality. Individual cities and other water purveyors prepare Urban Water Management Plans, but as of now this information is not being aggregated on a regional basis (although the DWR's SWAN process is making progress along these lines). In light of this shortfall, this section attempts to synthesize much of the available information on groundwater demand in the San Joaquin Valley.

Groundwater demand in the San Joaquin Valley is strongly related to overlying dynamic land uses. As a result of a rapid process of urban development, the mix of groundwater demands is expected to change over time. The section contains a detailed description of a land use forecasting model developed as part of this SEP. The model is calibrated and applied to the entire San Joaquin Valley. Again, this model can be used for future planning processes undertaken by the Regional Board or other agencies.

In aggregate, groundwater is an integral component of California's water supply, meeting roughly 30 percent of the state's needs in a typical year. Nationwide, California is responsible for 20 percent of total groundwater extraction, more than any other state.[1] One of the largest and most important of California's 431 groundwater basins is the 8,862,000-acre San Joaquin Valley Groundwater Basin, which supplies groundwater to much of the area examined in this study. Table 1 provides data on size, recharge, and extraction for different areas of this basin, or sub-basins. The overall basin covers roughly half of the 17.4 million-acre San Joaquin Valley. Total urban extraction across the basin is 582,356 AF per year.

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[1] 20 percent follows from the estimated 14.5 million acre-feet that was extracted in California in 1995. Bulletin 118 Update 2003, Section 1, p.20.

Table 1: Sub-basin Recharge and Extraction

Basin Number	Sub-basin	Counties	Surface Area (ac.)	Natural Recharge	Artificial Recharge	Applied Recharge	Urban Extraction	Agriculture Extraction	Storage Capacity	Overdraft?
5-22.01	Eastern San Joaquin	San Joaquin, Stanislaus, and Calaveras	707,000	-	-	593,356	47,493	761,828	42,400,000	Yes
5-22.02	Modesto	Stanislaus	247,000	86,000	-	92,000	81,000	145,000	6,500,000	No
5-22.03	Turlock	Stanislaus, Merced	347,000	33,000	-	313,000	65,000	387,000	15,800,000	No
5-22.04	Merced	Merced	491,000	47,000	-	243,000	54,000	492,000	21,100,000	No
5-22.05	Chowchilla	Madera	159,000	87,000	-	179,000	6,000	249,000	8,000,000	No
5-22.06	Madera	Madera	394,000	21,000	-	404,000	15,000	551,000	18,500,000	No
5-22.07	Delta-Mendota	Stanislaus, Merced, Madera, Fresno	747,000	8,000	-	74,000	17,000	491,000	30,400,000	No
5-22.08	Kings	Fresno, Kings, Tulare	976,000	-	-	-	-	-	-	No
5-22.09	Westside	Fresno, Kings	640,000	-	-	-	-	-	-	No
5-22.10	Pleasant Valley	Fresno, Kings	146,000	-	-	4,000	5,700	90,000	14,100,000	No
5-22.11	Kaweah	Tulare, Kings	446,000	62,400	-	286,000	58,800	699,000	15,400,000	No
5-22.12	Tulare Lake	Kings	524,000	89,200	-	195,000	24,000	648,000	17,100,000	No
5-22.13	Tule	Tulare	467,000	34,400	-	201,000	19,300	641,000	14,600,000	No
5-22.14	Kern County	Kern	1,945,000	150,000	308,000	843,000	154,000	1,160,000	40,000,000	No
5-22.15	Tracy	San Joaquin, Contra Costa, Alameda	345,000	-	-	-	-	-	-	No
5-22.16	Cosumnes	Sacramento, San Joaquin	281,000	-	-	269,518	35,063	94,198	6,000,000	No
Total			**8,862,000**	**618,000**	**308,000**	**3,696,874**	**582,356**	**6,409,026**	**249,900,000**	

Source: DWR Bulletin 118, Sub-basin information work

Notes:

Recharge and extraction in acre-feet/year; Storage capacity in acre-feet; Surface Area in acres.

In terms of above-ground watersheds, two hydrologic regions, San Joaquin River and Tulare Lake, cover the San Joaquin Valley. Table 2 describes these areas in detail. Over half of all water demand met by groundwater occurs in these two regions.[2]

Table 2: Annual Groundwater Demand

Hydrologic Region	Total Demand (TAF)	Demand met by Groundwater (TAF)	Demand met by Groundwater (%)
North Coast	1,063	263	25%
San Francisco Bay	1,353	68	5%

[2] Bulletin 118 Update 2003

Central Coast	1,263	1,045	83%
South Coast	5,124	1,177	23%
Sacramento River	8,720	2,672	31%
San Joaquin River	7,361	2,195	30%
Tulare Lake	10,556	4,340	41%
North Lahontan	568	157	28%
South Lahontan	480	239	50%
Colorado River	4,467	337	8%

Source: Bulletin 118 Update 2003, Section 7, Table 12.

1. San Joaquin River

The 9.7 million-acre San Joaquin River region covers the northern section of the San Joaquin Valley, including the representative area. The population within the regional boundaries was 1.8 million in 2000, and is expected to reach 3.4 million by 2030. The total reservoir storage capacity is 11,477 thousand acre-feet (TAF).

The region has a total annual agricultural and municipal water demand of 7,361 TAF. Of the total annual demand, 2,195 TAF (30 percent) is met with groundwater. Irrigated crop area in 2000 was 2.1 million acres. Compared to other regions, the total irrigated crop area was second in the state behind the Tulare Lake region and accounts for 22 percent of total irrigated land in California. Groundwater use in this hydrologic region makes up 18 percent of all groundwater used in the State of California.

In 2000, 44 percent of the region's developed water supply came from local surface sources, 23 percent was from imported surface supplies, and roughly 33 percent of the water supply came from groundwater. In 2001 the net withdrawal of groundwater was 1.2 million AF and the total surface water supply from all sources was 5.3 million AF.[3,4]

Most urban communities in the region rely solely on groundwater as their primary source of supply. Total urban water use in 2001 was 629,100 AF.[5] Overdrafts are increasing with urban growth, and surface water transfers are being negotiated to meet the demand.

Surface water is the primary water source for agriculture in the San Joaquin River region. Surface water tends to contain less dissolved solids, making it well suited to agricultural use. Applied agricultural water use was estimated to be 7.2 million AF in 2001.[6] Although the primary source of agricultural water for the region is surface water, groundwater contributes significantly to the supply. Groundwater is typically pumped to condition the root zone levels and to insure applied water has adequate room to flow. Thus, most wells are shallow (less than 100 ft) and pumped water is blended with surface water before it is applied to land. The amount of groundwater applied for agricultural use in 2001 was approximately 261,000 AF.[7]

[3] Includes: local deliveries, local imported deliveries, Colorado River deliveries, CVP base and project deliveries, other federal deliveries, and SWP deliveries required environmental in-stream flow
[4] California Water Plan; Update 2005 Bulletin 160-05, December 2005 (Table 7-2)
[5] *Ibid*
[6] *Ibid*
[7] *Ibid*

2. Tulare Lake

The Tulare Lake region covers the southern section of the San Joaquin Valley, covering roughly 11 million acres. The population living within the regional boundaries was at 1,884,675 in 2000 and is expected to reach 3,121,625 by 2030. The total reservoir storage capacity is 2 million AF and irrigated crop area in 2000 spanned 3,219,000 acres. Compared to other hydrologic regions in the Valley, the total irrigated crop area is the largest and accounts for 34 percent of total irrigated land in California.[8]

The Tulare Lake region has a total annual agricultural and municipal water demand of 10.5 million AF; 2001 applied water use for urban users was 677,400 AF.[9] Roughly 40% of total annual demand is met by groundwater.[10] Within the region, groundwater has historically been important for urban and agricultural uses. Approximately a third of the region's total annual water supply is pumped from the basin's aquifers, comprising 35 percent of all groundwater use in California.[11]

The Tulare Lake region receives most of its surface water from the Kings, Kaweah, Tule, and Kern Rivers. The State Water Project provides an average of 1.2 million acre-feet of surface water annually to the region for both agricultural and urban purposes. The U.S. Bureau of Reclamation supplies an average of 2.7 million acre-feet from the CVP through the Mendota Pool, the San Luis Canal, and the Friant-Kern Canal, primarily for agricultural uses.

Groundwater is important for both urban and agricultural uses in the Tulare Lake region, accounting for 33 percent of the region's total annual water supply. Total groundwater withdrawal in 2001 was 4.1 MAF and continues to increase in response to growing urban and agricultural demands, resulting in overdraft in some cases. One effect of long-term groundwater overdraft is land subsidence, which has already damaged canals, utilities, pipelines, and roads in the region, in addition to reducing overall storage capacity. In an effort to slow subsidence, many water agencies have adopted groundwater replenishment programs; storing excess water supplies in wet years and minimizing seepage from unlined canals.[12]

3. Water Quality

Salinity levels strongly determine potential uses for groundwater. For example, highly saline groundwater requires treatment to make it potable for urban users, and irrigators may be forced to blend it with higher-quality sources to prevent reduction in crop yield.

The San Joaquin River region has generally good quality groundwater suitable for most uses. During a six year study from 1994 to 2000, 689 public supply water wells were sampled. The results found that 523 wells, or 76 percent, could be deemed safe for drinking water and 166 wells, or 24 percent, had constituents that exceeded one or more MCL.[13] Contaminant groups

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[8] See California Hydrologic Region Characteristics for a detailed discussion of all 10 regions. Bulletin 160-05, Volume 3.
[9] California Water Plan; Update 2005 Bulletin 160-05, December 2005 (Table 8-3)
[10] Bulletin 118, Update 2003, Section 7, Table 12. *(table states "Source: DWR 1998")*
[11] Bulletin 160-05, Volume 3, Section 8, p.6.
[12] California Water Plan; Update 2005 Bulletin 160-05, December 2005 (P. 8.6)
[13] Bulletin 118-03, Section 7, p.170.

included pesticides (33%), radiological (30%), nitrates (16%), VOCs/SVOCs (11%), and inorganic (10%).[14]

The Tulare Lake region also generally enjoys good quality groundwater. During a six year study from 1994 to 2000, 1,476 public supply water wells were sampled. The results found that 1,049 wells, or 71 percent, could be deemed safe for drinking water and 427 wells, or 24 percent, had constituents that exceeded one or more MCL.[15] Contaminate groups included pesticides (35%), radiological (19%), nitrates (20%), VOCs/SVOCs (10%), and inorganic (16%),.[16]

4. Groundwater Budgets

Groundwater budgets are developed to track changes in groundwater storage by examining inflows and outflows in a groundwater basin. Inflows include natural recharge, intentional and unintentional recharge, seepage, subsurface inflows; outflows occur through extraction, groundwater discharge to surface water, evapotranspiration, and subsurface outflows. The main goal of a groundwater budget analysis is to provide information that will lead to a better understanding of the basin in question.

Table 3 provides information regarding the San Joaquin River and Tulare Lake hydrologic region water balance summaries for 1998, 2000, and 2001. In both regions, total groundwater storage appears to be decreasing; in the most extreme example, Tulare Lake groundwater storage declined 4,115 thousand acre-feet by 2001.

[14] Bulletin 118-03, Section 7, p.171.
[15] Bulletin 118-03, Section 7, p.178.
[16] Bulletin 118-03, Section 7, p.179.

Table 3: San Joaquin River and Tulare Lake Water Balances

	TAF applied in		
Region and Use	**1998**	**2000**	**2001**
San Joaquin River			
Urban	560.4	600.2	629.1
Agricultural	5,458.0	7,017.8	7,243.0
Environmental	5,604.5	4,637.1	2,930.1
Tulare Lake			
Urban	546.4	653.5	677.4
Agricultural	8,566.8	10,802.6	10,566.7
Environmental	3,267.9	1,404.8	1,040.4

Source: Bulletin 118 Update 2003.

C. Urban Demand

The demand for groundwater from urban communities depends on its location and size, and the availability of alternative water supplies. Table 4 illustrates the extent to which communities in the San Joaquin Valley depend on groundwater to fulfill urban demand: of the 43 with a population of more than 10,000, 31 rely solely on groundwater for their drinking water supply.[17] Ten of the twelve remaining mix groundwater and surface water; Avenal and Coalinga are the only two communities that do not use groundwater, instead relying on the Central Valley Project.[18] The average population of communities that rely completely on groundwater was 26,835. The average population of the 10 communities with a conjunctive use program was 131,112.

Table 4: Sources of Drinking Water

					Water supply includes	
Community	**Population (2000)**	**County**	**CVP**	**SWP**	**Groundwater**	**Streams & Reservoirs**
Arvin	12,956	Kern			X	
Atwater	23,113	Merced			X	
Avenal	14,674	Kings	X			
Bakersfield	247,057	Kern		X	X	X
California City	8,385	Kern		X	X	
Ceres	34,609	Stanislaus			X	
Chowchilla	11,127	Madera			X	
Clovis	68,468	Fresno			X	X
Coalinga	11,668	Fresno	X			
Corcoran	14,458	Kings			X	
Delano	38,824	Kern			X	

[17] Includes (in order of size) Visalia, Merced, Lodi, Turlock, Tulare, Madera, Hanford, Porterville, Delano, Ceres, Los Banos, Atwater, Wasco, Reedley, Lemoore, Selma, Sanger, Dinuba, Riverbank, Oakdale, Corcoran, Arvin, Shafter, Patterson, Parlier, Chowchilla, Tehachapi, Livingston, Ripon, McFarland, and Kingsburg,.

[18] Includes (in order of size) Fresno, Bakersfield, Stockton, Modesto, Clovis, Tracy, Manteca, Lathrop, Lindsay, and California City, see Table XX.

Dinuba	16,844	Tulare		X	
Fresno	427,652	Fresno	X	X	X
Hanford	41,686	Kings		X	
Kingsburg	9,199	Fresno		X	
Lathrop	10,445	San Joaquin		X	X
Lemoore	19,712	Kings		X	
Lindsay	10,297	Tulare	X	X	
Livingston	10,473	Merced		X	
Lodi	56,999	San Joaquin		X	
Los Banos	25,869	Merced		X	
Madera	43,207	Madera		X	
Manteca	49,258	San Joaquin		X	X
McFarland	9,618	Kern		X	
Merced	63,893	Merced		X	
Modesto	188,856	Stanislaus		X	X
Oakdale	15,503	Stanislaus		X	
Parlier	11,145	Fresno		X	
Patterson	11,606	Stanislaus		X	
Porterville	39,615	Tulare		X	
Reedley	20,756	Fresno		X	
Ripon	10,146	San Joaquin		X	
Riverbank	15,826	Stanislaus		X	
Sanger	18,931	Fresno		X	
Selma	19,444	Fresno		X	
Shafter	12,736	Kern		X	
Stockton	243,771	San Joaquin		X	X
Tehachapi	10,957	Kern		X	
Tracy	56,929	San Joaquin	X	X	X
Tulare	43,994	Tulare		X	
Turlock	55,810	Stanislaus		X	
Visalia	91,565	Tulare		X	
Wasco	21,263	Kern		X	

Source: http://www.water-ed.org/watersources/default.asp

Results are similar at the regional level.

Table 5 displays relative urban groundwater consumption for San Joaquin Valley counties from 1998 to 2003, the most recent years for which data are available. Reliance on groundwater is above 50% in every case, although it has declined considerably since 1998. In fact, this trend is observed through the state; of the 58 California counties, 32 report a decrease in groundwater use between 1998 and 2003, 18 report no change, and eight report an increase in the percent of groundwater as a source of supply.

Table 5: Groundwater as a Percent of Total Urban Supply, 1998—2003

County	1998	1999	2000	2001	2002	2003
Fresno	100%	54%	67%	56%	54%	54%
Kern	92%	85%	90%	86%	85%	85%
Kings	100%	72%	73%	73%	72%	72%
Madera	100%	88%	87%	87%	88%	88%
Merced	100%	71%	72%	72%	71%	71%
San Joaquin	54%	54%	54%	54%	54%	54%
Stanislaus	100%	60%	60%	60%	60%	60%
Tulare	100%	93%	93%	93%	93%	93%

Source: Department of Water Resources;
http://www.landwateruse.water.ca.gov/annualdata/urbanwateruse/urbanlevels.cfm

1. Groundwater Management

Although groundwater and surface water are hydrologically interconnected, they are regulated in very different manners. Statewide regulation of surface water began in 1914, when California created a system of appropriative and riparian surface water rights. Riparian rights allow diversion of water based on land ownership that is adjacent to a natural watercourse, with all water users given equal priority. Appropriative rights allow for a water user to divert, store and use water regardless of proximity to a natural watercourse. Groundwater rights are analogous to a riparian surface water right in that they vary with location, but groundwater use is not regulated by the state. Instead, an overlaying landowner has the right to build a well and extract groundwater under the doctrine of "correlative rights and reasonable use." In practice, the correlative rights are only quantified if the basin is adjudicated; the California legislature has repeatedly upheld the notion that groundwater management should not be regulated by the State and instead should be a local responsibility.

Groundwater management typically occurs in one of three ways: active management by local water agencies, management through local ordinances, or court adjudication. Local governments are becoming increasingly involved in groundwater management: 24 of the 27 management ordinances have been enacted since 1990.[19] Within the San Joaquin Valley, county-wide ordinances have been adopted in Kern, Fresno, Madera and San Joaquin counties.[20]

Local agency management entails the creation of an association of local agencies which are mutually dependent on a groundwater basin. One such example is the Stanislaus and Tuolumne River Groundwater Basin Association, formed by the City of Modesto, the Modesto Irrigation District, the City of Oakdale, the Oakdale Irrigation District, the City of Riverbank, and Stanislaus County. By coordinating planning, the association recognizes the mutual interest of its constituents in achieving sustainable, efficient use of the groundwater basin. The association has

[19] Bulletin 118, Section 2, p.36.

[20] Fresno County was enacted in 2000 and states that export permit required (extraction & substitute pumping), Kern County was enacted in 1998 and states, conditional use permit for export to areas both outside county and within watershed area of underlying aquifer in county. Only applies to southeastern drainage of Sierra Nevada and Tehachapi mountains, Madera County was enacted in 1999 and states, permit required for export, groundwater banking, and import for groundwater banking purpose to areas outside local water agencies, San Joaquin County was enacted in 1996 and states, export permit required (extraction & substitute pumping). Bulletin 118, Section 2, p.36.

created an integrated regional groundwater management plan that complies with state planning acts to formally manage extraction from the basin.

A less common basin-wide form of management in California is court adjudication. When extraction issues arise between landowners and other parties, a court has the authority to assign extraction rights. An adjudicated groundwater basin gives statutory authority to a local agency to manage the resource. There are currently 20 basins under adjudication, mostly in Southern California.[21] These decisions guarantee to each party a proportionate annual share of groundwater production. In 15 decisions, the court has placed limits on the extraction based on a court-determined safe yield.[22]

It is important to recognize that groundwater is a complex resource and that regulation is often hampered by a lack of information. Statewide data is uncommon due to the fact that gathering the data is very expensive and the historical lack of statewide involvement in management as well as monitoring. Important information that is missing includes data regarding the total natural recharge, subsurface inflow and outflow, recharge and extraction, groundwater levels and water quality. There also exists a great deal of variance over where data is collected in California that is dependent on the level of development. As the awareness of groundwater and its importance to the California water supply increases, these data constraints should lessen.

Acquiring surface water is often challenging for urban communities because of location or excessive cost. Some urban communities have adopted a collective approach to solving these problems through the formation of irrigation districts. By harnessing their collective bargaining power, member communities of an irrigation district frequently enjoy better access to surface water sources.

These efforts have met with varying success. Joint Powers Authority (JPA), established in 1990 by the cities of Ceres, Hughson, Modesto, Turlock, and the communities of Delhi, Denair, Keyes, and Hilmar, sought to divert surface water from the Tuolumne River for urban use. The Turlock Irrigation District responded by offering raw water rights to the JPA, but no agreement could be reached on price. Negotiations stalled in 1997 and the JPA has been inactive ever since, however the city of Ceres did reach an agreement with TID for surface water rights.

Modesto and several other communities north of the Tuolumne River receive surface water from the Modesto Reservoir through an agreement with the Modesto Irrigation District (MID). A portion of the City of Modesto lies south of the River, and Modesto supplies well water to a portion of Ceres residents who were historically served by the Del Este Water Company. Modesto has approached the City of Ceres concerning the expansion of their surface water project, but to date only preliminary discussions have taken place. Modesto is now focused on surface supplies that may become available from the TID.[23]

The South County Water Supply Program (SCWSP) is another example of a joint effort to increase surface water deliveries to urban communities. SCWSP members include the South San

[21] Adjudicated basins include the Mojave, Warren Valley, Chino, Cucamonga, San Bernardino, and Goleta basins. Bulletin 160.
[22] Bulletin 118, Section 2, p.40.
[23] From City of Ceres, 2005 UWMP and Conservation Plan, December 2005

Joaquin Irrigation District (SSJID) and the cities of Escalon, Manteca, Lathrop, and Tracy. The SCWSP provides treated surface water from the Stanislaus River, including a new water treatment plant (WTP) located near Woodward Reservoir capable of supplying 44,000 AF/Y. Lathrop has entered into an agreement with SSJID resulting in future surface water supply. The SCWSP will initially meet half of Lathrop's annual water demand; by 2020, that number will rise to 75 as full production capability comes online.[24]

The SCWSP is a model for how cities can bargain with regional irrigation districts, which typically enjoy ample and senior surface water diversion rights, to reduce groundwater pumping to a safe yield. For example, Manteca's groundwater basin safe yield was estimated in a 1985-groundwater study at 1.0 AFY per acre. Historically, the City of Manteca extracted groundwater at a rate of approximately 2.4 AFY per acre. The City of Manteca entered into an agreement with SCWSP that will allow the City to reduce local groundwater extraction to the basin safe yield of 1.0 AF/year per acre. Looking ahead, Manteca expects SSJID surface water deliveries to account for approximately 53 percent annual supply.[25] Overall projected SCWSP deliveries are shown in Table 6.

Table 6: Projected Annual SCWSP Deliveries

	Annual Deliveries, AF/Y				
City	**2,005**	**2,010**	**2,015**	**2,020**	**2,025**
Manteca	9,914	12,064	14,214	16,364	18,500
Escalon	0	0	2,520	2,799	2,799
Lathrop	5,200	8,000	8,000	10,780	11,791
Tracy	10,000	10,000	10,000	10,000	10,000
Total	**25,114**	**30,064**	**34,734**	**39,943**	**43,090**

Source: City of Lathrop, 2003 UWMP, 5-3

2. Urban Water Management Plans

The California Water Code requires urban water suppliers servicing 3,000 or more connections or supplying more than 3,000 acre-feet per year (AFY), to submit an Urban Water Management Plan every five years to the Department of Water Resources (DWR). These plans include detailed information on expected urban growth, future sources of water supply, water quality, and other key aspects of water planning.

Section III Appendices: Appendix III.5 summarizes the most recent UWMP available for the 34 communities in the San Joaquin Valley with population greater than 10,000.[26]

D. Agricultural Demand

California is one of the most agriculturally productive areas in the world, and the San Joaquin Valley is the state's most productive agricultural region (43% of total production.)[27] Agricultural production employs 427,000 people (26.9 percent of the region's jobs), generates $10 billion in

[24] City of Lathrop, 2003 UWMP, August 2004
[25] City of Manteca, 2005 UWMP
[26] Six additional communities with more than 10,000 people did not have UWMPs available for review.
[27] Agriculture's role in the economy, November 26, 2006 (P. 11):
http://aic.ucdavis.edu/publications/MOCA_Ch_5.10aPrePrint.pdf

labor income (18.1 percent) and $16.8 billion in value added income (20.3 percent).[28] The Valley's total agricultural output was valued at $42 billion in 2002.

Agriculture requires significantly more water than urban uses: 33.7 million AF versus 8.6 million AF in 2001. Applied water varies significantly based on precipitation: in 2001, a dry year, it totaled 64.8 million AF; in 1998, a wet year, it was 94.5 million AF.[29] The net changes to urban and agricultural use are marginal with the majority of the decreased water supply affecting environmental uses.

Water demand can change with the combination of land uses in the region. In the Central Valley, land use has remained relatively constant over the past century. Even accounting for the accelerating pace of development, the Valley will remain an agricultural stronghold. Accordingly, water use in the Central Valley is stable, although it remains dependent on rainfall and water recharge to prevent groundwater over-drafting.

Like urban demand, agricultural demand for water is largely stable over time. Nearly 20 percent of the harvested acres in the San Joaquin Valley are fruit and nut crops. These crops are considered permanent because of the large capital investment required to create a mature, producing orchard. Some field crops could also be considered permanent, especially if they are used as inputs to other regional agriculture. For example, crops used for animal feed experience consistently high demand from the numerous dairies located in the region.

E. Future Uses of Groundwater

Demands on both groundwater and surface water will increase in response to a large population influx expected over the coming decades. Urban communities in the San Joaquin Valley are growing rapidly, with four out of the ten fastest growing counties in the state located in the study area. Table 7 shows Department of Finance projections from 2000 to 2050. Population will nearly double by 2030 and some counties' populations—Merced, San Joaquin—will roughly triple. The region will add a total of 4.6 million people over the next 50 years, of which 2.6 million will arrive by 2030.

Table 7: Population Projections for the San Joaquin Valley by County 2000 through 2050

County	2000	2010	2020	2030	2040	2050
Fresno	803,401	949,961	1,114,654	1,297,476	1,476,699	1,658,281
Kern	664,694	808,808	950,112	1,114,878	1,325,648	1,549,594
Kings	129,823	156,334	184,751	223,767	252,762	282,364
Madera	124,372	150,278	183,966	219,832	259,353	302,859
Merced	210,876	277,715	360,831	437,880	528,788	625,313
San Joaquin	567,798	747,149	989,462	1,229,757	1,457,128	1,707,599
Stanislaus	449,777	559,051	653,841	744,599	843,523	941,562
Tulare	369,355	447,315	543,749	650,466	754,790	867,482
Total	**3,320,096**	**4,096,611**	**4,981,366**	**5,918,655**	**6,898,691**	**7,935,054**

Source: California Department of Finance, Demographic Research Unit, May 2004.

[28] *Ibid*
[29] California Water Plan; Update 2005 Bulletin 160-05, December 2005 (Table 1-3)

1. UWMPs

Table 8 presents a selection of urban communities with the highest UWMP-projected growth over the 2005 through 2025 time period. In relative terms, the largest amount of growth is expected in the community of Shafter, from 14,000 in 2005 to 94,415 in 2025, or 547% growth.[30] Likewise, Livingston expects to grow from 14,135 to 79,490 over the same time period.[31] The other leading communities include Selma, Lathrop, Ripon and Riverbank.

Table 8: Projected Growth

City	2005	2010	2015	2020	2025	Growth 2005 - 2025
Coalinga	14,057	16,855	19,540	22,652	26,260	87%
Corcoran*	22,475	27,704	31,983	36,923	42,625	90%
Lathrop	22,800	33,854	44,912	57,146	68,779	202%
Lemoore	23,983	29,179	35,500	43,191	52,484	119%
Livingston	14,135	24,921	47,073	62,636	79,490	462%
Los Banos	32,380	39,395	47,930	58,314	70,949	119%
Madera	51,845	61,874	73,842	88,126	105,172	103%
Manteca	61,500	72,600	85,900	101,500	119,950	95%
Patterson	16,150	21,000	25,500	30,000	34,000	111%
Porterville*	44,555	57,707	69,832	84,506	102,263	130%
Ripon	14,600	19,700	24,800	29,900	35,000	140%
Riverbank*	19,986	24,528	30,569	38,100	47,485	138%
Selma	23,500	58,720	66,400	75,090	84,920	261%
Shafter	14,000	34,104	54,208	74,312	94,415	574%
Tulare*	49,545	62,042	73,738	87,639	104,160	110%
Turlock	65,970	77,899	91,984	108,616	128,256	94%
Total	**491,481**	**662,082**	**823,712**	**998,650**	**1,196,207**	**143%**

Source: Information gathered from most recent UWMPs.

* UWMP not available or did not include population forecasts. California Department of Finance estimates were used to forecast future population growth.

To accommodate this growth, increasing demand will be placed on groundwater resources. Figure 1 depicts water supply by source, based on UWMP forecasts. Surface water deliveries are expected to remain relatively constant over the next 20 years as total urban demand nearly doubles. Figure 2 and Figure 3 map this demand for 2005 and 2025, respectively; the majority of communities in the San Joaquin Valley are completely dependent on groundwater for urban supply in both years.

[30] According to Shafter's 2005 UWMP, a major impact on the population growth is the nnexationof about 4,912 acres of planned residential property in the southeast portion of the City's service area. This annexation is projected to add about 11,778 residential units over a twenty year build-out period.

[31] According to Livingston's 2005 UWMP, this expansion is a result of eastward expansion of growth from the San Francisco Bay Area as well accelerated growth from the University of California, Merced.

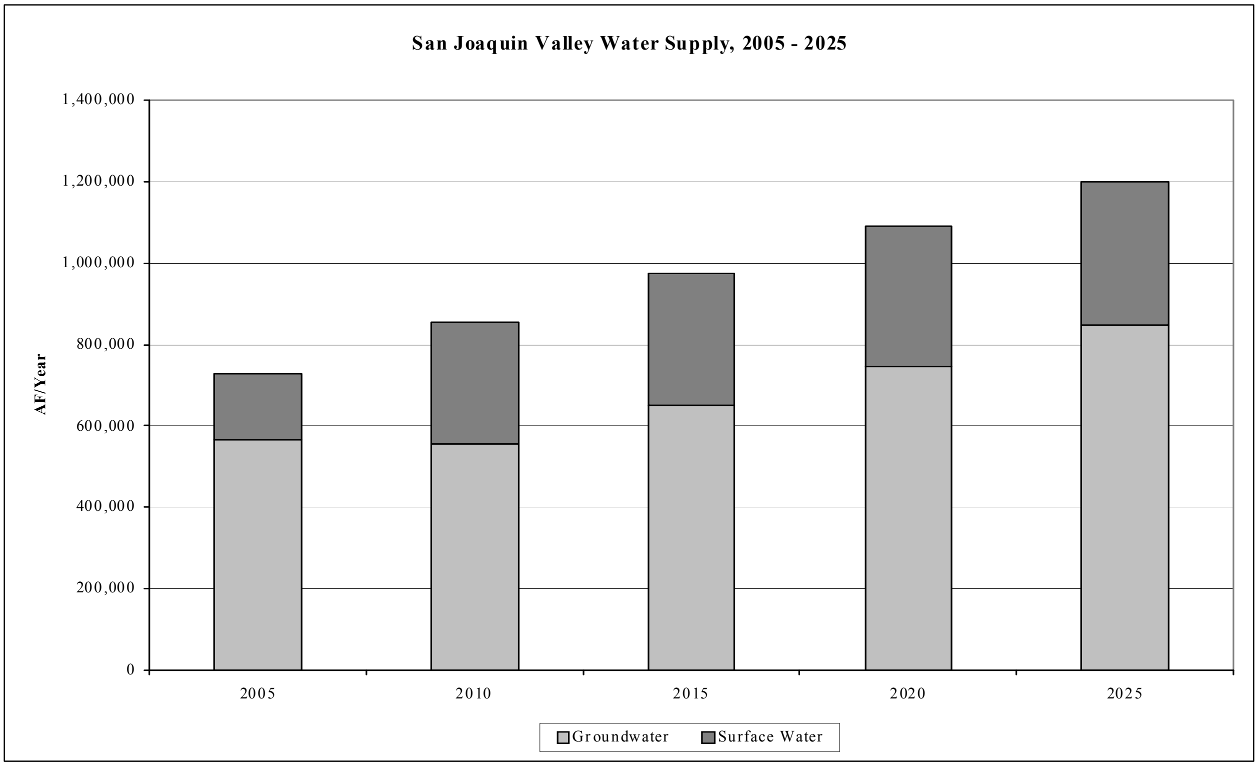

Figure 1

Sources: UWMPs of communities in San Joaquin Valley.

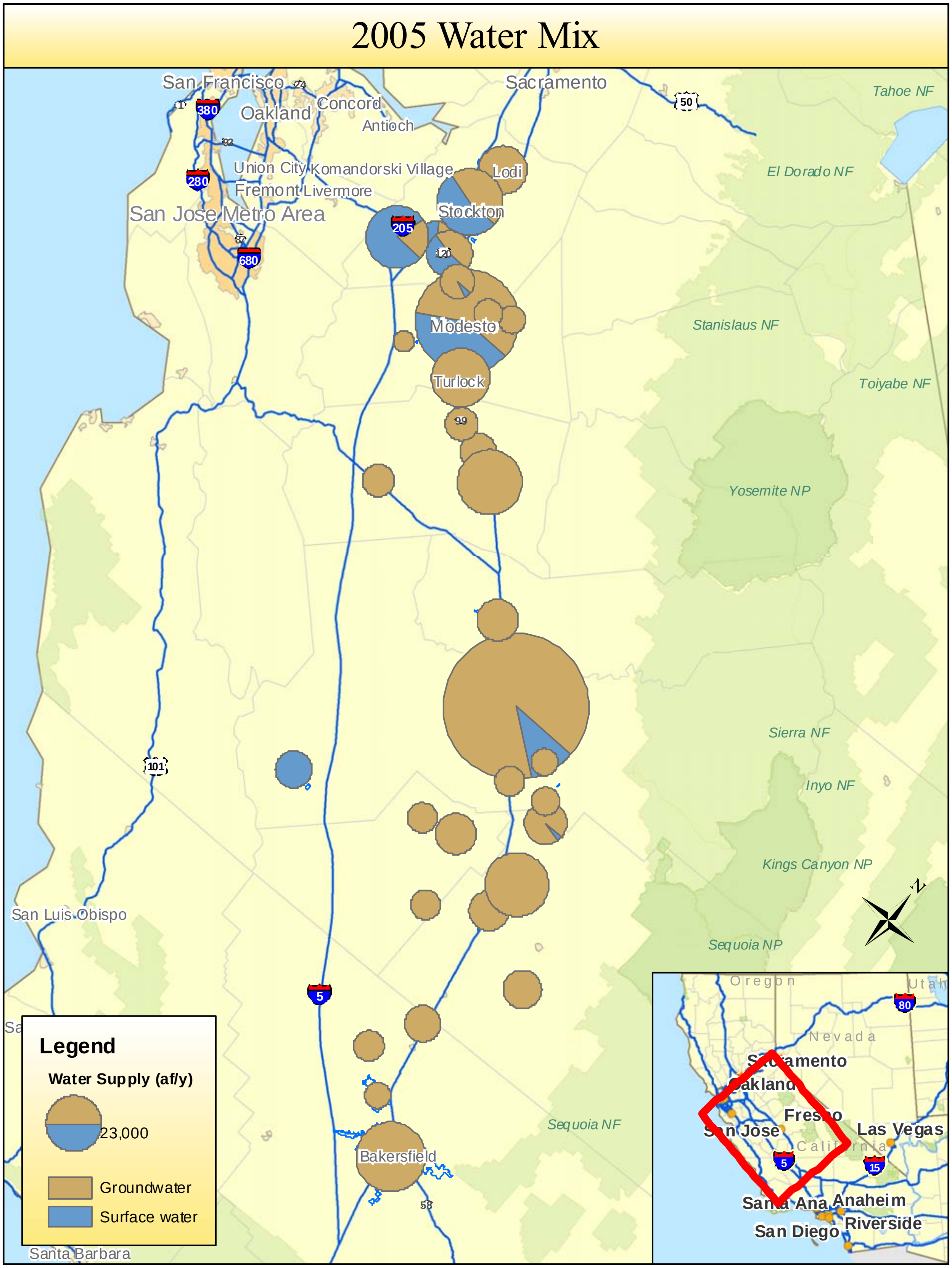
2005 Water Mix
San Francisco
Oakland
Concord
Antioch
Sacramento
Union City
Komandorski Village
Fremont
Livermore
San Jose Metro Area
Lodi
Stockton
Modesto
Turlock
Bakersfield
San Luis Obispo
Santa Barbara
Tahoe NF
El Dorado NF
Stanislaus NF
Toiyabe NF
Yosemite NP
Sierra NF
Inyo NF
Kings Canyon NP
Sequoia NP
Sequoia NF
Legend
Water Supply (af/y)
23,000
Groundwater
Surface water
Oregon
Utah
Nevada
California
Sacramento
Oakland
Fresno
San Jose
Las Vegas
Santa Ana
Anaheim
San Diego
Riverside

Figure 2

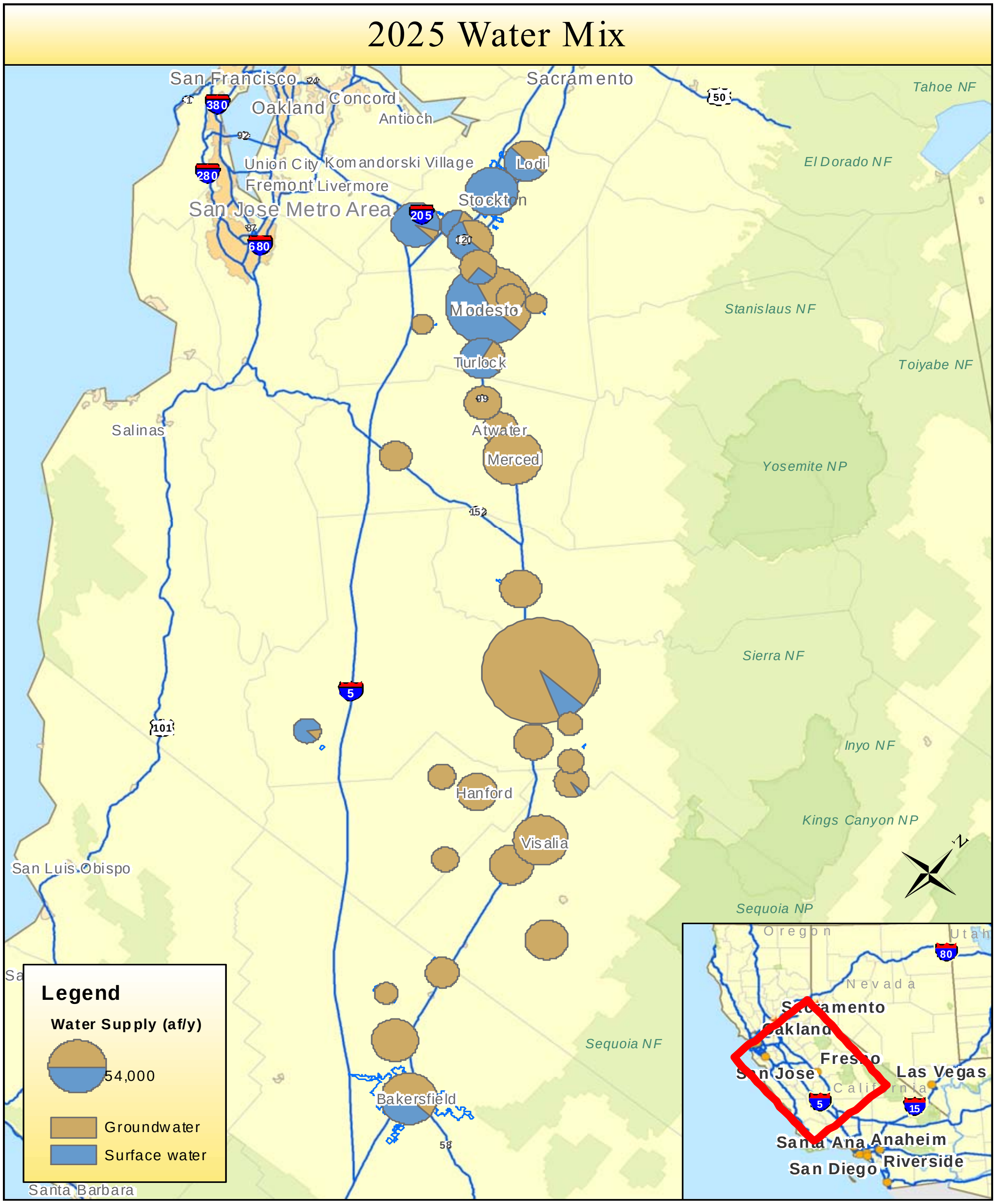
2025 Water Mix
San Francisco
Oakland
Concord
Antioch
Sacramento
Tahoe NF
El Dorado NF
Lodi
Union City
Komandorski Village
Fremont
Livermore
San Jose Metro Area
Stockton
Modesto
Stanislaus NF
Turlock
Toiyabe NF
Salinas
Atwater
Merced
Yosemite NP
Sierra NF
Hanford
Inyo NF
Visalia
Kings Canyon NP
San Luis Obispo
Sequoia NP
Sequoia NF
Bakersfield
Santa Barbara
Legend
Water Supply (af/y)
54,000
Groundwater
Surface water
Oregon
Utah
Nevada
Sacramento
Oakland
Fresno
San Jose
Las Vegas
California
Santa Ana
Anaheim
San Diego
Riverside

Figure 3

Table 9 aggregates these data for the eight counties in the San Joaquin Valley. Fresno County is the largest consumer of groundwater, followed by Tulare and Stanislaus. As Table 10 illustrates, roughly half of all urban water is consumed by single family residences and an additional third by multi-family dwellings.

Table 9: Groundwater Use

County	2005	2010	2015	2020	2025
Fresno	177,442	171,031	205,234	236,815	257,038
	31%	*31%*	*32%*	*32%*	*30%*
Kern	57,267	62,076	68,293	80,447	93,739
	10%	*11%*	*11%*	*11%*	*11%*
Kings	25,733	32,177	36,999	42,681	49,938
	5%	*6%*	*6%*	*6%*	*6%*
Madera	12,886	15,932	19,014	22,692	27,081
	2%	*3%*	*3%*	*3%*	*3%*
Merced	56,274	69,264	83,109	98,034	114,302
	10%	*12%*	*13%*	*13%*	*13%*
San Joaquin	71,508	59,143	63,003	65,183	71,029
	13%	*11%*	*10%*	*9%*	*8%*
Stanislaus	98,746	64,131	80,619	91,137	109,377
	17%	*12%*	*12%*	*12%*	*13%*
Tulare	65,611	80,378	94,131	109,325	126,371
	12%	*15%*	*14%*	*15%*	*15%*
Total	**565,467**	**554,132**	**650,404**	**746,315**	**848,874**
			100%		

Source: Urban water management plans.

Table 10: Urban Water Consumption, 1998

County	Single Family Residential	Multi-family Residential	Commercial	Industrial	Large Land
Fresno	48%	32%	7%	10%	3%
Kern	49%	30%	8%	9%	3%
Kings	48%	32%	7%	10%	3%
Madera	48%	32%	7%	10%	3%
Merced	48%	32%	7%	10%	3%
San Joaquin	54%	14%	6%	17%	9%
Stanislaus	48%	32%	7%	10%	3%
Tulare	48%	32%	7%	10%	3%

Source: DWR; http://www.landwateruse.water.ca.gov/annualdata/urbanwateruse/years.cfm?use=6

2. Population Growth and Land Use Changes

Urban and agricultural landowners are the main water consumers in the San Joaquin Valley, and their future water needs will largely shape the outcomes of potential management scenarios. These needs, in turn, are predicated on the location and extent of future urban growth. Constructing accurate urban growth forecasts is therefore an important first step to a credible analysis of the management alternatives.

Cities in the San Joaquin Valley are surrounded by agriculture, and will grow through a combination of infill development and expansion into present-day farmland (see "Land Use and Conversion" below). However, many unknowns remain within the context of this general pattern. For example, high growth areas will experience an increase in residential and commercial demand, but this demand could be offset by the corresponding losses in farmland needed to expand the urban footprint. Urbanizing what is now irrigated farmland will result in a smaller net increase in water demand than if the city had expanded into grazing land. If fields containing highly salt-sensitive crops are converted to housing, this will affect management efforts differently than if they contained salt-tolerant crops.

These scenarios illustrate how salinity management decisions are contingent on the complex interplay between existing land uses and future expansion. Accurately predicting the location and extent of future urban growth is therefore of primary importance.

3. Model

This analysis builds on work by UC Berkeley urban planning researchers in constructing a spatially-oriented predictive land use model for the State of California (Landis 1997). Discrete observations of land characteristics are obtained by partitioning the study area into a uniform grid and examining temporal land use data in each cell. These data are fed into a discrete choice model, producing estimates of the partial effects on land use decisions of salient covariates. The model is calibrated using historical data and then applied to the present-day landscape, yielding forecasts of future land use.

Formally, consider a partition which divides the study area into a grid of *N* square parcels. Similarly, partition time into two periods, $t \in \{0,1,2\}$. The present day is denoted $t=1$, $t=0$ is some point in the past, and $t=2$ is a point equally far into the future.[32]

Our aim is to forecast future development based on observable data from the initial period. Let D_{it} be an indicator variable equal to one if parcel *i* was developed in period *t*, $1 \le i \le N$ and zero otherwise. Restricting our attention to only those parcels which were not already urbanized in the initial time period, we pose the question: what factors affected development between $t=0$ and $t=1$?

We answer this question in the context of a discrete choice framework. Utility-maximizing developers optimize over the set of vacant land parcels, urbanizing the most desirable locations first. "Desirability" may include factors such as location, slope, proximity to existing infrastructure, freeway accessibility, legal climate, etc. By calibrating the model on historical data, we quantify desirability along each of these dimensions. These estimates are then applied to present-day data, yielding forecasts of the likelihood of development within each parcel.

The set of interest consists of those parcels which became developed between $t=0$ and $t=1$: $U = \{i \mid D_{i1} - D_{i0} = 1\}$. Based on observations on characteristics within and surrounding these parcels, we wish to forecast the likelihood that those parcels which are currently undeveloped

[32] Due to data limitations, we define the year 2004 as present day. See "Data Coverage and Availability," below.

will be urbanized at $t = 2$, that is, $\mathrm{E}\left[D_{i1} \mid D_{i0} = 0\right]$. These probabilities are estimated using a standard binomial logistic model

$$\gamma_i = \alpha + \mathbf{X}_i^T \boldsymbol{\beta},$$

where $\mathbf{X}_i^T$ is a vector of location-specific covariates, α is a constant, β is a vector of parameters and γ is the log odds ratio, $\gamma = \log\left[P(i \in U)/P(i \notin U)\right]$. Historical data, obtained by observing actual decisions made by developers over the past two decades, are used to calibrate this model, yielding the sample parameter vector $\hat{\boldsymbol{\beta}}$. We then substitute present day data for the $\mathbf{X}_i^T$ to obtain out-of-sample fitted values $\hat{\gamma}_i$. These are the inferred values for the future (log) likelihood of development at each land parcel *i* based on past observations. The likelihood ratio can then be transformed to yield the predicted probability of development at *i*.

Finally, post estimation adjustments are performed to correct for areas where known land use policies completely preclude development. Two such examples are conserved lands falling under state and/or federal jurisdiction, such as national parks and forests, and land which is zoned as open space under a city or county general plan. Parcels in either of those two classifications were assumed to have no probability of development.[33]

4. Implementation

Following Landis (1999), four categories of explanatory variables are included in the model. Demand variables measure a location's proximity to jobs and relative wealth. Geographic variables measure time-invariant landscape features such as slope, elevation and soil quality. Political variables indicate whether a site is within an incorporated city and account for county-level variation in development patterns and regulation. Finally, neighborhood variables repeat some of these measures for the areas surrounding a parcel.

a) Demand Variables

Three measures of demand were included in the model. First, neighborhood-level median household income was measured relative to the county-level median to control for local socioeconomic characteristics which might influence development patterns. As Landis (1999) notes, sites in upper income communities may be less likely to be developed if higher earners prefer open space.[34] A second demand measure was constructed to model job accessibility. California job markets tend to be regional in nature, with a network of urban cores surrounded by suburban and exurban residential development. Employment opportunities are rarely confined to a single city, and it is important to allow for this feature when modeling. We model job accessibility by summing the total populations of the incorporated cities within a one hour drive of a given development site, providing a measure of the jobs that are available within an average commute radius.[35]

[33] A lack of historical zoning data prevents the inclusion of this effect in the model; in any case, it is likely a perfect or near-perfect predictor of the response variable, violating a key regression assumption.
[34] We define neighborhood-level as the finest Census aggregation unit for which data are available. For the 1990 and 2000 Census, this is the block group. For the 1980 census, it is the tract.
[35] There are several conceivable ways to measure employment opportunities proximate to a given location, however most are infeasible due to data constraints. For example, there are no historical job censuses for the study area which meet the needs of the model.

Finally, we measure Euclidean distance to the nearest major interstate or state highway. Disincentives associated with developing both too close and too far from major transportation arteries suggest development likelihood is likely nonlinear in this parameter. Accordingly, we also added the squared distance to the model.

b) Geographic Variables

Three geographic variables were included in the model. The first is slope. Slope strongly informs development patterns and is usually negatively correlated; increasing slope decreases development potential to the point where areas with a slope exceeding 20% are rarely developed.

The model also includes an indicator variable denoting presence in the 100-year flood plain, defined by the Federal Emergency Management Agency as the locations that have a 1% chance of flooding in any given year. Presence in the flood plain is a strong disincentive to housing development.

A factor that may be especially important in determining future development in the lower San Joaquin Valley is soil quality. Most land that becomes urbanized in the area was previously farmland. Within the context of potentially developable farmland, soil quality likely influences which parcels are ultimately converted. We control for this by adding an indicator variable equal to one if a parcel is classified as "prime" farmland. This classification, developed by the USDA, applies to areas with soil characteristics which are especially good for agricultural production. It seems likely that conversion from farmland to housing will occur first on areas that are least productive, and, conversely, that prime farmland would be among the least likely areas to be urbanized.

c) Political Variables

Two political variables were added to the model to account for the effect of political boundaries on growth. The first indicates whether a parcel is in an incorporated city. Access to urban services like water, garbage disposal and sewage is highly desirable for residential locations. Remaining parcels of undeveloped land within the city limits are relatively more likely to be developed that those outside of the city.

Fixed effects were also added to control for idiosyncratic growth policies pursued by individual counties. A common example is a density requirement specified in a county's general plan. All other factors equal, a county with higher density requirements will experience smaller urban footprint growth. While it is difficult to model the full gamut of development policies pursuable by a county, the fixed effects help to absorb this variation.

d) Neighborhood Variables

Neighborhood variables represent averages of several of the measures described above for the area surrounding a given location. These variables help to control for autocorrelation, a statistical condition inherent to spatial datasets which potentially biases parameter estimates. We added variables for the mean values of slope, the flood plain indicator, and the prime farmland indicator within a 1km radius of each parcel as well as its mean within a 2-3km ring.

An additional neighborhood variable measures the percent of developed land within a 5km radius of each parcel. In addition to controlling for autocorrelation, this also has an economic interpretation. Holding other factors constant, parcels located near existing development are more likely to be developed since cities tend to grow from the fringes outward. Developing away from existing commercial and residential structures, known as "leapfrogging," is costly and atypical, since homes cannot connect to pre-existing infrastructure.

F. Data Sources

1. Farmland Mapping and Management Program

The California Farmland Mapping and Management Program (FMMP) is a biennial survey of land use conducted by the state's Department of Conservation. Categories include urbanized land, water features, and several gradations of farmland. The data are used to construct snapshots of the development landscape in both the initial and current time periods. By comparing urbanized land at $t = 0$ and $t = 1$, we form the urban conversion component (dependent variable) of the discrete choice framework described above.

a) Data Coverage and Availability

The FMMP currently categorizes nearly 96% of the state's privately held land, making it well suited for the study of land use conversion. The oldest available FMMP surveys are from 1984. Coverage has evolved over time from an initial extent of 30.3 million acres in 38 counties to the current 47.9 million acres in 49 of the 57 California counties. Of the eight counties in the study area, five were surveyed in every time period. FMMP surveys have a resolution of 10 acres, or approximately $200m^2$. Accordingly, this was the unit of analysis adopted for this study.

Three counties were not surveyed until several years after the program started. Tulare and Kern were not added to the survey until 1988, and San Joaquin was not added until 1990. For the purposes of model calibration, surveys from the earliest available year for each county in the study area were composited to form a uniform data set. Subsequent references to 1984 FMMP data in this study refer to the first available year in these three instances. The most recent available survey for all counties was conducted in 2004. These two points are referred to throughout the study as initial ($t = 0$) and present ($t = 1$) time, respectively.

Within surveyed counties, some omissions still remain. In keeping with its mandate to "[assess] the location, quality, and quantity of agricultural lands and conversion of these lands over time," the program does not study areas which are not arable or have no agricultural use. Figure 4 maps coverage in 1984 and 2004 over the study area. Lands comprising the Sequoia-Sierra-Stanislaus system of national forests and parks are not surveyed in either year since no agricultural activities can occur in those areas. By the same reasoning, these areas face no potential for development, so their omission is not material to this study.

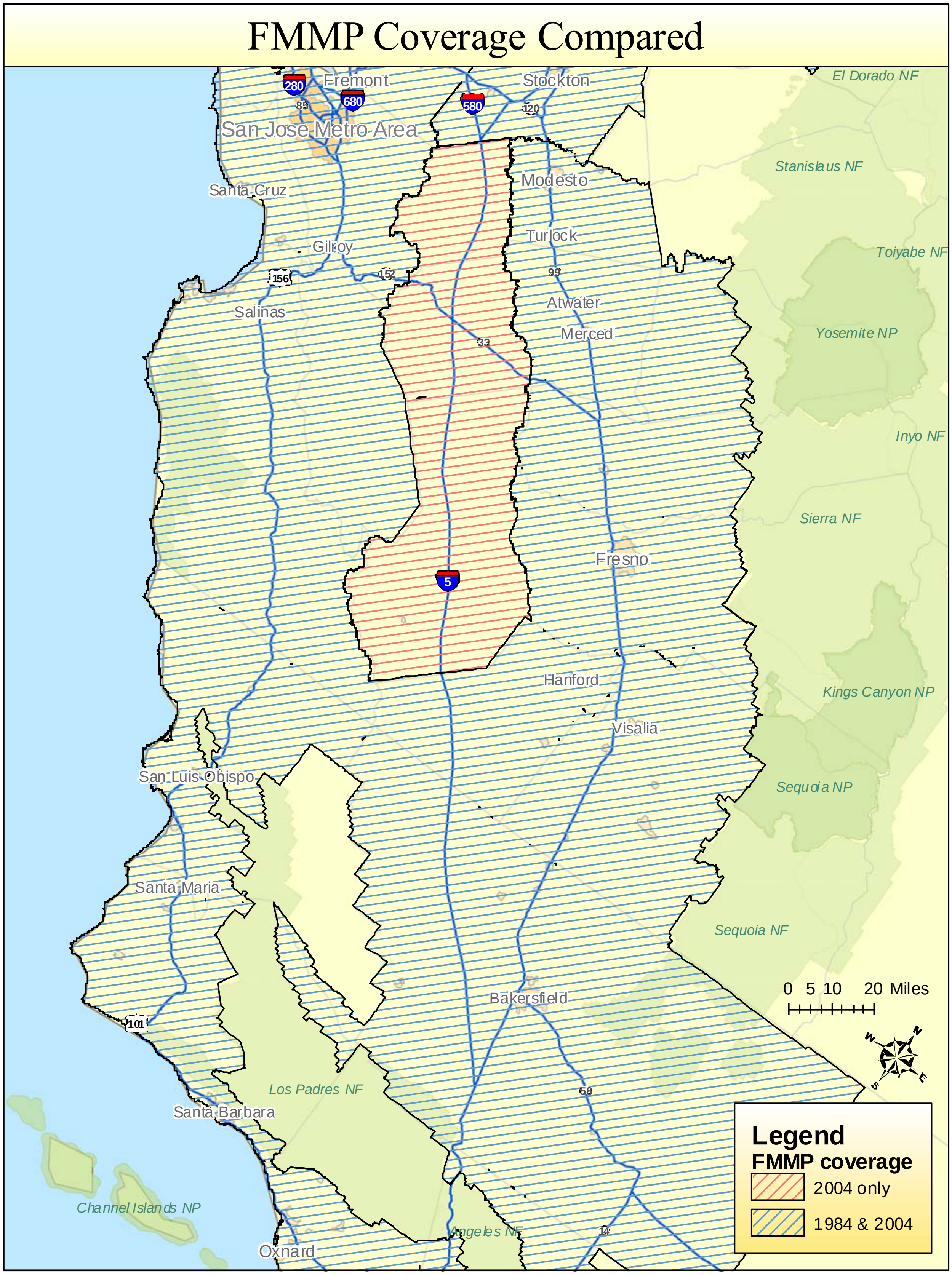
FMMP Coverage Compared
Fremont
Stockton
San Jose Metro Area
El Dorado NF
Stanislaus NF
Modesto
Santa Cruz
Turlock
Gilroy
Toiyabe NF
Salinas
Atwater
Merced
Yosemite NP
Inyo NF
Sierra NF
Fresno
Hanford
Kings Canyon NP
Visalia
San Luis Obispo
Sequoia NP
Santa Maria
Sequoia NF
Bakersfield
0 5 10 20 Miles
Los Padres NF
Santa Barbara
Channel Islands NP
Oxnard
Angeles NF
Legend
FMMP coverage
2004 only
1984 & 2004

Figure 4

b) Uses

FMMP data were used in several manners. First, they were used to study general trends in urbanization and farmland conversion within the study area. For further discussion of this topic, refer to "Land Use Changes" below. Within the model, variables pertaining to urbanization were constructed by comparing FMMP data in the initial and present years. Cells that were not classified as "urban and built-up land" in 1984, but which were in 2004, were deemed to have "urbanized" over that time period. Cells which were already urbanized in 1984 were excluded from the model.

FMMP data were also used to create maps of the state's "prime" farmland according to USDA classification, as described in the Geographic Variables section above.

1. FEMA

The Federal Emergency Management Administration publishes maps of the 100-year flood plain, as described in the Geographic Variables section above.

2. NED

The National Elevation Dataset is a United States Geological Survey data product containing elevation readings for the conterminous United States. The data are updated continually using the latest advances in remote sampling technology and are highly accurate. NED data were used to calculate slope, which is often negatively correlated with development; hillside development decreases feasible density, and development is impossible on extremely steep slopes.

3. US Census

Data from the 1980, 1990 and 2000 Decennial Censuses were used to construct demand variables. County and neighborhood median income data were obtained directly from the Census with no additional manipulation. Similarly, job accessibility was calculated using raw population counts from the three censuses.[36]

A second demand measure was constructed to model job accessibility. In doing so, it is important to model the polyurban as described in the Demand Variables section above.

A variable reflecting proximity to highways was constructed using data from the Census Topologically Integrated Geographic Encoding and Referencing system. Commonly referred to as TIGER, this database digitally maps every street, road, highway and water feature in the United States. Archived releases of TIGER were used to reconstruct historical road features where they differed from present.

4. Planning Data

Maps of city and county general plans were used to highlight conserved areas where development is not foreseeable (see "Model" above). They were derived from several sources, including the respective planning organizations of Stanislaus, San Joaquin, Merced, and Madera,

[36] There are several ways in which to gauge job accessibility. In this study, the primary factor governing the choice of measure was data availability; no reliable, thorough job census was available for the study area in the initial time period.

as well as a statewide layer of planning information assembled by researchers at the University of California, Davis.

G. Results

Regression results are presented in Table 11; fixed effects for the 38 counties in the data are omitted for brevity. Roughly 3.8 million observations were used to calibrate the model, yielding an overall (pseudo) R2 of .359. All coefficients, including fixed effects, are significant at well below the 1% level.

Table 11: Model Results

Variable	Coefficient
Prime farmland?	-0.08
	(6.70)**
In FEMA flood plain?	-0.64
	(26.58)**
% within 1km in FEMA flood plain	-1.04
	(25.18)**
% within 2-3km in FEMA flood plain	0.43
	(11.00)**
Slope	-0.10
	(39.79)**
Avg. slope within 1km	-0.27
	(67.77)**
Avg. slope within 2-3km	0.12
	(41.91)**
Distance to nearest highway (km)	-0.217
	(64.34)**
$Distance^2$ to nearest highway (km^2)	0.01
	(23.53)**
Population within 1hr commute (millions of people)	0.227
	(86.02)**
% urbanized within 5km	5.12
	(164.41)**
Within city limits?	1.02
	(97.00)**
Neighborhood : county income ratio	0.48
	(35.71)**
Constant	-4.06
	(117.14)**
Observations	3,579,402
Pseudo-R2	0.3587
Absolute value of z statistics in parentheses	
* significant at 5%; ** significant at 1%	

Parameter estimates generally conform to what is expected from economic theory. Slope and presence in a flood plain negatively affect the likelihood of development, including when averaged over the surrounding 1km area. Highway distance is quadratically related to development, confirming the presence of disincentives for developing too close and too far from transit arteries. Prime farmland records a small negative coefficient, demonstrating that soil quality only slightly affects development choices. Job availability, as measured by the number of people within a one hour commute, is only moderately positive; this effect may capture other externalities associated with developing near the existing urban network.

The effect of job availability is captured in a more direct manner by two variables which have the largest positive effects on development: the percent of area urbanized within five kilometers, and the presence within city limits. Undeveloped parcels within city limits stand a high chance of development provided that they are not being intentionally preserved.[37] The nearby presence of urban development is the single largest factor driving future urbanization. The coefficient on percent urbanized within five kilometers is positive and is the highest in magnitude of all the variables in the model, reflecting the large economic benefits associated with developing close to existing urban infrastructure. Readily-available road and utility networks lower the average cost of construction for developers. Homeowners tend to prefer these locations as well, for their proximity to existing shopping, schools and jobs. This interpretation is also consistent with observed growth patterns over the past two decades, which find that so-called "leapfrogging" is uncommon in the study area; growth generally occurs around the edges of existing cities.

H. Land Use Changes

Land use is the strongest predictor for water demand and also plays a primary role in determining the benefits and costs of the analyzed scenarios. This section examines historical land use and conversion in order to establish a baseline against which to measure forward-looking effects.

1. Comparative Growth Rates

Table 12 compares past and future growth rates for the region.[38] The second column displays the net increase in urban footprint for each county, and the third column expresses this as a percentage of the size of the 1984 urban footprint. All counties witnessed substantial growth.[39] Leading the region was Kings County, where the total urbanized area nearly doubled from 1984 to 2004. Other counties grew by between 24 and 45 percent. A total of 141,661 acres of land were urbanized between 1984 and 2004. Kern County experienced the greatest absolute growth, with 37,758 acres of land urbanized, followed by Fresno and San Joaquin.

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[37] FMMP surveys contain no mention of zoning, so it was necessary to perform some corrections to the model to compensate for the existence of parks, etc. within city limits. See

[38] This section discusses growth in terms of the size of the urban footprint. An additional axis along which to measure growth is population. For a discussion of projected population growth, refer to section XX.

[39] A portion of the calculated changes in growth is due to the inclusion of additional land in the FMMP survey area over time. However, these effects are minor since most of the additional areas contain farmland. See "Data Coverage and Availability," above.

Table 12: Past and Future Urbanization

County	1984—2004	1984—2004 % Change	2004—2024	2004—2024 % Change	Future vs. Past % Change
Fresno	28,822	39%	54,607	53%	89%
Kern	37,758	45%	33,601	28%	-11%
Kings	14,639	92%	16,258	53%	11%
Madera	5,249	27%	9,922	40%	89%
Merced	5,100	24%	14,850	56%	191%
San Joaquin	20,371	32%	30,052	36%	48%
Stanislaus	14,411	35%	25,072	45%	74%
Tulare	15,311	40%	20,867	39%	36%
Total	**141,661**		**205,229**		**45%**

For comparison, the table also presents results from the urban growth model. The fourth and fifth columns contain the expected acres of growth within each county and the relative percent increase represented by this total. Column six compares the expected growth over the next two decades with the observed growth over the past two (columns four and two.)

Looking forward to 2030, an additional 205,229 acres are expected to become urbanized, representing a 45% increase over the initial time period. Urbanization will generally accelerate over the coming two decades; however growth rates vary widely between counties. Kern County will experience a decline in its growth rate, with roughly 4,000 fewer acres expected to become urbanized over the next two decades than in the two preceding. The remaining counties will experience larger growth in the urban footprint between 2004 and 2024 than they did between 1984 and 2004. Merced will see the largest jump in growth, with nearly three times (191%) as many acres becoming urbanized compared to the initial time period. Two other counties, Fresno and Madera, will experience almost double growth.

Growth is also accelerating in most counties when considered in relative terms; column four exceeds column two in five of eight counties. The county with the greatest relative increase is Merced, where future growth in the urban footprint will be 32% larger than over the past two decades. Kings County will experience the largest relative decline at 39%.

2. Land Use and Conversion

The effects of urban growth on the management scenarios contemplated in this study depend on both its magnitude and location. For example, urbanization of farmland affects baseline water use differently than if a city expands into vacant land. Historical trends in land use are an important indicator of how urban expansion will occur.

Figure 5 maps FMMP data for the entire study area in 1984 and 2004. From this broad perspective, land use in the San Joaquin Valley is stable and agriculture-oriented. Farming and grazing are the predominant uses both today and in the past. Urbanized land comprises a small portion of the landscape, although it is growing measurably. Urban growth tends to occur around existing cities; there is little evidence of growth over the past 20 years in areas that were not already urbanized to some degree.

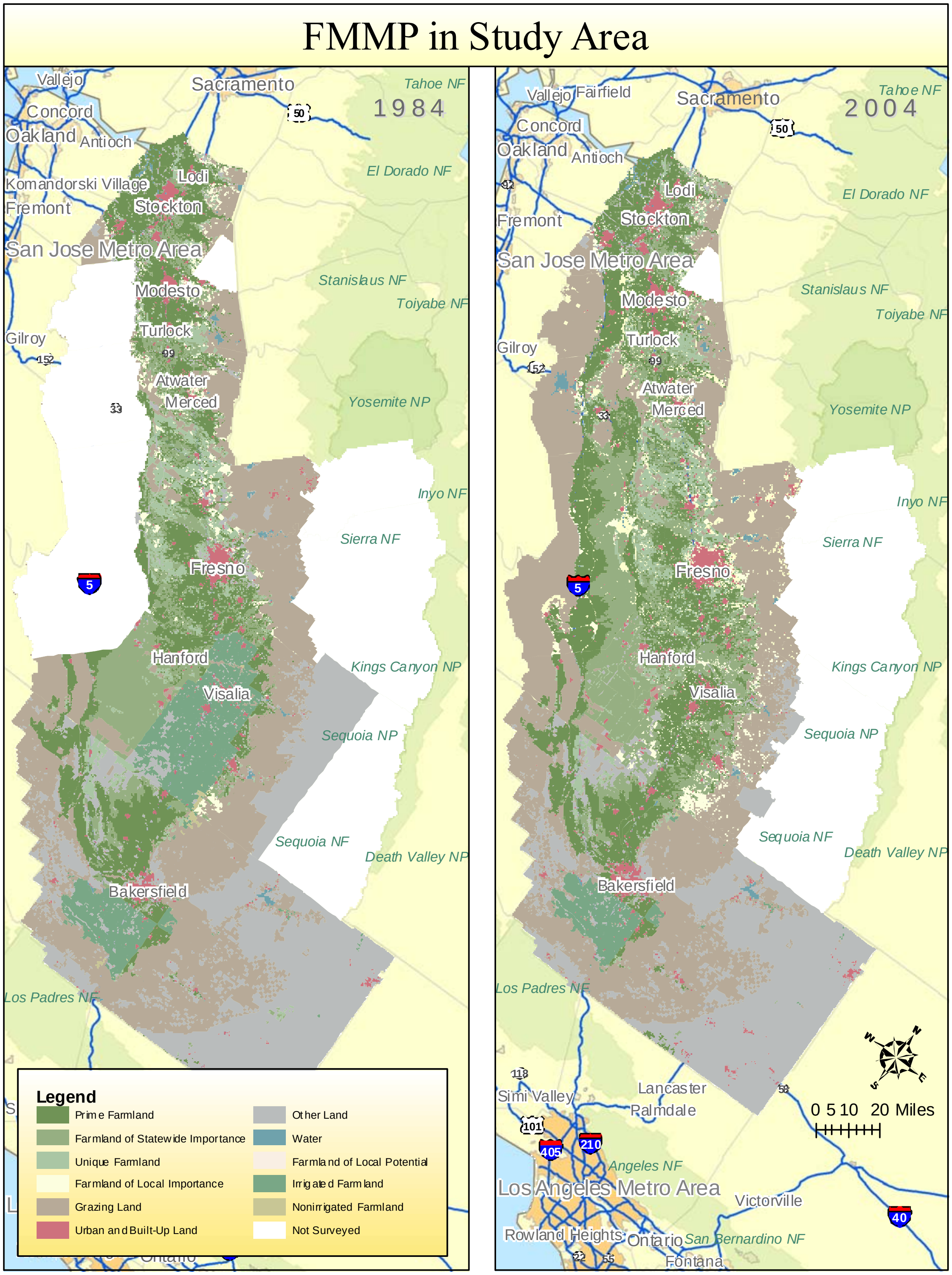
FMMP in Study Area
1984
2004
Sacramento
Vallejo
Fairfield
Concord
Oakland
Antioch
Komandorski Village
Fremont
Lodi
Stockton
San Jose Metro Area
Modesto
Turlock
Gilroy
Atwater
Merced
Fresno
Hanford
Visalia
Bakersfield
Tahoe NF
El Dorado NF
Stanislaus NF
Toiyabe NF
Yosemite NP
Inyo NF
Sierra NF
Kings Canyon NP
Sequoia NP
Sequoia NF
Death Valley NP
Los Padres NF
Simi Valley
Lancaster
Palmdale
Angeles NF
Los Angeles Metro Area
Victorville
Rowland Heights
Ontario
San Bernardino NF
Fontana
0 5 10 20 Miles
Legend
Prime Farmland
Farmland of Statewide Importance
Unique Farmland
Farmland of Local Importance
Grazing Land
Urban and Built-Up Land
Other Land
Water
Farmland of Local Potential
Irrigated Farmland
Nonirrigated Farmland
Not Surveyed

Figure 5

These trends are confirmed when quantified. Table 13 compares land use in 1984 and 2004. The first column provides the total area within the county for reference. The next group of three columns displays total farmland measured for both years, along with the percent change within the two years. The succeeding group repeats these measures for grazing land. The two final columns contain the total amount of farm and grazing land that was converted to urban land over the 20-year time span.

The table illustrates prevailing land use patterns in the Central Valley which can be expected to continue into the future. First, agriculture is and will continue to be the primary land use in the region. In each county in both years, the majority of arable land was devoted to farming or grazing activities.[40] Relative to agriculture, urban use is a small fraction of the overall landscape: ratios of agricultural to urbanized land in 1984 varied from 10:1 (Stanislaus) to 54:1 (Kings.) In 2004, those figures declined slightly, indicating increasing urbanization, to between 7:1 (Stanislaus) and 30:1 (Kings).

This decline illustrates the gradual conversion of farm and grazing land to urban uses which is occurring throughout the region. Overall, farmland has declined by 3% and grazing land by 1% over the past 20 years. Seven of the eight counties in the region experienced a decline in total farmland while one, Tulare, saw a 9% increase.[41] Similarly, grazing land decreased in six of the eight counties, with Tulare experiencing the largest decrease at 14%. Two counties, Kern and Kings, saw three and five percent increases in total grazing land; they also experienced the largest decline in farmland, illustrating the substitutable nature of these two activities.

The final two columns in Table 13 tabulate the areas which became urbanized between 1984 and 2004. Two findings are immediately evident. First, farm to urban conversion tends to eclipse the urbanization of grazing land by a wide margin. This is consistent with the notion that cultivated lands tend to be located nearest existing cities as a means of increasing packing, transportation and labor efficiency. Second, comparing these results with those of Table 12, it is clear that farmland conversion largely explains the growth in urban footprint observed over that time period; the figures closely align for most counties. A typical example is Kings County, depicted in Figure 6. In 1980, the cities of Hanford and Lemoore were completely surrounded by prime farmland and farmland of statewide importance. Virtually all expansion seen by 2004 occurred through the conversion of farmland to urban purposes.

Some outliers require further explanation. Kern County saw urbanization equal to more than twice the amount of converted farmland. Figure 7 shows maps of the county for both years. The city of Bakersfield can be seen expanding mainly to the west of State Highway 99, into areas that were not used for either farming or ranching in 1984. Future development could expand into the fields surrounding the western portion of the city, or also to the northeast, where additional grazing and nonagricultural land is found.

[40] Numbers do not represent a full census within each county, but do reflect a near complete count of all arable land. See "Data Coverage and Availability," above, for further discussion on FMMP sampling methodology and criterion.
[41] This increase was primarily the result of the cultivation of grazing land in the region east of Porterville, south of highway 198, and north of the White River.

Table 13: Land Use

		Farmland In			Grazing Land In			Urbanized, 1984—2004	
County	**Total Acres**	**1984**	**2004**	**% Change**	**1984**	**2004**	**% Change**	**Farmland**	**Grazing**
Fresno	3,851,267	653,238	634,883	-3%	334,027	319,290	-4%	22,220	840
Kern	5,223,345	1,067,950	969,572	-9%	1,730,074	1,789,458	3%	16,101	3,163
Kings	890,657	641,555	605,280	-6%	222,681	233,198	5%	11,377	3,805
Madera	1,378,184	387,254	371,597	-4%	407,309	399,698	-2%	4,468	3,143
Merced	1,261,121	413,902	408,248	-1%	216,870	212,807	-2%	7,818	415
San Joaquin	911,726	637,275	622,567	-2%	156,774	147,225	-6%	19,828	385
Stanislaus	969,630	290,062	280,988	-3%	124,225	114,509	-8%	14,658	79
Tulare	3,098,359	799,356	873,537	9%	512,062	440,658	-14%	12,375	613
Total	**17,584,290**	**4,890,591**	**4,766,673**	**-3%**	**3,704,021**	**3,656,843**	**-1%**	**108,845**	**12,444**

Kings County FMMP

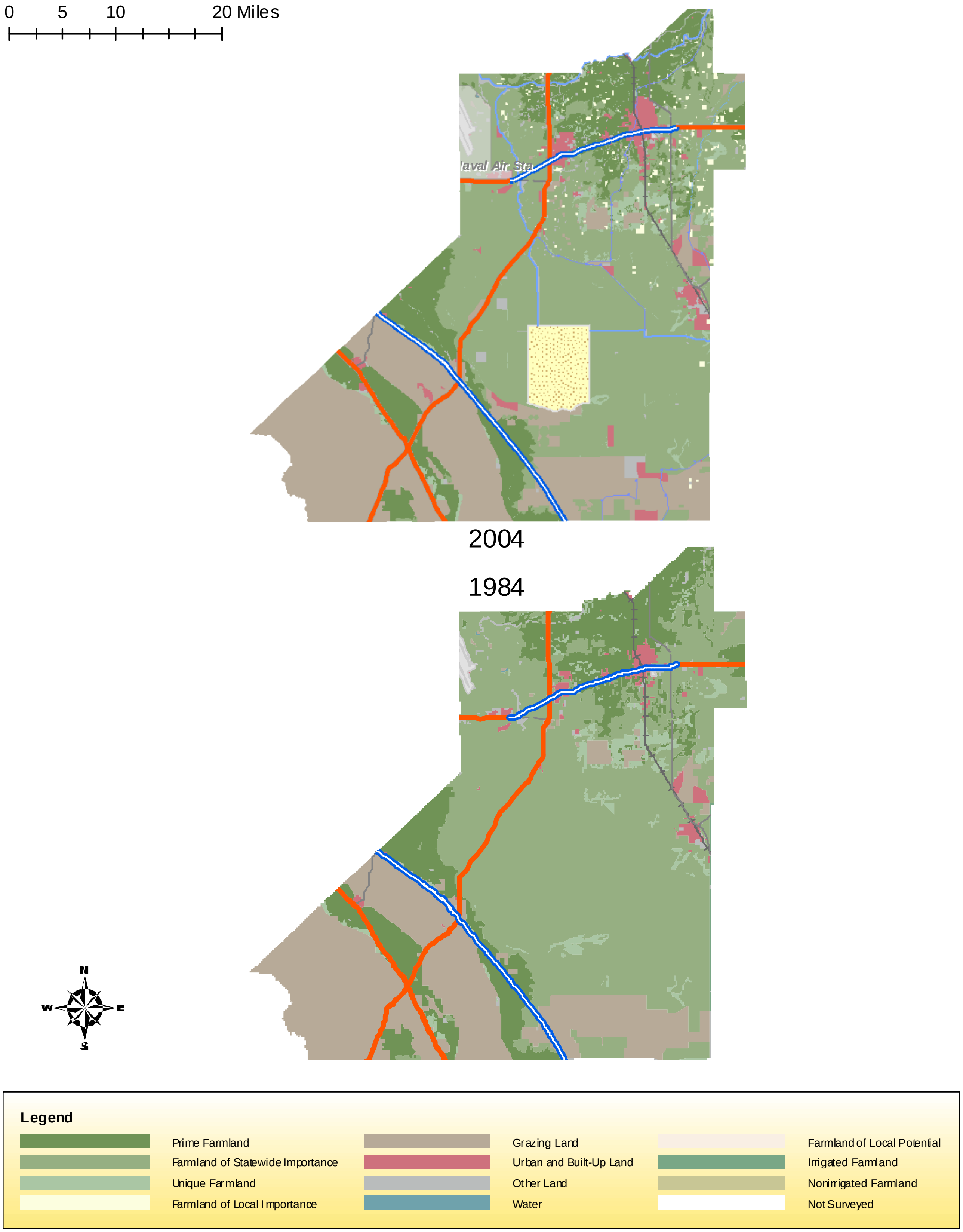

Figure 6

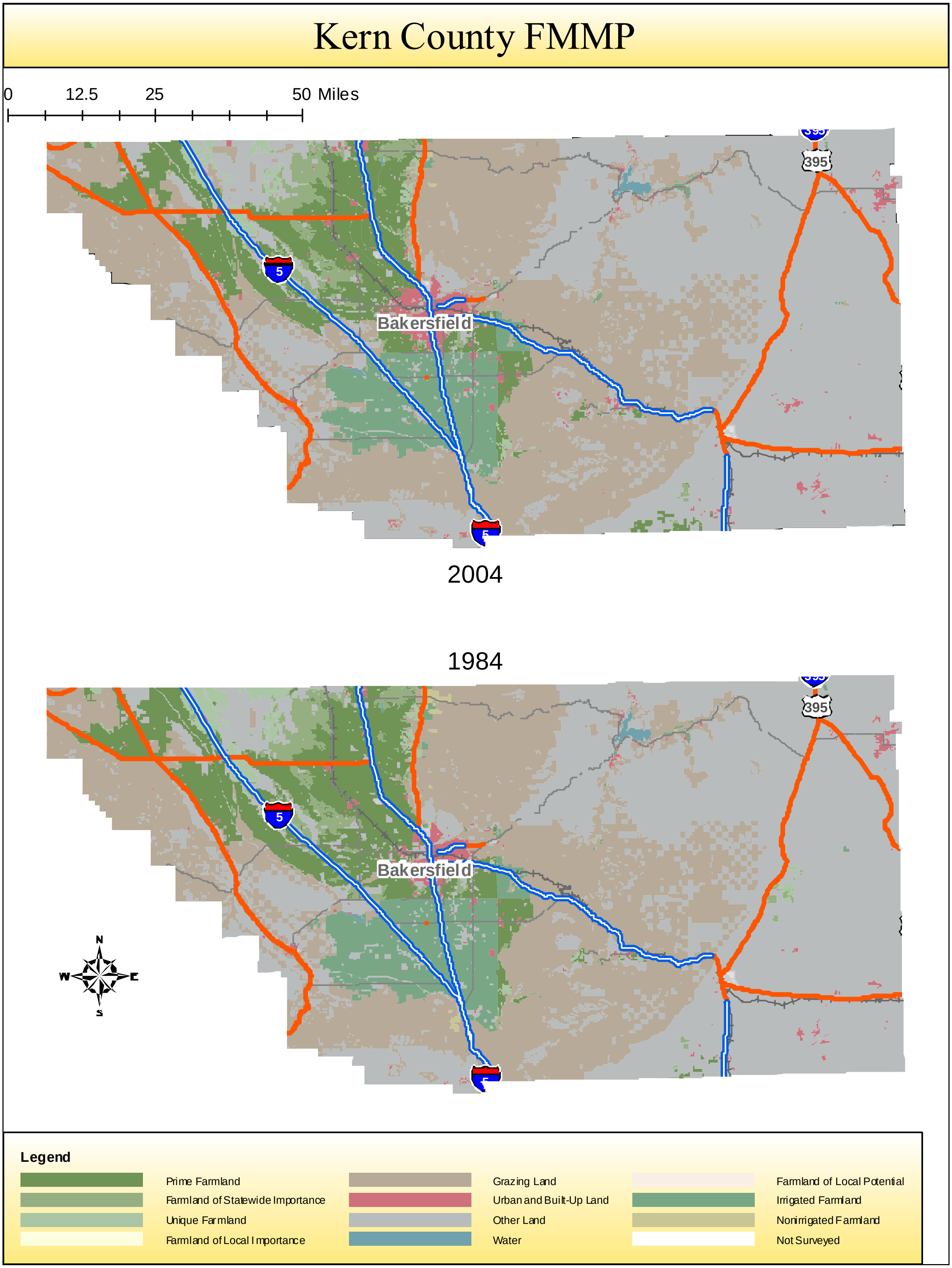
Kern County FMMP
0 12.5 25 50 Miles
Bakersfield
5
395
2004
1984
Bakersfield
5
395
N
W
E
S
Legend
Prime Farmland
Farmland of Statewide Importance
Unique Farmland
Farmland of Local Importance
Grazing Land
Urban and Built-Up Land
Other Land
Water
Farmland of Local Potential
Irrigated Farmland
Nonirrigated Farmland
Not Surveyed

Figure 7

III.2 Benefits of Groundwater Quality Improvements

As described in the Board's Salinity Overview, there is growing concern that increasing salinity concentrations will harm consumers, agriculture, industry, and the environment in the Central Valley.[42] In this section we review the evidence regarding these costs and provide dollar estimates. This information is essential to the balancing test required under California's anti-degradation policy, according to which regulators must compare the benefits that would be achieved by reducing or limiting salinity concentrations measured by the costs on consumers, agriculture, industry, and the environment avoided by such reductions or limitations.

A. Consumer Costs

Groundwater quality degradation affects residential water users by causing capital depreciation and negatively affecting taste.[43] Capital depreciation results from accelerated mineral buildup and corrosion of plumbing fixtures and water appliances. Small variations in taste may have no economic consequence, but a large degradation will produce a behavioral response in water consumers, for example through the purchase of home water softeners or dispensed water.

Several studies have investigated the effects between changes in salinity levels on households.[44] The most common household costs associated with increased salinity are:

- accelerated depreciation of water fixtures and appliances, including:
  - water pipes
  - faucets
  - garbage disposals
  - washing machines
  - dishwashers
  - water heaters
- investment in water softeners; and
- investment in home water treatment.

One of the most comprehensive studies was performed by the Metropolitan Water District in 1999. The study found that a TDS concentration decrease of -100mg/L leads to approximately $43 million in annual residential benefits across all MWD users.[45]

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[42] Central Valley Regional Water Quality Control Board, "Salinity in the Central Valley, An Overview," May 2006. These are consistent with the definitions of beneficial use.
[43] The salinity concentration at issue here do not represent human health risks so there are no consumer effects associated with this potential beneficial use category.
[44] A review of these studies can be found in Bookman-Edmonston Engineering, "Economic Impacts of Changes in Water Supply Salinity and Salinity Economic Impact Model," Final Report, Technical Appendix 5 in Metropolitan Water District of Southern California and United States Bureau of Reclamation, "Salinity Management Study Final Report," June 1999.
[45] *Ibid*, TA5-4. Prices adjusted for inflation.

This section details the mathematical relationships that were adapted to model depreciation and consumer response behavior due to salinity. Economic impacts of reduced life for water-using appliances and plumbing are calculated by determining the life span of the appliance or plumbing at different salinity levels. If higher salinity levels reduce the life span, the annualized cost of purchasing the appliance increases. For example, a $100 appliance lasting five years has an annual cost of $20. If the appliance lasted ten years at a lower salinity level, the annual cost would be $10.

1. Capital Depreciation

To determine capital depreciation, the study modeled the lifespan of various water fixtures and appliances as a function of water salinity, $f(T)$, where T is salinity measured in TDS (mg/L). This function can be used to determine an annualized cost for each appliance at a given salinity level by dividing the replacement cost of the appliance by the expected lifespan. The annual economic loss resulting from an increase in salinity is then the difference in annualized costs:

$$L = C\left(\frac{1}{f(T_1)} - \frac{1}{f(T_0)}\right),$$

where L is the annual loss, C is the replacement cost, and T_1 and T_0. The overall annual capital cost of a salinity increase is then the weighted average annual loss across all appliances and plumbing fixtures:

$$L_K(T_0, T_1) = \sum_i p_i L_i \, ,$$

where p_i is the percentage of residential users who have appliance *i*. Because the study focused on MWD's service area, these shares were recomputed for the representative area (
Table 15). Appliance replacement costs were also updated to reflect current economic conditions using the most recent Residential Cost Handbook, published by Marshall & Swift (Table 16).

To measure the cost of responses to water taste, the study determined the elasticity of consumption for water softeners and dispensed water with respect to salinity by surveying MWD customers. Market surveys were also performed to estimate the annual operating costs of water softeners, and the annual expenditures for dispensed water. The total annual cost due to taste changes is then

$$L_T(T_0, T_1) = C_S\left[p_S(T_1) - p_S(T_0)\right] + C_D\left[p_D(T_1) - p_D(T_0)\right]$$

where $C_S\,(C_D)$ is the annual per-capita operating cost for water softeners (dispensed water), and $p_S\,(p_D)$ is the percent of households that have a water softener (water dispenser) at a given TDS level.

The overall annual cost to residential consumers of increased salinity is then $L_T + L_K$.

a) Galvanized and Copper waters supply pipes

Several studies did not find evidence of reduced life of copper, plastic, or cast iron pipes due to TDS. According to the study it was concluded that all new houses have copper piping for water and plastic piping for wastewater, and that the existing galvanized and cast iron piping in older homes are being replaced with copper and plastic as they wear out. Based on available housing information for the Metropolitan service area, it was estimated that about 13 percent of houses have galvanized piping for water service that are subject to TDS impacts.[46]

b) Water Heaters

Most investigations reviewed in the study did find a correlation between TDS and the useful life of water heaters. While there is speculation on the relationship between the use of water softeners and the life span of water heaters, there is no data to establish what that relationship may be. A case could be made that water softeners either increase or decrease the life span of water heaters. However, there is no basis to quantify the life span of water heaters as a function of water softener use. Thus, no adjustment has been made for the presence of water softeners.[47]

c) Faucets and Garbage Disposals

Several studies report data on faucets. Each of these studies notes that the data gathered was extremely inconsistent. While manufacturing technology has changed (more plastics, reduced lead), there is no basis to quantify the impacts of these changes on the life span of faucets.[48] Several studies examined in the MWD research showed a relationship between TDS and life span of garbage disposals.[49]

d) Toilet Flushing Mechanisms

The Metropolitan study discusses the relationship between the life span of toilet tank mechanisms and TDS. The toilet mechanisms were previously manufactured with copper and brass at that time of one study. Today, toilet flushing mechanisms are made of plastic with small amounts of stainless steel and occasionally copper alloy screws. Technology has changed substantially and the available data is not applicable to existing technology. Plastic is inert in saline solutions. No statistically significant relationship was found between life of modern toilet flushing mechanisms and TDS levels. There are no identifiable economic impacts from TDS on toilet flushing mechanisms. Thus, no impacts are included in this investigation.[50]

e) Washing Machines and Dishwashers

One of the studies reviewed by Metropolitan found the relationship between TDS and the life span of washing machines to be statistically significant. Another study combined the data on washing machines and dishwashers. Metropolitan indicated that roughly 10 percent of Maytag's washers now come with plastic tubs. Also, pump impellers and volutes are plastic. While it appears likely that these changes have reduced the impacts of salinity, we have no basis to quantify the change.[51] The review of studies related to dish

[46] *Ibid* TA5-10
[47] *Ibid* TA5-8
[48] *Ibid* TA5A-9
[49] *Ibid*
[50] *Ibid*
[51] *Ibid*

washers was varied. One study did not find the relationship between dishwasher life span and TDS to be statistically significant at the 10 percent level. Another study did not address dishwashers. One study did find a statistically significant relationship for dishwashers, however, there was no data available to quantify the impacts of changes in materials.[52]

2. Impact Functions

Table 14 summarizes the inputs to the model for calculating the economic impacts of salinity on water using appliances and plumbing. Based on this review of available information, there is no basis to quantify any changes in the impact functions previously identified in the 1988 study for these items.53 Since some aspects of the study were proprietary to the MWD service area and customer base, several assumptions were updated to better reflect conditions in the valley. Specifically, data on unit cost and market penetration of different water appliances and fixtures were recalculated to better reflect conditions in the representative area in 2007. These changes are summarized in

Table 15 and Table 16.

Table 14: Impact Functions

Item	Impact Function (y = useful life (years), x = TDS (mg/L))
Galvanized Water Pipe	$y = 12 + \exp(3.4 - .0018x)$
Water Heaters	$y = 14.63 - .013x - .689(10^{-5})x^2 - .011(10^{-8})x^3$
Faucets	$y = 11.55 - .00305x$
Garbage Grinders	$y = 9.23 - .00387x + 1.13(10^{-6})x^2$
Clothes Washers	$y = 14.42 - .0114x + .46(10^{-5})x^2$
Dishwashers	$y = 14.42 - .0114x + .46(10^{-5})x^2$

Table 15: Percent of Residences with Appliances

	Percent of residences with appliance in		
Item	**MWD**	**RA**	**Source**
Galvanized steel pipes	13%	5%	Recalculated
Water heater	97%	100%	Assumed
Faucet	100%	100%	Assumed
Garbage disposal	75%	82%	American Housing Survey
Washing machine	67%	79%	American Housing Survey
Dishwasher	51%	77%	American Housing Survey

[52] *Ibid* TA5A-10
[53] *Ibid*

Table 16: Replacement Costs

Item	1999 (MWD study) *Replacement cost in*	Current
Galvanized steel pipes	$2,600	$12,450
Water heater	$300	$750
Faucet	$442	$905
Garbage disposal	$120	$205
Washing machine	$425	$575
Dishwasher	$450	$575

3. Dispensed Water and Home Water Treatment

In order to avoid the impacts of high salinity, residents may choose to purchase dispensed water or to install home water treatment systems. Studies have established relationship between dispensed water purchase and TDS, and between installation of water softeners and TDS. These impacts are quantified by determining the additional expenditures as salinity increases. Table 17 displays these relationships. For each component, demand (expressed as a percentage of the total user base) was estimated as a function of TDS. Multiplying the resulting percentage by the total number of residential accounts yields overall demand. Finally, total cost is calculated as the product of total demand and the annual cost of operation for each method. Annual costs have been updated from the initial study to reflect current prices.[54]

Table 17: Water Treatment & Dispensed Water Costs

Avoidance Method	Household Uptake (% of users)	Annual Cost
Water Softener	$6.758 + .007TDS + 3.01(10^{-6})TDS^2 + 2.2(10^{-10})TDS^3$	$434
Filtration / Dispensing	$.611 + 3.23(10^{-5})TDS$	$79

B. *Agriculture*

Water quality has a strong determining effect on agricultural production. This section examines this effect within the study area. A considerable body of academic research has been devoted to quantifying the relationship between salinity and output, and those results are first summarized to provide an underpinning for concrete analysis. Agricultural practices in the study area are then reviewed to determine specific areas and commodities that could be most affected by salinity increases. Finally, these results are combined to model the economic effects of changes in water quality on agricultural producers.

[54] Homeowners relying on well water could find it necessary to drill deeper wells to avoid high salinity. Costs will vary depending on geological conditions. In view of the findings reported in volume II, however, drinking well exposure seems unlikely.

1. Literature Review

Irrigation water that is high in salt content is a quality issue that has received significant attention from the academic community. The inverse relationship between agricultural output and irrigation water salinity has been demonstrated in multiple empirical studies, for example Francois and Maas (1978, 1985) and Ulery et al. (1998.) Research has focused on determining appropriate, crop-specific yield functions to model output as a function of salinity. The literature explores the development of the problem, consequences of irrigating with saline waters, and management strategies to cope with this issue.

The seminal analysis of salinity effects on crop yield is Maas and Hoffman (1977.) The paper developed a threshold-slope model which describes crop yield as a piecewise linear response to salinity:

$$Y = \begin{cases} Y_m & 0 \le c \le c_t \\ Y_m - Y_m s(c - c_t) & c_t \le c \le c_0 \\ 0 & c > c_0 \end{cases}$$

Equation 1

Equation 1 is constructed of three piecewise linear curves and has three independent parameters: the salinity threshold (c_t), the slope (s), and the yield under non-saline conditions (Y_m). Below c_t , salinity levels have no impact on yield. Once the salinity level passes this "threshold," yields decrease linearly with salinity. Y and Y_m are scaled output parameters ranging from zero to one; Equation 1 provides the percent change in overall output. Y_m is defined as the yield which occurs when salinity has little or no impact on output. In this manner, calculations are normalized across crops which may produce inherently different yields.[55] Maas and Hoffman then manually fitted this function with data from 60 crops from published literature. Maas later published a paper that uses data to map yield reductions of over 90 different crops to soil salinity.[56]

An alternative formulation for quantifying the salt tolerance of crops is a sigmoidal-shaped response function shown in Equation 2. In this formulation, C_{50} is the salinity level that reduces yield by 50% and p is an empirical constant.

$$Y = \frac{Y_m}{\left[1 + \left(\frac{c}{c_{50}}\right)^P\right]}$$

Equation 2

[55] See Maas, 1990.

[56] Also included are threshold salinity values and percent yield reductions expected for salinity levels exceeding the threshold. See Mass, *Testing Crops for Salinity Tolerance*.

Steppuhn et al. conducted a study comparing different response functions and found that the modified-discount, sigmoidal-shape response function produced the lowest root mean square error and the highest R^2 value.[57] This established that the nonlinear response function of Equation 2 was more accurate than the linear threshold-slope response model. Steppuhn went on to further explore how the linear model might serve as an approximation by using C_t and s to estimate C_{50}, s, and p. Data on 108 crops provide the nonlinear tolerance parameters.[58]

Salt tolerance data for many crops is available in published literature (Francois and Maas, 1993.) The salinity tolerance is expressed as a threshold level at which yield begins to decline at an observed rate. For example, almond sensitivity to salt concentrations shows a narrow range of effectiveness. Yield begins to decrease at an EC level of 1.5 dS/m and at 4 dS/m almonds experience a 50% decrease in yield (see "Measurement," below.)

As a result of variable yield functions for each crop a relative sensitivity classification has been developed to describe salt tolerances. The specific categories assigned are sensitive, moderately sensitive, moderately tolerant, tolerant and unsuitable. The corresponding salinity levels for each category are represented in Table 18.[59]

Table 18: Relative Salinity Tolerance Levels

Tolerance Category	c_t
Sensitive	< 1.3 ds/m
Moderately sensitive	1.3 – 3.0 ds/m
Moderately tolerant	3.0 – 6.0 ds/m
Tolerant	6.0 – 10.0 ds/m
Unsuitable for most crops	> 10.0 ds/m

2. Measurement

The two primary measurements of salinity are electrical conductivity (EC) and total dissolved solids (TDS.) In contrast to most water policy and planning analysis (including this report,) which discuss salinity in terms of TDS, most agricultural studies rely on EC. As dissolved solids increase, so too does the solutions ability to conduct electrical current, so higher EC levels denote increased salinity. While the EC level indicates the level of over all dissolved salts, it does not provide information regarding the salt composition; sodium, magnesium, calcium, chloride, sulphate and bicarbonate contribute to the overall salt level. The units of reporting for EC are typically millimhos per centimeter (mmhos/cm) or decisiemens per meter (dS/m), and TDS is reported in milligrams per liter (mg/L). A general conversion between the two is:

$$\text{TDS (mg/L)} = 640 \times \text{ECw (dS/m) when ECw} < 5 \text{ dS/m}$$

[57] See Steppuhn et al.: Selecting a Function and Index for Crop Salinity Tolerance.
[58] See Steppuhn et al.: Indices for Salinity Tolerances of Agricultural Crops.
[59] Ayers, R.S., and D.W. Westcot. 1985. *Water Quality for Agriculture*. Food and Agricultural Organization (FAO) of the United Nations. FAO Irrigation and Drainage Paper 29.

TDS (mg/L) = 800 x ECw (dS/m) when ECw > 5 dS/m

Adjustments to this relationship may be required in specific cases, for example if the solution contains large quantities of sulfate.[60]

The literature also distinguishes between salinity in the root soil zone (EC_s) and the salinity of applied irrigation water (EC_i) Relationships between EC_i and EC_s were developed by Ayers and Westcot (1985) and assume steady state conditions. The relationships include a leaching fraction (LF) which is used to relate the fraction of water applied that drains below the rootzone. This fraction is calculated as a ratio of EC_i to EC_s.

- LF 10% leads to EC_i x 2.1 = EC_s
- LF 15-20% leads to EC_i x 1.5 = EC_s
- LF 30% leads to EC_i = EC_s

These relationships assume that EC_s increases with depth.[61] Table 18, below, displays the crop tolerance and yield potential as influenced by the different sources of salinity for a selection of crops.

Table 19: Crop Tolerance and Yield Potential

	100%		*90%*		*75%*		*50%*		*0%*	
Commodity	**EC_s**	**EC_i**	**EC_s**	**EC_i**	**EC_s**	**EC_i**	**EC_s**	**EC_i**	**EC_s**	**EC_i**
Barley	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28.0	19.0
Cotton	7.7	5.1	9.6	6.4	13.0	8.4	17.0	12.0	27.0	18.0
Rice (paddy)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11.0	7.6
Corn (maize)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0	6.7
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13.0	8.4
Orange	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Strawberry	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4.0	2.7

3. Salinity Management

Farmers can compensate for high salt concentrations using a variety of practices, including more frequent irrigation, selection of more salt-tolerant crops, additional leaching, pre-plant irrigation, bed forming and seed placement. In extreme instances, the grower may opt for alteration of the water supply, land-leveling, modifying the soil profile, or installing subsurface drainage.[62]

Irrigation practices can have an impact on the salinity levels. For example, trickle irrigation tends to push salts away from the root zone. This practice might be adopted by farmers that are forced to work with highly saline water. This method has the opposite

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[60] Irrigation Water Salinity and Crop Production, Grattan, Stephen R.; UCANR publication number 8066; 2002

[61] Ayers, R.S., and D.W. Westcot. 1985. *Water Quality for Agriculture*. Food and Agricultural Organization (FAO) of the United Nations. FAO Irrigation and Drainage Paper 29.

[62] Fipps, Guy, *Irrigation Water Quality Standards and Salinity Management*, Texas A&M University System.

effect of furrow irrigation, which tends to push salts into the root zone. Water users can also mix different forms of water to produce a desirable salinity level prior to application.

Academic research has also focused on management strategies designed to help farmers cope with increasing salinity levels either in the soil root-zone or in the applied irrigation water. For example, reclamation leaching is a strategy designed to flush out the root-zone when harmful salinity levels are present. The application of this strategy can reduce the salinity in the top one foot of the root-zone by as much as 80 to 90 percent by intermittently applying one acre-foot of water per acre of land.[63] Of course, this requires a clean source of water to flush out any harmful salts. Unfortunately the quality of the water is usually homogenous given the available sources. Thus a greater quantity of moderately saline water may be applied to continue leaching dissolved salts out of the root zone until a favorable salt balance is achieved.
The most common salts in irrigation water are table salt (sodium chloride, NaCl), gypsum (calcium sulfate, $CaSO_4$), Epsom salts (magnesium sulfate, $MgSO_4$), and baking soda (sodium bicarbonate, $NaHCO_3$).[64]

As stated above, an EC measurement can be taken from the irrigation water source or from the soil. It is important to investigate if plants respond different to a mixture of clean soil and applied saline irrigation water versus salty soil and applied clean irrigation water.

4. Prior Modeling Efforts

a) Delta Agricultural Production (DAP) Model

Mathematical modeling helps to quantify the severity of hypothetical salinity increases in the San Joaquin Valley. One such model is the Delta Agricultural Production (DAP) model, which explores agricultural responses as a function of salinity. The model is especially relevant to investigating the impacts of salinity increases in the Delta because it is designed specifically with the Delta in mind, and accounts for idiosyncratic features of Delta agricultural production in a manner that more general models may not.

The model provides a reasonable indication of how farmers are likely to adapt to changes in water availability, water quality, and, particularly local salinity. The research was recently included in *Envisioning Futures for the Sacramento-San Joaquin Delta,* a report issued by the Public Policy Institute of California (PPIC).

b) Theoretical Development

The model employs standard economic theory by considering each individual farmer in the region as a self-interested, profit-maximizing producer. Farmers adapt to changes in the price, quantity, and salinity of available water by allocating production resources in a

[63] Grattan, Stephen R., *Irrigation Water Salinity and Crop Production*, FWQP Reference Sheet 9.10, Publication 8066.
[64] Grattan, Stephen R., *Irrigation Water Salinity and Crop Production*, FWQP Reference Sheet 9.10, Publication 8066.

way that maximizes their returns. Mathematically, this can be stated as a nonlinear programming equation subject to multiple constraints:

$$\max \quad \sum_g \sum_i \left[p_{gi} Y_{gi} Y_{gi}^r - \delta_{gi} e^{\gamma_{gi} x_{gi,\text{land}}} - \sum_{j \neq \text{land}} c_{gij} X_{gij} \right]$$

$$\text{s.t.} \qquad \mathbf{Ax} \leq \mathbf{b}$$

$$Y_{gi} = \tau_{gi} \left(\sum_i \beta_{gij} X_{gij}^{\frac{\sigma_i}{\sigma_i - 1}} \right)^{\frac{\sigma_i - 1}{\sigma_i}}$$

where:

- i indexes crops;
- g indexes regions;
- j indexes production inputs (land, water and labor);
- p_{gi} is the price of region crop i in region g;
- Y_{gi}^r is the reduced salinity yield for crop i in region g, defined according to the relation $Y_{gi}^r = \left[1 + \left(C_g / C_{i_{50}}\right)^2\right]^{-1}$, with C_g equaling the root zone salinity, and $C_{i_{50}}$ equal to the salinity that reduces yield by 50%;
- σ_i is the elasticity of substitution for crop i, assumed constant over regions;
- τ_{gi} is a scale factor; and
- β_{gij} is a share parameter for input j.

Y_{gi} will be recognized as the standard multiple-input constant elasticity of substitution production function, and AX is a resource constraint.

The $\delta_{gi} e^{\gamma_{gi} x_{gi,\text{land}}}$ term is exponential cost of production function for crop i in region g; δ_{gi} are the fixed costs of production and γ_{ij} is the slope of variable costs. These parameters were obtained from a least squares regression on the first order profit maximization conditions using observed values of input usage and exogenous supply elasticities.

c) Results

Regarding salinity, the historical salinity distribution was used as the base case. Two additional salinity scenarios were explored. The spatial distribution for each scenario was obtained by scaling the base case values by factors of 10 and 20, respectively. The base case scenario was calculated based on EC levels reported by DWR. Total agricultural revenues for this base case scenario are $381 million per year, with profits estimated at $196 million per year.

A tenfold increase in Delta salinity would reduce overall agricultural revenues to $285 million per year in the base case a decrease of $95 million per year or about 25 percent. Profits would be reduced by almost 30 percent ($58 million per year) to $138 million per year and irrigated land area would be reduced by about 8 percent.

Results from a salinity increase by a factor of 20 are also reported. In this scenario overall crop revenues and profits in the delta are reduced by about one-third. The corresponding results for a twenty fold salinity increase on overall crop revenues and profits in the Delta are reduced by about 60 percent and 66 percent to $153 million per year and $66 million per year, respectively, with production ending in several regions.

Salinity will also have an impact on acreage devoted to agriculture. The research explores how acreage quantity will be affected. The report finds that overall crop acreage declines by about 2 percent and 10 percent, respectively, in the 10 and 20 fold increase scenarios. Crops also display some shifts from high value fruits and vegetables toward field crops and pasture as salinity is increased.

Although this research is based on the Delta region of California, the results are useful to discuss in this report that focuses on a different region of California. The impacts of increased salinity will have similar results on profits and land allocation in the San Joaquin Valley.

d) Delta Risk Management Strategy

The Delta Risk Management Strategy (DRMS) was developed to assess the risks of salt water intrusion due to levee failure in the Sacramento-San Joaquin Delta.[65] The model uses the widely accepted salinity sensitivity information developed by Maas-Hoffman. Crop yield loss functions are constant across the region with yields varying by soil and water quality. Using revised assumptions, this model was applied to the representative area to estimate of agricultural losses resulting from increased salinity. Refer to Section I.5.C, below, for discussion of these results.

5. Crop Composition

Each county will be affected by soil salinity differently. This is due to the combination of crops grown in each county and the relative flexibility farmers will have to switch to crops or farming practices that are better suited to saline water use. Different types of crop afford the grower different levels of flexibility to respond to changing conditions. For example, in cases where fixed startup costs are large (such as fruit and nut / tree crops,) the flexibility will be low and other measures to mitigate saline soils will need to be taken. In contrast, crops that require little up-front investment to produce viable output are more easily substituted for.

a) Field Crops

Field crops include commodities such as barley, cotton, and alfalfa. This category constitutes 73% of the total agricultural land use in the study area. The total value in 2005 for field crops in the central valley was $2.35 billion. Although each crop is uniquely sensitive to soil salinity, in general field crops are relatively salt tolerant. Table 20 shows the county summary for field crops harvested acres and total value for 2004-2005.

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[65] Delta Risk Management Strategy Home Page: http://www.drms.water.ca.gov/

Table 20: 2004-2005 Field Crop Summary

County	Year	Harvested Acres	Total Value
Fresno	2004	1,384,850	$594,728,000
	2005	1,387,090	$476,554,000
Kern	2004	514,974	$510,079,000
	2005	509,189	$407,655,000
Kings	2004	699,129	$379,551,000
	2005	710,331	$381,789,000
Tulare	2004	1,308,930	$420,701,000
	2005	1,293,502	$404,130,000
Merced	2004	974,149	$286,060,000
	2005	973,408	$287,912,000
San Joaquin	2004	389,000	$151,763,000
	2005	399,547	$160,948,000
Stanislaus	2004	607,000	$137,871,000
	2005	605,000	$147,744,000
Madera	2004	475,200	$91,648,000
	2005	469,800	$89,032,000
Total		**12,701,099**	**$4,928,165,000**

b) Seed Crops

Seed crops can include a variety of vegetable and grain crops. The contribution to total agricultural land use in the study area is 0.31% and contributes $41.8 million to the total value of production. Relative salinity tolerances can range from sensitive to tolerant in this category. Table 21 shows the county summary for field crops harvested acres and total value for 2004-2005.

Table 21: 2004-2005 Seed Crop Summary

County	Year	Harvested Acres	Total Value
Fresno	2004	14,340	$18,972,000
	2005	10,580	$19,429,000
Kern	2004	1,502	$12,598,000
	2005	1,743	$5,198,000
Kings	2004	6,694	$7,112,000
	2005	9,164	$8,340,000
Tulare	2004	210	$2,355,000
	2005	422	$1,497,000
Merced	2004	1,888	$873,000
	2005	2,708	$3,319,000
San Joaquin	2004	2,610	$6,559,000
	2005	1,969	$3,198,000
Stanislaus	2004	510	$401,000
	2005	525	$810,000
Madera	2004	0	$0
	2005	0	$0
Total		**54,865**	**$90,661,000**

c) Deciduous Crops

Deciduous crops are typically fruit and nut tree commodities. Some examples are apples, almonds and grapes. This category accounts for nearly 20% of total agricultural land use and has the highest value at $8.3 billion. Most tree crops are classified as sensitive to soil salinity. A moderate increase in soil salinity would represent a significant loss due to the initial investment and time lapse to maturity; substitution in favor of more tolerant crops may not be an option in many cases. Table 22 shows the county summary for deciduous crops harvested acres and total value for 2004-2005.

Table 22: 2004-2005 Deciduous Crop Summary

County	Year	Harvested	Total
Fresno	2004	420,003	$1,806,133,000
	2005	421,591	$1,992,093,000
Kern	2004	267,135	$1,513,770,000
	2005	274,611	$1,904,764,000
Kings	2004	48,575	$172,792,000
	2005	49,201	$245,365,000
Tulare	2004	300,961	$1,590,610,000
	2005	307,741	$1,745,966,000
Merced	2004	122,468	$427,040,000
	2005	122,706	$409,696,000
San Joaquin	2004	196,000	$617,275,000
	2005	209,230	$714,469,000
Stanislaus	2004	154,000	$616,452,000
	2005	152,000	$686,897,000
Madera	2004	185,400	$618,686,000
	2005	185,100	$632,179,000
Total		**3,416,722**	**$15,694,187,000**

d) Vegetable Crops

Vegetable crops consist of melons, onions and corn as well as a variety of other commodities. Vegetables account for 10.7% of total agricultural land use in the study area and $2.3 billion of the total value. Vegetable crops typically fall within the moderately sensitive to moderately tolerant salinity classification. This would indicate alternative farming practices may be useful in mitigating the salinity levels in soil and water.

Table 23 shows the county summary for Vegetable crops harvested acres and total value for 2004-2005.

Table 23: 2004-2005 Vegetable Crop Summary

County	Year	Harvested Acres	Total
Fresno	2004	261,628	$1,189,460,000
	2005	273,850	$1,114,181,000
Kern	2004	97,695	$470,692,000
	2005	83,586	$445,513,000
Kings	2004	32,224	$97,199,000
	2005	31,597	$103,380,000
Tulare	2004	7,916	$37,252,000
	2005	6,878	$26,942,000
Merced	2004	46,764	$216,275,000
	2005	47,197	$219,957,000
San Joaquin	2004	79,600	$273,140,000
	2005	84,328	$263,553,000
Stanislaus	2004	49,000	$125,903,000
	2005	39,900	$91,454,000
Madera	2004	4,500	$24,344,000
	2005	5,100	$21,033,000
Total		**1,151,763**	**$4,720,278,000**

e) Nursery Products

Nursery products are a small portion of total agricultural area in the Central Valley. Nursery includes commodities such as ornamental trees and shrubs, Christmas trees and cut flowers. With only five of the eight central valley counties reporting acreage allocation Nursery products utilize 0.12% of the total land and contribute $506 million to the total value. Soil salinity information does not typically exist for these agricultural products because they do not contribute to the food supply. Table 24 shows the County summary for Nursery Products harvested acres and total value for 2004-2005.

Table 24: 2004-2005 Nursery Crop Summary

County	Year	Harvested Acres	Total
Fresno	2004	1,096	$35,067,000
	2005	1,387	$38,091,000
Kern	2004	4,551	$101,850,000
	2005	3,876	$105,728,000
Tulare	2004		$69,423,000
	2005		$82,260,000
Merced	2004	1,920	$30,354,000
	2005	1,735	$33,329,000
San Joaquin	2004		$137,657,000
	2005		$141,473,000
Stanislaus	2004	2,501	$111,272,000
	2005	2,344	$71,240,000
Madera	2004	720	$30,861,000
	2005	740	$34,585,000
Total		**20,870**	**$1,023,190,000**

C. Representative Area Analysis

1. Spatial Distribution of Salt Sensitivity

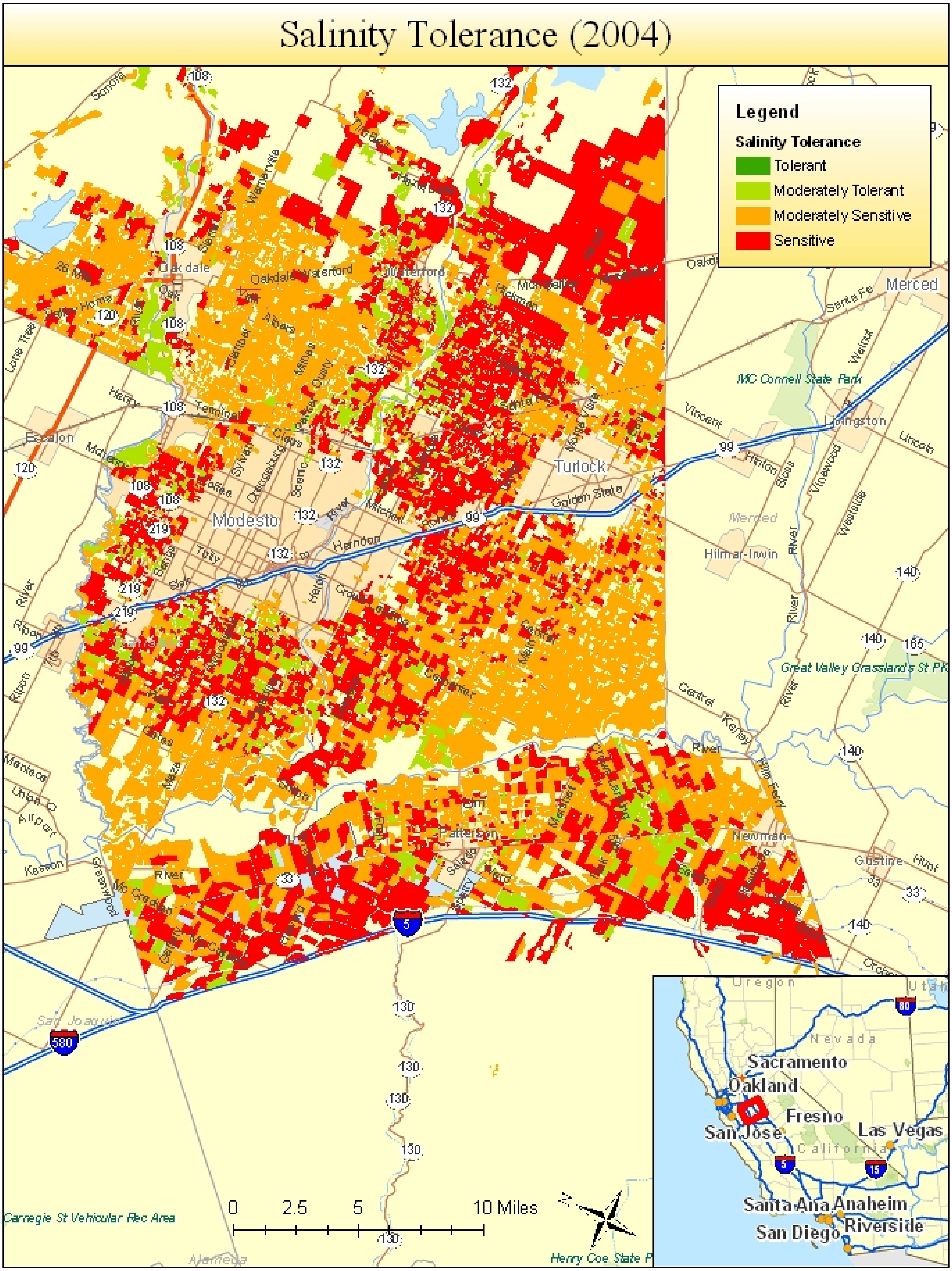
The crops grown in the representative area vary in salinity tolerances. There is a large quantity of permanent tree crops making up the agricultural landscape in Stanislaus County. Tree crops constitute approximately 20% of the total harvested acreage and nearly 35% of the total agricultural value ($686 million).[66] Table **25** displays total acreage for the major crops grown in Stanislaus County in 2005, along with salt sensitivity. Almonds, which occupy the most area, are also among the most salt-sensitive crops.

Table 25: 2005 Stanislaus County Crop Yield and Sensitivity

Crop	Harvested Acres	Sensitivity
Alfalfa hay	35,000	MS
Almonds, Meat	97,300	S
Apples	1,350	S
Apricots	5,000	S
Cherries	2,000	S
Corn	63,500	MS
Grapes, Red Varieties	5,200	S
Grapes, White Varieties	4,900	S
Melons, Cantaloupe	1,320	MS
Melons, Other Musk	355	MS
Melons, Watermelon	300	MS
Peaches, Cling	6,350	S
Peaches, Freestone	1,690	S
Pumpkins	194	MS
Rice	1,060	S
Silage Cereal	38,800	MS
Squash	300	MT
Sudan grass	3,900	MT
Tomatoes	14,198	MS
Walnuts	26,700	MT
Wheat	3,600	MT

Figure 8 combines these data with parcel-level crop location information recorded by DWR to produce a map of salt sensitivity throughout the county. The majority of the crops grown in the county are moderately to highly salt sensitive. Sensitive crops seem to be especially clustered around the outskirts of Modesto and Turlock.

[66] Stanislaus County Crop Report, 2005 Ayers, R.S., and D.W. Westcot. 1985. *Water Quality for Agriculture*. Food and Agricultural Organization (FAO) of the United Nations. FAO Irrigation and Drainage Paper 29



Salinity Tolerance (2004)
Legend
Salinity Tolerance
Tolerant
Moderately Tolerant
Moderately Sensitive
Sensitive
Modesto
Turlock
Oakdale
Merced
Patterson
Newman
Gustine
Livingston
Hilmar-Irwin
Escalon
MC Connell State Park
Great Valley Grasslands St PK
Carnegie St Vehicular Rec Area
0 2.5 5 10 Miles
Sacramento
Oakland
Fresno
San Jose
Las Vegas
Santa Ana
Anaheim
Riverside
San Diego
Oregon
Nevada
California
Utah

Figure 8

Water Providers in Representative Area

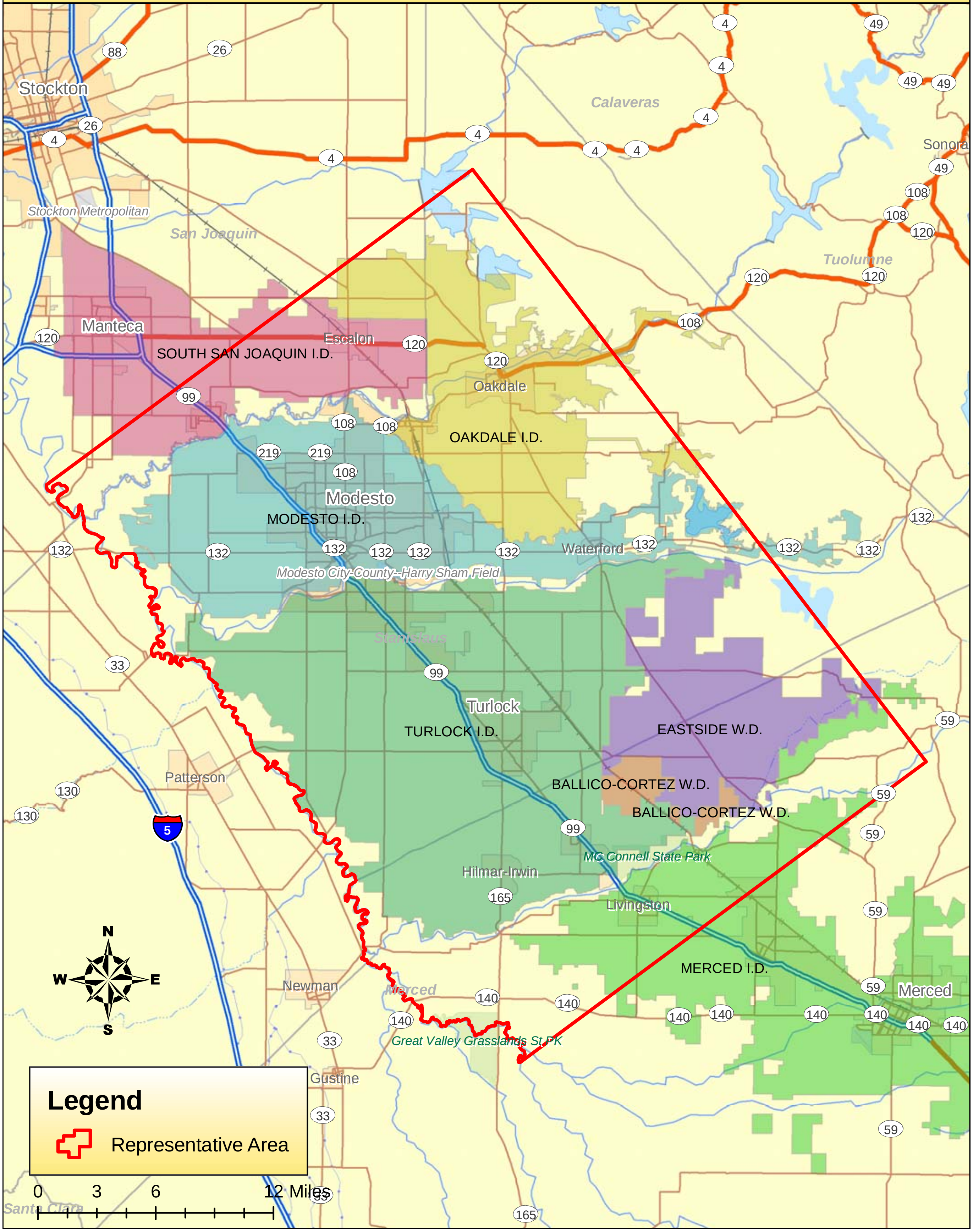


Figure 9

2. Water Sources

There are seven main irrigation districts serving the representative area: the Modesto Irrigation District (MID), Turlock Irrigation District (TID), Oakdale Irrigation District (OID), Eastside Water District (EWD), and Ballico-Cortez Water District (BWD). The boundaries of these districts are mapped in. Because the districts enjoy different supply options, salinity changes affect growers differently depending on which district they fall in. TID, MID, and OID are largely dependent on surface water while EWD and BWD use groundwater as their primary source. Growers in the former group will be more able to smooth groundwater salinity spikes by blending groundwater with high quality surface water. Additionally, farms with private wells can use as much groundwater without recording or reporting the quantity extracted, however the quantity of private pumping occurs is not generally known.

3. DRMS Model

Table 26 combines information from the DRMS model and information taken from Stanislaus County Crop Report to estimate lost revenue relative to 2005 production value might result from different TDS levels.

The economic value of output at a given salinity level is simply the product of the crop yield at that level, discussed above, and prevailing commodity prices. The loss associated with a salinity increase is the difference between the value of output with and without increased salinity. Crop revenue and pricing data were obtained from the annual crop reports prepared yearly by the relevant county agricultural commissions. Data on output losses were calculated as discussed above. In some instances, crops contained in the DRMS model are not grown in the representative area. In these cases the loss is assumed to be zero.[67]

Relative to 2005 production levels, the total loss expected if root zone salinity were 700 TDS is $31,458,417.

[67] The crops not grown in Stanislaus County are: asparagus, corn sweet and grain, cotton, cucumber, sorghum, onions, potatoes, rye grass, and seed crops. Excluded from the analysis due to the uncertainty of crop mix and monetary values are: miscellaneous field crops, miscellaneous vegetables and miscellaneous fruit and nut crops (deciduous.)

Table 26: Lost Agricultural Value in Stanislaus at 700 TDS, Relative to 2005

Crop	Harvested Acres	Value Per Unit ($)	Total Value ($)	Yield at 700mg/L	Lost Revenue ($)
Alfalfa hay	35,000	1,255.80	43,953,000	100%	0
Almonds	97,300	4,968.19	483,405,000	95%	22,961,738
Apples	1,400	6,489.29	9,085,000	96%	327,060
Apricots	5,600	4,023.57	22,532,000	96%	811,152
Barley	500	108.00	54,000	100%	0
Cherries	1,850	6,408.11	11,855,000	96%	426,780
Corn, silage	63,500	779.45	49,495,000	99%	296,970
Dry Beans	11300	745.67	11,421,000	86%	1,200,710
Grain Hay	24,200	353.06	8,544,000	100%	0
Irrigated Pasture	72,000	134.00	9,648,000	100%	0
Melons	1,975	2,514.43	4,966,000	100%	0
Non-corn Silage	38,800	268.89	10,433,000	99%	62,598
Peaches	8,040	5,755.35	46,273,000	99%	485,867
Proc. Tomatoes	12,540	1,871.85	23,473,000	100%	106,802
Pumpkins	194	1,762.89	342,000	99%	2,052
Rice	1,060	828.30	878,000	100%	0
Squash	300	4,143.33	1,243,000	100%	0
Sudan Grass	3,900	275.64	1,075,000	100%	0
Fresh Tomatoes	3,194	19,361.30	61,840,000	100%	281,372
Walnuts	26,700	3,007.83	80,309,000	95%	3,814,678
Wheat	3,600	327.50	1,179,000	100%	0
Wine Grapes	10,100	2,807.92	28,360,000	98%	680,640
Total	**423,053**	**$2,151.89**	**$910,363,000**		**$31,458,417**

Table 27 compares lost revenues for at incrementally higher levels of salinity for the salient crops in Stanislaus County. Lost profits are zero when TDS is below 400 mg/L. Dry beans are the most sensitive crop, with yield losses beginning to occur at 500 mg/L. Most other crops have a threshold value of at least 700. The lost profits that would occur given a TDS value of 700 would be $31,458,417. This number gets increasingly higher as the TDS values make their way toward 1000. Figure 10 graphs total lost revenue as a function of TDS thought 1000. The results are linear since the yield loss information is taken from the DRMS Model, which is a linear threshold model.

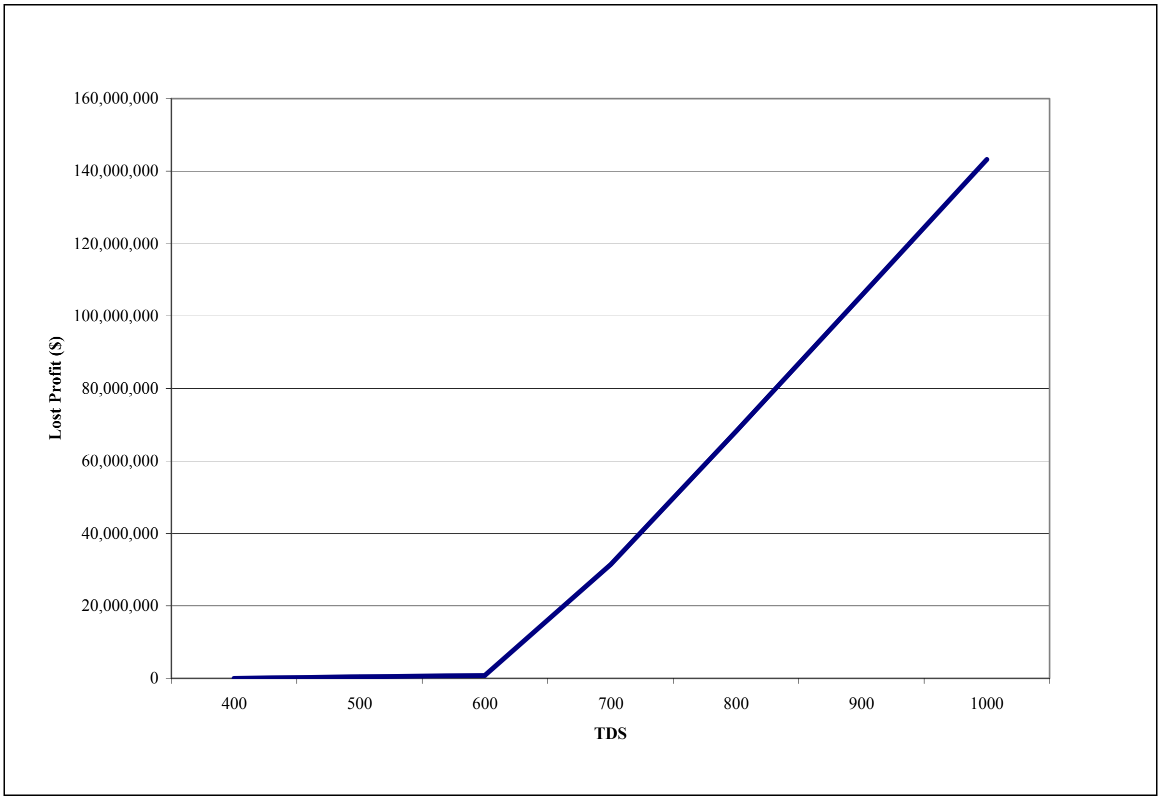


Figure 10

Agricultural Lost Revenue in Stanislaus County as a Function of TDS

Table 27: TDS vs. Lost Revenue

Crop	400	500	600	700	800	900	1000
Alfalfa Hay	$0	$0	$0	$0	$0	$802	$1,604
Almonds	$0	$0	$0	$22,962	$45,923	$68,885	$91,847
Apples	$0	$0	$0	$327	$872	$1,417	$1,962
Apricots	$0	$0	$0	$811	$2,163	$3,515	$4,867
Barley	$0	$0	$0	$0	$0	$0	$0
Cherries	$0	$0	$0	$427	$1,138	$1,849	$2,561
Corn, Silage	$0	$0	$0	$297	$1,782	$3,267	$4,752
Dry Beans	$0	$400	$800	$1,201	$1,601	$2,001	$2,401
Grain Hay	$0	$0	$0	$0	$0	$0	$0
Irrigated Pasture	$0	$0	$0	$0	$0	$0	$0
Melons	$0	$0	$0	$0	$0	$30	$179
Non-corn Silage	$0	$0	$0	$63	$376	$689	$1,002
Peaches	$0	$0	$0	$486	$2,915	$5,345	$7,774
Proc. Tomatoes	$0	$0	$0	$107	$641	$1,175	$1,709
Pumpkins	$0	$0	$0	$2	$12	$23	$33
Rice	$0	$0	$0	$0	$0	$0	$0
Squash	$0	$0	$0	$0	$0	$0	$0
Sudan Grass	$0	$0	$0	$0	$0	$0	$0
Fresh Tomatoes	$0	$0	$0	$281	$1,688	$3,095	$4,502
Walnuts	$0	$0	$0	$3,815	$7,629	$11,444	$15,259
Wheat	$0	$0	$0	$0	$0	$0	$0
Wine Grapes	$0	$0	$0	$681	$1,361	$2,042	$2,723
Total	**$0**	**$400**	**$800**	**$31,458**	**$68,102**	**$105,578**	**$143,173**

Note: Figures in 1000s of $

The consumer and agricultural losses presented here reflect the current mix of urban and agricultural uses in the Central Valley and the Representative Area and hypothetical changes in salinity levels. In Section 7 we consider the effect of changing land use patterns based on our land use forecasting model and salinity levels based on our hydro-geological models to estimate consumer and agricultural costs associated with food processor wastewater discharge in the Representative Area.

D. Environmental Benefits

Avoiding environmental damages such as critical habitat loss is a salinity management concern that must be included in establishing reasonable food processor salinity discharge limits. As shown in Volume II, Section 5, while environmentally sensitive areas are, in some instances, located within several miles of a food processor, the limited migration of high salinity waste water makes damages unlikely. Of course, this concern must be addressed on a case-by-case basis, but a single discharge limit to protect the environment is not supported by this analysis.

III.3 Economic Impacts of Environmental Regulation of the Food Processing Industry in the San Joaquin Valley

A. Overview

The purpose of this section is to describe the potential economic effects of salinity discharge reductions imposed on the food processing industry in the San Joaquin Valley. To this end, the section begins with a description of the size of the food processing industry in the San Joaquin Valley. The section also discusses the economic linkages of the food processing industry with other markets in the region, including the labor market. The section discusses competitive conditions in the industry, as these affect the ability of California producers to pass along costs to customers. This section also presents estimates of the economic consequences, direct and indirect, associated with a salinity discharge limit of 500mg/liter. The focus is on Stanislaus County which approximates the Representation Area used in this study. Finally environmental concerns are discussed.

B. Background

The primary data available at the regional level necessary to characterize the food processing sector in the San Joaquin Valley is U.S. Census data governing manufacturing industries. The U.S. food processing sector is classified by industry and by State and County of production according to the North American Industry Classification System (NAICS) under two categories within the manufacturing sector: (1) food manufacturing (code 311), and (2) beverage and tobacco product manufacturing (code 312). California, which does not have a tobacco product manufacturing sector, lists identical values under beverage and tobacco product manufacturing and the 4-digit industry classification of beverage manufacturing (code 3121). The 4-digit classification provides the highest level of aggregation used in the study to characterize the beverage segment of the food processing industry. The U.S. Census data are further classified by industry at the 5-digit and 6-digit levels of categorization, although regional data available at the County level is often masked at this level of resolution for confidentiality purposes.

Food processing establishments engage in the mechanical, physical, or chemical transformation of raw agricultural products into a variety of food and beverage products. The processed food and beverage products may be finished products ready for utilization or consumption or may be semi-finished products utilized by other food processing establishments as an input for further manufacturing. For example, initial processing by manufacturing establishments in California's processing tomato industry primarily manufacture tomato paste, a raw ingredient that is distributed and sold to manufacturing plants further downstream for use in retail and foodservice packs of soups, sauces, catsup, and paste.[68]

[68] Brunke and Sumner, 2002

According to information from the 2002 U.S. Census, the U.S. food processing sector employs 1,140,558 workers and produces a total value of $458.8 billion in shipments. The U.S. beverage manufacturing sector employs an additional 70,340 workers and produces a total value of $66.1 billion in shipments. The combined value of U.S. food and beverage shipments in 2002 was $524.9 billion and represented over 5 percent of U.S. Gross Domestic Product (GDP).[69]

1. The Food Processing Sector in California

California has the largest concentration of food processing facilities in the nation. In 2002, the California food processing sector was comprised of 3,814 food manufacturing establishments and 846 beverage manufacturing establishments, which together employed 196,258 workers and produced a $61.6 billion value in shipments[70] The combined value of food and beverage shipments in California represented 12 percent of the total value of processed food shipments in the U.S. ($61.6 billion out of $549.9 billion) and amounted to 3.4 percent of California Gross State Product (GSP).

Table 28: Food Processing Industry in California by Industry Group Classification

		Number of		Value … ($1000s)	
NAICS	**Industry**	**Plants**	**Employees**	**Shipments**	**Added**
3111	Animal Food Manufacturing	147	4,069	$3,077,479	$1,138,873
3112	Grain and Oilseed Milling	98	4,042	$2,838,113	$1,345,992
3113	Sugar and Confectionery Product Manufacturing	220	10,054	$2,410,338	$1,261,512
3114	Fruit and Vegetable Preserving and Specialty Food Manufacturing	336	38,409	$10,390,703	$5,407,430
311421	*Fruit and Vegetable Canning*	*145*	*15,867*	*$4,314,740*	*$1,990,574*
3115	Dairy Product Manufacturing	211	14,802	$9,077,621	$2,671,503
311513	*Cheese Manufacturing*	*50*	*4,217*	*$2,337,002*	*$479,879*
3116	Animal Slaughtering and Processing	279	21,019	$4,359,315	$1,806,870
311611	*Animal (Except Poultry) Slaughtering*	*89*	*5,344*	*$1,272,345*	*$316,181*
311615	*Poultry Processing*	*48*	*8,489*	*$1,063,139*	*$501,129*
3117	Seafood Product Preparation and Packaging	57	3,465	$823,657	$218,365
3118	Bakeries and Tortilla Manufacturing	1,814	43,527	$6,003,852	$4,006,125
3119	Other Food Manufacturing	652	25,130	$7,539,834	$4,226,810
3121	Beverage Manufacturing	844	31,741	$15,054,126	$8,201,993
312130	*Wineries*	*669*	*19,391*	*$8,229,722*	*$4,519,551*
Total		**4,658**	**196,258**	**$61,575,038**	**$30,285,473**

Source: U.S. Department of Commerce (2005)

Table 28 shows the number of plants, number of employees, value of shipments, and value-added in selected food processing industries. Within California's food processing sector, the fruit and vegetable processing industry is the largest industry group in terms of the value of shipments, with sales representing 16.8 percent of the total value of all processed goods (fruit and vegetable canning alone accounts for 7 percent), followed by

[69] U.S. Department of Commerce, 2005
[70] U.S. Department of Commerce, 2005

dairy product manufacturing with 14.7 percent, wineries with 13.4 percent, other food (primarily snack food and nuts) with 12.2 percent, and bakeries and tortillas with 9.7 percent.

Four industries of particular interest in this study are (1) fruit and vegetable canning, (2) cheese manufacturing, (3) meat packing, and (4) wineries. These operations are concentrated in the San Joaquin Valley, with regional production centers for fruit and vegetable canning in Stanislaus, San Joaquin, Fresno and Merced counties; for cheese manufacturing in Stanislaus, Tulare, Kings and Merced counties; for meat packing in Fresno, Stanislaus and Merced counties; and for wine production in San Joaquin, Fresno and Madera counties. These industries are discussed in greater detail in Section 3.2.

In terms of food processing value-added, which is the difference between the total value of shipments and the total cost of raw agricultural products that support them, the mean value-added across all California food processing industries combined is 49 percent of the value of shipments. The value-added in the food processing sector represents a larger share of the value of shipments in the wine processing industry (54.6 percent), in fruit and vegetable processing (52.0 percent), and a lower share of the value of shipments in animal slaughtering (41.3 percent), and in cheese manufacturing (20.5 percent).

2. Processing Plant Location

The location of food processing establishments is primarily determined by: (1) raw material costs (in particular, the delivered prices of raw agricultural products), (2) labor costs, (3) environmental compliance costs, and (4) proximity to consumer markets. Food processing plants are typically located in close proximity to areas with significant agricultural activity, which reduces the length of time between harvest and processing to ensure freshness. The co-location of agricultural producers and food processing facilities and the discrete nature of processing plant location decisions cause processing plant location decisions to have important implications for regional production patterns and prices.[71] For example, processing tomatoes harvested in California's Central Valley are typically transported to food processing plants and transformed into tomato paste and other processed products within 6 hours after harvest.[72] For this reason, adjustments in the location of food processing industries are closely linked with adjustments in the regional pattern of farm production.

Due to the large amount of agricultural production in California (and the variety in the types of products grown), California is currently home to some of the largest food processing establishments in the nation. Food processing establishments in California tend to be concentrated in product categories such as fruit and vegetable canning and wine production for which favorable conditions exist in California for the production of raw agricultural products.

Food processing plants generate both valuable consumption goods and waste. Environmental regulations that influence the compliance costs for the handling of waste

[71] Apland and Anderson, 1996
[72] Brunke and Sumner, 2002

products in the food processing sector are also important for the location decision of food processing establishments, particularly in industries where competing processed goods are produced in regions facing less stringent regulations and where transshipment to consumer markets from these regions is not costly.

The expansion decisions of food manufacturing establishments in California are driven by the costs of operating in California compared to other locations with growing conditions favorable to the production of raw agricultural products. For instance, in the cheese processing industry, Hilmar Cheese is now preparing to build a cheese factory in Dalhart, Texas after receiving a $7.5 million grant from the Texas Enterprise Fund.[73] In the processing tomato industry, China's tomato paste production capacity has doubled over the last three years, eroding U.S. export share in world markets.[74]

Given the co-location decision of farming operation and food processing establishments, policies that affect the vitality of food processing plants also affect the vitality of farmers who serve these markets. When processing plants enter or exit a region of production, farm products migrate to these regions as well, so that overall changes in market activity as a result of environmental regulations that are reflected in consumer prices can potentially mask large changes in the regional distribution of production between regulated and unregulated regions of production.

C. Historical Trends in California's Food and Beverage Processing Sector

1. Competitive Advantage in California Food Processing Industries Relative to Other States

It is possible to measure the competitive advantage of each of the various food processing industries in California relative to other regions in the United States by calculating specialization indices for each industry. A specialization index, or location quotient, measures the concentration of California's production activities in particular food processing industries relative to the concentration of the same industry in other states.

For each processed food category, a specialization index is calculated as the ratio of the value of shipments as a share of GSP in California to the value of shipments as a share of GDP in the U.S. If the share of value in a certain processed food industry in California is greater than the share of value in the same processed food industry in the U.S., then the California economy devotes more resources to the production of this good than the share of resources devoted to this same good in other regions in the U.S. Accordingly, an index number greater than 1 suggests that California has competitive advantage over other states in the production of the good, whereas an index number less than 1 suggests that California is at a competitive disadvantage relative to other states in the production of the food product.

[73] http://www.expansionmanagement.com/Industryspotlights/Food_Processing/16892
[74] Carter, 2006

There has been recent concern over the flight of manufacturing jobs, in general, from California to other regions in the U.S. (or internationally) with lower production costs. Overall, within the entire manufacturing sector (NAICS codes 31-33), this trend towards declining competitive advantage in California's manufacturing sector is revealed by a decline in the specialization index within the sector from 0.80 to 0.74 between the 1997 and 2002 Census years. This trend towards declining competitive advantage in California's manufacturing industries was not mirrored across all manufactured food and beverage products.

Figure 11 depicts specialization indices for selected food processing industries as well as for all food and all beverage items in California, in the U.S. Census years 1997 and 2002. Unlike the overall trend in competitive advantage among California's manufacturing establishments, California's competitive advantage increased between 1997 and 2002 in both food and beverage processing segments of the food processing sector. The specialization index for all processed food products in California rose moderately from 0.77 in 1997 to 0.78 in 2002, and California increased its competitive position substantially in processed beverage products over the period, with an increase in the index of specialization from 1.49 to 1.74 between Census years. The increase in California's competitive advantage in food processing between the 1997 and 2002 Census years was led by gains in animal food manufacturing, grain and oilseed milling, dairy product manufacturing, and bakeries and tortilla manufacturing.

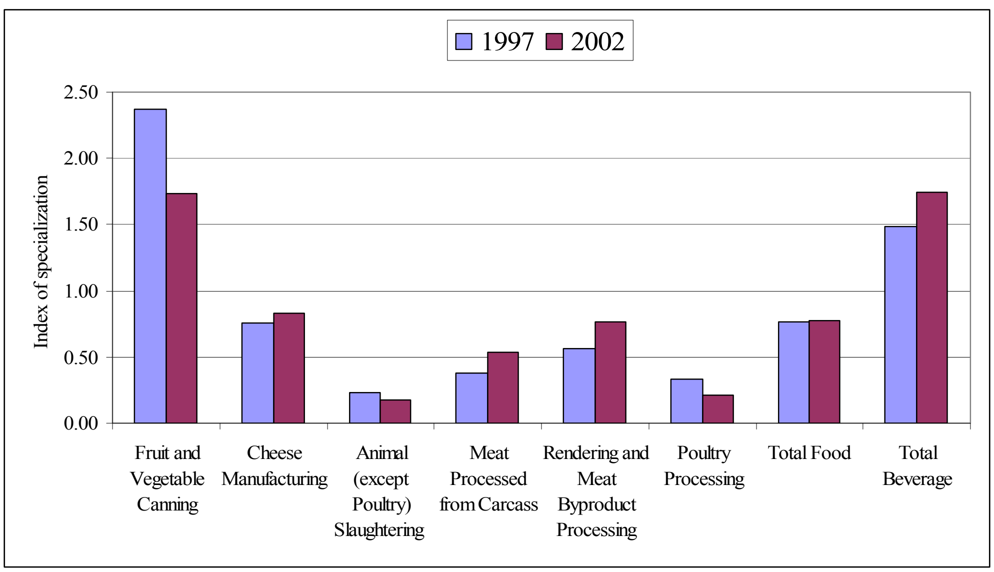


Figure 11

Source: U.S. Bureau of Census, Annual Survey of Manufacturers

Despite the gain in competitive advantage between Census years in the manufactured beverage segment, the index of specialization for California wineries fell between 1997 and 2002 (from 7.25 to 6.67). The volume of California wine shipments increased by 9 percent over the period from 423.1 million gallons in 1997 to 464.3 million gallons in

2002;[75] however, the rate of growth of the wine sector failed to keep pace with the rate of California's GSP growth over the period (15.4 percent) while other states, particularly Oregon and Washington, expanded winery operations. Nonetheless, California retains a strong competitive advantage in wine production over other regions in the U.S.

California has a relatively strong competitive position in fruit and vegetable canning production, a category that includes processing tomatoes; however, the competitive advantage of California fruit and vegetable canning industry eroded substantially between 1997 and 2002 from an index of specialization of 2.37 in 1997 to an index of 1.74 in 2002. Within the fruit and vegetable canning products category, moreover, California's competitive advantage is extremely high in canned tomato products and canned peaches. In 2002, the value of U.S. shipments of canned catsup and other tomato-based sauces (NAICS code 311421D) was $3.68 billion.[76] While the value of California shipments of processing tomatoes is not separate from the fruit and vegetable canning category in the 2002 Census data, 95 percent of all U.S. processing tomato production (11.1 million short tons out of 11.7 million short tons) was produced by California farmers in 2002.[77] This implies that the value of California shipments of canned catsup and other tomato-based sauces was approximately $3.49 billion (95 percent of $3.68 billion) in 2002, which corresponds with a specialization index of 7.24.

The specialization index for California cheese manufacturing rose from 0.76 in 1997 to 0.83 in 2002, suggesting a slight improvement in competitive position, although California remains at a competitive disadvantage in the production of both cheese and processed meat products.

The index of specialization for all animal slaughtering and processing in California declined for the category from 0.30 in 1997 to 0.27 in 2002, led by declines in animal (except poultry) slaughtering (from 0.23 to 0.18) and in poultry slaughtering (from 0.34 to 0.22). Competitive advantage within the animal slaughtering and processing sector shifted into the meat processed from carcass industry, represented by a rise in the index number from 0.38 to 0.53 over the period 1997-2002. A shift also occurred in the rendering and meat byproduct processing industry which saw a rise in the index number from 0.56 to 0.76 over the period 1997-2002, although California remains at a substantial competitive disadvantage relative to other U.S. states in each of these industries.

2. Competitive Advantage in San Joaquin Valley Relative to Other Food Processing Regions in California

Within California, the regional location of food processing plants has shifted substantially over the period 1993-2005. In general, this shift is characterized by two trends: (1) a general shift in all food and beverage processing establishments from coastal and urban areas in California into the Inland Empire and San Joaquin Valley; and (2) regional development of wineries in regions that emphasize the premium segment of the wine industry such as Napa, Sonoma, and San Luis Obispo-Paso Robles.

[75] Wine Institute
[76] U.S. Department of Commerce, 2004, this category was not reported in the 1997 Census.
[77] National Agricultural Statistical Service, 2005

Table 29 compares the number of wage and salary workers in the food and beverage product manufacturing industries in California regions over the period 1993-2005. The total number of workers is averaged over the three-year periods 1993-1995, 1998-2000, and 2003-2005 to reduce the variation in regional employment levels that can arise due to variability in crop production among the raw agricultural products emphasized in each region.

Overall, employment at California's food processing facilities declined 8.4 percent between the period 1993-1995 and the period 2003-2005. This decline in wage and salary workers in the California food processing sector was coupled with a rise in the real value of food and beverage shipments in California from $51.2 billion to $59.7 billion (in 1997 dollars), which suggests that the decline in employment was driven predominantly by a substitution of capital and other labor-saving inputs for workers. Newer food processing establishments utilize labor-saving technology to a greater degree than older establishments. Hence, the decline in food processor workers is not only the result of competition between regions and states, but because of technological change.

Table 29: California Wage Statistics in Food & Beverage Manufacturing Industries

Region	Mean 1993-1995	Mean 1998-2000	Mean 2003-2005	% Change
San Joaquin Valley	*58,933*	*60,433*	*65,033*	*10.4*
Bakersfield	4,600	5,200	7,133	55.1
Fresno	14,233	15,300	16,967	19.2
Hanford-Corcoran	1,633	2,033	2,667	63.3
Madera	1,267	1,333	1,367	7.9
Merced	5,300	6,567	7,400	39.6
Modesto	15,600	14,800	15,033	-3.6
Stockton	11,867	11,367	9,733	-18.0
Visalia-Porterville	4,433	3,833	4,733	6.8
Northern Central Valley	*12,100*	*12,967*	*10,933*	*-9.6*
Chico	1,133	1,033	1,233	8.8
Redding	1,600	1,200	400	-75.0
Vallejo-Fairfield	4,433	5,300	5,067	14.3
Yolo County	3,733	3,767	3,067	-17.9
Yuba City	1,200	1,667	1,167	-2.8
Wine Appellations	*14,167*	*17,967*	*21,167*	*49.4*
Napa	4,633	6,067	7,133	54.0
Santa Rosa-Petaluma	6,033	7,867	9,400	55.8
San Luis Obispo-Paso Robles	600	900	1,300	116.7
Santa Barbara-Santa Maria	2,900	3,133	3,333	14.9
Coastal Agricultural	*15,700*	*14,900*	*13,167*	*-16.1*
Salinas	6,000	5,933	5,433	-9.4
Santa Cruz-Watsonville	3,700	2,633	2,133	-42.3
Oxnard-Ventura	6,000	6,333	5,600	-6.7
Major Urban	*202,533*	*198,933*	*163,167*	*-19.4*
LA-Long Beach-Glendale	49,967	49,333	48,300	-3.3
Santa Ana-Anaheim-Irvine	34,000	32,467	29,333	-13.7
San Diego-Carlsbad	27,600	30,433	26,033	-5.7
Oakland-Fremont-Hayward	25,733	26,300	21,700	-15.7
San Francisco-San Mateo	31,067	27,867	15,600	-49.8
San Jose-Santa Clarita	16,067	15,600	8,500	-47.1
Sacramento-Arden-Roseville	18,100	16,933	13,700	-24.3
Inland South	*6,633*	*7,700*	*10,667*	*60.8*
El Centro	967	800	1,567	62.1
Riverside-San Bernardino	5,667	6,900	9,100	60.6
Total	**310,067**	**312,900**	**284,133**	**-8.4**

Source: Source: California Department of Finance, Employment Development Department (http://www.labormarketinfo.edd.ca.gov)

Wage and salary workers in California's food processing sector increased in areas such as Napa, Sonoma, and San Luis Obispo-Paso Robles that specialize in premium wine production, in the Riverside-San Bernardino area, and in the San Joaquin Valley. These regions absorbed approximately 44 percent of the 39,366 displaced workers over the period 1993-2005 corresponding with the decline in food processing employment in the major urban areas of California.

Within the major urban centers, the most substantial losses in food processing employment occurred in beverage processing. The Los Angeles-Long Beach-Glendale area maintained fairly stable employment in dairy (a decline from 5,300 to 5,100 workers over the period) and in animal slaughter (a decline from 5,600 to 5,400 workers over the period), while employment in beverage processing declined 20 percent from 5,300 to 4,200 workers over the period. Food and beverage manufacturing activity in the Oakland-Fremont-Hayward, San Francisco-San Mateo-Redwood City, and San Jose-Sunnyvale-Santa Clarita metropolitan regions declined roughly proportionately in each category.

Within the Central Valley, over the 1993-2005 period food processing employment centers shifted southward into the San Joaquin Valley. In Bakersfield, food and beverage manufacturing employment increased 55 percent, led by a 74 percent increase in food processing employment (from 2,700 to 4,700 workers) over the period, while beverage manufacturing employment in Bakersfield increased more slowly by 18 percent (from 2,000 to 2,433 workers).

In Fresno, food processing employment increased 30 percent, from 9,967 workers to 12,733 workers over the period, while beverage manufacturing employment remained relatively experiencing a slight decline from 4,267 to 4,233 workers.

Stockton and Modesto are the only two metropolitan areas in the San Joaquin Valley that did not expand food and beverage processing operations in terms of the number of wage and salary workers over the period. One reason for this difference is the increased desirability of these areas for housing among commuters to employment centers in the Greater Bay Area, and the associated rise in land prices in Stockton and Modesto over the period relative to other areas in the San Joaquin Valley. In Stockton, food processing employment declined 30 percent (from 7,600 workers to 5,300 workers) during the period, and beverage manufacturing employment declined 10 percent (from 4,900 workers to 4,400 workers). In Modesto, the overall decline in food and beverage processing employment masks a shift from processed foods, which declined 20 percent (from 12,400 to 9,800 workers), towards beverage processing, which increased 42 percent (from 3,300 to 4,700 workers). It is interesting to note that the rate of employment growth in the beverage processing industry in Modesto closely mirrors the rate of growth in beverage processing employment in the wine appellations between the periods 1993-1995 and 2003-2005.

D. The Economic Value of the Food Processing Sector in the San Joaquin Valley

1. Food Processing Values by County

Food production in the San Joaquin Valley contributes substantial economic value to the regional economy. This value is comprised of consumption of agricultural products and consumption of processed food products. The consumption of agricultural products is further decomposed into products sold directly to consumers in a "fresh market" segment and products sold to food processors in a processed market segment. The county-level data does not distinguish between sales of agricultural products that are independent of processing activity and those that depend on the food processing sector.

The 2002 U.S. Census data contains the most comprehensive information available on the value of the food processing sector in the San Joaquin Valley. U.S. Census data is available for every county in the San Joaquin Valley on the total value of processed food shipments, although the county-level data lose resolution at 4-digit and higher levels of classification due to a masking of values for confidentiality reasons. In cases where data is not provided for the value of shipments, the Census data reports only the number of firms and a range of wage and salaried workers. In industries where the data are not available to decompose the value of food manufacturing shipments at the 6-digit level -- necessary to assign value to the particular industries in the San Joaquin Valley that are most impacted by wastewater regulations -- a range of values is calculated based on the range of employees reported in the industry and the average value of food processing shipments per employee (reported in the 2002 Census data for all California plants). Given the growth of food processing industries in the San Joaquin Valley described in Section 2.2, and the greater labor efficiency of newer processing establishments, these calculations provide conservative estimates of the value of shipments in each food processing industry.

Table 30: Gross Value of Agricultural Production and Total Value of Food Manufacturing Shipments

Rank	County	Agricultural Production ($1,000s)	Food Manufacturing Shipments ($1,000s)
1	Stanislaus	$1,367,971	$3,654,421
2	Fresno	$3,437,431	$3,042,586
3	Tulare	$3,200,552	$2,661,214
4	San Joaquin	$1,353,918	$2,516,834
5	Merced	$1,730,720	$1,588,373
6	Kern	$2,595,360	$1,214,111
7	Kings	$1,023,808	$1,057,686
8	Madera	$778,385	$115,699
	Total	**$15,488,145**	**$15,850,924**

Source: Gross value of agricultural production (California Agricultural Commissioners' Reports: http://ucce.ucdavis.edu/counties/common/countyagreports.pdf); value of processed food shipments (U.S. Census Bureau, Annual Survey of Manufacturers: http://www.census.gov/econ/census02)

Table 30 provides a comparison of the gross value of agricultural production and the value of food manufacturing shipments (excluding beverages) in the counties located in the San Joaquin Valley. In 2002, the eight counties in the San Joaquin Valley region comprised 49 percent of the total farm production in the State of California and produced over $15 billion in value of agricultural production. Due to data limitations in the beverage sector, the value of food manufacturing shipments in Table 30 includes only processed food products listed under NAICS code 311, rather than the combined value of both food products (NAICS code 311) and beverage products (NAICS code 312) in the region. The value of food manufacturing shipments in the table understates the value of the San Joaquin Valley food processing sector by an amount calculated in Section 3.2 to be in the range of $1.9 billion to $3.3 billion. Exclusive of the value of beverage manufacturing in the San Joaquin Valley, the value of processed food production alone in the San Joaquin Valley in 2002 ($15.9 billion) was comparable to the value of all agricultural production ($15.5 billion), a total that includes agricultural products such as wine and table grapes that ultimately were allocated to the beverage processing segment of the market.

In Table 30, the value of agricultural production in each County includes products allocated to the food processing sector. Because of the co-location of agricultural production and food processing operations, a portion of the agricultural value listed in the table depends on the existence of the food processing sector that consumes these products. Without processing plants in the San Joaquin Valley, the acreage allocated to cropping activities that support processed food production would be allocated to alternative land uses.

Across all manufactured food products produced in California that are listed under NAICS code 311, the average share of value-added by the processing sector is 49 percent of the value of food manufacturing shipments. Thus, approximately $8 billion (51 percent of $15.9 billion) of the value of agricultural production in the San Joaquin Valley was embodied in manufactured food shipments, and an additional $1 billion to $1.7

billion was embodied in manufactured beverage shipments. Accordingly, the value of agricultural products produced in the San Joaquin Valley sold through marketing channels that do not involve food processors was roughly $5.8 billion to $6.5 billion in 2002 and the total value of all agricultural sales of food products, including processed food products, was $22 billion ($6 billion in direct sales of raw agricultural products to consumers and an additional $16 billion in processed food sales). Including beverage manufacturing, the total value of all food and beverage sales from crop production in the San Joaquin Valley was in the range of $24 billion to $25 billion. Thus, approximately 80 percent ($18 billion out of $24 billion) of the combined value of agricultural activities in the San Joaquin Valley at the primary production (farming) and secondary production (food processing) levels is sourced through marketing channels that depend on the San Joaquin Valley food processing sector.

Food processing establishments also account for a large share of agricultural employment in the San Joaquin Valley. Direct farm employment in the region constituted 12 percent of total jobs, with an additional 28 percent of employment in the San Joaquin Valley derived from food processing industries.[78]

The importance of the food processing sector to the regional economies in the San Joaquin Valley differs by county. Fresno, Tulare, and Kern counties are the leading regions in terms of the value of agricultural production, whereas Stanislaus, Fresno, Tulare, and San Joaquin counties are the leading regions for food manufacturing.

a) Fresno County

According to Census data, the food and beverage processing sector in Fresno County employed 11,727 wage and salary workers in 2002 and 11,134 in 1997. The largest employment concentrations in Fresno County are in fruit and vegetable processing (29 percent) and in animal slaughtering and processing (37 percent). In 2002, Fresno County operated 25 fruit and vegetable processing plants, which employed 2,619 wage and salary workers, largely in the fruit and vegetable canning and dried and dehydrated food segments of the industry. In 1997, Fresno County operated 22 fruit and vegetable processing plants, which employed between 2,500 and 4,999 employees. The animal slaughtering and processing industry also contributed significantly to the employment base of Fresno County in 2002, with 4,391 employees operating 15 plants. In 1997, this sector provided 3,452 jobs across 16 plants. This is a significant employment increase for this sector.

More than half of the employment in Fresno County's animal slaughtering and processing industry (between 2,500 and 2,800 employees) is allocated to 3 plants in the poultry processing segment of the industry. According to the 1997 Census, this sector reported the same number of plants but was classified in a lower employee range of 1,000 to 2,499. The remaining employment in Fresno County food processing is largely in bakeries and tortilla manufacturing (1,563 employees), beverage product manufacturing (1,141 employees of which 338 are employed in wineries), and other food manufacturing

[78] Munroe et al., 2001

(902 employees). It is unclear how these sectors have changed since 1997 since for each sector the reported range in 1997 includes the employment number for 2002.

b) Kern County

The food and beverage processing sector in Kern County employed 5,977 wage and salary workers in 44 plants in 2002 and represents the largest sector. In 1997, this sector had 7,192 paid employees in 39 plants. The second largest employment concentration is in other food manufacturing, with 3,477 wage and salary workers (58 percent of the County total) allocated at 10 plants compared to 1997, when this sector had 3,755 employees at 9 plants. The two industries above both had declining employment numbers across the 1997 through 2002 time period. The frozen food manufacturing segment of the fruit and vegetable preserving industry represents the largest remaining employment concentration, with 1,624 wage and salary workers (27 percent) operating 5 plants, virtually all of which are allocated to frozen food manufacturing. The frozen food sector was not discussed in the 1997 data so no comparison can be made here.

c) Kings County

The food and beverage processing sector in Kings County employed 2,041 wage and salary workers in 2002, 25-50 percent of which is allocated to cheese manufacturing, 24-50 percent in fruit and vegetable canning, and 12-25 percent in animal (except poultry) slaughtering. According to the 1997 Census data, this sector has 15 plants with 1,029 paid employees. This shows a significant increase that occurred in this sector in Kings County over the 1997 through 2002 time period.

d) Madera County

The food and beverage processing sector in Madera County is relatively small, employing between 758 and 1,257 wage and salary workers in 2002, virtually all of which are allocated to wine production. In 1997, this sector had 14 establishments and had 608 paid employees.

e) Merced County

The food and beverage processing sector in Merced County employed between 4,332 and 4,481 wage and salary workers in 2002, about half of which is concentrated in poultry processing. The majority of the remaining employment is concentrated in fruit and vegetable processing, nearly all of which is in the combined industries of frozen food manufacturing and fruit and vegetable canning. In 1997, this sector was responsible for employing 4,600 workers in 28 establishments. The largest sectors included preserved fruit, dairy product manufacturing, and meat product manufacturing.

f) San Joaquin County

The food and beverage processing sector in San Joaquin County employed 6,833 wage and salary workers in 2002, with over 1,000 workers employed in wineries (16 percent), 1,195 employees in other food manufacturing (17 percent), and nearly 2,000 employees (27 percent) in fruit and vegetable canning. In 1997, this processing sector employed

7,744 wage and salary workers in 84 establishments. The largest sectors included preserved fruit, fruit and vegetable canning, bakeries, and wineries.

g) Stanislaus County

The food and beverage processing sector in Stanislaus County was the largest in the region in 2002, employing between 11,075 and 13,574 wage and salary workers. Compared to data from 1997, which had 11,227 paid employees across 74 establishments, this sector has remained constant. Winery employment in Stanislaus County is roughly equal to the combined total employment level in all other counties in the San Joaquin Valley. Winery employment accounted for 2,500-4,999 wage and salary workers, the same range reported in 1997. Fruit and vegetable processing accounted for 3,438 employees, 2,027 of which were concentrated in the fruit and vegetable canning segment. Dairy processing employment accounted for 1,146 wage and salary workers, with 305 employees at cheese processing plants and the remainder largely allocated to dry, condensed and evaporated dairy product manufacturing. Stanislaus County also has large animal slaughtering operations, with 2,049 wage and salary workers employed in animal slaughtering and processing at 13 plants in 2002. According to 1997 data, this sector employed 2,589 individuals across 12 plants.

h) Tulare County

The food and beverage processing sector in Tulare County employed 5,224 wage and salary workers in 2002 at 57 plants, with the largest employment concentrations in frozen fruit and vegetable processing (32 percent), other food manufacturing (24 percent) and dairy manufacturing (33 percent). In 1997, the food and beverage processing sector employed 3,979 wage and salary workers at 47 plants. Dairy manufacturing in the County is allocated broadly across fluid milk, cheese, dry, condensed and evaporated dairy products, and ice cream and frozen deserts segments, with slightly higher employment concentrations in cheese and dry, condensed and evaporated dairy products.

2. San Joaquin Valley Food Processing Values by Industry

Table 31 shows the number of food processing plants, the range of wage and salaried employees, annual payroll and the value of shipments by processing industry in the San Joaquin Valley.

The calculated range of values is conservative. This can be seen by adding up the calculated value of shipments in each industry across all food processing industries listed under NAICS code 311 and comparing this range of values with the reported aggregate value of all shipments in the region. The calculated values across all categories is in the range of $11.2 billion and $17.4 billion, with a median value of $14.3 billion, which underestimates the reported total value of food manufacturing shipments for the region by $15.8 billion (9 percent).

The value of shipments in the San Joaquin's beverage manufacturing industries is in the range of $2.6 billion to $4.1 billion. The combined value of shipments in the food and beverage manufacturing sectors in the San Joaquin Valley was therefore between $18.5

billion and $20 billion in the year 2002, which represented approximately 1.5 percent of California's GSP.

Table 31: Manufacturing Establishments in San Joaquin Valley, 2002

Industry (by NAICS code)	Number Plants	Number Employees[1]	Annual Payroll ($1,000)[2]	Value of Shipments ($1,000)[3]	Value Minimum ($1,000)[4]	Value Maximum ($1,000)[4]
31: Manufacturing	**2,731**	**107,329**	**$3,882,822**	**$32,347,385**		
311: Food Manufacturing	**444**	**42,493**	**$1,464,476**	**$15,850,924**	***$11,232,109***	***$17,440,913***
3111:Animal Food Manufacturing	57	1,467-1,704	D	D	$1,109,526	$1,288,775
3112: Grain & Oilseed Milling	14	789-1,213	D	D	$554,001	$851,715
3113: Sugar & Conf. Products	13	740-1,695	D	D	$177,407	$406,357
3114: Fruit & Vegetable Manufacturing	86	14,203	D	D	$2,789,709	$5,292,853
31141: Frozen Food	16	3,270-7,594	D	D	$646,913	$1,502,341
311421: Fruit &Vegetable Canning	47	4,983-9,564	D	D	$1,355,692	$2,602,015
311422: Specialty Canning	3	120-384	D	D	$71,447	$207,195
311423: Dried & Dehydrated Food	20	2,034-2,789	D	D	$715,657	$981,301
3115: Dairy Product Manufacturing	43	5,402-6,150	D	D	$2,700,733	$4,928,909
311511: Fluid milk	9	950-1,996	D	D	$540,500	$1,135,618
311512: Creamery Butter	1	20-99	D	D	$17,388	$86,072
311513: Cheese	17	1,768-2,784	D	D	$1,001,232	$1,576,601
311514: Dry, Condensed, Evaporated	10	1,094-1,900	D	D	$745,298	$1,294,393
31152: Ice Cream	6	600-1,266	D	D	$396,315	$836,225
3116: Animal Slaughter & Processing	48	9,392-9,720	D	D	$1,220,859	$1,900,849
311611: Animal (except Poultry)	20	2,051-2,477	D	D	$503,498	$608,077
311612: Meat from Carcass	11	367-503	D	D	$107,931	$147,927
311613: Rendering and Byproducts	8	160-546	D	D	$33,338	$113,767
311615: Poultry Processing	8	4,600-8,223	D	D	$576,091	$1,031,078
3118: Bakeries & Tortilla Mfg.	115	2,634-2,802	D	D	$363,318	$386,491
3119: Other Food Mfg.	68	7,721-7,949	D	D	$2,316,556	$2,384,964
3121: Beverage Product Mfg	**71**	**5,572-8,719**	**D**	**D**	***$2,642,689***	***$4,135,249***
31213: Wineries	48	4,478-7,858	D	D	$1,900,505	$3,335,009

D denotes missing data value from at least one reporting county

[1] Values based on labor classification within each category aggregated across counties in the San Joaquin Valley region.

[2] Values aggregated across reporting counties in the San Joaquin Valley region from the County Business Patterns database, U.S. Census Bureau: http://censtats.census.gov/cbp.

[3] Values aggregated across reporting counties in the San Joaquin Valley region from the Economic Census database, U.S. Census Bureau: http://www.census.gov/econ/census02/data.

[4] Values based on the number of employees in the San Joaquin Valley region and the average value of shipments per employee reported by California plants.

[5] Value based on average value of shipments per employee reported by all U.S. plants

Within the food processing sector, the Fruit and Vegetable Preserving and Specialty Food Manufacturing industries provide the highest value of shipments. The value of all processed fruit and vegetable products in the San Joaquin Valley was in the range of $2.8 billion to $5.3 billion, and the value of the largest component industry in the sector, fruit and vegetable canning, was in the range of $1.4 billion to $2.6 billion in 2002. These estimates are conservative. In 2002, 93.7 percent of U.S. processing tomatoes were produced in California's Central Valley.[79] The value of shipments of canned catsup and other tomato-based sauces in the U.S was $3.7 billion.[80] Since approximately 70 percent of production of Central Valley processing tomatoes can be attributed to processing establishments in the San Joaquin Valley, the value of canned catsup and other tomato-based sauces sourced from San Joaquin Valley processing facilities alone amounted to $2.4 billion in 2002.

Other food processing industries that contribute substantial value to the San Joaquin Valley region include animal food manufacturing, frozen fruit and vegetables, fluid milk, cheese, dry, condensed and evaporated dairy products, poultry processing and other food manufacturing (primarily snack food and nuts). Each of these industries contributed more than $1 billion in value to San Joaquin Valley producers in 2002.

Within the beverage manufacturing sector, the calculated value of winery shipments in the San Joaquin Valley is between $1.9 billion and $3.3 billion.[81] Thus, wine shipments from the San Joaquin Valley represented between 23 percent and 40 percent of the total value of all winery shipments in California of $8.2 billion in 2002. Much of the remaining value in the beverage manufacturing sector is in soda manufacturing, with a smaller amount in bottled water and ice.

The following sections discuss the largest food processing industries.

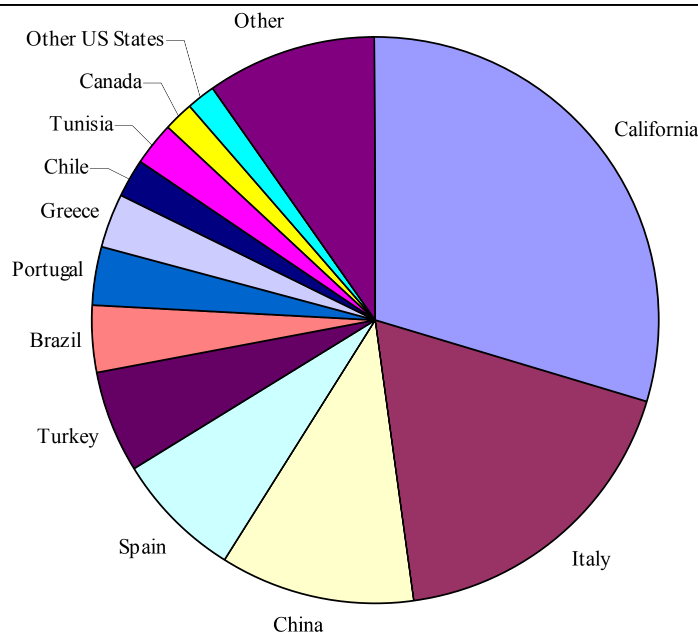
a) Processing Tomatoes

The tomato processing industry in the San Joaquin Valley is comprised primarily of tomato pastes, sauces and canned tomato products and is distinctly separate from the fresh-market industry. The tomatoes entering the fresh and processing markets are distinguished by differences in their characteristics. Relative to fresh market varieties, processing tomatoes contain higher percentages of soluble solids, are vine-ripened, and have a thicker skin designed to facilitate highly mechanized harvesting processes and bulk transport.[82]

Figure 12 shows the allocation of global processing tomato production. The United States has been a net exporter of processed tomato products since 1991.[83] Over the three-year period of 2003 through 2005, California produced 30 percent of world processing

[79] National Agricultural Statistical Service, 2005
[80] U.S. Department of Commerce, 2004
[81] For comparative purposes, E&J Gallo shipped 55 million cases of wine worth $1.5 billion in 2002 (Rural Migration News, 2003).
[82] Brunke and Sumner, 2002
[83] Brunke and Sumner, 2002

tomato output, and processing tomatoes ranked 10th in terms of the value of California exports in 2005.[84] According to the World Processing Tomato Council, the value of U.S. exports amounted to $270.2 million compared with imports valued at $129 million in 2004. In terms of average annual production over the three year period, other major players in the global processing tomato market include Italy with 18 percent of world output, followed by China, Spain, Turkey and Brazil with 11, 7, 6, and 4 percent, respectively.[85] Processing tomato output in China, which exports 70 percent of production to world markets, has trended up sharply over the last few years. Between 2005 and 2006, processing tomato output in China increased 34 percent, from 3.2 to 4.3 million metric tons.[86]



Source: World Processing Tomato Council

Figure 12

California is the leading producer of processing tomatoes in the United States. Over the three year period of 2003 through 2005, California produced an average of 10.2 million tons of processing tomatoes per year, which represented 95 percent of U.S. supply.[87] The remainder of U.S. supply was produced in Indiana and Ohio with 2 percent each and Michigan with 1 percent.[88] States including Texas, Utah, Illinois, Virginia, and Delaware once harvested thousands of acres, but today have little or none.[89]

[84] National Agricultural Statistical Service, USDA
[85] World Processing Tomato Council, World Production Estimate as of March 31, 2006
[86] World Processing Tomato Council, World Production Estimate as of March 31, 2006.
[87] Processing Tomato Advisory Board
[88] National Agricultural Statistical Service, USDA
[89] ERS Briefing Room

Within California, virtually all processing tomatoes are grown in the Central Valley. According to the California League of Food Processors (CLFP), 15 primary producers operate 30 plants located throughout the Central Valley, with the largest concentrations of tomato processing plants in San Joaquin County, and significant operations in Merced, Stanislaus, Yolo, and Solano counties. Smaller tomato processing plants are also located in Santa Clara County and northern San Benito County.

In 2005, the Sacramento Valley contributed 25 percent and the San Joaquin Valley contributed 73 percent of processing tomatoes, with the majority of acreage in Fresno County. Using historical data obtained from the USDA California Agricultural Statistical Service, production trends can be examined for the San Joaquin Valley and the State of California. Production of processing tomatoes in California has remained relatively stable over the period 1989-2005, with an average of 9,852 thousand metric tons per year. Yet, there has been a shift in processing tomato production towards processing centers in the San Joaquin Valley over this period. The share of processing tomatoes harvested in the San Joaquin Valley rose from 53 percent of Californian production in 1989 to over 70 percent of Californian production in 2005.[90]

Production data taken from the USDA and the World Processing Tomato Council will be combined to allow for an accurate picture of San Joaquin Valley processing tomato production's contribution to global production. The USDA provides information that 72 percent of California production came from the San Joaquin Valley in 2005.[91] Since California contributed 27 percent of global total production in the same year, it is reasonable to conclude that the San Joaquin Valley contributed approximately 19 percent to global processing tomato production.[92] In summary, processed tomato products in the San Joaquin Valley represents 72 percent of California output, 68 percent of U.S. output, and 19 percent of world output.

b) Cheese

The examination of the San Joaquin Valley market for cheese is complicated by three factors. First, farm milk supply can be allocated to several alternative uses that include fluid milk, cheese, dry, condensed, and evaporated dairy products, yogurt and ice cream. Second, California operates its own regulated milk marketing system independent of the Federal price support system. Finally, industry-specific import barriers and export subsidies in the U.S. are present that are unique to the dairy industry.
Trade barriers are the most significant feature of U.S. dairy policy. Under the 1996 Fair Act, imports of dairy products in the United States have been limited to about 2 to 3 percent of U.S. consumption each year, which insulates U.S. dairy product markets from world market forces and leads to significantly higher domestic prices than world prices.[93] Current trade negotiations initiated with the Doha Round may lead to increased import access and greater exposure of the San Joaquin Valley producers to international

[90] See Exhibit XX, Production of Tomatoes for Processing, 1989 through 2005.
[91] USDA, California Agricultural Statistical Service
[92]g 27 percent figure comes from the World Processing Tomato Council
[93] Brunke and Sumner, 2002

competition over time. For the purpose of this study, the U.S. market is considered to remain insulated from foreign import trade.

The operation of an independent marketing system in California for fluid milk used in cheese (class 4b) also confounds the market outlook for cheese production in the San Joaquin Valley. To the extent that California adjusts support prices and transportation allowances within the milk marketing system to compensate for higher processing costs due to environmental regulations, this can mitigate the effect of wastewater regulations on cheese production in the San Joaquin Valley. This study considers wastewater regulations in isolation, apart from potentially offsetting (or exacerbating) changes that may occur independently in California's dairy marketing program.

Supply factors are the key determinants of the regional distribution of milk production used to manufacture cheese. Between 1970 and 1991, California's share of U.S. milk production for the dairy processing sector increased from 8.0 to 14.5 percent, an amount three times larger than California's share of the U.S. population increase (from 9.8 percent to 12 percent) over the period. Because an active interregional trade exists in the U.S. for hard manufactured products, including cheese, it is possible to meet regional changes in population that affect supply and demand of dairy products through transshipment between U.S. states. These factors in combination, suggest that supply variables (including wastewater disposal costs at cheese manufacturing plants) are the major aspects that influence the regional distribution of U.S. dairy product manufacturing.[94]

In the 1990s, California surpassed Wisconsin to become the leading dairy production state.[95] Within the dairy products sector, California food processing plants tend to specialize in production of hard manufactured products such as butter, non-fat dry milk and cheese.[96] In 2001, approximately 19 percent of milk produced in California was used for fluid consumption, 72 percent was used for hard products, and the remaining 9 percent was used for intermediate products such as yogurt, sour cream and ice cream.[97]

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[94] Yavuz et al., 1996
[95] National Agricultural Statistical Service, USDA
[96] Brunke and Sumner, 2002
[97] CDFA, 2005

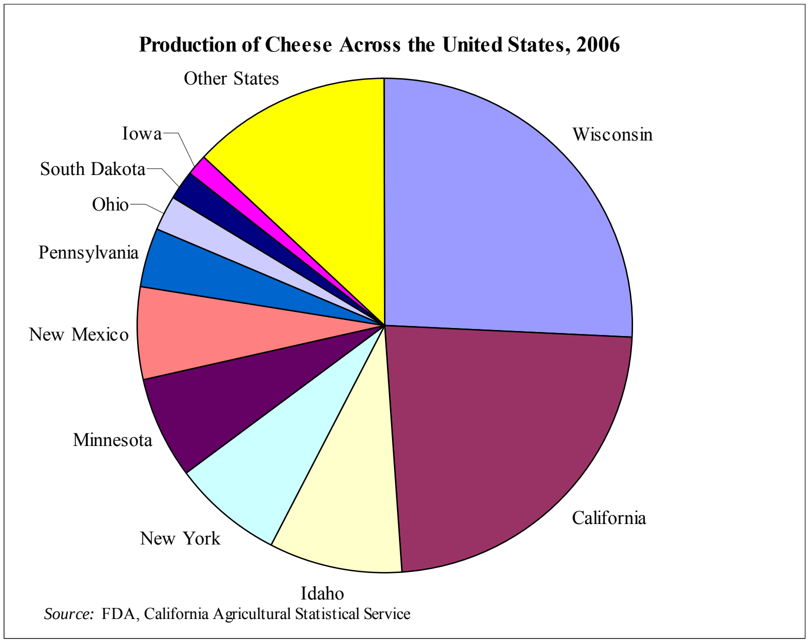

Figure 13

Figure 13 shows the regional production of cheese in the U.S. in the year 2006.

Wisconsin, which was the largest cheese producer in the U.S. in 2006, accounting for 26 percent of the U.S. total, and California which was the second-largest producer of cheese, accounting for 23 percent of U.S. supply.[98]

Within the San Joaquin Valley region, 17 cheese manufacturing establishments operated in 2002.[99] Cheese processing activity in terms of number of wage and salary workers employed is concentrated with 3 plants in Kings County with a total of 500 – 999 wage and salary workers, 4 plants in Tulare County with a total of 463 wage and salary workers, 5 plants in Stanislaus County with a total of 305 wage and salary workers, 2 plants each in San Joaquin and Merced Counties with 250 – 499 wage and salary workers, and one plant in Fresno County with 0-19 paid employees. Total employment from the 2002 Census in cheese production was 4,217.

Based on the range of wage and salaried employees reported for the San Joaquin Valley in relation to total employment at all California cheese manufacturing establishments, San Joaquin Valley plants produced 42 percent to 67 percent of California's cheese. By conservatively selecting the median of this range, we can assume that 55 percent of California cheese is produced in the San Joaquin Valley. Since California's contribution to total U.S. cheese production was 23 percent in 2006, it follows that San Joaquin Valley producers represent 12.7 percent of total U.S. cheese production. In summary, processed cheese products in the San Joaquin Valley represents 55 percent of California output and 12.7 percent of U.S. output.

[98] USDA, California Agricultural Statistics Service
[99] U.S. Department of Commerce, 2005

c) Animal Slaughtering and Processing

California is an important producer of meat products in the United States. In 2001, California ranked sixth in terms of total animals slaughtered, after Nebraska, Kansas, Texas, Colorado and Wisconsin. In California's beef industry, the total animals (cattle and calves) slaughtered in California amounted to 1.16 million in 2001, which represents 3.2 percent of the total U.S. cattle and calves slaughtered in 2001.[100]

U.S. Poultry processing is largely concentrated in Arkansas and Georgia, which leads the nation in terms of the largest number of facilities, employment, and value of shipments. Alabama and North Carolina rank third and fourth in these measures, while California ranks 10th in terms of employment and value of shipments and 8th in number of facilities.

Cattle trade occurs both in processed meat and live cattle. The U.S. imports a significantly greater value of cattle than it exports. Mexico and Canada represent the largest U.S. trading partners for both imports and exports.[101] In 2002, 17 percent of the total U.S. supply of beef was imported.[102]

Within the San Joaquin Valley, 29 animal slaughtering establishments operated in 2002; 20 in the animal non-poultry slaughtering industry and 9 in the poultry processing industry.[103] The operating scale of poultry processing plants is larger than animal non-poultry slaughtering establishments in the San Joaquin Valley, with over twice the number of wage and salary workers allocated to poultry processing than to other animal slaughter in the region. Fresno County is the leading county in terms of meat processing employment with 1,543 wage and salary workers operating 6 animal non-poultry slaughtering establishments and over 2,500 wage and salary workers operating 3 poultry processing establishments. Kings County operates in animal non-poultry slaughter as well, with 2 plants and 250-499 wage and salary workers relative to 1 plant with 20-99 wage and salary workers in poultry processing. Stanislaus County is the only other major producer with 218 wage and salary workers at 4 processing plants. Outside of Fresno County, Merced and Stanislaus Counties represent most of the remaining poultry processing in the San Joaquin Valley, with 1,000 – 2,499 wage and salary workers each.

Historical data on San Joaquin Valley production of beef was available for three years starting in 1990 and six years starting in 2001 from the USDA Statistical Service. This data shows a general decrease in production of beef from 253,000 beef cows in 1990 and falling to 176,000 beef cows in 2006.[104] The data gap was the result of funding cuts, but a general trend is still identifiable.

According to cattle and calve inventory data from the National Agricultural Statistical Service at the USDA, California had 6 percent of total U.S. cattle and calve inventory in

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[100] National Agricultural Statistical Service, USDA

[101] For instance, the U.S. exports feeder cattle to Canada, which are raised on Canadian feedlots, then imported in the U.S. as slaughter-ready animals. See Brunke and Sumner, 2002

[102] Brester and Marsh, 2003

[103] U.S. Department of Commerce, 2005

[104] USDA California Agricultural Statistical Service.

2006.[105] From the same data source for the cattle and calve commodity within California, the San Joaquin Valley had 3,355,000 total cattle, 160,000 beef cows and 1,463,600 total milk cows. Statewide California totals are 5,450,000 total cattle, 680,000 total beef cows and 1,770,000 total milk cows; therefore, the San Joaquin Valley has a market share of 62 percent of total cattle, 24 percent of total beef cows and 83 percent of total milk cows. Comparing California data to total U.S. figures provides information that California had a six percent market share for total cattle, two percent share for total beef cows and 20 percent share for total milk cows in 2006. It follow that the San Joaquin Valley had a four percent market share of total U.S. cattle, .5 percent share of total U.S. beef and 17 percent share of total U.S. milk cow production in 2006.

d) Wineries

Total wine consumption in the United States was 703 million gallons in 2005.[106] California shipped a total of 532 million gallons to the U.S. and abroad, of which 441 million gallons were purchased by U.S. consumers in 2005.[107] Of the total wine consumption, 619 million gallons or 88 percent was table wine, 53 million gallons or 7.5 percent was dessert wine, and the remaining 30 million gallons was consumption of champagne and sparkling wine. Among table wines, red wines represented 41.7 percent of sales, white wines 41 percent, and blush wines 17.4 percent.

California produces 91 percent of the total U.S. wine production and is home to 847 wineries. Historical wine production data obtained from the Wine Institute indicate that California has averaged 90 percent of total U.S. production over the past ten years.[108] This is significant due to the growth of wine production in California which has grown from 437,034 thousands gallons in 1995 to 715,942 thousand gallons in 2005. New York produces 4 percent of the total followed by Washington, Oregon and Idaho, which collectively produce approximately 3 percent.[109] Premium table wines produced in California that command a price above $7 a bottle, represented 35 percent of California wine shipments and 66 percent of the value of shipments at $4.99 billion out of $7.58 billion in 2005. Everyday wine sold at prices below $7 a bottle represented the remaining 65 percent of total California wine shipments and 34 percent of value.[110]

The California wine industry is comprised of a handful of relatively large firms; about 25 firms produce about 90 percent of the wine. The Central Valley contains some of the largest wineries, but comparatively few small wineries. Ernest & Julio Gallo, headquartered in Modesto, produced about one third of the total wine volume in California in 2000.[111]

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[105] NASS USDA, Cattle & Calves – All Inventory Numbers.
[106] The Wine Institute, Key Facts: Wine Consumption in the US, Updated September 2006.
[107] The Wine Institute, California Wine Industry Statistical Highlights, Updated September 2006.
[108] The Wine Institute, Key Facts: Wine Production, Updated November 2006.
[109] Sumner et al., 2001
[110] The Wine Institute, 2005 California Wine Sales Continue Growth Trend As Wine Enters Mainstream U.S. Lifestyle, April 3, 2006.
[111] Sumner et al., 2001

The San Joaquin Valley produces 80 percent of California's grapes and more than one-half of all the grapes grown in the United States each year. Yields per acre are considerably higher in the San Joaquin Valley than in other wine-producing regions of California.[112] Grapes produced in the San Joaquin Valley have a high sugar content that is ideal for the production of sweet wines, raisins, and table grapes, but the wines produced from San Joaquin Valley grapes cannot compete with coastal counties in the premium table-wine market.[113]

In 2006, the San Joaquin Valley represented 52.3 percent of the total crush in California and 47 percent of the total wine crush.[114] The crush produced in the San Joaquin Valley was 80.7 percent wine grapes, with the remainder comprised of table grapes and raisin grapes at 15.6 percent and 4.6 percent, respectively.[115] Comparatively, almost all of the grapes crushed in other districts are wine varieties. About one-third of the total crush in the San Joaquin Valley is estimated to be used for grape juice concentrate.[116]

Wine production in the state of California and in the San Joaquin Valley are both on a steady increase, but looking at historical data since 1991, it is apparent that production is growing at a slower rate in the San Joaquin Valley. Grape crush data was obtained from the USDA Statistical Service and breaks down the State into different production regions. In 1991, wine production in the San Joaquin Valley accounted for 61 percent of total statewide production, but this number has since dropped to 47 percent in 2006 even though both totals are increasing. This indicates that more wine production is occurring outside of the San Joaquin Valley.

Table 32: World Wine Production Top Ten Countries

Country	Wine Production (Hectoliters 000)	Percent of World Total
France	50,000	19%
Italy	44,604	17%
Spain	36,639	14%
United States	22,329	9%
Argentina	12,695	5%
Australia	11,509	4%
China	11,200	4%
Germany	9,885	4%
South Africa	7,189	3%
Portugal	6,651	3%
World Total	**261,240**	

Large quantities of wine are produced in other locations outside the United States. Table 32 compares wine production levels for the top ten producing countries in 2002. France,

112 Sumner et al., 2001
113 Peters, 1984
114 California Grape Crush Report, 2006.
115 California Grape Crush Report, 2006.
116 Sumner et al., 2001

Italy and Spain were the top three producing countries producing 19, 17, and 14 percent, respectively, of the world total which was 261,240 hectoliters in 2002. The U.S. was the third highest producing country accounting for nine percent of world production.

Combining production data from the Wine Institute with California Crush Reports, we can estimate San Joaquin Valley's contribution to both U.S. and global production. In 2002, wine produced in the San Joaquin Valley accounted for 53 percent of total California production.[117] From production data provided by the Wine Institute, California production accounted for 89 percent of U.S. production in 2002.[118] Furthermore, in the same year, the U.S. accounted for nine percent of global production.[119] It follows from the above percentages, that San Joaquin Valley's contribution to global production is estimated at 4.04 percent. In summary, wine production in the San Joaquin Valley represents 53 percent of California output, 47 percent of U.S. output, and 4.04 percent of world output.

E. Incidence Analysis

This portion of the study describes the incidence of water quality regulation on food processors in the San Joaquin Valley. Environmental regulations that lead to increased production cost at food processing plants have several types of impacts on agricultural producers and consumers of processed goods. These impacts generally differ according to the type of cost (fixed cost or variable cost) and the time horizon considered (short-run horizons in which the number of operating plants is fixed and long-run horizons in which entry and exit of plants can occur). Because cropping decisions in the farm sector and co-location decisions in the food processing sector occur on a long-run horizon, this analysis primarily considers the long-run implications of an increase in waste water treatment costs at food processing plants in the San Joaquin Valley.

The short-run implications of an increase in wastewater disposal costs can differ markedly from long-run implications due to land use allocation and inventory decisions that occur over time in the farm sector. Land use allocation decisions by farmers are generally determined by lagged variables, in particular by past prices used to forecast returns to alternative crops at the end of the growing season. In the short-run, once the cropping decisions has been made by agricultural producers, the quantity of farm output delivered to the processing market is less responsive to changes in the farm price than over a longer horizon that allows farmers to allocate land to different crops according to differences in expected returns. For this reason, the long-run implications of environmental regulations, which include adjustments in the farm sector to alternative crops and the commensurate potential for the exit of food processors to ensue, are emphasized here due to the greater policy relevance.

In the long-run, both fixed and variable cost components to wastewater regulations have the potential to alter market activity. An increase in food processor fixed cost, which

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[117] California Crush Report, 2002
[118] The Wine Institute, Key Facts: Wine Production, Updated November 2006
[119] The Wine Institute, Key Facts: World Wine Production by Country, March 2004

refers to any cost that does not vary with the level of processed output, for instance the infrastructure required to connect an individual plant to a publicly owned treatment works (POTW), can change the desired operating scale of food processing plants in the San Joaquin Valley. Fixed cost components of wastewater treatment, including some portions of the infrastructure expense, create economies of scale that favor the operation of larger plants, since larger plants better economize on fixed costs by spreading these costs across a larger number of units. Similarly, public investment in regional infrastructure, such as the proposed increase in wastewater treatment capacity by the City of Fresno POTW, can lead to regional economies of scale in processing activity and cause the long-run migration of plants to areas with the public infrastructure necessary to handle the increased wastewater flow.

Variable, or per unit cost components of wastewater regulations, are particularly important from a policy perspective, because these costs transmit to other markets in the form of price changes. Variable costs that depend on the level of production, such as charges at a POTW based on the volume of wastewater treated or on both the volume and salinity level of the wastewater, increase the cost of each unit of processed food output. In the long-run, changes in the processing sector occur in response to environmental regulation that alters both the operating scale of plants and their regional distribution. Thus, result is an increase in the average cost of output (at component of variable cost) although processors are acting in a manner that minimizes the average cost of production.

An increase in the variable cost of food processing operations in the San Joaquin Valley due to wastewater regulations creates three types of incidence effects in California's food system: (1) a portion of the cost is shifted forward to consumer markets in the form of higher prices for processed goods, which harms consumers; (2) a portion of the cost is shifted backward to agricultural producers in the form of lower prices for raw agricultural products, which harms farmers; and (3) market transfer effects occur that lead to the relocation of processed food production to regions with lower costs, which hampers the regional economic activity among both farmers and food processors.

The analysis considers a competitive food processing sector. Available evidence indicates that the food processing industries subject to wastewater regulation in the San Joaquin Valley are highly competitive. Apart from processing tomatoes, the market share of San Joaquin Valley producers in national (and international) markets is relatively small, suggesting little room to exercise market power, and, in the case of processing tomatoes, Durham and Sexton (1992) find evidence of vigorous price competition among food processors. The U.S. meat processing industry has also been characterized as highly competitive (Morrison-Paul, 1999; Sexton, 2000).

The following sections separate the long-run effects of wastewater regulations into price effects and market transfer effects. The next section considers supply and demand elasticities, which have important implications for both types of effects.

1. The Price Elasticity of Farm Supply and Consumer Demand

The magnitude of forward shifting, backward shifting, and market transfer effects in a particular food processing industry depends on the economic characteristics of the market in terms of agricultural supply and consumer demand. In terms of consumer market effects, the degree to which increased food processing costs are passed forward to consumer markets in the form of higher prices for processed goods depends on the ability of consumers to find reliable substitute goods to replace the relatively high-cost processed goods produced by regulated firms. For processing industries where proximity to consumer markets is important, for instance when product quality degrades quickly over time or distance, transshipment of lower-cost processed goods from other production regions produces lower-quality goods that are imperfect substitutes for goods produced regionally under water quality regulations. In these cases, higher food processing costs in regions proximate to consumer markets readily pass forward to consumers. For processed foods that can be transported long distances without suffering significant declines in product quality, transshipment of processed goods from other regions can provide adequate substitutes in consumer demand, which in turn limits the ability of increased production costs in one food processing region to pass forward to consumers in the form of higher consumer prices.

In terms of producer market effects, the degree to which increased food processing costs are passed backwards to agricultural producers in the form of lower prices for raw agricultural products depends on the alternative land uses available to farmers. In the short-run, a decline in the price of an agricultural product that occurs after the acreage has been allocated to the crop may have little effect on the quantity produced, which facilitates backwards shifting of cost into agricultural production markets. In the long-run, the ability of farmers to allocate their land to the production of alternative crops (or to alternative uses such as real estate development if this is not precluded by zoning restrictions) limits the degree that food processing costs are shifted backwards into agricultural production markets in the form of lower prices for agricultural products.

The relative degree to which an increase in food processing costs following wastewater regulations is passed forward to consumer markets and passed backwards to agricultural producer markets depends on the price elasticity of demand and the spatial flexibility of supply. The price elasticity of demand for a particular food product represents the percentage change in the quantity of the product demanded as a result of a 1 percent change in price (holding other variables such as the price of substitute goods constant). When reasonably close substitutes exist for a processed food product, consumers are readily able to switch to these substitute products in response to a price increase, and demand is said to be price-elastic. Price-elastic demand (values less than -1) implies that an increase in consumer prices leads to a disproportionately large decrease in the quantity consumed. Price-inelastic demand (values between -1 and zero) implies that an increase in the price of a processed food product triggers a relatively small decrease in the quantity of the good consumed.

The spatial flexibility of supply is a measure of the degree to which agricultural producers switch to alternative crops (or exit agricultural production entirely) when the price of the product decreases. The exit of agricultural producers from a cropping region tends to occur spatially from the most distant shipment points, because the effective price of the delivered agricultural product to a processing facility (gross of the transportation cost) rises over distance from a food processing plant. Farmers located at greater distances from processing facilities are more likely to switch into alternative crops, land quality held constant, than those located at shorter shipment distances. For the agricultural production region as a whole, the spatial price flexibility is the reciprocal of the elasticity of farm supply (Durham and Sexton, 1992). The price elasticity of supply for a particular agricultural product represents the percentage change in the overall quantity of the product supplied in the market as a result of 1 percent change in price (holding other variables such as the price of alternative crops constant). Price-elastic supply in a processing market implies that a decrease in the price of an agricultural product leads to a disproportionately large decrease in the overall quantity of the product delivered to food processors in the industry.

Figure 14 demonstrates how relative values of the price elasticity of farm supply and the price elasticity of consumer demand determine the degree of forward and backward shifting that occur following wastewater regulations at food processing plants. For illustrative purposes, units of the raw agricultural good and the processed good are scaled so that consumer demand and farm supply are measured in equivalent units. Prior to environmental regulation, the quantity produced (in both panels) is labeled Q_0 and the consumer price and farm price are P_0^c and P_0^f, respectively. The shaded region represents food processing revenue net of raw product procurement cost, the difference between the consumer price (P_0^c) and farm price (P_0^f) multiplied by the number of units sold (Q_0).

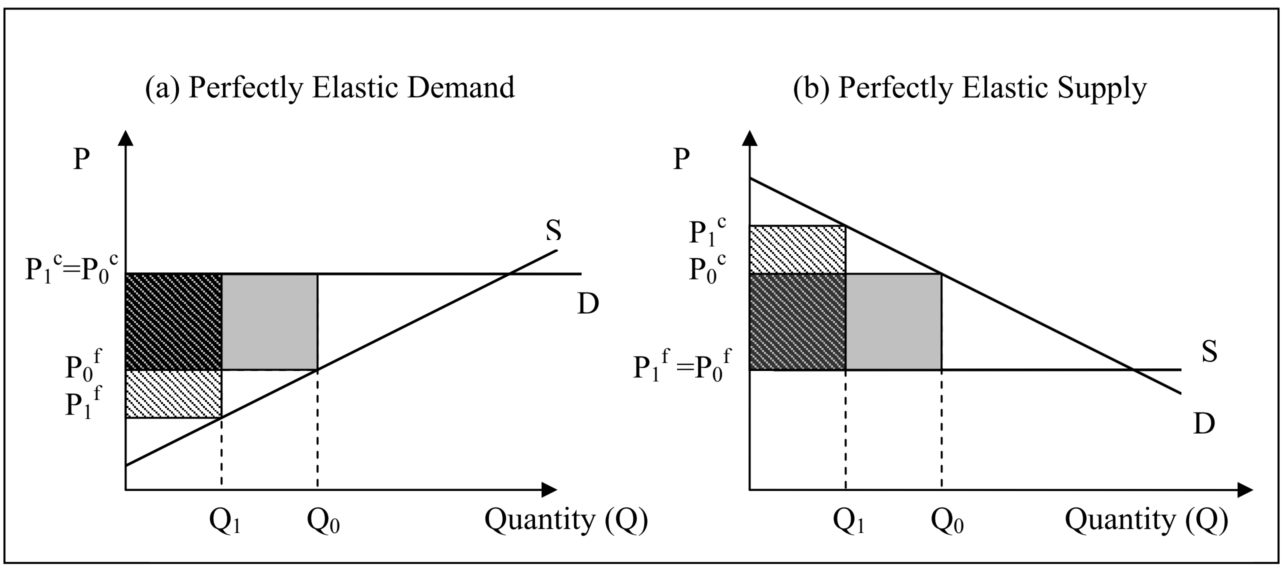

Figure 14

Under long-run competitive conditions in the food system, the shaded region, which represents value-added in the processing industry --the gross margin (P_0^c - P_0^f) multiplied by the number of units transacted (Q_0)-- is equal to the total economic cost of processed food production prior to wastewater regulations. For wastewater regulations that increase the unit cost of producing processed food in the San Joaquin Valley by \$r per unit of output, the gross margin in the processing industry must increase by \$r in the long-run to recover the incremental costs of waste disposal.

Panel (a) of Figure 14 depicts the incidence of wastewater regulations on food processors in the case of perfectly elastic demand. With perfectly elastic demand, the increase in unit processing cost is unable to shift into the consumer price due to perfect substitution possibilities in the consumer market. Instead, 100 percent of the food processing cost increase shifts backwards into the raw product market. The price of the raw agricultural product decreases by $r, the entire increment in food processing costs due to wastewater regulations, and the resulting farm price decreases in the long-run to the level P_1^f.

Figure 14 depicts the incidence of wastewater regulations on food processors in the case of perfectly elastic farm supply. With perfectly elastic supply, the increase in unit processing cost is unable to shift into the farm price due to perfect substitution possibilities available to farmers in the land market. Instead, 100 percent of the food processing cost increase shifts forward into the consumer market. The price of the processed food products in the consumer market rises by $r in the long-run to the level P_1^c.

In the intermediate cases most relevant to the present study of wastewater regulations, neither the price elasticity of supply nor the price elasticity of demand is perfectly elastic (or alternatively, perfectly inelastic). In this case, a portion of the increase in food processor variable cost following wastewater regulations is shifted forward into consumer markets for processed goods and the remaining portion shifted backward into farm markets for agricultural products. The degree of shifting that occurs in each market, as indicated in the figure above, depends on the relative price elasticity of supply and demand. When demand is more elastic than supply, a greater portion of the cost shifts backward into the agricultural product market and the remaining portion shifts forward to the consumer market, when supply is more elastic than demand, a greater portion of the cost shifts forward into the consumer market than shifts backward into the agricultural product market, and, when demand and supply are equally elastic, 50 percent of the cost is shifted into each market.

The price elasticities of supply and demand are also important determinants of the market transfer effect of San Joaquin Valley wastewater regulations. In terms of the market transfer effect of food processing (and farming) activity from the regulated region to regions with lower production costs, the location of food processors is influenced both by proximity to consumer markets and proximity to the supply of raw agricultural products. Because the joint location decision of farming and processing operations, moreover, market transfer in the processing industry tends to occur in conjunction with market transfer in the farm production industry as well. In a given industry, the transfer of processed food production out of a particular region is closely tied to the land allocation decision of farmers in the region, and hence the elasticity of farm supply. Likewise it is tied to the ability to transship processed goods into the consumer market from other regions, and hence the elasticity of demand.

Figure 15 depicts the market transfer effect of wastewater regulations in a long-run competitive food industry. Prior to environmental regulation, the quantity produced (in both panels) is labeled Q_0 and the consumer price and farm price are P_0^c and P_0^f, respectively. The shaded region, as before, represents the value-added component in the food processing industry. In both panels of the figure, the increase in the variable cost of food processing brought about by more stringent wastewater regulations is shifted in some combination backwards into agricultural product markets (represented by the decline in the farm price from P_0^f to P_1^f) and forward into consumer markets for the processed food (represented by the rise in the consumer price from P_0^c to P_1^c).

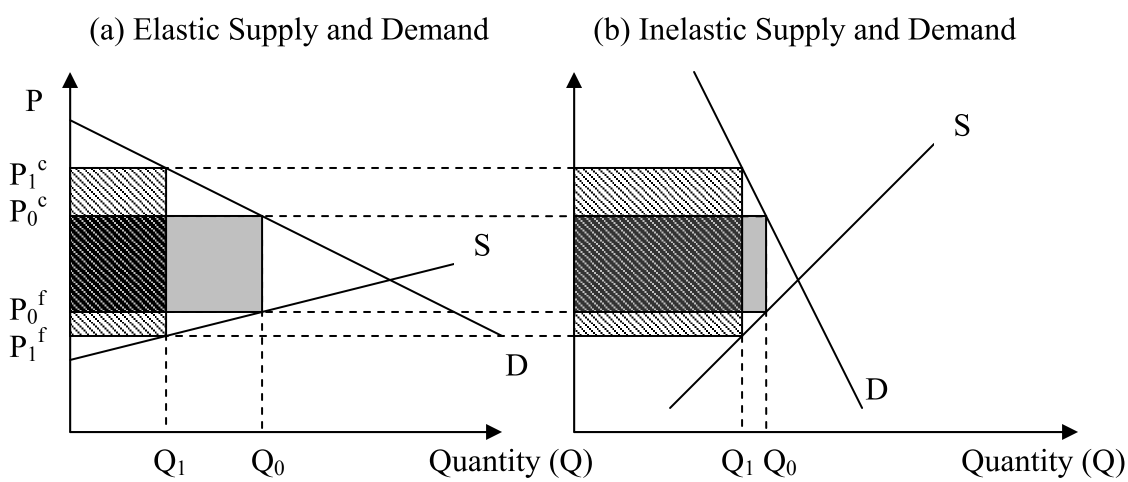

Figure 15

Panel (a) of Figure 15 depicts the case of elastic supply and demand conditions. In the case where both supply and demand facing the food processor are relatively elastic, the market transfer effect (the decrease in regional processed food production from Q_0 to Q_1) is relatively large. The reason is that, under elastic supply and demand conditions, agricultural producers have reasonable attractive alternative uses for their land and, at the same time, consumers have reasonably good substitution possibilities available in alternative processed goods. A relatively large amount of food processing activity transfers out of the region in this case to other regions through a combination of agricultural producers switching into alternative crops as farm prices decrease and consumers switching into alternative processed foods produced in other regions as consumer prices for regionally-produced processed foods increase.

Figure 15(b) depicts the case of inelastic supply and demand conditions. In the case of inelastic demand, consumers face few reliable substitutes for the regionally produced food product, so that the consumer price rises in response to wastewater regulations without an appreciable decline in the quantity produced. Similarly, in the case of inelastic supply, farmers have few alternative uses for land, so that farm prices decline in response to wastewater regulations without causing a large switch away from the production of the crop and towards other potential uses of the land. As a result, the market transfer effect (the decrease in regional processed food production from Q_0 to Q_1) is relatively small.

The incidence of an increase in food processing costs is calculated using reported values in the literature on the demand elasticity and long-run supply elasticity for each product. Regional estimates of supply and demand conditions are employed whenever possible. To identify market transfer effects of processing and farming operations from the San Joaquin Valley in response to wastewater regulations, it is important to consider long-run supply elasticities, because the long-run is defined for each industry as the time-horizon for which entry and exit can occur. In the long-run, a rise in the unit cost of processed food production following wastewater regulations reduces processor profits and induces the relocation of a portion of the region's food processing operations to other production regions. In a competitive food industry, the entire increase in food processor cost following an environmental regulation is entirely passed through to consumers and growers in the long-run (Gardner, 1975).

a) Elasticity Values

The economics literature includes a large number and variety of estimates of the elasticity of supply of and demand for processed food products. Some of the variation among the elasticity estimates reflects differences in the context to which they are meant to apply (e.g. different products or different stages of production), some of the variation reflects differences in the time horizon considered, and some of the variation represents measurement or estimation error. The values reported here are selected from studies in the literature that most closely approximate the conditions facing San Joaquin Valley producers over a long-run time horizon.

In general, demand conditions are available from a number of studies for each category of processed food product, while supply conditions are available only in the subset of industries for which data are readily accessible. One reason for the lack of data at the farm level is that supply to food processing establishments is often procured through contracts with agricultural producers, so that data on actually market trades is either missing or incomplete. There is no data available on the long-run supply elasticity of wine grapes and only limited supply information is available in the case of fed cattle, pork, and poultry supply.

Table 33 reports values for the estimated supply and demand elasticities provided by the literature for the primary industries considered in this study. The estimated values of the long-run supply elasticities are selected according to the length of time necessary for inventory adjustment to occur. The time horizon is particularly important for the cheese market, where the short-run (less than one year) adjustment to a change in the milk price paid by cheese manufacturers occurs entirely through adjustment in the amount of milk production per cow, whereas the long-run adjustment (five years or more) occurs predominantly through changes in the size of the dairy herd (Chavas and Klemme, 1986).

Table 33: Price Elasticity of Supply and Price Elasticity of Demand

Industry	Supply Elasticity	Demand Elasticity
Processing Tomatoes	25.0	-0.5
Durham and Sexton (1992)	8.6 – 55.49	
Huang and Sexton (1996)	3.9	-0.5
Huang (1993)		-0.168
Cheese	1.0	-0.5
Chen, Courtney, and Schmitz (1976)	2.53	
Chavas and Klemme (1986)	2.2	
Helmberger and Chen (1994)	0.583	
FAFRI (1995)	0.370	
Balagtas and Sumner (2003)	1.0	
Sullivan, Wainio and Roningen (1989)		-0.60
Heien and Wessells (1990)		-0.57
Huang (1993)		-0.33
Blisard et al (1999)		-0.62
Schmit and Kaiser (2002)		-0.459
Schmit and Kaiser (2004)		-0.347
Beef	3.24	-0.8
Marsh (1994)	3.24	
Chavas (1983)		-0.89 to -0.59
Dorfman, Kling, and Sexton (1990)		-0.7
Eales and Unnevehr (1993)		-0.85 to -0.57
Huang (1993)		-0.62
Brester and Schroeder (1995)		-0.56
Piggott and Marsh (2004)		-0.924
US EPA (2002)		-2.59 to -0.15
Pork	1.80	-0.8
Lemieux and Wohlgenant (1989)	1.80	
Chavas (1983)		-0.73 to -0.71
Eales and Unnevehr (1993)		-1.2 to -0.8
Huang (1993)		-0.73
Brester and Schroeder (1995)		-0.69
Piggott and Marsh (2004)		-0.701
US EPA (2002)		-1.24 to -0.07
Poultry	10.0	-0.5
Brester, Marsh and Atwood (2004)	10.0	
Chavas (1983)		-0.7 to -0.45
Eales and Unnevehr (1993)		-0.23 to -0.16
Huang (1993)		-0.37
Brester and Schroeder (1995)		-0.33
Dahlgren and Fairchild (2002)		-1.16
Piggott and Marsh (2004)		-0.328
US EPA (2002)		-1.25 to -0.104

Industry	Supply Elasticity	Demand Elasticity
Wine	1.0	-1.0
Folwell and Baritelle (1978)		-0.81 to -0.64
Pompelli and Heien (1991)		-0.85
Leung and Phelps (1993)		-1.86 to -0.88
Buccola and VanderZanden (1997)		-1.19
Wittwer and Anderson (2002)		-0.71

The time horizon considered for the elasticity of supply differs across industries. For processed tomato products, the supply elasticity is calculated on a 1-year production horizon, which is sufficient for acreage adjustments to occur. For cheese manufacturing, Chavas and Klemme (1986) report an annual supply response to changes in the (U.S. class II) milk price, in which the elasticity of farm supply increases from a value of 0.28 in year 1 to a value of 3.51 in year 10, and the value reported in the table corresponds to the comparable 3-5 year time horizon reported in the other studies. For beef, the long-run supply elasticity for fed cattle is reported for a 10-year horizon to take into account the 8-12 year inventory cycle in cattle production (Rosen, Murphy, and Scheinkman, 1994).

i. Baseline Elasticity Values Employed

This section establishes the baseline values of the supply and demand elasticities to be used to compute incidence in the following section. Where possible, the baseline values are taken from studies that employ micro-data at the consumer level to estimate consumer demand, and studies of food demand that include a wide variety of substitution possibilities with other categories of food.

•Processing Tomatoes

For processing tomatoes, regional estimates of the long-run elasticity of supply and demand of California processing tomatoes are provided in the comprehensive study of the California processing tomato market by Durham and Sexton (1992). The long-run supply for processing tomatoes in the San Joaquin Valley takes into account the spatial structure of regional processing tomato supply in the Central Valley and is price elastic in all regions encompassed by their study. The long-run supply elasticity for processing tomatoes in the Central Valley is reported by Durham and Sexton (1992) in the range of 8.6 in Fresno and Merced counties to 55.49 in Santa Clara County, with an intermediate value of 26.42 in the combined region of San Joaquin and Contra Costa Counties. The baseline value used in the study is a long-run price elasticity of supply of 25, which closely approximates supply conditions in the San Joaquin County and is roughly at the mid-point of the range of reported values. Huang and Sexton (1996) characterize supply conditions in the traditionally export-oriented processing tomato industry in Taiwan, which is less relevant to the present study, but may proxy conditions in the growing export industry for processing tomatoes in China.

The demand for California processing tomatoes depends on market conditions that influence the various end-uses of processed tomato products. Data is lacking in many of these markets, both because consumer demand is for finished goods such as catsup and tomato sauce that are typically processed in an independent stage of production, and because a significant share of the consumption of processed tomato goods occurs through catsup packets at fast food restaurants, which are not transacted directly, but are provided to facilitate demand for other complementary goods. Nonetheless, the existing studies of canned tomato demand in the U.S. (Huang, 1993) and catsup and tomato juice in Taiwan (Huang and Sexton, 1992) indicate relatively inelastic demand conditions in the world market for processed tomato products. The baseline values used for the present study are a price elasticity of demand of -0.5.

•Cheese

For the processed cheese market, the estimated values of the long-run price elasticity of supply for raw milk range from 0.14 (Weersink and Howard, 1990) to 2.53 (Chen, Courtnet, and Schmitz, 1976). The baseline value taken in this study for elasticity of supply of raw milk in the U.S. is 1, which is the value selected by Balagtas and Sumner (2003) after a review of the literature for their simulation model of U.S. dairy milk supply.

The price elasticity of demand for cheese is reported in the literature to be in the range of -0.62 to -0.33. As in the case of processed tomato products, demand for cheese is price inelastic, and the baseline value selected for the study is -0.5.

•Processed Meats

The U.S. market for processed meat is decomposed into separate markets for processed beef, pork, and poultry products. For the baseline study, the long-run elasticity of supply of fed beef for slaughter is taken at the value of 3.84 estimated by Marsh (2003). The long-run elasticity of supply of pork and chicken are taken for the baseline model to be 1.8 and 10, respectively.

Market demand for meat products reported in the literature ranges from inelastic to moderately elastic. In a comprehensive review of the literature, the U.S. EPA (2002, Table 3A) reports estimated demand elasticities from a wide range of studies. These values range from -2.59 to -0.15 for boxed beef, -1.234 to -0.07 for pork, -1.25 to -0.104 for broilers, and -0.68 to -0.372 for turkey. The majority of the estimated values reported above are in the range -0.9 to -0.5 for boxed beef, -1.2 to -0.7 for pork, and -0.7 to -0.2 for poultry. The baseline values used for the present study are -0.8 for beef and pork, and -0.5 for poultry, values which are well within the range of estimates in the literature.

•Wine

For the wine market, there are no available supply elasticities reported for wine grapes. Zhao, Anderson, Wittwer (2003) estimate the elasticity of supply for Australian table grapes to be in the range of -1.0 to -0.8, which is the only reported value. For the baseline model, the long-run supply elasticity is set at 1.0, which is equal to the lowest value of the supply elasticity selected for any of the regions.

Given the high degree of product differentiation in the consumer wine market, the price elasticity of demand for wine in the U.S. is generally classified according to both color (white and red), market segment (premium and non-premium), and region of production. The demand elasticities reported in the literature are in the range from -0.64 to -1.19 for white wine, from -0.193 to -0.81 for red wine, and -0.7 for non-premium wine. In terms of region of production, Buccola and VanderZanden (1997) estimate demand for California wines sold in Oregon and find California red wine demand to be highly inelastic (-0.193) and California white wine demand to be moderately elastic (-1.19). Because wines produced in the San Joaquin Valley are generally non-premium wines and emphasize sweeter, white wine varieties, the baseline value of the demand elasticity is taken to be -1.0.

ii. Residual Demand Elasticities

Market demand for each processed food product is either price inelastic or unit elastic, while long-run supply in each market is generally more elastic. The implication is that, overall, an increase in food processor cost that affected all processors in the market would have a tendency to shift forward into consumer prices. For regional environmental regulations that affect only a subset of producers, however, this is not the case. An increase in cost among food processors in one region creates an economic opportunity for a market transfer to occur that redistributes processed food production to other regions. A rise in price of 1 percent driven by an increase in regional production costs may lead to less than a 1 percent decline in overall market quantity, but the decrease in overall market quantity may mask a substantial decline in regional production activity when the decline in regional production raises market prices for processed goods and facilitates increased production in regions outside the regulated area. Markets for processed food products are national (and in many cases international) in scope, and demand for processed food can be readily met through the transshipment of goods from production regions with lower costs.

Residual, or regional, demand for a processed good refers to the portion of market demand that is met by producers in a given region. In the case of wastewater regulations in the San Joaquin Valley, the relevant definition of residual demand is the demand facing the set of food processors in the region which face an increase in unit cost under the regulation, for instance food processing plants not currently discharging into a POTW. Let Q_T denote total demand for a processed food product in the market and let Q_R refer to the production level of firms facing a regulatory increase in cost and Q_U refer to the production level of unregulated firms. Under this designation, total demand in the market is met by total production, which defines the residual demand facing regulated firms as

$$Q_R = Q_T - Q_U \,.$$

Differentiating this equation with respect to the market price and converting the resulting expression into elasticity form allows the elasticity of residual demand to be expressed as

$$\varepsilon_R = \frac{\varepsilon_T}{s} + \left(1 - \frac{1}{s}\right)\varepsilon_U \,,$$

where s is the market share of producers affected by wastewater regulation, ε_R is the price elasticity of residual demand, ε_T is the market demand elasticity, and ε_U is the elasticity of supply in the unregulated region of production. If the regulation uniformly increases production costs for all firms in the market, then the combined market share of the regulated firms is 100 percent of the market ($s = 1$), and $\varepsilon_R = \varepsilon_T$. As the market share of firms subject to environmental regulation falls ($s < 1$), an increase in price charged by regulated firms stimulates the production of goods in the unregulated region until the supply of unregulated firms equates with the higher market price, and the residual demand facing the regulated firms is more elastic due to the replacement of regional production. The market transfer of production to other regions of production causes a price increase in the regulated region to have a larger effect on regional quantity than the effect on total market quantity, and this makes residual demand facing the regulated firms more elastic.

The magnitude of the market transfer effect to other regions is determined by the elasticity of supply in other production regions as well. If market supply in unregulated regions is highly elastic, then a small increase in the market price greatly stimulates production in these regions. Because the long-run supply is relatively price-elastic for raw agricultural products used to produce manufactured food and beverage products, the potential exists for a large amount of processed food production to shift out of the San Joaquin Valley and into other regions that can accommodate these industries at lower cost.

In the following subsections, the values of supply and demand elasticities detailed above for each industry are combined with data from NASS on market share to compute the residual demand elasticity for San Joaquin Valley producers.

•Processing Tomatoes

Based on the distribution of California processing tomato acreage and the location of processing plants, San Joaquin Valley food processors produce 73 percent of all processed tomato products in California and provide 19 percent of World tomato supply. For the baseline calculation, this implies a residual demand elasticity for processed tomato products facing San Joaquin Valley producers of $\varepsilon_R = -108$.

•Cheese

Based on the distribution of labor across California cheese manufacturing establishments, San Joaquin Valley cheese manufacturers produce 55 percent of all cheese in California and provide 13 percent of U.S. cheese supply. Given the current trade situation in global cheese, and the premium prices received for U.S. cheese products relative to rest-of-world prices, the U.S. cheese market is considered as an isolated entity from the world cheese market. In 2002, the U.S. was a net importer of cheese from other countries, exporting \$169 million and importing \$767 million in manufactured cheese products; however the total level of net imports (\$628 million) represents a small share (2.8%) of the total U.S. value of cheese shipments. Taken at the San Joaquin Valley producer share of 13 percent of the U.S. market, this implies a residual demand elasticity for San Joaquin Valley cheese of ε_R = -11.

•Processed Meats

For all processed meat products, the market share of San Joaquin Valley producers is taken to be the share of U.S. processed meat production, rather than world production. In 2002, the U.S. was a net exporter of processed meat products, with net exports of $2.3 billion in animal processing (except poultry) (comprised of exports of $6.8 billion and imports of $4.5 billion) and net exports of $1.7 billion in poultry processing ($1.8 billion exported, $113 million imported). However, the volume of the net trade flow is relatively small in each case, representing 4% and 4.5%, respectively, of the U.S. value of shipments for these processed goods. Moreover, the market share of San Joaquin Valley producers in the U.S. market is sufficiently small that accounting for market transfer effects from environmental regulations on San Joaquin Valley meat processors to producers in regions outside the U.S. would not significantly alter the calculations.

In 2006, the beef cow inventory in the San Joaquin Valley represented 25 percent of the beef cow inventory in California (176 thousand out of 700 thousand head). According to the U.S. Census of agriculture in 2002, the beef cow inventory in California was 2.2 percent of the U.S. beef cow inventory (735,045 out of 33.4 million head). Thus, the market share of San Joaquin Valley beef processors is 0.55 percent of the U.S. market, which implies a residual demand elasticity for San Joaquin Valley processed beef of ε_R = -840.

Data from NASS are not available at the county level for hog and poultry production. These values are taken from the value of shipments data listed in the County Agricultural Commissioner's reports in 2005 and the market share of San Joaquin Valley producers in California in 2005 is matched to the 2006 NASS data on California and U.S. production shares.

In 2005, 93 percent of the value of hog and pig shipments in California originated from counties within the San Joaquin Valley ($35.67 million out of $38.24 million), with Tulare county, alone, representing 67 percent ($25.5 million) of the State total. According to the U.S. Census of agriculture in 2002, the number of hogs and pigs sold in California represented 1.7 percent of U.S. sales (308,769 out of 185 million head). This implies the market share of San Joaquin Valley pork producers is 1.5 percent of the U.S. market, which leads to a residual demand elasticity facing San Joaquin Valley pork producers of ε_R = -163.

The poultry processing industry in the San Joaquin Valley is predominantly comprised of chicken processing (broilers) and turkey processing. Merced and Stanislaus Counties are the dominant producers of both types of products, while Fresno and Kings Counties specialize in turkey processing. In 2005, San Joaquin Valley processors accounted for 90 percent of the value of boiler shipments in California ($303.2 million out of $336.7 million) and virtually all of the $142.3 million in processed turkey shipments. According to the U.S. Census of agriculture in 2002, the number of boilers and other meat-type chickens sold in California was 3 percent of U.S. total (260.45 million out of 8.5 billion), while the number of turkeys sold was roughly 6 percent of the U.S. total. Overall, the combined market share of San Joaquin Valley poultry producers (weighted by the value of shipments in processed broilers and turkey) is 3.5 percent of the U.S. market, which implies a residual demand elasticity for San Joaquin Valley processed poultry products of ε_R = -287.

•Wine

As in the case of processing tomatoes, the global trade volume in wine is substantial. The U.S. ranks fourth in the world in terms of value of wine production, behind Italy, France, and Spain, and the U.S. is a substantial net importer of wine. In 2002, U.S wine exports totaled $567 million (predominantly to the U.K. and Canada), and U.S. wine imports totaled $3.32 billion (predominantly from France, Italy, Spain and Australia). The value of net imports in 2002 ($2.75 billion) amounted to 29 percent of the value of U.S. wine shipments ($9.4 billion) in 2002. Given the large market share of California wines in U.S. production, this implies a substantial potential for an increase in winemaking costs in the San Joaquin Valley to create market transfer effects to regions outside the U.S.; hence the residual demand elasticity is calculated based on the share of San Joaquin Valley wine producers in the world wine market.

Data on the market share of San Joaquin Valley wine producers in the U.S. market is available from U.S. Department of the Treasury's Alcohol and Tobacco Tax and Trade Bureau, and these data are matched with the value of wine shipments in the 2002 Census data and global production data from the Wine Institute.

In 2002, the U.S. Department of the Treasury reported that wineries in the San Joaquin Valley distilled 343.2 million gallons of wine. Total U.S. production of table wines, sparkling wines, and dessert wines in 2002 was 690.85 million gallons, which implies a San Joaquin Valley share of U.S. wine production of nearly 50 percent. In 2004, the Wine Institute reports the total U.S. production represented an 8.4 percent market share (by volume) of the world wine production of 290 million hectoliters (7.66 billion gallons). This implies the market share of San Joaquin Valley wine producers by volume is 4.2 percent of the world wine market, which implies a residual demand elasticity for San Joaquin Valley wine of ε_R = -47.

2. The Incidence of Wastewater Regulations

This section calculates the incidence of wastewater regulations on farmers and food processors in the San Joaquin Valley. For each food processing industry, the calculations are made for the case of wastewater regulations that impact all food processors in the San Joaquin Valley. For regulations that impact only a subset of food processors in the industry, the results would be modified in the following ways: (i) the market share of the processing plants facing increased regulatory costs would be smaller than the market share of all San Joaquin Valley processors, which would increase the residual demand elasticity for the effected plants and the associated market transfer away from these plants; and (ii) the plants in the San Joaquin Valley not subject to increased wastewater disposal costs would expand operations and process a larger share of the San Joaquin

Valley's agricultural products. In net, the market transfer of production from effected plants would be larger in percentage terms than in the case where all plants are subject to increased regulatory cost, but a share of this would transfer to other plants in the San Joaquin Valley, and the total market transfer out of the region would be smaller.

a) Evaluation of Incidence at Baseline values

Table 34 reports the calculated incidence effects of wastewater regulations in the San Joaquin Valley on regional agricultural product prices, on consumer prices for processed food products, and on the market transfer in each of the industries examined. In all processing markets studied, the degree of backward shifting into agricultural producer markets is large in relation to the degree of forward shifting into consumer markets, because the availability of alternative sources of supply from production regions outside the San Joaquin Valley mitigates consumer price effects. Consequently, the majority of the cost increase is passed backwards to agricultural producers in the form of lower prices for raw agricultural products.

The fourth column of Table 34 shows the market transfer effect. The extent of the market transfer in each industry is determined by the share of cost that is shifted backwards into reduced prices for agricultural producers and the long-run elasticity of supply in each raw product market. The market transfer effects are relatively large in the processing tomatoes, beef packing, and poultry processing industries, while the market transfer is moderated in the case of cheese and wine production by the relatively inelastic supply conditions in these markets.

Table 34: Effects of a 1% Increase in Food Processing Costs

	Share of Cost		
Industry	**Shifted Backward**	**Shifted Forward**	**Market Transfer**
Processing Tomatoes	81.1%	18.9%	20.29
Cheese	91.4%	8.6%	0.91
Beef	99.5%	0.5%	3.82
Pork	98.9%	1.1%	1.78
Poultry	96.6%	3.4%	9.66
Wine	97.9%	2.1%	0.98

i. Processing Tomatoes

For processing tomatoes, 81 percent of the increase in food processing costs from wastewater regulations is shifted backwards into the farm price of processing tomatoes, and the remaining 19 percent of the increase in unit production cost is shifted forward into consumer prices. A one percent increase in tomato processing costs following wastewater regulations leads to a 20 percent decline in the quantity of processed tomato products produced in the San Joaquin Valley. This may overstate the impact if tomato processors in other regions face similar salinity controls or if less elastic supply elasticities from the literature are assumed. (See sensitivity analysis below). The market transfer effect of processed tomato production from the San Joaquin Valley to other regions in the U.S. and internationally is large, because of elastic supply conditions in the market for processing tomatoes. Processing tomato acreage in the San Joaquin Valley and ultimately the tomato processing plants that utilize this input, contracts substantially in response to changes in the price of raw processing tomatoes, so that regional production levels in the long-run are highly sensitive to changes in food processing costs.

In 2002, U.S. tomato processor value-added was $1.63 billion and amounted to 44 percent of the value of shipments of canned catsup and other tomato based sauces.[120] At this rate, given the farm price of processing tomatoes of $57 per ton in 2005, this implies value-added in the tomato processing sector of approximately $45 per ton of processing tomatoes. In a long-run competitive market, value-added is approximately equal to total variable cost. Therefore, an increase of $1 per ton in tomato processing costs due to wastewater regulations in the San Joaquin Valley represents roughly a 2 percent rise (1/45) in the cost of processing a ton of raw tomatoes. This implies that a $1 increase in the cost of processing a ton of tomatoes due to wastewater regulations would precipitate the exit of 40 percent of processing plant operations in the San Joaquin Valley and 40 percent of the production of raw processing tomatoes (approximately 4.3 million short tons per year).

ii. Cheese

The incidence of wastewater regulations on cheese producers is complicated by the fact that the formula price for class 4b milk for cheese production in California is based on the commodity market price of cheddar cheese less a manufacturing cost allowance.[121] The share of the cost of wastewater regulations that is passed backwards to milk producers is limited by the support price, which may or may not be adjusted through the manufacturing cost allowance to account for the increased cost of wastewater disposal. The incidence analysis considered here allows for the full range of market price adjustments to occur in the formula price of class 4b milk.

Following an increase in wastewater disposal costs, 91 percent of the cost increase at cheese manufacturing plants is shifted backwards into the price of raw milk, and the remaining 9 percent of the increase in unit production cost is shifted forward into consumer cheese prices. A one percent increase in cheese manufacturing costs following wastewater regulations leads to a 0.9 percent decline in the quantity of cheese products manufactured in the San Joaquin Valley. The market transfer effect from the San Joaquin Valley to other regions in the U.S. is mitigated for two reasons: (i) the long-run supply of raw milk is not highly elastic, and (ii) the market transfer of cheese production to regions outside the U.S. is precluded by current trade restrictions.

In 2002, the value-added in California cheese production was $499 million and amounted to 21 percent of the value of shipments of California cheese.[122] California cheese production in 2002 was 1.722 billion pounds (781 thousand metric tons), so that the value-added per pound of cheese was approximately $0.29 per pound (499/1,722) of cheese. Since this value is equal to the log-run variable cost of producing a pound of cheese in a competitive processing industry, wastewater regulations that lead to a $0.01

[120] U.S. Department of Commerce (2005).
[121] California Department of Food and Agriculture (2005).
[122] U.S. Department of Commerce (2005).

per pound increase in cheese manufacturing costs in the San Joaquin Valley increase the unit manufacturing cost of cheese by approximately 3.5 percent and induces the exit of 3 percent of cheese manufacturing plants in the San Joaquin Valley. The impact of this reduction in cheese production would reduce the supply of class 4b milk accordingly by 3 percent, although the implication of the regulation on dairy operations overall would depend on how much of this production decrease could be absorbed by the remaining classes and on corollary adjustments in the class 4b support price through the manufacturing cost allowance component.

iii. Processed Meats

Following an increase in wastewater disposal costs, between 97 percent and 100 percent of the increase in unit production costs at meat packing plants is shifted backwards in the long-run into livestock prices. The largest impact of wastewater regulations on consumer prices (3.4%) occurs in the market for processed poultry products. Forward-shifting into consumer prices is limited in the case of processed meats, because San Joaquin Valley processors produce a small share of U.S. meat, which makes residual demand highly elastic in these markets. In the case of poultry, the moderate degree of forward-shifting that occurs in this market is due to elastic long-run supply conditions relative to other meats.

A one percent increase in meat processing costs in the San Joaquin Valley following wastewater regulations leads to a 3.82 percent decline in the quantity of beef processed in the San Joaquin Valley, a 1.78 percent decline in the quantity of pork, and a 9.66 percent decline in the quantity of processed poultry products. The market transfer effect from the San Joaquin Valley to other regions in the U.S. is largest in the case of poultry processing, because the relatively elastic supply conditions in this market favor a rapid increase in production in other U.S. regions in response to a rise in consumer prices.

In 2002, the value-added in California's animal (except poultry) slaughtering industry was $321 million, which amounted to 24.5 percent of the value of shipments in California.[123] In 2006, California beef packing plants slaughtered 2.02 billion pounds (commercial live weight) of beef cattle and paid an annual average price for beef cattle of $67.30 per hundredweight (cwt). Taken at the 24.5 percent value-added rate for the animal (except poultry) slaughtering industry, the value-added for beef processing (on a live weight basis) was approximately $21.82/cwt. Using this value as a proxy for the variable cost per cwt of processing beef cattle, wastewater regulations that lead to a $1/cwt increase in cattle processing costs in the San Joaquin Valley raise the unit processing cost of beef by approximately 4.6 percent (1/21.82). Given the market transfer of 3.82 percent for every one percent increase in the unit processing cost of beef at baseline values of the model, a $1/cwt increase in cattle processing costs in the San Joaquin Valley following wastewater regulations would induce the exit of 17.5 percent of beef packing operations (and 17.5 percent of the beef cattle inventory) from the San Joaquin Valley.

[123] U.S. Department of Commerce (2005).

California animal slaughtering plants processed 614 million pounds (commercial live weight) of hogs in 2006 and agricultural producers received an average annual price of $47.90/cwt. At the 24.5 percent value-added rate for the animal (except poultry) slaughtering industry, the value-added for hog processing (on a live weight basis) was approximately $15.53/cwt in 2006. Taking this value for the variable cost per cwt of processing hogs, wastewater regulations that lead to a $1/cwt increase in hog processing costs in the San Joaquin Valley raise the unit processing cost of hogs by 6.4 percent. Given the market transfer of 1.78 percent for every one percent increase in the unit processing cost of hogs in the baseline calculation, a $1/cwt increase in hog processing costs in the San Joaquin Valley following wastewater regulations would induce the exit of 11.5 percent of hog processing operations (and 11.5 percent of hog producers) from the San Joaquin Valley.

In 2002, the value-added in California's poultry slaughtering industry was $501 million, which amounted to 47 percent of the value of shipments in California.[124] In 2005, California poultry processing plants processed 772 million pounds of broilers at an annual average price of $43.60/cwt and 331 million pounds of turkey at an annual average price of $43.00/cwt. (Data from NASS is not available on broiler prices in California or on poultry prices in 2006). At the 47 percent value-added rate for the poultry processing industry, the value-added for poultry processing (on a live weight basis) was approximately $38.88/cwt for chicken and $38.34/cwt for turkey. Taking these values as proxies for the variable cost per cwt of processing broilers and turkey, wastewater regulations that lead to a $1/cwt increase in poultry processing costs in the San Joaquin Valley increase the unit cost of each type of poultry processing by approximately 2.6 percent. Given the market transfer of 9.66 percent for every one percent increase in the unit processing cost of beef at baseline values of the model, a $1/cwt increase in poultry processing costs in the San Joaquin Valley following wastewater regulations would induce the exit of 25 percent of poultry processing operations (and 25 percent of the poultry production) from the San Joaquin Valley.

iv. Wine

Following an increase in wastewater disposal costs, 98 percent of the cost increase at wineries in the San Joaquin Valley is shifted backwards into the price of wine, raisin and table grapes that comprise the region's crush. The remaining 2 percent of the increase in unit production cost of wine is shifted forward into consumer wine prices.

In 2002, the value-added in California's wine industry was $4.52 billion, which amounted to 54.9 percent of the value of shipments in California.[125] In 2006, California produced 3.48 million tons of crush, much of which was used for wine production, and the average price per ton paid across all grape varieties was $547/ton. Taken at the 54.9 percent value-added rate for the winery industry, the value-added in wine making per ton of crush was (on average) $667/ton. Given the high degree of variability in the scale (and target quality level) of California wineries, both the value-added component and the price per ton paid for crush are considerably larger in Napa, Sonoma, and San Luis Obispo

[124] U.S. Department of Commerce (2005).
[125] U.S. Department of Commerce (2005).

Counties than in Fresno, Madera, and San Joaquin Counties; however, the data are not available to calculate regional value-added rates for California wineries. Using $667/ton for the variable cost of San Joaquin Valley wineries is extremely conservative, as this likely over-states true production costs considerably. At this rate, wastewater regulations that lead to a $10/ton increase in the cost of fermenting crush in wine stills in the San Joaquin Valley raise the unit cost of wine production by 1.5 percent. Given the market transfer of 0.98 percent for every one percent increase in the unit wine-making cost in the baseline calculation, a $10/ton increase in the cost of fermenting crush in the San Joaquin Valley following wastewater regulations would induce the exit of 1.5 percent of winery operations from the San Joaquin Valley.

b) Sensitivity Analysis

This section considers the sensitivity of the baseline results on incidence of wastewater regulations to changes in the values of the market supply and demand elasticities within the range of values reported in the literature.

i. Variations in Demand

The outcome for each food processing industry is extremely robust with regard to alternative specifications market demand conditions. For the case of processing tomatoes, when the price elasticity of demand is varied between the values of -0.5 and -0.168 reported in the literature, the residual demand elasticity for San Joaquin Valley producers remains in the range of -108 to -106, and the implications of the policy for shifting and market transfer remain essentially the same. For variations in the price elasticity of demand for cheese in the reported range of -0.62 and -0.33, the degree of backwards-shifting varies between 90-92 percent, and the market transfer is between 0.9 and 0.92 percent for every 1 percent increase in processing cost. For variations in the price elasticity of demand for meat products, even in the case of beef demand, which had the highest reported variation in the literature (between -2.59 and -0.15), the degree of backwards-shifting remains stable between 99.4 and 99.7 percent, and the market transfer is between 3.82 and 3.83 percent for every 1 percent increase in processing cost. For variations in the price elasticity of demand for wine in the range of -1.86 and -0.64 reported in the literature, the degree of backwards-shifting varies between 97.5 percent and 98.5 percent, and the market transfer is between 0.97 and 0.99 percent for every 1 percent increase in fermenting cost.

ii. Variations in Supply

The results on the effect of wastewater regulations on San Joaquin Valley food processors are more sensitive to variations in supply conditions, particularly pertaining to the market transfer effects. The reason is that the price elasticity of supply determines both the sensitivity of agricultural production to farm price changes in the San Joaquin Valley as well as the ability of food processors in regions outside the San Joaquin Valley to procure a greater amount of agricultural products necessary to increase processed food production. That is, a change in the price elasticity of supply affects both market supply conditions and the residual demand elasticity facing food processors in the San Joaquin Valley. When the price elasticity of supply is less elastic, residual demand is also less price elastic, which allows increased food processing costs in the region to be absorbed into prices with relatively smaller market transfer effects.

Variations in the price elasticity of supply also provide important insights into the series of changes which may occur in a particular processing industry over different time horizons. For each of the food processing industries encompassed by the study, the price elasticity of supply is larger on long-run time horizons than on short-run time horizons. Accordingly, variations from the baseline model to circumstances with less price-elastic supply conditions characterize effects which are likely to occur on relatively shorter time horizons. Alternatively, variations from the baseline model to conditions with more price-elastic supply characterize effects which are likely to occur on relatively longer time horizons. Relative to supply conditions used in the baseline case, less elastic supply conditions (that characterize shorter time horizon) are associated with smaller market transfer effects, while the market transfer of processed food production out of the San Joaquin Valley is exacerbated when longer time horizons are considered.

c) Processing Tomatoes

For processing tomatoes, the price elasticity of supply was varied between the values of 8.6 and 55.5 reported for Central Valley producers. For a price elasticity of supply of 8.6, the price elasticity of residual demand is -39, whereas, for a supply elasticity of 55.5, the price elasticity of residual demand is -359. Residual demand facing San Joaquin Valley food processors is an order of magnitude larger in the case of elastic supply conditions, because highly price-elastic supply facilitates relatively large increases in processed food production in other regions following a small change in consumer prices. In either case, between 82 percent and 87 percent of the cost is shifted backwards into the farm price of processing tomatoes, with the remaining 13 percent to 18 percent shifted forward into consumer prices, but the implications of a change in supply conditions has important implications for the degree of market transfer.

On a relatively short time horizon, the supply of processing tomatoes is less elastic than on a longer time horizon, and this limits the transfer of processing tomato production to other regions. If the price elasticity of supply is 8.6, a 1 percent increase in processing costs leads to a 7.4 percent market transfer of processing tomato production to regions outside the regulated zone. If the price elasticity of supply is 55.5, a 1 percent increase in processing costs generates a 47.3 percent market transfer of processing tomato production to other regions.

d) Cheese Manufacturing

For cheese manufacturing, the price elasticity of supply was varied between the values of 0.22 and 1.22, which corresponds with the annual supply response to changes in the raw milk price over a graduated 10-year horizon reported by Chavas and Klemme (1986). In their study, the elasticity of farm supply increases over time through adjustments in the milk cow inventory from a value of 0.28 in year 1 to a value of 3.51 in year 10.

For a price elasticity of supply of 0.28, the price elasticity of residual demand is -5.78, 95 percent of the cost increase is shifted backwards into the class 4b milk price, and a 1 percent increase in processing costs leads to a moderate 0.27 percent market transfer of cheese production to regions outside the San Joaquin Valley. For a price elasticity of supply of 3.51, 90 percent of the cost increase is shifted backwards into the class 4b milk price, and the larger shift into consumer prices facilitates a large market transfer from the regulated region. A 1 percent increase in processing costs in this case leads to a 3.16 percent market transfer of cheese production to regions outside the San Joaquin Valley.

e) Meat Processing

For processed meats, the price elasticity of supply was varied 50 percent from the reported value in the baseline cases (from 1.92 to 5.76 in the case of beef; from 0.9 to 2.7 in the case of pork; and from 5 to 15 in the case of poultry). In each case, the degree of backwards shifting remained above 97 percent and less than 3 percent of the cost was shifted forward into consumer prices. For the case of beef, a 1-percent increase in processing cost following wastewater regulations stimulated a market transfer effect of between 1.9 percent and 5.7 percent to regions outside the San Joaquin Valley, with larger market transfers occurring with the more elastic supply conditions that are associated with longer time horizons. For the case of pork, a 1-percent increase in processing cost following wastewater regulations stimulated a market transfer effect of between 0.9 percent and 2.7 percent to regions outside the San Joaquin Valley. For the case of poultry, a 1-percent increase in processing cost following wastewater regulations stimulated a market transfer effect of between 4.8 percent and 14.7 percent to regions outside the San Joaquin Valley.

f) Wine

For wineries, the price elasticity of supply was varied 50 percent from the reported value in the baseline cases (from 0.5 to 1.5). For a price elasticity of supply of 0.5, the price elasticity of residual demand is -35.7, 98.6 percent of the cost increase is shifted backwards into the market price of crush, and a 1 percent increase in fermenting costs leads to a modest 0.49 percent market transfer of wine production from San Joaquin Valley wineries to wineries in other regions. For a price elasticity of supply of 1.5, 97.5 percent of the cost increase is shifted backwards into the market price of crush, and a 1 percent increase in fermenting costs in this case leads to a 1.5 percent market transfer of wine production to regions outside the San Joaquin Valley.

In each case, given the relatively elastic demand conditions facing winemakers in the San Joaquin Valley, the market transfer of wine production to other wine production regions is determined almost entirely by the supply elasticity of crush. Given the time lags between planting wine grape varieties and crush production, there are likely to be considerable differences between the short-run and long-run elasticity of supply in the crush market. The lack of studies in the literature that consider dynamic supply conditions in the crush market complicates the calculation of market transfer effects that are likely to follow an increase in wastewater treatment costs among San Joaquin Valley winemakers.

F. Multiplier Effects

By combining various pieces of analyses above, we can now estimate the total economic impact that will be caused by the costs imposed upon food processors to reduce salinity levels. The market transfer effect gives us the change in product (output) from the change in salt management costs. Using the market transfer effect along with salinity effluent characteristics and treatment costs, we can estimate food processor industry output reduction and the regional economic impacts of conforming to potential salinity regulation. Industry-specific output reduction must first be calculated before estimating total regional economic impacts. The economic impacts of salinity reduction in the representative food processing industries of tomato processing, cheese and milk processing, animal and poultry processing, and wineries are calculated for San Joaquin, Stanislaus, Merced, and Fresno Counties.

To calculate an output reduction due to an increase in cost of production caused by salinity removal requirements, we need to estimate the percent increase in variable cost imposed by the salinity removal. The value-added per ton of output for each type of food processor is used as our variable cost metric, since the two are approximately equal in a long-run competitive market.

The number of liters of water discharged per ton of output produced is from Section I.8 because production figures are not found in the Regional Board files. Multiplying the above number by the average salinity levels in TDS from Section I.8, we can estimate the number of tons of salt per ton of output.

By specifying a target salinity TDS level, the cost of salt removal per ton of output can be calculated. An average cost per ton of salt removal is calculated from the non-trading linear program model in Section III.11.C.2. Dividing the cost of salt removal per ton of output by the variable cost yields the percent increase in variable cost to meet the salinity level target. Finally, multiplying the increase in variable cost by the market transfer ratio gives us the estimated percent of output reduction caused by the increased costs of a salinity reduction measure.

Table 35 shows the inputs and the results of these calculations. A salinity TDS target of 500 mg/L will cause an output reduction from 0.37% in cheese processing up to 3.34% in beef processing (excluding tomato processing, which has an output *gain* from salinity reduction). While the effect seems modest in percentage terms, the size of the food processing industry in the Central Valley means that even a one percent reduction in output is equal to hundreds of millions of dollars lost.

Table 35: Calculation of Output Reduction Percentage from Salinity Reduction

						= 3.785*[5]		= 1.1*10^-9*[6]*[7]			= 1 - [10]/[7]	= [8]*[9]*[11]	= [12]/[4]	= [13]*[1]
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
Industry	Market Transfer	Variable Cost	Unit	Variable Cost in Tons	Effluent per Ton Output (Gallons)	Effluent per Ton Output (liters)	TDS (mg/L)	Tons Salt per Ton Output	Avg. Cost per Ton of Salt Removal	Target TDS	% Salt Removal Required	Cost per Ton Added to Variable Cost	Percent Increase in Variable Cost	% Output Reduction
Tomato Processing	20.29	$45.00	ton	$45	920	3,483	531	0.00204	-$1,730	500	6%	-$0.21	-0.5%	-9.28%
Cheese	0.91	$0.29	lb	$580	360	1,363	1,592	0.00239	$1,437	500	69%	$2.36	0.4%	0.37%
Beef	3.82	$21.82	cwt	$436	2,460	9,312	604	0.00620	$3,576	500	17%	$3.82	0.9%	3.34%
Pork	1.78	$15.53	cwt	$311	2,460	9,312	604	0.00620	$3,576	500	17%	$3.82	1.2%	2.19%
Poultry	9.66	$38.88	cwt	$778	1,710	6,473	564	0.00402	$3,576	500	11%	$1.63	0.2%	2.03%
Wine	0.98	$667.00	ton	$667	1,125	4,259	1,176	0.00552	$1,627	500	57%	$5.16	0.8%	0.76%

Notes:
1) The Market Transfer is the decline in output of regional food processors given a 1% increase in processing costs.

The percent output reduction is used as input into the IMPLAN model to calculate indirect and induced effects on the local economy. Separate IMPLAN models are run for each of San Joaquin, Stanislaus, Merced, and Fresno Counties.

The IMPLAN Model is widely used for analyses of economic events such as a change in industrial output. IMPLAN was developed by the U.S. Forest Service and is now used by 1,500 agencies, universities, and companies, including the Environmental Protection Agency, the Army Corp of Engineers, the Florida Departments of Labor and Environmental Protection, the University of Florida, Florida State University, the University of California at Berkeley, and private consulting firms.[126] The core of IMPLAN is an input-output model. This type of model represents the economy of a particular region through a description of the sale and purchase of commodities and services across sectors of the economy.[127] Each individual county's economy is described by 509 IMPLAN industry sectors, which are based on the North American Industry Classification System (NAICS) and the Bureau of Economic Analysis (BEA) commodity classifications. Economic impacts are described in IMPLAN using three measures: direct effects, indirect effects and induced effects. Direct effects are the direct purchases by the facility or industry under study. Indirect effects are the purchases made by the firms supplying the facility. Induced effects are purchases by employees of the facility/industry and the indirect firms. In IMPLAN, induced effects are captured when the model is "closed" with respect to households. The version of IMPLAN used here is closed.

When analyzing a particular industry, IMPLAN calculates the impacts, or indirect effects, on "upstream" industries. These upstream industries provide the input goods and services to the analyzed industry. For example, tomato farming would be one of the upstream industries affected by a tomato canning shutdown. IMPLAN does not directly take into account the impacts on "downstream" industries. Downstream industries purchase the commodity or service produced by the relevant industry. The effects of output reduction on downstream users must be calculated separately.

The IMPLAN model contains countywide output, value-added, and employment for each of the 509 industry sectors. Our representative food processors of tomato processing, milk processing, meat and poultry processing, and wineries correspond to IMPLAN sectors 61-70 and 87. Note that, except for wineries, there is not a one-to-one match between our food processing industries and the IMPLAN industry sectors. For example, tomato processing would fall under IMPLAN sector 61 (Fruit and Vegetable Canning and Drying), but the sector contains much more than just tomato processing. Similarly, meat and poultry processing is spread out over four IMPLAN sectors: 67 through 70. In our scenarios, we calculate economic impacts based on all of the corresponding IMPLAN sectors (61-70 and 87), even though this is over-inclusive of some industries.

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[126] http://www.implan.com/references.html

[127] For a detailed discussion of this modeling method see, Ronald Miller and Peter Blair, *Input Output Analysis, Foundations and Extensions*, New Jersey: Prentice Hall.

Table 36: IMPLAN Sectors for the Representative Food Processor Industries

IMPLAN Sector	Sector Name
61	Fruit and vegetable canning and drying
62	Fluid milk manufacturing
63	Creamery butter manufacturing
64	Cheese manufacturing
65	Dry- condensed- and evaporated dairy products
66	Ice cream and frozen dessert manufacturing
67	Animal- except poultry- slaughtering
68	Meat processed from carcasses
69	Rendering and meat byproduct processing
70	Poultry processing
87	Wineries

Table 37 through Table 41 show the direct, indirect, and induced effects of output reduction on the local economies of the four counties due to a salinity target TDS level of 500 mg/L. For Stanislaus County, there is a $19 million loss of output attributed to direct impacts, or roughly 0.5% of the industry output of $3.98 billion. Indirect and induced output losses are nearly $18 million more. The output losses correspond to 183 jobs lost in Stanislaus County.

Table 37: Economic Impacts of Output Reduction due to Salinity Management
Stanislaus, San Joaquin, Fresno, and Merced Counties

Data for Representative Food Processing Industries

IMPLAN Sectors	61-70, 87
Industry Output	$11,311,451,646
Industry Value Added	$2,336,463,931
Employment	29,892

	Direct	Indirect	Induced	Total
	[I]	[II]	[III]	[IV]=[I]+[II]+[III]
Impacts: Loss of Output in Sectors 61-70 and 87				
Industry Output	$77,566,721	$55,453,540	$18,027,268	$151,047,529
Industry Value Added	$14,467,006	$21,739,600	$10,879,554	$47,086,159
Employment	271	334	182	787

Notes:
[I]: Direct effects are loss of output, value added, or employment directly attributed to output reduction caused by salinity management.
[II]: Indirect effects are changes in inter-industry purchases from output reduction caused by salinity management.
[III]: Induced effects are losses that reflect changes in spending from households as income decreases due to changes in output reduction.

Table 38: Economic Impacts of Output Reduction due to Salinity Management (Stanislaus County)

Stanislaus County Data for Representative Food Processing Industries	
IMPLAN Sectors	61-70, 87
Industry Output	$3,983,198,397
Industry Value Added	$981,820,627
Employment	9,628

	Direct	Indirect	Induced	Total
	[I]	[II]	[III]	[IV]=[I]+[II]+[III]
Impacts: Loss of Output in Sectors 61-70 and 87				
Industry Output	$19,089,158	$12,841,857	$4,830,564	$36,761,579
Industry Value Added	$4,739,360	$5,289,996	$2,934,636	$12,963,992
Employment	61	74	49	183

Notes:
[I]: Direct effects are loss of output, value added, or employment directly attributed to output reduction caused by salinity management.
[II]: Indirect effects are changes in inter-industry purchases from output reduction caused by salinity management.
[III]: Induced effects are losses that reflect changes in spending from households as income decreases due to changes in output reduction.

Table 39: Economic Impacts of Output Reduction due to Salinity Management (San Joaquin County)

San Joaquin Data for Representative Food Processing Industries	
IMPLAN Sectors	61-70, 87
Industry Output	$1,427,755,180
Industry Value Added	$270,551,018
Employment	3,605

	Direct	Indirect	Induced	Total
	[I]	[II]	[III]	[IV]=[I]+[II]+[III]
Impacts: Loss of Output in Sectors 61-70 and 87				
Industry Output	$8,261,778	$4,820,262	$1,834,110	$14,916,150
Industry Value Added	$1,534,944	$2,080,115	$1,109,439	$4,724,497
Employment	24	31	18	73

Notes:
[I]: Direct effects are loss of output, value added, or employment directly attributed to output reduction caused by salinity management.
[II]: Indirect effects are changes in inter-industry purchases from output reduction caused by salinity management.
[III]: Induced effects are losses that reflect changes in spending from households as income decreases due to changes in output reduction.

Table 40: Economic Impacts of Output Reduction due to Salinity Management (Fresno County)

Fresno County Data for Representative Food Processing Industries	
IMPLAN Sectors	61-70, 87
Industry Output	$3,937,637,911
Industry Value Added	$763,263,142
Employment	11,145

	Direct	Indirect	Induced	Total
	[I]	[II]	[III]	[IV]=[I]+[II]+[III]
Impacts: Loss of Output in Sectors 61-70 and 87				
Industry Output	$33,461,064	$25,809,611	$8,576,112	$67,846,786
Industry Value Added	$5,490,149	$10,054,074	$5,175,453	$20,719,676
Employment	120	171	86	377

Notes:
[I]: Direct effects are loss of output, value added, or employment directly attributed to output reduction caused by salinity management.
[II]: Indirect effects are changes in inter-industry purchases from output reduction caused by salinity management.
[III]: Induced effects are losses that reflect changes in spending from households as income decreases due to changes in output reduction.

Table 41: Economic Impacts of Output Reduction due to Salinity Management (Merced County)

Merced County Data for Representative Food Processing Industries	
IMPLAN Sectors	61-70, 87
Industry Output	$1,962,860,158
Industry Value Added	$320,829,145
Employment	5,514

	Direct	Indirect	Induced	Total
	[I]	[II]	[III]	[IV]=[I]+[II]+[III]
Impacts: Loss of Output in Sectors 61-70 and 87				
Industry Output	$16,754,721	$11,981,810	$2,786,482	$31,523,013
Industry Value Added	$2,702,553	$4,315,415	$1,660,027	$8,677,994
Employment	66	58	30	154

Notes:
[I]: Direct effects are loss of output, value added, or employment directly attributed to output reduction caused by salinity management.
[II]: Indirect effects are changes in inter-industry purchases from output reduction caused by salinity management.
[III]: Induced effects are losses that reflect changes in spending from households as income decreases due to changes in output reduction.

In the four counties combined, direct impacts account for $78 million in lost industry output, equal to 0.7% of the industry output of $11.31 billion. Indirect and induced output losses contribute an additional $73 million in output losses. These losses correspond to 787 jobs lost in the four counties. Even seemingly modest costs to conform to salinity standards will cause millions of dollars of output reduction in local economies.

Three additional IMPLAN scenarios were run to compare the economic impacts after adjusting for different input characteristics. The above “baseline” scenario uses in-plant treatment methods and the market transfer rates derived from the baseline supply elasticities. As a sensitivity analysis check, market transfer rates are derived from the minimum supply elasticities, which results in reduced economic impacts. Additionally, economic impacts using average costs of a brine line in the representative area, with both market transfer rates, are calculated. Table 42 shows a list of the assumptions that are changed during the sensitivity runs.

Table 42: Assumptions for Sensitivity Scenarios

	Market Transfer Rates		Costs per Ton of Salt Removal	
Industry	**Baseline**	**Low**	**In-Plant**	**Brine Line**
Tomato Processing	20.29	7.04	-$1,730	$3,658
Cheese	0.91	0.27	$1,437	$3,658
Beef	3.82	1.91	$3,576	$3,658
Pork	1.78	0.89	$3,576	$3,658
Poultry	9.66	4.84	$3,576	$3,658
Wine	0.98	0.49	$1,627	$3,658

The economic impact results across all four counties are listed in Table 43, and the results for Stanislaus County (which is where most of the representative area resides) are shown in Table 44. Compared to the baseline scenario, utilizing the low supply elasticities reduces economic losses by a little over half. Industry output loss for the four-county region is reduced from $151 million to $72 million, with corresponding industry value-added loss reduced from $47 million to $23 million. The number of jobs lost is reduced from 787 to 378. Similarly, industry output loss for Stanislaus County is reduced from $37 million to $17 million, industry value-added loss is reduced from $13 million to $6 million, and jobs lost reduced from 183 to 86.

The brine line alternative scenario assumes that all food processing industries join a brine line and pay the same costs per ton of salt removed. The economic impacts for this scenario increases significantly, by a factor of 10 or more. Industry output loss increases to nearly $1.8 billion, industry value-added loss is $625 million, and the number of jobs lost is over 8,350. Losses in Stanislaus County are of an equivalent magnitude. This vast increase in magnitude is mainly caused by the increased costs borne by tomato processors. Whereas in the baseline scenario tomato processors experienced a net gain because of food loss recovery, in the brine line scenario the increase in costs due to exporting salt via the brine line causes variable costs to increase by one percent, which in turn causes an output reduction of 20 percent due to the high market transfer effect. Because the IMPLAN sector 61 which includes tomato processing (Fruit and Vegetable Canning and Drying) is such a big portion of the economies of the Central Valley counties, the somewhat modest increase in costs to these food processors causes much larger economic impacts.

The fourth scenario, with the brine line alternative and the lower supply elasticities, shows reduced economic impacts compared to the brine line scenario with the baseline supply elasticities, but still are much larger than the in-plant treatment scenarios. While the lower supply elasticities result in smaller market transfer effects, the reduction in industry output is still over $643 million, industry value-added loss is over $224 million, and jobs lost exceeds 3,000. The effects on Stanislaus County are of an equivalent degree.

Table 43: Sensitivity Scenarios for Economic Impacts Analysis
Stanislaus, San Joaquin, Fresno, and Merced Counties

Scenario	Industry Output	Industry Value Added	Employment
Baseline (In-Plant Treatment)	$151,047,529	$47,086,159	787
In-Plant Treatment, Low Supply Elasticity	$72,143,518	$22,687,401	378
Brine Line Alternative	$1,791,889,613	$624,943,099	8,358
Brine Line, Low Supply Elasticity	$643,982,450	$224,423,009	3,017

Notes:
1) Values denote total economic impacts: direct, indirect, and induced.
2) Brine line scenarios use costs for a brine line in the representative area.

Table 44: Sensitivity Scenarios for Economic Impacts Analysis
Stanislaus County Only

Scenario	Industry Output	Industry Value Added	Employment
Baseline (In-Plant Treatment)	$36,761,579	$12,963,992	183
In-Plant Treatment, Low Supply Elasticity	$17,128,226	$6,136,113	86
Brine Line Alternative	$649,377,992	$232,664,193	2,927
Brine Line, Low Supply Elasticity	$231,335,246	$83,176,873	1,045

Notes:
1) All values denote total economic impacts: direct, indirect, and induced.
2) Brine line scenarios use costs for a brine line in the representative area.

The results above indicate the potential magnitude of effects to the Central Valley economy that can transpire due to increased costs to food processors. Many food processors are particularly sensitive to localized cost increases. These cost increases may cause certain food processing industries, such as tomato processors, to relocate if cost pressures are too high. In addition to the direct losses associated with food processor output reductions, the associated upstream and downstream effects to the regional economy are significant. The regional economic effects should be carefully considered before setting salinity management policies.

G. Environmental Justice

The Regional Board must also consider the impacts on environmental justice associated with any salinity management strategy it develops. Typically, environmental justice concerns are raised when a pollutant or project is expected to impose greater burdens on a disadvantaged group. The limited migration of food processors salinity discharge combined with the lack of health risks should allay any such concerns. Another environmental justice concern, however, may be the impact on employment. Will a regulation for example, negatively impact jobs disproportionately held by disadvantaged group or groups? As discussed above, under most salinity control approaches, total employment losses are minor. In addition, the most affected industries—agriculture and food processors—are not particularly labor intensive. Consequently, disproportional impacts are not likely to be substantial. While labor requirements may be greater at harvest time where a particular group may be affected, chronic labor shortages suggest that no adverse impact will occur.

III.4 Land Application in the Representative Area

Although crop damages associated with high salinity were estimated in Section 3 the estimate did not capture the impact that changing land use patterns will have. These damages are likely to reduce agricultural losses in some areas where urban south is expected. Salinity will also improve costs for residential users associated with urban south. This section presents estimates of these costs calculated by combining the hydrology and land use forecasting models with the residential and agricultural damage functions described in the previous section. Our focus is the representative area (RA) Recall that the representative area represents the lower San Joaquin River Basin and is located in the Northern San Joaquin Valley. It includes most of Stanislaus County and the northern portion of Merced. The RA contains a total of 18 communities, including the major cities of Modesto, Turlock, and Ceres, as well as smaller communities such as Salida, Livingston, Newman, and Escalon.

The Modesto and Turlock sub-basins are the primary source of groundwater for the representative area. The Modesto sub-basin is managed by the Modesto Irrigation District (MID) and the Oakdale Irrigation District (OID). The Turlock sub-basin is managed by the Turlock and Merced Irrigation Districts as well as the Ballico-Cortez and Eastside Water Districts.

A. Communities

Figure 16 shows overall water supply projections for the area. Because agriculture consumes significantly more water than urban uses, overall supply is skewed towards surface water. Surface water use is generally confined to agriculture, and urban communities are generally dependent on groundwater for supply. Surface water use increases significantly at 2010 due to the availability of additional diversions in the City of Modesto.

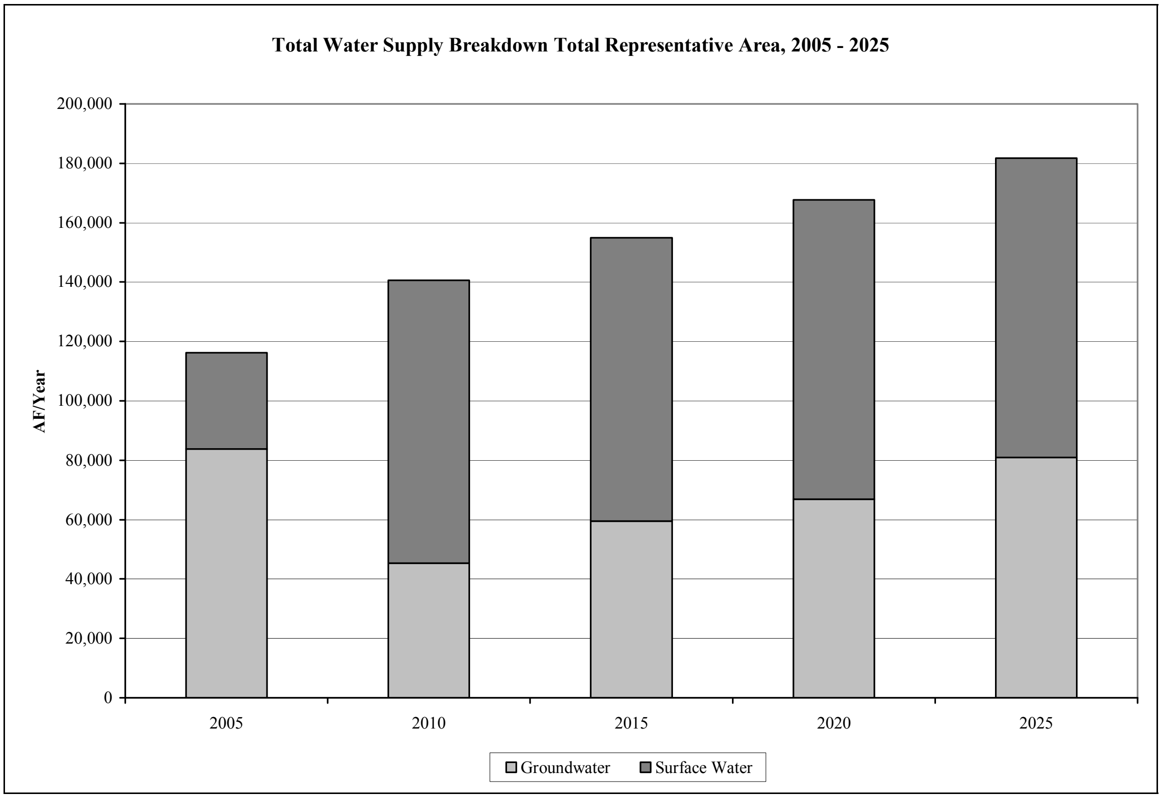

Figure 16

1. City of Modesto

The City of Modesto is located in Stanislaus County. The service area's estimated population was 264,209 in 2005 and is expected to reach 358,850 by 2025.[128] In general, the City of Modesto and its contiguous service areas (Salida and Empire) located north of the Tuolumne River, rely on treated surface water year-round. Surface water supplies are augmented with groundwater to meet increased demands in summer months. Demands originating south of the Tuolumne River are met with groundwater supplies year-round.

Annual groundwater production for Modesto and outlying areas averaged 46,275 AFY from 2000 to 2005. Although the city has recently increased its groundwater pumping to meet current growth demands, current pumping levels are less than historic highs and overdraft conditions have not occurred in either sub-basin. In 2005, Modesto pumped 46,295 AF of groundwater, or 60% of its overall demand. Pumping is expected to increase to 52,133 AF by 2025, when it will comprise 44 percent of total deliveries. Additional demand is met by supplies from the Modesto Irrigation District, which are expected to total 67,204 AF by 2010.

Residential use is responsible for the majority of water demand in Modesto. Table 45 displays current and projected deliveries by customer class. Single family residences account for around 60% of demand in every year, with multi-family dwellings

[128] The service area includes the City of Modesto as well as Empire, Salida, Waterford, Del Rio, Hickman, Grayson, Turlock, Bret Harte, Shackleford, West Modesto, and North Ceres.

demanding an addition 15%. Commercial, industrial, institutional, government and landscape customers account for the remaining quarter.

Table 45: Customer Accounts, City of Modesto

	Deliveries in … (% of total) (AF/Y)									
Customer Class	**2005**		**2010**		**2015**		**2020**		**2025**	
Single Family	48,532	62%	43,902	57%	59,065	62%	66,030	62%	73,902	62%
Multi-Family	10,950	14%	12,376	16%	13,987	15%	15,808	15%	17,866	15%
Commercial	11,788	15%	13,323	17%	15,057	16%	17,018	16%	19,233	16%
Industrial	6,674	8%	6,739	9%	6,804	7%	6,870	6%	6,937	6%
Inst./Gov.	652	1%	736	1%	832	1%	941	1%	1,063	1%
Landscape	206	0%	232	0%	263	0%	297	0%	335	0%
Total	**78,802**	**100%**	**77,308**	**100%**	**96,008**	**100%**	**106,964**	**100%**	**119,336**	**100%**

Source: Modesto UWMP.

Historically, single-family accounts have been un-metered in Modesto, but the city is in the process of converting all residential accounts to metered pricing. In 2005, approximately 71 percent of all single family accounts were un-metered accounts. In 2015, this number is expected to fall to 15 percent and by 2020 no un-metered accounts will remain. Since metered accounts provide a conservation incentive, water demand may fall below projections.

In the past decade, Modesto has transitioned its water supply away from groundwater pumping and replaced it with diverted surface water. In 1995 it began acquiring surface water from MID as part of the Modesto Domestic Water Project (MDWP). MDWP a joint association between the City of Modesto, MID and the Del Este Water Company to use a portion of MID's surface water supplies for domestic use. Phase One of the MDWP-operated Modesto Regional Water Treatment Plant (MRWTP,) a 33,000 AFY surface water treatment plant, was completed in 1995. Phase Two will provide an additional 33,602 AFY. The city also recently entered into an agreement with TID on the Surface Water Supply Project (SWSP), which will deliver 12,881 AFY of surface water to the south Modesto area. According to the UWMP, the SWSP is expected to become operational in the 2011.

The City of Modesto is also evaluating a potential Surface Water Supply Project (SWSP) with TID and a Phase Three MRWTP expansion with MID which could result in additional treated water deliveries. For example, the SWSP could provide up to 12,881 AFY of surface water supplies to offset groundwater pumping to meet demands south of the Tuolumne River.

2. Turlock

The City of Turlock is located in Stanislaus County, 15 miles south of Modesto and 20 miles north of Merced. The service area's estimated population was 65,970 in 2005 and is expected to reach 128,256 by 2025. Table 46 displays customer account data for Turlock. Residential uses account for around 70% of consumption, with half of all water being delivered to single-family homes. Commercial, industrial, landscaping and government comprise the remaining 30%.

Table 46: Customer Accounts, City of Turlock

	Deliveries in … (% of total) (AF/Y)									
Customer Class	**2005**		**2010**		**2015**		**2020**		**2025**	
Single Family	14,157	53%	14,505	54%	14,820	54%	15,339	52%	15,680	51%
Multi-Family	4,520	17%	3,936	15%	3,950	14%	4,543	16%	5,224	17%
Commercial	2,332	9%	2,744	10%	2,750	10%	3,235	11%	3,514	11%
Industrial	4,295	16%	4,300	16%	4,300	16%	4,300	15%	4,300	14%
City Use	678	3%	600	2%	859	3%	982	3%	1,105	4%
Landscape	808	3%	916	3%	780	3%	855	3%	988	3%
Total	**26,790**	**100%**	**27,001**	**100%**	**27,459**	**100%**	**29,254**	**100%**	**30,811**	**100%**

Source: Turlock UWMP.

Turlock currently relies completely on groundwater to meet urban demand; in 2004, total groundwater extracted was 25,465 AF, or over 90% of total deliveries. The city plans to substantially reduce its groundwater reliance over the next two decades through the acquisition of surface water. It estimates that groundwater production will decrease to 10,201 AF by 2010 and 8,811 AFY in 2025, when it will account for 17 percent of total supply. The city will compensate for this reduction by purchasing treated surface water from the Turlock Irrigation District (TID). Surface water deliveries are expected to amount to some 22,400 AF by 2025.

3. Ceres

The City of Ceres is located south of Modesto in central Stanislaus County. The service area's estimated population was 39,520 in 2005 and is expected to reach 66,000 in 2025. Groundwater is currently the city's sole source of supply; over the past five years approximately 10,000 AF have been extracted annually from city wells. Recently, the city signed a supply agreement with the Turlock Irrigation District (TID) for 11,000 AFY beginning in 2010. The plan also envisions groundwater supplies increasing to 20,000 AFY by 2015 and remaining at that level through 2025. Table 47 shows consumption by customer class for the city. Residences generate the majority of all demand. Commercial, industrial and landscaping uses are 15-20% in all years.

Table 47: Customer Accounts, City of Ceres

	Deliveries (% of total) (AF/Y)									
	2005		**2010**		**2015**		**2020**		**2025**	
Single/Multi-Family	8,200	76%	9,300	75%	10,600	76%	12,100	75%	13,800	73%
Commercial	870	8%	1,100	9%	1,400	10%	1,700	11%	2,100	11%
Industrial	100	1%	200	2%	300	2%	500	3%	700	4%
Landscape	600	6%	730	6%	890	6%	1,090	7%	1,330	7%
System Loss	1,000	9%	1,100	9%	700	5%	800	5%	900	5%
Total	**10,770**	**100%**	**12,430**	**100%**	**13,890**	**100%**	**16,190**	**100%**	**18,830**	**100%**

Source: Ceres UWMP.

B. Agricultural Suppliers

In addition to cities, a number of agricultural suppliers are active in the representative areas. Although these suppliers have traditionally focused on providing farmers with irrigation water, they are beginning to become key suppliers of water for urban purposes as well.

1. Modesto Irrigation District

The Modesto Irrigation District (MID) is responsible for supplying irrigation water for agriculture in and around Modesto. The district possesses a large portfolio of water rights and facilities, including canal networks, pipelines, pumps, drainage features, and control structures. MID uses a combination of Tuolumne River water and groundwater. Table 48 breaks down the total water supply; approximately 27 percent of total water supply is derived from groundwater.

Table 48: MID Water Supplies in 1997

Water Supplies	Volume (AF)
Surface Water	349,800
Groundwater	143,600
Annual Effective Precipitation	34,900
Water Purchases	0
Transfers or Exchanges into District	0
Total	**528,300**

The primary products grown within the MID service area are tree, vine, grain, row and pasture crops. Agriculture planning and operations within this district have undergone some significant changes that impacts groundwater demand. For example, cropping patterns have become more intensive. Instead of a single crop planted across thousands of acres, cropping patterns have shifted to many small parcels for a wide variety of high value specialty crops. Land in the region is also diverted away from pasture and converted to permanent crops. As crops are converted and agricultural patterns shift, so do irrigation methods. Irrigation systems move from flood irrigation toward more efficient systems like drip and micro sprinkler irrigation. Table 49 presents data on agricultural water demand within MID for the top ten crops based on acreage. In 1997, there was a total of 70,608 acres of irrigated farmland with a total crop water demand of 213,700 AF.

Table 49: MID Irrigation Budget

Type of Crop	Total Acreage	Total Crop Water Needs (AF)
Almonds	18,182	57,241
Pasture, Irrigation	11,968	52,333
Silage, Corn	8,898	18,314
Walnuts	8,141	25,398
Hay	6,235	9,574
Peaches	3,842	11,683
Grapes, Wine	3,478	8,752
Alfalfa Hay	3,300	13,910
Oats	1,197	2,194
Rice	975	3,339

Source: Water Management Plan for the Modesto Irrigation District, March 3, 2000.

Although its primary mission is to supply agricultural users, MID also has several supply arrangements in place with the City of Modesto. MID does not provide any water directly to urban communities, but rather supplies water to the City of Modesto's Municipal Water System, where it is subsequently delivered to urban communities. The overlap between MID and the City of Modesto is where the treated water is delivered.

2. Turlock Irrigation District

The Turlock Irrigation District (TID) serves over 5,800 irrigation customers covering approximately 149,500 acres of farmland. Its water supply is sourced from the Tuolumne River and the San Joaquin River, and the district also incorporates pumped groundwater in dry years.

Like MID, TID is responsible for providing irrigation water for agricultural customers that operate within the districts boundaries. TID uses a mixture of surface water and groundwater to supply the irrigation demands. Groundwater is pumped to supplement surface water deliveries. Once the groundwater has been extracted it is blended with surface water in the canals and delivered for irrigation. Table 50 outlines the surface and groundwater supplies as well as the acreage of land the water was applied to for 1993 though 1997. There is not a clear movement toward one particular source of water present during this time period. On average, groundwater made up 21 percent of total supply.

Table 50: Summary of Surface and Groundwater Supplied by TID

Year	Turlock Lake (AF)	Groundwater (AF)	Area Receiving TID Water (ac.)
1993	501,805	129,329	143,741
1994	497,815	151,552	143,140
1995	506,393	137,939	142,700
1996	549,254	151,650	142,299
1997	585,242	148,017	141,900

Source: TID Agricultural Water Management Plan, June, 1999.

TID is one of four agricultural water agencies located within the Turlock basin; the other three are the Ballico-Cortez and Eastside Water Districts, and Merced Irrigation District.

Total annual groundwater pumping approaches roughly 300,000 AF. Groundwater is the sole water-supply source in the Ballico-Cortez Water District and the Eastside Water District except for small areas intermittently irrigated with surface water. In the Turlock Irrigation District, surface water is the principle water-supply source, but supplemental groundwater is pumped; TID's annual diversion from the Tuolumne River is approximately 540,000 AFY.[129] For the Merced Irrigation District, surface water diversions from the Merced River are the principle source of supply, but supplemental groundwater is also produced. The annual Merced River diversion is about 20,000 AFY.[130]

The Turlock groundwater basin comprises an area of about 350,000 acres, or 540 square miles. The basin is bounded on the north by the Tuolumne River, on the west by the San Joaquin River, on the south by the Merced River, and on the east by the rocks of the Sierra Nevada foothills.

The Turlock basin contains both large urban and large agricultural areas. The urban areas cover about 20,000 acres or six percent of the basin. The agricultural areas with irrigated crops cover about 250,000 acres or 72 percent of the basin. The remaining 22 percent includes areas of non-irrigated crops and native vegetation.

Nine communities are located within the basin. These include the cities of Ceres, Hughson, and Turlock, part of the city of Modesto, and the communities of Delhi, Denair, Hickman, Hilmar, and Keyes. Groundwater is the water-supply source for these communities. The current groundwater pumping for these communities is about 42,000 AFY.

3. Oakdale Irrigation District

The Oakdale Irrigation District (OID) is another irrigation district located in the representative area. Most of the water is delivered to agricultural irrigation. Within OID, there was a total of 55,292 acres of irrigated land in 2001. According to the most recent *Water Management Plan* by OID, the district has 21 groundwater production wells with an annual production capacity of 32,560 AF.[131] Since water demand varies throughout the year, actual production ranges between 5,000 and 10,000 AF. It is estimated that about 147,000 AF was supplied by surface and groundwater deliveries.

C. Future Land Use

Over the past two decades, cities in the representative area followed the general trends discussed above. Table 51 examines the above metrics for the cities of Turlock and Modesto by tabulating FMMP data within the current city limits. Both cities experienced significant growth in their urban footprints over the past two decades, and this growth was largely achieved through the urbanization of farmland which once surrounded the cities. Farmland declined by roughly 200%, and the decline was sufficient to explain more than 90% of overall growth, in both cases.

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[129] Turlock Groundwater Basin Water Budget 1952-2002, December 2003, 1-2
[130] Turlock Groundwater Basin Water Budget 1952-2002, December 2003, 1-2
[131] Water Management Plan, Oakdale Irrigation District, September 9, 2005, iii

Table 51: Representative Area Land Conversion

	Urbanized Acres in			Farmland In				
City	**1984**	**2004**	**% Change**	**1984**	**2004**	**% Change**	**Farmland Urbanized**	**% of Total**
Modesto	16,279	20,193	19%	6,128.21	1,918	-220%	3,786	97%
Turlock	5,160	7,354	30%	3,093.76	1,077	-187%	1,997	91%
Total	**21,439**	**27,547**	**22%**	**9,221.97**	**2,995**	**-208%**	**5,782**	**95%**

Looking ahead, the model predicts these trends will continue. Satellite imagery and a reference map for Modesto are displayed in Figure 17. Green-shaded areas delineate the extent of the urban footprint in 1984. Red- and yellow-shaded areas denote currently undeveloped areas where the likelihood of development over the next twenty years is judged to be high and moderate, respectively. Urbanized areas visible in the satellite image that lie between the 1984 urban footprint boundaries and the forecasted areas were developed in the last two decades. Areas to the north and west of the current urban fringe will experience the greatest development pressure over the next two decades.

Development pressure generally declines moving away from the existing city boundaries. At the northern edge of the map, additional development pressure is witnessed extending outward from the city of Patterson; it appears likely the two cities will eventually form a contiguous urban corridor.

Figure 18 displays a similar map for the city of Turlock. Although less development is expected overall, it displays the same general build-out characteristics. The highest development pressure is along the State Highway 99 corridor. Undeveloped parcels within the city are also likely to urbanize.

Of particular interest are those areas which are currently surrounded by urban features. Figure 19 and Figure 20 show examples of this within the two cities. The parcels in question are clear candidates for urbanization; as development progresses, the existence of farmed land in the middle of the cities will become increasingly anomalous. In the Modesto map, the presence of grading and roadbeds demonstrates that development is in fact imminent. In Turlock, the parcel east of state highway 99 also appears to be under preparation. Note also the public park opposite this parcel; it underscores the need for careful checking of the urbanization model results in order to correct for exogenous impediments to development such as zoning.

Modesto Build-Out

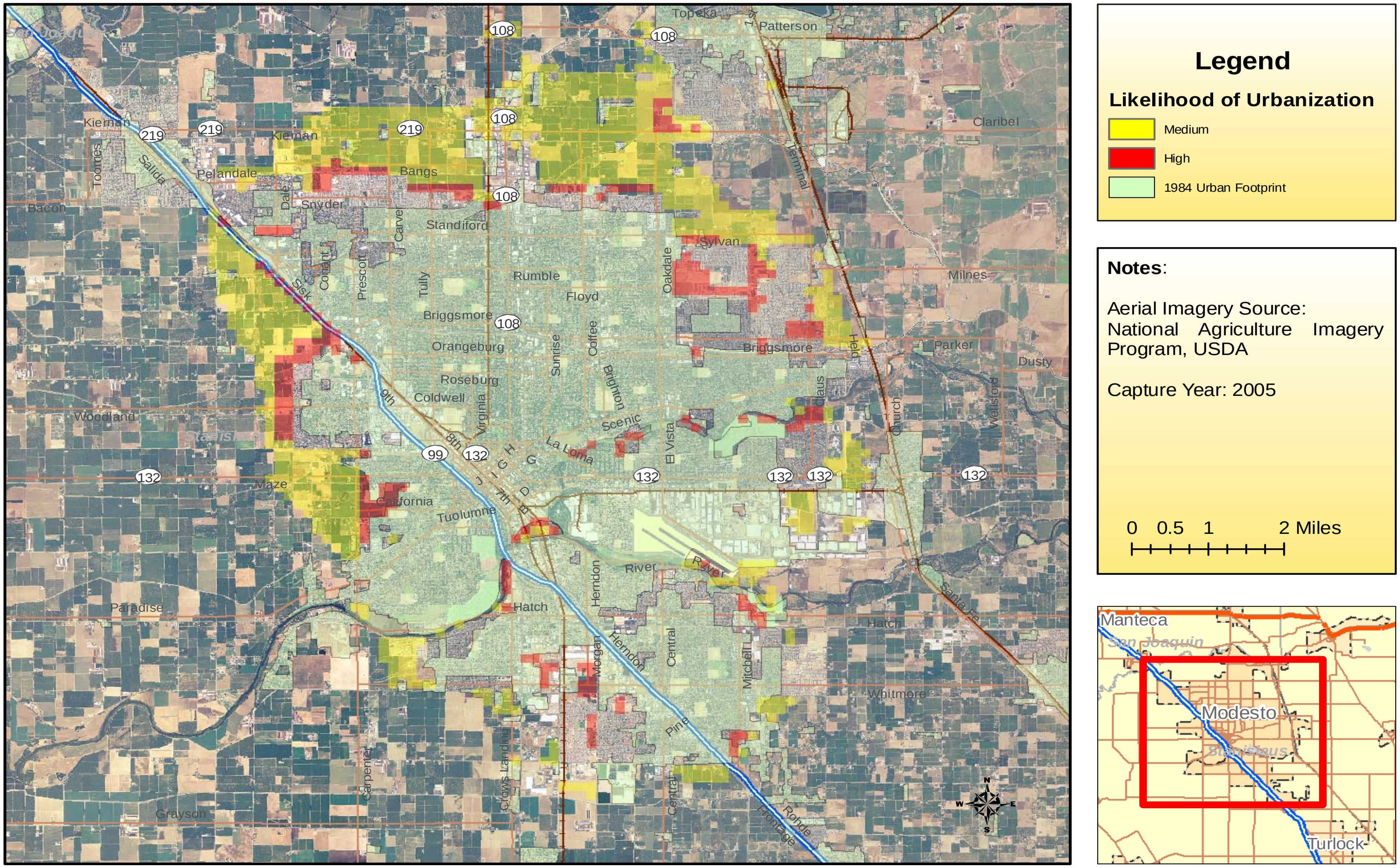
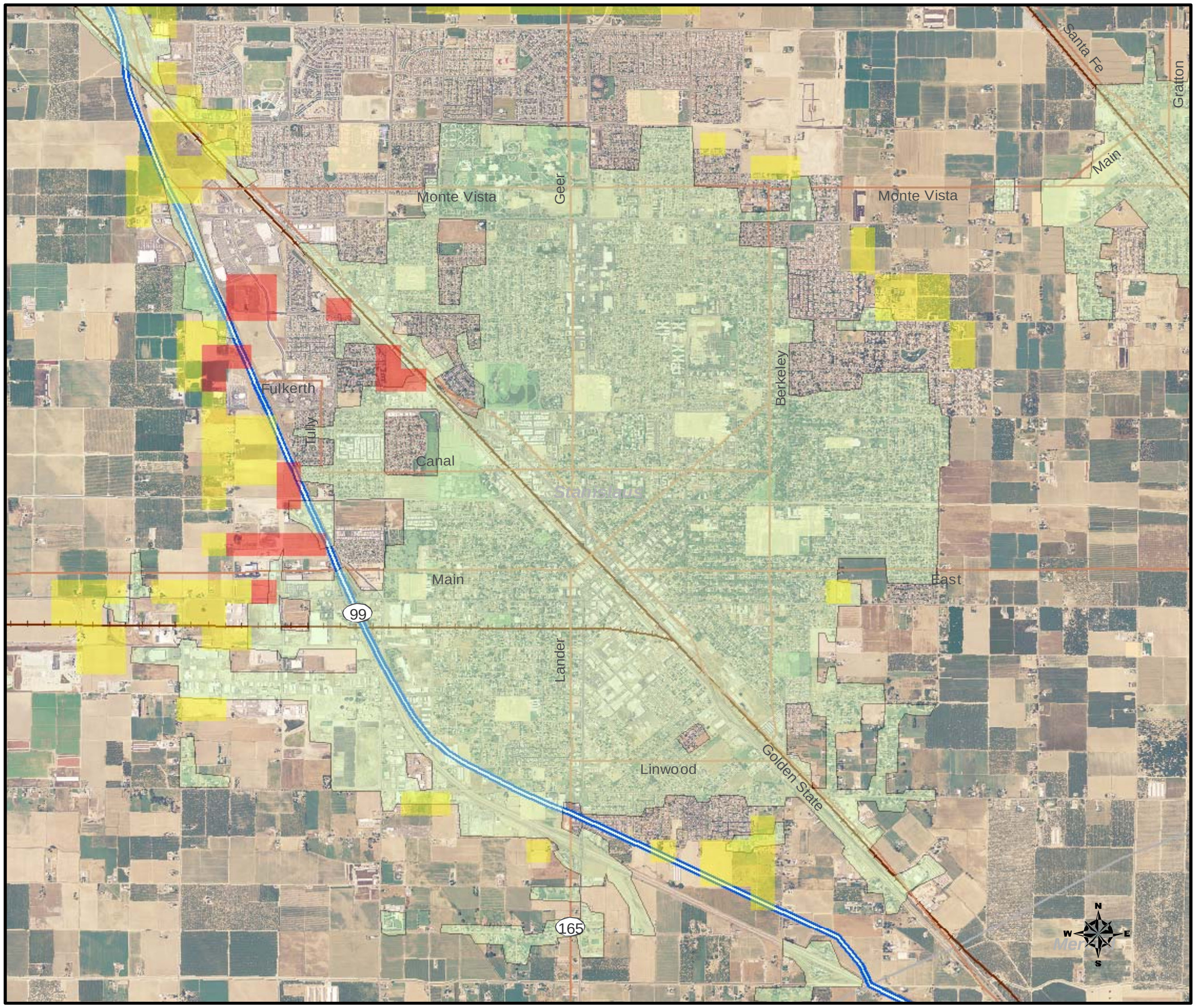


Figure 17

Turlock Build-Out



Legend

Likelihood of Urbanization

- Medium
- High
- 1984 Urban Footprint

Notes:

Aerial Imagery Source:
National Agriculture Imagery Program, USDA

Capture Year: 2005

0 0.25 0.5 1 Miles

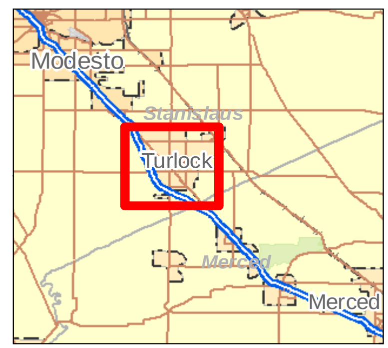
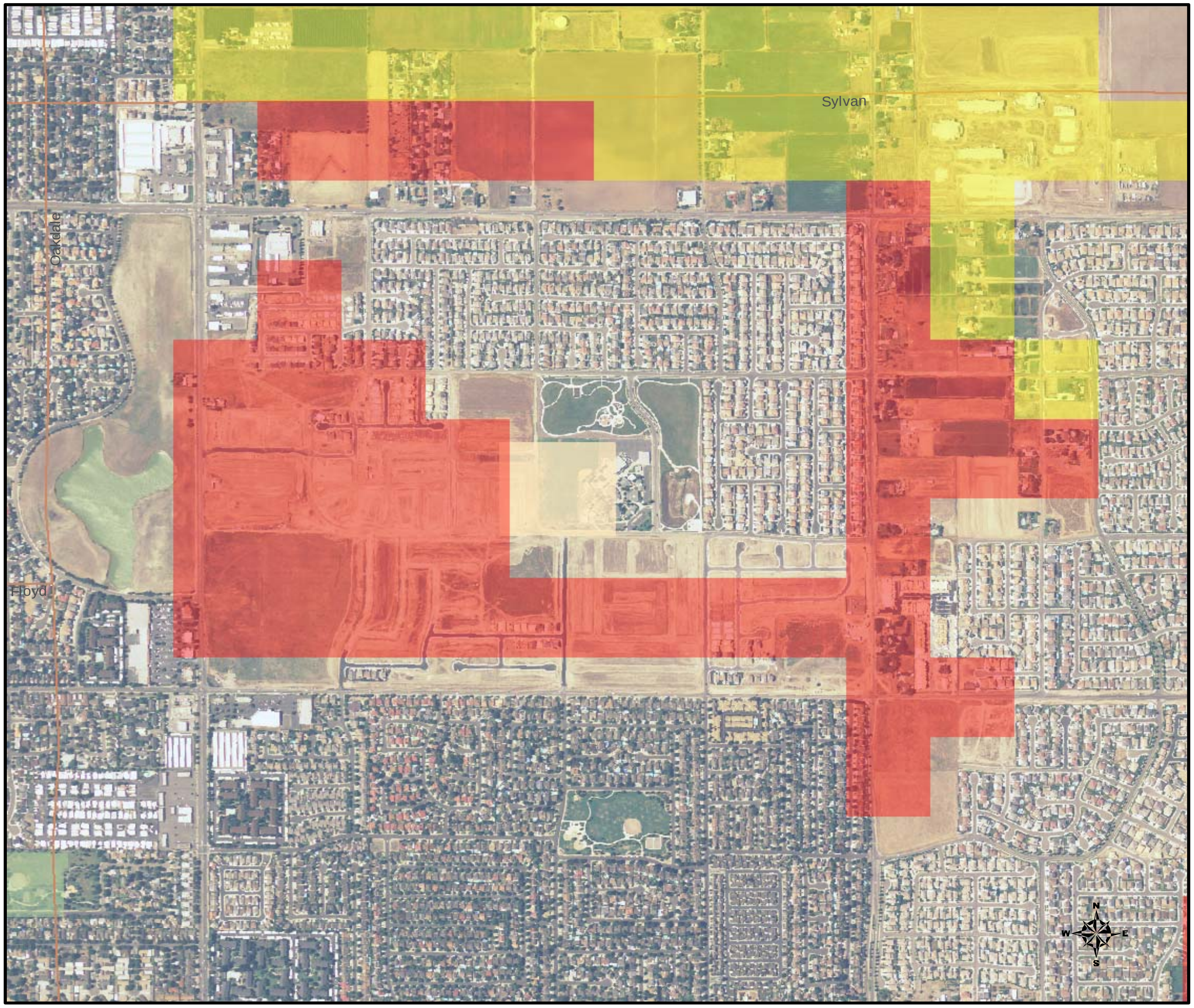


Figure 18

Modesto: High Development Pressure



Legend

Likelihood of Urbanization

- Medium
- High

Notes:

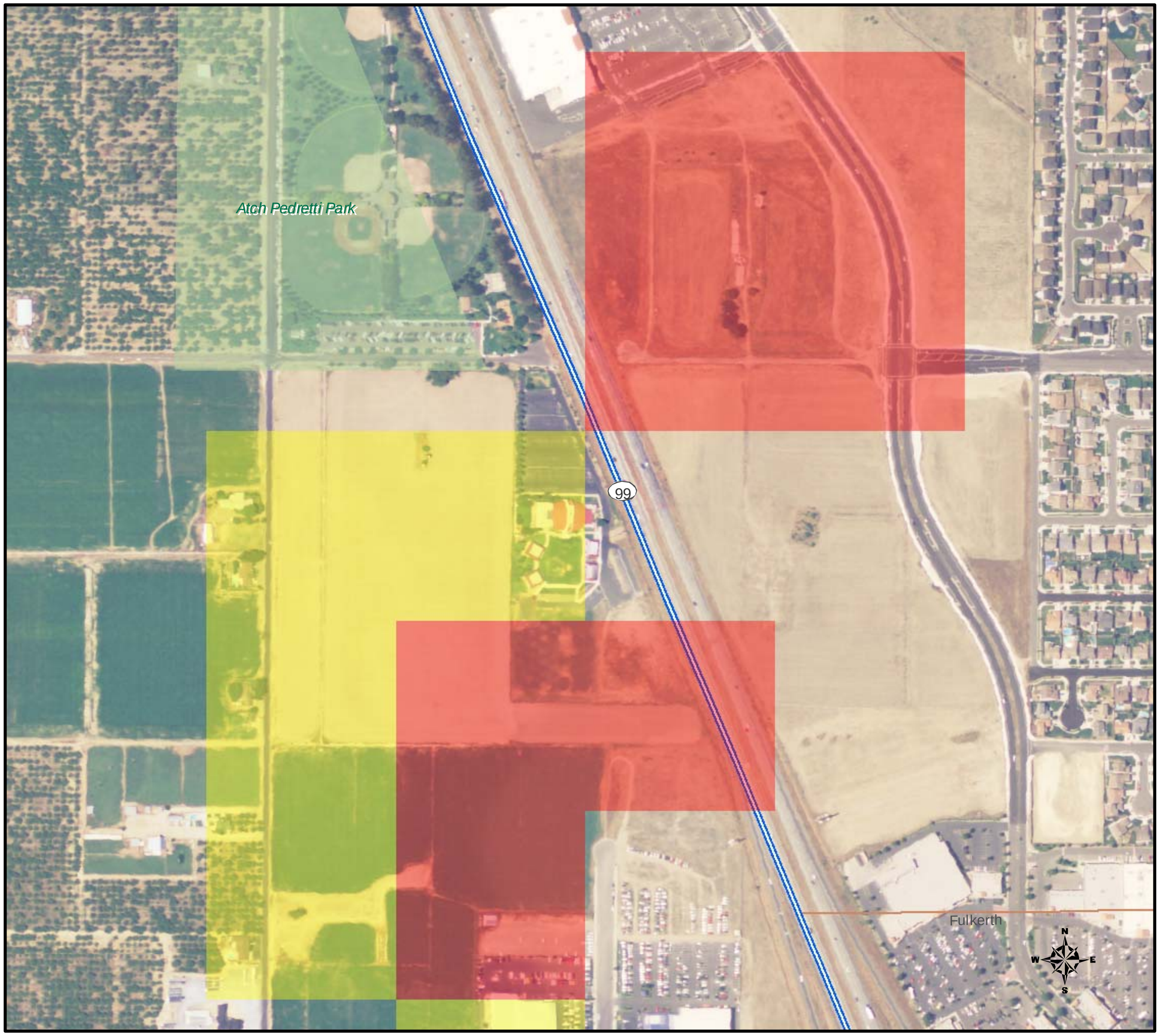
Aerial Imagery Source: National Agriculture Imagery Program, USDA

Capture Year: 2005

0 412.5 825 1,650 Feet

Figure 19

Turlock: High Development Pressure



Legend

Likelihood of Urbanization

- Medium
- High

Notes:

Aerial Imagery Source: National Agriculture Imagery Program, USDA

Capture Year: 2005

0 180 360 720 Feet

Figure 20

1. Future Population Growth

Three metropolitan planning organizations (MPOs) are responsible for planning within the representative area: The Stanislaus Council of Government (StanCOG); the San Joaquin Council of Governments (SJCOG); and the Merced County Association of Governments (MCAG.) MPOs are charged with planning for and managing urban growth, so they are usually best-positioned to forecast regional development.

Table 52 displays COG projections for cities, communities and unincorporated areas in each of the three counties. Merced is expected to grow by 168,000 people over the 30-year time frame; San Joaquin by 474,000; and Stanislaus by 318,000. In relative terms, Merced will grow by 86%; San Joaquin by 76%; and Stanislaus by 63%.

Table 52: COG Projection Data

	Population in year (thousands of people)					
City or Community	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Merced						
Atwater	27.9	30.8	33.7	36.5	39.5	42.7
Dos Palos	4.9	6.7	7.1	7.5	8.0	8.5
Gustine	5.4	6.1	6.8	7.5	8.2	9.0
Livingston	12.0	13.6	15.2	16.9	18.6	20.6
Los Banos	32.3	39.3	46.0	52.9	59.5	67.1
Merced	72.6	81.9	89.4	97.7	106.8	116.8
Delhi	10.7	13.0	15.5	17.5	19.3	21.3
Franklin / Beachwood	4.6	5.1	5.6	6.0	6.5	7.1
Hilmar	5.5	6.2	7.0	7.8	8.6	9.5
Le Grand	1.9	1.9	2.0	2.1	2.3	2.4
Planada	4.8	5.1	5.5	5.9	6.4	6.9
Santa Nella	1.9	2.4	3.2	4.2	5.8	8.2
Winton	9.9	10.9	11.4	12.2	13.1	13.9
UC Merced	1.2	4.3	8.2	14.1	21.7	29.3
Merced Total	**195.5**	**227.3**	**256.6**	**288.8**	**324.3**	**363.3**
San Joaquin						
Escalon	6.7	7.5	8.4	9.4	10.5	11.8
Lathrop	12.4	15.5	19.5	24.1	31.1	41.6
Lodi	60.9	65.0	69.1	73.1	77.3	81.7
Manteca	57.5	66.2	75.7	85.6	96.6	108.7
Ripon	11.8	13.6	15.4	17.4	19.5	21.8
Stockton	268.3	298.3	331.3	366.3	402.0	438.8
Tracy	70.5	85.8	102.5	125.2	153.7	189.4
Unincorporated	141.3	153.7	166.7	180.5	194.6	209.4
San Joaquin Total	**629.4**	**705.6**	**788.5**	**881.7**	**985.2**	**1,103.1**
Stanislaus						

City or Community	2005	Population in year (thousands of people) 2010	2015	2020	2025	2030
Carpenter/Crows Landing	5.5	0.0	0.0	6.0	6.6	8.6
Ceres	50.6	0.0	0.0	69.3	76.2	80.3
Greater Denair	4.2	0.0	0.0	4.5	4.9	5.2
Greater Keyes	4.7	0.0	0.0	7.6	8.7	9.4
Hughson	6.1	0.0	0.0	9.6	11.4	11.5
Modesto	234.4	0.0	0.0	300.0	313.9	323.3
Newman	10.7	0.0	0.0	23.9	31.0	37.9
Oakdale	25.8	0.0	0.0	46.2	54.4	56.9
Patterson	18.2	0.0	0.0	28.8	32.1	38.9
Riverbank	22.4	0.0	0.0	32.9	35.7	38.0
Turlock	70.1	0.0	0.0	93.0	102.1	105.9
Waterford	10.8	0.0	0.0	15.3	16.0	16.4
Yosemite Ind. Area	5.4	0.0	0.0	5.6	5.8	5.6
Unincorporated	36.0	0.0	0.0	0.0	0.0	0.0
Stanislaus Total	**504.8**	**0.0**	**0.0**	**693.6**	**758.1**	**822.0**

D. Model Application and Results

The costs of land application in the representative area were calculated using results of the hydrogeologic, industrial discharge, and urban growth models discussed in Section II.4, III.1, and III. 2 First, waste streams were characterized for four representative classes of emitters: tomato processors, wineries, dairy processors, and POTWs. Next, the effects of land application on groundwater quality were estimated by modeling the percolation and transport of these streams over the next thirty years. Future land use changes in those areas were then examined to determine how those changes will affect landowners. Finally, these changes were monetized using economic models specific the expected land use.

1. Residential Effects

Residential effects were calculated using a model created by the US Bureau of Reclamation and the Los Angeles Metropolitan Water District. The model is summarized in Section I.5.

2. Agricultural Effects

As discussed in Section I.5, increases in salinity have an economic impact on agriculture by reducing crop yield. Crop rotation and fluctuating market conditions make it difficult to predict the spatial distribution of crops over the 30 year time frame used in the analysis. Accordingly, an "average" crop was defined for each county, and responses of this crop to salinity changes were tallied to quantify costs. The average crop is the weighted sum of the crops in Table 53, and the response of this average crop to salinity increases (in terms of expected revenue per acre) is graphed in Figure 21. Because salinity response varies among the specific crops representing this average, the response curve for each average curve is necessarily nonlinear. (For a more detailed discussion of the salinity response functions used to model yield changes, refer to Section I.5.)

3. Urban Growth Modeling

Modeling the magnitude and location of urban growth over the thirty year window time frame examined by this report informs the costs of increasing groundwater salinity. For a detailed discussion of the urban growth model employed in this report, refer to Section III.1

The model determines the relative importance of the two cost accounting models discussed above throughout the representative area. In areas that have a high probability of urbanizing, the residential model explains the bulk of costs; and similarly for the agricultural model in areas that have a low probability of growth.[132]

Modeling results for the dischargers in the representative area are shown in Table 54. Table 54 examines projected growth within the areas that currently serve as land application sites. There are a total of 10,947 acres of land currently receiving discharge from food processors. The discharge sites expected to experience significant residential growth are those that lie on the current city borders: tomato processors 1 and 2, dairy processor 21, and meat processor 25. All other processors in the residential area will experience minimal growth. In total, nearly all (10,156 acres) of the present-day land application area would be expected to remain in agricultural production absent the food processing industry.

An additional table,

Table 55, examines additional growth that occurs in the areas surrounding the land application sites. These estimates are used in section "Result," to gauge the incidence of losses resulting from food processor discharges.

E. Results

Results of the model are presented in Table 56. These results present a "most-likely" scenario in which water users in and immediately surrounding land application sites experience degraded water quality as a result of discharge, but are able to partially mitigate this discharge by blending groundwater with available surface water. This scenario conforms to observed water usage in the representative area, where surface water diversions typically comprise the bulk of overall water supply. Land application sites were matched to their respective water districts, and were assumed to blend groundwater with low-salinity surface water in equal proportion to the most recent ground: surface water delivery ratios published by the districts. Areas that were outside any water district were assumed to have no surface water rights, and would continue to be wholly reliant on groundwater. In this case, urban losses total roughly $255,000 per year,

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[132] Nearly all land application sites are far removed from existing urban development, so it is appropriate to consider only future development for these sites. Two land application sites, 18 and 25, abut the cities of Ceres and Livingston, respectively; however in both cases the application sites are sufficiently small that the groundwater transport model showed no measurable change in groundwater quality.

and agricultural losses are roughly $137,000. Taken together, these impacts are in the range of $400,000 annually.

An additional scenario is considered in Table 57 in which customers surrounding land application sites rely wholly on groundwater. These results should be taken as an upper-bound on the conceivable effects of land application, since they rest on the improbable assumption that no additional surface or higher-quality groundwater supplies would be acquirable. In this case, annual costs to residential users are approximately $1.27 million per year, or $298 per affected household per year. Lost agricultural revenues total roughly $261,000 per year, or roughly $8.28 per acre.

Additional analysis shows that these costs are largely confined to the land application properties themselves; there is little spillover to entities who are not stakeholders in the discharge and land application process. It is conceivable, to the contrary, that impacts extend well beyond these boundaries, which obviously play no determining role in groundwater transport. If this were true, estimating costs based solely on lost development and agricultural opportunities within the sites themselves would seriously underestimate total costs associated with land application. Additionally, externalities—those costs attributable to food processors but not borne by them—would be much higher.

To test this hypothesis, an additional scenario was considered in which impacts are measured within the boundaries of the land application sites themselves.[133] If significant economic effects exist "downstream" of the food processors, then results in this scenario would decrease considerably relative to those presented earlier. Table 58 and

Table 59 present results from this set of calculations and show that the majority of effects are concentrated on land owned by the food processors and POTWs. Urban and agricultural losses are $189,000 and $117,000 annually with blending, and $945,000 to $233,000 million without blending. These findings suggest that dischargers themselves bear roughly three-quarters of the costs of increased groundwater salinity resulting from land application of food processing wastewater.

[133] Sites 1, 2 and 24 are within 800m of each other and were combined for this portion of this analysis.

Table 53: Crop Shares within Representative Area

Use	Land Share	Revenue / Acre	Salinity Tolerance
Merced			
Rangeland	49%	$22	Tolerant
Almonds	8%	$3,363	Sensitive
Corn silage	7%	$695	Moderately sensitive
Alfalfa hay	7%	$1,137	Moderately sensitive
Cotton	6%	$983	Tolerant
Non-corn silage	5%	$239	Moderately sensitive
Irrigated pasture	5%	$142	Moderately sensitive
Grain hay	3%	$313	Moderately sensitive
Processing tomatoes	1%	$1,679	Moderately sensitive
Grapes	1%	$2,978	Moderately sensitive
San Joaquin			
Rangeland	19%	$40	Tolerant
Grapes	14%	$3,011	Moderately sensitive
Alfalfa hay	14%	$728	Moderately sensitive
Grain corn	8%	$462	Moderately sensitive
Processing tomatoes	7%	$2,199	Moderately sensitive
Walnuts	6%	$2,260	Moderately tolerant
Almonds	6%	$3,874	Sensitive
Corn silage	6%	$772	Moderately sensitive
Non-corn silage	4%	$287	Moderately sensitive
Wheat	3%	$362	Moderately tolerant
Stanislaus			
Rangeland	44%	$29	Tolerant
Corn silage	13%	$586	Moderately sensitive
Almonds	12%	$4,862	Sensitive
Irrigated pasture	9%	$134	Moderately sensitive
Alfalfa hay	4%	$1,256	Moderately sensitive
Walnuts	3%	$3,008	Moderately tolerant
Grain hay	3%	$353	Moderately sensitive
Processing tomatoes	2%	$2,392	Moderately sensitive
Dry beans	1%	$1,002	Sensitive
Grapes	1%	$2,808	Moderately sensitive

Sources: Maas & Hoffman (1977); county crop reports.

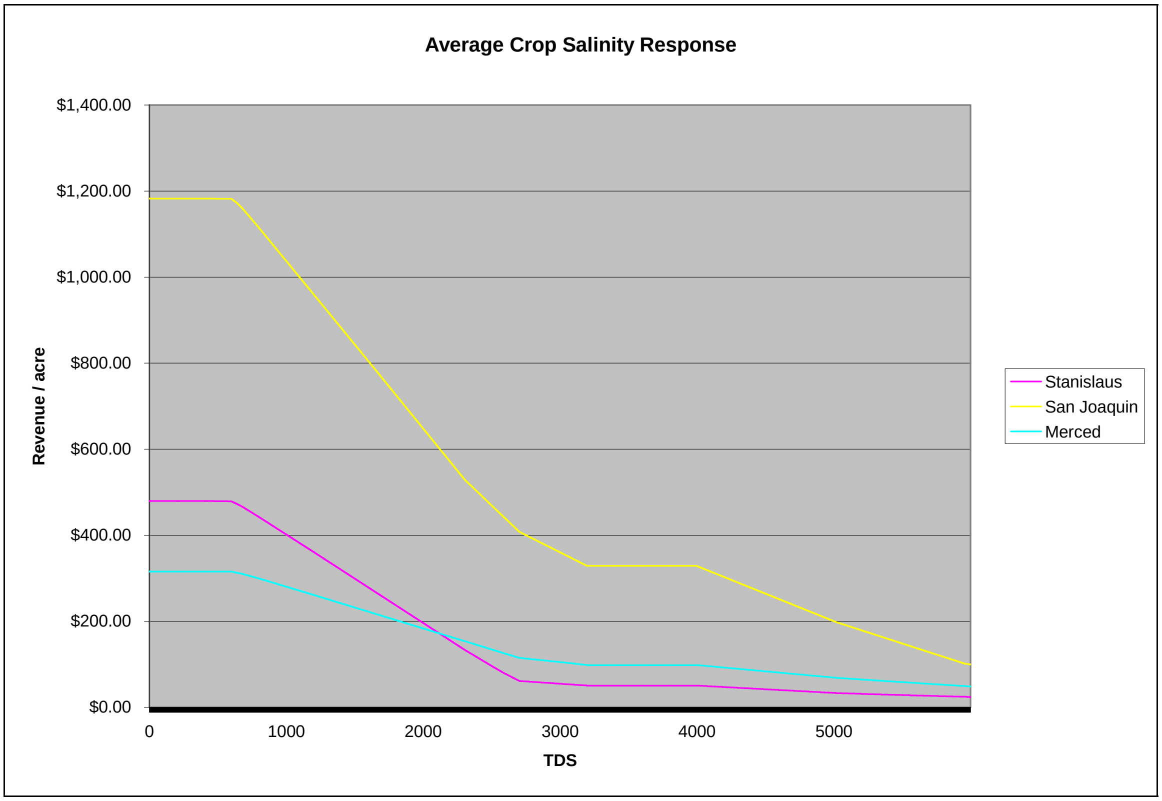
Average Crop Salinity Response
$1,400.00
$1,200.00
$1,000.00
$800.00
$600.00
$400.00
$200.00
$0.00
Revenue / acre
0
1000
2000
3000
4000
5000
TDS
Stanislaus
San Joaquin
Merced

Figure 21

Table 54: Urban Growth

Site ID	Type	Size (acres)	New Households	Greenfield acres	Projected Marginal Density	Acres of Agriculture
1	Tomato	1,231	275	58	4.73	1,173
2	Tomato	470	240	51	4.73	419
3	POTW	2,835	35	141	0.25	2,694
14	Winery	965	5	53	0.09	913
15	Winery	4	0			4
16	Winery	99	7	38	0.17	61
17	Meat	16	9	17	0.55	16
18	Tomato	61	0			61
19	Winery	99	2	4	0.46	95
20	Dairy	1	0			1
21	Dairy	2,250	131	219	0.60	2,031
22	Winery	2,106	5	86	0.06	2,020
23	Meat	61	0	3	0.08	57
24	Winery	3	0			3
25	Meat	110	104	69	1.51	41
26	Tomato	636	4	68	0.06	568
Total		**10,947**	**817**	**808**		**10,156**

Table 55: Urban Growth (800m Buffer)

Site ID	Type	Size (acres)	New Households	Greenfield acres	Projected Marginal Density	Acres of Agriculture
1*	Tomato	5,267	1,654	680	2.43	4,587
3	POTW	6,961	128	724	0.18	6,237
14	Winery	3,105	31	267	0.12	2,839
15	Winery	633	4	69	0.06	564
16	Winery	1,311	22	142	0.16	1,169
17	Meat	714	23	42	0.55	672
18	Tomato	1,078	252	891	0.28	187
19	Winery	1,243	62	119	0.52	1,125
20	Dairy	543	18	82	0.22	461
21	Dairy	5,306	922	843	1.09	4,463
22	Winery	5,677	21	350	0.06	5,327
23	Meat	1,034	48	155	0.31	879
25	Meat	1,463	1,070	724	1.48	739
26	Tomato	2,402	8	131	0.06	2,271
Total		**36,736**	**4,263**	**5,218**		**31,518**

Notes:

*1,2,24 merged due to buffer overlap

Table 56: Model Results, Blending

Site ID	Type	Residential Losses	Per Household	Agricultural losses	Per acre
1	Tomato	$9,617	$35	$0	
		2 combined with 1 & 24			
3	Potw	$191,151	$5,479	$128,169	$20.55
14	Winery	$139	$29	$0	
15	Winery	$0		$0	
16	Winery	$25	$4	$0	
17	Meat	$24	$3	$0	
18	Tomato	$0		$0	
19	Winery	$404	$197	$0	
20	Dairy	$0		$0	
21	Dairy	$46,572	$356	$0	
22	Winery	$2,770	$529	$9,246	$1.74
23	Meat	$159	$545	$0	
		24 combined with 1 & 2			
25	Meat	$4,555	$44	$0	
26	Tomato	$77	$19	$0	
Total		**$255,493**	**$59.93**	**$137,415**	**$4.36**

Table 57: Model Results, No Blending

Site ID	Type	Residential Losses	Per Household	Agricultural Losses	Per Acre
1	Tomato	$340,699	$1,239	$4,584	$1.00
		2 combined with 1 & 24			
3	Potw	$229,798	$6,586	$177,177	$28.41
14	Winery	$2,284	$475	$0	
15	Winery	$0		$0	
16	Winery	$340	$52	$0	
17	Meat	$223	$24	$0	
18	Tomato	$430		$0	
19	Winery	$3,641	$1,780	$5	
20	Dairy	$97		$0	
21	Dairy	$573,616	$4,383	$66,740	$14.95
22	Winery	$3,181	$607	$10,042	$1.89
23	Meat	$1,345	$4,599	$0	
		24 combined with 1 & 2			
25	Meat	$110,711	$1,063	$0	
26	Tomato	$4,481	$1,089	$2,386	$1.05
Total		**$1,270,845**	**$298.12**	**$260,933**	**$8.28**

Table 58: Model Results within Land Application Sites, Blending

Site ID	Type	Urban Losses	Per Household	Agricultural Losses	Per acre
1	Tomato	$3,871	$14	$0	
2	Tomato	$4,384	$18	$0	
3	POTW	$144,814	$4,150	$108,136	$40.14
14	Winery	$118	$25	$0	
15	Winery	$0		$0	
16	Winery	$4	$1	$0	
17	Meat	$0		$0	
18	Tomato	$0		$0	
19	Winery	$34	$17	$0	
20	Dairy	$0		$0	
21	Dairy	$33,730	$258	$0	
22	Winery	$2,581	$493	$8,717	$4.32
23	Meat	$6	$21	$0	
24	Winery	$0		$0	
25	Meat	$27		$0	
26	Tomato	$72	$18	$0	
Total		**$189,643**	**$232**	**$116,854**	**$3.71**

Table 59: Model Results within Land Application Sites, No Blending

Site ID	Type	Residential losses	Per Household	Agricultural Losses	Per acre
1	Tomato	$137,387	$500	$2,964	$2.53
2	Tomato	$158,964	$663	$1,368	$3.26
3	POTW	$181,448	$5,200	$153,811	$57.09
14	Winery	$1,970	$410	$0	
15	Winery	$0		$0	
16	Winery	$68	$10	$0	
17	Meat	$0		$0	
18	Tomato	$0		$0	
19	Winery	$312	$152	$5	$0.05
20	Dairy	$0		$0	
21	Dairy	$456,432	$3,487	$63,621	$31.33
22	Winery	$2,718	$519	$9,205	$4.56
23	Meat	$54	$186	$0	
24	Winery	$0		$0	
25	Meat	$1,182	$11	$0	
26	Tomato	$4,272	$1,039	$2,359	$4.15
Total		**$944,808**	**$1,156**	**$233,332**	**$7.40**

III.5 In-Plant Measures to Reduce Salt Discharges from Food Processing Plants

This section is a review of salt reduction measures that can be implemented in food processing plants to reduce salt discharges. Major sources of salt in the food plants are identified. Potential technology to reduce salt from these sources are identified and described. The cost and benefits of the technologies are evaluated. As with other sections of this report these are conceptual level descriptions and cost relationships to enable comparisons with other potential types of solutions and does not recommend and "preferred" alternative for the Representative Area on the Central Valley. The application of these technologies in four leading food processing industry sectors; tomato, wine, milk and meat; are evaluated and the costs of reducing the salt discharges are estimated. A brief review of emerging technologies with possible applications in salt management is presented.

A. Background

Inorganic salts unlike organic matter do not decompose into benign compounds in the environment. Once salts have become part of the effluent, concentration for alternative disposal is the only possible method of reducing salts. It is technically feasible to concentrate effluent by reverse osmosis, electrodialysis or evaporation. However, treating large volumes makes all three methods expensive in practice.

It should be mentioned at the outset that not all salts in food plant effluent are harmful to plants in land applications. Actually some salts are considered beneficial. These include salts containing potassium, phosphorus, calcium, magnesium and nitrogen.[134]

The end of pipe effluent from food plants is contaminated with high concentrations of organic matter like fats, sugars, starches and proteins. These contaminants are considered conventional pollutants and can be disposed of by land application at a relatively low cost. Sometimes food process effluent application can benefit the land by providing water when it is needed in summer and also by providing nutrients like potassium.

However, if the salts have to be removed from the effluent to allow land application it is usually necessary to remove organic matter by biological treatment before the salts concentrate. This is to prevent fouling of membranes in reverse osmosis and electrodialysis. This process adds to the overall cost of disposal. The fruit and vegetable industry is seasonal by nature. Constructing large biological treatment plants that are used only for a few months of the year is not an attractive investment.

Concentration of salts by any method produces a large volume of relatively good quality water, sometimes better than the supply water. However, this water often cannot be reused in food

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[134]Brown and Caldwell and Kennedy/Jenks Consultants. 2007 Manual of ood practice for land application of food processing rinse water. California League of Food Processors, Sacramento, CA.

processing applications due to health concerns and regulatory restrictions. Land application of such high quality water produced at a high cost defies common sense.

In-plant measures to reduce salt overcome these difficulties. When properly planned and executed it is often possible to meet even strict regulatory limits by in-plant measures alone. Other ancillary benefits of in-plant measures include: reducing salt and chemical use, reducing water and energy use, reducing product losses, recovery of by product, and reuse of water.

1. Determination of Salt Content

Salts are broadly defined as inorganic compounds dissolved in water. Fixed dissolved solids (FDS) is the best measure of salt content in food processing plant effluent. FDS is determined by filtering a sample through a 1.2 μm filter and firing the filtrate in a muffle furnace at 550 ^{o}C. Filtering removes suspended solids and firing removes dissolved organics leaving only inorganic compounds behind.

When dealing with well water and secondary treated effluent, where organic matter is negligible, total dissolved solids (TDS) is used as a measure of salt content. It is determined by filtering a sample through a 1.2 μm filter and drying the filtrate in an oven at 105 ^{o}C.

It is generally assumed that all the FDS in fresh water and secondary treated effluent is equal to TDS because organic matter content in these sources is very low. However, close examination of wastewater monitoring records from food processing plants collected in this study (see Volume II) that reported both these values for the same source indicates that this assumption is not very accurate. In these records FDS was about 80 to 90% of the TDS. Nonetheless, for comparison purpose TDS is used to normalize the costs of the various control technologies reviews in this study.

The difficulty and cost of these procedures has prompted the use of more convenient but less accurate alternatives. Most common inorganic compounds are fully ionized in dilute solutions and conduct electricity. Therefore, electric conductivity (EC) is used as a more routine measure of salt content. EC measurement involves dipping an electrode in the sample and does not involve transporting samples to a laboratory, like it does for FDS and TDS measurements. It is common to assume that TDS=0.6 EC in fresh water and secondary effluent. The primary disadvantage of this measure is the contribution by ionized organics. Different ions contribute differently to EC. Table 60 is a listing of the EC of several ions commonly found in food plant effluents. The electrical conductivity of specific ions as listed here is useful in comparisons of different cleaning and process chemicals.

Table 60: Electrical conductivity (EC) of Common Ions[135]

Cations	Equivalent Weight	EC □S/cm	Anions	Equivalent Weight	EC □S/cm
H^{+}	1	349.8	OH^{-}	17	198.6
Na^{+}	23	50.1	Cl^{-}	35.5	76.4
K^{+}	39	73.5	NO_3^{-}	62	71.4
NH_4^{+}	18	73.5	HCO_3^{-}	61	44.5
1/2 Ca^{++}	20	59.5	½CO_3^{--}	30	69.3
1/2 Mg^{++}	12.15	53.0	½$H_2PO_4^{--}$	48.5	33.0
			½SO_4^{--}	48	80.0
			1/3 $PO4^{---}$	31.7	69.0
			1/3 $Citrate^{--}$	53	70.2
			1/2 Tartrate	74	59.6

The contribution of charged organics to the EC of the effluent is a major concern when EC is used as an indicator of salt content in untreated food plant effluent. Citrates in milk and tomatoes and tartrates in grapes contribute significantly to the EC of the effluent from these processes. The EC of these ions can be used to correct the effluent EC for the contribution of charged organics.

2. Salt Balance

The first step in formulation of a sound in-plant strategy is to identify the sources of salt. This requires a thorough salt accounting study of the overall production process. A salt account typically involves measuring volumes of major point sources of process water in the plant and sampling and analyzing these sources for salt content. The sum of the point source contribution is tallied with the volume and salt content of the end-of-pipe effluent.

An alternative to this time consuming method is a salt audit of the plant based on available records of chemical use in different unit operations. This is also tallied with the end-of-pipe effluent. In practice a combination of both methods is the most expeditious approach to identifying plant salt sources.

Normalization of the salts added in a process in relation to the amount of raw material processed or the final product output is a very important result of a salt balance. This parameter can be used as a bench mark to compare performance of different plants in a given industry sector. This will be a valuable addition to other benchmarks like kWh, therms, and gallons of water per ton of product that are frequently used in comparisons. Unfortunately, the production figures are not provided by the plants in their effluent monitoring reports and plants are reluctant to provide this information.

B. Technology for Salt Reduction

The review of salt sources in food processing plants in the study has identified several leading sources of salts. Potential strategy for treating these sources for reduction of salts involves several

[135] CRC Handbook of Chemistry and Physics. 76th Edition. CRC Press. New York. Page 5-89

technologies in different combinations. Table 61 list of sources of salt reduction applications and a partial list of potential technologies.

Table 61: Salt Reduction Technologies

	Application	Potential Technologies
1	Supply water treatment	Ion exchange, electrodialysis, reverse osmosis
2	Brine treatment	Seeded evaporation, crystallization, spray drying, evaporation ponds
3	Salt disposal	Brine disposal, dry solids disposal
4	Boiler water treatment	Reverse osmosis
5	Product loss reduction	reverse osmosis, evaporation
6	Cleaning and process chemicals reduction	Alternative chemicals, microfiltration, ultrafiltration, nanofiltration, evaporation, disposal

In cases where in-plant point source treatment does not produce sufficient salt reduction, end-of-pipe effluent treatment is also evaluated briefly as the last resort.

1. Supply Water Treatment

Supply water is a large contributor of salinity in many food plants, particularly those located in areas of highly saline ground water. The electrical conductivity and TDS of supply varied more than fivefold among the food plants in the study area, as found in waste water monitoring records (Table 62). In locations with high ground water salinity (like Gustine, Ripon, Volta and Hilmar) treatment of supply water and off-site disposal of salts could meet typical effluent salinity limits like 300 FDS above background or even more stringent limits like zero FDS increase.

Table 62: Supply Water Characteristics of Several Locations in the Study Area

Location	Electrical Conductivity (uS/cm)	Total Dissolved Solids (mg/L)
Hanford	340	227
Helm	427	241
Los Gatos	435	247
Livingston	352	230
Atwater	630	410
Lemoore	630	430
Hilmar	982	622
Volta	1,200	700
Ripon	1,051	782
Gustine	1,750	1,019

Treatment of water to reduce salinity can de done by ion exchange, electrodialysis, reverse osmosis or distillation. The cost of desalination by these processes as a function of salt concentration is presented in Figure 22. Ion exchange and electrodialysis remove salts from the solution and so are less expensive at low salt concentrations. Distillation removes water from the solution and hence is the process of choice at very high concentrations. Reverse osmosis and electrodialysis are competitors for treatment of supply water in food plants, based on the salt concentration.

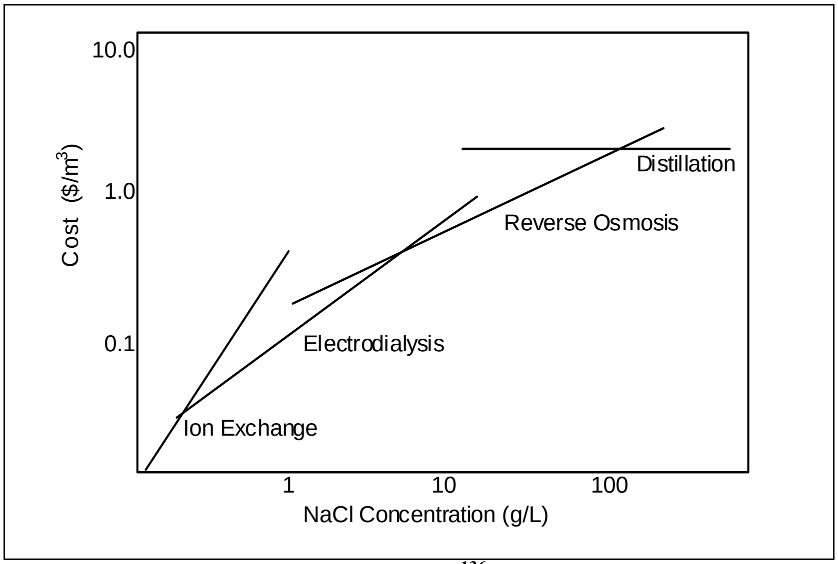

Figure 22[136]

Conventional supply water treatment systems produce two water streams. Low salt product water and high salt concentrate, also called retentate. These systems are optimized to produce low salt water at the lowest cost assuming that the retentate disposal cost is minimal. These systems produce a large volume of retentate.

Treatment of supply water for salinity reduction in the Central Valley where retentate disposal is expensive has to be approached as a zero liquid discharge (ZLD) situation. Figure 1 illustrates that the cost of the technology increases as salt concentration increases. Therefore, it is important to achieve the highest possible recovery of product water using the lowest cost technologies, such as reverse osmosis.

The recovery of water by RO is limited by the hardness of supply water that is caused by divalent salts of calcium and magnesium and also by silica concentration. A two stage RO system with intermediate softening (Figure 23) is a design that can achieve high recovery and minimize retentate volume. The first stage consists of a low pressure RO (LPRO) unit operating at about 200 psi. This is expected to recover 80% of the water at 90% salt rejection without significant chemical addition and not exceeding the solubility limits of the scalants in the retentate.

There are several options for dealing with the scaling issue of LPRO retentate. When the silica concentration is low, softening by ion exchange (IX) unit and treating the softened product by high pressure RO (HPRO) is possible. This option is relatively inexpensive. It is also possible to use the HPRO retentate to regenerate the ion exchange unit which minimizes additional salt contribution by the process.

[136] Strathmann, H. 1992. Design and Cost estimates (of electrodialysis). In Membrane Handbook edited by W. S. W. Ho and K. K. Sirkar. Van Nostrand Reinhold, New York, pp. 246.

However, when silica concentration is high a different approach is required. High efficiency reverse osmosis (HERO) treatment is a possible alternative. This proprietary process involves ion exchange to remove hardness, degasification to remove carbon dioxide and alkalization to increase the silica solubility followed by high pressure reverse osmosis. Figure 2 illustrates this system.

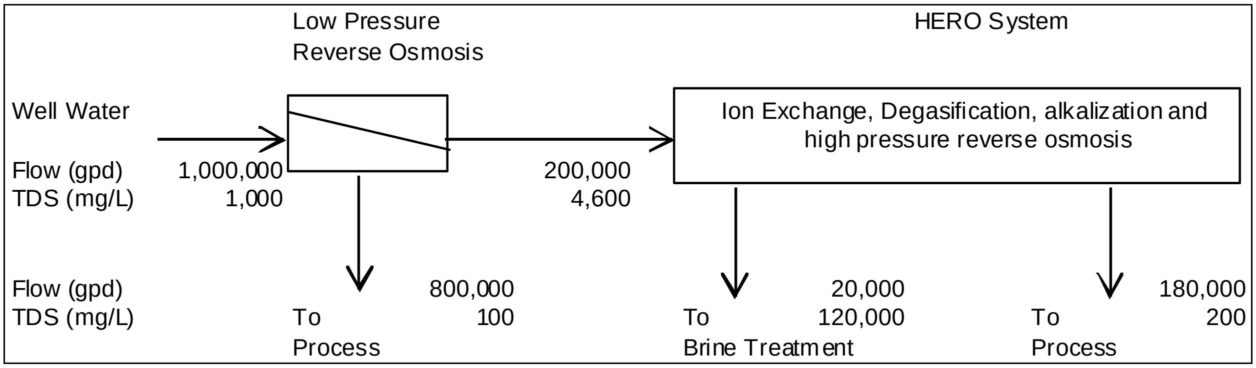

Figure 23

Electrodialysis is another alternative that can accommodate higher silica contents than RO. The water chemistry and cost considerations will determine the actual recovery possible and final treatment configuration. The cost analysis is based on LPRO followed by HERO system which is the most conservative and costliest alternative.

a) Low Pressure (LPRO) Reverse Osmosis

Reverse osmosis involves driving water through a membrane that is permeable to water but not to salt. This is a pressure driven process and requires pressures in excess of the osmotic pressure of the solution. Therefore, pump design, energy consumption and cost of water produced by the reverse osmosis increase with salt concentration.

The LPRO system was designed to operate at 200 psi.[137] It consists of 240 eight inch membrane modules and 83 kW of connected pumps. The systems are of single pass configuration with tapered arrangement of pressure vessels.

[137] Lien, Larry. 2007. GE-Osmonics. Personal communication.

Table 63: Cost Analysis of Low Pressure Reverse Osmosis (LPRO) System

System Parameters	LPRO
System capacity feed (gpd)	1,000,000
Feed water TDS (mg/L)	1,000
Permeate recovery (gpd)	800,000
Permeate TDS (mg/L)	100
Retentate TDS (mg/L)	4,600
Electrical Power (kW)	83
System operation (hours/year)	7,200
Permeate production (million gal/year)	240
Total solids in retentate (tons/year)	1,145
Capital Cost ($)	
Site development and utilities	54,200
Equipment	425,000
Installation	56,800
Contingencies	49,000
Total Capital Cost	585,000
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	103,500
Energy (7,200 hours; $0.13/kWh)	77,700
Membrane replacement ($950/element;every 3 years)	76,000
Labor	24,000
Supplies	34,300
Chemicals	14,100
Total annual operating cost	**329,600**
Unit Cost ($/kgal of permeate)	**1.37**

b) HERO System for LPRO Retentate

The cost analysis presented in Table 45 is an approximation based on a larger system.[138]

[138] Fritz, C. H., and V. J.Nathan. HERO Process – Recovery-reuse of cooling tower blowdown and as a Preconcentration for ZLD application. Paper No. TP-10 available at http://www.aquatech.com/

Table 64: Cost Analysis of HERO System for LPRO Retentate

System Parameters	
System capacity feed (gpd)	200,000
LPRO retentate hardness (mg/L)	800
Capital cost of the system ($)	500,000
Total operating cost ($/year)	150,000
Total solids (tons/year)	3,000
Permeate production (million gal/year)	54
Capital Cost ($)	??????
Equipment	1,600,000
Buildings	260,000
Installation	190,000
Total capital cost	2,050,000
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	362,800
Electricity	62,400
Chemicals	87,500
Operations and maintenance	107,000
Total annual operating cost	**619,700**
Unit Cost ($/kgal of permeate)	**11.47**

c) Electrodialysis

Electrodialysis is an electrically driven membrane process in which an electric potential is applied across charged membranes to separate ionized solutes from a solution. Electrodialysis is claimed to be more cost effective in desalting high hardness and high silica water supplies. The cost analysis139 summarized in Table 61 includes system parameters, capital costs and operating costs for a reverse osmosis system processing 1,000,000 gallons per day of supply water.

[139] Anonymous. 2005. WATER (Water Treatment Estimation Routine). An MS Excel developed by the U.S. Bureau of Reclamation (USBR) "Water Treatment Engineering and Research Group". Downloaded from the website http://www.usbr.gov/pmts/water/awtr.html

Table 65: Cost Analysis of Electrodialysis of Supply Water

System Parameters	
System capacity feed (gpd)	1,000,000
Permeate Recovery (gpd)	750,000
Feed Water TDS (mg/L)	1,000
Permeate TDS (mg/L))	500
Permeate production (million gal/year)	225
Total Capital Cost	**504,800**
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	89,400
Energy	47,400
Membrane replacement	63,200
Labor and overhead	45,400
Supplies	2,500
Chemicals	1,100
Filters	20,900
Total annual operating cost	**269,800**
Unit Cost ($/k gal of permeate)	**1.20**

2. Brine Treatment

The supply water treatment system provides low salinity water for the process by concentrating all the salts into a much smaller volume called retentate. This reduces the cost of further treatment or disposal. The objective of brine treatment is to reduce the volume further to decrease the cost of transport. This necessarily involves the use of thermal energy to evaporate water. Solar evaporation in evaporation ponds is the most common method. Crystallization and spray drying are other alternatives

The strategy for treatment and disposal of retentate brine are also applicable to other high salinity effluents like, ion exchange regenerants, boiler blow-down, cooling tower blow-down, spent chemical cleaners and spent process chemicals.

a) Evaporation Ponds

Evaporation ponds are the most common destination for retentate from reverse osmosis and electrodialysis. The salts leftover after evaporation can be disposed in landfills. The ponds have to be properly lined with two layers of 60 mil geosynthetic sheeting with a leak detection layer in between. The operation of evaporation ponds require at least two ponds to allow for alternate filling and drying. The cost analysis summarized in Table 47 is for a double composite lined evaporation pond system.[140]

[140] Richgels, Chris. 2007. Golder Engineering, Roseville, CA. Personal communication.

Table 66: Cost Analysis of Evaporation Ponds for Brine

System Parameters	
Evaporation rate (inches/year)	67
Evaporation rate (gal/acre/year)	2,040,000
Brine inflow rate (gal/day)	20,000
Brine inflow rate (gal/year)	7,300,000
Brine TDS (mg/L)	50,000
Pond area (acres with 12.5% over sizing)	4.5
Pond depth (with 2-foot freeboard)	7
Solids at 50% moisture (tons/year)	2,290
Total evaporation (gallons/year)	6,935,000
Capital Cost ($)	
Land ($11,000 per acre)	49,500
Excavation ($56,500 per acre)	254,250
Primary liner single sided HDPE ($26,100 per acre)	117,450
Geocomposite leak detection($28,700 per acre)	129,150
Primary liner double sided HDPE ($25,700 per acre)	115,650
Total Capital Cost (with 20% contingency)	799,200
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	141,600
Solids collection (lump sum)	35,000
Reporting (lump sum)	15,000
Total annual operating cost	**191,600**
Unit Cost ($/kgal water evaporated)	**27.62**

b) Seeded Evaporation

Precipitation of divalent salts like sulfates and carbonates of calcium and magnesium severely limits the common concentration technology like reverse osmosis, electrodialysis and evaporation. Seeded evaporation technology overcomes this limitation by introducing seeds of the precipitate that form salts in the solution. The activation energy for growth of an existing crystal is lower than the activation energy to form a new crystal. Therefore, when the solubility limit of the salt is exceeded the salts will deposit on existing seed crystals and not on the evaporator surfaces. This prevents fouling of heat exchanger surfaces.

A seeded evaporation system (Figure 24) consists of a vertical tube falling film evaporator, a recirculation pump for the solution and a mechanical vapor recompressor (MVR). The energy consumption by the MVR system is about 80 kWh per kgal of evaporated water. This amounts to about 103 Btu per lb of water which is equivalent to a 10-effect evaporator.

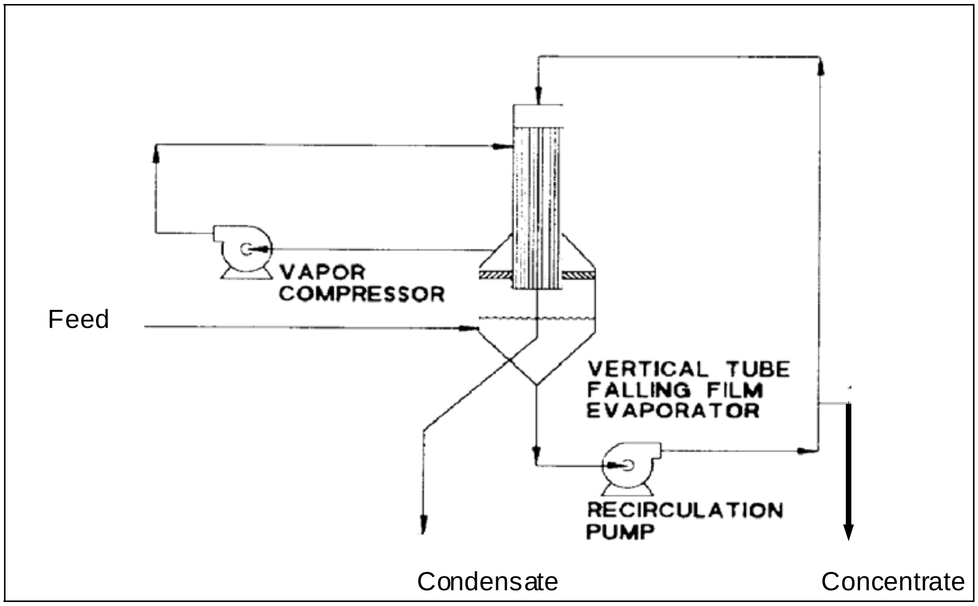

Figure 24

A preliminary cost analysis of a 200,000 gpd seeded evaporation system (Table 8) was prepared with the assistance of the system supplier.[141]

Table 67: Cost Analysis of Seeded Evaporation

System Parameters	
System capacity feed (gpd)	200,000
Condensate recovery (gpd)	190,000
Concentrate volume (gpd)	10,000
Feed Water TDS (mg/L)	5,000
Condensate TDS (mg/L))	10
Concentrate TS (mg/L)	100,000
Total evaporation (million gallons/year)	57
Total Capital Cost	**5,500,000**
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	973,500
Energy (80 kWh/kgal, $0.13/kWh)	561,600
Operations and maintenance (2% of capital cost)	110,000
Total annual operating cost	**1,645,100**
Unit Cost ($/kgal evaporated)	**28.9**

c) Crystallization

Crystallization is one method of producing solids from the concentrated brine. A forced circulation crystallizer (Figure 25) is used for this purpose. The slurry containing brine and crystals is

[141] Kasnitz, Bruce. 2007. Private communication. GE Water and Process Technologies, RCC @ Thermal Products. 3006 Nortrup Way, Bellevue, WA 98004. Web www. gewater.com

circulated through a flooded shell and tube heat exchanger and a crystallizer chamber. Small amount of water evaporates and increases the crystal fraction in the slurry in each pass. Steam is compressed in a MVR and reused. The energy consumption by the MVR based system is about 250 kWh per kgal of evaporated water.

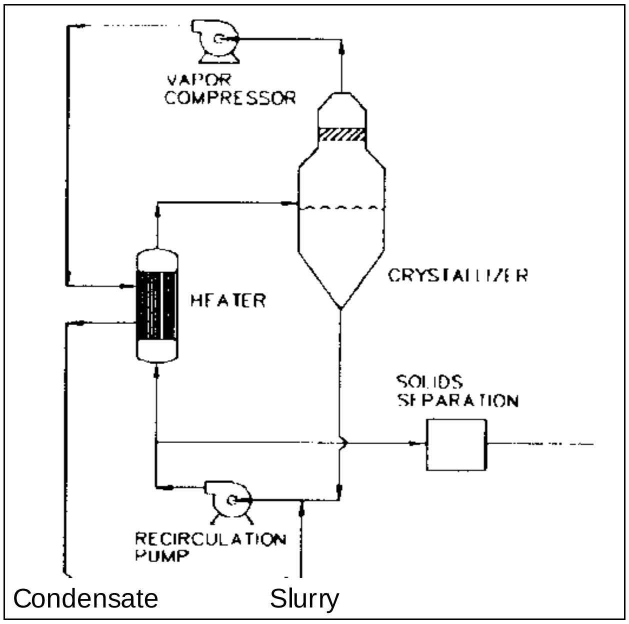

Figure 25

Table 68: Cost Analysis of Forced Circulation Crystallization

System Parameters	
System capacity feed (gpd)	15,000
Feed slurry TDS (mg/L)	100,000
Condensate recovery (gpd)	12,000
Condensate TDS (mg/L))	50
Solids recovery (tpd-wet)	12.5
Solids water content (%)	50
Total evaporation (million gallons/year)	3.6
Total Capital Cost	**2,500,000**
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	442,500
Electrical Energy (250 kWh/kgal, $0.13/kWh)	146,250
Operations and maintenance (2% of capital cost)	50,000
Total annual operating cost	**588,800**
Unit Cost ($/kgal evaporated)	**163.6**

d) Spray Drying

Spray drying is another technology for producing disposable solids from the concentrated slurry produced by seeded evaporation. A spray dryer (Figure 26) consists of an atomizing wheel which sprays the slurry into a hot gas-fired drying chamber. The output from the drying chamber is drawn into a bag house filter where solids in powder form are separated from air and vapor.

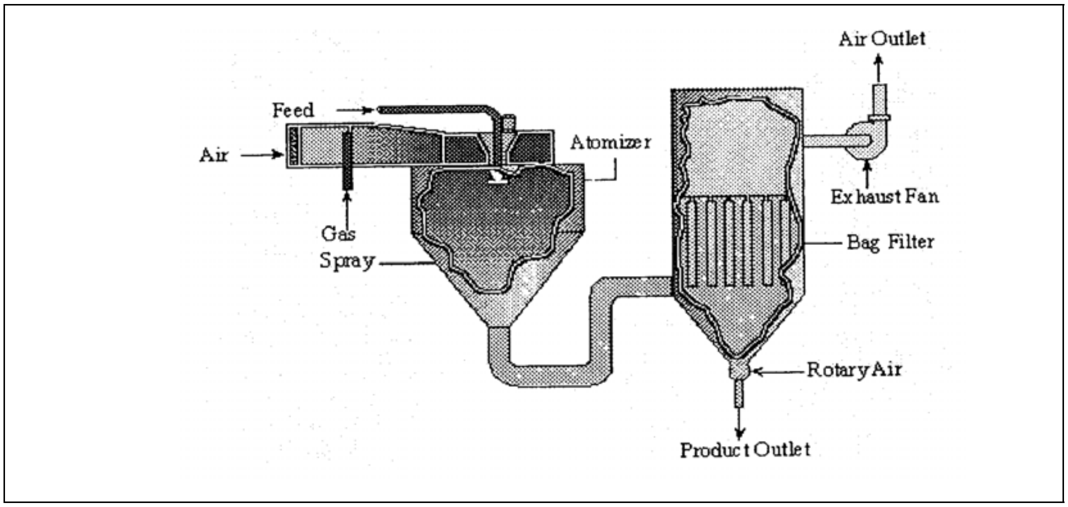

Figure 26

Table 69: Cost Analysis of Spray Drying Process

System Parameters	
System capacity feed (gpd)	36,000
Solids recovery (tpd)	42
Feed slurry TDS (mg/L)	100,000
Dry solids Water content (%)	1
Total evaporation (million gallons/year)	9.7
Total Capital Cost	**2,400,000**
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	424,800
Electrical Energy (155 kW, $0.13/kWh)	145,080
Thermal Energy (20.9 MMBtu/h, $7/MMBtu)	1,053,360
Operations and maintenance (2% of capital cost)	48,000
Total annual operating cost	**1,671,240**
Unit Cost ($/kgal evaporated)	**172.3**

3. Disposal of Brine and Solids

Effluent with high salinity can be disposed at POTW's located in favorable geographic locations. East Bay Municipal Utility District's (EBMUD) wastewater treatment plant in Oakland near the entrance of the San Francisco-Oakland Bay Bridge currently operates below 50% design capacity. It discharges to the bay hence salinity is not a concern. The charge by the utility is $0.07 per gallon.

The cost of transport by truck over 98 miles is reported[142] as $0.04 per gallon.

Disposal of solids from evaporation ponds or mechanical separation is the final step in the source water treatment process. Altamont Landfill Facility is equipped to receive non-hazardous solid waste and supplied the rates below.[143] Note that these costs do not include transport costs.

Bulk solids greater than 50% moisture with some free liquid	
Solidification disposal	$125 per ton
Bulk solids less than 50% moisture with no free liquid	
Class II disposal – Direct landfill	$75 per ton
Bulk solids less than 50% moisture with no free liquid	
Class II cover, minimum debris	$20 per ton

The solids generated by any of the drying methods would qualify for the lowest disposal rate of $20 per ton. The cost of transport for a distance of 100 miles is assumed to be $15 per ton. Table 11 summarizes the cost of transport and disposal of brine and solids from the treatment of one million gallons per day of supply water.

Table 70: Cost Analysis of Disposal of Brine and solids

System Parameters	
Brine output (gal/day)	20,000
Brine output (gal/year)	7,300,000
Dry solids in brine HERO (tons/year)	3,000
Dry solids in brine SE (tons/year)	1,145
Total Cost of transport and disposal of brine	**803,000**
Unit Cost ($/kgal disposed)	**122.2**
Water content in solids (%)	50
Weight of solids HERO (tons/year)	6,000
Weight of solids SE (tons/year)	2,290
Total Annual Cost of transport and disposal of solids HERO	**210,000**
Total Annual Cost of transport and disposal of solids SE	**80,150**
Unit Cost ($/kgal water disposed)	**145.3**

4. Supply Water Treatment Summary

The information presented in supply water treatment, brine treatment and liquid/solid disposal is summarized in a flow diagram (Figure 27) which shows six different technology combinations and approximate total cost of each combination. The number inside the process box is the operating cost of the process per million gallons of feed water. The costs are evaluated for a system

[142] Fleischer, Burt, 2007. Hilmar Cheese Company, Hilmar, CA. Personal communication.
[143] Thompson 2007. Waste Management. Personal communication

processing 300 million gallons of supply water and producing 294 million gallons of product water per year.

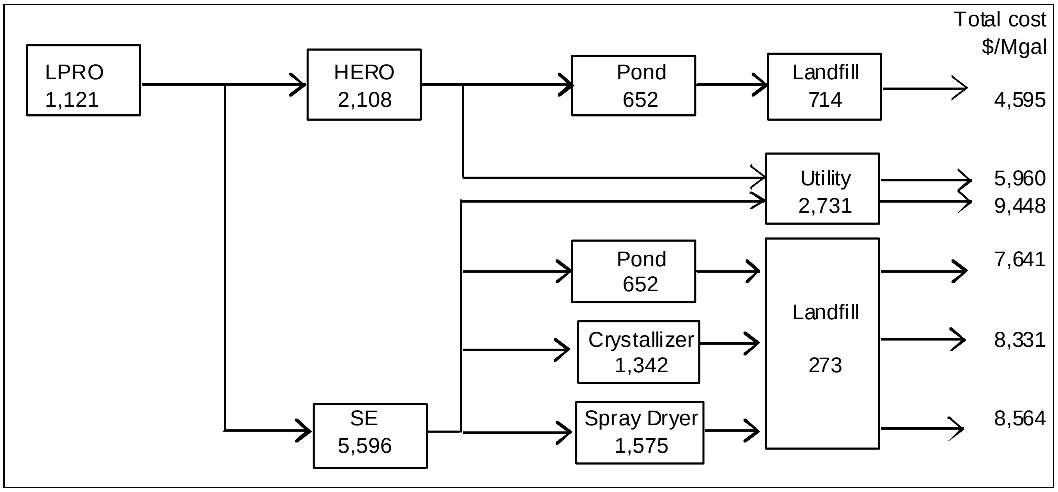

Figure 27

The cost of intermediate stage concentrating LPRO retentate is very high for a relatively small volume. Therefore, this stage should be the focus of studies on cost reduction of supply water treatment.

The total costs of six different alternative routes of treatment are listed in the extreme right. The combination of LPRO- HERO-evaporation pond-landfill resulted in the lowest total operating cost. The cost analysis of this combination is summarized in Table 12

There are many other potential technology combinations, some of which may have competitive costs. Electrodialysis reversal was not included in this summary due to lack of reliable cost data. Including electrodialysis will add many more treatment combinations. This technology is claimed to be more successful in accommodating silica in the feed water compared to reverse osmosis.

Table 71: Cost Analysis of Selected ZLD Supply Water Treatment System

System Parameters		
Water input (gpd)		1,000,000
Water output (gpd)		980,000
Supply water TDS (mg/L)		1,000
Product water TDS		118
Product water volume (Mgal/year)		294
Costs	Capital Cost ($)	Operating Cost ($/year)
LPRO	585,000	329,600
HERO	2,050,000	619,700
Evaporation pond	799,200	191,600
Landfill		210,000
Total	3,434,200	1,350,900
Total cost of treatment ($/Mgal feed water)		4,595

It is also possible to vary the operating range of technologies. The unit cost of water evaporation by seeded evaporation was nearly the same as for evaporation ponds under the assumed conditions. For example, seeded evaporators can receive the retentate from HERO system, concentrate it to 200,000 mg/L and discharge it to a much smaller evaporation pond. Such alternatives are possible and may be cost effective.

The unit cost of processing water by different technologies is summarized in Table 72. The cost is based on volume of water permeated, evaporated or disposed depending on technology type. The comparison of the cost of technologies illustrates the importance of achieving the highest possible recovery in the early stages in keeping the total treatment cost low. The numbers listed in this table may be used in the initial decision making process.

Table 72: Comparison of Water Removal Costs

Technology	Solids (mg/L)	Unit cost($/kgal)
LPRO	Low	1.4
Electrodialysis	Low	1.2
HERO	Medium	11.5
Seeded Evaporation	Medium	28.9
Evaporation pond	High	27.6
Crystallizer	High	145.4
Spray Dryer	High	172.3
Brine disposal at utility	High	122.2
Landfill for solids	Very High	145.3

5. Boiler Feed Water Treatment

Salts in supply water result in two salt discharges in the boiler operation. Boiler feed water is softened using ion exchange. The ion exchange resins are regenerated using salt and the spent regenerant is discharged. Softening exchanges sodium ions from the IX resin for calcium and magnesium ions in the feed water. Inside the boiler the sodium salts concentrate as water evaporates to produce steam. Concentrated salts are discharged periodically as boilers blow-down.

Treatment of boiler feed water by reverse osmosis can remove most calcium, magnesium and sodium salts. It can reduce the softener regenerant and boiler blow-down volumes by about 90% and reduce the salt discharges considerably. A low recovery reverse osmosis (LRRO) system can operate with minimal chemical addition and would allow using the RO retentate for food processing operations instead of requiring dedicated disposal systems like evaporation ponds. Boiler feed water softening and boiler blow-down data for a tomato canning plant is used to compare its boiler water system and the proposed system (Figure 28.)

The low recovery reverse osmosis system was designed to operate at 150 psi. It is of single pass design and consists of 36 eight inch membrane modules and 25 kW of connected pumps. Table 14 is a preliminary cost analysis of the proposed system. The reduction in FDS allows for the FDS in the retentate to pass over to the plant as processed water.

Boiler blowdown is discharged at a high temperature, about 250 ^{o}F. Therefore, reduction in boiler blowdown volume results in significant savings in thermal energy in addition to water and salt reductions. These benefits are also included in the cost analysis.

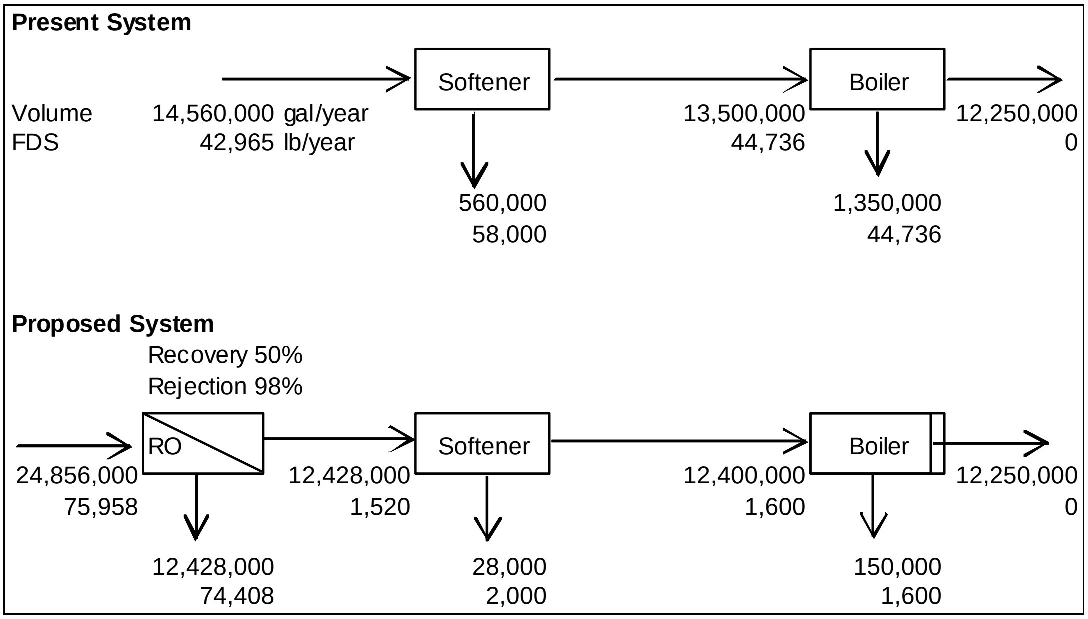

Figure 28

Table 73: Cost Analysis of Boiler Feed Water Treatment System

System Parameters	
System capacity feed (gpd)	248,560
Feed water TDS (mg/L)	368
Permeate recovery (gpd)	124,280
Permeate TDS (mg/L)	15
Retentate TDS (mg/L)	721
System operation (hours/year)	2,400
Permeate production (million gal/year)	12.4
Salt discharge reduction (tons/year)	30.7
Capital Cost ($)	
Site development and utilities	16,300
Equipment	120,000
Installation	17,000
Contingencies	14,800
Total Capital Cost	168,100
Operating Cost ($/year)	
Capital Recovery (10 years @ 12%)	29,754
Energy (25 kW; 2,400 hours; $0.13/kWh)	9,360
Membrane replacement ($950/element every 3 years)	6,840
Labor	12,000
Supplies	1,800
Chemicals	2,800
Total operating cost	62,554
Benefits ($/year)	
Water saved (1,630kgal@ $1)	1,630
Thermal energy saved(1,278 MMBtu@ $7)	8,946
Net operating cost ($ per year)	51,978
Unit net annual operating cost ($/Ton of salt reduced)	**1,693**
Unit net annual operating cost ($/kgal of permeate)	**4.19**

Water softeners can also be replaced by high recovery (~80%) RO systems. A high recovery RO system would reduce the total salt discharge by 27.4 tons when the retentate is added to the plant effluent. When the retentate is disposed separately HRRO system reduces salt discharge by 39 tons. Therefore, the choice between LRRO and HRRO should be done within the context of the salinity reduction plan for the overall plant. LRRO is the preferred choice when the plant can meet the regulatory FDS limits without resorting to off-site disposals.

6. Product Loss Reduction

Food products contain mostly organic matter and very little inorganic matter. Published data on composition of foods is very helpful in analyzing the contribution of food product losses on the composition of the effluent. Table 74 contains composition data of some food products processed in the study area.[144]

Table 74: Analysis of Selected Foods

Food	Water (%)	Protein (%)	Fat (%)	Fiber (%)	CHO (%)	Ash (%)	BOD (lb/lb)	BOD/ash
Tomatoes	93.5	1.1	0.2	0.5	4.7	0.5	0.044	8.7
Milk	87.4	3.5	3.5	0	4.9	0.7	0.099	14.2
Olives	80.0	1.1	13.8	1.4	2.6	2.5	0.151	6.0
Orange	88.3	0.7	0.2	0	10.4	0.2	0.084	13.9
Grapes	81.6	1.3	1.0	.6	15.7	0.4	0.124	31.1
Beef Carcass	60.1	18.0	21.0	0	0	0.9	0.372	41.4
Chicken	75.7	18.6	4.9	0	0	0.9	0.235	26.1
Carrots	88.2	1.1	0.2	1.0	9.7	0.8	0.076	9.5

When food products are lost to process water during processing, fats, proteins and carbohydrates contribute to BOD of the effluent at the ratios of 1.03, 0.89, 0.65 lb of BOD per pound, respectively.[145] Ash contributes to salt at the ratio of 1 lb of BOD/lb. These ratios can be used to determine the contribution of food loss to the salt content by assuming that the BOD in the effluent is caused entirely by the product loss. The BOD/ash ratio of the selected food items are listed in the last column. For example, if BOD in the effluent of a tomato plant is 1,000 mg/L, it implies that 23,260 (=1000/.043) mg/L is the food content in the plant effluent and its salt content due to food loss is 118 (=1000/8.5) mg/L.

Good housekeeping measures like dry cleaning or scooping of spilled products instead of hosing down with water is the best method of reducing the product loss. These measures allow the recovered product to be used for other useful purposes like animal feed and bring in extra revenue. Keeping products away from the effluent reduces BOD and TSS in the effluent in addition to salts.

Once salt in a food product enters the effluent, its separation requires the same set of technologies used to separate salts from supply water, namely RO, ED and evaporation. However, presence of other food components like, fats, proteins, carbohydrates makes separation more difficult and expensive. Four industry sectors require different technology for product recovery hence they are discussed separately by industry.

7. Cleaning Chemicals and Processing Chemicals

The reduction of salt contribution from cleaning and processing chemicals can be accomplished by substitution to low salinity chemicals and by reusing the chemical solutions several times. Gravity

[144] Watt, B. K. and Merrill, A. L. 1963. Composition of Foods. Agriculture Handbook No. 8. United States Department of Agriculture.

[145] Carawan, Roy E., J. V. Chambers, and R. R. Zall, 1977. Spin-off on Dairy Processing Water and Wastewater Management. Extension Special report No. AM18B, The North Carolina Agricultural Extension Service, Raleigh, N. C.

settling, microfiltration, ultrafiltration, nanofiltration and evaporation are used to maintain the quality and strength of the chemicals in reuse schemes.

It is necessary to dispose reject fractions of recovery processes. Rejected fractions can be concentrated by evaporation to reduce volume before disposing. This is an expensive process but is much less costly compared to treatment of the large volumes of composite plant effluent. It may be possible to convert the concentrate into byproducts that can generate revenue to at least partially offset the treatment cost.

The simplest chemical reuse system is to store used chemicals in a tall storage tank for several hours, typically overnight, and drain the sediments at the bottom and reuse the clear supernatant with fresh chemical makeup. The extent of draining is decided by visual observation. The complete tank is dumped periodically, typically once a week.

a) Microfiltration of Chemicals

Tubular ceramic and stainless steel microfiltration membranes are used to recover chemical solutions when suspended solids are the primary contaminant. Microfiltration typically involves 0.1 micron cutoff membranes which remove all visible suspended solids leaving a clear filtrate. It does not remove soluble solids like sugars, amino acids and salts. Stainless steel membranes have the advantagesof being able to withstand thermal and mechanical shocks over ceramic membranes.

Microfiltration is generally used with more concentrated chemicals like evaporator caustics because the capital and operating cost necessitates the recovery of high value chemicals. It is possible to recover about 90% of the used chemical solution by microfiltration and to use the filtered chemicals indefinitely. A preliminary cost analysis (Gerold Luss, 2004) of an 80 sft stainless steel microfiltration skid processing 5% caustic (Table 75) shows a very attractive payback. The benefits of the system decrease when recovering more dilute chemical solutions.

Table 75: Cost Analysis of Microfiltration of Caustic Solutions

System Parameters	
Microfiltration capacity (gpd)	4,000
Capital investment ($)	100,000
Electric power (kW)	30
Hours of operation (hours/day)	20
Days of operation (days/year)	300
Solution (5%) recovery (gal/year)	1,200,000
Salt reduction (tons/year)	143
Expenses ($/year)	
Energy cost (198,000 kWh @ $0.13)	25,740
Membrane cost ($10,000 every ten years)	1,000
Cleaning (lump sum)	1,000
Total operating costs	**27,740**
Potential Benefits ($/year)	
Chemical Saving (120,000 gal 50% @ $0.4)	48,000
Disposal saving (1,200 kgal @ $1.07)	1,280
Net Operating cost	**-21,540**
Net annual Operating cost ($/ton)	**-150**

b) Nanofiltration of Chemicals

Microfiltration of clean in place (CIP) chemicals remove only the suspended solids hence the microfiltrate contains sugars, salts, amino acids and other soluble compounds. These contaminants reduce the effectiveness of the chemicals. Nanofiltration with much finer membranes, removes some of these solutes and produces a higher quality permeate for reuse. Recent developments in caustic resistant polymeric nanofiltration membranes have opened up new possibilities for chemical recovery. These membranes are available as less expensive spiral modules or more expensive tubular modules that can accommodate suspended solids like tomato peels. A detailed cost analysis of a nanofiltration system for spent caustic recovery in tomato lye peeling operation is presented later.

c) Reuse of Recovered Chemicals

Decanting, microfiltration, ultrafiltration, and nanofiltration produce reusable chemicals solutions of increasing purity in that order. Cost and benefits of the three alternatives should be evaluated in detail with respect to plant specific conditions to decide on the optimum technology application. Premixed CIP chemical agents contain surfactants, chelators, etc in addition to acids and caustics. Membranes that pass acid and caustic may pass only smaller fractions of these compounds. Therefore, these additives should be replenished accordingly for the filtered chemical to be effective.

d) Disposal of Spent Chemicals

Disposal of used chemicals becomes inevitable even with the most stringent recovery/reuse technology. Chemicals after several reuse cycles, bottoms from decanting tanks and retentate from membrane treatment eventually have to be disposed. Disposing with the plant effluent is the first option when it does not force the effluent above the discharge FDS limits.

Disposing small volumes of used CIP chemicals mixed with food solids as animal feed is a possibility. It is important to ensure that all chemicals used are food grade and are in relatively small quantities. The presence of milk solids in used CIP chemicals may add some nutritional value but this is not significant. However, the salt content of the chemicals may become significant and should be accounted in feed formulation.

When the chemicals have to be transported for a long distance, reduction of volume becomes beneficial. Reverse osmosis is the most economical method of concentration. However, it is not effective with acids and caustics of extreme pH because they tend to pass through the membranes and membrane life is reduced especially at high pH. When chemicals are neutralized, for example by mixing caustics with acids, they can be concentrated by reverse osmosis to about 5% TDS content. Evaporation has to be used for concentrations above this level.

Spent processing and cleaning chemicals are highly corrosive and hence require expensive evaporators made of corrosion resistant alloys. Table 76 is a cost analysis of an evaporator handling 60 gpm of 5% brine.

Table 76: Cost Analysis of Evaporation of Spent Chemicals

System Parameters	
Evaporator capacity feed (gpd)	86,400
Feed solids (%)	5
Concentrate output (gpd)	10,800
Concentrate solids (%)	40
Days of operation (days/year)	300
Salt reduction (tons/year)	583
Electrical power (kW)	75
Thermal energy (MMBtu/hr)	8.2
Capital cost ($)	4,000,000
Expenses ($/year)	
Electrical energy (540,000 kWh @ $0.13)	70,200
Thermal energy (59,040 MMBtu@ $7)	413,280
Operations and maintenance (2% of capital cost)	80,000
Total annual operating costs	**563,480**
Net annual Operating cost ($/ton of salt)	**966**
Net annual Operating cost ($/kgal water evaporated)	**24.8**

8. End of Pipe Effluent (EOP) Treatment

In-plant measures are expected to reduce salt discharge within regulatory limits in many situations. However, in extreme cases this may not be feasible and it may become necessary to treat the end-of-pipe effluent form the plant. This is very often the case when supply water has a very low FDS content.

The plant effluent has to be treated first to reduce organic matter and then to reduce salts. Water Factory 21 of the Orange County Water District (OCWD) operated a plant for a long period to produce 5 mgd desalted water from secondary treated municipal effluent. Figure 29 is a flow diagram of a possible treatment process based on the experience of Water Factory 21. The cost of chemical treatment and reverse osmosis were reported as $1.01 and $0.96 per kgal of water produced respectively.[146]

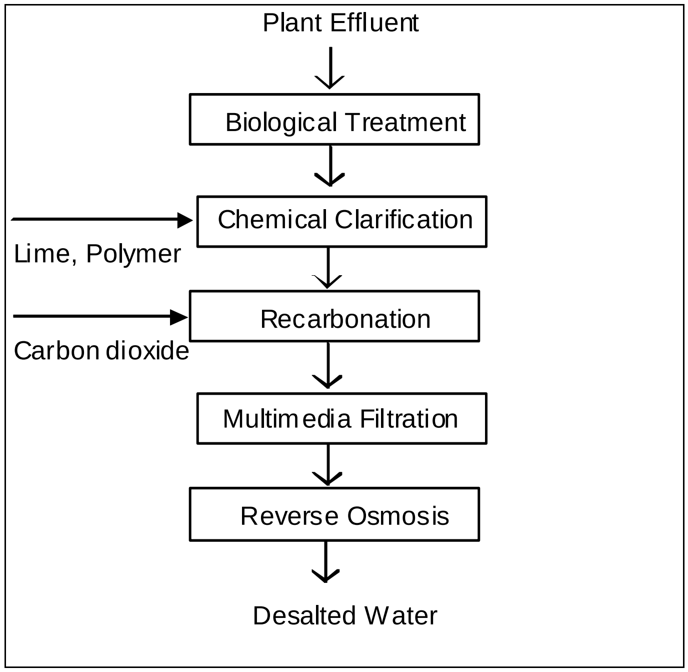

Figure 29

The sewer rates charged by POTW's that treat food plant effluent using biological reactors are a fair representation of the cost of biological treatment of the end of pipe effluent. Many POTW's accept food processing plant effluent and dispose it by land application after primary treatment. City of Tulare is one POTW that treats about 6 million gallons per day of food processing effluent in its biological reactors. The following are rates charged by the City of Tulare for food processing effluent were used in the estimation of cost of on-site biological treatment of the effluent:

- Flow $1,070 per million gallons
- BOD $79.80 per thousand pounds
- TSS $103.30 per thousand pounds

The total cost of effluent treatment for salinity reduction for a winery discharging 295 million gallons per year with 3,555 mg/L of BOD and 1,016 mg/L TSS is summarized in Table 77. This process combines biological treatment costs for the City of Tulare, chemical clarification of OCWD and ZLD cost developed earlier in this study for supply water.

[146] Anonymous. 1996. Water Factory 21. Orange County Water District, 10500 Ellis Avenue, Fountain Valley, CA. http://www.ocwd.com/_html/wf21.htm

Table 77: Cost Analysis for End-of-Pipe Effluent Treatment for Salinity Reduction

	Unit	Quantity	$/unit	Cost
Volume	kgal	295,000	1.07	315,650
BOD	klb	8,704	79.8	694,613
TSS	klb	2,488	103.3	256,977
Subtotal biological treatment				1,267,239
Chemical Clarification	kgal	295,000	1.01	297,950
Zero liquid discharge	kgal	295,000	4.56	1,345,200
Subtotal salinity treatment				1,643,150
Total				2,910,389
Total annual cost $ per Mgal of feed				9,866

The total cost of this treatment train amounts to $10,986 per million gallons. Salinity treatment costs more than twice the biological treatment. The byproduct of this process is about 292 million gallons of very high quality water. It is assumed that this water can be discharged to surface water at minimal cost.

C. Salt Reduction in Selected Food Processing Industry Sectors

1. Tomato Canning

Tomato plants receive fresh tomatoes from the field during the harvesting season lasting from July to October. These are processed into tomato paste in the paste line and into canned diced tomatoes, whole tomatoes, and tomato juice products in the retail line. Tomato paste is stored and remanufactured into retail products during the off-season. Figure 30 is a simplified flow diagram of the tomato process.

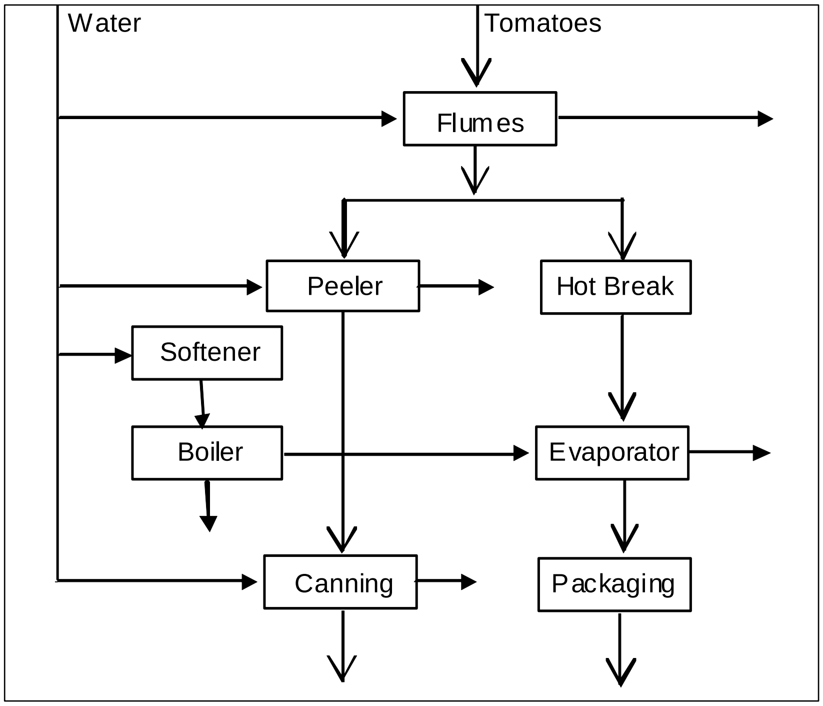

Figure 30

Fresh tomatoes trucked to the facility are discharged using water jets and are transported by water flume into the processing plant. The flume water is screened to remove coarse solids and recycled several times. However, flume water ultimately makes up approximately 35% to 45% of the process wastewater generated in the plant.

Condensate recovered from the evaporation process is about 200 gal/ton of tomatoes or about 20% of the wastewater volume. Water softener regeneration, boiler blowdown and cleaning are other sources of wastewater. Steam peeler, can fillers and can cooling are wastewater sources in retail line. The industry average for tomato processing is about 920 gallon of water and 8 lb of BOD per ton of tomatoes.[147]

The study area in the Central Valley contains eight tomato plants with land discharges. These are located in Merced, Fresno and Kings Counties. One plant discharged process effluent to a POTW and land-applied only flume mud. This plant was excluded and the other seven plants were used in the FDS analysis (Table 78). Five of these seven plants (Plants 2, 4, 5, 6, and 8) had relatively moderate added FDS ranging from 140 to 600 mg/L. These plants used steam peeling in the process. Plants 3 and 7 used lye peeling and had distinctly higher FDS.

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[147] Mannapperuma, J. D., Yates, E. D., and Singh, R. P. 1993. Survey of water use in the California Food Processing Industry, *Proceedings of the Food Processing Environmental Conference, Atlanta, Georgia.*

Table 78: Analysis of FDS for Seven Tomato Processing Plants

	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
Effluent							
Production (ktons/y)	*993*	*506*	*155*	*208*	*220*	*350*	*192*
Volume Mgal/y	914	466	147	191	202	322	177
EC uS/cm	2,114	2,790	1,473	1,505	1,443	3,175	1,104
FDS mg/L	1,163			647			570
TDS mg/L	1,541			1,033	1,404	3,977	1,249
BOD mg/L	*571*	1,319	1,098	796	1,055	1,822	1,072
Supply							
EC uS/cm	1,750	1,200	*1,200*	427	453	340	630
TDS mg/L	1,019	700	*700*	241	247	227	430
Added FDS mg/L	145	*954*	*164*	405	*594*	*1701*	140

Salt audits or salt accounts were not reported for any of the seven plants analyzed above. However, it was possible to locate effluent characteristics and a salt audit for a different plant in the literature. The data is used to illustrate the in-plant salt reduction strategy in tomato processing (Table 74**)**

Table 79: Analysis of FDS of the Selected Tomato Processing Plant

Effluent volume (Mgal/year)			110.6
Effluent Characteristics			
Electrical Conductivity EC (uS/cm)			1,237
Fixed Dissolved Solids FDS (mg/L)			531
Fixed Dissolved Solids FDS (tons/year)			244
Total Dissolved Solids TDS (mg/L)			1,248
Biochemical Oxygen Demand BOD (mg/L)			1,038
Supply Characteristics			
Electrical Conductivity EC (uS/cm)			630
Total Dissolved Solids TDS (mg/L)			384
Added FDS (mg/L)			**147**
Sources of FDS	**Tons/year**	**mg/L**	**(%)**
Supply	176	383	55.3
Product loss	87	190	27.3
Softener regeneration	29	63	9.1
Boiler blowdown	10	22	3.1
Cleaning chemicals	13	28	4.1
Process chemicals	3	7	1.0

The added FDS in this plant is only 147 mg/L which is well below the 300 mg/L limit mandated in some areas of the Central Valley. Therefore FDS reduction for this plant is required only to meet the more stringent limit of zero added FDS limit. Water supply, boiler feed and product loss are the FDS sources that can be treated to achieve this limit. The cost analysis for treatment of water supply and boiler feed water developed earlier, was used directly for this purpose. Only the product loss reduction was analyzed separately for the peeling operation.

a) Water Supply

The plant used 110.6 million gallons of supply water. Most of the water use (96.5%) is during the harvest season which is approximately 100 days long. The cost of several supply water treatment technology combinations were analyzed and summarized earlier. The combination of treating supply water by LPRO, softening and HPRO followed by brine treatment in evaporation ponds and solids disposal in a landfill was found to be the most l least costly combination. The estimated total operating cost was $5,675 per Mgal of feed water.

b) Boiler Feed Water

The boiler feed water treatment using low recovery reverse osmosis LRRO was analyzed in the technology section using the data for this tomato plant. The capital cost of this system was estimated at $168,100 and the net annual operating cost with allowance for water and energy savings was $51,978 which amounts to $4.19 per kgal of permeate.

Tomato plants with paste operations have large volumes of evaporator condensate which can be used as boiler feed water with proper precautions. This is a more cost effective method of reducing salt as compared to RO treatment.

c) Product Loss - Steam Peeler

Tomato plants have two major avenues of product loss, flumes and peelers. Tomatoes get damaged during transport in the trucks and leaches juice and other tomato solids end-up in the flumes. Tomatoes are peeled in lye peelers or vacuum peelers. This plant uses steam peelers. The discharge water from steam peelers is assumed to contain about 0.5% tomato solids.

This relatively pure dilute tomato juice can be evaporated to produce tomato paste with 30% solids in case if the evaporator has spare capacity. When the evaporator does not have spare capacity reverse osmosis can be used to preconcentrate it to about 6% solids (equivalent to tomato juice) and be fed to the evaporator. Preconcentration of tomato solids requires tubular reverse osmosis systems to accommodate suspended solids. These systems are much more expensive compared to spiral membrane systems proposed for supply water treatment.

This process not only removes salts from the effluent, but recovers valuable tomato solids. A study at another tomato plant has reported that 25% of the product loss occurs at the peelers with 10% of the effluent volume of the retail process.[148] The average composition of tomato is assumed to be 6.5% total solids, 5% total dissolved solids and 0.5% fixed dissolved solids. The cost analysis summarized in

[148] Mannapperuma, Jatal D., Mate, Juan I., and Singh, R. Paul. 1993. Reduction of environmental impact and energy use through water recycling and byproduct recovery in food processing. A report submitted to California Institute for Energy Efficiency.

Table 80 assumes these proportions. The evaporator is assumed to have four effects with a steam economy of 3.5.

Table 80: Cost Analysis of Tomato Solids Recovery from Steam Peeler Discharge

Peeler Discharge Parameters	
Peeler discharge flow (gal/year)	3,350,000
Peeler discharge TDS (tons/year)	59
Peeler discharge FDS (tons/year)	5.9
Peeler discharge TS (Tons/year))	77
RO System Parameters	
Capital cost ($)	310,000
Electric power (kW)	40
Preconcentrate volume (gal/year)	258,000
Evaporator Parameters	
Evaporator duty (lb/year)	1,677,000
Steam consumption (lb/year)	479,000
Thermal energy consumption (MMBtu@ 800 lb/MMBtu)	598
Paste recovery (30% solids; tons/year)	232
Costs ($/year)	
RO System capital recovery (10 year @ 12%)	54,870
RO System energy cost (96,000 kWh@$0.13)	12,480
RO System membranes ($42,000 every 3 years)	14,000
Evaporator energy cost ($7 per MMBtu)	4,200
Operations and maintenance (2% of capital cost)	6,200
Total annual operating costs ($/year)	**91,750**
Value of paste recovery(@ $560/ton)	129,920
Net annual operating cost	**-38,170**
Salt reduction annual cost ($/ton)	**-6,469**

2. Cost Analysis of FDS Reduction in Tomato Canning

The cost analysis was performed for the selected tomato plant discharging 318 tons of FDS per year in 110.6 million gallons of water. This plant has steam peeling. Costs were obtained for technologies for possible FDS reduction through food product recovery, boiler feed water treatment and supply water treatment. End-of-pipe effluent ZLD treatment was included for comparison with in-plant measures. The costs for this item were obtained by prorating the costs determined earlier.

Table 81: Cost Analysis for FDS Reduction in Tomato Canning

	Total FDS		**FDS Reduction**		**Annual Cost of FDS Reduction ($)**		
	Tons	mg/L	Tons	mg/L	Total	per ton	per mg/L
Food Loss	87	190	6	13	-38,170	-6,469	-2,969
Boiler feed water	39	85	31	67	51,978	1,693	777
Supply water	176	383	156	341	515,946	3,298	1,514
EOP Effluent	318	693	318	693	1,215,052	3,821	1,754

The added FDS at this plant is only 147 mg/L which is below the 300 mg/l added FDS limit. It can meet the zero added FDS limit by in-plant measures alone. Food product recovery has a negative cost of salt removal, because of the high value of the product recovered from peeler discharge. The peeler discharge constitutes only 5% of the FDS by product loss. Most of the remainder is likely through truck serum and flume overflow. The treatment of these sources for food product recovery is difficult due to contamination hence was not evaluated.

The treatment of boiler feed water is a very effective method of reducing FDS discharge with several other benefits. This system becomes redundant when the supply water treatment option is considered. In tomato paste plants it is also possible to use evaporator condensate as boiler feed water with appropriate pretreatment.

Cleaning chemicals and food ingredients are the two FDS sources that were not considered for treatment in this study. These account for 4.1% and 1% of the total FDS discharge, respectively. These are relatively small contributions and these sources constitute multiple chemicals. Management approaches are more appropriate for these sources than technological approaches. Technology and cost of lye recovery from lye peeling operation was discussed but not included in the cost function because the selected plant does to include lye-peeling.

3. Milk Processing

Dairy processing plants receive milk in refrigerated tankers daily from dairy farms throughout the year. Milk is stored in refrigerated silos and processed into cheese, butter, dry milk powder (DMP), condensed milk, yogurt, ice cream, and other products. Cheese making is the leading dairy processing industry in the Central Valley.

A simplified flow diagram of the cheddar cheese making process is shown in Figure 31. Milk is converted to curd and salted in this process. Whey separated from curd making is processed further by membrane filtration to separate whey proteins and concentrated in evaporators to produce whey protein concentrate (WPC). The separated lactose stream is used as animal feed directly or after concentration by reverse osmosis. It is also used produce lactose and other products.

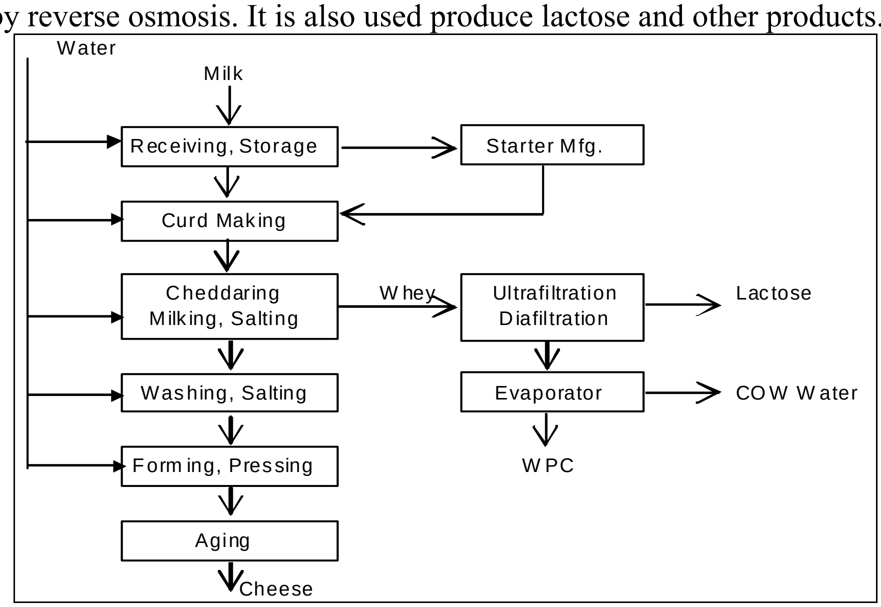

Figure 31

The nine county study area has six milk processing plants with some land or surface water discharges. The processes, products and effluent treatment by these plants have little in common Table 82.

Table 82: Descriptions of Six Dairy Processing Plants

Plant	Product	Effluent Treatment
1	Cheese WPC	Process effluent is trucked-off site or discharged to POTW. COW water and non contact cooling water are discharged to a creek.
2	Cheese WPC	Process effluent is treated in anaerobic digesters and the treated effluent is land applied.
3	Cheese WPC Lactose	Process effluent is treated in anaerobic and aerobic digesters. Part of the treated effluent is discharged to land directly and remainder is treated by RO and discharged to land. RO retentate is evaporated and trucked off-site. COW water is recovered and used for process purposes.
4	Cheese	Non Contact cooling water is discharged to a creek. Process effluent is discharged to a POTW
5	Cheese DMP WPC	Non Contact cooling water and COW water are discharged to a creek. Process effluent is discharged to a POTW
6	Butter, DMP	High strength process effluent is treated in an evaporator and used for animal feed. Lower strength process water is treated in aerated lagoons and land applied or discharged to creek. Non process effluent is also land applied or discharged to creek

Process effluent from milk plants 1, 4 and 5 are discharged to POTWs and hence do not land apply directly. The FDS analysis for the process effluent from the three plants that have direct land applications is summarized in Table 83.

Table 83: Milk Process Effluent

	Plant 2	Plant 3	Plant 6
Volume (Mgal/y)	204	594	120
Production (ktons/y)	*567*	*1,650*	*333*
Effluent Characteristics			
Conductivity EC (uS/cm)	3,467	2,566	891
Fixed Dissolved Solids FDS (mg/L)		1,264	
Total Dissolved Solids TDS (mg/L)	1,592	1,551	
BOD (mg/L)	74	125	31
Supply Characteristics			
Conductivity	630	982	224
Total Dissolved Solids (TDS)	410	622	
Added FDS (mg/L)	***1,182***	**642**	***400***

Salt accounts or audits of in-plants activities were not available from any of the plants listed in Table 84. However, a recently completed study of six dairy plants in City of Tulare contained salt accounts of four cheese plants.[149] A summary of these salt accounts is listed in Table 82.

Table 84: FDS Analysis for Four Cheese Plants in Tulare 2004

	Plant A	Plant B	Plant C	Plant D
Volume (Mgal/year)	222	226	756	262
Production (ktons/y)	*616*	*628*	*2,100*	*728*
Effluent Characteristics				
Conductivity EC (uS/cm)	1003	1246	701	889
Fixed Dissolved Solids FDS (mg/L)				
Total Dissolved Solids TDS (mg/L)	*602*	*748*	*421*	*533*
BOD (mg/L)	1097	1545	1005	1104
Supply Characteristics				
Conductivity	504	205	205	205
Total Dissolved Solids (TDS)				
Added FDS (mg/L)	***299***	***625***	***298***	***410***
Sources of FDS (%)				
Supply	31.2	9.9	14.7	13.3
Product loss	10.6	12.0	13.9	10.2
Cleaning Chemicals	45.0	57.4	46.9	23.8
COW Water	0.9	4.9	3.5	2.5
Process Chemicals	-	-	-	50.3
Unknown	12.3	15.8	21.0	-

The results of this audit provide limited direction in formulating a salt reduction strategy. The results are that cleaning chemicals are the leading contributor of salts in three plants. Process chemicals were the highest contributor in the other plant. Three plants obtain supply water from the city. Plant A which obtains supply water from wells has a high salt contribution from water supply.

However, it is not possible to formulate an in-plant salt reduction strategy without access to salt accounting information from any of the milk plants in the area. We assume the FDS distribution for Plant 2 (Table 85) based on the salt audits of Tulare plants.

[149] Mannapperuma, Jatal D. and M. R. Santos, 2004. Salinity reduction in dairy processing plants. A report prepared for the City of Tulare.

Table 85: Analysis of FDS of the Selected Milk Processing Plant

Effluent volume (Mgal/year)		204	
Effluent Characteristics			
Electrical Conductivity EC (uS/cm)		3,467	
Fixed Dissolved Solids FDS (mg/L)		1,592	
Total Dissolved Solids TDS (mg/L)		1,592	
Supply Characteristics			
Electrical Conductivity EC (uS/cm)		630	
Total Dissolved Solids TDS (mg/L)		410	
Added FDS (mg/L)		**1,182**	
Sources of FDS	**Tons/year**	**mg/L**	**(%)**
Supply	347	410	26
Product loss	150	177	11
Cleaning chemicals	500	591	37
Unknown	350	414	26
Total	**1348**	**1,592**	**100**

a) Alternative Cleaning Chemicals

Chemical cleaners can be formulated to reduce salt content while maintaining the same level of cleaning effectiveness. Ecolab has formulated a high temperature alkaline cleaner, Conquest, to replace the high-sodium containing AC-1351. They also have two alternatives to their chlorinated alkaline detergent Principal. Exxelerate CIP is a low-sodium replacement for Principal. Solodigm is an enzyme based detergent that adds virtually no incremental conductivity.

The salt content of the cleaners and their recommended concentration can be used to estimate the cost of reducing salt contribution (Table 86). An important result in this table is that replacing Principal with Exxelerate CIP results in substantial cost savings while also reducing salt discharge.

Table 86: Cost Analysis of Alternative Chemical Cleaners

Cleaner (Alternative)	Sodium (lb/gal)	Concentration in solution (%)	Cost of Sodium reduction ($/lb of sodium)
AC 1351	3.63	0.85	
(Conquest)	2.00	0.79	1.17
Principal	1.15	0.4	
(Exxelerate CIP)	0.65	0.4	-8.00
Principal	1.15	0.4	
(Solodigm)	0.04	0.15	1.01

Ecolab has also introduced a chelating agent, Exxelerate 320 that is used as an additive to alkaline cleaners in high temperature applications. This combination removes most of the mineral deposits in the alkaline cleaning step allowing for infrequent acid cleanings.

It should be noted that the use of these alternative chemicals is limited by the process in which they are proposed to be used. Factors such as equipment temperature, chemical cost, compliance with USDA guidelines and customer specifications are some factors limiting their use.

b) Recovery of CIP Chemicals

Recovery of CIP chemicals for reuse is a common practice in dairy plants. The extent of reuse varies among plants and among CIP systems within a plant. Reusing the chemical solutions with makeup throughout a day and dumping the solution at the end of the day is practiced with CIP systems in many plants. However, HTST system CIP solutions are considered difficult to reuse without further treatment due to high degrees of contamination. This makes a simple reuse strategy less effective since a large quantity of the chemicals is used in the HTST systems.

The microfiltration system for chemical recovery presented earlier (Table 75) is applicable under the condition of this plant. This 4,000 gpd system reduces 143 tons of FDS per year which is about 25% of the assumed FDS contribution of cleaning chemicals.

c) Product Loss

High solids process water streams such as initial rinses of tanks and equipment, product spills, etc., can be collected and concentrated in an evaporator. The product can be used as animal feed and generate revenue. A cost analysis for this system is presented in Table 87. It may be possible to feed the retentate from the cleaning chemical recovery systems to increase the effectiveness of the system.

Table 87: Cost Analysis of Evaporation of Food Solids

System Parameters	
Evaporator capacity feed (gpd)	54,000
Feed solids (%)	3
Concentrate output (gpd)	5,400
Concentrate solids (%)	30
Days of operation (days/year)	300
Salt reduction (tons/year)	101
Electrical power (kW)	55
Thermal energy (MMBtu/hr)	4.7
Capital cost ($)	2,000,000
Expenses ($/year)	
Electrical energy (396,000 kWh @ $0.13)	51,480
Thermal energy (33,840 MMBtu@ $7)	236,680
Operations and maintenance (2% of capital cost)	40,000
Total annual operating costs	**328,160**
Total Annual Operating cost ($/ton of salt)	**3,249**
Total Annual Operating cost ($/kgal water evaporated)	**22.5**

d) Cost Analysis of FDS Reduction in Milk Processing

The cost analysis is prepared for the selected milk processing plant discharging 1,348 tons of FDS per year with 204 million gallons of effluent. The cost of technologies for possible FDS reduction through food product recovery, and chemical recovery were evaluated for this plant. Supply water and end-of-pipe effluent treatment were included by prorating the costs determined earlier.

Table 88: Cost Analysis of FDS Reduction in Milk Processing

	Total FDS		**FDS Reduction**		**Cost of FDS Reduction ($)**		
	Tons	mg/L	Tons	mg/L	Total	per ton	per mg/L
Food Loss	150	177	101	119	328,160	3,249	2,751
Chemicals	500	591	143	169	27,740	194	164
Supply water	347	410	317	374	1,054,658	3,327	2,817
Unknown	350	413	-	-	-	-	-
EOP Effluent	1,348	1,592	1,348	1,592	2,241,144	1,663	1,408

The added FDS of this plant is 1,182 mg/L at present. Reducing this number to 300 is not possible even by implementing all three technologies considered. However, it is entirely possible that a combination of technologies discussed in this study would be able to achieve this limit as proven possible by several milk processing plants in Tulare.

The treatment of boiler feed water and evaporation of high strength chemical sources, are two possible areas for evaluation. Use of condensate to replace well water in plant applications is also a very effective method of salt reduction in plants with large evaporators. Brief analysis indicated that using alternative chemicals has the potential to reduce the salt discharge, sometimes even with a cost saving. This method was not included due to lack of data from the plant.

4. Wineries

Wineries receive grapes from vineyards during the harvesting season which lasts from September to October. The wine making process that produces wines from grapes has many variations. Figure 32 is a simplified flow diagram indicating basic steps of the process for red and white wines.

Grapes are de-stemmed and crushed to produce must. In red wine process, must is sent direct to tanks for fermentation and then pressed to remove skins, pulp and seeds from wine. In the white wine process must is pressed and juice is fermented to make wine. Wines go through several types of stabilization and clarification steps. These involve addition of physical or chemical fining agents and filtration. Tartrate stabilization is achieved by cold storage or ion exchange. When ion exchange is used regeneration of ion exchange becomes a major source of salts in the wineries. Aging, long term storage and bottling are the remaining steps of the wine making process.

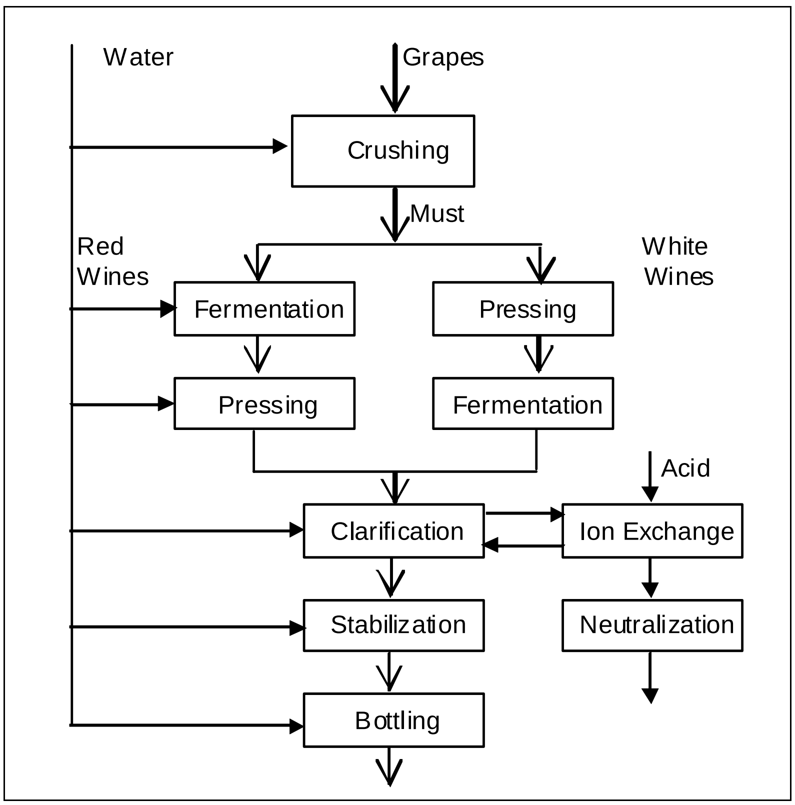

Figure 32

We were not successful thus far in locating any reports of salt audits done at wineries. Therefore, effluent characteristics reported to the SWQCB by the wineries were used to estimate possible sources of salinity. Four wineries in the Stanislaus County and adjacent areas that reported adequate quality parameters were in the FDS analysis which is summarized in Table 89.

The FDS contribution from food loss was estimated using the reported BOD and the BOD/ash ratio of 31.1 determined in Table 15. Contribution from cleaning chemicals was assumed to be the same as for tomato plants which is 28 mg/L. However, the FDS contributions from these two fractions and the water supply did not add up to 100% of the total. The unexplained balance ranged from 11% to 51% among four wineries. Conducting salt accounts at wineries is necessary to improve the accuracy of the study.

Table 89: FDS Analysis for Four Wineries

	Winery 1	Winery 2	Winery 3	Winery 4
Volume (Mgal)	295	125	79	51
Production (ktons/y)	*262*	*111*	*70*	*45*
Effluent Characteristics				
EC (uS/cm)	1,239			
FDS (mg/L)	769	1,176	775	522
TDS (mg/L)	2,091	3,178	1,223	1,076
TSS (mg/L)	1,016	1,918		
BOD (mg/L)	3,555	4,108	2,500	3,565
Supply Characteristics				
EC (uS/cm)	710	1,051	375	473
TDS (mg/L)	389	782	274	320
Added FDS (mg/L)	**380**	**394**	**502**	**202**
Sources of FDS (%)				
Supply	51	66	35	61
Product loss	15	11	10	22
Cleaning Chemicals	4	2	4	5
Unknown	31	20	51	11

a) Ion Exchange Regenerant

When tartrate stabilization of wines is done by ion exchange, regeneration of the resin is done by sulfuric acid. Potassium salts produced during regeneration, excess sulfuric acid and neutralization of the excess acid are major sources of salinity. Stabilization of one million gallons of wine by ion exchange is estimated to produce 2,280 lb of potassium sulfate assuming 25% excess acid use. If the winery uses 3 gal of water per gallon of wine, ion exchange discharge results in 92 mg/L of FDS. Including tartrate stabilization practices should help improve the accuracy of the FDS analysis.

Cold storage is an alternative method of tartrate stabilization but is more costly compared to ion exchange. In cold stabilization potassium bitartrate is precipitated and disposed as a solid. Electrodialysis is an emerging alternative but it uses nitric acid in the process and its contribution to FDS in the discharge is comparable to ion exchange. It may be possible to recover nitric acid using reverse osmosis. This would reduce both water use and salt discharge.

Bipolar electrodialysis can help salinity reduction in wineries. It can remove only the potassium from the wines and stabilize and reduce pH in one operation. Bipolar ED can also be used to produce potassium hydroxide and tartaric acid by splitting the potassium bitartrate that results from wine stabilization by cold storage or electrodialysis. The products of these processes, potassium hydroxide and tartaric acid can be used in chemical cleaning and wine acidification respectively.

b) Cleaning and Sanitizing Chemicals

Chemicals used in the cleaning and sanitizing of tanks and equipment are the other significant source of salts in the winery discharge. Sodium hydroxide that was used predominantly in alkali cleaning is increasingly being replaced by potassium hydroxide. This helps land applications because potassium is a plant nutrient. However, it does not help reduce FDS or EC to meet the limits imposed by the regulators.

Sodium hypochlorite ($NaOCl$) is the sanitizer of choice in wineries. This compound converts to $NaCl$ during the sanitization process and contributes heavily to salinity in the discharge. In May 1997, an expert panel assembled by the Electric Power Research Institute (EPRI) declared ozone to be Generally Recognized as Safe (GRAS) for use in food processing in the U.S.[150] Since then, wineries have begun using ozone for barrel cleaning and sanitation, tank cleaning and sanitation, clean-in-place systems, and for general surface sanitation. Ozone converts to gaseous oxygen and water during the sanitization process and does not contribute to salinity in the effluent.

c) Cost Analysis of FDS Reduction in Wineries

Winery 2 was selected for the costs analysis, discharging 610 tons of FDS per year with 125 million gallons of effluent. The estimated contribution by food product loss and cleaning chemicals was only 13 % of the total. Supply water contributed 66% of the FDS in the effluent.

This plant presently adds 394 mg/L FDS to the effluent. Reducing this number to 300 mg/L should be possible by good housekeeping and management measures alone. The next limit of zero added FDS could be reached by supply water treatment. End-of-pipe effluent treatment would allow near zero FDS discharge. Supply water and end-of-pipe effluent treatment costs were determined by prorating the costs determined earlier.

[150] Graham, Dee M. 1997. Use of Ozone in Food Processing. Food Technology, 50(6) 72-75.

Table 90: Cost Analysis of FDS Reduction in Wineries

	Total FDS		**FDS Reduction**		**Cost of FDS Reduction ($)**		
	Tons	mg/L	Tons	mg/L	Total	per ton	per mg/L
Food Loss	68	132	-	-	-	-	-
Chemicals	15	28	-	-	-	-	-
Supply water	406	782	360	695	583,122	1,619	839
Unknown	121	234	-	-	-	-	-
EOP Effluent	610	1,176	610	1,176	1,373,250	2,251	1,168

The treatment of boiler feed water and evaporation of high strength chemical sources, are the two possible areas identified for evaluation. The analysis conducted for the milk industry indicated that using alternative chemicals has the potential to reduce the salt discharge, sometimes even with a cost saving. This method may have potential in the wine industry as well.

5. Meat Processing

In poultry processing, live birds are received at the plant; birds are killed; blood is drained; and birds are scalded by dipping in hot water tanks to loosen feathers. Defeathered and eviscerated birds are chilled in cold water tanks, drained and packaged for marketing. Meat processing does not involve defeathering while cooling is done with air.

Solid waste from meat and poultry processing and fatty waste from milk processing and other food industries are processed in rendering plants to extract byproducts for human and animal consumption. All three processes use large supplies of fresh water for processing and cleaning operations. Boilers are used to generate steam and hot water for processing and cleaning operations.

Meat processing does not seem to be a major activity in the Central Valley. About 12 plants were listed as meat plants in the study area but only four of these -- one meat plant, one poultry plant and two tendering plants -- had any processing activity or land discharges. All four plants have some variation of biological treatment before the effluent is discharged to land. Table 91 is a summary of FDS analysis for these four plants

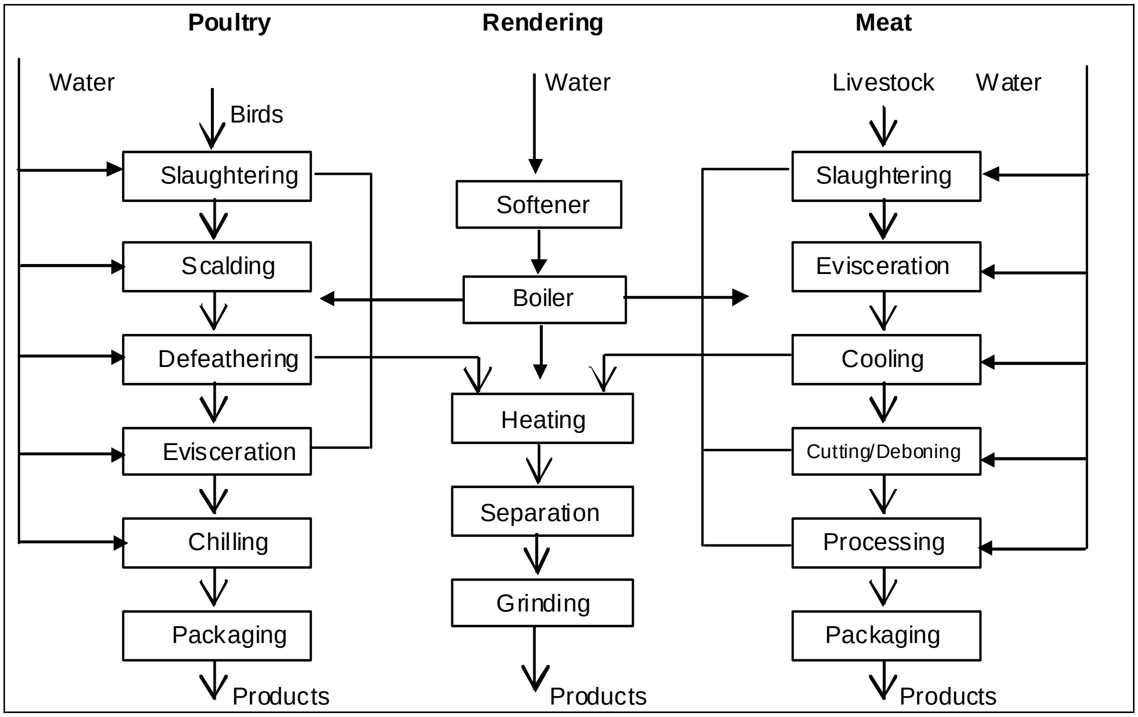

Figure 33

Table 91: FDS Analysis for Four Rendering/Meat Plants

	Rendering 1	**Rendering 2**	**Poultry**	**Meat**
Volume Mgal/y	38	40	706	212
Production (ktons/y)			*412*	*86*
Effluent Characteristics				
Conductivity EC (uS/cm)		5,388	1,142	1,105
Fixed Dissolved Solids FDS (mg/L)		730	564	
Total Dissolved Solids TDS (mg/L)	1,737	1,225	620	663
BOD (mg/L)	143	850	101	
Supply Characteristics				
Conductivity		435	352	341
Total Dissolved Solids (TDS)	316	320	230	
Added FDS (mg/L)	***1,421***	**410**	**334**	***459***

a) Cost Analysis of FDS Reduction in Meat Plants

We do not have access to salt accounts or audits from any of the meat processing plants. It is not possible to estimate FDS contribution of food loss because the BOD data for raw effluent is not available. The FDS contribution by cleaning chemicals also could not be estimated because it does not seem fair to approximate this industry with tomato and milk plants for cleaning chemical usage. Therefore, the FDS analysis summarized in Table 88 is limited to supply water and end-of-pipe effluent.

We use rendering plant 2 in this analysis, primarily because this plant provides the most complete set of data. This plant discharges 212 tons of FDS per year with 212 million gallons of effluent. The costs of supply water and end-of-pipe effluent treatment were determined by prorating the costs determined earlier.

Table 92: Cost Analysis of FDS Reduction in a Meat Plant

	Total FDS		FDS Reduction		Cost of FDS Reduction ($)		
	Tons	mg/L	Tons	mg/L	Total	per ton	per mg/L
Supply water	53	320	47	284	186,599	3,956	656
EOP Effluent	121	730	121	730	439,440	3,626	602

This plant presently adds 410 mg/L FDS to the effluent. Reducing this number to 300 mg/L seems to be possible with ZLD treatment of supply water alone. It may be possible to achieve the next limit of zero added FDS by management of boiler feed water, product loss and cleaning chemical use. However, we do not have sufficient information for a detailed analysis.

6. Selected Unit Operations

Lye peeling of tomatoes and density grading of peas are two unit operations that add substantial quantities of salt to the discharge. The plants analyzed in this study did not include these operations. A separate analysis of salt reduction measures in these two processes is included because of their importance. These measures may also be applicable to density separation of pitted olives, lye peeling of peaches and other similar operations.

a) Density Grading

Vegetables like peas and beans are graded by flotation in sodium chloride brine before freezing to achieve uniformity in density. Typical density grading systems are designed and operated without much concern for salt discharge because of the low cost of salt. Figure 34 is a simplified flow diagram of a typical density grading system.

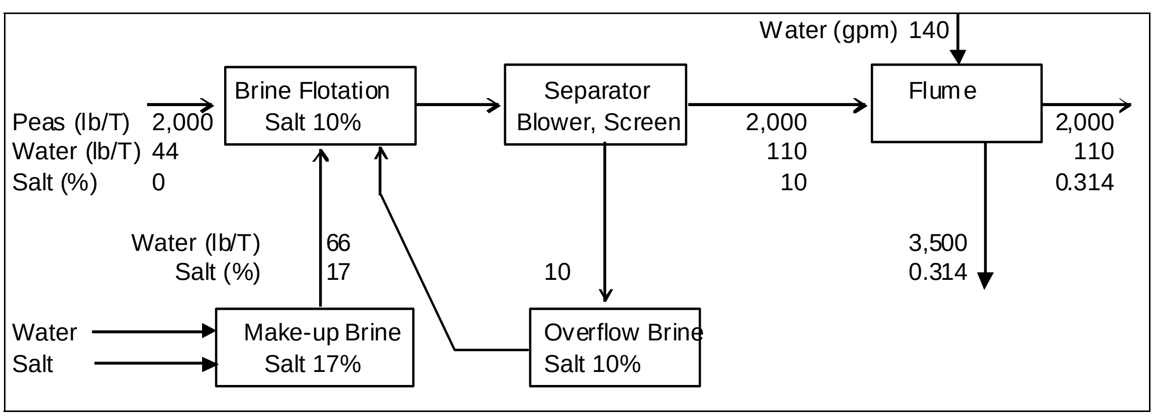

Figure 34

In a typical system the brine is maintained at 10% concentration. The water brought in by the peas dilute the brine in the grader. This is compensated by adding more concentrated brine at 17% which brings in more water. The water balance is maintained by brine leaving the grader with the peas or by overflow, both adding to salt in the effluent.

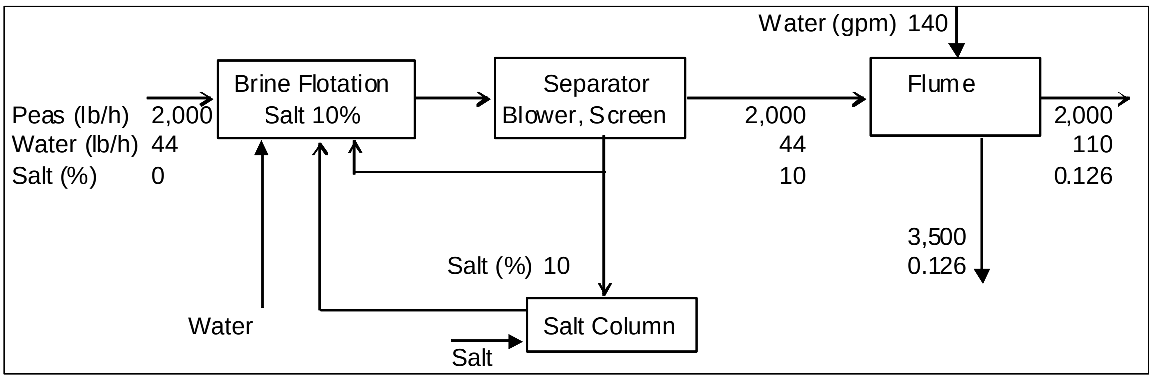

Figure 35

An improved system (Figure 35) will involve brine being circulated through a solid salt column to adjust the density of brine. The brine leaving with the peas is reduced to match the water arriving with the peas. This could be done using a vibratory screen similar to the screen used with peas entering the grader. This arrangement has the potential to reduce the salt content in the flume from 0.314% to 0.126%. or by 60%. This amounts to a reduction of salt discharge from 110 lb/ton of peas to 44 lb/ton of peas.

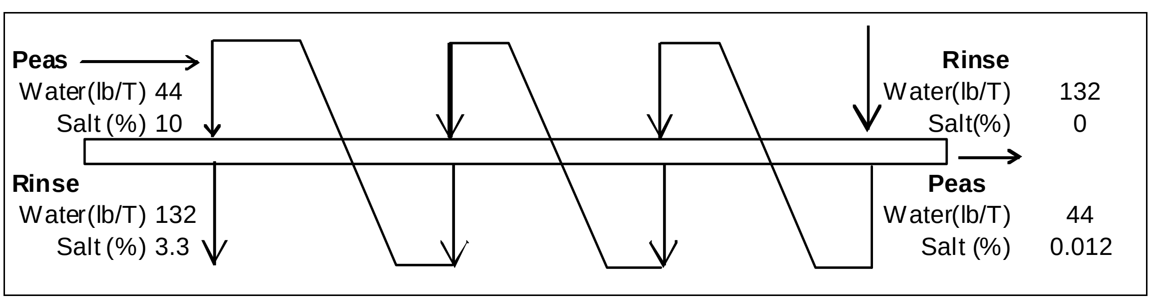

Figure 36

The salt discharge can be further reduced by employing a counter current rinse system before peas enter the flume (Figure 36). A three stage counter current system using about 120 lb of water per ton of peas can reduce the salt discharge further by about 90%. This flow rate is about 5 gal/min for a 20 ton/hour process line. The resulting rinse is about 3% salt concentration and has to be disposed separately or further concentrated and reused. Both of these are costly options.

b) Recovery of Lye from Peeling Operation

Lye peeling of tomatoes is practiced at a few tomato plants in the Central Valley. It is also the peeling method practiced exclusively with peaches. Therefore, strategy for recovery and reuse of lye from peeling operation is of broad interest as a salt reduction measure. Data available from one tomato plant with lye peeling is summarized in Table 93 to quantify the contribution of lye peeling operation. This plant processed 4,375 tons of tomatoes per day.

Table 93: FDS Analysis of Lye Peeling Operation

	Volume (gpd)	EC (uS/cm)	TDS (mg/L)	FDS (mg/L)	FDS (tons/day)
Plant Effluent	3,300,000	2,591	3,070	1,740	23.8
Well Water	-	410	277	*277*	3.8
Lye peeler discharge	454,107				11.7
Neutralized lye-salt				*1,074*	*14.7*
All other sources				*388*	*5.3*

Lye peeling operation contributes 62% of the FDS in the plant effluent. It is apparent that reduction of FDS to even the least stringent 300 mg/L above supply cannot be met without treating the lye peeler effluent. The flow diagram of the typical tomato lye peeling system is shown in Figure 37.

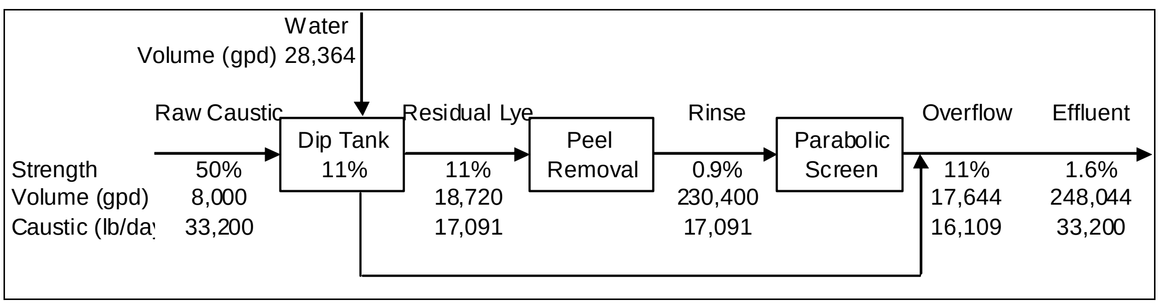

Figure 37

Overflow from the peeler contributes about 50% of the caustic to the effluent and has a lye concentration of 10%. A partial lye recovery system from this stream is presented in Figure 17. This system employs a solvent resistant tubular nanofiltration unit to recover about 80% of the overflow lye solution. The recovered lye is fed to the lye dip tank in place of water used to dilute raw lye. The cost analysis of the lye recovery operation (Table 94) indicates the possibility of significant reduction of salt discharge.

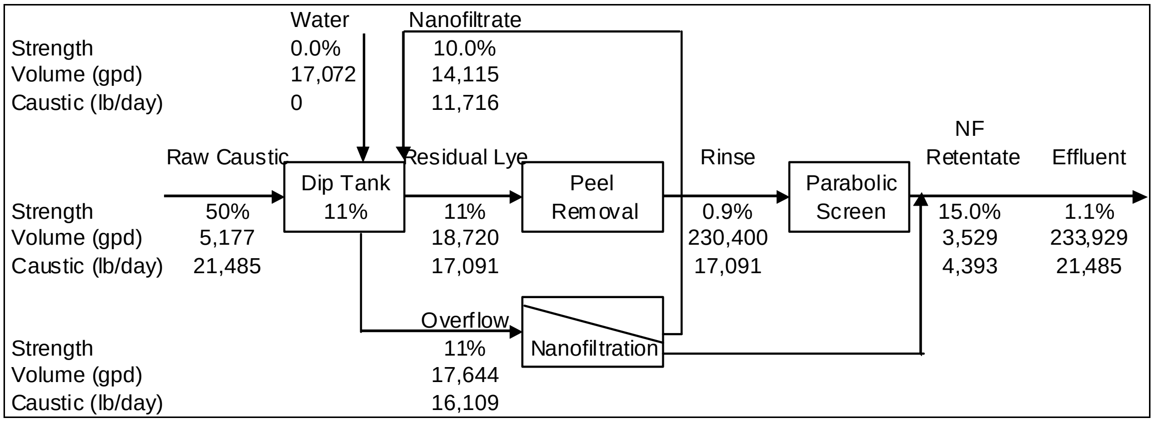

Figure 38

The cost of operating the lye recovery system is exceeded by the value of the chemical recovered, resulting in a negative cost for salt reduction. A more thorough evaluation of this application should be conducted for potential introduction to the industry. Nanofiltration retentate containing 15% lye can be transported off-site for disposal. This would cost $38,800 per year and reduce the salts by a further 240 tons.

Table 94: Cost Analysis of Nanofiltration of Lye Peeler Overflow

System Parameters	
System capacity (gpd)	18,000
Solution recovery (gpd)	16,000
Capital investment ($)	$300,000
Electric power (kW)	30
Hours of operation (hours/day)	24
Days of operation (days/year)	75
Caustic (10%) recovery (gal/year)	1,200,000
Salt reduction (tons/year)	626
Expenses ($/year)	
Capital recovery (10 years @12%)	53,100
Energy cost (54,000kWh @ $0.13)	7,020
Membrane cost ($20,000 every 2 years)	10,000
Cleaning (lump sum)	4,000
Total operating costs	**74,120**
Potential Benefits ($/year)	
Chemical Saving (240,000 gal 50% @ $2.03)	487,200
Net annual operating cost	**-413,080**
Net annual Operating cost ($/ton of salt)	**-660**

It is possible to recover more lye using nanofiltration since another 17,072 gallons of make-up water to the dip tank can be replaced by NF treated spent lye, possibly with 0.9% lye rinse. However, if the present one pass rinsing system can be modified by a countercurrent rinse system (similar to Figure 36) it may be possible to further increase the lye recovery potential significantly.

D. *Emerging Technologies for Salt-Water Separation*

1. Seeded Reverse Osmosis

Hardness of water caused by salts of the divalent metals, calcium and magnesium, is a major problem in separation of salts from water because they tend to precipitate on heat exchangers and membrane during concentration. Hardness is removed by chemical softening, ion exchange or reduced by acidification to overcome this difficulty. Seeding the hard water with nuclei of the hardness causing compounds provides preferential sites for precipitation when solubility limits are exceeded and prevents precipitation on external surfaces. This principle of seeding can be employed in evaporation or in reverse osmosis.

Seeded evaporation was commercialized in the 1970's and there are over 100 industrial plants currently in operation.[151] Some of these are very large ZLD plants reaching 5 million gallons per day capacity. Seeded reverse osmosis trials lasting over 6,000 hours without membrane cleaning has been reported[152] but it has not become an industrial reality. Seeded reverse osmosis requires membrane modules that can withstand high pressures and can accommodate suspended solids (crystals). At present only tubular modules meet these requirements. The high cost of these modules is one reason for the slow progress of this technology.

The specific energy consumption of seeded reverse osmosis is estimated at about 30 kWh/kgal. The comparative figure for seeded evaporation is about 80 kWh per kgal. Therefore, seeded reverse osmosis has the potential to become an integral part of ZLD treatment systems in relatively small applications like food plants.

2. Bipolar Electrodialysis

Bipolar electrodialysis membrane, also called water splitting membrane produces H^+ and OH^- ions from water by the passage of a DC current. In a typical three compartment arrangement, one BP membrane is placed between the cation membrane and the cathode and another between anion membrane and the anode (Figure 39).

When brine containing salt MX and water are passed through the compartments as shown, and a DC current is passed across the membranes, H^+ ions from the BP membrane and X^- ions from anion membrane accumulate in the compartment in between and form acid HX. OH^- ions from the BP membrane and M^+ ions from cation membrane accumulate in the compartment in between and form base MOH. The net result of this process is producing an acid and a base from a salt. A typical commercial unit consists of over 100 compartments.

This technology became successful after the development of low resistance bipolar membranes. Its industrial applications include production of organic acids like succinic acid. Using this process potassium bitartrate removed during tartrate stabilization of wines and grape juice can be used to produce tartaric acid and potassium hydroxide. It is claimed that about 5% acid and base

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[151] Anonynous. 2007. Industrial Wastewater Recycling. GE Water and Process Technologies, RCC Thermal Products. 3006 Nortrup Way, Bellevue, WA 98004.

[152] Harries, R. C. 1985. A field trial of seeded reverse osmosis for the desalination of a scaling type mine water. Desalination, 56; 227-236.

concentrations can be achieved under industrial conditions. Tartaric acid can be used for pH adjustment of wines and KOH can be used in plant cleaning in wineries. At the prevailing high costs of KOH (~$0.32 per lb) even short distance transport of these chemicals for use at other food plants may be cost effective.

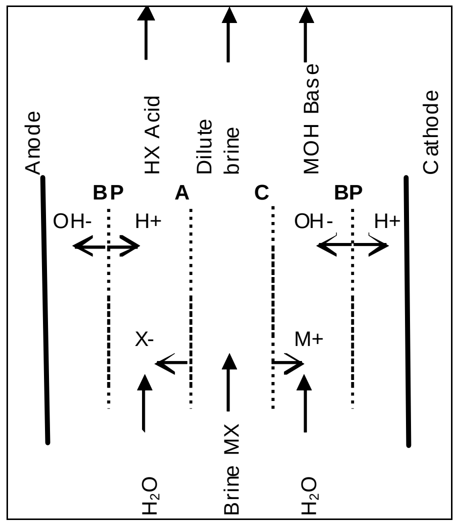


Figure 39

The variations of bipolar ED include two compartment cation cells and two compartment anion cell. The two compartment cation cell employs a BP membrane with only a cation membrane and converts a salt of a weak acid into a base stream and a mixed acid-salt stream. This can be used to stabilize wines where pH adjustment is also necessary. In practice it does tartrate stabilization and pH adjustment in one step. This process was demonstrated in a central valley winery.[153]

3. Capacitive Deionization Technology (CDT)

A brackish water stream flows between pairs of high surface area carbon electrodes that are held at a potential difference of about 1.2 Volts. The ions and other charged particles are attracted to one another and held on the electrode of opposite charge. Eventually, the electrodes become saturated with ions and require regeneration. The applied potential is removed, and since there is no longer any reason for the ions to remain attached to the electrodes the ions are released and flushed from the system, producing a more concentrated brine stream. In practice, about 80% of the feed volume is recovered as deionized potable water, and the remainder is discharged as a concentrated brine solution containing virtually all of the salts in the feed.

[153] Dahlberg, Eric T, Domingo Rodriguez, Carl O. DiManno, (Winesecrets) 2006. Electrodialysis Systems for Tartrate Stabilization of Wine California Energy Commission, PIER Energy-Related Environmental Research, Industrial/Agricultural/Water End-Use Energy Efficiency, CEC-500-2002-009

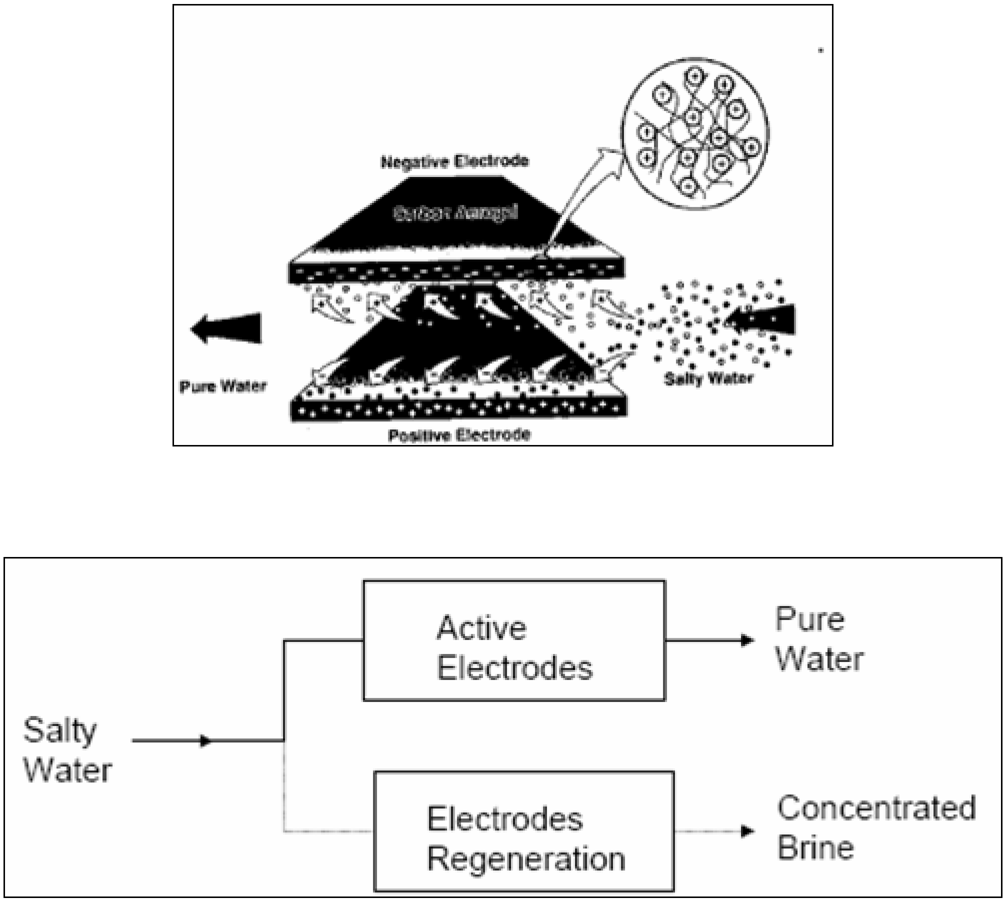


Figure 40

CDT Systems, Inc. located in Dallas, Texas is solely dedicated to the commercialization of CDT and has its first demonstration plant up and running in Carlsbad, California. CDT Systems has licensed the original Lawrence Livermore National Laboratory patent on CDT (Farmer, 1995), as well as several Livermore patents on methods for making the electrodes.

4. Electrodeionization (EDI)

Electrodeionization is based on ion exchange resins used in conventional mixed bed ion exchange. It separates anions and cations from feed water, yielding high-purity product water. The conventional ion exchange process requires chemical regeneration using acids and alkali when the resin becomes fully loaded with ions. Electrodeionization eliminates chemicals by regenerating the resin by a water splitting process. An electric potential is applied across the EDI modules' two electrodes. EDI also uses ion selective cation and anion membranes to form alternating concentrate and dilute chambers. A typical EDI device consists of a mixed ion exchange resin compartment separated from the concentrate chambers by ion selective cation or anion membranes. The membranes are constructed of a polystyrene based material, similar to resin. Development of compact spiral modules and use of concentrate recycle to reduce electrical resistance have helped reduce the cost of this technology and make it competitive with established technologies.

5. Ion Exchange

Water softening is the most common ion exchange process. In this process calcium and magnesium ions that cause hardness in water are exchanged for sodium ions, thereby softening water. The reverse of this concept can be used to remove sodium chloride from saline water. The water containing NaCl is passed through a mixed bed of ion exchange resins. The cation exchanger is in calcium form and anion exchanger is in the hydroxide form. Sodium exchanges for calcium and chloride exchanges for hydroxide.[154]

Cation: $R_2 Ca + 2 Na Cl = 2 R Na + Ca Cl_2$

Anion: $2 R OH + Ca Cl_2 = 2 R Cl + Ca (OH)_2$

Calcium hydroxide formed in the process remains in solution or precipitates depending on concentration. The precipitated calcium hydroxide is easily separated by filtration. The spent resin is regenerated by passing a solution or a suspension of calcium hydroxide. The spent regenerant is a solution of sodium chloride, concentrated at least ten-fold.

6. Freeze concentration

The latent heat of evaporation of water is about 972 Btu/lb (at 212 ^oF) and latent heat of freezing is only 144 Btu/lb (at 32 ^oF). Therefore, freezing has an energy advantage over evaporation even after allowing for the higher value of electricity over thermal energy. Freeze concentration has been developed as an industrial unit operation to exploit this advantage and the higher quality of separated fractions. However, high cost of equipment is an obstacle for wider adoption of this technology. A freeze concentration process involves equipment for refrigeration, freezing, ice crystal separation and heat exchangers to improve efficiency. About 50% solute concentration is possible according to equipment manufacturers.

7. Eutectic Freeze Crystallization

Eutectic freeze crystallization (EFC) is an energy efficient process for the separation of a salt solution into salt and water. This emerging separation process is best illustrated using Figure 20 which is a typical phase diagram of the salt water system. When a salt solution is cooled from point A to Point B, ice begins to form and separates from the solution. This increases the concentration of the solution to point C and eventually to point D. This is called the 'eutectic point' where the solution is saturated with salt. When it is cooled further, ice and salt crystals form separately.

[154] National Canners Association. 1971. Reduction of Salt Content of Food Processing Liquid Waste Effluent. Water Pollution Control Research Series, Environmental Protection Agency, Water Quality Office. Publication 12060 DXL 01/71

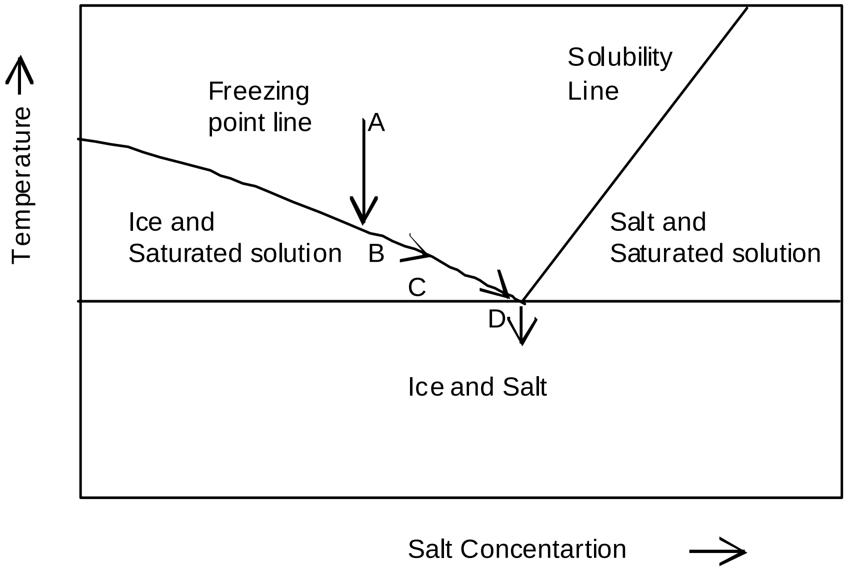


Figure 41

These solid phases are then separated utilizing the density difference between the phases. The ice crystals are washed and melted to produce pure water, and the salt crystals are filtered to produce pure crystals. Figure 21 is a flow diagram of this process. A practical process will involve several internal heat exchangers to improve the energy efficiency. The theoretical energy requirement of single stage EFC process for the separation of NaCl from water is listed in Table 95 as a function of NaCl concentration of the feed solution.

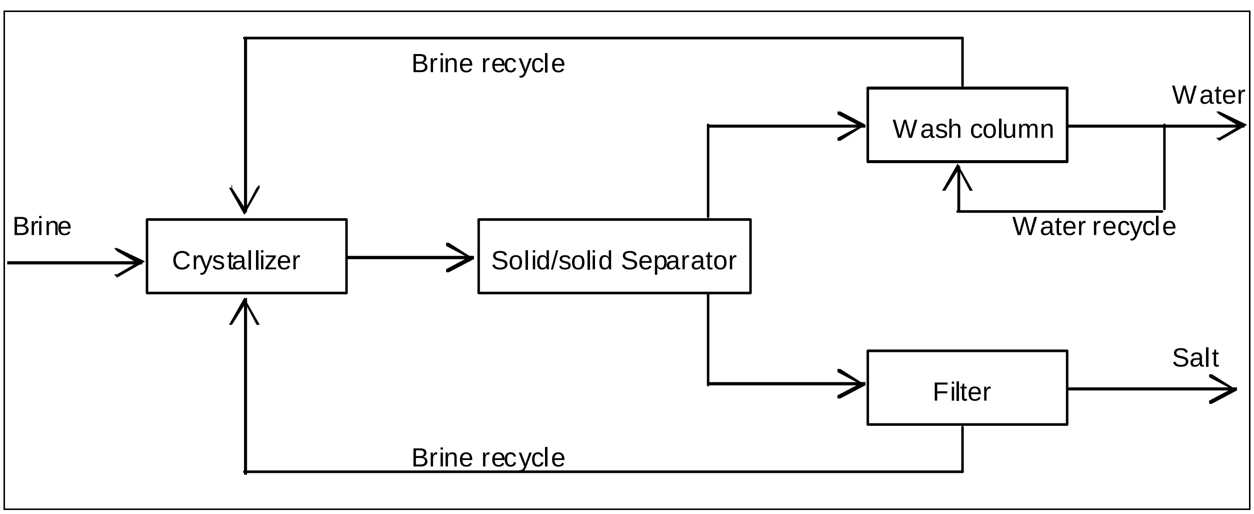


Figure 42

Table 95: Theoretical Energy Requirement of Single Stage EFC Process

Concentration of NaCl in feed (%)	5	10	15	20
Energy consumption (Btu/lb of salt)	1,032	473	301	258

The energy efficiency of the EFC process is favorable compared to competing technologies like evaporation and drying. It also has the advantage of separating salts as a solid product. However, EFC technology is still in the developmental stage. It may be several years before it becomes an industrial process. The capital cost of equipment is expected to be relatively high.

8. Spray Solar Evaporation

Evaporation for a body of water is proportional to the exposed surface area. Therefore, increasing the surface area is a very effective method of increasing evaporation from ponds. Sprays, sprinklers and showers increase the surface area many fold compared to a horizontal surface. Operation of a pilot-scale solar evaporator demonstrated (Faria et al) that it could enhance evaporation up to 3.3 times the normal pan evaporation rate using 1.5 ft high fan sprinklers with minimum salt drift. Evaporation rates could be increased further by raising the height of the fan sprinklers in conjunction with using a tree barrier to help control salt drift. The results of these trials could be used to develop simple and efficient solar evaporators for management of brine effluents from desalting operations. Successful application of this approach could reduce the cost of solar evaporation ponds significantly.

9. Developmental Status of Emerging Technologies

The emerging technologies described in this section are at different stages of development. Some are still in bench testing while others are commercially available. Table 96 provides a summary of developmental status.

Table 96: Developmental Status of Emerging Technologies

	Technology	Developmental Status
1	Seeded reverse osmosis	Pilot tested – some time ago
2	Bipolar electrodialysis	Commercially available
3	Capacitive deionization	Prototype plant
4	Electrodeionization	Commercially available
5	Ion Exchange	Pilot tested – some time ago
6	Freeze Concentration	Commercially available
7	Eutectic freeze crystallization	Bench testing
8	Spray solar evaporation	Pilot testing

E. Summary and Suggestions

A detailed evaluation of a technology portfolio for the in-plant measures for the reduction of salt discharges from food processing plants was conducted in this study. Major point sources of salt in food processing were identified as supply water, boiler feed water treatment, product loss, and cleaning and processing chemicals. The technology portfolio comprised reverse osmosis, electrodialysis, softening, evaporation ponds, seeded evaporation, crystallization, spray drying for supply water and boiler feed water, reverse osmosis, microfiltration, nanofiltration and evaporation for food loss and cleaning and processing chemicals.

An integral part of the study was estimating the cost of treatment using these technologies. Vendors and users of technology provided capital and operating cost estimates. The study reports realistic estimates for representative cases based on the information provided by these sources. Actual capital and annual operating costs at a given plant are highly plant specific, depending on characteristics of the source and plant-specific costs of infrastructure, pretreatment and post treatment.

In supply water treatment, recovering about 80% of the volume by concentrating the salts to the remaining 20% volume of brine seems to be relatively straight forward. It is desirable to reduce the brine volume further to reduce cost of brine disposal. This step was found to be one of the costliest of the treatment train. The developed technologies evaluated were generally meant for much harsher sources like cooling tower blowdown from power plants.

Electrodialysis is a long established process of salt separation and the costs are competitive with reverse osmosis. It is claimed to be more tolerant of silica which requires costly softening treatment in the HPRO approach evaluated.

Boiler feed water treatment by low recovery RO was evaluated. It is also possible to use high recovery RO for this purpose. The selection depends on the overall salt reduction plan of the plant. Tomato plants and milk processing plants often have large evaporators. The evaporator condensate can be used as boiler feed water with proper pre-treatment. This is a more cost effective method of reducing salt compared to RO treatment of supply water.

An attempt was made to normalize the cost of treatment technologies for comparison purposes. Normalization with respect to volume of water separated was preferred over weight of salt separated because the latter was affected heavily by the concentration of the starting source. A summary of normalized results is listed in Table 97. The energy consumption numbers in this table should be compared with the theoretical thermal energy requirement of 8.7 MMBtu per kgal of water evaporated.

Table 97: Energy and Cost Comparison of Selected Salt Separation Technologies

	Energy Consumption per kgal			*Cost*
	Electrical kWh	**Thermal MMBtu**	**Total MMBtu-eq**	**$/kgal**
Low Pressure RO	2.49		0.027	1.37
HERO	8.89		0.095	11.5
Electrodialysis	1.60		0.017	1.20
Evaporation Ponds				27.62
Seeded Evaporation	80		0.856	28.90
Crystallization	250		2.675	145.40
Spray Drying	115	15.5	16.731	172.30
Evaporator - 5effect	23.8	2.6	2.855	24.80

The tomato, milk, wine and meat industry sectors were selected for FDS analysis of representative plants. Absence of salt accounts was a major obstacle in preparing accurate FDS and cost analyses.

The FDS analysis presented for the industries indicate that the 300 mg/L added FDS limit may be achieved by most of the plants with only in-plant measures. Two exceptions were tomato plants using lye peeling and a rendering plant. A strategy for partial recovery of spent lye was presented. It may be possible to extend this strategy to increase lye recovery further and bring the added FDS below 300 mg/L. We did not have access to salt account from rendering plants to propose any possibilities.

Most of the plants may be able to achieve zero added FDS limit by ZLD treatment of the supply water. Interestingly, this strategy works better for plants receiving high FDS supply water because of high margins for FDS reduction. When supply water FDS is very low, treatment of the end-of-pipe effluent is the last resort for meeting the zero added FDS limit.

The technologies included in the FDS reduction strategy are all proven and are currently in industrial use, as claimed by the vendors consulted during the study.

Notation

EC	electrical Conductivity
FDS	fixed Dissolved Solids
TDS	total Dissolved Solids
BOD	biochemical Oxygen Demand
COD	chemical oxygen demand
COW	condensate of Whey
DMP	dried milk powder
WPC	whey protein concentrate
POTW	publicly owned treatment works
ZLD	zero liquid discharge
IX	ion exchange

Assumptions

All the effluent characteristics listed for tomato, milk, wine and meat processing plants in this section (I.VII) are extracted from wastewater monitoring reports made available by the CVRWQCB, unless stated otherwise. Names of the plants are not mentioned.

1. When FDS is not reported and TDS is reported, FDS = TDS for supply water and biologically treated process effluent. The actual relation may be close to FDS = 0.9 TDS. This assumption likely over estimates FDS in supply water and underestimates added FDS

2. When TDS is not reported and EC is reported TDS (mg/L) = 0.6 EC (uS/cm) for supply water and biologically treated process effluent. This relation is widely used for convenience.

3. When supply water characteristics is not reported for a food plant data from a city or a food plant in close proximity was used.

. When BOD is not reported but COD is, then BOD = 0.6*COD is used to estimate BOD in food processing effluent

5. Production figures are typically not found in the CRWQCB files. Therefore, available norms of gallons of water discharged per ton of commodity processed were used to estimate production figures. These norms were; 920 gal per ton of tomatoes; 1,125 gal per ton of grapes; 360 gal per ton of milk, 1,710 gal per ton of poultry, 2,460 gal per ton of meat.

In tables throughout the text italics are used when data is synthesized using any of these assumptions.

III.6 POTW Salinity Management

An alternative for post-facility management of food processing wastewaters is collection of the wastewaters for treatment at one or more existing municipal wastewater treatment plants, also known as Publicly Owned Treatment Works (POTW). This section compares POTW treatment to treating the same wastewaters at a new, centralized, treatment facility dedicated to food processing wastewater. As with the other sections of this report discussing salinity management alternatives, this section provides conceptual-level descriptions and cost relationships to enable comparisons with other potential types of solutions, and does not recommend any “preferred alternative” for the Representative Area (lower San Joaquin River Basin) or the Study Area (San Joaquin Valley).

A. POTWs in the Representative Area

There are 16 POTWs in the Representative Area, as shown on Figure 43. Most of the facilities are associated with relatively small towns and service areas, and the Modesto and Turlock POTWs are the area’s two largest plants. Key information for each existing POTW is provided in Table 94.

Table 98

Existing POTW	Address	City	NPDES and/or WDR Status	Regional Water Quality Control Board Office	Design Capacity (MGD)	Average Effluent Flow (MGD)
Ceres WWTP	4200 Morgan Rd.	Ceres	WDR	Sacramento	N/A	N/A
Delhi	N/A	N/A	WDR	Fresno	N/A	N/A
Escalon WWTP	25100 West River Rd.	Escalon	WDR Order 5-00-142	Sacramento	N/A	Domestic: 0.65 Industrial: 1.6
Gustine WWTF	26501 Carnation Rd., #W	Gustine	WDR Order 96-193	Fresno	1.2	1.0
Hilmar	N/A	N/A	WDR	Fresno	N/A	N/A
Hughson WWTP	6700 Leedom Rd.	Hughson	N/A	Sacramento	0.8	0.73
Livingston Industrial WWTP	N/A	Livingston	WDR Order 79-209	Fresno	N/A	3.0
Modesto WQCF	1221 Sutter Ave. and 7007 Jennings Rd.	Modesto	Major NPDES and WDR Order 5-01-120	Sacramento	63 (primary clarifiers)	26.3
Newman WWTP	600 Hills Ferry Rd.	Newman	WDR Order 98-163	Sacramento	N/A	0.68
Oakdale WWTP	9700 Liberini Ave.	Oakdale	N/A	Sacramento	2.4	1.77
Patterson WWTP	14901 Poplar Ave.	Patterson	WDR Order 5-00-146	Sacramento	N/A	0.96
Ripon WWF	1220 Vera Ave.	Ripon	WDR Order 94-263	Sacramento	N/A	Domestic: 1.12 Industrial: 0.15
Riverbank WWTF	23865 Santa Fe Rd.	Riverbank	WDR Order 94-100	Sacramento	N/A	Domestic: 1.3 Seasonal Cannery Waste: up to 4
Salida WWTP	6100 Pirrone Rd.	Salida	WDR	Sacramento	N/A	1.52
Turlock WWTP	901 S. Walnut Rd.	Turlock	Major NPDES and WDR 5-01-122	Sacramento	20	10.3
Waterford WWTP	335 S. Western Ave.	Waterford	WDR	Sacramento	N/A	N/A

Notes:

1. Information obtained from the California Integrated Water Quality System (CIWQS) website (http://ciwqs.waterboards.ca.gov/ciwqs) on May 31, 2007.
2. USEPA Classification System defines "Major Dischargers" as municipal wastewater treatment plants (WWTP) with flows ≥ 1 million gallons per day (MGD) and those with pretreatment programs.
3. Modesto WQCF information obtained from City of Modesto's Wastewater Master Plan, Phase 2 Update, Master Plan Report. March 2007, prepared by Carollo Engineers.
4. N/A: Not available

Existing POTW	Domestic Wastewater Influent (% of flow)	Food Processor Wastewater Influent (% of flow)	Other Wastewater Influent (% of flow)	Tributary Food Processors	Service Area	Segregation of Process Streams	Average Influent TDS (mg/L) (or FDS or EC)
Ceres WWTP	N/A	0%	N/A	None	City of Ceres	N/A	N/A
Delhi	N/A	0%	N/A	None	N/A	N/A	N/A
Escalon WWTP	24%	56%	0%	Escalon Premier Brand; Ekert Cold Storage	City of Escalon	Yes	N/A
Gustine WWTF	N/A	55%	N/A	Two milk processing facilities (Morningstar West and Beatrice Cheese Company); Hillview Packing; Valley Gold	City of Gustine	No	N/A
Hilmar	N/A	0%	N/A	None	N/A	N/A	N/A
Hughson WWTP	N/A	50%	N/A	Dairy Farmers of America, Inc.	City of Hughson	No	N/A
Livingston Industrial WWTP	0%	100%	0%	Foster Farms exclusively	City of Livingston	No	N/A
Modesto WQCF	N/A	24%	N/A	Foster Farms; Gilroy; Kraft; Signature; Gallo Winery; Stanislaus Food Products; Tri Valley Plants 1, 7, and R; Del Monte; Recot Manufacturing	City of Modesto and Community Service District of Empire	Yes	870 mg/L TDS
Newman WWTP	N/A	60%	N/A	F&A Dairy; Leprino Foods	City of Newman	N/A	N/A
Oakdale WWTP	N/A	19%	N/A	Hershey	City of Oakdale	N/A	N/A
Patterson WWTP	N/A	0%	N/A	None	City of Patterson	N/A	N/A
Ripon WWF	88%	12%	0%	Nulaid	City of Ripon	Yes	N/A
Riverbank WWTF	84%	16%	0%	Tomato canneries (names N/A)	City of Riverbank	No	N/A
Salida WWTP	N/A	3%	N/A	Alliance Foods; Michael Angelos	City of Salida	N/A	N/A
Turlock WWTP	N/A	44%	N/A	Valley Fresh	City of Turlock; Community Service Districts of Keyes and Denair	N/A	N/A
Waterford WWTP	N/A	0%	N/A	None	N/A	N/A	N/A

Notes:

1. Information obtained from the California Integrated Water Quality System (CIWQS) website (http://ciwqs.waterboards.ca.gov/ciwqs) on May 31, 2007.
2. USEPA Classification System defines "Major Dischargers" as municipal wastewater treatment plants (WWTP) with flows ≥ 1 million gallons per day (MGD) and those with pretreatment programs.
3. Modesto WQCF information obtained from City of Modesto's Wastewater Master Plan, Phase 2 Update, Master Plan Report. March 2007, prepared by Carollo Engineers.
4. N/A: Not available

Existing POTW	Treatment Process	Average Effluent TDS (mg/L) (or FDS or EC)	Current TDS or EC Effluent Limit	Effluent Disposal Method (surface water, land application, evaporation ponds, reuse, other)
Ceres WWTP	N/A	N/A	N/A	N/A
Delhi	N/A	N/A	N/A	N/A
Escalon WWTP	Screening and discharge to mechanically aerated treatment ponds.	Domestic: 412 Industrial: 575	N/A	Percolation/Evaporation Ponds
Gustine WWTF	Bar screen, two aerated ponds, nine oxidation ponds, six marsh cells, and chlorine disinfection and dechlorination units.	2,044	N/A	Land Application
Hilmar	N/A	N/A	N/A	N/A
Hughson WWTP	Screening/grit removal, extended aeration activated sludge treatment, secondary clarification, sludge drying, and optional chlorination of treated effluent.	593	N/A	Percolation/Evaporation Ponds
Livingston Industrial WWTP	One aerated lagoon and eight stabilization ponds for final disposal.	N/A	N/A	Land Application
Modesto WQCF	Preliminary screening, grit removal, primary clarifiers, anaerobic digesters, sludge-drying beds, fixed-film reactors, recirculation channel, facultative ponds, disinfection.	502 mg/L TDS	924 mg/L TDS (daily maximum)	Land Application & River Discharge
Newman WWTP	Bar screen, two aeration basins, an oxidation pond, overland flow slopes, an irrigation storage reservoir, irrigation system, and an irrigation tailwater return system.	1,998	N/A	Land Application
Oakdale WWTP	Two aerated lagoons for primary treatment, secondary clarifier.	373	N/A	Percolation/Evaporation Ponds
Patterson WWTP	Aeration pond, extended aeration oxidation ditch, clarifiers, chlorination, and dechlorination.	1,158	N/A	Percolation/Evaporation Ponds
Ripon WWF	Grinders, 15 acres of treatment ponds for BOD reduction. The industrial wastewater flows do not receive any treatment before being disposed to the sixteen-acre industrial wastewater percolation area.	Domestic: 675 Industrial: 1532	N/A	Percolation/Evaporation Ponds
Riverbank WWTF	Aeration and ponding.	492 (FDS)	N/A	Pond Disposal
Salida WWTP	Imhoff tank, aeration tank, four facultative lagoons, two sequential batch reactors (SBR), sludge drying beds, and six rapid infiltration basins.	509	N/A	Rapid-infiltration Basin (RIB) & Land Application
Turlock WWTP	Initial screening, dissolved air flotation with grit removal, anaerobic and aerobic digesters, sludge drying beds, activated biofilter (ABF) towers, activated sludge, and final clarification with disinfection by chlorination followed by dechlorination.	578	N/A	River Discharge (Harding Drain to San Joaquin River)
Waterford WWTP	N/A	N/A	N/A	N/A

Notes:

1. Information obtained from the California Integrated Water Quality System (CIWQS) website (http://ciwqs.waterboards.ca.gov/ciwqs) on May 31, 2007.

2. USEPA Classification System defines "Major Dischargers" as municipal wastewater treatment plants (WWTP) with flows ≥ 1 million gallons per day (MGD) and those with pretreatment programs.

3. Modesto WQCF information obtained from City of Modesto's Wastewater Master Plan, Phase 2 Update, Master Plan Report. March 2007, prepared by Carollo Engineers.

4. N/A: Not available

Existing POTW	Other Notes
Ceres WWTP	-
Delhi	-
Escalon WWTP	The industrial dischargers' processing season is from approximately May through December. The industrial dischargers presently screen their wastewater to remove solids prior to discharge to the WWTP.
Gustine WWTF	The WWTF completed a master plan in 1995 to upgrade and expand the capacity of its existing WWTF in phases from its current capacity of 1.2 MGD to 2.5 MGD to accommodate industrial and non-industrial wastewater flows through the year 2014. The WWTF proposed to eliminate its current year-round direct discharge to its agricultural drainage ditch and instead discharge seasonally to 220 acres of adjacent grassland for pasture of non-milking animals and nesting bird habitat. The proposed reuse area is adjacent to and southwest of the WWTF, between Carnation Road and Gun Club Road.
Hilmar	-
Hughson WWTP	The City of Hughson plans to develop and implement a pre-treatment program for its tributary food processor to control potential shock loadings.
Livingston Industrial WWTP	Treated effluent from the facility is also reclaimed and utilized by Foster Farms for seasonal irrigation on fodder crops.
Modesto WQCF	Pre-treatment for industrial discharges is implemented by the City of Modesto.
Newman WWTP	Treated wastewater is discharged to land for reuse as irrigation. Land discharge is accomplished by the overland flow system on 58 acres and the irrigation area of 240 acres. Fiber and fodder crops are grown on the reuse acreage. The WWTP's 29-acre storage reservoir is also used to accumulate effluent during the winter months for summer irrigation. The irrigated reuse area has a tile drain to reduce salt buildup and protect the root zone. The effluent is high in electrical conductivity (EC). The City has adopted local industrial limits on EC.
Oakdale WWTP	-
Patterson WWTP	The City has not discharged treated effluent to the San Joaquin River since 1983 and with proposed expansion of its land disposal facilities, it will have sufficient capacity to continue with full land disposal in the future. The City proposed the construction of an Advanced Integrated Pond System (AIPS), which is designed for a capacity of 0.5 mgd, and the construction of 40 acres of new percolation/evaporation ponds for final disposal of treated effluent.
Ripon WWF	The wastewater influent flows are typical of a small community, containing primarily domestic sewage from residential and support services. Industrial influent flow is from Nulaid. Nulaid's 60,000-gpd flow consists primarily of washwaters containing a light caustic solution for cleaning raw eggs prior to packaging.
Riverbank WWTF	The City of Riverbank wastewater treatment plant is adjacent to the Stanislaus River. The City discharges 1.3 million gallons per day of domestic waste and discharges seasonally 4.0 million gallons per day of cannery waste to evaporation/percolation ponds. Future cannery waste is not expected to exceed 5.0 million gallons per day. The cannery processes tomatoes from July through October. Industrial and domestic waste is combined for treatment.
Salida WWTP	Excess from RIBs is land-applied over 378 acres of peaches, 106 acres of almonds, and 91 acres of row crops and unused land.
Turlock WWTP	Facilities also include a 37.2-MG earthen emergency storage basin, which allows diversion and storage of primary effluent if necessary. Biosolids generated are reused in agricultural land application and for agricultural distribution.
Waterford WWTP	-

Notes:

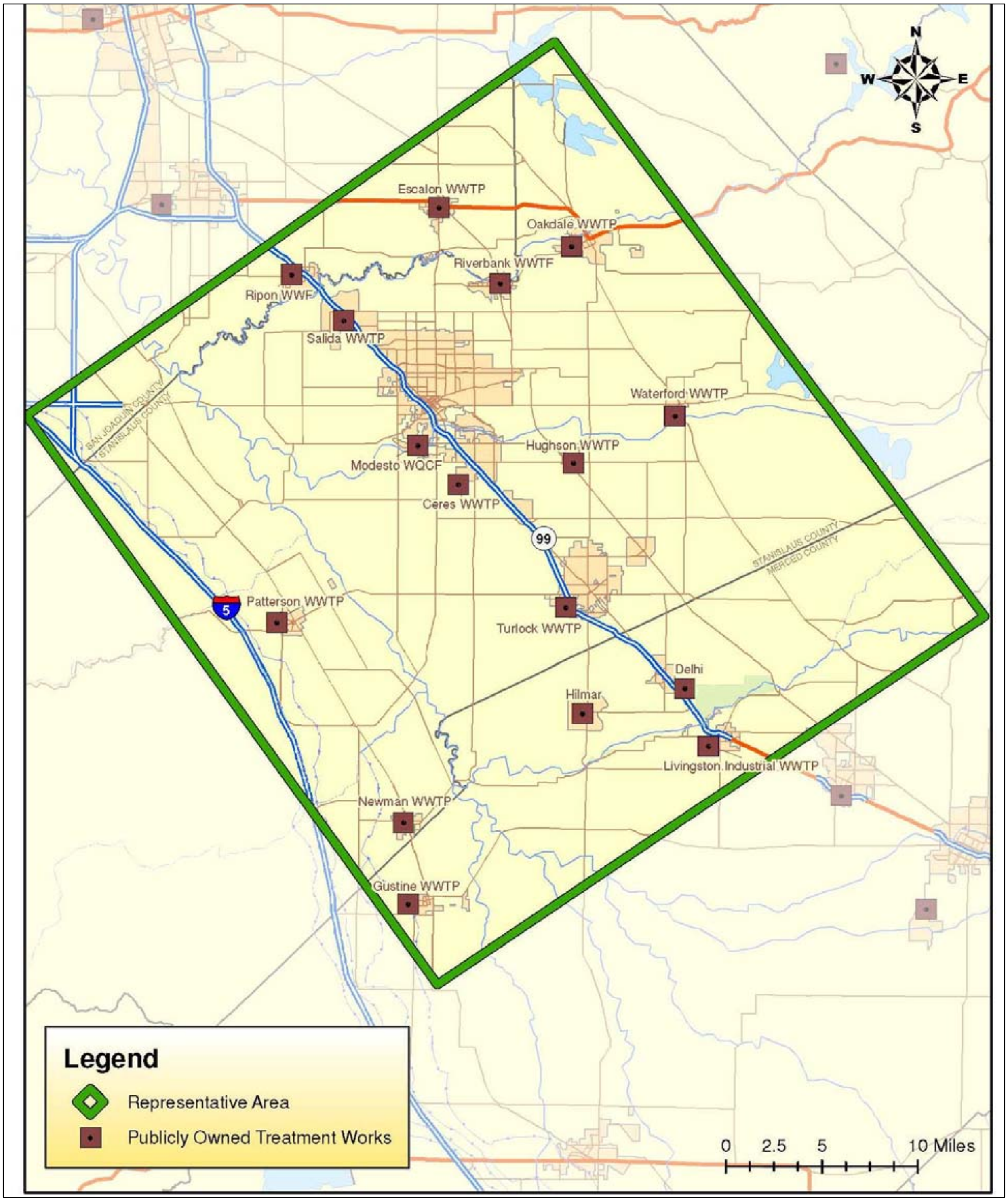
1. Information obtained from the California Integrated Water Quality System (CIWQS) website (http://ciwqs.waterboards.ca.gov/ciwqs) on May 31, 2007.

2. USEPA Classification System defines "Major Dischargers" as municipal wastewater treatment plants (WWTP) with flows ≥ 1 million gallons per day (MGD) and those with pretreatment programs.

3. Modesto WQCF information obtained from City of Modesto's Wastewater Master Plan, Phase 2 Update, Master Plan Report. March 2007, prepared by Carollo Engineers.

4. N/A: Not available

Although most (11 of 16) of the plants already accept some degree of food processing wastewater, none of them has technology designed to treat for salinity/TDS, that is, to remove dissolved constituents from wastewater. Also, as shown in Table 94, 5 of the 16 POTWs do not receive any food processing wastewater, the influent at 1 of the 16 POTWs is made up entirely of food processing wastewater, and the influent to the remaining 10 POTWs consists of between 24% and 60% food processing wastewater. On a simple average basis (used because design capacities and average flow rates were not available for all Representative Area POTWs), 27% of the Representative Area's POTW influent flows are made up of food processing wastewater.



N
W
E
S
Escalon WWTP
Oakdale WWTP
Riverbank WWTF
Ripon WWF
Salida WWTP
Waterford WWTP
SAN JOAQUIN COUNTY
STANISLAUS COUNTY
Hughson WWTP
Modesto WQCF
Ceres WWTP
99
STANISLAUS COUNTY
MERCED COUNTY
5
Patterson WWTP
Turlock WWTP
Delhi
Hilmar
Livingston Industrial WWTP
Newman WWTP
Gustine WWTP
Legend
Representative Area
Publicly Owned Treatment Works
0 2.5 5 10 Miles

Figure 43

B. Typical treatment technologies of existing POTWs

Treatment technologies in place at the Representative Area POTWs are typical for plants designed primarily for domestic/municipal wastewaters, and are focused on reduction of key domestic wastewater strength/quality parameters such as Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) to acceptable concentrations for discharge to land, receiving waters, or via an alternative disposal method.

Therefore, in order to utilize existing POTWs to achieve removal or reduction in salinity from food processing wastewater, one or more technologies to remove salt from water would need to be deployed at the POTW(s) of interest in the Representative Area. Effluent standards for Total Dissolved Solids (TDS) or Electrical Conductivity (EC) were only available for one of the 16 POTWs, the Modesto Water Quality Control Facility (WQCF), in the Representative Area, as indicated in Table 1.

TDS is used throughout this section to represent salinity and not Fixed Dissolved Solids (FDS) or other parameter because:

1. TDS is the basis of the Modesto WQCF's current effluent salinity limit.
2. TDS is generally the basis for available desalination technology performance information.
3. TDS data is available for all Representative Area food processing facilities used in this section, whereas FDS data is only available for 6 of the 11 facilities.[155]

The purpose of the desalination technologies discussed in this section and throughout this report is to remove dissolved solids from wastewater, not necessarily to address organics or other compounds that in some cases may be reflected in analytical TDS measurements.

This section does not explore every possible combination of food processor, POTW, and technology scenarios, but rather works through a representative infrastructure example and selected possible treatment goal scenarios for illustrative purposes and for consideration along with other post-facility salinity management measures described in this report.

C. Desalination treatment methods and technologies

Desalination refers to any of several treatment processes that can remove salt from water or wastewater streams for portability, environmental, or other purposes. The generalized desalination process is as follows:

1. Water from a water source is pretreated prior to entering one or more parallel desalting process "trains" (sequence of individual processes) in which salt is removed from the

[155] Actual water quality and technology effectiveness are often represented in TDS thus are comparison of technology is made using TDS. Our hydrogeological modeling, however, is conducted using FDS or EC measurements. We recognize that TDS and FDS are not always equivalent.

water.
2. Desalted product water receives post-treatment, as appropriate for the application, is stored, and pumped to the distribution system.
3. The salts and other residuals separated out of the feed water in the desalting process are discharged to waste as a concentrate. (If needed for the specific application, the concentrate may be further treated to allow disposal.)

Desalination technologies can be divided into two major categories based on the underlying mechanism for removing salt ions from water: (1) membrane processes and (2) thermal processes.

Membrane processes use either electrical forces or mechanical forces (pressure) for the separation process. Membranes are used in the two available desalting processes for drinking water treatment and brine treatment: reverse osmosis (RO) and electrodialysis reversal (EDR). Both of these processes use membranes to selectively separate salts and water, but use different driving forces. RO uses pressure to separate water and salts by inducing some of the feedwater to move through a membrane that blocks the passage of salts and produces high-purity water ("permeate") while also producing a concentrated salt solution ("reject" or "centrate") that is typically disposed of. EDR employs electrical potential to move salts selectively from the feed water through membranes leaving fresh high-purity water behind as product water, and leaving a concentrated waste stream for disposal.

Thermal processes remove salt ions by causing water to go through a change of phase. Virtually all thermal distillation plants operating today use boiling or evaporation to change water to a gas phase followed by condensation of that gas to a liquid containing only trace concentrations of salts. The distillation/evaporation process (often called simply "evaporation") mimics the natural water cycle in that saline water is heated, producing virtually pure water vapor that is subsequently condensed to form water essentially devoid of salt. The typical thermal desalting process uses external energy, often in the form of steam from an electric power generating station, to heat the incoming water (for thermal desalting, typically seawater) to its boiling point. The temperature necessary to boil seawater is lower at pressures below sea-level atmospheric. By reducing the boiling point, less energy is needed to boil the water, and multiple boiling steps (evaporative effects) can be utilized within thermal desalination plants. All three available thermal desalting processes—multi-stage flash (MSF), multiple-effect distillation (MED), and vapor compression (VC)—use these principles. Other, less common thermal technologies include thermo-compression and solar distillation.

While the more commonly used desalination technologies include membrane and thermal desalting technologies, other technologies that are capable of removing salts exist, such as ion exchange (IX), demineralization, and freezing; others are in the development process (e.g. capacitative deionization). Many overviews of desalination technologies are available in the literature, for example, *Water Quality and Treatment: a Handbook of Community Water Supplies* and *Water Desalting Planning Guide for Water Utilities*, both produced by the American Water Works Association.

In summary, the available desalination technologies include:

- Membrane Processes
  - Reverse Osmosis (RO)
  - Electrodialysis Reversal (EDR)
- Thermal Processes/Evaporation
  - Multi-stage flash (MSF)
  - Multi-effect distillation (MED)
  - Vapor compression distillation (VC)
  - Thermo-compression
  - Solar distillation
- Other Processes
  - Ion Exchange (IX)
  - Freezing
  - Capacitative deionization

Worldwide, RO accounts for 46% of global desalination treatment capacity, followed by MSF (36%), ED and VC at 5% each, MED at 3%, and other technologies collectively at 5%. In the US, RO accounts for a higher percentage (69%) of desalination capacity than it does worldwide, with the technologies in place in California being even more predominantly RO. Specifically, RO accounts for 85% of desalination technologies installed in California, followed by other technologies each at 5% or less of installed capacity[156].

In the study team's experience, RO, EDR, and evaporation would be the most feasible potential technologies for the desalination component of the POTW alternatives discussed in this section and for the dedicated treatment plant discussed in Section 1.11 of this report.

For illustrative purposes, and due to the availability of performance and cost information and industry experience with the technology, RO is used in this section. If desalination were to become necessary or desired at any POTW in the Representative Area, a comprehensive technology screening process and alternatives analysis would be necessary prior to planning, design, and construction of such infrastructure. The use of RO for the POTW treatment alternative explored in this section is not intended to "endorse" RO or misrepresent it as the single available desalination technology.

The technologies presented briefly above are discussed in detail in **Section III Appendices: Appendix III.2.**

D. Background groundwater quality and possible treatment goals for POTW desalination treatment

To establish potential POTW desalination infrastructure sizes and configurations, it is necessary to assume future regulatory scenarios or other drivers that would dictate levels of treatment to be

[156] Cooley, H.; Gleick, Peter H.; Wolff, Gary. 2006. *Desalination, With a Grain Of Salt – A California Perspective*. Pacific Institute. June.

achieved. To this end, a range of such scenarios was considered and modeled. To enhance the meaningfulness of this exercise, it was also necessary to choose a Representative Area POTW. The existing Modesto WQCF was selected for this purpose because of its relatively large size, central location in the Representative Area, and availability of recent information (*Wastewater Master Plan, Phase 2 Update, Master Plan Report*, prepared by Carollo Engineers for the City of Modesto, March 2007). Use of the Modesto WQCF for the illustrative purposes of this report is in no way intended to indicate any agreement between that plant and any food processing facility or group of facilities, nor does it imply that any available hydraulic/treatment capacity at the Modesto WQCF would necessarily be available to the food processing industry. Also, the analysis presented in this section does not make any adjustments for treatment upgrade infrastructure or costs as a result of the Modesto WQCF's existing segregated cannery wastewater flow capacity, so that the results of this section may be more readily applied to any POTW in the Representative Area or Study Area.

The potential future scenarios used and their relationship to desalination infrastructure described in this and the subsequent section of this report (Section III.8) are summarized in Table 99. Four discharge limits were selected to collectively provide a range of possible future treatment/effluent quality scenarios—from the "anti-degradation" scenario (assuming a 320-mg/L effluent goal) to a scenario modeled on one POTW's current effluent limit of 924 mg/L of TDS—for infrastructure and cost modeling purposes. Two of the salt discharge limits (320 and 620 mg/L) are related to background groundwater quality, while the two other values (924 and 502 mg/L) are based on current Modesto WQCF effluent permit limit and performance, respectively.

Table 99: Potential Future Treatment/Effluent Quality Scenarios

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	POTW Desalination (Report Section 9B)	Centralized Plant Desalination (Report Section 1.11)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	√	√
Background Groundwater TDS in Representative Area + 300 mg/L	620	√	√
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502	√	√
Background Groundwater TDS in Representative Area	320	√	√

Modesto WQCF information was obtained from the referenced master plan document. Section III.2 develops the background concentration of 320 mg/L indicated in Table 99 is based on data obtained from Annual Consumer Confidence Reports published by public domestic water systems operating in the Representative Area.[157] In brief, it is a weighted average of Representative Area municipal water supply well TDS concentrations. This was determined to be most representative of the groundwater quality in the Representative Area.

Other reasonable methods of calculating a representative background groundwater TDS value to form the basis of the scenarios indicated in this section include (1) simply indicating the TDS in groundwater directly beneath the area of land disposal of the treated wastewater or (2) calculating a weighted average of tributary food processor source water TDS concentrations. In any case, if a treatment/regulatory scenario were to be implemented based on a background groundwater concentration, the method by which that background concentration was determined would need to be specified.

[157] Data was collected from 17 public water systems maintained by the California Department of Health. The 320 mg/L volume is a weighted average of each system's average TDS according to system size.

The option of routing Representative Area food processing wastewater to one or more POTWs without considering the addition of desalination capability was also considered during this study. This scenario is not explored beyond this subsection for two main reasons:

1. It essentially does not represent any difference in net salt load to the Representative Area subsurface compared to the current state. In other words, if an existing food processor relying on land discharge instead discharges its wastewater to a POTW without desalination capability, the same concentration and mass load of TDS will be discharged to the environment. This conservatively assumes that zero TDS removal is achieved at a typical secondary POTW, which is discussed in 9B.6 below.

2. Doing so may jeopardize current permit compliance at a typical POTW, as illustrated by the mass balance and concentration analysis presented for the Modesto WQCF in Table 3. TDS in this Representative Area POTW is regulated according to a daily maximum value, so times of maximum discharge from food processing facilities represent the most likely times for this effluent limit to be exceeded. As shown in the table below, even assuming an annual average flow rate (4.9 MGD) for the food processors instead of their combined 7.2-MGD monthly peak flow results in likely exceeding of the existing Modesto WQCF TDS effluent limit. Additional details on the development of the flows and TDS values indicated in the table are included in Section E and **Section III: Appendix III. 3**.

Table 100: Discharge to POTW with no Desalination Treatment

Parameter	Flow (MGD)	TDS Concentration (mg/L)
Representative Area food processor combined wastewater (averages)	4.9	1,570
Modesto WQCF (averages)	25.8	870
Combined WQCF influent	30.8	979
Projected WQCF effluent (conservatively assuming no TDS removal)		979
Current Modesto WQCF effluent TDS limit (daily maximum)		924

E. Illustrative options for POTW treatment of food processing wastewater in the Representative Area

There are a large number of potential combinations of POTWs and food processors in the regional treatment model discussed in this section, based on the numbers of each type of facility in the Representative Area. To develop the most useful scenario for the illustrative purposes of this section, the following assumptions were made. The scenario developed is depicted in Figure 44. As the figure title indicates, this illustration also applies to the potential centralized dedicated treatment facility discussed in Section III.8 of this report.

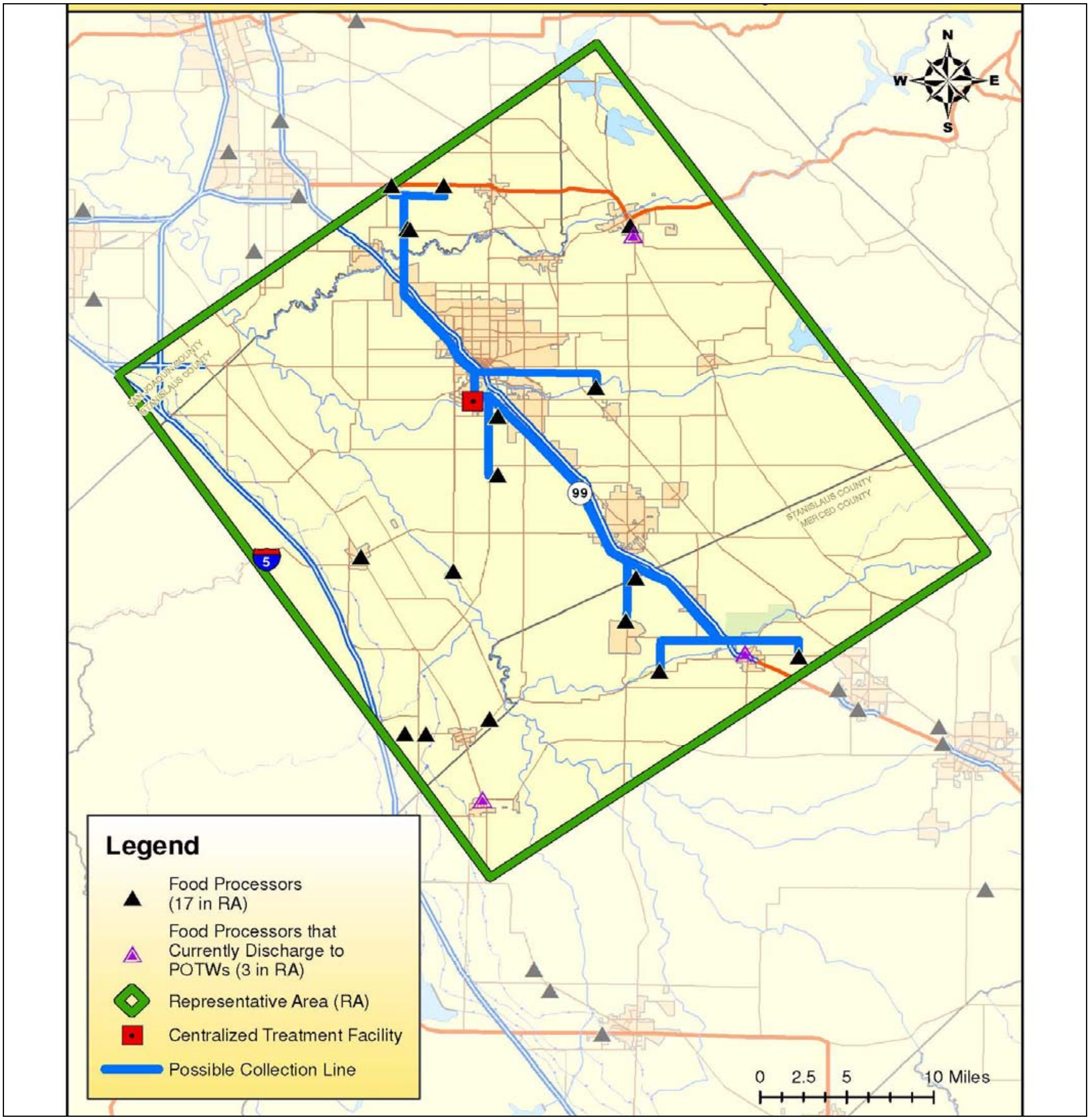


Figure 44

Representative Area

1. Those food processors in the Representative Area currently discharging to a local POTW (there are three such cases based on available information) would continue to do so.

2. A single, centrally located POTW (Modesto WQCF) would receive the wastewaters from the new participants under this scenario.

3. This POTW would receive food processing wastewater from those Representative Area facilities for which it was most reasonable from a geographic perspective; that is, those six processors of the 20 in the Representative Area relatively distant from the Highway 99 corridor not already discharging to local POTWs would not participate in this centrally located POTW alternative under this assumed scenario, as indicated in Figure 44. This assumption is also in general agreement with other sections of this report discussing hydrogeologic modeling, because five of those six facilities are located on or west of the San Joaquin River, outside the Representative Area hydrogeologic model boundaries.

4. As was the case for the brine line alternative, a possible collection system was indicated aligned with Highway 99 and the north-south and east-west orientation of the majority of the secondary roads in the area.

Clearly, many other options exist for using existing POTW locations for receiving and desalinating food processing facility wastewater in the Representative Area. Two others initially illustrated by the study team and discussed with stakeholders were:

1. Routing of each food processor's wastewater to its nearest POTW. This would minimize the amount of new collection system infrastructure needed for the Representative Area, but maximize the number of POTWs that would need to be upgraded with desalination technology.

2. Utilization of both of the two largest Representative Area POTWs for receipt of additional wastewater and desalination upgrades, namely, the Modesto and Turlock POTWs. This would enable the processors located in the northwest and southeast halves of the Representative Area to be served by their nearest respective POTW and reduce the length of collection system infrastructure somewhat, but would also involve desalination upgrades at two facilities instead of one.

In any case, if POTW desalination were to proceed for the Representative Area, or for the Study Area (San Joaquin Valley) as a whole, a detailed alternatives analysis would be necessary to determine the optimum configuration based on cost and other factors. For the purposes of this section, and to facilitate comparison to a single new, centralized treatment facility described in Section III.8 of this report, the configuration indicated in Figure 44 was selected.

F. Treatment criteria, processes, and infrastructure upgrades

To develop infrastructure upgrade sizes and configurations, it is necessary to characterize the influent flow rates and quality, and to define the treatment criteria and processes. The general guidelines in this study were as follows:

1. Continue to meet all present POTW NPDES/WDR treatment requirements and effluent quality limits.
2. Indicate and configure treatment systems necessary to also achieve potential salinity effluent goals indicated in Table 95.

Several specific assumptions were also made to enable the analysis:

1. Zero removal of TDS through a typical secondary-treatment POTW was conservatively assumed, although available process and effluent data from the Modesto WQCF indicates that up to 40% TDS removal may be achieved at that particular facility. This appears to be a function of organic compounds being measured as TDS or EC being removed in Modesto's facultative ponds and/or the secondary biological process. Conservatively assuming a 0% TDS reduction through secondary POTWs like Modesto is appropriate for this study because:

    a. Any TDS removal mechanism in facultative ponds or the typical secondary wastewater treatment process is not well-understood or commonly recognized and may be in part a result of the analytical method used for TDS measurement capturing certain organic compounds in addition to dissolved solids.
    b. It is important to distinguish between unit processes designed for TDS removal and those that may remove TDS as only a side benefit to their main purpose and are therefore much less reliable.
    c. This study is meant to be general enough that the methodology could be applied to any Study Area POTW or group of POTWs, and TDS removal apparent at the Modesto WQCF is not representative of typical secondary POTWs.

2. The design food processing facility flow rate was chosen to be 7.2 MGD, the monthly peak combined flow rate from the facilities assumed to be participating under this scenario, as indicated in the spreadsheets included as **Section III Appendices: Appendix III.3**. This is based on individual monthly food processor facility flow data from years 2003-2005 collected by the study team. Most food processing facilities' flow profiles are quite seasonal, as indicated by the graphs also included in **Section III Appendices: Appendix III.3**, with the highest aggregate flow typically occurring in mid-to-late summer each year and lower flows the rest of the year, particularly in winter. As a result, treatment infrastructure improvements indicated in this report section would be well-utilized during the mid-to-late summer months when most processor facilities are in full operation, but only a portion of their capacity would be used during several months of the year.

3. The example POTW upgrades presented in this report section are based on the treatment necessary to achieve effective and reliable desalination of the combined wastewater flow and strength/quality based on the food processor wastewater database available to the study team. Governing parameters in addition to flow and TDS concentration include BOD, TKN, nitrate, phosphorus, and hardness.

4. The flows indicated for side-stream treatment are the result of mass balance calculations using the example suite of potential future target effluent TDS concentrations indicated in Table 95. Individual steps of this analysis are indicated in the **Section III Appendices: Appendix III.4** spreadsheet. In general, the desired effluent quality (TDS) from any POTW, centralized, or other desalination treatment system is a critical design parameter because it dictates the necessary technology and size of treatment systems as well as reject water disposal options and size (e.g. evaporation ponds).

5. In addition to desired effluent TDS concentrations, the following necessary conceptual performance assumptions were also made:

    a. 99% removal of BOD, typical for membrane bioreactor (MBR) systems.
    b. 90% removal of TDS, typical-to-conservative for reverse osmosis (RO) systems and the TDS concentration ranges of concern for this study.
    c. An RO permeate (treated water) of 75% of flow, and an RO centrate (reject stream) of 25% of flow, typical percentages for RO system production efficiency in the range of TDS concentrations of interest in this study.

Following are a series of tables indicating the information collected and steps to develop the necessary processes and infrastructure needs for achieving the range of desalination targets presented above.

First, the main treatment processes at the example Representative Area POTW were summarized and reviewed for hydraulic capacity to accept an incremental additional flow from additional food processing discharges, as indicated in Table 97. Those processes for which no excess capacity is indicated based on this preliminary analysis (the chlorination/dechlorination, anaerobic digestion, and effluent pumping processes) do not all necessarily need to be hydraulically upgraded were this POTW to accept the additional assumed food processing wastewater, depending on the configuration of the side-stream desalination treatment as discussed later in this section.

Nevertheless, the preliminary analysis indicated in the table shows the importance of performing a hydraulic analysis in addition to addressing treatment/wastewater quality concerns when considering adding new influent streams to an existing POTW. All Modesto WQCF information was obtained from the plant's most recent publicly available wastewater planning document (*Wastewater Master Plan, Phase 2 Update, Master Plan Report*, prepared by Carollo Engineers for the City of Modesto, March 2007).

Table 101: Main Treatment Processes at Modesto WQCF

Existing Processes	*Rated Capacity* Average Dry-weather Flow (MGD)	*Present Usage* Average Dry-weather Flow (MGD)	Peak Wet-weather Flow (MGD)	Available Capacity
Headworks (influent pumps, bar screens, grit chamber)	81	26.3	71.7	Yes
Primary clarifiers[a]	63-126	26.3	71.7	Yes
Biotowers	115	26.3	71.7	Yes
Facultative ponds	115	26.3	71.7	Yes
Chlorination/dechlorination	71.7	26.3	71.7	No
Anaerobic digesters	27 (influent)	26.3	71.7	No
Effluent pump station	70	26.3	71.7	No

a. Utilizing overflow rate of 1000 gpd/sf for average dry-weather flow and 2000 gpd/sf for peak wet-weather flow.

Next, the food processing facilities indicated to be tributary to this POTW alternative were reviewed for wastewater effluent flows and quality, and considered as a single combined new influent stream to the Modesto WQCF as indicated in Table 98. This summary is reflective of the 11 food processors in the Representative Area that do not currently discharge to POTWs and are relatively close to the Highway 99 corridor as discussed earlier. The summary was based on available facility data, which consisted of flow data from years 2003-2005 and wastewater quality data from 2005, in some cases supplemented by pre-2005 data where 2005 information was not available. For one Representative Area processor (a meat processor), facility data was not available, so data from other Study Area facilities in that food processing sector were averaged to represent that facility. Averages indicated for wastewater quality parameters are flow-weighted averages to best reflect the characteristics that would be expected in a combined influent stream to an existing POTW. That is, mass loads were calculated for each of the contributing streams and used to develop a combined stream TDS concentration, instead of an arithmetic average of the facility TDS concentrations, which would not necessarily be representative of the TDS concentration of the combined stream. The monthly peak flow rate of 7.2 MGD indicated was used as the design flow rate for sizing potential new infrastructure, while the average annual flow (when operating) of 4.9 MGD was used to calculate average TDS loadings and removals, as described in later subsections.

Table 102: Summary of Combined Food Processor Effluent Key Parameters

Parameter	Unit	Value (all concentrations are flow-weighted averages)
Average Flow	MGD	4.9
Monthly Peak Flow	MGD	7.2
Total Dissolved Solids (TDS)	mg/L	1,570 (based on a representative year per available 2003-2005 data)
Biochemical Oxygen Demand (BOD_5)	mg/L	1,230
Total Kjeldahl Nitrogen (TKN)	mg/L	60
Nitrate as Nitrogen (NO_3^--N)	mg/L	2.4
Total Phosphorus (P)	mg/L	10
Hardness as $CaCO_3$	mg/L	220

1. A similar summary was then compiled for the existing Modesto WQCF as shown in Table 103 and Table 104. As above, all information was obtained from the *Wastewater Master Plan, Phase 2 Update, Master Plan Report*, prepared by Carollo Engineers for the City of Modesto, March 2007. Influent and effluent information are based on data from years 2001 to 2004.

Table 103: Modesto WQCF Influent Wastewater Quality for Key Parameters

Parameter	Average Daily (2001-2004)	Maximum Monthly (2001-2004)
Flow (MGD)	25.8	28.1
BOD_5 (mg/L)	415	485
TSS (mg/L)	329	385
Total Dissolved Solids (TDS)	870	970
Electrical Conductivity (µS/cm)	1,230	1,370
Ammonia (mg/L)	25	32

Table 104: Modesto WQCF Effluent Wastewater Quality and Permit Limits for Key Parameters

Parameter	Units	Current Permit Limits	Average Daily (2001-2005)	Maximum Daily (2001-2005)
Flow	MGD	Varies	26.3	42.3
BOD_5	mg/L	30	9.55	48
Total Suspended Solids (TSS)	mg/L	45	16.71	170
Total Dissolved Solids (TDS)	mg/L	924	502	912
Electrical Conductivity	µS/cm	1,689	1,069	1,715
Ammonia-N	mg/L	None	5.52	27.2

2. After characterizing existing POTW influent wastewater parameters and the possible future additional influent stream as indicated in the tables above, a conceptual model of the upgraded POTW was constructed, as indicated in Figures 3 and 4, which indicate, respectively, likely upgrades necessary at a typical biotower ("trickling filter") POTW and a typical activated sludge POTW.

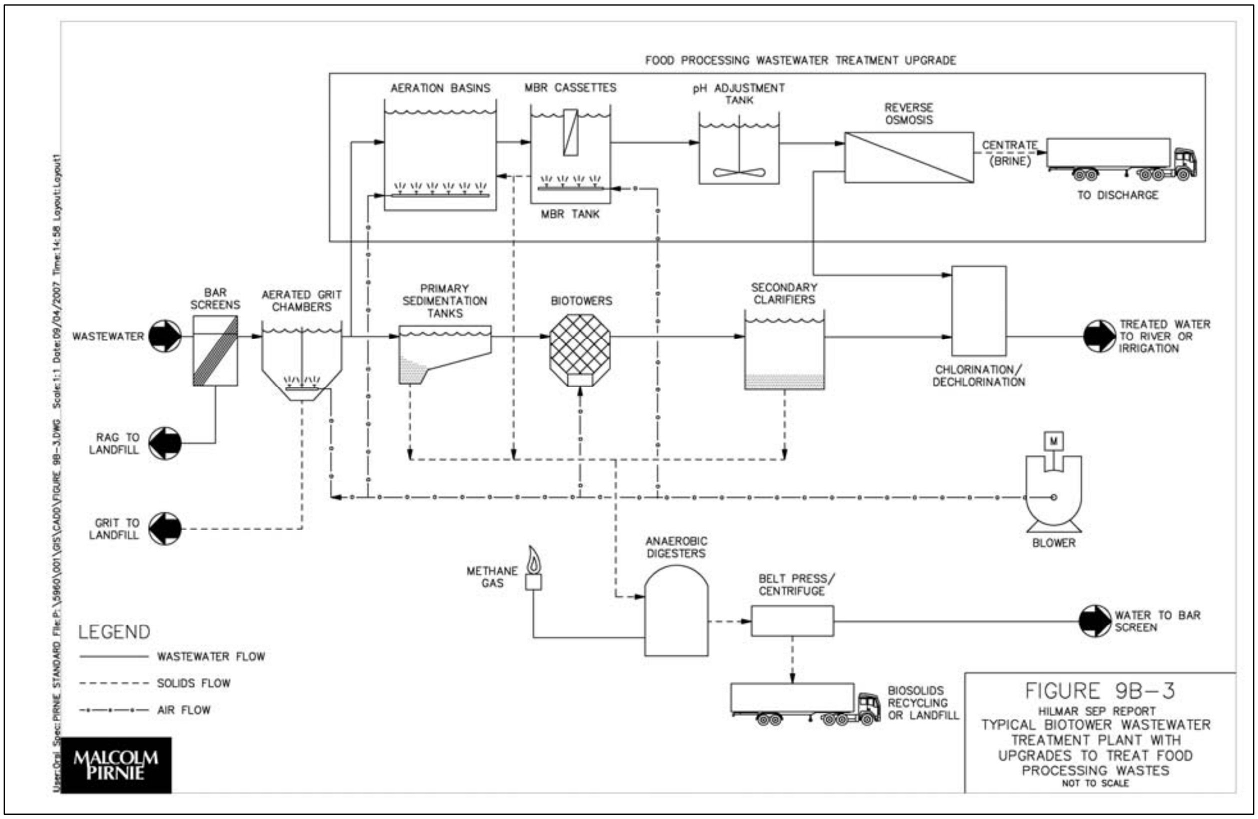

FOOD PROCESSING WASTEWATER TREATMENT UPGRADE
AERATION BASINS
MBR CASSETTES
pH ADJUSTMENT TANK
REVERSE OSMOSIS
CENTRATE (BRINE)
TO DISCHARGE
MBR TANK
BAR SCREENS
AERATED GRIT CHAMBERS
PRIMARY SEDIMENTATION TANKS
BIOTOWERS
SECONDARY CLARIFIERS
WASTEWATER
TREATED WATER TO RIVER OR IRRIGATION
CHLORINATION/ DECHLORINATION
RAG TO LANDFILL
GRIT TO LANDFILL
BLOWER
METHANE GAS
ANAEROBIC DIGESTERS
BELT PRESS/ CENTRIFUGE
WATER TO BAR SCREEN
LEGEND
WASTEWATER FLOW
SOLIDS FLOW
AIR FLOW
BIOSOLIDS RECYCLING OR LANDFILL
MALCOLM PIRNIE
FIGURE 9B–3
HILMAR SEP REPORT
TYPICAL BIOTOWER WASTEWATER TREATMENT PLANT WITH UPGRADES TO TREAT FOOD PROCESSING WASTES
NOT TO SCALE

Figure 45

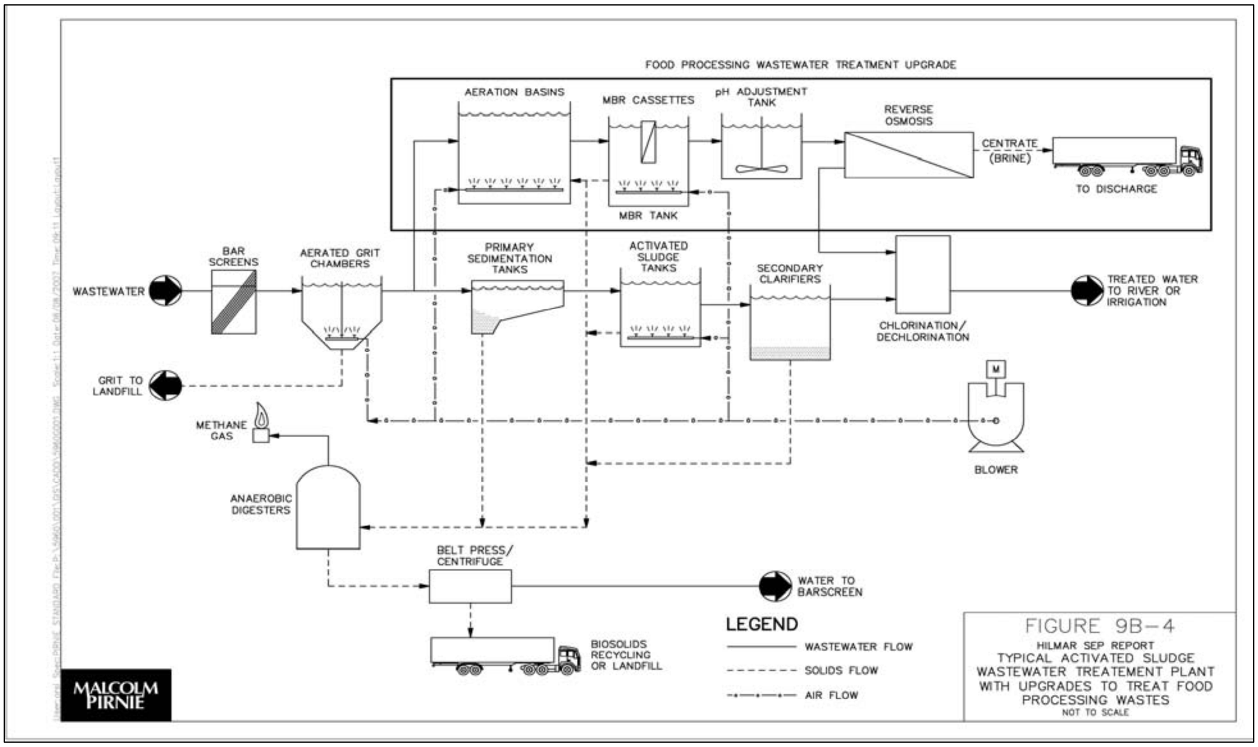


Figure 46

Below are key facts regarding the conceptual POTW upgrades indicated:

- Side-stream treatment is indicated because of the range of possible desired POTW effluent TDS concentrations. That is, unless a final desired TDS concentration is very low (i.e., less than ~100 mg/L for a ~1,000-mg/L influent stream), it is not necessary to treat an entire process flow for salt removal. It is more efficient from capital, operations, and cost perspectives to treat a side-stream to very low TDS concentrations and blend it back into the main process stream to achieve the desired final effluent quality. This concept is discussed further in **Section III Appendices: Appendix III.4.**

- In addition to desalination technology, additional biological and particulate removal capacity would need to be incorporated into a typical POTW side-stream process for desalination to achieve sufficiently low-particulate and low-biological strength water prior to the desalination step. This represents additional infrastructure and costs. Aeration basins followed by membrane bioreactors are the current state-of-the-art-practice in this regard and are therefore indicated in Figures 46 and 47.

- Desalination technologies commonly used in drinking water and wastewater plants are non-destructive and therefore generate a concentrated brine waste stream that must be disposed of. Alternatives for this step may include discharge to evaporation ponds or trucking to an off-site disposal facility.

3. Next, mass balance calculations were performed to determine the side-stream flows necessary to achieve each example future final effluent TDS concentration indicated in Table 95, based on the calculated influent quality and typical unit process performance criteria as indicated above. The POTW flow schematics and calculations used for this step are presented in **Section III Appendices: Appendix III.4** and summarized in Table 105, which is constructed to follow on the scenarios introduced in Table 99. As indicated by the calculated side-stream flows, more salt removal at a given POTW is achieved by installing a side-stream desalination process for a larger portion of the main process stream.

   As example final effluent TDS goals get lower, the magnitude of the side-stream flows necessary begin to approach the magnitude of the full plant's flows. Therefore, if the "anti-degradation" or similarly aggressive/ambitious final effluent scenario were to be realized, it would be prudent to also consider upgrading the entire plant process flow for desalination instead of adding a desalination side-stream. As noted earlier in this report, the study team recognizes such a scenario has been envisioned before and is already understood to represent what are likely prohibitive infrastructure upgrades and costs.

Table 105: Summary of POTW Treatment Upgrade Mass Balance Calculations to Determine Side-stream Process Sizes

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Design Representative Area Food Processor Flow		Representative Area POTW Influent		Design Combined (Food Processor + POTW) Influent TDS (mg/L)		Side-stream Flow Rate (MBR + RO) to Meet TDS Goal (MGD)
		Monthly Peak Flow Rate (MGD)	Flow-weighted Average TDS (mg/L)	Average Flow Rate (MGD)	Maximum TDS (mg/L)	Flow Rate (MGD)	TDS (mg/L)	
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	7.2	1570	26	970	33.2	1100	7.4
Background Groundwater TDS in Representative Area + 300 mg/L	620							18.5
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502							22.3
Background Groundwater TDS in Representative Area	320							27.6

G. Estimated capital and O&M costs for POTW desalination treatment upgrades

Based on the process and flow rate information described in the previous sections, conceptual-level cost estimates were developed for POTW desalination upgrades corresponding to the four treatment/effluent quality scenarios. [158]

Conceptual-level MBR costs are typically developed as a single value, while RO costs are typically a combination of the two components indicated above: equipment costs and facility costs. These three components were brought current to 2007 dollars using an industry-standard tool,[159] then summed to develop total conceptual-level costs as shown in Table 107, which follows directly from Table 101. As seen in the table, MBR costs for a given side-stream flow rate are higher than the corresponding RO costs; that is, although desalination is the main purpose of the side-stream treatment, it is the necessary particulate/biological pre-treatment, not the desalination technology itself, that represents the majority of the main new unit process capital costs. The table presents total treatment upgrade capital costs in the right-hand column, which consist of the sum of the MBR and RO costs.

Table 106: Conceptual-level Treatment Capital Costs (2007) for POTW Desalination Upgrades

Side-stream Flow Rate (MBR + RO) to Meet TDS Goal (MGD)	Treatment Upgrade Capital Costs ($)		Total Treatment Upgrade Capital Costs ($)
	MBR	RO (equipment + facility)	
7.4	$40,800,000	$22,600,000	$63,400,000
18.5	$50,700,000	$43,700,000	$94,400,000
22.3	$61,000,000	$50,000,000	$111,000,000
27.6	$75,800,000	$58,500,000	$134,300,000

Planning-level operations and maintenance (O&M) cost information is available from the same sources referenced above, and is summarized in Table 103 based on the detailed calculations included in **Section III Appendices: Appendix III.4**. As with the capital costs, MBR O&M costs are estimated as higher than RO O&M costs; and a column representing a total of the two for each scenario is included.

[158] These estimates were developed for the major new unit processes indicated and from industry-standard cost sources as follows: Membrane bioreactor (MBR) complete facility costs: *Membrane Bio-Reactor (MBR), An Innovative Technology*, J. Daily and D. Fry, Parsons, Feb. 2005 and Reverse osmosis (RO) equipment and facility costs: *The Cost of Membrane Softening and Desalting for Municipal Water Supplies*, J. Elarde and R. Bergman, American Water Works Association Membrane Technology Conference Proceedings, 2003.

[159] Engineering News Record's *ENR Construction Cost Index History*, Aug 2007.

Table 107: Conceptual-level Treatment Annual O&M Costs (2007) for POTW Desalination Upgrades

Side-stream Flow Rate (MBR + RO) to Meet TDS Goal (MGD)	Treatment Upgrade O&M Costs ($/yr)		Total Treatment Upgrade Annual O&M Costs ($/yr)
	MBR	RO	
7.4	$5,400,000	$1,100,000	$6,500,000
18.5	$13,400,000	$2,100,000	$15,500,000
22.3	$16,200,000	$2,300,000	$18,500,000
27.6	$20,100,000	$2,700,000	$22,800,000

The costs presented in the above tables are conceptual-level estimates designed for high-level comparisons with other salinity management alternatives described in this report. These cost estimates by definition have a -30% to +50% range of uncertainty for use in preliminary feasibility assessments. Reject brine stream management costs are explicitly noted as a component of the RO capital costs; MBR and RO capital costs also include other key factors including site preparation, ancillary structures and buildings, yard and process piping, and electrical and instrumentation costs. Actual costs will vary based on these and other site-specific factors, in particular, the method of reject water disposal selected, which can account for up to 25% of RO system capital costs (e.g., for evaporation pond construction). Brine disposal would also be an important component of O&M costs (e.g., deep-well injection operation or trucking/landfilling) and is only implicitly included in the RO O&M costs indicated. Therefore, actual O&M costs may vary significantly based on the method of brine disposal chosen and permitted in the Representative Area. The annual O&M costs indicated do not reflect any annual financing costs associated with the respective capital improvements.

H. Estimated capital and O&M costs for Representative Area collection system

The food processing facility wastewater collection system for the Representative Area suggested in Figure 45 would represent an additional cost associated with this salinity management alternative beyond the treatment upgrade costs discussed in the above sections. An approximate $6.00 to $9.00 per inch diameter per linear foot for collection system costs can be assumed based on the study team's experience with similar recent US sewer system projects costed out at: construction costs of $4.00 to $6.00 per inch diameter per linear foot, plus 10% engineering costs, plus a 20% contingency, then scaled up by approximately 15% to account for possible differences in translating the costs to California.

The collection system indicated in Figure 45 represents approximately 60 miles of sewer infrastructure based on the study team's GIS plotting of the Representative Area food processing facility, POTW, and reasonable collection system locations indicated in the figure. Although average and maximum flows from the Representative Area food processors vary by orders of magnitude between facilities and sizing of specific collection system segments would be inappropriate for this conceptual-level study, an average diameter can be assumed for the purposes of order-of-magnitude cost estimating. Assuming an average 8-inch diameter results in a $23 to $35 million-dollar cost estimate for the possible collection system depicted in Figure 45 based on the cost assumptions in the previous paragraph. No pumping was assumed necessary for the collection system configuration assumed; if pumping were necessary based on a more detailed hydraulic analysis, it would represent additional capital and O&M costs proportional to those indicated for the longer collection system distances associated with the brine line alternative discussed in Section III.8 of this report.

Although the assumed collection system unit cost range indicated above is intended to be all-inclusive, actual costs may vary widely depending on right-of-way, land acquisition/easement, environmental permitting/documentation, river/highway crossing, existing facility tie-in, and other site-specific issues. Applying an additional 15% cost for these unknowns and conservatively using the high end of available collection system unit costs indicated above, an approximate $40M estimate can therefore be assumed for the purposes of this report as an order-of-magnitude estimate to consider along with the treatment cost estimates presented above.

Collection system O&M costs can be approximated based on published averages; escalating total O&M costs from a USEPA collection system O&M reference document.[160] Table 108 therefore indicates both treatment and collection system costs for each treatment/effluent quality scenario considered based on the collection system cost estimates presented in this subsection and treatment costs presented in previous tables.

As shown in the table, estimated total desalination treatment and collection system upgrades associated with directing wastewater from selected Representative Area food processors to a single centrally located POTW range from approximately $103M to $174M, corresponding to assumed effluent quality limits of 924 and 320 mg/L of TDS, respectively. Estimated total annual O&M costs range similarly from approximately $7M to $23M.

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[160] USEPA. 1999. *Collection Systems O&M Fact Sheet – Sewer Cleaning and Inspection*. EPA 832-F-99-031. September.

Table 108: Capital and O&M Costs (2007) for Representative Area POTW Desalination Upgrades

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Side-stream Flow Rate (MBR + RO) to Meet TDS Goal (MGD)	Total Treatment Upgrade Costs		Collection System Costs		Total Treatment Upgrade and Collection System Costs	
			Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	7.4	$63,400,000	$6,500,000			$103,400,000	$6,720,000
Background Groundwater TDS in Representative Area + 300 mg/L	620	18.5	$94,400,000	$15,500,000			$134,400,000	$15,720,000
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502	22.3	$111,000,000	$18,500,000			$151,000,000	$18,720,000
Background Groundwater TDS in Representative Area	320	27.6	$134,300,000	$22,800,000	$40,000,000	$220,000	$174,300,000	$23,020,000

As with the brine line discussed in Section III.8 of this report, potential economic efficiencies could result with an increased number of participants in POTW desalination from the food processors in the Study Area, or with the addition of other industrial discharge sectors to POTW treatment. This is discussed further in the following section of this report (III.8), which discusses centralized dedicated facility treatment of the food processor wastewater stream presented in this section.

I. Estimated TDS removal results for scenarios modeled

Based on flow, TDS concentration, and typical desalination technology performance, the approximate mass of salt removed by POTW desalination can be developed for each assumed treatment/effluent quality scenario. The list below indicates the information used for this analysis:

1. Average flow of 30.9 MGD through POTW (result of average of 26 MGD of existing process flow plus an average of 4.9 additional MGD from acceptance of food processor combined stream).
2. Assumed effluent TDS concentration of 1100 mg/L from Representative Area POTW with the addition of the food processor combined stream, and conservatively assuming zero TDS removal through facultative ponds or any other existing secondary treatment process not designed for dissolved constituent removal, as previously indicated in Table 8.
3. Effluent TDS concentrations with the implementation of desalination technology corresponding to the four treatment/effluent quality scenarios discussed throughout this section.

The results of this analysis are presented in Table 109. These TDS mass removal values can readily be paired with equivalent annual total costs for each scenario based on cost information presented in previous tables to develop cost-per-unit-of-TDS-removed estimates for each treatment/effluent quality scenario.

It is important to remember that TDS “removed” in this context refers to TDS removed from the combined food processor and existing POTW process stream; complete “removal” of that mass of TDS from the Representative Area or Study Area requires additional desalination reject stream management.

Table 109: Conceptual-level POTW Effluent TDS Mass Reduction for Treatment/Effluent Quality Scenarios Considered

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Representative Area Food Processor Average Flow Rate (MGD)	Representative Area POTW Influent Average Flow Rate (MGD)	Combined (Food Processor + POTW) Influent TDS (mg/L)	POTW Effluent TDS Reduction	
					Concentration (rounded) (mg/L)	Load (lb/d)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	4.9	26	1100	180	46,400
Background Groundwater TDS in Representative Area + 300 mg/L	620				480	123,700
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502				600	154,600
Background Groundwater TDS in Representative Area	320				780	200,900

III.7 Centralized Treatment Facility Salinity Management

Another alternative for post-facility management of food processing wastewaters considered in this report is collection of the wastewaters for treatment at one or more new centralized treatment facilities dedicated to food processing wastewater.

This section provides discussions of:

1. Concept of centralized, dedicated treatment
2. Illustrative options for centralized treatment of food processing wastewater in the Representative Area
3. Treatment criteria, processes, and infrastructure
4. Estimated capital and O&M costs for centralized desalination treatment facility and Representative Area collection system
5. Estimated TDS removal results for scenarios modeled
6. Comparison with POTW treatment alternative presented in Section III.6

As with the other sections of this report discussing salinity management alternatives, this section provides conceptual-level descriptions and cost relationships to enable comparisons with other potential types of solutions, and does not recommend any "preferred alternative" for the Representative Area or the Study Area (San Joaquin Valley).

A. Concept of centralized, dedicated treatment

As discussed elsewhere in this report, food processing facilities in the Representative Area currently employ a variety of management/disposal methods for their wastewater flows. Many land-apply their wastewater, while others discharge to a local POTW, as noted in Section III.6. This section discusses the potential implementation of a new centralized, dedicated facility for the treatment and desalination of food processing wastewaters in the Representative Area.

In brief, this alternative would call for essentially the same wastewater collection system as described in Sections III.6 and III.8 of this report, with routing of the wastewater not to a brine line or existing POTW as described in those sections, but rather to a new, centrally located facility dedicated to food processing facility wastewater treatment and desalination. This section does not explore every possible combination of food processor, centralized treatment facility, and technology scenarios, but rather illustrates four infrastructure examples based on the potential future treatment/effluent quality goals introduced in Section III.6 for consideration along with other post-facility salinity management measures described in this report.

The desalination methods and technologies described in Section III.6 apply equally to this centralized treatment discussion and are therefore not described again here. For illustrative purposes, and due to the availability of performance and cost information and industry experience with the technology, reverse osmosis (RO) is used in this section, as in Section III.6. If centralized desalination were to become necessary or desired for the Representative Area, a comprehensive technology screening process and alternatives analysis would be necessary prior to planning, design, and construction of such infrastructure. The use of RO for the centralized, dedicated treatment alternative explored in this section is not intended to "endorse" RO or misrepresent it as the single available desalination technology.

Section III.6 presented background groundwater quality information along with possible treatment goals for both POTW and centralized treatment. As indicated in Section III.6. Table 99, four such possible goals were selected; two values indicated (320 and 620 mg/L) are related to background groundwater quality, while the two other values (924 and 502 mg/L) are based on current Modesto WQCF effluent permit limit and performance, respectively. These four values were selected to collectively provide a range of possible future treatment/effluent quality scenarios—from the "anti-degradation" scenario (assuming a 320-mg/L effluent goal) to a scenario modeled on one POTW's current effluent limit of 924 mg/L of TDS—for infrastructure and cost modeling purposes.

B. Illustrative options for centralized treatment of food processing wastewater in the Representative Area

There are a large number of potential combinations of new centralized facility locations and food processors in the regional treatment model discussed in this section, based on the numbers of each type of facility in the Representative Area. To develop the most useful scenario for the illustrative purposes of this section, the following assumptions were made. The scenario developed is depicted in Section III.6 Figure 44. (As the figure title indicates, this illustration applies equally to the POTW upgrade scenario discussed in Section III.6 and the possible new, centralized treatment facility discussed in this section of the report.)

1. Those food processors in the Representative Area currently discharging to a local POTW (there are 3 such cases based on available information) would continue to do so.

2. A single, centrally located new dedicated treatment facility would receive the wastewaters from the new participants under this scenario.

3. This new facility would receive food processing wastewater from those Representative Area facilities for which it was most reasonable from a geographic perspective; that is, those 6 processors of the 20 in the Representative Area relatively distant from the Highway 99 corridor not already discharging to local POTWs would not participate in this centrally located treatment alternative, as indicated in Section III.6 Figure 44. This is also in general agreement with other sections of this report discussing hydrogeologic modeling, because five of those

six facilities are located on or west of the San Joaquin River, outside the Representative Area hydrogeologic model boundaries.

4. As was the case for the brine line alternative (Section I.8) and POTW alternative (Section III.6), a possible collection system was indicated aligned with Highway 99 and the north-south and east-west orientation of the majority of the secondary roads in the area as discussed in Section III.6

Clearly, many other options exist for locating possible new dedicated treatment facilities for treating food processing wastewater in the Representative Area. If centralized food processing wastewater treatment were to proceed for the Representative Area, or for the Study Area (San Joaquin Valley) as a whole, a detailed alternatives analysis would be necessary to determine the optimum configuration based on cost and other factors. For the purposes of this section, and to facilitate comparison to the single POTW upgrade described in Section III.6 of this report, the configuration indicated in Section III.6 Figure 44 was selected.

C. Treatment criteria, processes, and infrastructure

To develop centralized treatment infrastructure sizes and configurations, it is necessary to characterize the influent flows and quality, and to define the treatment criteria and processes. The general guidelines in this regard were as follows, and were analogous to those presented in Section III.6 for the POTW desalination analysis:

1. Provide treatment for organic strength and suspended solids consistent with what would be required to meet typical secondary wastewater treatment standards and consistent with existing Representative Area POTW NPDES/WDR treatment requirements and effluent quality limits.
2. Indicate and configure treatment systems necessary to also achieve potential salinity effluent goals indicated in Section III.6 Table 95.

Several specific assumptions were also made to enable the analysis, many of which were identical to those presented in Section III.6:

1. The design food processing facility flow rate was chosen to be 7.2 MGD, the monthly peak combined flow rate from the facilities assumed to be participating under this scenario, as discussed in Section III.6.
2. The example centralized treatment alternatives presented in this report section were based on the treatment necessary to achieve effective and reliable desalination of the combined wastewater flow and strength/quality based on the food processor wastewater database available to the study team. Governing parameters in addition to flow and TDS concentration included BOD, TKN, nitrate, phosphorus, and hardness.
3. The flows indicated for side-stream treatment are the result of mass balance calculations using the example suite of potential future target effluent TDS

concentrations indicated in Section III.6 Table 95. Individual steps of this analysis are indicated in the spreadsheets included as **Section III Appendices: Appendix III.4**.

4. In addition to desired effluent TDS concentrations, the same necessary conceptual performance assumptions regarding BOD removal, TDS removal, and desalination technology performance were made for the centralized treatment facility as for the POTW alternative.

The paragraphs and tables below indicate the information collected and steps to develop the necessary centralized treatment facility processes and infrastructure needs for achieving the range of desalination targets presented above. In general, the methodology closely mirrors that presented in Section III.6, but is less complex because it does not involve the hydraulics, treatment processes, wastewater quality, or other characteristics of any existing treatment facility or influent process stream.

1. The first step in this process, reviewing the wastewater flows and effluent quality from food processing facilities indicated to be tributary to this centralized treatment alternative, was identical to the same step in Section III.6 and is therefore not repeated here.

2. Next, a conceptual model of a possible future centralized treatment facility was constructed, as indicated in Figures 47 and 48. The unit processes depicted is a result of the study team's professional engineering experience with treating wastewaters with characteristics similar to the combined food processor wastewater stream used for this analysis. The configuration depicted in Figure 44 assumes hardness removal is necessary in addition to the other treatment processes shown and therefore includes a chemical precipitation step not shown in Figure 45. Both configurations are shown in this report because the combined hardness and background wastewater chemistry of the indicated tributary food processors is such that it is difficult to know at this level of analysis whether or not hardness removal would be necessary for effective desalination treatment. More detailed knowledge of exactly which facilities would discharge to such a treatment facility, and possibly wastewater quality modeling or bench-scale experimentation, would be necessary to determine whether hardness removal would actually be required.

3. Below are key facts regarding the conceptual centralized treatment facility processes indicated:

    - Side-stream desalination treatment is indicated because of the range of possible desired effluent TDS concentrations, as discussed in Section III.6. A much simpler side-stream process is indicated in this section as compared to the POTW alternatives presented in Section III.6 because this is a potential facility dedicated to food processing wastewater, not a POTW with existing treatment processes to treat typical domestic/municipal wastewater. Therefore, a single stream for biological and particulate treatment is indicated here, with side-stream treatment only for the desalination process, as governed by the final effluent TDS requirement as indicated above.

- Biological and particulate treatment capacity is indicated here because the full wastewater flow from each facility is assumed to contribute. If tributary facilities all employed wastewater stream segregation such that a brine-only stream were directed to this potential centralized treatment facility, a smaller hydraulic capacity and simpler pre-desalination treatment steps would be indicated.
- As with the POTW alternatives described in the previous section, aeration basins followed by membrane bioreactors (MBR) are the current state-of-the-practice in stand-alone facility or process stream biological and particulate treatment and are therefore indicated in Figures 47 and 48.
- The concentrated reject brine stream will require management (e.g., discharge to evaporation ponds, trucking to an off-site disposal facility) as it does under the POTW alternatives discussed in Section III.6.

4. Next, mass balance calculations were performed to determine the side-stream desalination flows to achieve each example future final effluent TDS concentration indicated in Section III.6 Table 95, based on the calculated influent quality and typical unit process performance criteria as indicated above. The facility flow schematic and calculations used for this step are presented in **Section III Appendices: Appendix III.4** and summarized in Table 110, which is constructed to follow on the scenarios introduced in Section III.6 Table 95.

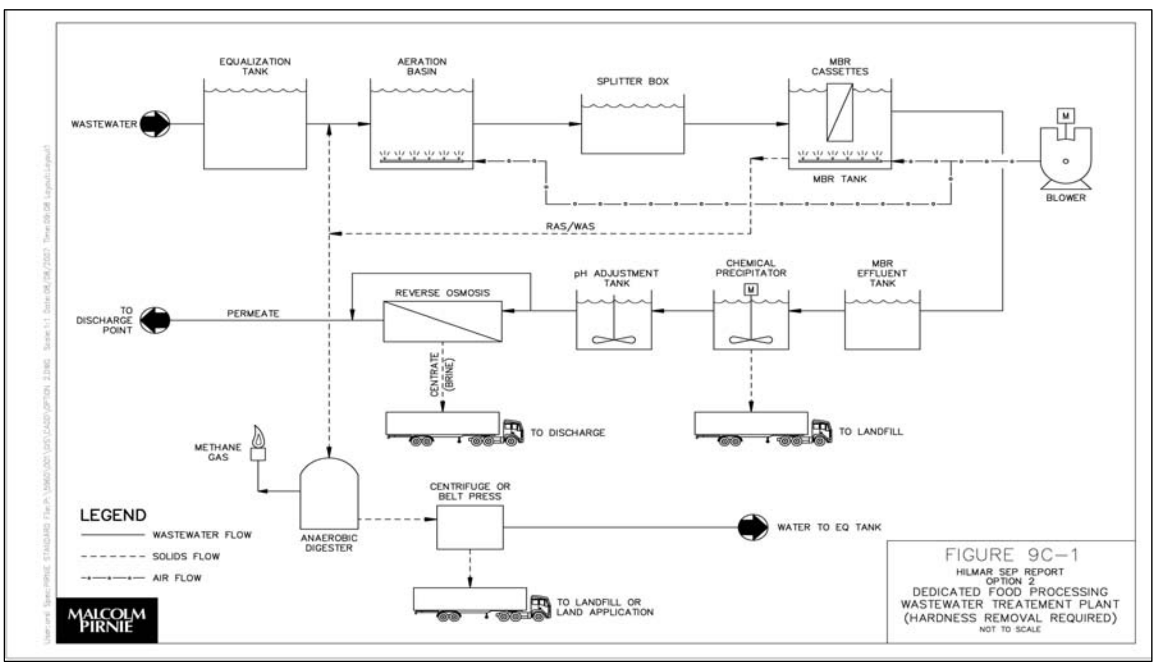

Figure 47

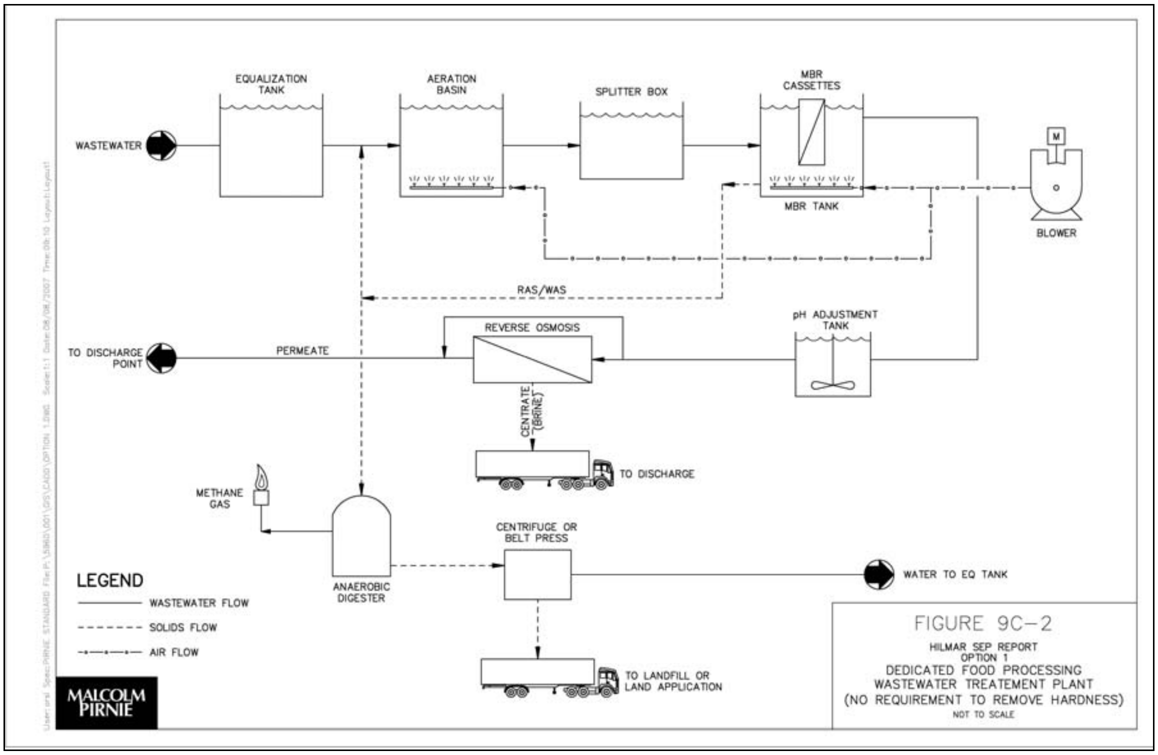
EQUALIZATION TANK
AERATION BASIN
SPLITTER BOX
MBR CASSETTES
WASTEWATER
MBR TANK
BLOWER
M
RAS/WAS
pH ADJUSTMENT TANK
REVERSE OSMOSIS
TO DISCHARGE POINT
PERMEATE
CENTRATE (BRINE)
TO DISCHARGE
METHANE GAS
CENTRIFUGE OR BELT PRESS
ANAEROBIC DIGESTER
WATER TO EQ TANK
LEGEND
WASTEWATER FLOW
SOLIDS FLOW
AIR FLOW
TO LANDFILL OR LAND APPLICATION
MALCOLM PIRNIE
FIGURE 9C-2
HILMAR SEP REPORT
OPTION 1
DEDICATED FOOD PROCESSING
WASTEWATER TREATEMENT PLANT
(NO REQUIREMENT TO REMOVE HARDNESS)
NOT TO SCALE

Figure 48

Table 110: Summary of Centralized Treatment Facility Mass Balance Calculations to Determine Side-stream Process Sizes

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Design Representative Area Food Processor Flow		Design Flow Through MBR (MGD)	Side-stream Flow Rate (RO) to Meet TDS Goal (MGD)
		Monthly Peak Flow Rate (MGD)	Flow-weighted Average TDS (mg/L)		
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	7.2	1570	7.2	3.8
Background Groundwater TDS in Representative Area + 300 mg/L	620				5.3
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502				5.8
Background Groundwater TDS in Representative Area	320				6.6

D. *Estimated capital and O&M costs for centralized desalination treatment facility and Representative Area collection system*

Based on the process and flow rate information described in the previous sections, conceptual-level cost estimates were developed for centralized treatment facility desalination facilities corresponding to the four treatment/effluent quality scenarios. These estimates were developed for the major new unit processes indicated and from industry-standard cost sources as follows:

- Membrane bioreactor (MBR) complete facility costs: *Membrane Bio-Reactor (MBR), An Innovative Technology*, J. Daily and D. Fry, Parsons, Feb. 2005.
- Reverse osmosis (RO) equipment and facility costs: *The Cost of Membrane Softening and Desalting for Municipal Water Supplies*, J. Elarde and R. Bergman, American Water Works Association Membrane Technology Conference Proceedings, 2003.

Conceptual-level MBR costs are typically developed as a single value, while RO costs are typically a combination of the two components indicated above: equipment costs and facility costs. These three components were brought current to 2007 dollars using an industry-standard tool (Engineering News Record's *ENR Construction Cost Index History*, Aug 2007), then summed to develop total conceptual-level costs as shown in Table 111, which follows directly from Table 110. As discussed in Section III.6, MBR costs generally dominate. This is especially true in this centralized treatment facility alternative, where the MBR facility must be designed for the full monthly maximum flow rate from the group of tributary food processors, while the RO facility only needs to be as large as necessary for sufficient side-stream desalination treatment to achieve a given final effluent TDS target. As a result, the total capital cost for the centralized treatment facility associated with a 320-mg/L effluent goal is not much higher (less than 15%) than the capital cost for the facility necessary to meet the 924-mg/L potential effluent goal. Cost tables throughout this section are structured similarly to those in Section III.6.

Table 111: Conceptual-level Capital Costs (2007) for Centralized Desalination Treatment Facility

Design Flow Through MBR (MGD)	Side-stream Flow Rate (RO) to Meet TDS Goal (MGD)	Treatment Capital Costs ($)		Total Centralized Dedicated Treatment Capital Costs ($)
		MBR	RO (equipment + facility)	
7.2	3.8	$35,500,000	$14,000,000	$49,500,000
	5.3		$17,600,000	$53,100,000
	5.8		$18,900,000	$54,400,000
	6.6		$20,500,000	$56,000,000

Planning-level operations and maintenance (O&M) cost information is available from the same sources referenced above, and is summarized in Table 112 based on the detailed calculations included in **Section III Appendices: Appendix III.4**. As with the capital costs, MBR O&M costs are estimated as higher than RO O&M costs, leading to relatively little difference between the total O&M costs among the scenarios.

Table 112: Conceptual-level Treatment Annual O&M Costs (2007) for Centralized Desalination Treatment

Design Flow Through MBR (MGD)	Side-stream Flow Rate (RO) to Meet TDS Goal (MGD)	Treatment O&M Costs ($/yr)		Total Centralized Dedicated Treatment O&M Costs ($/yr)
		MBR	RO	
7.2	3.8	$5,200,000	$810,000	$6,010,000
	5.3		$1,000,000	$6,200,000
	5.8		$1,040,000	$6,240,000
	6.6		$1,070,000	$6,270,000

The costs presented in the above tables are conceptual-level estimates designed for high-level comparisons with other salinity management alternatives described in this report. As with the conceptual-level cost estimates presented in Section III.6 and III.9 of this report for the brine line and POTW upgrade alternatives, these cost estimates by definition have a -30% to +50% range of uncertainty for use in preliminary feasibility assessments. Reject brine stream management costs are explicitly noted as a component of the RO capital costs; MBR and RO capital costs also include other key factors including site preparation, ancillary structures and buildings, yard and process piping, and electrical and instrumentation costs. Actual costs will vary based on these and other site-specific factors, in particular, the method of reject water disposal selected, which can account for up to 25% of RO system capital costs (e.g., for evaporation pond construction). Brine disposal would also be an important component of O&M costs (e.g., deep-well injection operation, trucking/landfilling) and is only implicitly included in the RO O&M costs indicated. Therefore, actual O&M costs may vary significantly based on the method of brine disposal chosen and permitted in the Representative Area. The annual O&M costs indicated do not reflect any annual financing costs associated with the capital improvements.

Section III.6 Figure 45 represents the centralized treatment facility alternative as well as the POTW upgrade alternative. (The only conceptual difference between the two alternatives is the type of treatment facility; therefore, from a geographic perspective relative to the Representative Area or Study Area, the alternatives are essentially the same.)

The necessary collection system for the Representative Area suggested in Section III.6 Figure 45 represents an additional cost associated with this salinity management alternative, as it does for the POTW upgrade alternatives. As discussed in Section III.6, the approximate capital and annual O&M costs associated with a new collection system for the food processors assumed to be tributary to the new centralized treatment facility considered in this section are $40M and $220,000, respectively.

Table 114 therefore indicates both treatment and collection system costs for each treatment/effluent quality scenario considered based on the collection system cost estimates presented in this subsection and treatment costs presented in previous tables.

As shown in the table, estimated total centralized desalination treatment and collection system infrastructure capital costs range from approximately $90M to $96M corresponding to assumed effluent quality limits of 924 and 320 mg/L of TDS, respectively. Estimated total annual O&M costs range similarly from approximately $6.2M to $6.5M.

Table 113: Conceptual-level Treatment and Collection System Capital and O&M Costs (2007) for Representative Area Centralized Dedicated Desalination Facility

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Design Flow Through MBR (MGD)	Side-stream Flow Rate (RO) to Meet TDS Goal (MGD)	Total Centralized Dedicated Treatment Costs		Collection System Costs		Total Treatment Upgrade and Collection System Costs	
				Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	7.2	3.8	$49,500,000	$6,010,000	$40,000,000	$220,000	$89,500,000	$6,230,000
Background Groundwater TDS in Representative Area + 300 mg/L	620		5.3	$53,100,000	$6,200,000			$93,100,000	$6,420,000
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502		5.8	$54,400,000	$6,240,000			$94,400,000	$6,460,000
Background Groundwater TDS in Representative Area	320		6.6	$56,000,000	$6,270,000			$96,000,000	$6,490,000

As with the brine line and POTW upgrades discussed in Sections III.6 and 9 of this report, respectively, potential economic efficiencies could result with an increased number of participants in centralized treatment facility desalination from the food processors in the Study Area, or with the addition of other industrial discharge sectors to centralized treatment.

E. Estimated TDS removal results for scenarios modeled

Based on flow, TDS concentration, and typical desalination technology performance, the approximate mass of salt removed by centralized, dedicated desalination treatment can be developed for each assumed treatment/effluent quality scenario. The list below indicates the information used for this analysis:

1. Average flow of 4.9 MGD through centralized treatment facility due to collective food processor effluent stream.
2. Assumed average combined effluent TDS concentration of 1,570 mg/L from Representative Area food processing facilities tributary to the centralized treatment facility, as described in Section III.6 and used earlier in this section.
3. Effluent TDS concentrations with the implementation of desalination technology corresponding to the four treatment/effluent quality scenarios discussed throughout this section.

The results of this analysis are presented in Table 110. These TDS mass removal values can readily be paired with equivalent annual total costs for each scenario based on cost information presented in previous tables to develop cost-per-unit-of-TDS-removed estimates for each treatment/effluent quality scenario.

Table 114: Conceptual-level Food Processing Facility Effluent TDS Mass Reduction for Centralized Dedicated Treatment/Effluent Quality Scenarios Considered

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Representative Area Food Processor Average Flow Rate (MGD)	Representative Area Food Processor Effluent Flow-weighted Average TDS (mg/L)	TDS Reduction	
				Concentration (rounded) (mg/L)	Load (lb/d)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	4.9	1570	650	26,600
Background Groundwater TDS in Representative Area + 300 mg/L	620			950	38,800
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502			1070	43,700
Background Groundwater TDS in Representative Area	320			1250	51,100

It is important to remember that TDS "removed" in this context refers to TDS removed from the combined food processor effluent stream; complete "removal" of that mass of TDS from the Representative Area or Study Area requires additional desalination reject stream management.

Another possible centralized treatment scenario for the Representative Area, but not modeled here, would be the segregation of all tributary food processor wastewater streams prior to centralized treatment. Such segregation might result in 10-20% of the total facility flow being a high-salinity brine-only stream, with the remaining 80-90% of the flow carrying the processors' organic and particulate wastewater load. Such a scenario would require additional investment at the facility-specific level, but result in a much lower volume of wastewater requiring desalination than that considered in this section. The treatment and/or disposal method for the majority of the wastewater (high organic and particulate strength, but lower in salinity than a full wastewater stream) would need to be determined, and might consist of land application or routing to one or more existing POTWs.

F. Comparison with POTW treatment alternative presented in Section III.6

As indicated by the results of the analyses in this section and Section III.6, there are some important differences between the POTW upgrade and centralized treatment alternatives for salinity removal:

1. For a given effluent TDS concentration goal, a larger side-stream flow through the desalination treatment unit process is indicated for the POTW upgrade alternative as compared to the centralized treatment facility. For example, to achieve an effluent quality of 620 mg/L under the POTW upgrade alternative, a side-stream flow of 18.5 MGD is required, as indicated in Section III.6 Table 105. To achieve the same effluent TDS concentration under the centralized treatment alternative calls for a side-stream flow of less than one-third the size (5.3 MGD), as shown in Table 110. This is a result of the POTW alternative treating a more dilute wastewater stream (26 MGD of existing municipal wastewater mixed with 7.2 MGD, monthly maximum, of food processing wastewater) with respect to salinity than the centralized treatment alternative, which is dedicated to the food processing wastewater flow.

2. As a result, the capital costs associated with a given effluent TDS concentration target are much lower for the centralized treatment alternative than the POTW upgrade alternative. For example, achieving an effluent quality of 620 mg/L requires an approximate $94M POTW upgrade capital investment as compared to a $53M centralized treatment capital cost.

3. Similarly, total treatment O&M costs for a given effluent TDS concentration are significantly less under the centralized treatment scenario than the POTW upgrade scenario. Again, using the 620-mg/L TDS effluent target, annual treatment O&M costs for the POTW upgrade alternative are approximately $15.5M as compared to $6.2M for the centralized treatment option discussed in this section.

4. To achieve a given effluent TDS concentration, a much higher mass of TDS must be removed from the process stream under the POTW upgrade alternative as compared to the centralized treatment alternative. For example, 123,700 lb TDS/day removal is needed under the POTW upgrade alternative to yield a 620-mg/L-TDS total effluent, while only 38,800 lb/day of TDS are removed to achieve the same final effluent concentration (620 mg/L) under the centralized treatment scenario. This is because the average flow rate for the POTW alternative (30.9 MGD) is more than six times the average flow rate for the centralized treatment alternative, but the average TDS concentrations in each stream are much closer to each other (1100 mg/L for the POTW alternative as compared to 1570 mg/L for the centralized treatment alternative.)

5. The cost and TDS removal values indicated in this and Section III.6 suggest that centralized treatment is likely more cost-effective than POTW treatment in achieving a given effluent TDS concentration from the collective food processor

facility wastewater stream. However, POTW desalination upgrades would represent the more cost-effective way of preventing a given mass of TDS from being discharged to the Representative Area subsurface through wastewater effluent disposal. This is due to the efficiencies of scale involved with treating the much higher flow rates required to achieve a given effluent TDS concentration under the POTW upgrade alternative. This can be confirmed through performing equivalent annual cost analyses on both the Section III.6 and III.9 scenarios.

As with all post-facility salinity management measures presented in this report, the potential participation of additional industry sectors to a centralized treatment facility would result in efficiencies for participants due to both cost-sharing and additional economies of scale with increased flows and therefore larger facilities.

III.8 Brine Line Salinity Management

A. Introduction

The term "brine line" refers to a pipeline conveyance used to collect and convey high-salinity wastewaters from one or more types of sources for discharge to a treatment facility and/or receiving water (typically an ocean). Sources of wastewater for such a facility may include industrial wastewaters, excess non-potable water flow, ocean desalination reject streams, and brackish groundwater desalination reject streams.

This section presents a brief background on existing brine lines in Southern California (for context), evaluates this out-of-basin salinity management option for the Representative Area of the Northern San Joaquin Valley, discusses potential scaling-up issues to the Study Area (San Joaquin Valley), and presents end-of-pipe discharge issues related to such brine lines.

B. Background

The idea of a brine line in the Central Valley started in the mid-1950s with the plan for the San Luis Unit of the Central Valley Project. The purpose of the brine line component of this project was to construct a drain to provide agricultural drainage service that achieved long-term, sustainable salt and water balances in the root zone of irrigated lands. Construction started in the early 1970s; by 1975, an 82-mile segment of the San Luis drain (ending at Kesterson Reservoir) had been completed, with 120 miles of collector drains. In 1983, the construction of the line was halted, due to the discovery of drainage water quality issues and deformities in waterfowl, at the reservoir regulating water flow to the drain. The Central Valley Project, the San Luis Drain, and the 1983 event are documented thoroughly in the literature and are not discussed in depth here.

Furthermore, the Central Valley Regional Water Quality Control Board (Board) has recommended the implementation of an out-of-basin option, such as an out-of-valley drain to manage basin-wide saline discharges, as discussed in the Board's May 2006 *Salinity in the Central Valley* document. Specifically, the Board has discussed the benefits of a Central Valley brine line similar to the Santa Ana River Interceptor line in Southern California (discussed later in this section).

It is important to recognize that the focus of both the San Luis Drain and the brine line discussed by the Board has been the management of agricultural drainage waters, not necessarily food processing facility or other types of wastewaters. They are discussed here simply to provide a brief context for the concept of a potential out-of-basin management alternative for food processing facility wastewaters, per the scope of this study.

Southern California has used brine lines to manage their high-saline wastewater from desalination plants and industrial processes for over 50 years. Two large brine lines currently service Orange, Riverside, San Bernardino, and Los Angeles Counties. Both brine lines collect waste brines and also receive domestic and other wastewaters. Because waste brines are mixed with domestic and other wastewaters in these cases, the contents of the lines are treated at their terminuses by the Orange County Sanitation District No. 2 Treatment Facility and the Los Angeles County Sanitation District Joint Water Pollution Control Plant, respectively.

Another California brine line, the Calleguas Regional Salinity Management Pipeline, is currently in construction in Ventura County. This facility will only carry waste brine (i.e., not domestic, industrial, or other mixed wastewaters), which will be discharged directly into the Pacific Ocean, without treatment.

Figure 49 shows the locations of the three Southern California brine lines, and Table 115 summarizes their key information.

Figure 49

Table 115: Southern California Brine Line Key Information Summary

Santa Ana Watershed Project Authority (SAWPA) **Santa Ana Regional Interceptor (SARI)** • 93 miles long • 5-10 MGD average flow; 30-MGD capacity • Saline wastewater; domestic and other industrial wastewaters • Treatment plant: Orange County Sanitation District No. 2 • Outfall: 5 miles offshore • $135 million for replacement of 73 miles (2002 construction costs)
Los Angeles County Sanitation District (LACSD) **Wastewater Conveyance Line** • 40 miles long • 4-50 MGD average flow • Brine from desalting projects; domestic and industrial wastewater • Treatment plant: Joint Water Pollution Control Plant • Outfall: 2 miles offshore • Cost information not available
Calleguas Municipal Water District (CMWD) **Calleguas Regional Salinity Management Pipeline – Currently in Construction** • 30 miles long • 19-MGD capacity • High-salinity brine only • No treatment plant • Outfall: approximately 1 mile offshore • $140 million (estimated total costs)

1. Potential Brine Line in the Representative Area

a) Concept

The concept of a brine line alternative to carry wastewater (or a segregated waste brine stream) from food processors in the Representative Area consists of constructing a collection line from each participating food processor facility to a main conveyance that ultimately extends to a marine outfall. The connection of each food processor varies depending on each facility's existing wastewater disposal method and degree of stream segregation, but generally involves plumbing sufficient to tie into the local collection line.

b) Sizes and Options

The sizes of facility connections and the collection lines, and the main out-of-basin conveyance depend upon the design effluent flow from each facility and the total Representative Area design flow, respectively. The determination of the design effluent flow and the total Representative Area design flows depends on two possible general discharge options for food processor facilities, including:

1) Full wastewater streams from each food processor facility or
2) Segregated brine-only streams from each food processor facility.

In either case, pretreatment and/or monitoring of the waste brine or wastewater may be required to comply with standards of the involved regulatory agencies. This topic is discussed further under “End-of-Pipe Discharge Issues” below.

c) Location

San Joaquin Valley geography, mountain ranges in California, and the locations of potential receiving waters all limit the potential locations of a brine line serving the Representative Area (or the San Joaquin Valley as a whole). One brine line configuration for the Representative Area is illustrated in Figure 50.

The layout indicates the main conveyance line paralleling State Highway 99 due to its:

1) Proximity to most of the food processing facilities in the Representative Area
2) Southeast-northwest orientation along the axis of the San Joaquin Valley and in the general direction of the receiving water, and
3) Likelihood of existing utility corridors.

Collection lines are indicated reflecting the general north-south and east-west orientation of secondary highways and roads in the Representative Area. More detailed alignment studies including assessing existing rights-of-way for flood control, existing utility corridors, railroad, and/or power facilities are necessary prior to design and construction.

Additionally, acquisition of additional land/easement may be necessary, which is an important issue due to the high value of land in California. This potential out-of-basin salinity management alternative is unique because of the large number of counties, local agencies, and other jurisdictions that the main conveyance brine line traverses, which may pose issues related to acquisition of easement and agency operational control.

d) Discharge

This alternative, as shown in Figure 50, includes discharge to the San Francisco Bay Area. Other possible ultimate discharge points include Point Estero and Monterey Bay, as previously indicated by the Bureau of Reclamation (March 2007); however, only a San Francisco Bay option is indicated here for illustrative purposes. There are many possible San Francisco Bay points of discharge for the brine line effluent, each of which would have a wide range of unique associated concerns that would not be appropriate to evaluate in detail at this conceptual level.

In general, however, the two types of possible discharge scenarios would be (1) direct discharge to the Pacific Ocean, San Francisco Bay, or tributary waters; or (2) discharge to an existing or new wastewater treatment facility, and then to a receiving water. As noted above, there is the potential that a brine-only stream resulting from the collection of segregated food processing wastewater streams could be directly discharged to receiving water; however, any mixed wastewater stream would certainly require treatment prior to discharge as discussed below.

e) Infrastructure Length

The length of pipeline required for this configuration is approximately 180 miles, including 140 miles of main conveyance line and 40 miles of collection system in the Representative Area. Other collection system configurations (and therefore lengths) are possible, depending on the food processing facility participants and the detailed alignment studies; however, this would not affect the approximate length of the main conveyance line for the Representative Area.

Note that the collection system for this alternative does not service every food processing facility in the Representative Area. This is consistent with the other post-facility salinity management alternatives presented in this report, and is based on providing brine line service to those facilities within a reasonable proximity to the Highway 99 corridor.

f) Costs

Total costs for brine line construction typically include right-of-way, land acquisition/easements, design and construction (excavation, materials, backfill), and environmental permitting/documentation, with 30% of the total costs dedicated to right-of-way, design, and permitting. The most current cost information available for brine line construction is from the current construction of the Calleguas Regional Salinity Management Pipeline in Ventura County, as defined above and summarized in Table 116.

Table 116: Calleguas Regional Salinity Management Pipeline Information

Brine Line Characteristics	
Total Length	Approximately 30 miles
Pipeline Diameter	18 – 48 inches
Capacity	19 MGD
Outfall Characteristics	One mile long, 30 inches in diameter
Brine Treatment	None
Cost Information	
Total Cost	$140 M (2007 dollars)
Outfall Cost	$8 M
Brine Line Cost per Mile (without outfall)	~ $4.4M

Using the reported cost information for the Calleguas Regional Salinity Management Pipeline currently under construction, and assuming 30% of the total costs (right-of-way, design, and permitting) would be similar between the two projects (due to being independent of pipe diameter or materials), assumptions and conceptual-level cost estimates for a potential brine line in the Representative Area, as illustrated in Figure 50, are presented in Table 117.

Table 117: Summary of Brine Line Options and Conceptual-level Capital Cost Estimates

Parameter	Calleguas Regional Salinity Management Pipeline	*Potential Representative Area Brine Line*	
		Full Facility Wastewater Discharge	Segregated (Brine-only) Discharge
Estimated Pipeline Capacity	19 MGD	7.5 MGD (based on tributary food processor flows)	<5 MGD (assumed)
Estimated Pipeline Diameter	18-48 inches	4-24 inches	2-18 inches
Estimated Total Cost per Mile	$4.4M	~$3.0M	~$2.7M

Depending on the discharge option chosen, the total costs for the potential 140- mile main conveyance brine line for the Representative Area range up to and perhaps greater than $400M, including an assumed $8M for the construction of an outfall. These are conceptual-level cost estimates, which by definition have a -30% to +50% range of uncertainty. An additional level of qualification is appropriate for these costs, due to the long-distance, multi-jurisdictional, and likely highly political nature of a constructed salt drainage facility from the San Joaquin Valley to the San Francisco Bay Area. Additionally, these estimates are highly dependent on location and material costs, which are subject to change variably depending on market conditions.

Waste brine discharged to the Calleguas Regional Salinity Management Pipeline, because of its composition, does not require downstream treatment and will be discharged directly into the Pacific Ocean. This may be the case as well for a brine-only stream from the Representative Area but this would require additional investigation to confirm.

Full wastewater streams from food processor facilities are expected to require a minimum of BOD removal, tertiary treatment for nitrogen and phosphorus removal, and possible metals removal prior to discharge. Required treatment of waste brine before discharge either through an existing wastewater treatment facility, which may need to be upgraded to accept/treat the wastewater, or through a new, dedicated wastewater treatment facility represent substantial potential additional costs that are not reflected in Table 117. Also not shown in the table are the costs associated with the collection system. These would be less on a per-mile basis (and much less on an absolute basis) than the main conveyance line, but would represent another incremental cost addition nonetheless.

In the case of full wastewater discharge and the associated treatment needs, assessments of and negotiations with existing wastewater treatment plants (location, available capacity, existing TDS effluent limits, existing discharge permit) or siting of a new wastewater treatment plant would be necessary.

g) Multi-sector Participation

Multi-sector participation in such large wastewater conveyance projects can make both operational and economic sense. For example, the Santa Ana Watershed Project Authority (SAWPA) Santa Ana Regional Interceptor (SARI) serving Orange, Riverside, and San Bernardino Counties was historically designed to receive only brine streams from desalination projects and highly saline industrial dischargers in the 1970s, and has a design capacity of 30 MGD. However, SARI has needed to accept multiple sources of wastewaters, including domestic and mixed industrial wastewater, and agricultural return water, in an effort to maximize use of the SARI's design capacity and recover construction and maintenance costs. SARI is still only operating between 5 and 10 MGD as compared to its 30-MGD design capacity.

Multi-sector industry participation is also an option to consider for the Representative Area brine line alternative. In addition to food processor facilities, other possible waste discharges to the brine line in the Representative Area include domestic wastewater, mixed industrial wastewaters, brine from desalination projects, and agricultural return water. However, as noted above, if the potential brine line receives mixed wastewaters in addition to brine-only waste streams, treatment by an existing or dedicated wastewater treatment facility will be mandatory and more extensive than for exclusively brine, prior to discharge to the ultimate receiving water (e.g. ocean).

Table 118 summarizes the potential combinations of facility waste segregation options and brine line participant options.

Table 118: Potential Brine Line Characteristics and Participation

		Participation Type	
		Food Processing Facilities Only	**Multi-Sector Participation**
Waste Stream Configuration	Segregated (Brine-only) Streams	• Lowest volume of wastewater • Simplest wastewater quality/treatment issues and discharge permitting • Lowest economies of scale	• Average to high volume of wastewater • Simple wastewater quality/treatment issues and discharge permitting • Great economies of scale
	Full Wastewater Streams	• Low to average volume of wastewater • Complex wastewater quality/treatment issues and discharge permitting • Low economies of scale	• Highest volume of wastewater • Most complex wastewater quality/treatment issues and discharge permitting • Greatest economies of scale

h) Potential Scale-up Issues

Scale-up of the potential brine line in the Representative Area to the entire Study Area (San Joaquin Valley) presumably extends the facility southeast to the Bakersfield area. This configuration requires approximately 180 more miles of main conveyance brine line than would serve the Representative Area alone (i.e. 320 total miles), assuming the same ultimate region of discharge (San Francisco Bay Area), and assuming a layout aligned with the Highway 99 corridor as for the Representative Area.

Variations on collection system configurations (and therefore lengths) are possible, depending on the food processing facility participants and the detailed alignment studies; however, this would not affect the approximate length of the main conveyance line for the Study Area.

Unlike a facility in a single location (e.g., a treatment plant), total costs would essentially increase linearly with increasing size (length) of the brine line facility through the Study Area. For a long-distance conveyance facility, the most important efficiencies of scale would be expected to be realized due to additional participants sharing costs, as opposed to efficiencies associated with the increased size of the infrastructure.

In four potential brine line configurations examined, the minimum-average cost per food processor participant is for a brine line that runs through the representative area plus the Fresno area, roughly 220 miles in length total. Annual capital and O&M costs per participant for this configuration are lower than for a brine line extending through the representative area alone due to the increased number of participants sharing the costs. Extending the brine line down to Visalia or Bakersfield increases the capital cost per participant more than is offset by the added number of participants sharing the costs.

Other scaling-up issues include the multiple additional counties, municipalities, and other stakeholders as this alternative traverses a greater distance. Extending a potential brine line further southeast in the San Joaquin Valley offers the benefit of having both (1) additional food processors and (2) additional non-food-sector dischargers participate to realize added efficiencies.

The cost implications of scaling up are summarized in Table 119.

Table 119: Brine Line Costs

Brine Line Extent in Study Area	Approximate Segment Lengths (miles)	Approximate Cumulative Length (miles)*	Estimated Brine Line Capital Cost per Mile of Largest-diameter Segment (2007 $/mi)	Cumulative Design (Maximum Monthly) Food Processor Flow Rate (MGD)	Cumulative Annual Average Food Processor Flow Rate (MGD)	Cumulative Pump Station Capital Costs (2007 $)	Cumulative Quantity of salt (TDS) removed (lb/day)	Cumulative Total Capital Cost (2007 $)	Cumulative O&M Cost (2007 $/yr)	Number of Assumed Participants per Segment	Cumulative Number of Assumed Participants	Unit Capital Cost ($/participant)	Unit O&M Costs ($/year/participant)
Length of "Representative Area" (Segment 1)	40	140	$3.0M	7.2	4.9	$2.5M	64,100	$420M	$15.5M	17	17	$24.7M	$0.91M
Further South to Fresno Area (Segment 2)	80	220	$4.4M	21.8	14.7	$7.5M	192,500	$912M	$24.4M	34	51	$17.9M	$0.48M
Further South to Visalia Area (Segment 3)	60	280	$6.8M	32.6	22.1	$11.7M	289,400	$1,562M	$31.2M	26	77	$20.3M	$0.41M
Further South to Bakersfield Area (Segment 4)	80	360	$9.8M	47	32	$16.8M	420,300	$2,480M	$40.1M	34	111	$22.3M	$0.36M

* Includes 100 miles of conveyance from Representative Area to San Francisco Bay Area; no brine/wastewater contribution is assumed in this reach.

1. The brine line will carry whole wastewater streams from food processor facilities only. The most likely scenario in which a brine line would be implemented would be in conjunction with other discharger sectors; however, modeling such a scenario was outside the scope of this project and would involve determining/estimating the flow from participants other than food processor facilities.

2. As indicated in Table 120 the estimated total brine line capital cost per mile for a 21.8-MGD design flow is based on the cost being incurred for the very similarly sized Calleguas brine line, currently in construction as discussed earlier in this section. The total brine line capital costs per mile for the other three design flows were estimated proportionally from those associated with the 21.8-MGD design flow, and are not based on any new hydraulic engineering calculations for the Representative/Study Area.

3. This table contains information on the main conveyance line. Information on the length and cost of the associated collection system is not included here, but is addressed with respect to the POTW and centralized, dedicated treatment alternatives described in Sections III.6 and III.9 of this report, respectively.

4. Food processor facility locations and characteristics within the Representative Area were available to the study team; such information outside of the Representative Area was not. Therefore, for the purposes of sizing, costing, and estimating numbers of participants for the brine line alternative through reaches southeast ("upstream" through the Study Area of San Joaquin Valley), the study team assumed food processing facilities are located along the Highway 99 corridor in the same approximate density as the participating facilities in the Representative Area as described in Sections III.6 and III.7 of this report. That is, using the Representative Area as the model, the design (maximum monthly) food processor flow for the 40 miles of Highway 99/main conveyance line was calculated to be 7.2 MGD, and this ratio of contributing design flow to main conveyance line length (0.18 MGD design flow per mile) was applied throughout the three additional brine line reaches indicated in the table, roughly following the Highway 99 corridor.

5. The average salinity concentration in food processing facility wastewater for the Representative Area (1,570 mg/L) and the average food processing flow rate for the Representative Area (4.9 MGD) were used to estimate the quantity of salt removed (in lb/day) in each of the scenarios indicated in the table, using a similar extrapolation of average flow rate throughout the Study Area (San Joaquin Valley) as described for the design (monthly maximum) flow rate in #4 above.

6. All costs included in this table are conceptual-level for preliminary/feasibility-level studies such as this, and therefore carry a -30% to +50% variability, as

discussed in Sections III.6 and III.7 of this report, which discuss POTW and centralized, dedicated treatment facilities, respectively. For this brine line alternative, this level of variability should be considered a minimum (i.e., actual costs could easily vary much more from the conceptual-level cost estimates presented here), because of the:

- Large numbers of municipalities, counties, special districts, and other stakeholders that would be involved in the implementation of brine line in either the Representative Area or the Study Area.
- Low degree of precedence (limited number of similar previous projects).
- High degree of right-of-way, easement, land acquisition, and environmental permitting/documentation issues, costs, and unknowns associated with such a geographically extended project in California.

7. Pump station costs assume one pump station every 70 miles. Based on information available to the study team, the SARI brine line operates without any pumping, also through relatively flat topography, but pumping was conservatively assumed to be necessary for the brine line considered for the Representative Area and Study Area given the flat nature of the San Joaquin Valley and the long distances being considered. Each assumed pump station is assumed to consist of several 100-hp booster pumps of 2.4-MGD capacity each. The number of booster pumps at each station depends on the design flow at that location in the brine line. The cost of one pump as described above was taken as approximately $840,000, based on recent pump costing information available to the study team.

8. Total capital costs indicated in the table were estimated by adding the estimated brine line cost per mile for corresponding design flows for each segment times the corresponding length and the assumed pump station costs. Corresponding lengths, design flow rates, and costs are presented in the table below.

Table 120: Cost of Construction Segments

Design Flow (MGD) [cost/mile] ($/mile)	140 miles	80 miles	60 miles	80 miles	Cumulative Capital Cost for Pipeline
Segment 1 : 140 miles					**$420M**
7.2 [$3.0M]	X				$420M
Segment 1-2 : 220 miles					**$912M**
14.4 [$3.7M]		X			$296M
21.8 [$4.4M]	X				$616M
Segment 1-3 : 280 miles					**$1,562M**
10.8 [$3.5M]			X		$210M
25.2 [$5.0M]		X			$400M
32.6 [$6.8M]	X				$952M
Segment 1-4 : 360 miles					**$2,480M**
14.4 [$3.7M]				X	$296M
25.2 [$5.0M]			X		$300M
39.6 [$7.8M]		X			$624M
47 [$9.0M]	X				$1,260M

9. Total O&M costs are based on the Santa Ana Watershed Project Authority (SAWPA) budget for FY 2008-09, which estimates Santa Ana Regional Interceptor (SARI) O&M costs at $8M/year for the 73 miles of the SARI maintained by SAWPA. The resulting annual unit O&M cost of $0.11M/mile/yr of brine line was used to estimate the brine line O&M costs for the alternative described in this section. These collection system O&M costs are much higher than those indicated in Sections III.6 and III.7 of this report, because they also include end-of-brine-line treatment-related recurring expenses (based on flow, BOD, and TSS) as well as costs for contracted O&M services, contracted pre-treatment program services, manhole lid adjustments and sinkhole repairs, and SAWPA staff time, as well as irregular O&M expenses including as-needed pipeline inspections, cleaning, and repairs; developer-requested SARI infringements or relocations; and other unscheduled activities. Total O&M costs shown also include an assumed annual pump station O&M cost of 3% of the respective pump station capital costs.

2. End-of-pipe Discharge Issues

Discharge from a brine line typically occurs via a submerged marine outfall, typically ranging from one to five miles in length. Discharge of brine waste usually requires extensive permitting. While there are no State Water Resources Control Board California Ocean Plan Water Quality Objectives that apply specifically to brine waste discharges from desalination plants or groundwater desalting facilities, baseline monitoring of some outfalls are being conducted under the 2005-2008 California Ocean Plan Triennial Review and Workplan.

If brine wastes are mixed with domestic and/or industrial wastewaters, then a NPDES permit is required for discharge to the ocean with regulations limiting temperatures, concentrations of salts, and toxic compounds that is more restrictive than if brine-only waste is discharged. In addition to discharge permitting, generally administered by a Regional Water Quality Control Board on behalf of the State Water Resources Control Board, multiple other federal, state, and local agencies may need to be involved in a brine line project, including the following examples:

- Federal regulatory entities (US Army Corps of Engineers, US Fish and Wildlife Services, US Department of Interior)
- State regulatory entities (California State Historic Preservation Office, CEQA lead agencies, California State Lands Commission, San Francisco Bay Conservation and Development Commission, California Department of Fish and Game)
- Local regulatory entities (e.g., counties, municipalities)

When dealing with either brine-only waste or mixed brine waste discharged to the ocean, the main marine environmental issues of concern are:

- General water quality impacts (e.g., overexposure to strong brine can be toxic to marine organisms, change in temperature gradient can result in a decrease of dissolved oxygen necessary for marine organism respiration).
- Benthic toxicity (usually brine wastes are denser than receiving ocean water, tend to sink and are potentially a threat to benthic organisms for salinity increases of more than 1 part per trillion).
- Lack of dilution of dense brine effluents (mixing of different density entities such as discharge brine waste and receiving ocean water is limited along the ocean floor).

While mitigation measures are functions of the local receiving water ecosystem, generic possible mitigation options of brine-only waste or mixed brine waste discharge include:

- Reduce TDS and other salinity compounds by desalination treatment and/or mix brine wastes with treated effluents before discharge to the ocean.
- Avoid discharge in the vicinity of known sensitive ecosystems.
- Mix brine and non-brine wastewaters prior to ultimate discharge rather than allow mixing to occur on the ocean floor, especially because brine is denser than ocean water and mixing is limited on the ocean floor.
- Study the mixing/dilution zone and develop a discharge plume model to optimize discharge management.
- Conduct baseline tests prior to discharge and monitoring tests during discharge to account for impacts to marine life.

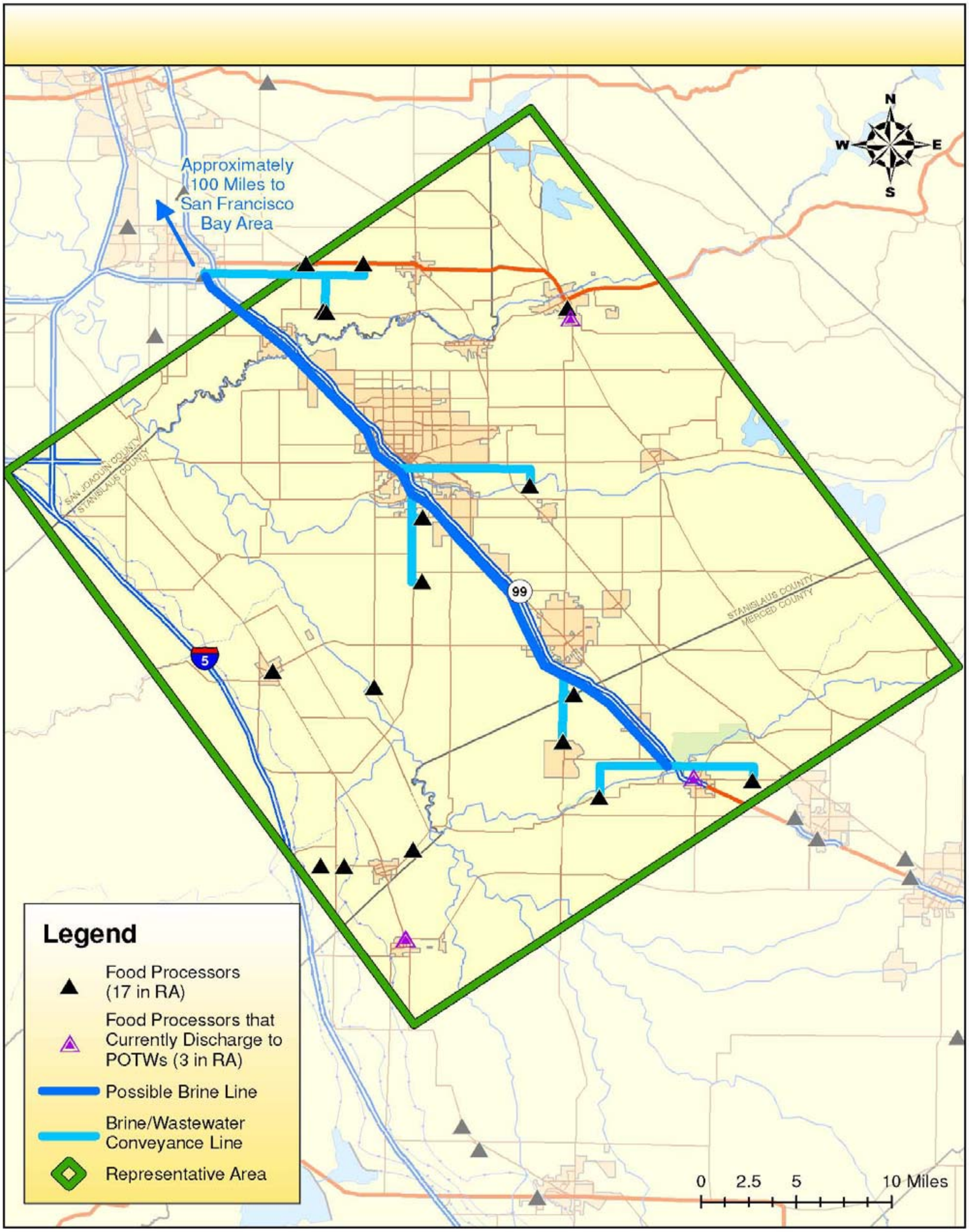
Approximately 100 Miles to San Francisco Bay Area
N
W
E
S
99
5
SAN JOAQUIN COUNTY
STANISLAUS COUNTY
STANISLAUS COUNTY
MERCED COUNTY
Legend
Food Processors (17 in RA)
Food Processors that Currently Discharge to POTWs (3 in RA)
Possible Brine Line
Brine/Wastewater Conveyance Line
Representative Area
0 2.5 5 10 Miles

Figure 50

III.9 Deep Well Injection Salinity Management

A. Technology Description

Deep Well injection provides another alternative salt management technology. As with the other sections describing salinity management technology options, this section provides conceptual-level descriptions and cost relationships to enable comparisons and does not recommend any "preferred alternative" for the Representative Area of the Central Valley.

Deep underground injection systems have been in use since the late 1950's for disposal of industrial and hazardous waste. The systems are designed to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers. Thus, these systems can be considered an out-of-basin solution to salt management. According to the US EPA, the equipment and methodology are readily available and well known although their use is strictly controlled.[161] Hilmar Cheese recently installed a deep well injection system for brine disposal, which is under US EPA review and another cheese manufacturer in the Central Valley has reportedly applied for a permit for a system as well. An earlier attempt to use deep well injection by the Westlands Water District was unsuccessful. The well clogged after only a few years of operation and had to shut down.

A typical injection well consists of concentric pipes extending down several thousand feet down from surface to highly saline, permeable injection zones that are confined vertically by impermeable strata. The outermost casing extends below the base of any underground sources of drinking water and is cemented back to the surface to prevent contamination.

Several factors may limit the applicability and effectiveness of deep well injection systems including:

- Potential seismic activity prevents the use of deep well injection
- Wastes must be compatible with the mechanical components of the injection well
- High concentrations of suspended solids (typically >2 ppm) can lead to plugging of the injection interval
- Corrosive media could react with the injection well components, with injection zone formation or confining strata. Wastes must be neutralized to avoid this.

[161] The Safe Drinking Water Act (SDWA, 1974) gave the United States Environmental Protection Agency (US EPA) the authority to control underground injection to protect underground sources of drinking water (USDW). EPA published final technical regulations for the Underground Injection Control (UIC) program in 1980, which, in particular, defines five types of injection wells. Many waste injection wells, including food processing brine disposal fall in Class 1. A Class 1 Injection Well is defined as a well injecting industrial or municipal wastewater beneath the lowermost formation containing, within one-quarter mile of the well bore, USDW. The exact definition is provided in title 40, Sections 144 and 146, of the Code of Federal Regulations. The Class 1 well requirements are designed to minimize risk of injectate migration into USDW.

- High iron concentrations may cause fouling
- Organic carbon may serve as an energy source promoting the growth of indigenous or injected bacteria resulting in fouling. Pretreatment may be required to avoid this.
- Waste streams combining organic contaminants above their solubility limits may require pretreatment before injection.
- Site assessment and aquifer characterization are required to determine suitability of site for wastewater injection
- Extensive assessments must be completed prior to receiving regulatory approval.[162]

B. Technology Costs

A study by Mickley et. al (2001) for the Department of Interior Bureau of Reclamation provides a starting point for estimating the costs of a deep well injection system.[163] The key planning and capital elements are:

1. testing and survey
2. drilling and reaming
3. installed casing
4. installed grouting
5. installed injection tube
6. installed packer
7. mobilization costs
8. monitoring well costs

These costs are all a function of tubing diameter and depth size. Assuming a tubing diameter of 5 inches and a depth of 3750 ft, the planning and capital costs would total about $7.4 million in 2007 dollars. Operating costs include pumping and pretreatment. Based on discussions with local engineers, these costs total $600,000 annually.[164] Additionally, the brine must be concentrated to reduce the volume of liquid disposed. Assuming that an RO system is installed to accomplish this, additional capital costs of about $1 million must be added and annual operating costs should be increased by an equivalent amount.[165] Thus, a total capital cost of $8.4 million would be incurred, with an annual total operating and maintenance cost of $1.6 million. Since the 5 inch diameter pipe can handle a flow rate of between 0.46 and 0.92 mgd depending on the flow velocity, assuming an average flow rate of 0.56 mgd and a brine concentration of 10,000 mg/L TDS results in an average cost of $258 per ton of salt removed. These calculations are summarized in Table 102 below.

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[162] U.S. EPA, Federal Remediation Technologies Screening Matrix and Reference Guide, Version 4.0.
[163] M. Mickley, "Membrane Concentrate Disposal: Practices and Regulation," Final Report Prepared for the United States Department of Interior, Bureau of Reclamation Agreement No. 98-FR-88-0059, Section 9, September 2001.
[164] Burt Fleisher, Hilmar Cheese and Phyllis Stanin, Todd Engineers.
[165] This figure is roughly consistent when scaled with the cost analysis of the Low Pressure Reverse Osmosis system in Section VIII of this report.

Table 121: Sample Deep Well injection Cost per Ton

Sample Well Depth	Expected Pipe Diameter	Flow Rate	Capital Cost	O&M Cost	Total Annualized Cost	Gallons per Ton Salt	Tons of Salt per Year	Cost per Ton of Salt
ft	in	mgd	2007 $	2007 $	2007 $	gal/ton	tons/yr	$/ton
3,750	5	0.56	$8,443,818	$1,615,377	$2,164,659	23,965	8,401	$257.66

Notes:
1) Gallons per ton of salt is estimated for a 10,000 mg/L TDS effluent (injectate) stream.
2) Capital cost includes deep well construction and materials, as well as $1 million for an RO pretreatment plant.
3) O&M cost includes deep well O&M as well as $1 million annual RO costs and $500k annual biocide and mineral anti-scaling pretreatment costs.
4) Deep well capital and O&M costs in 2001 dollars were inflated to 2007 dollars using the producer price index for Drilling Oil and Gas Wells.
5) Capital costs are amortized over 30 years with a discount rate of 5 percent.

Sources:
"Drilling Oil and Gas Wells - Producer Price Index, Bureau of Labor Statistics, Series PCU213111213111.
"Membrane Concentrate Disposal: Practices and Regulation," Mickley and Associates, September 2001. For US Dept. of Interior, Bureau of Reclamation, Water Engineering and Research Group.
Personal communications with local engineers.

III.10 Comparison of Alternatives

The preceding sections have described the configuration and potential costs and benefits of several alternative approaches to salt management in the food processing industry. This section presents a comparison of these alternatives. Recall that one of the principal messages of this SEP study is that local scale analyses are needed to correctly interpret the impacts of salt management policies and requirements. An implication of this observation is that we must be mindful that the comparison of alternatives is limited to the conditions prevailing in the representative area. Applying an analysis such as ours to different areas, even within the San Joaquin Valley, may produce different results.

1. *Land application is expected to result in relatively small impacts to urban and agricultural water consumers in the representative area.*

In the representative area, the impacts of current land application practices on agricultural and urban water use are small. Section III.4 documented that the expected consumer and producer losses resulting from salts in food processing industry wastewater are roughly $400,000 per year between now and 2030. At a 5 percent real rate of discount, these losses have a present value of less than $8 million.

The basic reasons for this finding are the highly localized nature of the salt plumes emanating from land discharge sites, the availability of surface water in the representative area, and the fact that there is little current or planned urban growth near land discharge sites.

This finding also implies that there is little expected benefit from the in-plant and regional solutions relative to the land application alternative. The main benefit of these alternatives, and others discussed below, is that they may provide an additional margin of safety with respect to avoidance of injury to water consumers in the future.

2. *Land application as it is now practiced results in few external impacts.*

There is a distinction between pollution and externality. Pollution occurs when environmental quality is degraded. An externality occurs when an action of one agent reduces the wellbeing of another. In the situation at hand, the effects of salts in wastewater as measures in Section III.4 occur almost entirely within the land application site itself. Thus, these effects are internalized by producers who own and operate the parcels of land where discharge occurs and are part of the recognized cost structure of land application.

The distinction between pollution and externality is an important one for regulators to bear in mind. External effects are a classic motivation for public intervention to prevent discharge of pollutants. If there is pollution without externality, then profit-maximizing firms will arrive at the optimal solution without help from the government. In such a case, the main motivations for government intervention would seem to be quantifying risk and uncertainty and providing the public with an adequate margin of safety.

3. *The localized nature of groundwater quality changes resulting from land application imply that land use and water quality regulation can be integrated to protect beneficial uses.*

In some cases, pollution causes changes in ambient conditions throughout an entire region. This circumstance is especially common in air pollution, where there can be thorough mixing of contaminants. In the case of the representative area, salt contamination of groundwater is a highly localized phenomenon, and discharge of saline wastewater does not have an effect on water quality beyond a radius of a few hundred meters.

Because water quality impacts of land discharge are so localized and specific, it is possible to integrate land use and water quality regulation to even further reduce expected externalities and provide a margin of safety. Separation of hazards over space is a basic principle of environmental planning, and is the principal motivation behind common land use regulations like zoning. Creation of a buffer zone between incompatible land uses can reduce externalities and increase social welfare. Of course, there are costs of zoning, particularly if it reduces the stock of developable land or relocates land uses to less desirable locations, but in general it represents a non-technological, non-structural alternative to salt management.

One possibility is to change the location of land discharge by engaging in targeted land application. In such an alternative, land application would occur in areas with poor quality (i.e., high-TDS) receiving water and even less chance of being urbanized that was modeled in the representative area. For example, the western side of Stanislaus County has generally less potential for urban development than the central and eastern portions of the county. Conveying wastewater to the western portion of the county and land applying would result in a small decrease in the expected costs of land application, and may also reduce uncertainty about external impacts. This latter effect may be economically more significant in the case of the representative area.

Another possibility is for land use planners and developers to recognize differences in water quality conditions and factor these into decisions about where to place housing. Such considerations are commonplace with respect to contaminants like solvents, perchlorate and the like. An important benefit of locating housing away from land discharge sites is that it can help reserve the agricultural economy in the Central Valley. Food processing is an essential component of the agricultural sector in California, and as discussed in Section III.3, many farmers co-locate with these facilities. Reducing environmental pressures on food processors can help sustain this economy and avoid the far-reaching consequences of processors choosing to leave the state.

4. *The costs of technological and structural alternatives can be compared in terms of cost per unit of salt removed.*

Table 122 shows the alternatives considered in the preceding sections in terms of their capital and operating cost per unit of salt removed. Two target levels of salinity reduction are considered: 300 mg/L TDS above background and complete removal of salt out of basin. Note that not all alternatives remove the same aggregate amount of salt. The text in Sections III.5 through III.8 contains information on the quantity of salt abated.

Table 122: Comparison of Costs per Ton for Various Salinity Reduction Methods

Method	Cost per Ton TDS 300 mg/L above Background	Cost per Ton TDS Out of Basin
In-Plant Treatments		
Food Loss Recovery		
Tomato Processor	-$6,469	N/A
Milk Processor	$3,249	N/A
Boiler Feed Water Treatment		
Tomato Processor	$1,693	$6,006
Chemicals Recovery		
Milk Processor	$194	N/A
Supply Water Treatment		
Tomato Processor	$3,315	$7,628
Milk Prcoessor	$3,017	$7,330
Winery	$1,627	$5,940
Meat Processor	$3,576	$7,889
EOP Effluent Treatment		
Tomato Processor	$3,821	$8,134
Milk Processor	$1,663	$5,976
Winery	$2,251	$6,564
Meat Processor	$3,626	$7,939
Regional Treatments		
POTW Upgrade and Treatment		
620 mg/L TDS Target	$1,083	$5,397
Centralized MBR-RO Treatment		
620 mg/L TDS Target	$1,761	$6,075
Out-of-Basin Alternatives		
Brine Line Export		
Representative Area (140 mi - 17 participants)	N/A	$3,658
To Fresno Area (220 mi - 51 participants)	N/A	$2,382
To Visalia Area (280 mi - 77 participants)	N/A	$2,513
To Bakersfield Area (360 mi - 111 participants)	N/A	$2,624
Deep Well Injection	N/A	$258

Notes:
1) Capital recovery for in-plant treatments over 10 years with 12% discount rate.
2) Capital recovery for regional treatments, brine line, and deep well injection over 30 years with 5% discount rate.
3) Cost per ton out of basin adds a $4,314 shipping cost per ton to transport brine by truck out to East Bay Municipal Utility District (EBMUD for disposal), and also includes a disposal fee. This additional cost is added to in-plant and regional treatment methods, which do not export salts out of the basin.
4) Food loss recovery and chemicals recovery are zero-waste methods of salinity reduction; no salt or brine needs to be exported.

There is a relatively wide variation in terms of the cost effectiveness of the alternatives. Generally, the costs of in-plant measures vary among industries but are among the most expensive alternatives considered. There are a few opportunities for reducing salt at low cost in-plant methods (i.e., choosing alternative cleaning products and chemicals recovery), but these address only a small amount of salt and are not applicable to all food processing industries. Supply water treatment and end-of-pipe (EOP) effluent treatment are viable options if water supply or effluent is highly saline: cost per volume of water is fixed for these treatments, and thus cost per ton of salt decreases as salinity increases.

Figure 51 compares the cost of different salinity management options assuming a target TDS level of 300 mg/L above background. The average costs for the in-plant treatment methods (supply water treatment and EOP effluent treatment) among the food processor types are shown. Treatment methods that are specific to certain food processing industries, such as food loss recovery and chemicals recovery, are not shown. Note that supply water and EOP effluent treatments are generally the costlier methods of in-plant treatments. Depending on the level of salinity reduction required, in-plant treatment options may be significantly cheaper than shown. Also note that the brine line and deep well injection alternatives remove all the salt from the basin, and therefore meet a more stringent standard than 300 mg/L TDS above background.

Similarly, Figure 52 compares the cost of the different salinity management options assuming complete removal of salt out of the basin. In this scenario, supply water treatment is not a complete solution because any salts added by food processing would not be exported. Thus, supply water treatment is not shown in the figure. For this complete removal scenario, in-plant and regional treatment options incur additional costs to move the concentrated brine out of the basin. We conservatively assume that brine is trucked and disposed out of the region. This is a very expensive method of exporting salt because transportation costs are high. There may be cheaper alternatives for salt disposal, such as the use of evaporation ponds and the disposal of solid salt waste at landfills.

Regional and in-plant treatment options are cheaper than a brine line for a target TDS level of 320 mg/L above background. When all salt needs to be removed out of basin, however, the brine line and deep well injection methods become more attractive. Deep well injection appears to be the least-cost method for areas where it is a viable option.

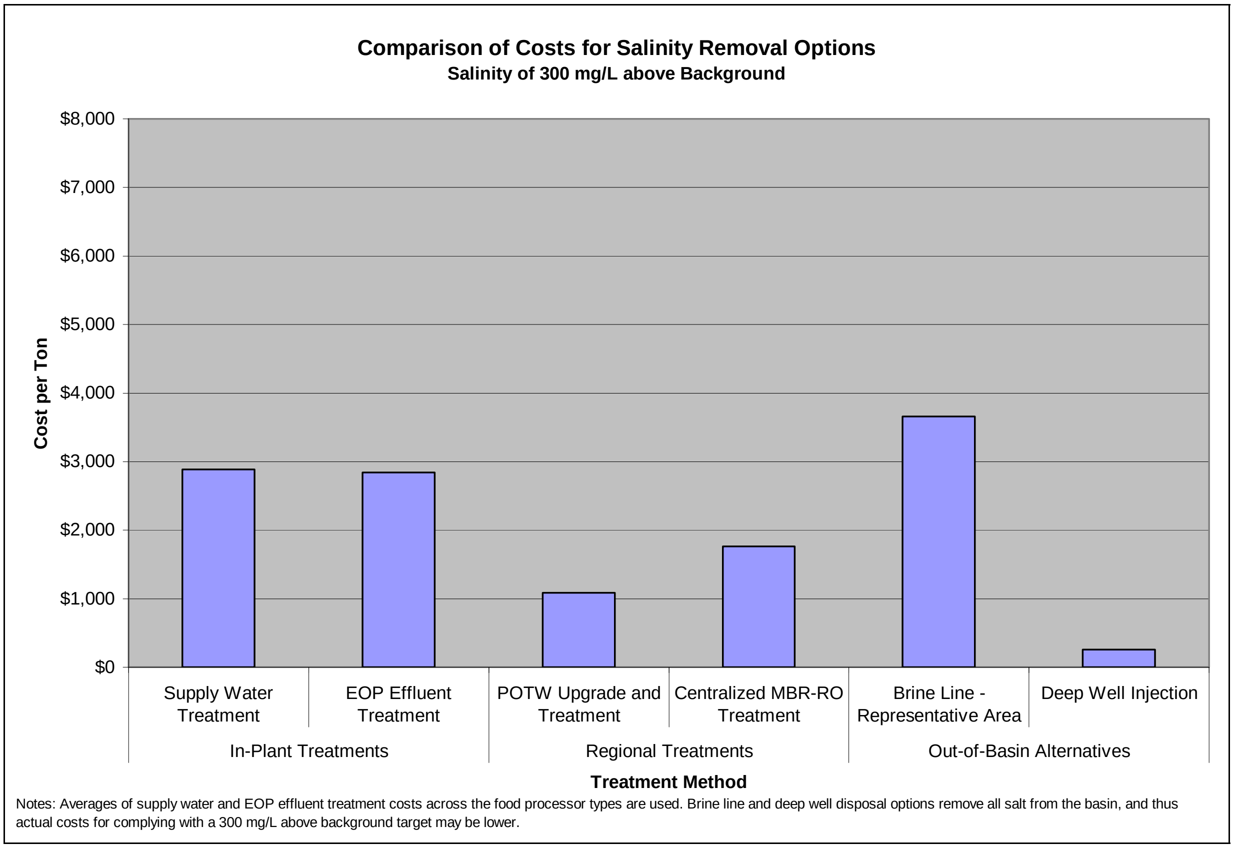
Comparison of Costs for Salinity Removal Options
Salinity of 300 mg/L above Background
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Cost per Ton
Supply Water Treatment
EOP Effluent Treatment
POTW Upgrade and Treatment
Centralized MBR-RO Treatment
Brine Line - Representative Area
Deep Well Injection
In-Plant Treatments
Regional Treatments
Out-of-Basin Alternatives
Treatment Method
Notes: Averages of supply water and EOP effluent treatment costs across the food processor types are used. Brine line and deep well disposal options remove all salt from the basin, and thus actual costs for complying with a 300 mg/L above background target may be lower.

Figure 51

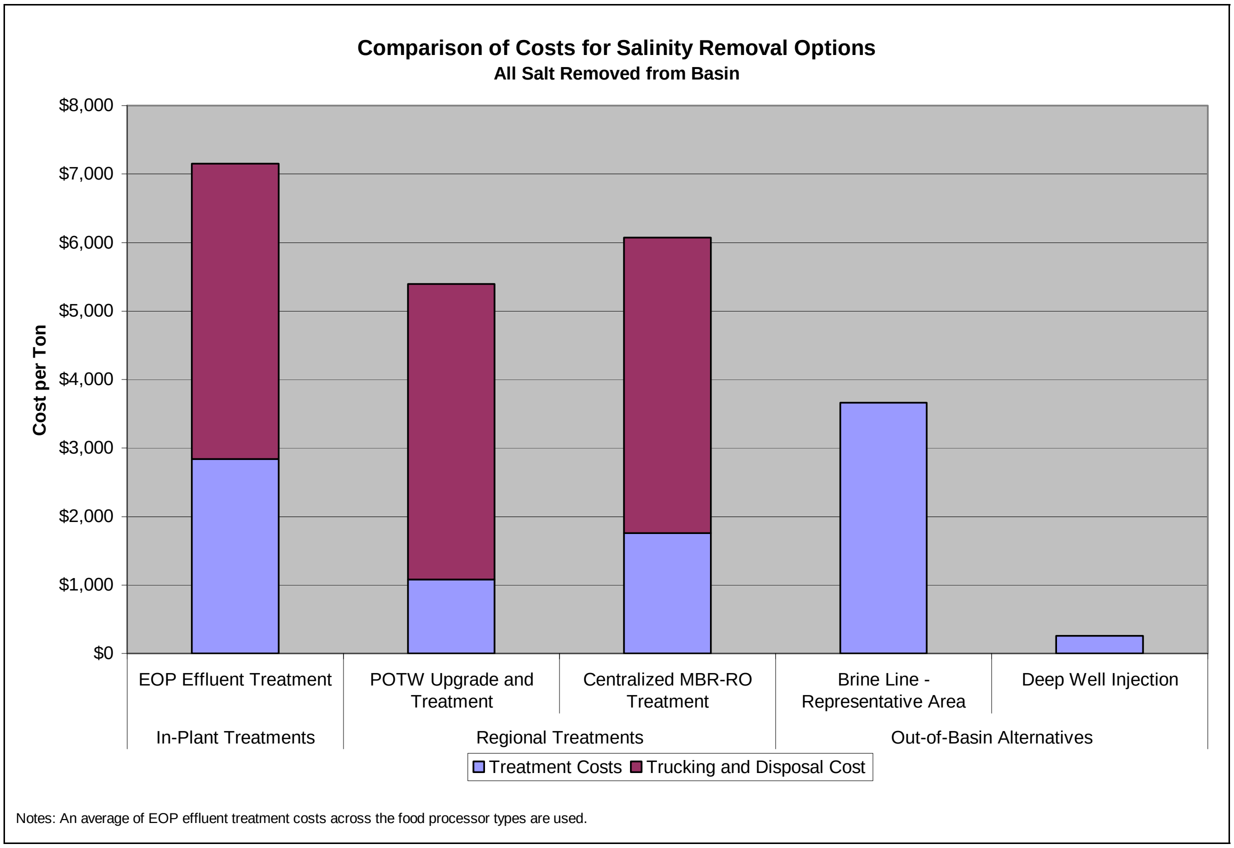

Figure 52

5. *Regional treatment options are less expensive than in-plant treatment in the representative area.*

There are two regional treatment options – POTW upgrades and construction of a dedicated facility. Discharge to a POTW is somewhat more cost-effective than construction of a dedicated facility owned by firms in the food processing industry. For comparable levels of salt reduction, the POTW option is roughly 40 percent less expensive than the dedicated facility.

For a 320 mg/L TDS above background target, the brine line option is more expensive than either of the two in-region central treatment alternatives. However, as a complete salinity removal option, it is cheaper than regional treatments plus trucking and disposal costs. Should evaporation ponds with landfill disposal be viable, however, a regional option could be less expensive as complete removal option. As discussed in Section III.8, the average cost of salt disposal via a brine line varies with the configuration and length of the line. As the line is extended, more food processors can be added which reduces average cost, but requires extra investment in capacity and construction costs. The minimum-average cost configuration is a line running 220 miles to the Fresno area; this design results in a cost per ton of salt removed of $2,382. The average cost of this option per food processing facility is roughly $1.6 million each year.

6. *Based on a preliminary review of available data, deep well injection may prove a very low cost alternative where geological conditions allow.*

Deep underground injection has been in use for decades for disposal of liquid waste. Environmental concerns led to strict regulatory control of this approach to protect underground sources of drinking water. Data collected to date suggest that deep well injection costs can be well below most of the alternatives considered. Thus, the limiting factor in the application of this approach will be access to land with the geologic conditions sufficient to avoid any threats to groundwater that is currently or expected to support an important beneficial use. Some land meeting this requirement does appear to exist within the representative area. It is not possible, however, without thorough testing to know how much of this land exists and where it is located.

It bears repeating that these comparisons of alternatives are valid only for the representative area, and only for the types of food processing facilities located there. Applied to another region of the Central Valley, the results may be quite different. However, one factor that is applicable to other regions is the general approach to consideration of impacts developed in this study. In particular, there appears to be a significant gain from consideration of land use changes, and from detailed hydrogeologic modeling. Without these two tools, it would be nearly impossible to compare the actual costs and benefits of water quality regulations at a specific location.

III.11 Policy Analysis

This section considers the implications of the hydrogeological and economic modeling results for salinity management in the Central Valley. This section also reviews existing salt management polices and describes various policy options that might be applied in the Central Valley. Concerns about salinity management are by no means restricted to the Central Valley. Other areas in the United States and abroad also face significant concerns regarding rising salinity levels. Several policies have been implemented by jurisdictions within the Valley as well.

A. Overview

The previous sections indicate that the costs of alternative salinity control measures available for food processing wastewater are generally well above the negative impacts of land application. For example, consider the POTW alternative that has relatively lower costs of salt removal than the other regional alternatives assuming a discharge target of 300 mg/L above background. For this alternative, annual capital and O&M costs of the POTW option range from $13 to $34 million for the entire representative area. The negative impacts of land application (including those experienced by the owners of the land application sites and thus incorporated into their costs) are around $400 thousand annually, again for the entire representative area. The complete removal of representative area salt discharge from the basin appears even less reasonable. Even if low cost deep well injection were universally available to accomplish this, its costs could not be justified by the modest negative impacts avoided. A more rigorous methodology for measuring these tradeoffs is presented in **Section III Appendices: Appendix III.1**

The previous sections also demonstrate that every disposal point is unique and should be judged on a case-by-case basis. This is consistent with the interim framework implemented by the Board as described in Volume 1. The modeling results also indicate that discharge thresholds should be established on a case-by-case basis recognizing the specific potentially negative impacts of particular locations and expected salinity concentration migration. This appears to be a departure from the interim framework that the Board should consider.

To the extent, however, that multiple food processors (or other salt discharge sources) are found to contribute to a common groundwater source, the results of our modeling suggest that a regional solution would be preferable to a plant by plant control strategy. This is supported by practical experience in the Central Valley and elsewhere and also makes sense as a matter of economics. These experiences are described below, followed by some examples of how one particular regional solution would work.

B. Domestic Salinity Control Policies

1. Salinity Management for Food Processors in the City of Tulare

The industrial POTW in the City of Tulare received a cease and desist order in October 2002 due to violations of new waste discharge requirements. Tulare also has a separate domestic treatment plant. Compliance issues included salinity (EC), biological oxygen demand (BOD), total suspended solids (TSS), and nitrate concentrations in the treated water.[166]

Under the old permit, oxygen demand limits were measured by chemical oxygen demand (COD), which the industrial plant satisfied. The new permit, however, switched to measuring biological oxygen demand, which the domestic plant satisfies, but the industrial plant does not satisfy.

The industrial plant also failed to meet the TSS requirements, since it was designed as a facultative lagoon and not concerned with TSS. Algae in the lagoon is the main contributor to the TSS problem. While the permit does not specify an effluent nitrate limit, there is a nitrate groundwater plume caused by over application of effluent to the land. These symptoms require that the industrial plant be replaced or redesigned.

Salinity in the industrial plant is largely caused by six milk processing sources. These six dairy processors contribute roughly 75% of the salinity discharged to the treatment plants. Consequently, Tulare chose to implement a surcharge or tax on salinity contingent on the amount of electrical conductivity (EC) above a threshold determined by ambient water conditions as shown in Table 123. The surcharge is based on the pounds of TDS equivalent in addition to the EC and increases as discharge further exceeds the established threshold:[167]

Table 123: Tulare EC Surcharge Schedule

EC (µS/cm) over threshold	Surcharge $ per lb TDS equivalent
0-100	0.20
101-200	0.30
201-300	0.40
301-400	0.60
Over 401	2.00

The surcharge is designed to create an incentive for improved salt management at the dairies. As an additional incentive, timely corrective action would result in a large portion (90%) of this surcharge being returned to the dairies to reimburse them for their

[166] Jatal D. Mannapperuma and Miguel R. Santos, "Salinity Reduction in Dairy Processing Plants," A Report Prepared for the City of Tulare, September 2004 and Lewis R. Nelson, "Case Study: How the City of Tulare Handled Salinity from Food Processors," PowerPoint Presentation, February 27, 2007.

[167] An approximate equivalence between TDS and EC is: TDS (mg/L) = 0.6 * EC (µS/cm).

investments. Salts in dairy plant effluent come from several sources: chemical cleaning agents, milk and whey loss, source water supply, condensate of whey from reverse osmosis units, and evaporator condensate. For five of the six plants surveyed, chemical cleaning agents accounted for the majority of EC discharged, ranging from 51% to 80%. Milk loss was the second leading EC contributor, ranging from 19% to 40% of EC contribution.

The surcharge policy resulted in all dairies meeting the reduced salinity target. While this suggests that the policy was a success, the conditions present did not test the efficacy of the policy. All but one of the dairies found relatively inexpensive ways to meet the more stringent target in part because their discharges were not substantially above the initial threshold and in part because low cost process changes (rather than high cost technology) were sufficient. In addition, the surcharge schedule was not based on any environmental damages associated with exceeding the salinity discharge limits. Nevertheless, the effort demonstrated that economic incentives can be used to influence salinity discharge compliance if there is an impact on a common point, i.e. a POTW.

2. The San Luis Drainage Project

In May 2007 the U.S. Bureau of Reclamation issued its Record of Decision regarding its plan to provide agricultural drainage service to the Central Valley's San Luis Unit. The plan was designed to meet four objectives. These objectives called for a complete solution from production to disposal on a timely basis that relies on proven and cost effective technologies and minimizes adverse environmental effects and risks. The Bureau considered several alternatives including ocean disposal, Delta disposal and In-Valley land retirement. The Bureau selected the In-Valley alternative, which requires the retirement of 193,956 acres along with additional drainage projects, recycling/reuse, and evaporation ponds. The Bureau rejected ocean disposal, which called for a pipeline conveyance system running from near Los Banos to just South of Kettleman City and then to the Pacific at Point Estero, a distance of approximately 212 miles, based largely on a U.S. EPA ranking that the project presented "environmental objections-insufficient information."[168] This ranking was apparently the result of concerns about the long run impacts on the ocean. The Delta alternative received a similar ranking in view of the outstanding environmental concerns in the Delta.

3. Chino Basin Desalting Program

The Inland Empire Utilities Agency (IEUA) is a wholesale distributor of water and recycled water and provides regional wastewater treatment. Over 800,000 residents in the Chino Basin of western San Bernardino County are serviced by the IEUA.[169] Roughly 70% of its water supplies are from groundwater and other local sources.

[168] U.S. Department of Interior, Bureau of Reclamation

[169] IEUA Salinity Characterization Study for CCWRF, p. 1.

In 2001, the IEUA Board of Directors began developing a Salinity Management Action Plan that included: using the non-reclaimable wastewater pipelines to keep high TDS water out of the regional wastewater treatment system,[170] developing a residential water softener salt reduction program, reducing the TDS contribution from IEUA's treatment plant operations, and implementing an organics management strategy to protect the Chino Basin from salts from dairy operations.

The current recycled water produced by the IEUA's wastewater treatment plants averages 500 mg/L. The 2004 amendment to the 2000 Chino Basin Optimum Basin Management Program sets an anti-degradation TDS objective range of 250 mg/L and 290 mg/L, as well as a "maximum benefit" TDS objective of 420 mg/L for the basin. The basin objectives result in a TDS concentration limit of 550 mg/L for recycled water used for recharge or other direct uses.[171]

The major source of salinity in wastewater is from the raw untreated water that is supplied. The imported water supplies can vary significantly in salinity content: State Water Project from Lake Silverwood has an average TDS of 260 mg/L, while Colorado River water has an average TDS of 625 mg/L. Groundwater sources have TDS ranging from 100 mg/L to over 1,000 mg/L, while surface supplies typically have TDS under 100 mg/L.

At each step of water treatment and consumption, TDS levels increase. Treatment of raw water to create potable water adds an average of 50 mg/L, while the consumption of the potable water adds an additional 200-400 mg/L. Wastewater treatment adds another 50-65 mg/L.

It is estimated that residential use of self-regenerating water softeners can contribute an average TDS of 30-120 mg/L to recycled water, a significant portion of added salinity. Residential customers, however, are resistant towards eliminating water softeners, but are willing to take steps to reduce the salt released by their water softeners.[172] To this effect, the IEUA has enacted a "Pinch the Salt" outreach program that includes a public awareness campaign via direct mail and a website to solicit homeowners to repair or replace inefficient water softeners, to re-plumb the unit to hook up to hot water only, or to use portable exchange canisters instead of self-regenerating water softeners.[173]

The IEUA expects to avoid $376 million in future costs that would be incurred if IEUA had to desalt its recycled water at wastewater treatment plants to comply with the 550 mg/L limit.[174] This $376 million includes $250 million in construction and operation of desalination facilities at the Regional Recycled Water Plants, $120 million for

[170] The two non-reclaimable wastewater pipelines are the Santa Ana River Interceptor (SARI) and the Non-Reclaimable Waste (NRW) pipelines. The two pipelines discharge wastewater that is treated at the Orange County Sanitation District or the Los Angeles Sanitation Districts into the ocean. (IEUA Salinity Characterization Study, pp. 8-9.)
[171] IEUA Salinity Characterization Study for CCWRF, p. 2.
[172] IEUA Salinity Characterization Study for CCWRF, p. 3.
[173] Salinity Reduction Study, July 2005, <Options for Reducing Salinity within the Chino Basin2.pdf>.
[174] IEUA Salinity Characterization Study for CCWRF, p. 2.

construction of secondary and tertiary treatment facilities for high TDS flows, and $6 million for the purchase of additional water for groundwater recharge.[175] The cost to remove salt through wastewater desalters would average $828 per ton. In comparison, the Chino desalter costs $525 per ton, brine export through NRW pipeline costs $290 per ton, and co-composter costs $100 per ton.[176]

4. Metropolitan Water District of Southern California

Other areas of Southern California have also taken steps to reduce salinity content in both influent and effluent water. The Metropolitan Water District, for example, blends the relatively high TDS Colorado River water with lower TDS State Water Project water to meet its treated water salinity objective of 500 mg/L (roughly half of the region's salt comes from imported water, while the other half comes from local sources). Additionally, local agencies within the Metropolitan Water District (including Chino Basin) have constructed groundwater desalters, improved wastewater collection systems, and established water softener regulations.[177]

Metropolitan estimated in its 1999 Salinity Management Study that annual benefits of reducing the salinity of imported Colorado River Aqueduct and State Water Project water by 100 mg/L would exceed $95 million, and that an equivalent cost would be incurred with a 100 mg/L increase in salinity. [178] Furthermore, annual benefits of $64 million would be achieved if local groundwater and wastewater had their salinity reduced by 100 mg/L. Benefits include the increased life of plumbing systems, pipelines, and other infrastructure, as well as increased crop yields and other agricultural benefits.

In the Metropolitan Water District, imported water accounts for roughly one half of the annual salt contribution. Water from the Colorado River Aqueduct averages 700 mg/L in salinity. State Water Project (SWP) water is much lower in salinity, averaging 250 to 325 mg/L, but SWP salinity levels are more variable and change rapidly in response to hydrologic conditions.

Local salinity sources include natural salts, salts added by urban users, brackish groundwater intrusion into sewers, irrigation runoff, and animal waste. Urban use increases the salinity in wastewater 250 to 400 mg/L above background. The many sources of salinity flowing into wastewater treatment systems include salts from residential water softeners and industrial and commercial discharges that are not monitored for TDS. Water conservation programs exacerbate the salinity issue: internal recycling and water use reduction increase salinity concentrations of wastewater by 2 to 5 percent.

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[175] IEUA Salinity Characterization Study for CCWRF, p. 19. (Note that cost for groundwater is $6 million (20,000 AF at $300 per AF), which added to $250 and $120 is $376, not $430 million as stated in the text. $60 million in water would translate to $3,000 per AF, much too high.)

[176] IEUA Salinity Characterization Study for CCWRF, p. 18.

[177] Metropolitan Water District of Southern California, "Annual Progress Report to the State Legislature,"pp. 27-30.

[178] Metropolitan Water District of Southern California and the United States Department of Interior, "Salinity Management Study," Final Report, June, 1999.

A lynchpin in Metropolitan's plan for salinity management is maintaining an imported water salinity target of 500 mg/L through the blending of the Colorado River water with SWP water. However, this target is susceptible to disruptions in SWP supply, which would increase the salinity of the imported SWP in addition to reducing the amount of SWP water imported relative to Colorado River water. The MWD estimates that the imported water salinity target will be met only seven out of every ten years. Short-term solutions to a missed target include use of local groundwater and additional local project management. As long-term solutions, MWD is hoping to enact a CALFED project to reduce the salinity of SWP water by up to 100 mg/L as well as looking into an exchange for lower salinity Sierra water. A final method of reducing salinity is through desalination; MWD has begun research and development into economically viable desalination technologies.

Groundwater sources increase salinity due to agricultural and urban processes, as well as groundwater overdraft. Inland areas that do not have ocean or stream discharges accumulate salts in groundwater when water is reused because salt accumulates but is never removed. Groundwater overdraft near the coastline contributes to seawater intrusion, which also damages freshwater aquifers. Many groundwater basins in Southern California were also recharged with Colorado River Water in the 1950s and 1960s, resulting in many groundwater basins containing TDS of 1,000 mg/L or more.
Salt is accumulated at roughly 600,000 tons per year in the coastal plain of Southern California.

The MWD authorized a Salinity Management Action Plan based on its management study in 1999 to address the need to reduce salinity levels in Southern California through collaboration with other agencies within the region. The Action Plan consists of ten action items:

1) Support funding for the Colorado River Salinity Control Program as a means of reducing imported salinity.

2) Work with State Water Project to encourage the Department of Water Resources to engage in management practices that would aid MWD's salinity management objectives.

3) Blend water so that the 500 mg/L salinity objective is met, subject to water supplies and operational costs.

4) Pursue storage and exchange agreements of Colorado River Aqueduct water and transfers of Sierra water to lower the salinity of imported water. Pursue a system to convey low salinity groundwater through MWD's distribution system.

5) Integrate water quality and quantity objectives into system overview planning studies and Integrated Water Resource Plan.

6) Support local recycled water and groundwater desalination projects through the Local Resources Program.

7) Pursue research and development of advanced desalination technologies through the Desalination Research and Innovation Partnership.

8) Collaborate with other agencies in creating a Southern California Salinity Coalition, which would address salinity issues in the region through public education, salinity report cards, water softener studies, and pursuit of federal funding for the Colorado River Salinity Control Program.

9) Manage local wastewater discharge through the creation of more stringent discharge permits; expansion of regional brine disposal, including the planning of new brine disposal lines; and management of water softener brines.

10) Pursue groundwater management practices to minimize groundwater basin salt loading.

5. Colorado Basin

The United States has a formal agreement with Mexico to annually deliver a specified amount of water with specified salinity content. Minute No. 242 of the International Boundary and Water Commission is an agreement that the United States will ensure that 1.36 million acre-feet of water delivered annually to Mexico will have average salinity content of no more than 115 +/-30 parts per million, as measured upstream of Morelos Dam in Mexico, over the average salinity of the Colorado River arriving at Imperial Dam in Yuma, Arizona. The 1974 Colorado River Basin Salinity Control Act authorized the construction, operation, and maintenance of works in the Colorado River Basin to control the salinity of the water delivered to Mexico. Title I of the Salinity Control Act addresses the United States' commitment to Mexico and provides the means for the U.S. to comply with Minute No. 242. Projects authorized under Title I include the construction of the Yuma Desalting Plant, the Coachella Canal Unit, a protective and regulatory pumping unit, and a Reject Stream Replacement Study.

Title II of the Salinity Control Act authorized specific salinity control units upstream from Imperial Dam to meet the requirements of the Clean Water Act. Projects that have been completed under Title II include the Grand Valley Unit, the Las Vegas Wash Unit, the Lower Gunnison Basin Unit, the McElmo Creek Unit – Dolores Project, the Meeker Dome Unit, the Paradox Valley Unit, the Price-San Rafael Unit, and the San Juan River Unit.

Overall, salinity damages in the Colorado River Basin due to agricultural harm and degradation of infrastructure are estimated to be in the range of $500 million to $750 million in the United States, and roughly $100 million in Mexico. Benefits of salinity control were estimated to be $340 a ton, while costs ranged from $20 to $100 a ton (in 1994 dollars).

Two factors led to the increase in salinity in the Colorado River water: the Wellton-Mohawk Irrigation and Drainage District began pumping saline waters to lower the high groundwater levels below the crop root zone in the aquifer and discharged the saline water in the Gila River, a tributary of the Colorado River; and excess Colorado River flows were decreased because of low runoff in the Upper Colorado River Basin, which left less water to be mixed with the saline Wellton-Mohawk water. The increase salinity of the water caused Mexico to formally protest to the United States.

The Yuma Desalting Complex was created to improve the quality of saline irrigation drainage water pumped from the shallow aquifer beneath the farmlands of the Wellton-Mohawk Division of the Gila Project such that the water would be usable for delivery through the Colorado River to Mexico. Plant reject water is disposed through the Santa Clara Slough in Mexico. The desalting plant has the capacity to treat 97,300 acre-feet of water per year, converting the input of 2,900 parts per million of total dissolved solids (TDS) into 68,500 acre-feet of water with 295 parts per million, and 28,800 acre-feet of reject water with TDS of 9,400 parts per million. The treated water is mixed with roughly 10,100 acre-feet of untreated water to create 78,600 acre-feet of water.

The plant cost $256 million to complete and is expected to cost $30 million a year to operate at full capacity. Estimates of treatment costs range between $305 and $425 per acre-foot of water. The desalting plant was actually only used for eight months in 1992 before flooding destroyed some of the intake canals. Due to a period of high water levels throughout the 1990s, the plant was mothballed for over 14 years since the flow in the river sufficiently diluted the salinity of the Wellton-Mohawk Irrigation and Drainage District water to satisfy delivery requirements to Mexico. Amid the fears of a sustained drought and rising salinity levels, in early 2007 the plant was put on a test run at 10 percent capacity. The trial run had a cost of $330 per acre-foot, near the low end of expected costs. At full capacity, the plant would produce 80 million gallons per day of water, or nearly 90,000 acre-feet per year.

C. International Salinity Management, Australia – Murray-Darling Basin

The Murray-Darling Basin is a major agricultural zone in Australia, accounting for 41% of Australia's gross value of agricultural production. Irrigation is only used for 2% of agricultural land in the Basin but generates 40% of the Basin's farm gate primary production. The Murray-Darling Basin in southeastern Australia is geologically and climatically prone towards salt concentrating. The region's flat terrain and low rainfall, coupled with native vegetation that uses almost all the rainfall, contributes to groundwater that is often as salty as the sea. While native species in the area are capable of dealing with high salinity levels, the agricultural sector and urban water users in the Basin are more sensitive. The land use changes caused by settlement have filled the shallow aquifers in the region, causing a rise in groundwater that has brought the natural salt to the surface, collecting in the rivers. The impacts of salinity in the Murray-Darling Basin have been estimated to exceed $294 million AUD a year.[179]

The Salinity and Drainage Strategy of 1988 (S&D) was created to protect the water quality of the River Murray against rising levels of salinity. One aspect of the S&D Strategy was that irrigation districts could acquire the right to dispose of saline drainage water so long as they collaborate in building and operating works downstream that reduce salinity by at least twice as much as the disposal contributed to salinity. These salinity credits are tradable pollution rights.

The Salinity and Drainage Strategy states that:

1) river salinity levels from 1975 to 1985 serves as a baseline for attributing impacts of future actions that would affect river salinity;

2) each State in the Basin is responsible for its actions that affect river salinity; and

3) no actions that would increase salinity are allowed unless they are offset by mitigating works.

An interim objective was to keep salinity levels at Morgan (on the River Murray) under 800 EC for over 95% of the time. The S&D Strategy also included a package of actions that would provide immediate salinity reductions through river dilution flows (35 EC), jointly-funded engineering works (80 EC), and further provided 30 EC in salinity credits for drainage works and irrigation development.

In addition to the joint S&D Strategy, 14 major irrigation districts in the Basin developed Salinity Action Plans or Land and Water Management Plans to address salinity issues.

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[179] $1 AUD = $0.82 USD (as of 5/25/07).

While the S&D Strategy held the states to be fully accountable for future actions, it did not address past actions or the background baseline trend of increasing salinity. Thus, the S&D Strategy is not a long-term solution to salinity problems in the Basin. The Basin Salinity Management Strategy 2001-2015 was drafted to extend the success of the S&D Strategy basin wide. Additionally, it addresses the concern of a 1999 Basin Salinity Audit that showed that salt was being mobilized by rising groundwater tables which would collect in the Murray River and other rivers.

The Basin strategic approach includes nine elements that the states are committed to implement:

1) develop capacity to implement the Strategy

2) identify values and assets at risk

3) set salinity targets

4) manage tradeoffs with the available within-valley options

5) implement salinity and catchment management plans

6) redesign farming systems

7) target reforestation and vegetation management

8) construct salt interception works

9) ensure Basin-wide accountability in monitoring, evaluating, and reporting.

Accountability is provided through end-of-valley report cards and targets, commission salinity registers, salinity credits and debits, and participation in join salt interception works.

A joint program of salt interception works was agreed upon to recognize the fact that the salinity problem is not localized, and that everyone, not only the affected regions, should bear the costs of salinity management in the basin. Part of the expected 46 EC reduction is used to offset the "legacy of history" (i.e., the responsibility to offset the future salinity impacts of past actions).

The overall basin target is to keep salinity at Morgan under 800 EC for over 95% of the time. Additional targets are set for each of the tributary valleys in the basin. Furthermore, within-valley targets are set for states which are consistent with the end-of-valley targets.

A number of land management options are identified in the Basin Salinity Management Strategy, including groundwater control, efficient water use, replacing old water supply infrastructure, and placing new agricultural developments in areas with low salinity impact.

Additionally, other management options include stewardship of native vegetation; salt interception and disposal projects that divert drainage water to disposal sites; reuse of low salinity drainage water; pumping of low-salinity groundwater; and flow management.

Salt interception works dispose saline water flows through evaporation or other means. The S&D Strategy provided a joint works program that would reduce salinity at Morgan by 80 EC. The Basin Salinity Audit of 1999, however, estimated that the trend in salinity levels was an increase of 4 EC a year, over double what was previously thought to be the trend of 1.5 EC a year. Thus, the Basin Salinity Audit found that an additional reduction of 100 EC at Morgan was needed to stay on the basin-wide salinity target. A new joint works project will reduce salinity at Morgan at least 46 EC to 61 EC and will cost around $60 million AUD.

A system of credits and debits, with the currency being EC units at Morgan, is also enacted as a part of the Basin management strategy. Annual valley report cards and commission registers will ensure accountability for salinity management in the basin.

The cost of dryland salinity in the Murray-Darling Basin is estimated at $247 million AUD yearly, and the impact to consumptive users (irrigation, domestic, and industrial) is estimated at $47 million AUD a year.[180]

D. Policy Alternatives

State and local regulators have a range of policy alternatives to manage salinity in the Central Valley as indicated by the preceding review. In this section several alternatives are discussed including the continuation of a command and control policy imposed on a case-by-case basis, a cap and trade approach, and discharge taxes.

1. Command and Control

Command and control regulation generally refers to the imposition of specific pollution control technology or technologies on industry to meet a pollution reduction target. All pollution sources must use one or more of the designated technologies to meet a specific emission or discharge limit. Current salinity regulations most closely resemble this approach with some important differences. For example, all sources discharging to a particular water body in the region may be required to individually meet a specific discharge limit. The sources may have some choice regarding the method they employ, but all of them must meet the same limit. In the case of ground water, salinity dischargers may face different discharge limits depending on ambient water conditions and actual or projected impacts on groundwater salinity levels. They too may have some choice in how they achieve the required reduction. Command and control is appropriate in many

[180] Dryland salinity refers to salt from agriculture and other manmade sources. It excludes salinity associated with groundwater contamination from ocean intrusion.

instances since it works best when there is a common resource at issue and costs are similar across pollution sources. As discussed in Volume II, groundwater impacts from food processors tend to be very localized. Thus, a case-by-case evaluation of the tradeoffs between the costs of reducing salinity discharge and the consequences for beneficial use may frequently be in order.

2. Cap and Trade

There are instances where a number of food processors discharge effluent into a common sink such as a POTW. In these cases, it may be economic to implement a salinity cap and trade scheme where food processors with higher costs of reducing salinity levels can pay food processors with lower costs of reducing salinity through the purchase and sale of salinity credits. A trading scenario reduces the costs to the food processors while maintaining aggregate salinity reduction targets (such as average salinity of incoming wastewater to a POTW). In addition to cost savings for food processors, this can be beneficial for the counties by reducing the risk that food processing plants will leave the local economy. The cap and trade approach has been encouraged by the US EPA where there is a common pollution problem, sources have different control costs, and there are numerous sources.[181] Cap and trade, as noted above, is currently in use in Australia to help control that country's serious salinity management problem.

Tradable salinity rights have been shown to be more efficient in addressing salt issues than a salt levy per unit of water traded (as used by the Victorian Government in Australia) or other methods of government policy intervention.[182] As opposed to a salt levy on traded water, salinity credits unbundle the salt from the water, thus separating the scarcity of water quantity with the scarcity of water quality. Furthermore, establishing salinity credits effectively caps the total amount of salts in a system, obviating the need to adjust levies when water transfers are increased.

A hypothetical example using four food processors illustrates the benefits of a trading scenario. These plants include a milk processor, a winery, a meat processor, and a tomato processor. Each of the different types of food processor has a different set of salinity reduction options, as well as different costs for each salinity reduction option. Costs for each type of food processor are taken from Section III.5, which are considered marginal costs for purposes of discussion. In both the trading and non-trading scenarios, the regulators have set a limit on the salinity (FDS) concentration of water that enters the common disposal source (the POTW) with which all food processors need to comply. Furthermore, all food processors must reduce the salinity of their effluent in order to meet the salinity standards. In other words, no food processor has salinity credits prior to implementing any salinity reduction methods. Table 124 shows the four food processor plants with their methods of salinity reduction and corresponding costs and capacities.

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[181] U.S. Environmental Protection Agency, "Tools of the Trade, A Guide to Designing and Operating a Cap and Trade Program for Pollution Control," June 2003, EPA430-B-002.

[182] See Charlotte Duke and Lata Gangadharan, "Regulation in Environmental Markets: What Can We Learn from Experiments to Reduce Salinity?" *The Australian Economic Review*, vol. 38 (2005), no. 4, pp. 459-69.

Table 124: Summary of Hypothetical Food Processor Characteristics and Salinity Reduction Methods and Costs

Food Processor	Flow (million L/year)	Base FDS (mg/L)
Tomato Processing	419	531
Milk Processing	772	1592
Winery	473	1176
Rendering/Meat Processing	151	730

Food Processor	FDS Reduction Cost ($ per ton)				
	Food Loss	Boiler Feed Water	Chemicals	Supply Water	EOP Effluent
Tomato Processing	-$6,469	$1,693		$3,315	$3,821
Milk Processing	$3,249		$194	$3,017	$1,663
Winery				$1,627	$2,251
Rendering/Meat Processing				$3,576	$3,626

Food Processor	Maximum FDS Reduction Amount (# tons)				
	Food Loss	Boiler Feed Water	Chemicals	Supply Water	EOP Effluent
Tomato Processing	6	31		156	318
Milk Processing	101		143	317	1,348
Winery				360	610
Rendering/Meat Processing				47	121

A linear program model was created to calculate the gains from trade, which solves the system of equations below:

$$\min \sum_{i,j} c_{ij} \cdot q_{ij}$$

$$s.t. \quad q_{ij} \geq 0$$

$$q_{ij} \leq q_{ij}^*$$

$$\sum_{i,j} q_{ij} \geq L$$

where c_{ij} = cost per ton of reducing salt at food processor *i* using reduction method *j*

q_{ij} = number of tons of salts reduced at food processor *i* using reduction method *j*

q_{ij}^* = maximum amount of salt that can be reduced at food processor *i* using reduction method *j*

L = total tons of salt reduction required by regulation across all food processors (calculated from concentration standard).

In words, the model finds the minimum cost solution necessary to reduce salinity levels by a certain amount, subject to each individual food processor's constraints in costs and ability to reduce salinity. Each food processor has different methods to reduce salinity with different costs per ton associated with them. For example, chemical recovery is a relatively cheap method of salinity reduction, but only the milk processor has this reduction option and it also has limited capacity for reducing salinity. EOP effluent treatment, on the other hand, is available to all food processors, and has the capability for meeting nearly all salinity reduction requirements, but at a higher cost.

In comparison, the total costs to all the food processors for meeting a salinity reduction regulation without trading is equal to:

$$\sum_i (\min \sum_j c_{ij} \cdot q_{ij})$$
$$s.t. \quad q_{ij} \geq 0$$
$$q_{ij} \leq q_{ij}^*$$
$$\sum_j q_{ij} \geq L_i \text{ for all food processors } i$$

where L_i = total tons of salt reduction required by food processor *i* to meet a salinity regulation. The total cost in a non-trading scenario is always greater than or equal to the cost of a trading scenario for the intuitive reason that a food processor would not trade for salinity credits if it cost them less to reduce salinity levels themselves. Similarly, a food processor would be willing to trade salinity credits only if it could gain more money from trade than it costs to implement a salinity reduction method. Trading thus enforces an efficient outcome of salinity reduction, where the least expensive salinity reduction methods are utilized before any costlier methods are employed.

Assuming a target FDS concentration of 500 mg/L,[183] the four plants will need to reduce their salinity levels by a total of 1,335 tons of salt per year. Table 125 summarizes the results of the trading and non-trading models. If all the plants must implement salinity reduction options separately (i.e., without trading), then the total costs incurred by the plants is $2,021,962. However, if plants are allowed to trade salinity credits, then total costs are reduced to $1,948,009. A cost savings of $73,954 is gained to the four food processors when trading is allowed, or roughly 3.7 percent of the costs when trading is not allowed. Savings are the result of the fact that plants with cheaper salinity reduction options can trade salinity credits to the plants with more expensive salinity reduction options. Plants such as the meat processor, the plant with the most expensive salinity reduction methods, can save dramatically by trading for salinity credits gained from other plants using the relatively cheaper chemicals recovery method and EOP effluent treatment; otherwise, it would have to use its own more expensive EOP effluent treatment method to reduce salinity levels. On balance, all food processors benefit from trading as the most efficient and cheapest methods of salinity reduction are utilized.

[183] For the purposes of the analysis, we assume that TDS = FDS = 0.6 * EC.

Table 125: Summary of Costs for Salinity Reduction with and without Trading

	No Trading	With Trading	Savings
Target FDS Concentration (mg/L)	500	500	
FDS Quantity Reduction (tons)	1,335	1,335	
Total Cost	**$2,021,962**	**$1,948,009**	**$73,954**

Notes:
1) FDS quantity reduction is the amount needed to reduce effluent salinity concentration levels to 500 mg/L.
2) We assume FDS (mg/L) = TDS (mg/L) = 0.6 * EC (uS/cm).

A more marked savings is achieved if we assume that the milk processor has deep well injection as a salinity management option. Deep well injection has the ability to remove all salts after some relatively inexpensive pretreatment. Costs for deep well injection where it is viable are generally cheaper than many other options. When the deep well injection option is introduced, the milk processor can save significantly without trading by using deep well injection instead of EOP effluent treatment. This causes overall total cost to decrease from $2.02 million to $916,599 because the milk processor contributes significantly to the total salt balance.

If the plants are allowed to trade, savings are even more dramatic. The milk processor attains surplus salinity credits through its deep well injection system because the system effectively reduces the milk processor's salinity concentration to zero, well below the 500 mg/L target. By trading for these salinity credits, the other food processors save by not having to implement costlier salinity management options. Total costs for achieving the salinity target level is reduced from $916,599 to $294,469. This represents a savings of 67.9 percent. Implementing a cap and trade policy in this hypothetical scenario is even more attractive and cost-effective than in the previous scenario because of the introduction of a cheap salinity disposal method.

Table 126: Summary of Hypothetical Food Processor Characteristics and Salinity Reduction Methods and Costs including Deep Well Injection Alternative

Food Processor	Flow (million L/year)	Base FDS (mg/L)
Tomato Processing	419	531
Milk Processing	772	1592
Winery	473	1176
Rendering/Meat Processing	151	730

	FDS Reduction Cost ($ per ton)					
Food Processor	Food Loss	Boiler Feed Water	Chemicals	Supply Water	EOP Effluent	Deep Well
Tomato Processing	-$6,469	$1,693		$3,315	$3,821	
Milk Processing	$3,249		$194	$3,017	$1,663	$258
Winery				$1,627	$2,251	
Rendering/Meat Processing				$3,576	$3,626	

	Maximum FDS Reduction Amount (# tons)					
Food Processor	Food Loss	Boiler Feed Water	Chemicals	Supply Water	EOP Effluent	Deep Well
Tomato Processing	6	31		156	318	
Milk Processing	101		143	317	1,348	1,348
Winery				360	610	
Rendering/Meat Processing				47	121	

Table 127: Summary of Costs for Salinity Reduction With and Without Trading including Deep Well Injection Alternative

	No Trading	With Trading	Savings
Target FDS Concentration (mg/L)	500	500	
FDS Quantity Reduction (tons)	1,335	1,335	
Total Cost	**$916,599**	**$294,469**	**$622,131**

Notes:
1) FDS quantity reduction is the amount needed to reduce effluent salinity concentration levels to 500 mg/L.
2) We assume FDS (mg/L) = TDS (mg/L) = 0.6 * EC (uS/cm).

E. Discharge Tax

Taxes designed to discourage salinity discharge present another alternative. Taxes, while not always politically attractive have some important attributes. The basic notion behind the use of taxes to control pollution is that in the absence of regulation the cost incurred in polluting to the polluter (if any) fails to account for the damage done to the environment. If the tax then is set to reflect the costs associated with the damage, the pollution source will find it economical to reduce emissions or discharge to avoid the damage. The Tulare surcharge comes close to this approach. While the City did use a graduated charge to encourage compliance, the charges were not set based on estimates of the environmental damages attributable to discharges above the threshold.

III.12 Appendices

A. Appendix III.1: Economic Model for Optimal Balancing

This section lays out a conceptual framework for an economic balancing analysis related to water quality management. We recognize that this analysis is technical, and will be of interest primarily to professional economists, who we hope will become more involved in the types of issues that are the subject of this study. The framework seeks to develop principles for socially-optimal balancing of competing objectives, including costs of regulation and benefits of improved water quality. We understand that Porter-Cologne does not, strictly speaking, require the Regional Boards to undertake actions that are socially optimal or pass a benefit-cost test. However, the analysis illustrates the economic tradeoffs that are required to be considered when developing water quality objectives and regulatory solutions to water contamination.

Many pollution problems originate from residues of production systems. Some of these residues are utilized inputs that move over space and generate negative externalities. This situation is characteristic of pesticides or fertilizer residues in agriculture or fuels in industry. In other instances, production processes generate by-products that are environmentally damaging. Examples include animal waste, and carbon dioxide generated by fuel combustion. A great deal of research in environmental economics aims to develop policies to address waste management problems. Generally, this literature recognizes certain types of technical solutions including reduction in input use, abatement, and disposal, and then aims to identify policies that frequently include incentives that aim to modify behavior and lead to improved resource allocation and technological choices.

Waste management problems frequently have some geographic dimensions. Firms are spread over space and may share a common aquifer as well as common means of transport and transfer of pollution. Spatial considerations are especially important when it comes to water quality problems, since frequently the effective solutions consist of disposal of residue material away from its source to other regions where disposal costs are cheaper.

This appendix aims to investigate and identify socially optimal, balanced waste management strategies for firms that are located at different points in a region. We consider several solutions. Following Caswell et al. (1990), we consider the possibility of adopting conservation technologies that will reduce residues as well as expenditures on abatement that will eliminate pollution after it was generated. Another solution considered here is a pipeline or canal that carries waste to a waste disposal facility. Two of the major issues we investigate is which of the firms will be connected to the waste disposal canal, and where will the waste be disposed?

The modeling of the waste disposal canal is similar to that of Chakravorty et al. (2001) and aims to find the optimal location to dispose drainage, recognizing the trade-off between investment in a disposal facility and the environmental cost of the waste materials once it is disposed. While the analysis of Chakravorty assumed that firms are located in a continuum over space, here we present a model where there is significant distance between firms, and thus movement of waste over space is potentially costly.

The framework of this appendix can be applied to the disposal of liquid waste of food processing and other activities. Firms may reduce waste by reducing output and investing in pollution-reducing devices, but may still generate some effluent that must be disposed, and our model combines the choice of a disposal strategy with other components of a comprehensive waste management policy.

Consistent with the approach of environmental economics and public finance, the analysis takes a welfare-optimization approach that aims to maximize the net benefit from production, pollution-control activities, waste disposal, and environmental damage of pollution. We will investigate the optimal outcomes under different assumptions regarding heterogeneity among firms and the magnitude of various variables that affect production and pollution management.

1. The Model

Consider a long, narrow region with production units spread along a line. Let j be an indicator of production unit, $j = 1, \ldots, J$, and units with lower j are closer to *point 0*, which is the point of entry and exit for the region. For example, if we consider the California Central Valley to be such a region, Sacramento or Stockton could be considered as a point of entry, or Bakersfield in the South. Each production unit can be a plant, a dairy, etc., and is located at distance l_j from the entry point. It has maximum capacity for production denoted $\overline{L_j}$, which may be interpreted as land (we will use the terms “land” and “capacity” interchangeably from here forward). The amount of utilized capacity or land is denoted by L_j , and we denote the constraint:

(1) $$0 \le L_j \le \overline{L}_j .$$

The output of each unit is Y_j , and the production function is $Y_j = L_j f_j(x_j, k_j)$. We assume constant returns to scale with respect to capacity and variable input. Let x_j be variable input per capacity unit (e.g., water, fertilizer, etc.). We assume that residues of this input are the source of environmental quality concerns. The best examples are water used for irrigation or manufacturing. Whatever is not consumed in production may end up as sewage or drainage water, which must be treated or disposed of.

The economic modeling considers recycling and reuse as conservation activities and, by recycling and other means of conservation, the productivity of water can be increased and the share of residue can decline. The analysis does not deal with toxic concentration and treats the residue as a homogenous product. Expanding the model to deal with concentrations is a subject for future research. Let the conservation effort per capacity unit be denoted by k_j . This cost may be interpreted as annualized cost of conservation capital (see Khanna et al.) or variable cost that enhances the productivity of the variable input, which is the source of pollution. The production function per capacity unit $y_j = f_j(x_j, k_j)$ is concave in x_j and monotonically increasing in k_j. For simplicity, we will consider the production function to be continuous in both inputs, but the model may be further developed to consider a discrete number of conservation technologies.

Let the output price of the *j*th unit be denoted by P_j and the price of the variable input at *j*th facility is denoted by W_j. The price of a unit of conservation is V. The price per unit of capacity at the *j*th unit is denoted by R_j. It may be interpreted as rent or opportunity cost of capacity unit.

The production process generates a waste residue. In the case of livestock, it is animal waste. In the case of chemical inputs in crop production, it is runoff or percolating chemical contaminants in groundwater. One way to reduce the chemical residue is through improved input use efficiency, through investment in improved technologies. For example, adoption of modern irrigation technologies or precision technologies will increase water use efficiency or reduce the drift from chemical application and thus reduce the residue.

Let the residue from the production process, per capacity unit, be denoted $q_j = g_j(x_j, k_j)$, and the initial residue from production, by unit *j*, is $Q_j^0 = L_j g_j(x_j, k_j)$. This initial level of waste can be reduced by abatement activity. Let A_j denote the quantity of abatement at the plant level, $C_j^A(A_j)$ is an increasing function of the cost of abatement, such that $\partial C_j^A(A_j) \big/ \partial A_j > 0$, and $\partial^2 C_j^A(A_j) \big/ \partial A_j^2 \geq 0$. The residue of the *j*th unit after abatement, the net residue, is $Q_j^1 = Q_j^0 - A_j$.

The net residue may either be transferred through a canal or other conveyance facility to a regional treatment or disposal unit, or disposed directly in the region and thus potentially contributing to regional groundwater pollutio. Let the residue of the *j*th firm that is moved away through the drainage canal be denoted by M_j, while the residue of the *j*th unit that ends up as pollution is denoted by Z_j. The material balance equation at the *j*th location, stating that the residue is equal to the sum of abated, disposed, and shipped residue, is

(2) $$L_j g_j(x_j, k_j) = A_j + Z_j + M_j.$$

The movement of drainage in the canal is reflected in the spatial equation of motion

(3) $$S_j = S_{j+1} + M_j = \sum_{j'=j}^{J} M_{j'},$$

where S_j is the amount of drainage that is moving through the *j*th unit. This is the drainage of the *j*th unit and all the units upstream. More drainage is transferred closer to the point of entry/exit for the region. The cost of movement of drainage through the *j*th segment (from the *j*th unit to the *j*-1th unit, the first segment is between $j = 1$ and the entry point 0) is

(4) $$C_{j-1}^{j} = (l_j - l_{j-1})c^m(S_j),$$

where $c^m(S)$ is the cost of moving S units of drainage for one unit of distance. Note that the length of the distance units is not necessarily uniform. We allow for variable spacing between firms along the length of the canal.

We assume that the marginal cost of moving drainage is positive and increasing, or $c^{m\prime} > 0,\ c^{m\prime\prime} \geq 0$. We will denote $(l_j - l_{j-1})$ as Δl_j for clarity, as this represents the distance from one firm to the next (which can vary along the length of the canal). Accordingly, we will denote the drainage cost equation from here on as $c_{j-1}^{j} = \Delta l_j c^m(S_j)$.

Environmental costs consist of three elements—the local cost of environmental damage of Z_j, denoted by $c_j^L(Z_j)$; the marginal cost of the local environmental costs, which is positive and increasing, $c_j^{L\prime} > 0, c_j^{L\prime\prime} \geq 0$; and the cost of aggregate pollution, $C^T(Z)$ (where $Z = \sum_{j=1}^{J} Z_j$), which is also increasing and convex. Finally, there are the environmental costs of drainage disposal which depends on the investment in damage reduction, I^D, and the volume of disposed drainage S_1. The environmental cost of drainage disposal is $c^D(S_1, I^D)$. This cost increases with the drainage and is reduced with the investment in damage reduction, so that $\partial c^D(S_1,I^D)/\partial S_1 > 0$, $\partial c^D(S_1,I^D)/\partial I^D < 0$.

With these definitions, the social optimization problem is to determine simultaneously the dimension of the canal, in terms of length and volume of drainage, disposal parameter, water use, investment in conservation, etc. We set up the social optimization problem to maximize social benefit (SB). Below we present the social optimization problem without constraints for clarity.

(5) $$\underset{\substack{L_j, x_j, k_j, A_j,\\ M_j, Z_j, I^D}}{Max} \quad SB = \sum_{j=1}^{J} \left\{ \begin{matrix} L_j[P_j y_j - V_j k_j - W_j x_j - R_j] \\ -c_j^A(A_j) - c_j^L(Z_j) - \Delta l_j c^m(S_j) \end{matrix} \right\} - c^D(S_1, I^D) - I^D - c^T(Z).$$

This optimization problem is subject to several constraints: (1) the land/capacity constraint, (2) the material balance equation, and (3) non-negativity constraints for $L_j, x_j, k_j, A_j, M_j, Z_j,$ and I^D. In the Appendix we solve the general problem by denoting the shadow prices of the capacity constraints as $\theta_j^{\bar{L}}$ and the shadow prices of the non-negativity constraints of the variables $x_j, k_j, A_j, M_j, Z_j, L_j$ as $\theta_j^x, \theta_j^k, \theta_j^A, \theta_j^M, \theta_j^Z, \theta_j^L$, respectively; and use equation (4) to substitute S_j by $\sum_{j'=j}^{J} M_{j'}$.

A Case Where All Feasible Choices Are Utilized

For simplicity, we will first solve formally for the case where all firms engage in production, conservation, abatement, drainage, and pollution. Namely, there is an internal solution for all decision variables, with the exception of land. We assume the land constraint to be binding, as well as the material balance constraint (which must be satisfied with equality), and we use the Kuhn-Tucker necessary conditions to impose these conditions. The mathematics is discussed in more detail in the Appendix.

We define two new terms for clarity in the interpretation of the results. Let

(6) $$U_j^Z(Z_j, Z) = \left[\frac{\partial c_j^L(Z_j)}{\partial Z_j} + \frac{\partial c^T(Z)}{\partial Z} \right]$$

denote the marginal cost of pollution by firm ***j***. It is the sum of marginal local and aggregate environmental cost of the *j*th firm pollution. It is a function of Z_j and Z, but to simplify the notation, we will present the total marginal costs of pollution by U_j^Z without the arguments of this function. Similarly, let the total cost of drainage of the *j*th firm be denoted by:

(7) $$U_j^D(S_1,...,S_j, I^D) = U_j^D = \frac{\partial c^D(S_1, I^D)}{\partial S_1} + \sum_{j'=1}^{j} \Delta l_{j'} \frac{\partial c^m(S_{j'})}{\partial S_{j'}}.$$

For simplicity, we will use U_j^D to denote the marginal drainage cost without the arguments of this function. U_j^D embodies the spatial accumulation of drainage; specifically, the summation term shows that the increased disposal of drainage by one firm affects drainage costs all the way down the line to the exit point. Both U_j^Z and U_j^D are simultaneously determined within the model as a result of choices about variable inputs x_j, conservation inputs k_j, abatement A_j, drainage M_j, pollution Z_j, and land use L_j. Recall that $Z_j = L_j q_j - A_j - M_j$, so when firms are faced with reducing pollution, they have a variety of ways to do so—they can increase drainage into the canal, increase abatement, increase conservation efforts, scale back production, or some combination of all of these.

Optimality Conditions

We denote $MRX_j = \partial g_j / \partial x_j$, the marginal residue from variable input use, and $MPX_j = \partial f_j / \partial x_j$, the marginal product of variable inputs, to obtain:

Proposition 1A:

(8) $$P_j MPX_j - W_j = U_j^Z MRX_j.$$

Proposition 1A indicates that optimal variable input is selected so that, at the margin, the value of marginal product of x_j, which is $P_j MPX_j$, minus the price of the input, equals the marginal cost of pollution damage, $U_j^Z MRX_j$, it produces. To determine the allocation of the optimal conservation efforts by the *j*th firm, let $MRK_j = \partial g_j / \partial k_j$, the marginal residue due to conservation efforts, and $MPK_j = \partial f_j / \partial k_j$, the marginal product of conservation efforts:

Proposition 1B:

(9) $$P_j MPK_j - U_j^Z MRK_j = V_j .$$

Conservation efforts k_j are assumed to reduce production residues, and thus $MRK_j < 0$. Thus, the necessary condition shows that conservation inputs should be used so that the sum of the value of its marginal product in production, $P_j MPK_j$, and its value of its marginal saving of pollution costs, $-U_j^Z MRK_j$, is equal to the price of the conservation input, V_j. Thus, conservation effort in going beyond the point where the firm's marginal increase in revenue from conservation equals their marginal cost, because of the extra social benefit from reduced pollution costs. In the case where firms are not regulated and do not have to pay for the environmental damage caused by pollution, they will not internalize the environmental benefits of conservation goods. Instead, they will only account for the production improvements caused by the conservation goods, setting marginal production revenue improvement equal to the input price, which will result in underutilization of conservation inputs in unregulated industry.

Abatement is another way of reducing pollution. Let $MAC_j = \partial c_j^A / \partial A_j$, be the marginal abatement cost for firm *j*. The necessary condition for optimal, non-zero, abatement is:

Proposition 1C:

(10) $$MAC_j = U_j^Z .$$

The marginal abatement cost will be set equal to the marginal environmental cost of pollution. Drainage is an alternative to abatement. The drainage canal exists so that residues can be diverted away from polluting the environment and collected at a centralized location for treatment, reducing the net environmental damage from production residues. The necessary condition for optimal drainage by the *j*th firm is:

Proposition 1D:

(11) $$U_j^Z = U_j^D = \frac{\partial c^D(S_1, I^D)}{\partial S_1} + \sum_{j'=1}^{j} \Delta l_{j'} \frac{\partial c^m(S_{j'})}{\partial S_{j'}}$$

When it is optimal for the *j*th firm to dispose drainage, an optimal point will be reached where, at the margin, the benefit of diverting pollution into the drainage canal will be equal to the environmental cost of releasing pollution into the surrounding environment. When a positive amount of drainage is disposed, the environmental cost of the disposal depends on the expenditure in drainage cost reduction (these may be annualized investment costs), I^D. The necessary condition for the optimal amount of investment is:

Proposition 1E:

$$-\frac{\partial c^{D}(S_1, I^{D})}{\partial I^{D}} = 1. \tag{12}$$

Assuming an internal solution, the quantity of drainage is positive and the expense in treatment facilities is also positive, so the marginal change in environmental damage from drainage is negative. Thus, the left-hand side of the equation is positive and represents a "savings" of environmental damage from drainage. The right-hand side of equation (12) represents the marginal cost of investment in treatment facilities, equal to 1, which simply reflects a choice of units. At the margin, the social choice of investment in drainage treatment facilities will set the benefit of environmental damage reduction equal to the cost of reducing environmental damage through drainage transport and treatment. We now consider the necessary condition with respect to optimal production capacity usage, recognizing that is the only variable where we assume a corner solution, i.e., that the capacity constraint is binding. The necessary conditions holding at the optimal are:

Proposition 1F:

$$\frac{\partial SB}{\partial L_j} \le 0; \frac{\partial SB}{\partial L_j} L_j = 0 \rightarrow \qquad P_j y_j - V_j k_j - W_j x_j - R_j - q_j U_j^{Z} \le \theta_j^{\bar{L}} \tag{13}$$

$$\theta_j^{\bar{L}} \ge 0 \quad \theta_j^{\bar{L}} L_j = 0.$$

In the case where the capacity constraint is binding, there would be some positive shadow price representing the value that can be obtained by increasing capacity. This shadow price, $\theta_j^{\bar{L}}$, is equal to the revenue per capacity unit minus the sum of the cost of the variable input, conservation cost, capacity costs, and pollution penalty cost. By the Kuhn-Tucker condition, this shadow price is non-negative and equals zero when not all the capacity is utilized and the constraint is not binding.

The above conditions suggest that when all decision variables are positive, society will attain the optimal resource allocation by balanced use of policy tools. In particular:

Proposition 2: For every firm, the optimal variable input use, conservation effort, abatement, drainage, and pollution are determined such that the marginal cost of a unit of pollution or pollution-reduction activities are equal across activities. Specifically,

$$U_j^{Z} = U_j^{D} = MAC_j = \frac{P_j MPX_j - W_j}{MRX_j} = \frac{P_j MPK_j - V_j}{MRK_j} \tag{14}$$

$$= \frac{P_j y_j - W_j x_j - V_j k_j - R_j}{q_j} \text{ when } \theta_j^{\bar{L}_j} = 0.$$

The proposition suggests that at the margin the cost of one unit of pollution is equal to the cost of removing it by drainage, abatement, reduction of variable input use, increased conservation efforts, or by reduction of capacity utilization when the capacity constraint is not binding. Proposition 2 applies to each firm, but to compare across firms we subtract $U_j^Z - U_{j-1}^Z$ using equation (11) to obtain:

Proposition 3: If all firms generate drainage and pollution, the marginal pollution and marginal drainage cost are equal to each other and increasing with distance from the entry point. The increased costs between two adjacent firms is equal to the distance times the marginal cost of drainage capacity, i.e.,

(15) $$U_j^Z - U_{j-1}^Z = U_j^D - U_{j-1}^D = \Delta l_j \frac{\partial c_j^m(S_j)}{\partial S_j} > 0 .$$

The proposition suggests that the increasing marginal costs of pollution and drainage between adjacent units increase with the distance separating them and the marginal cost of drainage capacity. Combining Propositions 2 and 3 suggests that the marginal abatement cost and the marginal rates of substitution of private profit to residue for variable and conservation inputs $\left(\frac{P_j MPX_j - W_j}{MRX_j} \text{ and } \frac{P_j MPK_j - V_j}{MRK_j} \right)$ are also increasing with distance from the entry point.

2. Policy Choice

The analysis thus far investigated the optimal policies assuming that the firms are competitive. We will consider policies that reach these optimal outcomes. Before doing so, note that without intervention, the profit-maximizing firms will only choose optimal variable inputs, conservation efforts, and capacity so that the value of marginal product of variable input use and of conservation effort are equal to their marginal costs. Also, the firm will operate with full capacity if positive profits (revenue minus costs of variable and conservation inputs and capacity) can be made; the firm will not operate if profits are negative, namely:

(16) $$\begin{aligned} &P_j MPX_j - W_j = 0,\ P_j MPK_j - V_j = 0, \\ &P_j y_j - V_j k_j - W_j x_j - R_j \le \theta_j^{\bar{L}}, \text{ and } \theta_j^{\bar{L}} \ge 0 \text{ŽŽŽ} \theta_j^{\bar{L}} L_j = 0. \end{aligned}$$

The exact policy design depends on what policymakers can observe and the institutional setup.

Proposition 4A: Suppose policymakers can observe gross pollution Q_j^0, abatement A_j, and drainage M_j, and there is a public utility providing drainage service. Then one optimal outcome is obtained by A) taxing gross pollution by U_j^Z, B) providing rebates equal to $(A_j + M_j)U_j^Z$, and C) the firm paying $M_jU_j^D$ to the drainage district for drainage. The net effect of pollution costs will be $Z_jU_j^Z$.

Proposition 4B: Alternatively, if the policymakers can observe net pollution directly, they can charge $Z_jU_j^Z$, and the firm again pays $M_jU_j^D$ for drainage disposal.

Comments: In both cases, the firm pays a net tax of $Z_jU_j^Z$ for pollution and drainage costs of $M_jU_j^D$. If the policymakers know the production and residue functions, and can only observe variable and conservation input use, capacity use, abatement, and drainage, then they can calculate the net pollution and tax and/or subsidize accordingly. Of course, the less direct monitoring of pollution may be a source of friction with the firms. To gain a better understanding of the patterns of resource use over space, we analyze the outcomes for special cases.

3. Homogeneous Firms—No Drainage Canal

First, consider the case where firms are homogeneous but the canal is not built. In this case, all the firms will face identical taxes and generate the same amount of output, pollution, and abatement, and use the same amount of variable inputs, conservation capital, and capacity. But, if a drainage canal is introduced, and the drainage canal is utilized by all firms, then by Proposition 3, the marginal cost of pollution will vary across firms, resulting in variation of resource allocation over space.
Because of the multi-dimensionality of choices, we will assume that the directional impact of a change in any parameter on a decision variable is determined from differentiation of the first-order conditions that establishes the necessary conditions for that variable, with respect to the variable and the parameter, i.e.,

$$\text{(17)} \qquad sign \ \frac{dVariable}{dParameter} = sign - \frac{\dfrac{\partial^2 SB}{\partial Variable \partial Parameter}}{\dfrac{\partial^2 SB}{\partial^2 Variable}}.$$

The rationale for this approximation is that the impact of a parameter change on a variable can be written as:

$$\text{(18)} \qquad \frac{dVariable}{dParameter} = -\frac{\dfrac{\partial^2 SB}{\partial Variable \partial Parameter}}{\dfrac{\partial^2 SB}{\partial^2 Variable}}\left(1 + Indirect\,Effect\right).^{184}$$

[184] Of course, comparative statics analysis requires total differentiation of first-order conditions with respect to all decision variables and parameters, but after manipulation one can reduce the final outcome to an equation similar to equation (18).

Our approximation is equivalent to the assumption that the direct effect of a change in a parameter on a choice variable dominates all secondary effects. This assumption prevents us from obtaining conditions that may lead to unintuitive outcomes, and we may miss some important situations, but it will provide the likely outcomes that occur when the direct effect dominates. This assumption holds for cases where all the variables in the objective function are additively separable – which is true for the variables in our model except the production and residue functions and the drainage damage function. For example, the effect of an increase in the price of output on variable input use is assumed to be positive, based on differentiation of equation (8) ($P_j MPX_j - W_j = U_j^Z MRX_j$), with respect to x_j and P_j. Under this assumption, given that the price of pollution and drainage increase with distance from the entry point, we obtain:

Proposition 5: Assuming homogeneous firms, all using the drainage canal, then firms that are farther from the entry point will use less variable inputs and more conservation efforts per capacity unit, and will have more abatement and release more pollution, while diverting less pollution to the drainage canal.

Comments: Figure 1 illustrates the impact of distance from the entry point on variable input use. The first-order condition equates the value of marginal product of the variable input $P_j\, MPX_j$ with the sum of variable input cost W_j and the marginal effect of variable input use on pollution costs $U_j^Z MRX_j$. The optimal input use for firm *j* is determined by point A in Figure 1. Since the marginal cost of pollution increases with distance from the entry point, and we assume homogeneous firms facing the same variable input cost W_j, the optimal input use for firm $j+1$ is at point B, representing lower variable input use because $W + U_{j+1}^Z MRX_{j+1} > W + U_j^Z MRX_j$.

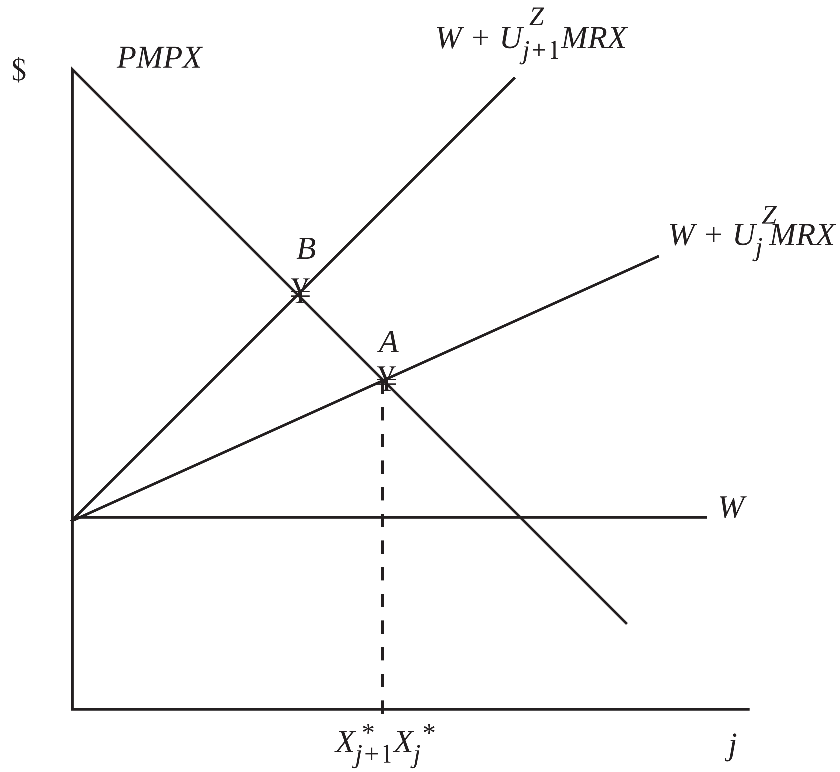

Figure 1

4. Homogeneous Firms—with Drainage Canal: Output Negatively Correlated, and Input Prices Positively Correlated, with Distance from Entry Point

There are several possible scenarios for the behavior of prices of inputs and output over space, and we will analyze them sequentially. First consider the case that net output prices received by the firm are negatively correlated with distance from the entry point, reflecting higher costs to market. Even without a drainage canal, it will lead to more input use, conservation, abatement, and pollution closer to the entry point. If all firms are connected to drainage, drainage capacity closer to the exit will be much more valuable than drainage capacity upstream, making the results of Proposition 5 more pronounced.

Now consider the case where input prices are increasing with distance from the entry point reflecting, for example, higher transportation costs. First, if drainage does not exist and output prices are homogeneous, and we apply the approximation in equation (17), then firms will use less variable inputs with distance, apply more conservation inputs relative to variable inputs, and cut back production. These changes will reduce the shadow price of pollution, and thus abatement and actual pollution will decrease with distance from the entry point. These results are consistent with Caswell, Lichtenberg, and

Zilberman (1990). Introducing drainage to all firms in this situation, we find that drainage capacity downstream will again be more valuable than drainage capacity upstream because of the decreased value of production farther from the entry point.

Now consider the case where output price declines with distance and input price increase with distance, reflecting higher transportation cost away from the entry point (reflecting better terms for lower transportation costs). Without drainage, that will lead to lower production and input use farther upstream. Conservation may increase upstream if its impact on input sue dominates its impact of productivity. Abatement is likely to increase down stream as the value of pollution reduction is likely of increase. That suggests that the marginal benefit of drainage, as function of drainage level, will be increasing closer to the entry point. The marginal social cost of drainage capacity increases rapidly with *j* because of the stock effect of drainage. This increasing optimal marginal cost of drainage, which must be equal to the marginal pollution tax, is the reason that U_j^Z must increase with *j*.

As we move further upstream along the canal, drainage becomes increasingly expensive and increasingly socially undesirable. This causes firms to substitute away from drainage, and into pollution, where higher pollution taxes will correspond with higher levels of pollution by upstream firms. Of course, it is important to recognize that firms do not just engage in simple substitution. When marginal costs of pollution increase and optimal drainage levels decrease, firms will optimize across all production decision variables to equate marginal costs and marginal benefits. Thus, as we move upstream and U_j^Z increases, we expect scaling back of production (by decreased use of variable inputs), increased conservation efforts, and increased abatement. Conversely, as we move downstream towards the exit point, we expect to see lower levels of pollution and abatement, and higher levels of drainage and production (if we assume the variable input effect to dominate the conservation effect).

5. Funding for the Drainage Canal

The cost of the drainage canal has two components. The first is I^D, which we model as investment in environmental damage reduction for drainage, or more simply, as the cost of treatment facilities. This is a social decision variable that could be handled via government transfer, internally via drainage users' association (i.e., the drainage equivalent of a water users' association), or via a private firm providing drainage services. The second cost component is the variable cost of drainage, which is reflected in the increasing cost of canal capacity as we move downstream along the canal, towards the treatment facility. Like the investment cost, variable drainage costs could be assessed by governments in the form of taxation, or by a drainage users' association, or private drainage services provided in the form of user fees.

While we impose pollution taxes and drainage fees in our examples of optimal policies, other policies may be more appropriate due to monitoring and enforcement costs, political economic considerations, equity considerations, etc., such as cap-and-trade systems, markets for pollution and drainage rights, and other policies. Cap-and-trade and tradable permit policies may be difficult to implement due to the changing effects of marginal pollution and drainage costs (with *j*) at the optimum.

6. Optimal Canal Length

Since U_j^Z and U_j^D are increasing with canal length, it is clear that the optimal canal will not go on forever; it will reach some point where the costs of additional canal length outweigh the benefits. Under our assumption of homogeneous firms, we return to the social optimization problem found in equation (5), which is rewritten as equation (15) in the Appendix. This time, since we do not assume an interior solution, we must actually impose, and solve for, all of the constraints and allow for Z_j as a separate decision variable.

Proposition 6:

The optimal canal length is determined by the greatest j such that $\frac{\partial SB}{\partial M_j} > 0$.

Since all firms are identical and optimal drainage fees U_j^Z will be equal to marginal pollution taxes U_j^D (both of which are strictly increasing with *j*), the optimal M_j will be strictly decreasing with *j*. M_j will eventually decrease to zero as marginal social costs of drainage go to infinity. For all *j* such that $M_j = 0$, the canal is not used in obtaining the social optimum, and is therefore no longer socially beneficial. Obviously, if $M_j = 0$ for all *j*, then no canal is optimal. Essentially, the optimal canal ends before drainage becomes a drain on society.

7. Environmental Heterogeneity

Now that we have the concept of optimal canal length established, we will continue with the example of homogeneous firms and introduce variation to understand the effects of heterogeneity in certain parameters on optimal canal length. Consider for example that firms are identical, but that local environmental considerations dominate the pollution effect and they vary systematically across locations. If the exit point for the drainage canal is located near a city, while upstream locations are increasingly rural, then it is reasonable to assume that for some classes of pollutants, health concerns increase dramatically with population density—so marginal local pollution effects are high at the base of the canal and lower as you move upstream. This type of situation would likely correspond to even lower pollution and higher drainage levels at the entrance to the canal, and the opposite at the far extreme. Essentially, this environmental situation would cause U_j^Z to increase even faster—decreasing the optimal canal length. Conversely, the opposite environmental situation, where upstream local environments are more adversely affected by pollution than those downstream, a longer canal would be socially optimal.

8. Heterogeneous Cost to Market

Another factor to consider is variation in output values of production. Say, for example, that output of firms is homogeneous but the cost to market impacts the net price producers receive for their goods. A relevant example of this scenario involves food processing or dairy industries, where items are perishable and transport cost/distance to market is a significant factor. If the primary markets are located near the entry/exit point to the region, then production is more valuable closer to the base of the canal. This implies more production and more drainage closer to market, and less production and less drainage farther from the market, suggesting a shorter canal would be optimal. Similarly, if the canal drains away from cities and the upstream firms are closer to market, the value of upstream production would be higher, suggesting a longer optimal canal length.

9. Relocation of Production Residues

So far, we have considered systematic variation of environmental or production factors along the length of the canal. Now we consider the case of varying local environmental sensitivity and varying net values of production (due to market placement) along the length of the canal in a nonsystematic fashion (still within the context of identical firms). For this scenario, we introduce a new policy solution—diversion of unprocessed waste from the drainage canal. While it may not be practical to build treatment facilities midstream, there could exist areas in mid-canal that are less environmentally sensitive (due to lack of population density, for example) where the release of drainage as pollution could have social value by allowing for increased production upstream. This concept is analogous to the use of landfill for household waste disposal in urban centers. While urban centers themselves are environmentally sensitive because the buildup of trash outside of private homes creates a large environmental cost, the decentralized landfill location is less environmentally sensitive, so society benefits from consolidating waste at that location. We approach the constrained social benefit maximization problem similarly to equation (15), allowing M_j to be negative, but restricting the amount of drainage removable from the canal to be less than or equal to the drainage already in the canal from upstream firms, so $M_j \geq (-)S_{j+1}$, where S_{j+1} represents the sum of drainage from all upstream firms. Note that we do not explicitly identify varying values of production due to distance to market, instead we incorporate them within P_j. Equation (18) is located in the Appendix.

We remove the materials balance constraint in equation (16) because the key concept here is that a firm can "pollute" or abate more than its production residues by diverting drainage from the canal to an area of low environmental impact for the greater social good. Consistent with all the other optimality conditions presented here, this scenario will have an equilibrium in which marginal benefits and costs of all production and pollution activities are balanced to maximize social benefits. The possibility of relocating untreated residues when environmental sensitivity to pollutants and output values vary can make optimal canals longer and increase total social benefits. However, the direct implications of this policy option will depend on the specific scenario. To determine optimal canal length for a given set of parameters, we defer to the general case where we allow variation across all firms for abatement and conservation technologies, input and output prices, production technology, and local environmental sensitivity to pollutants.

10. Optimal Canal Length (General Case)

By using the expanded framework, which allows for midstream diversion of residues from the canal, we can model optimal canal length as a direct result of the social optimization problem, as above. Additionally, we include the possibility of additional policy constraints such as overall canal capacity $\overline{S}$, location-specific canal capacity $\overline{S}_j$, and overall and location-specific caps on pollution levels, $\overline{Z}$ and $\overline{Z}_j$. We allow for heterogeneity across all modeled parameters, and the familiar Kuhn-Tucker conditions apply. Equation (18) and first-order conditions for the general case can be found in the Appendix.

Clearly, a necessary and sufficient condition for the drainage canal to exist is the existence of some positive canal length such that net social benefits with the canal are greater than those without the canal. This type of solution is determined endogenously to our optimization problem. If no canal is optimal, this will be reflected by a social optimal in which $M_j = 0$ for all *j*. It may also be the case for some regions that multiple short drainage canals are preferable to one long one, though the costs of drainage treatment, I^D, which may include high fixed costs will have to be considered. We leave the modeling of this case as an area for future research. The key considerations from the general case are the heterogeneity of technologies, output values, and environmental sensitivity. As discussed above, systematic changes in environmental conditions along the length of the canal can impact the optimal length of the canal and production and drainage decisions. By introducing the possibility of firms providing a pollution sink for other firms via diversion from the drainage canal, we see that optimal solutions could include canals purely for the relocation of waste to less environmentally sensitive areas. As an extreme example, if one area exhibits zero marginal costs for pollution and aggregate marginal costs are insignificant, it is possible that other firms could send drainage to be released as pollution in another section of the canal without any waste treatment. An optimal solution of this type being realized depends on optimal policies to support it. In the event that policies are not optimal, firms will respond to existing incentives. For example, if one region has no pollution controls and all others have taxes, fees, limits, or other disincentives to pollute, then incentives may dictate that the noncontrolled region becomes the garbage dump for other regions. Similarly, if one firm produces output that is tremendously more valuable than the output of other firms, other firms may end up serving as residue disposal for the primary producing firm.

Another case to consider is that of a complete ban on pollution. In that case, drainage will become the only non-abatement option for handling production residues, and may not be able to handle the full residue load from maintained production levels without large increases in marginal cost. It is likely in this case that conservation efforts will go up, but if production effects dominate, the remaining pollution reduction will have to come from curtailing production. The general case social optimization provides a measure for the marginal social loss of imposing such a policy. By setting $\bar{Z} = 0$ and solving, the shadow price associated with this constraint, θ^{14}, represents the marginal social cost of constraining pollution to zero. Alternately, this cost can be thought of as the marginal social benefit possible from re-optimizing if the constraint is relaxed by one unit in the positive direction.

Proofs

This section contains complete descriptions of the optimization problems, and proofs of the propositions.

Full Version of Equation (5) with All Constraints

$$\underset{\substack{L_j, x_j, k_j, A_j, \\ M_j, Z_j, I^D, \\ \theta_j^{\bar{L}}, \theta_j^{L}, \theta_j^{x}, \theta_j^{k}, \\ \theta_j^{A}, \theta_j^{M}, \theta_j^{Z}, \theta_j^{I}, \\ \theta_j^{AMZ+}, \theta_j^{AMZ-}}}{Max} \quad SB = \sum_{j=1}^{J} \left\{ \begin{array}{l} L_j[P_j y_j - V_j k_j - W_j x_j - R_j] - c_j^A(A_j) - c_j^L(Z_j) - \Delta l_j c^m(S_j) \\ +\acute{Z}\theta_j^{\bar{L}}(\bar{L}_j - L_j) + \theta_j^L(L_j) + \theta_j^x(x_j) + \theta_j^k(k_j) + \theta_j^A(A_j) + \theta_j^M(M_j) \\ +\acute{Z}\theta_j^L(Z_j) + \theta_j^{AMZ+}(L_j q_j - A_j - M_j - Z_j) - \theta_j^{AMZ-}(L_j q_j - A_j - M_j - Z_j) \\ -\acute{Z}c^D(S_1, I^D) - I^D + \theta^I(I^D) - c^T(Z) \end{array} \right\}.$$

We use θ_j^{AMZ+} and $-\theta_j^{AMZ-}$ to set the material balance constraint exactly equal to zero, since each constraint must be greater than or equal to zero by the Kuhn-Tucker conditions.

Equation (5) Re-Written for Internal Solution Case

$$\underset{\substack{L_j, x_j, k_j, A_j, \\ M_j, Z_j, I^D, \\ \theta_j^{\bar{L}}, \theta_j^{AMZ}}}{Max} \quad SB = \sum_{j=1}^{J} \left\{ \begin{array}{l} L_j[P_j y_j - V_j k_j - W_j x_j - R_j] - c_j^A(A_j) - c_j^L(Z_j) - \Delta l_j c^m(S_j) \\ +\acute{Z}\theta_j^{\bar{L}}(\bar{L}_j - L_j) - \theta_j^{AMZ}(L_j q_j - A_j - M_j - Z_j) - c^D(S_1, I^D) - I^D - c^T(Z) \end{array} \right\}.$$

We assume internal solutions for all variables except L_j, for which we assume $\bar{L}_j$ is binding for all *j*. We also assume the material balance constraint to be binding from below, i.e., firms would prefer to release production residue without having to pay pollution tax, drainage, or abatement costs. We now use $-\theta_j^{AMZ}$ to denote the material balance constraint binding from below. We use this re-written version of equation (5) to generate first-order conditions for the internal solution case:

FOC (1): $\partial SB / \partial x_j = L_j(P_j MPX_j - W_j) - \theta_j^{AMZ} L_j MRX_j = 0$

FOC (2): $\partial SB / \partial x_j = L_j(P_j MPK_j - V_j) - \theta_j^{AMZ} L_j MRK_j = 0$

FOC (3): $\partial SB / \partial L_j = P_j y_j - V_j k_j - W_j x_j - R_j - \theta_j^{\bar{L}} - \theta_j^{AMZ} q_j = 0$

FOC (4): $\partial SB / \partial A_j = -MAC_j + \theta_j^{AMZ} = 0$

FOC (5): $\partial SB/\partial M_j = -U_j^D + \theta_j^{AMZ} = 0$

FOC (6): $\partial SB/\partial Z_j = -U_j^Z + \theta_j^{AMZ} = 0$

FOC (7): $\partial SB/\partial I^D = -\dfrac{\partial c^D(S_1, I^D)}{\partial I^D} - 1 = 0$

FOC (8): $\partial SB/\partial \theta_j^{\bar{L}} = \bar{L}_j - L_j = 0$

FOC (9): $\partial SB/\partial \theta_j^{AMZ} = L_j q_j - A_j - M_j - Z_j = 0$

Proposition 1A:

(10) $$P_j MPX_j - W_j = U_j^Z MRX_j.$$

Proof: Directly follows from substitution of FOC (6) into FOC (1), and dividing both sides by L_j.

Proposition 1B:

(11) $$P_j MPK_j - U_j^Z MRK_j = V_j.$$

Proof: Directly follows from substitution of FOC (6) into FOC (2), and dividing both sides by L_j.

Proposition 1C:

(12) $$MAC_j = U_j^Z$$

Proof: Directly follows from combination of FOC (4) and FOC (6).

Proposition 1D:

(13) $$U_j^Z = U_j^D = \frac{\partial c^D(S_1, I^D)}{\partial S_1} + \sum_{j'=1}^{j} \Delta l_{j'} \frac{\partial c^m(S_{j'})}{\partial S_{j'}}$$

Proof: Directly follows from combination of FOC (5) and FOC (6).

Proposition 1E:

(14) $$-\frac{\partial c^D(S_1, I^D)}{\partial I^D} = 1.$$

Proof: Directly follows from FOC (7).

Proposition 1F:

(15) $$\frac{\partial SB}{\partial L_j} \le 0; \frac{\partial SB}{\partial L_j} L_j = 0 \rightarrow \qquad P_j y_j - V_j k_j - W_j x_j - R_j - q_j U_j^Z \le \theta_j^{\bar{L}}$$

$$\theta_j^{\bar{L}} \ge 0 \quad \theta_j^{\bar{L}} L_j = 0.$$

Proof: Directly follows from substitution of FOC (6) into FOC (3) and application of Kuhn-Tucker conditions for shadow prices.

Proposition 2:

(16)
$$U_j^Z = U_j^D = MAC_j = \frac{P_j MPX_j - W_j}{MRX_j} = \frac{P_j MPK_j - V_j}{MRK_j}$$
$$= \frac{P_j y_j - W_j x_j - V_j k_j - R_j}{q_j} \quad \text{when } \theta_j^{\bar{L}_j} = 0.$$

Proof: Follows from the combination of FOCs (1), (2), (3), (4), (5), and (7).

B. Appendix III.2: Desalination Treatment Technologies

1. Principle of side-stream (partial) treatment

In some applications, particularly in desalting relatively low-TDS brackish water, a portion of the feed stream may be bypassed around the desalting process and blended with the desalted product to achieve the desired finished water TDS concentration. This process will increase the net overall product water recovery. This "split-treatment" design is possible if the product water quality from a full-flow-through system would be significantly better than necessary and blending produces finished water that still meets goals. Often split-treatment can reduce the capacity of the relatively expensive desalting process component of a system and lower overall production costs. Figure A-1 illustrates the concept of side-stream treatment.

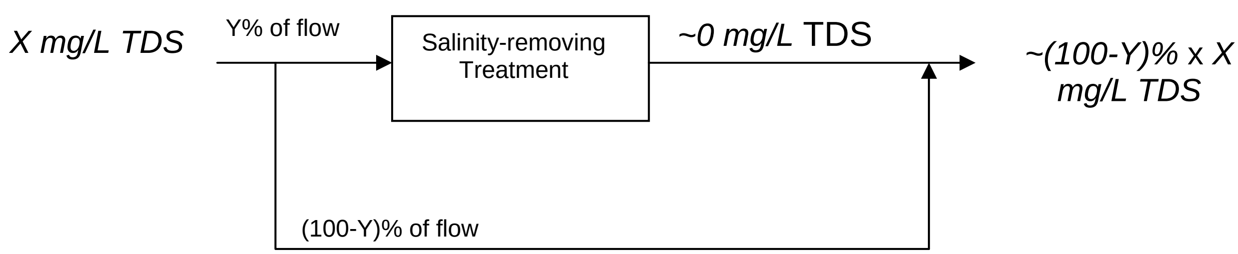

Figure A-1. Schematic of Side-stream Treatment

2. Pre-treatment requirements

Pretreatment conditions the raw water so that it does not damage components of the desalting process and also reduces maintenance on the desalting equipment. After this conditioning of the raw water, it is called "feedwater" and is ready for the desalting process. A pretreatment scheme prior to all desalting processes is necessary to create feedwater with the following characteristics.

- Low particulate matter or total suspended solids (TSS)
- Low alkalinity or pH
- Low biological activity
- Low concentration of heavy metals
- Absence of elements that will oxidize to form particulate matter

Each of the desalting technologies differs in its sensitivity to these five basic characteristics of feedwater; these differences will be identified later in this section. The extent of the pretreatment facilities, relative to both size and complexity, will depend on how well the raw water meets each of the basic characteristics. For example, raw water that is high in suspended solids will require more extensive pretreatment facilities than raw water with low suspended solids.

The following is a description of each of these characteristics and their importance, followed by discussions of currently available desalination technologies.

a) Total Suspended Solids

Suspended solids can block the feedwater channels in a membrane desalting process or accumulate in the brine collection compartments of a thermal desalting process. Both membrane technologies (RO and EDR, both discussed below) are significantly more sensitive to suspended solids than are the thermal technologies. Generally, membrane technologies require pre-removal of all particles larger than 10 microns, while thermal technologies are much less sensitive. All RO and EDR facilities use cartridge filtration with effective removal ratings between 1 and 10 microns as a final step in pretreatment. Additional pre-filtration may be necessary depending on the suspended solids content of the raw water.

Both RO and EDR membranes will be damaged by very small particulate matter, sometimes referred to as silt. This material is usually of clay origin and will deposit on the membrane surfaces, blocking the passage of water. The presence of this material is measured by the Silt Density Index (SDI) test. Properly conditioned feedwater must have a SDI value of approximately 3 or less. Removal of silt from the raw water generally requires coagulation, sedimentation, and filtration.

Whenever possible, it is best to develop a raw water source essentially free of suspended solids, thereby avoiding the capital and operating costs associated with pretreatment facilities.

b) Alkalinity

All desalting technologies operate by separating water molecules out of the feedwater, thereby leaving behind the dissolved solids in a more concentrated form. The dissolved salts, or ions, can become sufficiently concentrated to join with other ions to form precipitable compounds such as calcium carbonate, calcium sulfate, and barium sulfate. These compounds will form a scale on membrane surfaces, flow channels, or heat transfer surfaces, thereby reducing the effectiveness of the desalting process. The common pretreatment technique to prevent this scale-forming precipitant is addition of an acid, generally sulfuric or hydrochloric, to reduce the alkalinity of the raw water. It is common to reduce the raw water pH to a value of 6.0.

Another technique used to prevent the formation of scale is the addition of scale-inhibitor compounds. There are a large number of scale inhibitor compounds available and they function generally by binding selected ions to prevent their combining with other ions and forming a precipitant.

This pretreatment requirement is common to all desalting techniques.

c) Biological activity

Biological matter exists in virtually all waters and can have the same effect in a desalting process as either suspended solids or scale-forming precipitants. The desalting process concentrates the biological activity and frequently provides an ideal environment for their reproduction and growth. Pretreatment techniques for inactivation of biological activity generally involve application of a strong oxidant, such as chlorine or ozone. This technique works well as pretreatment upstream of EDR and thermal desalting technologies; however, RO membranes can be damaged by the presence of such strong oxidants. RO plants using this form of pretreatment require an additional step of deactivating any remaining oxidant present in the feedwater.

d) Heavy metals

The presence of heavy metals in a raw water source is generally not an issue with RO or EDR desalting technologies. However, heavy metals will attack the transfer surfaces in thermal technologies and must be removed. The common pretreatment technique to remove heavy metals is an ion trap that selectively removes heavy metals.

e) Ionized compounds

Certain compounds, most notably iron and hydrogen sulfide, commonly exist in a raw water source in the ionized form, which means they are a dissolved solid or gas. If oxygen is also present in the raw water, or is introduced by injection of an oxidant or exposing the raw water to air, these elements will react to form an un-ionized form that becomes a particulate or suspended solid. The preferred treatment approach is to prevent the introduction of oxygen into the raw water. If this is not possible, or if oxygen is already present, then sufficient oxygen and mixing energy must be introduced to completely form the un-ionized compounds and then remove them with methods described above for removal of suspended solids.

3. Reverse Osmosis

Reverse osmosis (RO) is a membrane filtration process defined by two basic criteria: 1) The filtration system must be a pressure- or vacuum-driven process and remove particulate matter larger than 1 μm using an engineered barrier, primarily via a size exclusion mechanism (physical); and 2) the process must have a measurable removal efficiency of a target compound that can be verified through the application of a direct integrity test.

RO is a pressure-driven separation process that utilizes semi-permeable membrane barriers. RO is most often used in applications that require the removal of dissolved contaminants, such as salinity, as described below. Osmosis is the natural flow of a solvent, such as water, through a semi-permeable membrane from a less concentrated solution to a more concentrated solution. This flow will continue until the chemical "potentials" (or concentrations, for practical purposes) on both sides of the membrane are equal. The amount of pressure that would need to be applied to the more concentrated solution to stop this flow of water is called the osmotic pressure.

RO, as illustrated in Figure 2, is the reversal of the natural osmotic process, accomplished by applying pressure in excess of the osmotic pressure to the more concentrated solution. This pressure forces the water through the membrane against the natural osmotic gradient, thereby increasingly concentrating the dissolved solids in the water on one side (i.e., the "feed") of the membrane and increasing the volume of water (with a resulting lower concentration of dissolved solids) on the opposite side (i.e., the "filtrate" or "permeate" side). The "centrate" or "reject" stream contains the substances removed from the feedwater after being rejected by the membrane barrier. A guideline for the osmotic pressure of fresh or brackish water is approximately 1 pound per square inch (psi) for every 100 mg/L difference in Total Dissolved Solids (TDS) concentration on opposite sides of the membrane. The actual needed operating pressure varies depending on the TDS of the feedwater (i.e., osmotic potential), as well as on membrane properties and temperature, and can be up to more than 1,000 psi for seawater desalting using RO.

RO membranes are available with different performance and operating characteristics, such as high-rejection and low-pressure. RO rejects both mono-valent and poly-valent ions. The RO rejection for mono-valent and poly-valent ions is between 85-95 percent. RO has been proven to remove TDS from potable waters by combination of sieving and electro-static repulsion.

The ratio of RO product water to feedwater is referred to as recovery. RO recoveries in potable water treatment vary from 30-85 percent. Two factors limit recovery in an RO system: 1) formation of solid compounds (scale and precipitate) and 2) net driving pressure. As water molecules pass through the membrane leaving behind dissolved solids, the solids rejected by the membrane concentrate in the remaining water. As dissolved solids concentrations increase, seals can form. More specifically, the RO recovery is dictated by the potential for fouling of the membranes from precipitation of limited-solubility minerals such as silica, calcium chloride, calcium fluoride, calcium sulfate, barium sulfate, and strontium sulfate. The presence of inorganic ions like calcium, magnesium, barium, strontium, sulfate, chloride, and carbonate can lead to inorganic scaling on the membrane surface if present in amounts exceeding their saturation potential. A point to be considered here is that in multi-stage systems, typically employed in RO treatment, these ions can be concentrated to levels as much as four to six times higher than in raw water. Inorganic scale is difficult to clean and causes a rapid decline in production during operation. As noted earlier in this appendix, RO feedwater is pre-treated using cartridge filters (to remove particulates) and dosed with acid and anti-scalant to increase solubility of the limiting salts.

Another inorganic component of concern is silica. Silica is known to polymerize at high concentrations. Silica polymerization can cause what is called “blinding” of the membrane by forming a layer of difficult to remove scale.

Net driving pressure limitations on RO recovery are strictly physical or structural. As water molecules pass through the membrane leaving behind dissolved solids, the solids concentration in the remaining water (concentrate) increases. This, in turn increases osmotic pressure. There are limitations to the pressure that can be applied to a membrane, backing sheet, and other components.

Depending on the recovery, RO treatment will result in a residuals stream (sometimes called “centrate” or “reject”) that is high in concentrations of contaminants and TDS. The RO concentrate water can be processed and recovered or disposed of as liquid waste.
In water and wastewater industries, reverse osmosis has been successfully implemented in the following applications: drinking water, humidification, ice-making, car-wash water reclamation, rinse waters, biomedical applications, laboratory applications, semiconductor production, pharmaceutical production, chemical processes, cosmetics, food and beverage production, and metal plating applications.

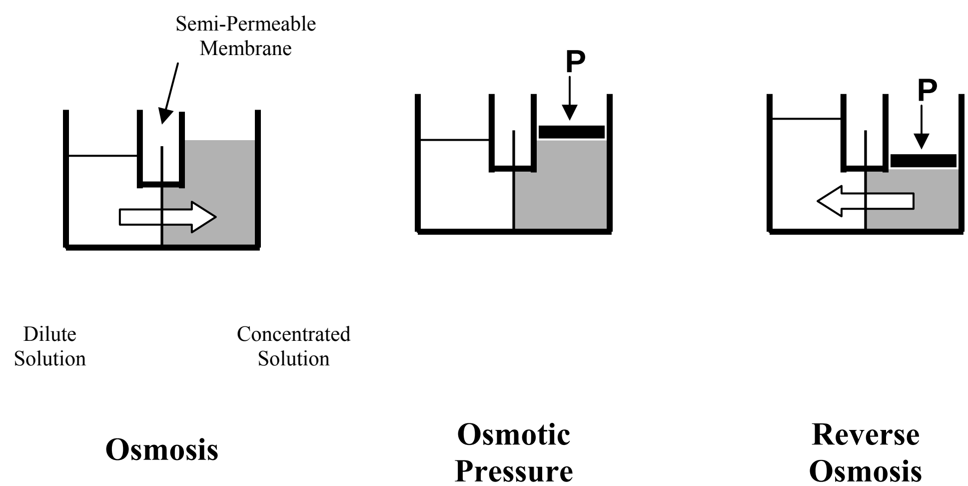

Figure 53

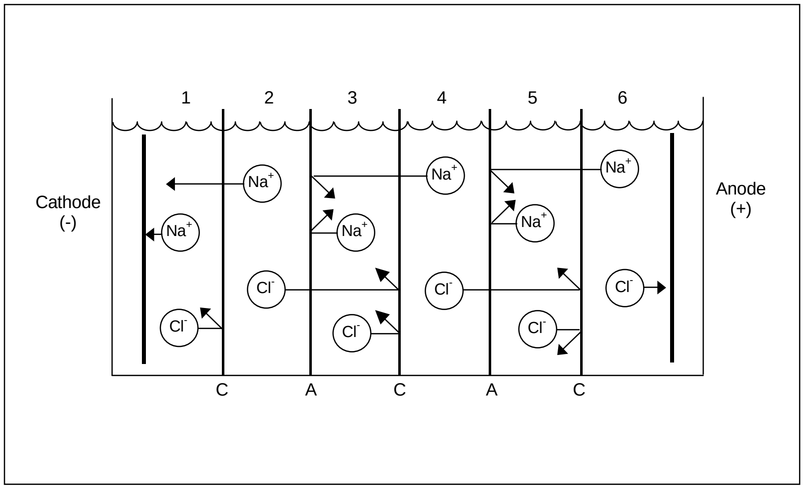

Figure 54

4. Electrodialysis

Electrodialysis reversal (EDR) is an electrochemical separation process in which ions are transferred through membranes from a less concentrated to a more concentrated solution due to the flow of direct electric current. EDR is a modification to electrodialysis (ED) where the polarity of DC power is reversed several times per day. ED is not discussed in detail in this appendix because EDR has superseded ED in the water/wastewater treatment industries. EDR membranes are electrically conductive and are essentially impermeable to water under pressure. Thus, EDR membranes are specifically applied for the removal of dissolved ionic constituents, i.e. salinity.

Figure 3 shows the typical EDR system, which consists of an anode, cathode, and stacks of alternating anion transfer and cation transfer membranes. Cations (such as Ca^{2+}, Mg^{2+}, and Na^{+}) are drawn towards the negatively charged cathode, and anions (such as SO_4^{2-} and Cl^{-}) are drawn towards the positively charged anode. Alternating anion and cation transfer membranes result in alternating compartments of ion-free water (compartments 2 and 4 in Figure 54) and ion-concentrated solution (compartments 1, 3, and 5 in Figure 54).

In the EDR process, the electrical polarity (anode and cathode) is periodically reversed to control membrane scaling and fouling (Figure 55). Polarity reversal typically occurs two to four times per hour. When the electrical polarity is reversed, the product and concentrate streams are also reversed. This prevents any of the flow compartments from being exposed to streams with high dissolved solids for extended periods of time and aids in controlling fouling of the membranes.

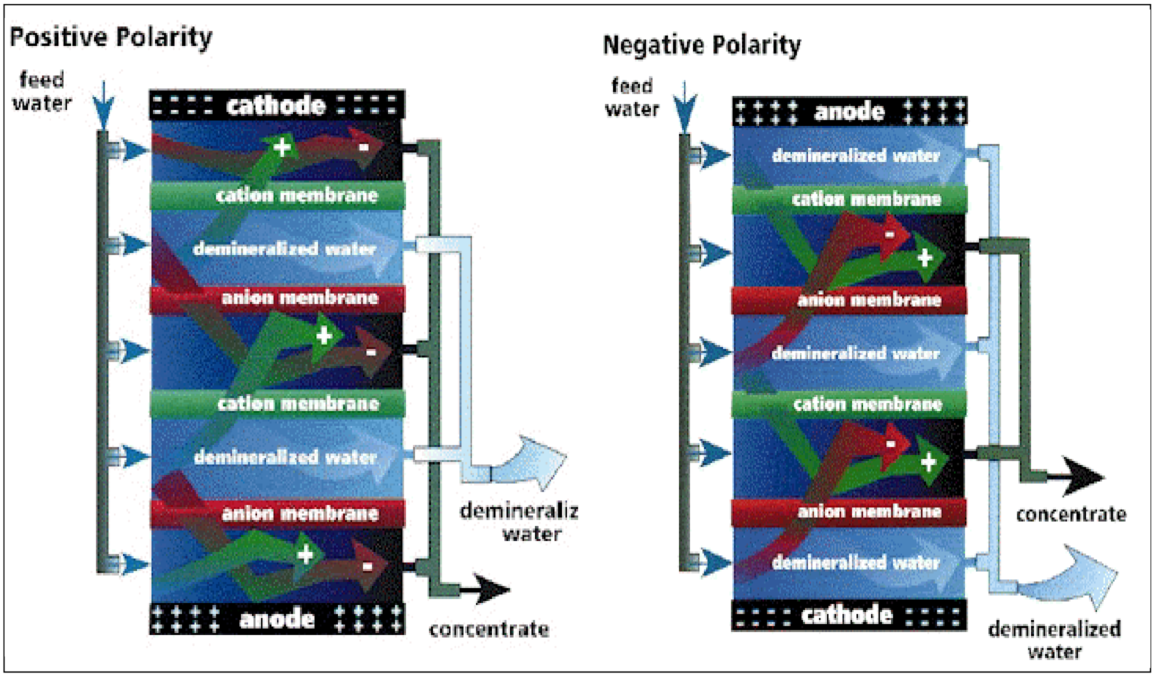

Figure 55

When the concentrations of the ions in the concentrate increase beyond their solubility limit, it causes fouling of the membranes from precipitation of limiting salts (or "foulants"). Typical EDR foulants include calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate, calcium fluoride, iron, manganese, and silica. Non-mineral substances such as colloids, particulates, bacteria, and polymeric materials may also foul EDR membranes. Fouling affects the productivity and performance of EDR membranes. The EDR feedwater is pre-treated to reduce fouling. Pre-treatment steps include (i) pre-filtration using cartridge or bag filters to remove particulates and (ii) acid and anti-scalant addition to increase solubility of mineral foulants.

EDR systems are often arranged in stages, wherein the product water from the first stage becomes the feed to the second stage, as compared to RO, where the concentrate from the first stage becomes the feed to the second stage. This is depicted in Figure 56. The number of EDR stages depends primarily on the feedwater quality and desired finished water quality. Most systems are designed to have 2 to 4 stages to achieve the desired degree of salt removal. The concept of staging leads to great flexibility in system design with standard components. To increase the amount of salt removal, more stages are added. To produce more product quantity, lines (trains) of stacks are operated in parallel. For most charged species, typical removals range from 45-60 percent per stage.

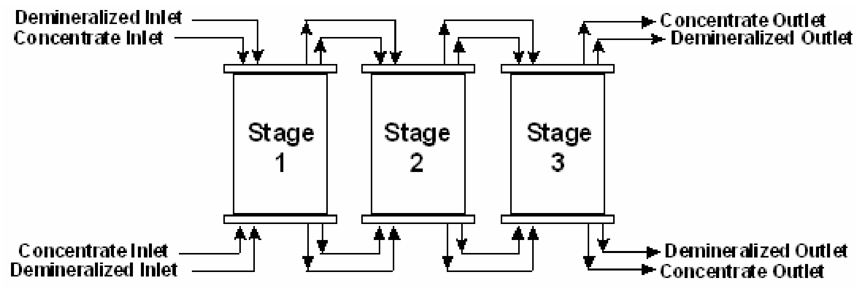

Figure 56

The ratio of the product water flow to the feedwater flow is known as the recovery. The recovery is impacted by the concentrations of dissolved species in the concentrate stream. As the recovery increases, the concentrate volume decreases, which results in increased concentrations of dissolved contaminants. Typical EDR system recoveries range from 75-94 percent.

EDR produces a concentrate stream equivalent to 10-15 percent of the flow. This stream will likely have a high concentration of dissolved solids (four to ten times the feedwater concentration). The EDR concentrate stream can be further processed and recovered.

EDR plant operations are highly automated and offer long-term reliable operation. EDR systems can be cleaned in place to restore system performance. Scales are removed by circulating a weak acid solution through the membrane stacks. Organic fouling is removed by circulating a brine solution through the membrane stack. Severe fouling or scale can be remedied by manually cleaning a disassembled membrane stack with little or no loss in membrane use or operating life. The membrane stacks can be sanitized by circulating a chlorine solution through the system.

As a general rule, salinities greater than about 5,000 mg/L are not economically desalted by EDR since the energy usage is proportional to the amount of salt removed. EDR does not remove non-ionized substances such as many particles, organics, and microorganisms. Therefore, EDR can treat water with a relatively high level of particles and turbidity. Without chemical addition, EDR can achieve the same water recovery as RO in low TDS water and significantly higher water recoveries can be achieved with chemical addition.

The most common application for EDR is the reduction of total dissolved solids (TDS) in brackish waters to meet drinking water standards. EDR systems typically remove 80 to 90% of the dissolved solids in the water. Other applications for EDR technology include municipal drinking water, industrial process water, and wastewater reuse projects. Municipalities find EDR successful for the desalination of well and surface waters where salt removal can be controlled to between 40 percent and 90 percent. EDR reliably desalinates water to specifications for industrial process requirements, such as boiler make-up water. Additionally, because of its rugged membranes and high chlorine tolerance, EDR membranes are also ideal for municipal and industrial wastewater reuse projects and recovery of RO reject.

5. Evaporation

In distillation, water is purified through evaporation. Water is heated to form steam and the steam is cooled and condensed to form purified water. Inorganic compounds and non-volatile organic compounds do not evaporate with the water and are left behind. The unevaporated compounds, including salts that settle at the bottom of the boiling chamber have to be periodically cleaned.

The introduction of flash evaporators in the 1950s resulted in the development of several large-scale high-performance distillation processes that were suitable for commercial operation. The majority of thermal desalination processes in use today are typically used for seawater desalination. In these processes, multiple evaporation and condensation stages (or "effects") are used to generate product water or distillate. A key advantage of thermal processes over membrane processes is that product water with a TDS of below 10 mg/L can be produced.

Water needs two important conditions to boil: 1) attaining of proper temperature relative to its ambient pressure, and 2) ensuring that sufficient additional energy is provided to ensure vaporization of the liquid. When water is heated to its boiling point and the heat is turned off, vaporization of steam will not occur because additional energy (the heat of vaporization) must be applied to the water to actually boil water and produce steam vapors. Boiling and vapor evolution can be maintained by either adding more heat or by reducing the ambient pressure above the water. If the ambient pressure is reduced, the water is at a temperature above its boiling point and vapor evolution occurs as "extra" heat is added to the process. As the heat of vaporization is applied, the temperature of the water falls to the new boiling point.

Aside from multiple boiling, the other important factor in thermal processes is scale control. Although most naturally occurring substances dissolve more readily in warmer water, some substance dissolve more readily in cooler water. Unfortunately, some of these substances, like carbonates and sulfates, are found in seawater. One of the most important substances related to scale formation is gypsum ($CaSO_4$), which begins to leave solution (precipitate into solid form) when water approaches about 95ºC (203ºF). This material forms a hard scale that can coat evaporator tubes or containers. Scale formation inhibits heat transfer across the evaporator tubes and reduces the efficiency of the distillation process. Scale formation also causes mechanical problems by plugging openings and, once formed, scale deposits are difficult to remove. One way to avoid scale formation is to keep the water temperature and water chemistry within prescribed limits.

The thermal process that accounts for the most desalting capacity is the multi-stage flash (MSF) distillation process; the second-most widely used thermal process in terms of installed capacity is multi-effect distillation (MED). Other distillation methods include vapor compression (VC) and solar distillation. Large thermal desalination plants are often combined with power generation stations. Since most large thermal desalination plants require steam as the driving force, thermal processes typically make economic sense when incorporated into a dual facility in which both electrical energy and desalted seawater are produced concurrently or in utility or industrial situations where significant quantities of exhaust or previously used heat are available. The O&M costs for distillation are generally higher than other forms of drinking water treatment. In water treatment, distillation is used when (i) lower-cost and lower-energy treatment alternatives are not feasible and (ii) to generate high-quality, purified water.

a) Multi-stage Flash (MSF)

The most common evaporators consist of the large-scale multi-stage flash units. MSF evaporators operate on the concept of releasing vapor from a boiling liquid by introducing it as a super-heated liquid into a chamber maintained at a lower pressure low enough to allow boiling to continue without introduction of additional heat energy. In the MSF process, water is heated in a vessel called the brine heater. In the brine heater, steam passes over a bank of tubes containing the feedwater. The heated feedwater then flows into another vessel called a "stage" in which the pressure is lowered such that the water entering the stage will immediately boil or flash into steam. Generally, only a small percentage of the heated water which enters the stage will flash to steam. The exact conversion quantities depend on the pressure maintained in the stage, as boiling continues only until the feedwater cools to the boiling point at that pressure. Using this process, feedwater can pass from one stage to another and be boiled repeatedly without adding more heat. Today, a typical MSF plant contains 4 to 40 evaporative stages.

Steam vapors generated by the flashing process are converted to fresh water by condensing the vapors on heat exchanger tubes that run through each stage. The heat exchanger tubes are cooled by incoming feedwater on its way to the brine heater. This action, in turn, heats the feedwater so that the amount of thermal energy needed in the brine heater to raise the temperature of the feedwater is reduced. Figure 6 presents a simplified schematic of the MSF process.

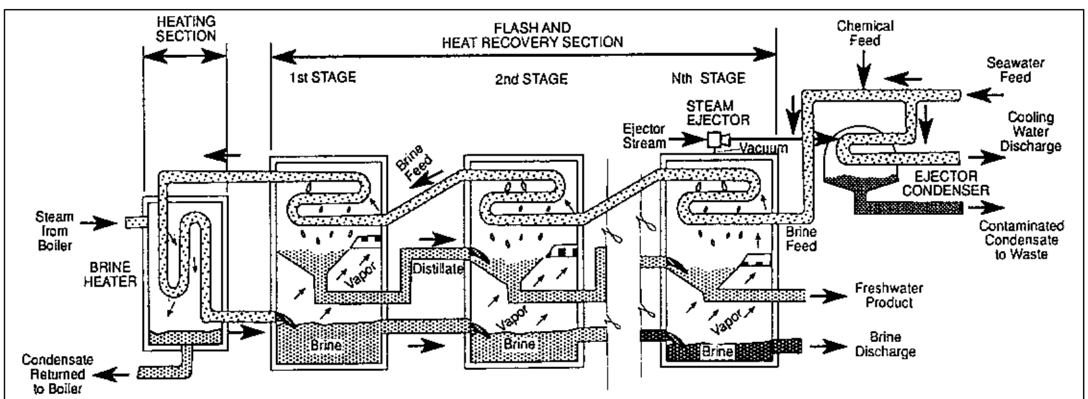

Diagram of a multi-stage flash distillation plant.

Figure 57

In addition to once-through MSF plants, "recycle" configurations are used so that part of the concentrate (brine) is mixed with the incoming feedwater and returned to the concentrate. Also, separate heat recovery and concentrate sections are incorporated in the recycle configuration. The recycle configuration is used to reduce pretreatment costs and improve the process's performance ratio by reducing heat loss.

Through the multiple staging of the MSF cycle, performance ratios in the range of 10 to 15 units of product water per kilogram of applied motive steam can be achieved. Typically, however, most MSF plants operate with performance ratios of less than 10. The MSF process has fixed orifice plates in each evaporative stage. Operation of the plant at conditions different from design conditions will result in changes in the pressure drop or flow rate in each stage. Large changes cause unstable water levels in each stage and can lead to reduced performance ratios or product water contamination. Plants with a significant number of flashing stages, say, 30 or more, are more sensitive to changes from design conditions than those with fewer than 30.

b) Multi-effect distillation (MED)

In the past decade, renewed interest in the MED process has produced a number of new high-efficiency MED designs. Most of these new units have been built around the concept of operating at low temperatures (up to 170°F). The theory behind MED is the following: steam generated from boiling saline water in each of the effects becomes the motive or driving stream for subsequent effects. The first effect of the process train is heated with supply steam, typically from a boiler, while steam generated in the last effect is sent on to a final condenser as in a single-effect evaporator. Operating in this manner requires a cascading down or decreasing of absolute pressure in steps from the first effect through the condenser. This pressure differential is the obvious driving force that draws steam from any effect to the next lower effect in series. Liquid flow is likewise cascaded from effect to effect. Because these streams are typically pumped, they do not necessarily follow the same flow pattern as the regular and decreasing arrangement of steam flow.

The MED process, like the MSF process, takes place in a series of vessels (also referred to as "effects") and uses the principle of reducing the ambient pressure in the various effects as the temperature decreases. This concept allows multiple boiling of feedwater and condensation of product distillate without supplying additional outside heat after the first effect. In an MED plant, feedwater enters the first effect and its temperature is raised to the process's first boiling point after initial preheating in feedwater tubes. Feedwater is then either sprayed, or otherwise distributed, onto the outside surface of tubes in a thin film to promote rapid boiling and evaporation. The tubes are heated on the inside by motive steam from a power plant or by steam from a boiler. The condensed motive steam is recycled to the power plant or boiler for reuse. Only a portion of feedwater applied to the tubes in the first effect is evaporated into the pure water vapor. The remaining feedwater is fed to the second effect where it is again applied to the outside surfaces of a tube bundle which are heated by vapor created in the first effect. This vapor is condensed in the second effect to form fresh water product. As product water is formed, heat is given up to evaporate a portion of the feedwater in the second effect. This process continues for several more evaporative effects. The number of stages is essential for returning better energy utilization. Typically, 8 or 16 effects are used in a large MED plant. MED is typically used for very large seawater distillation facilities.

Due to the horizontal arrangement of the evaporator tubes, feedwater remaining in each effect must usually be pumped to the next effect to apply it to the next tube bundle.

A schematic of the MED process is shown in Figure 58:

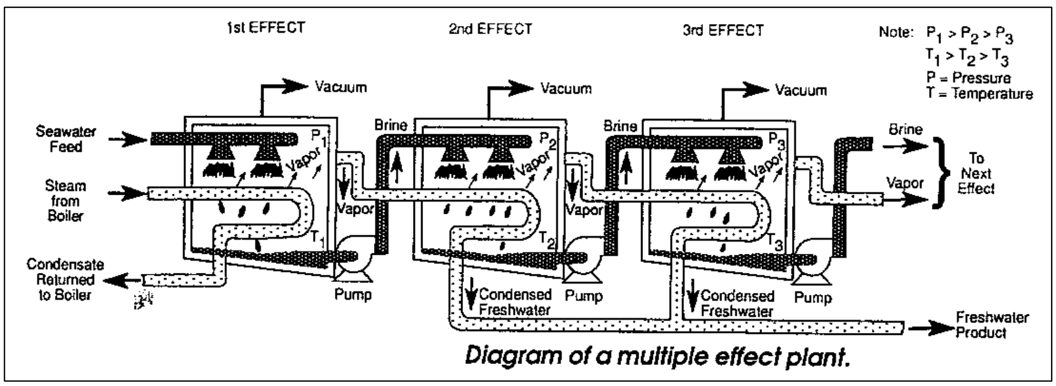

Figure 58

To significantly reduce the amount of energy needed for vaporization, the MED process uses multiple evaporation/condensation effects, which are arranged in successive distillation vessels. This process of successively reducing ambient pressure to promote boiling can continue downward across a temperature and pressure gradient. If carried to its extreme limits with the pressure sufficiently reduced, the point would be reached at which water would simultaneously boil and freeze. In commercial applications, the practical limit of evaporative/conditioning is usually controlled by the available heat sink, which is located at the final effect of the process.

While the performance ratio of the single-effect evaporator is limited to slightly less than one unit of product water produced from each unit of motive steam, the practical limitation of MED evaporator economy or performance ratio is approximately 10 to 24 units. This level of process efficiency is typically accomplished with 15 or more evaporator effects in series. In practice, the performance ratio of most commercially available MED evaporators in seawater desalination applications is limited to fewer than 15 units of product water per unit of steam due to economic considerations. Recent innovations in a vertically arranged MED unit promises to achieve performance ratios in excess of 20.

A major advantage of the MED process is the maximum attainable performance ratio. Assuming a performance ratio factor of 0.9 per effect, commercial MED plants do not usually exceed about 16 effects due to diminishing returns with increased capital costs.

The MED process operates at significantly lower maximum temperatures than the MSF process while maintaining relatively high performance ratios. Using the same temperature difference per effect, designing for a performance ratio of 12 can be accomplished in a MED plant with about 15 effects at a maximum brine temperature of 160ºF, compared to the MSF process' maximum operating temperature of 240ºF.

Another advantage offered by MED is that it can be configured in a vertical design (VTE-MED), which dramatically reduces the plant footprint and minimizes land costs. The heat exchange rates in a VTE-MED plant can be much higher due to the falling thin film evaporative process. Increased heat exchange rates result in lower tube bundle costs, a significant factor in overall plant costs.

6. Vapor-compression distillation (VCD)

The main mechanism of VCD is similar to MED except that it is based on compression of the vapor generated from the boiling solution, which raises the pressure and saturation temperature of the vapor so that it may be returned to the evaporator steam chest to be used as heating steam. Like the MSF and MED processes, the VC process is also designed to take advantage of the principle of reducing the boiling point temperature by reducing the process pressure. The heat for evaporating the water comes from the heat added to compress the vapor, rather than the direct exchange of heat from steam produced in a boiler. The primary method used to condense vapor to produce enough heat to evaporate incoming feedwater is a mechanical compressor. The compressor creates a vacuum in the vessel and compresses vapor removed from the vessel. As vapor leaves the vessel, it condenses on the inside of a tube bundle. Sea water is sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more vapor. Once the process is initiated, the primary form of energy is the electrical energy needed to operate the compressor and little to no makeup heat is necessary.

In some applications, a steam jet is used in lieu of a mechanical compressor. In this process, also referred to as a "thermo-compressor," a venturi orifice at the steam jet creates and extracts water vapor from the main vessel creating a lower ambient pressure in the main vessel. Extracted water vapor is compressed by the steam jet. This mixture is condensed on tube walls to provide the thermal energy (heat of condensation) to evaporate feedwater applied on the other side of the tube walls in the vessel. This is discussed in more detail in a following subsection.

VCD is considered to be the most efficient evaporation distillation process and is easily scaled down to the size of process appropriate for the project. The vapor compression (VC) distillation process is generally used for small-scale (less than 1.0 MGD) desalting units.

The most common VCD units operate with a seeded slurry process that allows the reject to be concentrated as much as 40 to 1 without scaling problems developing in the evaporator. Calcium sulfate seed crystals are typically used to precipitate calcium sulfate and silica, which prevents scaling of the evaporator tubes. Figure 59 is an illustration of a typical vapor compression distillation system.

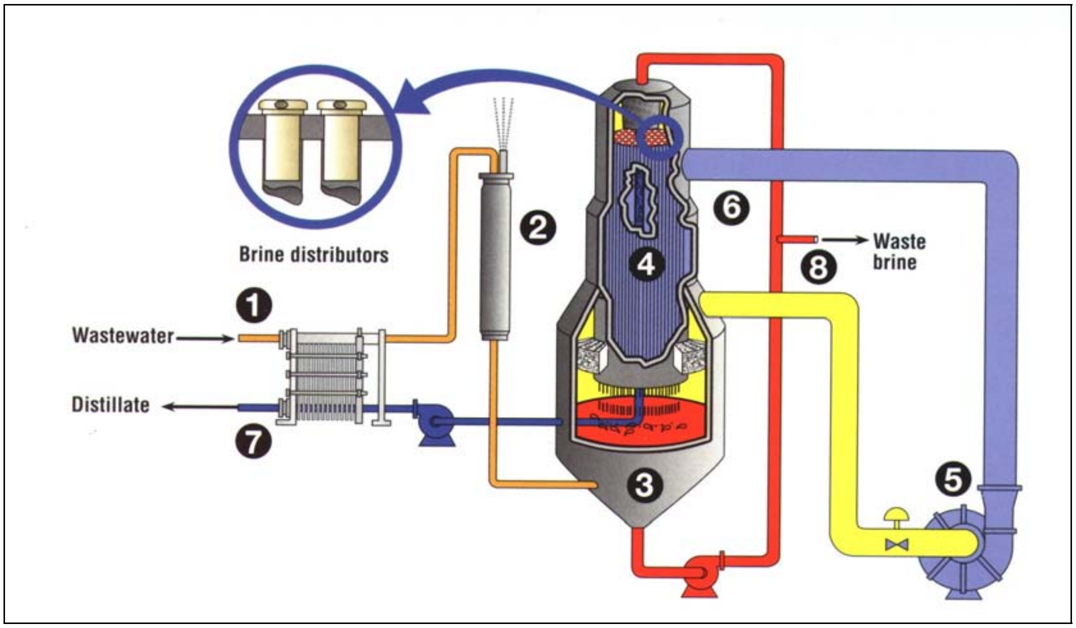

Figure 59

a) Mechanical Vapor Compression (MVC)

The mechanical vapor compression (MVC) cycle most commonly uses single-stage centrifugal compressors designed to bring steam through a compression ratio of approximately 1.5 to 2.0 on an absolute pressure basis. Mechanical compression cycles generally operate most practically at pressure levels either at, slightly above, or slightly below the atmospheric boiling point. Thus, the highest VC performance ratios can be achieved with mechanical equipment that delivers only a small pressure increase (temperature increase) to the steam. The disadvantage of this situation is that the net temperature difference driving force for heat exchange within the equipment is small. This, is turn, requires that evaporator tube bundles be constructed with large amounts of heat transfer surface. In general terms, VC processes require more complex mechanical cycles and greater heat transfer surface area than for equally efficient MED or MSF plants.

b) Thermo-compression

Thermo-compression (TO) is most commonly used to enhance the efficiency (to increase the economy or gain ratio) of multiple-effect VC evaporation systems. In certain applications, TO can double the economy of multiple-effect systems. Once again, system losses must be considered and in this case additional losses or inefficiencies due to the ejector compressor operation must also be considered. The most practical advantage of TO is boosting the comparatively low economies of multiple-effect VC systems to a higher or intermediate economy range without adding evaporator effects. The general disadvantage of TO systems is that they require moderately high-pressure steam sources to drive the ejectors. The advantage relative to MVC is that with no moving parts (i.e., no mechanical compressor) are not necessary, therefore, maintenance requirements of the TO process is generally less than for the MVC system.

MVC evaporation uses either electrical or mechanical energy to provide motive energy for the evaporative process. Medium-sized, high-efficiency MVC cycles often require approximately 57 kilowatt hours of electrical energy per 1,000 gallons of product water produced. Smaller "packaged" VC systems with less efficient compressors might require as much as 95 kilowatt hours per 1,000 gallons. Some highly engineered and highly efficient MVC systems, operating on low compression ratios, may require as little as 38 kilowatt hours per 1,000 gallons of product water.

In addition to the primary energy source (either steam, electrical, or other mechanical) needed to operate an evaporative desalination system, auxiliary energy is usually necessary. Electrical energy is needed for the recirculation, feed, and blow-down pumping system. High-pressure steam (approximately 10 bar or higher) for evaporators operating under vacuum conditions is usually needed as motive energy for ejector-driven vacuum systems. Mechanical vacuum pumps are normally not used except for the smallest packaged evaporators.
When source water is extremely high in dissolved solids, distillation by VC can be utilized as this process can accommodate high dissolved solids concentrations.

c) Solar distillation

In this process, a solar collector is used to concentrate solar energy to heat the feedwater so that it can be used in the high temperature end of a standard thermal desalination process. These units are regarded as highly capital-intensive and require specialized staff to operate them over a long period of time. Large-scale solar distillation is not used extensively in the world and remains largely experimental. There are very few large-scale installations, generally because of the large solar collection area requirements, high capital cost, vulnerability to weather-related damage, and complexity of operation.

7. Other desalination technologies

Previous sections discuss the more commonly used water desalting processes (reverse osmosis, electrodialysis, and distillation). This section briefly describes some of the other desalting processes: ion exchange demineralization, freezing, and capacitative deionization (CDI). Ion exchange is commonly used for low-TDS demineralization for industrial applications. Freezing and CDI are not yet commercially significant.

a) Ion exchange

Ion exchange (IX) processes are used to remove ionic contaminants from low-mineral content waters. In IX treatment, the targeted contaminant ions are exchanged with inert ions. The exchange of ions occurs at the surface of IX resin media.

IX resin is used for exchanging ions in water to an acceptable form. As water passes through the resin, an exchange of ions occurs on the resin surface (Figure 60). IX resins are classified into two broad categories: anionic resins and cationic resins. Anionic resins are used for removing ions that are negatively charged in water. Cationic resins are used for removing positively charged ions.

When the resin has reached its exchange capacity, the resin becomes exhausted and begins to leak, thereby passing contaminants. At that point, the resin is regenerated by passing a salt, base, or acid solution displacing ions exchanged during the service run and returning the resin to its initial condition. The regenerant wastewater can be collected, processed, and recovered.

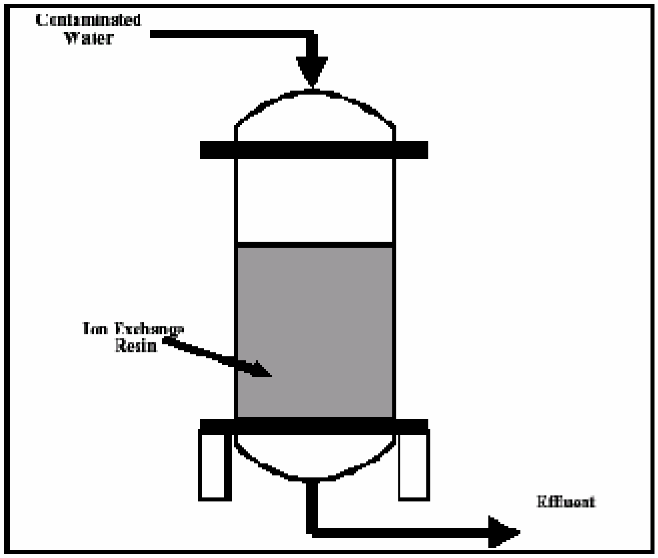

Figure 60

There are two types of exchange resins for anion exchange, strong-base anion (SBA) and weak-base anion (WBA). Weak-base resins are typically used with acidic pH waters (pH < 7), whereas strong-base resins are typically useful over essentially the full pH range (0 to 13). Both anionic resin types are present in a hydroxide or chloride form. The hydroxide form anionic resins are regenerated using caustic solution, whereas the chloride form anionic resins are regenerated using sodium chloride solution.

The cation exchange resins are available in two types, strong-acid cation (SAC) and weak-acid cation (WAC). The SAC resins can be used over a broad range of pH, because the surface functional group (typically sulfonate) is ionized over the entire range of pH (0-14). However, the WAC resins are only effective in the neutral to alkaline pH range because the functional group (typically carboxalate) is not ionized at low pH. The cation exchange resins are available in proton or chloride form. The proton and chloride cationic exchange resins are regenerated using acid and sodium chloride, respectively.

Because SBA resins prefer certain anions with higher valence states, higher atomic weights, and smaller radii, the affinity of SBA resins to various ions is shown below:

$$HCrO_4^- > CrO_4^- > ClO_4^- > SeO_4^{2-} > SO_4^{2-} > NO_3^- > Br^- > (HPO_4^{2-}, HAsO_4^{2-}, SeO_3^{2-}, CO_3^{2-}) > CN^- > NO_2^- > Cl^- > (HPO_4^-, H_2AsO_4^-, HCO_3^-) > OH^- > CH_3COO^- > F^-$$

If a particular resin prefers ion A over ion B, ion A may displace previously sorbed ion B from the resin surface, resulting in higher levels of ion B in the treated water than in the feedwater. This is referred to as chromatographic peaking. In order to avoid chromatographic peaking, beds should be monitored frequently and regenerated in a timely manner. Cation and anion exchange resins can be placed in separate vessels (dual-bed system) or in a single vessel (mixed bed).

Ion exchange demineralization with anion and cation exchange resins can be used to remove essentially all dissolved ions from water. In addition to its use in desalination, IX installations are mainly used for water softening (to remove calcium and magnesium). However, the relatively high cost of acid and caustic regenerants preclude ion exchange from being economical for high TDS removal applications, such as brackish or seawater desalting.

b) Freezing

Several freezing processes have been demonstrated for desalting water. Freeze desalting is based on the premise that ice crystals, formed when salt water is frozen, are essentially free of salt.

It takes only 13.5 percent as much energy, 144 BTU/pound, to convert water into ice as it does to convert water into vapor, 1070 BTU/pound. Several processes using these principles have been developed including direct freezing, indirect freezing, and absorption.

Direct freezing—vacuum freezing vapor compression. Direct freezing methods involve reducing feedwater temperature to near its freezing point, creating a nearly perfect vacuum and condensing the salt-free vapor that results. Vacuum freezing vapor compression (VFVC) is one variation on this method. It requires maintaining a vacuum as well as transport and compression of large volumes of water vapor.

Indirect Freezing. The indirect freezing process (IFP) was developed to overcome the problem of VFVC by using a refrigerant with a much higher vapor pressure than water. The refrigerant must, of course, be immiscible with water so that water can be separated from the refrigerant. The IFP is quite similar to the VFVC process, except that it operates at a higher pressure and uses a refrigerant.

Absorption. Water can be desalted using a hygroscopic material, a substance that absorbs and retains water, such as lithium chloride.

Absorption processes are based on water vapor being absorbed by the hygroscopic material, which is kept cold during the absorption step by heat exchange with melting ice. Heat is applied to the hygroscopic material driving off water as a vapor. The hygroscopic substance is then ready for reuse.

c) Capacitative Deionization

Capacitative Deionization (CDI) was developed at the Lawrence Livermore National Laboratory in California. The CDI process is based on the use of a substance called *carbon aerogel*, a highly porous and extremely light solid sometimes called "frozen smoke." It has a large surface area per unit volume of carbon aerogel. A desalting device using CDI would, in appearance, be much like an electrodialysis stack. Carbon aerogel is fastened to both sides of a metal plate. A number of these plates, separated by spacers and gaskets, are fastened together in a stack. Electrodes anodes and cathodes are placed on either end of the stack.

In operation, feedwater flows through the stack between the metal plates holding the carbon aerogel. Dissolved solids or ions in the feedwater are drawn into the carbon aerogel by the electrical attraction between the electrodes and ions. Water exiting the other side of the stack has fewer ions (dissolved solids) in it than the feedwater. Trapped ions are released into a relatively small stream of rinse water, which is one percent or less of the volume of product water.

C. Appendix III.3

Facility Name	City	County	Food Product	Data Year	Average Yearly Flows (kgal/d)	Average Yearly Flows (MGD)	Monthly Peak Flow (kgal/d)	Monthly Peak Flow (MGD)	Peak Flow Month	COD (mg/L)	BOD (mg/L)	Total BOD Average (lbs/d)	Total BOD Max (lbs/d)	TSS (mg/L)	Fixed Dissolved Solids (FDS) (mg/L)	Total FDS Avg (lbs/d)	Total FDS Max (lbs/d)	Conductivity (µs/cm)	TN (mg/L)	TKN (mg/L)	Total TKN (lbs/d)	NH_3 (mg/L)	NO_3-N (mg/L)	NO_3-N (lb/D)	TP (mg/L)	TP (lbs/day)	Alkalinity (mg/L)	Hardness (mg/L)	Total Hardness (lb/d)	Ca (mg/
Barrel Ten Circle Land, Inc.	Escalon	San Joaquin	Wine	2003	34	0.034	86	0.086	March		5312	1507.174	3812.263							165	46.81545		6	1.70238			315			
Bronco Wine Company	Ceres	Stanislaus	Wine	2005	333	0.333	512	0.512	September		2323	6455.35	9925.343	328				1383	40	27	75.0299		8	22.23108						
Conagra (CAG 45, Inc.)	Modesto	Stanislaus	Onion/Garlic	2005	645	0.645	1027	1.027	October		574	3089.569	4919.361	363				1193	18				1	5.382525						
E&J Gallo Grape Co.	Livingston	Merced	Grape Juice	2003	52	0.052	107	0.107	May		1019	442.1849	909.8804	540				2041	44	35	15.1879	0.83	16	6.94304	9	3.90546	130	160	69.4304	
E&J Gallo Winery	Livingston	Merced	Wine	2005	810	0.81	1816	1.816	September	5395	3555	24029.84	53874.32	1016	769			1239	100	94	635.3883	9	1	6.75945	15	101.3918	124			
Hilmar Cheese Company Primary	Hilmar	Merced	Cheese	2005	973	0.973	1132	1.132	January	623	179	1453.424	1690.931	2074	1731			3421		94	763.2504	54	1	8.119685	16	129.915	1231	351	2850.009	1
Hilmar Cheese Company Secondary	Hilmar	Merced	Cheese	2005	713	0.713	992	0.992	October		29	172.5496	240.069		574			1282		22	130.8997	18	3	17.84996	2	11.89997	331	96	571.1986	
Hughson Nut Co.	Hughson	Stanislaus	Almonds	2005	44	0.044	71	0.071	August		32	11.74976	18.95984		573			1245												
RJM Enterprises - Rivercrest Vineyards	Ripon	San Joaquin	Wine	2005	11	0.011	15	0.015	Dec		11262	1033.795	1409.721	1420				2091		61	5.599495	7	25	2.294875						
Schenone Speciality Food	Clements	San Joaquin	Chocolate/Ice Cream	2005	1	0.001	1	0.001			3	0.025035	0.025035	1873				749		36	0.30042		0					143	1.193335	
Sensient Technologies	Livingston	Merced	Fruit/Vegetables	2003	557	0.557	965	0.965	July		69	320.7234	555.6518		207			406		9	41.83349				3	13.9445				
Wine Group	Ripon	San Joaquin	Wine	2005	343	0.343	464	0.464	January		4108	11758.47	15906.5	1918	1176					68	194.6388		3	8.587005			147	133	380.6906	
Clausen Meat Packing*			Meat	2005	388	0.388																								
* data are averages from other available (14) meat facilities																														
Totals					4904	4.904	7188	7.188				50274.86	93263.03								1908.944			79.87		261.0566			3872.522	
Concentrations (mg/L)												*1228.497*	*1554.802*								*59.77345*			*2.445324*		*10.07504*			*222.8881*	
Blanks = data not available																														

Monthly Wastewater Flows for Representative Area Food Processors (kGal/mo)

2003

Facility Name	City	County	Food Product	Data Year Used	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03
Barrel Ten Circle Land, Inc.	Escalon	San Joaquin	Wine	2003	2551.889	1781.36	2669.999	1578.66	2242.571	1366.86	0	0	0	0	103.98	105.896
Bronco Wine Company	Ceres	Stanislaus	Wine	2005	16763	15652	20506	18905	14502	12692	13871	19822	22406	16758	12593	12219
Conagra (CAG 45, Inc.)	Modesto	Stanislaus	Onion/Garlic	2005	18220	9980	28210	28210	25430	30510	25960	22870	30170	31610	24860	23410
E&J Gallo Grape Co.	Livingston	Merced	Grape Juice	2003	2720	2740	2260	2729	3,320	2,496	1,445	399	43	6	267	386
E&J Gallo Winery	Livingston	Merced	Wine	2005	16100	23510	25397	13682	14711	8814		46017		66580	29998	23066
Hilmar Cheese Company Primary	Hilmar	Merced	Cheese	2005	39990	37240	32860	21420	21,700	22,200	14,663	16,802	15,720	14,012	15,300	18,073
Hilmar Cheese Company Secondary	Hilmar	Merced	Cheese	2005	7347	1988	11687	18780	19,747	18,690	26,443	26,102	26,700	28,458	27,180	25,792
Hughson Nut Co.	Hughson	Stanislaus	Almonds	2005												
RJM Enterprises - Rivercrest Vineyards	Ripon	San Joaquin	Wine	2005	187.488	171.416	207.328	67.05	191	114	104	50	332	207	232	260
Schenone Speciality Food	Clements	San Joaquin	Chocolate/Ice Cream	2005												
Sensient Technologies	Livingston	Merced	Fruit/Vegetables	2003	1021	219	3751	4114	23,546	27,322	29,919	28,869	26,907	26,858	28,342	3,413
Wine Group	Ripon	San Joaquin	Wine	2005	6510	5880	7750	10470	11,501	9,270	7,440	9,641	10,020	12,214	11,340	10,478
Clausen Meat Packing*			Meat	2005	13683	9472	10546	12326	11432	12868	13237	12447	12701	13572	11027	12347
* data are averages from other available (14) meat facilities																
Total Monthly Flow (kGal)					125093.377	108633.776	145844.327	132281.71	148322.903	146342.44	133081.819	183019.065	144998	210274.956	161242.67	129550.296
Total Monthly Flow (MG)					125.093377	108.633776	145.844327	132.28171	148.322903	146.34244	133.081819	183.019065	144.998	210.274956	161.24267	129.550296
Total Daily Flow (MGD)					4.03527023	3.87977771	4.70465571	4.40939033	4.78460977	4.87808133	4.2929619	5.90384081	4.83326667	6.7830631	5.37475567	4.17904181

2004

Facility Name	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04
Barrel Ten Circle Land, Inc.	77.655	81.144	97.712	79.41	119.226	112.5	116.994	174.499	165.6	151.342	272.82	163.742
Bronco Wine Company	8970	10214	8873	6269	6488	7026	11545	15961	13612	11970	10356	10400
Conagra (CAG 45, Inc.)	13970	13850	18440	25100	1898	1244	16410	31760	29610	32270	5750	17050
E&J Gallo Grape Co.	223	293	212						705	401		
E&J Gallo Winery	16854	14634	10399	18472	15025	13153	18993	70342	70336	39270	25639	14888
Hilmar Cheese Company Primary	24614	18067	19623	21240	22,847	21,360	25,544	30721	35910	40,610	42360	44113
Hilmar Cheese Company Secondary	26536	24244	27745	26430	27,559	25,492	21,387	20,008	8,019	6,637	5,290	
Hughson Nut Co.										3129	1428	36
RJM Enterprises - Rivercrest Vineyards	452.941	476.441	193.75	136.35	142	203	225	485	260	349	312	605
Schenone Speciality Food												
Sensient Technologies				3083	20,498	20,008	20,905	23,860	23,609	20,706	24,283	18,259
Wine Group	11842	7511	8029	6180	7,502	6,870	6,944	11,594	10,500	11,873	11,820	11,253
Clausen Meat Packing*	10772	12579	9876	8591	9942	99845	9501	9095	10974	11472	13690	10512
Total Monthly Flow (kGal)	114311.596	101949.585	103488.462	115580.76	112019.927	195313	131571.085	214000.091	203700.85	178838.092	141200.4	127279.242
Total Monthly Flow (MG)	114.311596	101.949585	103.488462	115.58076	112.019927	195.313	131.571085	214.000091	203.70085	178.838092	141.2004	127.279242
Total Daily Flow (MGD)	3.68747084	3.51550293	3.33833748	3.852692	3.61354603	6.51043333	4.24422855	6.90322874	6.79002833	5.76897071	4.70668	4.105782

2005

Facility Name	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	
Barrel Ten Circle Land, Inc.	0	0	0	0	0	0	0	51.894	86.49	929.597	
Bronco Wine Company	12055	9511	8609	7019	8132	6912	8643	12149	15346	13295	
Conagra (CAG 45, Inc.)	15970	0	24250	16150	19200	24690	24010	28060	7950	31840	
E&J Gallo Grape Co.						1,254	885			231	
E&J Gallo Winery	20038	17010	19786	19385	11104	12100	13643	28547	54472	43762	
Hilmar Cheese Company Primary	35092	22960	33201	29880	29,822	29,880	34,441	31,403	28,230	24,211	
Hilmar Cheese Company Secondary	12617	21025	18755	19110	22,754	18,960	18,414	23,152	24,934	30,752	
Hughson Nut Co.	294	1323	1836		1,884	1,305	573	2,188	1,547	1,246	
RJM Enterprises - Rivercrest Vineyards	363.537	343	352.284	202.23	357	380	0.39	393	463	424	
Schenone Speciality Food	24.025	19.656	19.561	31.68	28	21	23	25	22	14	
Sensient Technologies	3514	1674		17468	90,144	13,462	24,468	21,133	15,400	23,923	
Wine Group	14384	8540	10540	9330	10,974	8,370	8,711	10,726	10,710	12,245	
Clausen Meat Packing*	11724	9956	11952	11091	10880	14468	10490	10124	13071	18577	
Total Monthly Flow (kGal)	126075.562	92361.656	129300.845	129666.91	205278.865	131802.37	144301.581	167951.929	172231.32	201449.348	16
Total Monthly Flow (MG)	126.075562	92.361656	129.300845	129.66691	205.278865	131.80237	144.301581	167.951929	172.23132	201.449348	16
Total Daily Flow (MGD)	4.06695361	3.29863057	4.170995	4.32223033	6.62189887	4.39341233	4.65488971	5.41780416	5.741044	6.49836606	5.

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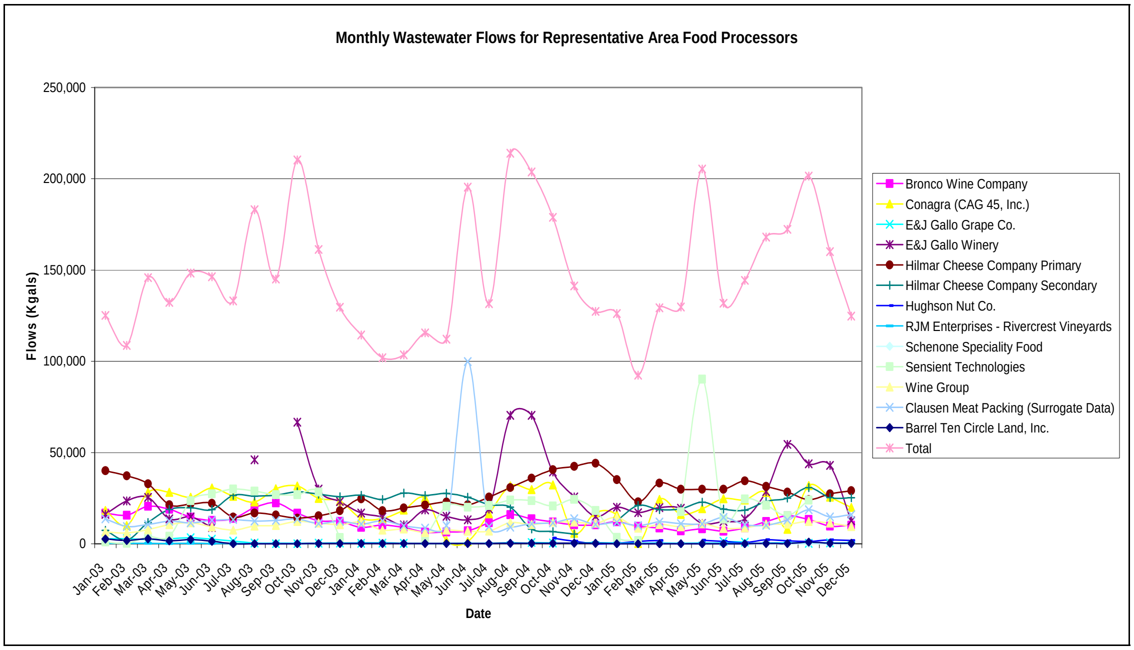

Wastewater TDS Concentrations and Loads for Representative Area Food Processors

TDS Concentration (mg/L)

Facility Name	City	County	Food Product	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05
				2003												2004												2005										
Barrel Ten Circle Land, Inc.	Escalon	San Joaquin	Wine	2550	3650	3800	2550	2550	715	780	680	1010	1630	1020	1310		210	31	77	34.5	20.9	151	80.5	72	204.5	820	4900	4500	4800	970	1500	2500	680	760	920	730	1400	110
Bronco Wine Company	Ceres	Stanislaus	Wine	800	960	1400	1100	790	930	870	1400	2100	1200	1000	965	690	2000	1200	2200	3100	2000	1400	1300	2400	1800	780	1900	880	1700	2500	2000	1000	950	1400	2200	2600	3200	2200
Conagra (CAG 45, Inc.)	Modesto	Stanislaus	Onion/Garlic	2050	1605	1098	933	855	940	760	903	892	885	1120	890	1725	1540	1298	1333	913	780	1290	1360	1003	1078	1310	1285	1725		1274	738	812	868	918	1290	1325	1475	1280
E&J Gallo Grape Co.	Livingston	Merced	Grape Juice	1500	6000	1700	1400	6000	2200	7000		1000			240	360	120			800		1000		900	700		843							900				1100
E&J Gallo Winery	Livingston	Merced	Wine	915	5359	5537	390	472	564		1802		2474	2713	10558	2153	426	2914	3461	346	271	1885	4207	3834	1428	2206	1264	1068	988	6023	714	568	414	3495	2523	3352	3003	2058
Hilmar Cheese Company Primary	Hilmar	Merced	Cheese	2700	5075	3800	4080	5525	4625	4420	3925	4040	6075	5775	8575	2400	6100	4240	4950	6175	5150	5160	3344	2399	2450	2560	2600	2050	1975	2020	1975	1940	2125	2075	2300	2275	2050	1880
Hilmar Cheese Company Secondary	Hilmar	Merced	Cheese	580	530	560	360	210	250	500	500	480	590	660	460	480	620	680	460	590	580	350	710	1100	1200				470	550	290	310	510	580	790	1638	2100	610
Hughson Nut Co.	Hughson	Stanislaus	Almonds																						670	860	830	660	680	780		440	920	1000	980	820	910	820
RJM Enterprises - Rivercrest Vineyards	Ripon	San Joaquin	Wine	2690	2460	1140	8020	3130	2060	1570	2800	8160	2000	1590	3180	4060	912	874	643	2310	530	1440	12800	2040	6100	1940	2890	1070	1740	7390	651	1740	1190	3010	1590	712	5370	2160
Schenone Speciality Food	Clements	San Joaquin	Chocolate/Ice Cream																									578	1000	650	423	880	834	755	768	760	920	850
Sensient Technologies	Livingston	Merced	Fruit/Vegetables	303	424	232		790	720	1075	934	1210	748	632	636				330	1115	722	452	776	793	984	1036	1200	334	369		365	316	748	674	964	878	760	
Wine Group	Ripon	San Joaquin	Wine	960	1100	1790	1300	1000	1600	1200	2765	4600	8800	2441.667	1300	460	4705	1300	2300	850	820	1843	5100	3350	3925	1697	410	1185	470	770	2000	515	2900		1700	16000	6067	1475
Clausen Meat Packing*			Meat																																			
* concentration data not available																																						

* Sep-05 RJM TDS assumed to be 712 per a

TDS Loading (lb/mo)

Facility Name				Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05
Barrel Ten Circle Land, Inc.				54303.5599	54258.89	84668.34	33593.49	47721.35	8155.609	0	0	0	0	885.0674	1157.65		142.2008	25.27761	51.02609	34.32546	19.62118	147.4236	117.2236	99.4991	258.2731	1866.88	6695.492	0	0	0	0	0	0	0	398.411	526.8841	10860.48	318.1523
Bronco Wine Company				111909.788	125391.3	239571.6	173538.4	95605.16	98500.71	100705.5	231580.4	392653.9	167814.6	105088.6	98398.69	51649.71	170471.7	88854.22	115092.6	167841.3	117263.9	134880.2	173152.9	272621.1	179801.4	67408.24	164897.2	88527.1	134927.8	179605.3	117147.1	67861.54	54796.61	100976.2	223043.5	332962.2	355029.7	176815.5
Conagra (CAG 45, Inc.)				311694.095	133669.4	258482.9	219639.8	181442.4	239329.6	164643.5	172337.7	224577.6	233450.1	232351.5	173867.2	201099.9	177990.5	199738.6	279209.5	14460.83	8097.32	176654.5	360450.6	247836.7	290298	62858.71	182832.7	229890.1	0	257814.6	99461.55	130101.9	178841	183933.6	302067.3	87904.14	391914.6	273449
E&J Gallo Grape Co.				34047.6	137191.8	32061.49	31882.91	166232.4	45824.06	84409.68		354.6625			773.0808	669.9366	293.4102							5294.903	2342.442									6646.793				4773.34
E&J Gallo Winery				122979.152	1051289	1173501	44528.75	57882.89	41483.8		692117.4		1374579	679154.3	2032265	302859.1	51962.37	252875.9	533509.1	43382.73	29745.44	298766.1	2469232	2250381	467967.2	471990.1	157039.8	178587.9	140292.4	994482.6	115502.2	52586.18	41752.96	397908.7	600921.8	1523715	1096495	735854.8
Hilmar Cheese Company Primary				901034.685	1577147	1042023	729299.6	1000503	856822.9	540843.3	550334.8	529980.9	710350.6	737343.3	1293275	492969.2	919691.6	694316.7	877376.6	1177314	917983.4	1099930	857237.6	718905.8	830281.6	904945.2	957119.8	600327.6	378412.4	559665.9	492463.5	482797.3	529865.8	596376.1	602733.5	535943	414183.6	429240.1
Hilmar Cheese Company Secondary				35560.2147	8792.626	54615.69	56418.88	34605.63	38992.01	110333.4	108910.6	106949.5	140114.4	149699.3	99007.75	106292.6	125436	157441.8	101456.8	135688.1	123383.8	62466.08	118546.4	73610.41	66462.92				82463.2	86080.76	46247.16	58863.46	80692.81	89125.6	152630.7	340894.9	538913.4	128584.8
Hughson Nut Co.																									17494.71	10248.33	249.3486	1619.264	7507.496	11950.71		6917.671	10019.01	4781.685	17893.68	10585.97	9462.062	14103.22
RJM Enterprises - Rivercrest Vineyards				4208.74	3518.948	1972.373	4487.449	4997.563	1952.52	1360.2	1169.819	22573.56	3454.096	3074.19	6910.261	15345.96	3626.021	1413.121	731.6316	2731.563	895.6271	2704.874	51762.18	4430.444	17752.94	5044.262	14578.76	3246.076	4980.463	21725.2	1098.634	5187.29	3776.687	9.871224	5214.368	2750.207	18999.98	6449.597
Schenone Speciality Food																												115.8824	164.0293	106.1038	111.8283	202.8376	146.5719	146.0954	160.5316	139.2747	105.6717	163.2157
Sensient Technologies				2581.63424	774.8833	7262.086		155228.2	164161.5	268399.6	225011.6	271692.1	167649.2	149476.8	18114.22				8490.12	190727.2	120550	78852.41	154510.7	156234.6	170026.9	209936.7	182845.6	9794.326	5154.757		53206.22	237711.5	84030.61	137621	170006.1	112834.4	151724.5	
Wine Group				52152.912	53975.46	115766	113583.8	95975.85	123773	74504.16	222455.7	384637.7	896947.3	231060.5	113670.6	45457.89	294906.1	87102.61	118615.8	53213.56	47010.72	106816.9	493434.8	293535.4	388889.7	167355.6	38501.58	142240.9	33495.16	67726.35	155717.7	47162.69	202558.2		152164.4	1429999	619919.5	139213.4
Clausen Meat Packing*				2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910
* data are annual average monthly loads from other available (14) meat facilities.																																						
Total Monthly TDS Loading (lb/month)				1633382.38	3148919	3012834	1409883	1843104	1621906	1348109	2206828	1936330	3697270	2291044	3840349	1219254	1747430	1484678	2037443	1788304	1367860	1964128	4681355	4025860	2434486	1904564	1707670	1257259	790307.7	2182068	1083866	1092302	1189390	1520436	2230144	4381165	3610518	1911875
Average TDS Concentration (mg/L)				1564.68604	3473.524	2475.48	1277.194	1489.071	1328.094	1213.892	1444.927	1600.262	2107.013	1702.656	3552.27	1278.138	2053.941	1719.151	2112.388	1913.021	839.236	1788.888	2621.388	2368.315	1631.252	1616.342	1607.756	1194.999	1025.364	2022.276	1001.659	637.6352	1081.371	1262.614	1591.189	3048.254	2147.718	1431.764

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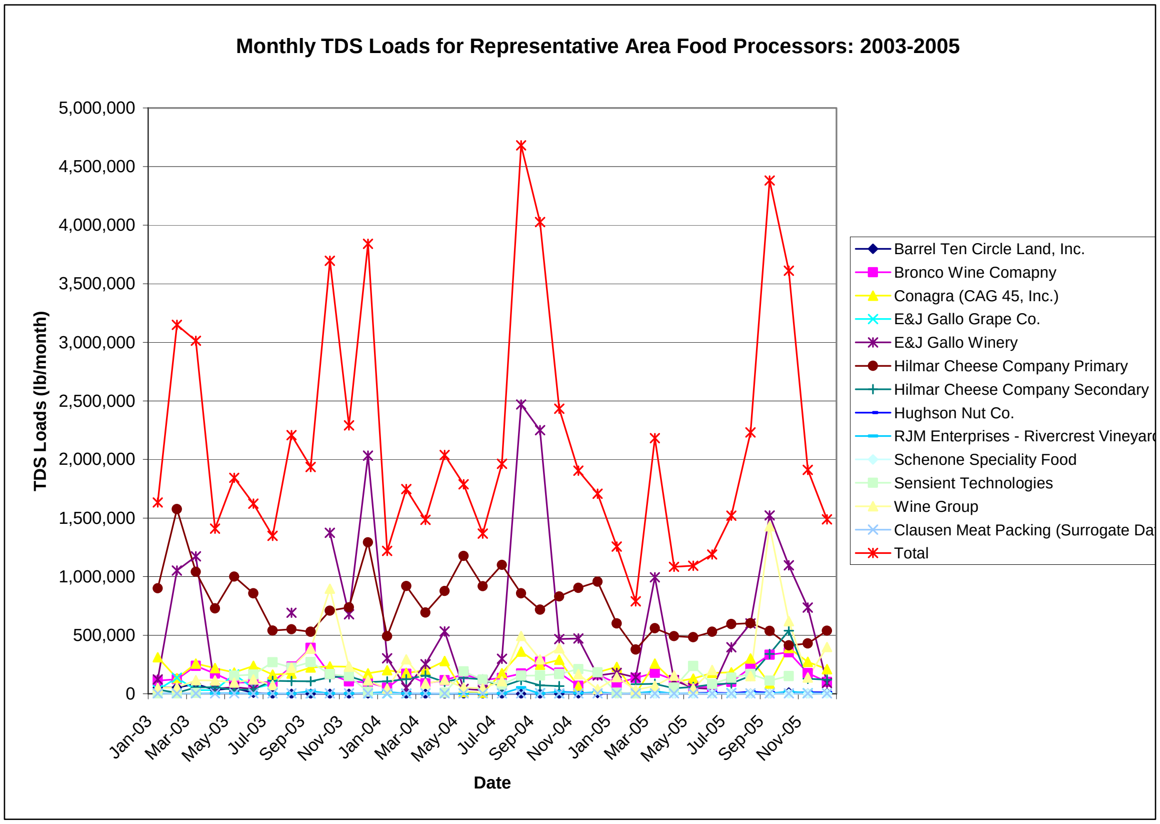
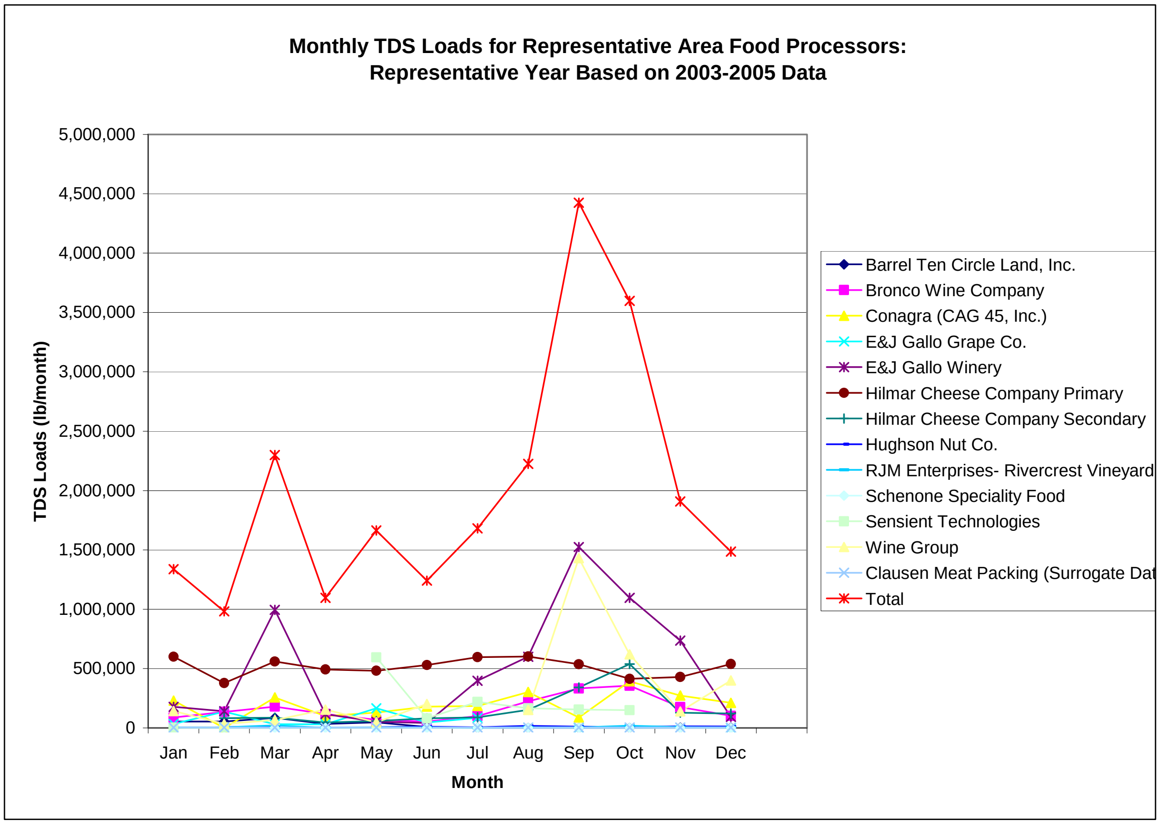


Facility Name	City	County	Food Product	Data Year Used	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					TDS Concentration (mg/L)											
Barrel Ten Circle Land, Inc.	Escalon	San Joaquin	Wine	2003	2550	3650	3800	2550	2550	715	780	680	1010	1630	1020	1310
Bronco Wine Company	Ceres	Stanislaus	Wine	2005	880	1700	2500	2000	1000	950	1400	2200	2600	3200	2200	1200
Conagra (CAG 45, Inc.)	Modesto	Stanislaus	Onion/Garlic	2005	1725		1274	738	812	868	918	1290	1325	1475	1280	1270
E&J Gallo Grape Co.	Livingston	Merced	Grape Juice	2003	1500	6000	1700	1400	6000	2200	7000		1000			240
E&J Gallo Winery	Livingston	Merced	Wine	2005	1068	988	6023	714	568	414	3495	2523	3352	3003	2058	887
Hilmar Cheese Company Primary	Hilmar	Merced	Cheese	2005	2050	1975	2020	1975	1940	2125	2075	2300	2275	2050	1880	2225
Hilmar Cheese Company Secondary	Hilmar	Merced	Cheese	2005		470	550	290	310	510	580	790	1638.333	2100	610	580
Hughson Nut Co.	Hughson	Stanislaus	Almonds	2005	660	680	780		440	920	1000	980	820	910	820	780
RJM Enterprises - Rivercrest Vineyard	Ripon	San Joaquin	Wine	2005	1070	1740	7390	651	1740	1190	3010	1590	712	5370	2160	922
Schenone Speciality Food	Clements	San Joaquin	Chocolate/Ice Cre	2005	578	1000	650	423	880	834	755	768	760	920	850	570
Sensient Technologies	Livingston	Merced	Fruit/Vegetables	2003	303	424	232		790	720	1075	934	1210	748	632	636
Wine Group	Ripon	San Joaquin	Wine	2005	1185	470	770	2000	515	2900		1700	16000	6066.667	1475	5050
Clausen Meat Packing*			Meat	2005												
* concentration data not available																

* Sept RJM data assumed to be 712 based on all other parameters reported, not 7.12

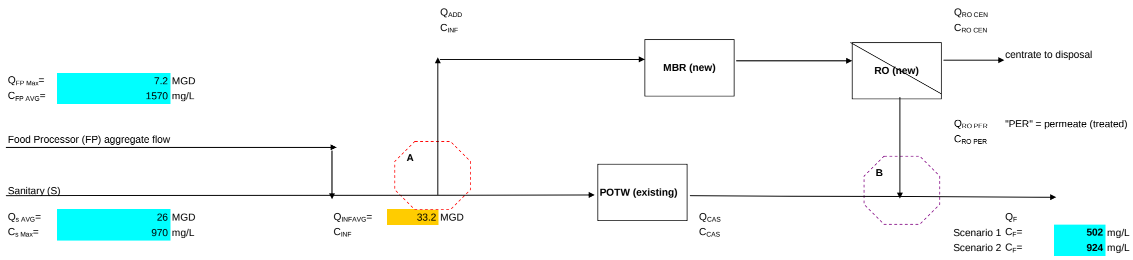
Facility Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Monthly TDS Load (lb/d)	Average Flow-weighted TDS Concentration (mg/L)		Maximum Monthly TDS Load (lb/d)
	TDS Loading (lb/month)															
Barrel Ten Circle Land, Inc.	54303.5599	54258.89	84668.34	33593.49	47721.35	8155.609	0	0	0	0	885.0674	1157.65				
Bronco Wine Company	88527.098	134927.8	179605.3	117147.1	67861.54	54796.61	100976.2	223043.5	332962.2	355029.7	176815.5	101882.4				
Conagra (CAG 45, Inc.)	229890.146	0	257814.6	99461.55	130101.9	178841	183933.6	302067.3	87904.14	391914.6	273449	210479.3				
E&J Gallo Grape Co.	34047.6	137191.8	32061.49	31882.91	166232.4	45824.06	84409.68		354.6625			773.0808				
E&J Gallo Winery	178587.873	140292.4	994482.6	115502.2	52586.18	41752.96	397908.7	600921.8	1523715	1096495	735854.8	93013.72				
Hilmar Cheese Company Primary	600327.617	378412.4	559665.9	492463.5	482797.3	529865.8	596376.1	602733.5	535943	414183.6	429240.1	538758.2				
Hilmar Cheese Company Secondary		82463.2	86080.76	46247.16	58863.46	80692.81	89125.6	152630.7	340894.9	538913.4	128584.8	121835				
Hughson Nut Co.	1619.2638	7507.496	11950.71		6917.671	10019.01	4781.685	17893.68	10585.97	9462.062	14103.22	11905.14				
RJM Enterprises - Rivercrest Vineyards	3246.0764	4980.463	21725.2	1098.634	5187.29	3776.687	9.871224	5214.368	2750.207	18999.98	6449.597	3469.942				
Schenone Speciality Food	115.882425	164.0293	106.1038	111.8283	202.8376	146.5719	146.0954	160.5316	139.2747	105.6717	163.2157	114.5734				
Sensient Technologies	2581.63424	5923.081			594278.8	80885.08	219499.4	164715.5	155500.7	149328.8						
Wine Group	142240.859	33495.16	67726.35	155717.7	47162.69	202558.2		152164.4	1429999	619919.5	139213.4	399761.4				
Clausen Meat Packing*	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910	2910				
* data are annual average monthly loads from other available (14) meat facilities.																
Total Monthly Loading (lb/month)	1338397.61	982526.7	2298797	1096136	1662823	1240224	1680077	2224455	4423659	3597262	1907669	1486060				
Total Daily Loading (lb/d)	43174.1165	35090.24	74154.75	36537.87	53639.47	41340.81	54196.03	71756.62	147455.3	116040.7	63588.95	47937.43	65409.35857	1567.629924		147455.3022
Daily Average TDS (mg/L) using 5 MGD	1034.73017	840.9883	1777.226	875.6829	1285.547	990.7924	1298.886	1719.751	3533.98	2781.083	1524.001	1148.89		(this value carried forward)		

Blanks = data not available



Monthly TDS Loads for Representative Area Food Processors:
Representative Year Based on 2003-2005 Data
TDS Loads (lb/month)
5,000,000
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Barrel Ten Circle Land, Inc.
Bronco Wine Company
Conagra (CAG 45, Inc.)
E&J Gallo Grape Co.
E&J Gallo Winery
Hilmar Cheese Company Primary
Hilmar Cheese Company Secondary
Hughson Nut Co.
RJM Enterprises- Rivercrest Vineyard
Schenone Speciality Food
Sensient Technologies
Wine Group
Clausen Meat Packing (Surrogate Dat
Total

D. *Appendix III.4*



Scenario 1:
Assumptions:
1. No deviation from current Modesto POTW average daily discharge TDS concentration as found in City of Modesto Wastewater Treatment Master Plan Update (Phase 2), Carollo Engineers, March 2007.
2. R/O will remove 90% of the R/O influent TDS.
3. R/O centrate is 25% of the R/O influent flow.
4. Assume Modesto WWTP does not remove significant amounts of TDS (conservative assumption)

Therefore, from assumptions the following unknowns can be defined:

C_F= 502 mg/L
C_{CAS}= C_{INF}
$C_{RO\ PER}$ = $(0.1)C_{INF}$
$Q_{RO\ CEN}$= $(0.25)Q_{ADD}$
$Q_{RO\ PER}$= $(0.75)Q_{ADD}$
Q_F= $Q_{INFAVG} - (0.25)Q_{ADD}$
Q_{CAS}= $Q_{INFAVG} - Q_{ADD}$

Step 1: Calculate C_{INF} using mass balance around Area A

[(C_{INF}	x	Q_{INFAVG})	=	($C_{FP\ AVG}$	x	$Q_{FP\ Max}$)	+	($C_{s\ Max}$	x	$Q_{s\ AVG}$)]
C_{INF}	x	33.2	=	1570	x	7.2	+	970	x	26

C_{INF} = 1100 mg/L

Step 2: Calculate Q_{ADD} using mass balance around Area B

[(C_F	x		Q_F)	=	($C_{RO\ PER}$	x	$Q_{RO\ PER}$)	+	(C_{CAS}	x	Q_{CAS})]

Using the equations derived from the assumptions

502	x		$(Q_{INFAVG} - (0.25)Q_{ADD})$	=	$(0.1)C_{INF}$	x	$(0.75)Q_{ADD}$	+	C_{INF}	x	$(Q_{INFAVG} - Q_{ADD})$
502	x	(	33.2 $-(0.25)Q_{ADD}$)	=	110.012	x	$(0.75)Q_{ADD}$	+	1100	x	(33.2 $-Q_{ADD}$)

Q_{ADD} = 22.26 MGD <----- sidestream flow required to meet total effluent TDS goal

Scenario 2:
Assumptions (same as above except #1):
1. Meet current permit for Modesto average daily discharge of TDS as found in City of Modesto Wastewater Treeatment Master Plan Update (Phase 2), Carollo Engnieers, March 2007.
2. R/O will remove 90% of the R/O influent TDS
3. R/O centrate is 25% of the R/O influent flow
4. Assume Modesto WWTP does not remove significant amounts of TDS

Therefore, from assumptions the following unknowns can be defined:

C_F= 924 mg/L
C_{CAS}= C_{INF}
$C_{RO\ PER}$ = $(0.1)C_{INF}$
$Q_{RO\ CEN}$= $(0.25)Q_{ADD}$
$Q_{RO\ PER}$= $(0.75)Q_{ADD}$
Q_F= $Q_{INFAVG} - (0.25)Q_{ADD}$
Q_{CAS}= $Q_{INFAVG} - Q_{ADD}$

Step 1: Calculate C_{INF} using mass balance around Area A

[(C_{INF}	x	Q_{INFAVG})	=	($C_{FP\ AVG}$	x	$Q_{FP\ MAX}$)	+	($C_{s\ Max}$	x	$Q_{s\ AVG}$)]
C_{INF}	x	33.2	=	1570	x	7.2	+	970	x	26

C_{INF} = 1100 mg/L

Step 2: Calculate Q_{ADD} using mass balance around Area B

[(C_F	x		Q_F)	=	($C_{RO\ PER}$	x	$Q_{RO\ PER}$)	+	(C_{CAS}	x	Q_{CAS})]	x 8.345 lb/(MG*mg/L)

Using the equations derived from the assumptions

924	x		$(Q_{INFAVG} - (0.25)Q_{ADD})$	=	$(0.1)C_{INF}$	x	$(0.75)Q_{ADD}$	+	C_{INF}	x	$(Q_{INFAVG} - Q_{ADD})$
924	x	(	33.2 $-(0.25)Q_{ADD}$)	=	110.012	x	$(0.75)Q_{ADD}$	+	1100	x	(33.2 $-Q_{ADD}$)

Q_{ADD} = 7.43 MGD

Cost Scenario 1:

Q_{ADD}= Q_{MBR}= Q_{RO} = 22.26 MGD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 16.69 MGD

Step 1: Calculate the Cost of the MBR Facility

Using "MBR Cost vs. Capacity Graph" from *Membrane Bio-Reactor (MBR), An Innovative Technology,* J. Daily and D.Fry, Feb 2005.

For 22 MGD plant cost= $2,500,000 per MGD in Feb 2005 dollars (conservative from available cost graph)

Therefore:

22 MGD plant= $55,600,000 in 2005 dollars

Using ENR Construction Cost Index History, Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Feb 2005 Index= 7298

Therefore:

Present-day cost of MBR =	**$61,000,000**

<-- cost inclusive of full MBR plant, not just MBR equipment

Calculate O&M Cost for MBR based on recent (2005) AWWA QualServe benchmark data
In 2005 Cost = $1,816.00 per MG processed
Using *ENR Construction Cost Index History* , Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for MBR=	**$16,200,000 /yr**

Step 2: Calculate the Cost of the RO Equipment using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

Must use the R/O Permeate Flow to calculate the $/GPD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 17

Use the following equation from the reference:

$/GPD= 0.9652 x $(Q_{RO\ PER})^{-0.4696}$

$/GPD= 0.26

Therefore in 2003 dollars:

$2003 = $4,300,000

Using ENR Construction Cost Index History, Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO EQUIP =	**$5,100,000**

Step 3: Calculate the Cost of the RO Facility using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

$/GPD= 3.6545 x $(Q_{RO\ INF})^{-0.2495}$

$/GPD= 1.69

Therefore in 2003 dollars:

$2003 = $37,500,000

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO FACILITY =	**$44,900,000**

Calculate O&M Cost for R/O based on "Unit O&M Cost of RO Membrane WTPs vs. Capacity" from The Cost of Membrane Softening and Desalting for Municipal Water Supplies, J. Elarde and R. Bergman, American Water Works Assosication, 2003
In 2003 Cost = $0.32 per 1000 gallons permeate
Using ENR Construction Cost Index History, Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for RO =	**$2,300,000 /yr**

Total Cost in Aug 2007 dollars= MBR Facility Cost + RO Equipment Cost + RO Facility Cost

Total Capital Cost of Upgrade (Scenario 1) =	**$111,000,000**

Total O&M Cost of Upgrade (Scenario 1) =	**$18,500,000 /yr**

Cost Scenario 2:

Q_{ADD}= Q_{MBR}= Q_{RO} = 7.43 MGD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 5.58 MGD

Step 1: Calculate the Cost of the MBR Facility

Using "MBR Cost vs. Capacity Graph" from *Membrane Bio-Reactor (MBR), An Innovative Technology,* J. Daily and D.Fry, Feb 2005.

For 7 MGD plant cost=$ $5,000,000 per MGD in Feb 2005 dollars

Therefore:

7 MGD plant= $37,200,000 in 2005 dollars

Using ENR Construction Cost Index History, Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Feb 2005 Index= 7298

Therefore:

Present-day cost of MBR =	**$40,800,000**

Calculate O&M Cost for MBR based on recent (2005) AWWA QualServe benchmark data
In 2005 Cost = $1,816.00 per MG processed
Using *ENR Construction Cost Index History* , Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for MBR =	**$5,400,000 /yr**

Step 2: Calculate the Cost of the RO Equipment using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

Must use the R/O Permeate Flow to calculate the $/GPD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 5.58

Use the following equation from the reference:

$/GPD= 0.9652 x $(Q_{RO\ PER})^{-0.4696}$

$/GPD= 0.43

Therefore in 2003 dollars:

$2003 = $2,400,000

Using ENR Construction Cost Index History, Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO EQUIP =	**$2,900,000**

Step 3: Calculate the Cost of the RO Facility using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

$/GPD= 3.6545 x $(Q_{RO\ INF})^{-0.2495}$

$/GPD= 2.22

Therefore in 2003 dollars:

$2003 = $16,500,000

Using *ENR Construction Cost Index History* , Aug 2007 calculate the cost in present-day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO FACILITY =	**$19,700,000**

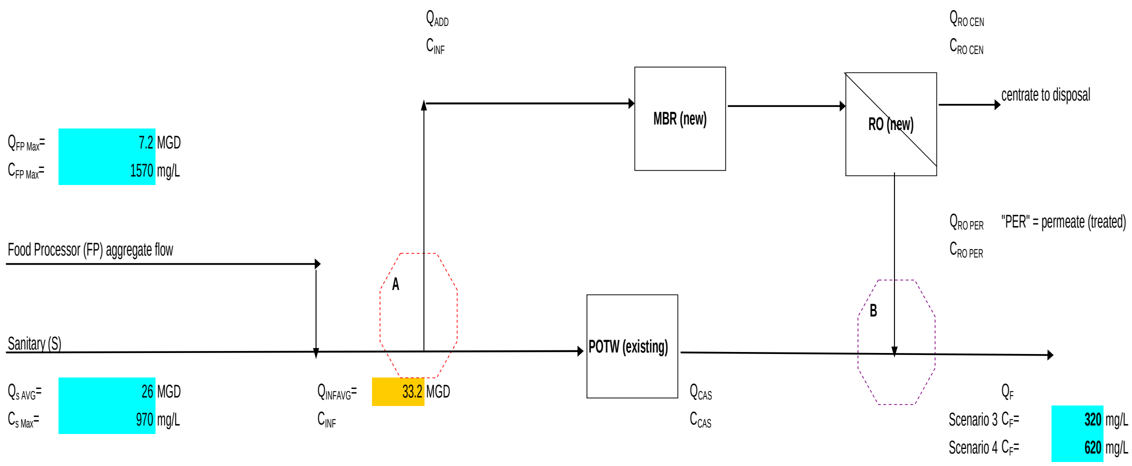
Calculate O&M Cost for R/O based on "Unit O&M Cost of RO Membrane WTPs vs. Capacity" from The Cost of Membrane Softening and Desalting for Municipal Water Supplies, J. Elarde and R. Bergman, American Water Works Assosication, 2003
In 2003 Cost = $0.45 per 1000 gallons permeate
Using ENR Construction Cost Index History, Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for RO =	**$1,100,000 /yr**

Total Cost in Aug 2007 dollars= MBR Facility Cost + RO Equipment Cost + RO Facility Cost

Total Capital Cost of Upgrade (Scenario 2) =	**$63,400,000**

Total O&M Cost of Upgrade (Scenario 2) =	**$6,500,000 /yr**



Scenario 3:

Assumptions:

1. Treat to background groundwater TDS concentration of Representative Area (i.e., 320 mg/L)
2. R/O will remove 90% of the R/O influent TDS
3. R/O centrate is 25% of the R/O influent flow
4. Assume Modesto WWTP does not remove significant amounts of TDS (conservative assumption)

Therefore, from assumptions the following unknowns can be defined:

C_F= 320 mg/L

C_{CAS}= C_{INF}

$C_{RO\ PER}$ = $(0.1)C_{INF}$

$Q_{RO\ CEN}$= $(0.25)Q_{ADD}$

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$

Q_F= $Q_{INFAVG} - (0.25)Q_{ADD}$

Q_{CAS}= $Q_{INFAVG} - Q_{ADD}$

Step 1: Calculate C_{INF} using mass balance around Area A

$[(C_{INF}$ x $Q_{INFAVG})$ = $(C_{FP\ Avg}$ x $Q_{FP\ Max})$ + $(C_{S\ Max}$ x $Q_{S\ AVG})]$

C_{INF} x 33.2 = 1570 x 7.2 + 970 x 26

C_{INF} = 1100 mg/L

Step 2: Calculate Q_{ADD} using mass balance around Area B

$[(C_F$ x $Q_F)$ = $(C_{RO\ PER}$ x $Q_{RO\ PER})$ + $(C_{CAS}$ x $Q_{CAS})]$

Using the equations derived from the assumptions

502 x $(Q_{INFAVG} - (0.25)Q_{ADD})$ = $(0.1)C_{INF}$ x $(0.75)Q_{ADD}$ + C_{INF} x $(Q_{INFAVG} - Q_{ADD})$

502 x (33.2 $-(0.25)Q_{ADD})$ = 110.012 x $(0.75)Q_{ADD}$ + 1100 x (33.2 $-Q_{ADD})$

Q_{ADD} = 27.62 MGD <----- sidestream flow required to meet total effluent TDS goal

Scenario 4:

Assumptions (same as above except #1):

1. Treat to background groundwater TDS concentration of Representative Area (i.e., 320 mg/L) + 300 mg/L (620 mg/L)
2. R/O will remove 90% of the R/O influent TDS
3. R/O centrate is 25% of the R/O influent flow
4. Assume Modesto WWTP does not remove significant amounts of TDS

Therefore, from assumptions the following unknowns can be defined:

C_F= 620 mg/L

C_{CAS}= C_{INF}

$C_{RO\ PER}$ = $(0.1)C_{INF}$

$Q_{RO\ CEN}$= $(0.25)Q_{ADD}$

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$

Q_F= $Q_{INFAVG} - (0.25)Q_{ADD}$

$Q_{CAS=}$ $Q_{INFAVG} - Q_{ADD}$

Step 1: Calculate C_{INF} using mass balance around Area A

[(C_{INF}	x	Q_{INFAVG})	=	(C_{FPAVG}	x	$Q_{FP\ MAX}$)	+	($C_{s\ Max}$	x	$Q_{s\ AVG}$)]	x 8.345 lb/(MG*mg/L)
C_{INF}	x	33.2	=	1570	x	7.2	+	970	x	26	

C_{INF}	**=**	**1100 mg/L**

Step 2: Calculate Q_{ADD} using mass balance around Area B

[(C_F	x	Q_F)	=	($C_{RO\ PER}$	x	$Q_{RO\ PER}$)	+	(C_{CAS}	x	Q_{CAS})]	x 8.345 lb/(MG*mg/L)

Using the equations derived from the assumptions

620	x	($Q_{INFAVG} - (0.25)Q_{ADD}$)	=	$(0.1)C_{INF}$	x	$(0.75)Q_{ADD}$	+	C_{INF}	x	($Q_{INFAVG} - Q_{ADD}$)
620	x	(33.2 $-(0.25)Q_{ADD}$)	=	110.012	x	$(0.75)Q_{ADD}$	+	1100	x	(33.2 $-Q_{ADD}$)

Q_{ADD}	**=**	**18.48 MGD**

Cost Scenario 3:

Q_{ADD}= Q_{MBR}= Q_{RO} = 27.62 MGD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 20.72 MGD

Step 1: Calculate the Cost of the MBR Facility

Using "MBR Cost vs. Capacity Graph" from *Membrane Bio-Reactor (MBR), An Innovative Technology,* J. Daily and D.Fry, Feb 2005.

For 27.62 MGD plant cost= $2,500,000 per MGD in Feb 2005 dollars (conservative from available cost graph)

Therefore:

27.62 MGD plant= $69,100,000 in 2005 dollars

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Feb 2005 Index= 7298

Therefore:

Present-day cost of MBR =	**$75,800,000**

<-- cost inclusive of full MBR plant, not just MBR equipment

Calculate O&M Cost for MBR based on recent (2005) AWWA QualServe benchmark data
In 2005 Cost = $1,816.00 per MG processed
Using *ENR Construction Cost Index History* , Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for MBR=	**$20,100,000 /yr**

Step 2: Calculate the Cost of the RO Equipment using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

Must use the R/O Permeate Flow to calculate the $/GPD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 20.72

Use the following equation from the reference:

$/GPD= 0.9652 x $(Q_{RO\ PER})^{-0.4696}$

$/GPD= 0.23

Therefore in 2003 dollars:

$2003 = $4,800,000

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO EQUIP =	**$5,700,000**

Step 3: Calculate the Cost of the RO Facility using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies* , J. Elarde and R. Bergman, American Water Works Assosication, 2003

$/GPD= 3.6545 x $(Q_{RO\ INF})^{-0.2495}$

$/GPD= 1.60

Therefore in 2003 dollars:

$2003 = $44,100,000

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO FACILITY =	**$52,800,000**

Calculate O&M Cost for R/O based on "Unit O&M Cost of RO Membrane WTPs vs. Capacity" from The Cost of Membrane Softening and Desalting for Municipal Water Supplies, J. Elarde and R. Bergman, American Water Works Assosication, 2003
In 2003 Cost = $0.30 per 1000 gallons permeate
Using ENR Construction Cost Index History, Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for RO =	**$2,700,000 /yr**

Total Cost in Aug 2007 dollars= MBR Facility Cost + RO Equipment Cost + RO Facility Cost

Total Capital Cost of Upgrade (Scenario 3) =	**$134,300,000**

Total O&M Cost of Upgrade (Scenario 3) =	**$22,800,000 /yr**

Cost Scenario 4:

Q_{ADD}= Q_{MBR}= Q_{RO} = 18.48 MGD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 13.86 MGD

Step 1: Calculate the Cost of the MBR Facility

Using "MBR Cost vs. Capacity Graph" from *Membrane Bio-Reactor (MBR), An Innovative Technology,* J. Daily and D.Fry, Feb 2005.

For 18.48 MGD plant cost=$ $2,500,000 per MGD in Feb 2005 dollars

Therefore:

18.48 MGD plant= $46,200,000 in 2005 dollars

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Feb 2005 Index= 7298

Therefore:

Present-day cost of MBR =	**$50,700,000**

Calculate O&M Cost for MBR based on recent (2005) AWWA QualServe benchmark data
In 2005 Cost = $1,816.00 per MG processed
Using *ENR Construction Cost Index History*, Aug 2007 calculate cost in present-day dollars

Present-day Cost of O&M for MBR =	**$13,400,000 /yr**

Step 2: Calculate the Cost of the RO Equipment using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies*, J. Elarde and R. Bergman, American Water Works Assosication, 2003

Must use the R/O Permeate Flow to calculate the $/GPD

$Q_{RO\ PER}$= $(0.75)Q_{ADD}$= 13.86

Use the following equation from the reference:

$/GPD= 0.9652 x $(Q_{RO\ PER})^{-0.4696}$

$/GPD= 0.28

Therefore in 2003 dollars:

$2003 = $3,900,000

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO EQUIP =	**$4,700,000**

Step 3: Calculate the Cost of the RO Facility using "Reverse Osmosis Equipment Cost vs. Capacity" from *The Cost of Membrane Softening and Desalting for Municipal Water Supplies*, J. Elarde and R. Bergman, American Water Works Assosication, 2003

$/GPD= 3.6545 x $(Q_{RO\ INF})^{-0.2495}$

$/GPD= 1.77

Therefore in 2003 dollars:

$2003 = $32,600,000

Using *ENR Construction Cost Index History,* Aug 2007 calculate the cost in present day dollars (Aug 2007)

Aug 2007 Index= 8007
Annual AVG 2003 Index= 6694

Therefore:

Present-day cost of RO FACILITY =	**$39,000,000**

Calculate O&M Cost for R/O based on "Unit O&M Cost of RO Membrane WTPs vs. Capacity" from The Cost of Membrane Softening and Desalting for Municipal Water Supplies, J. Elarde and R. Bergman, American Water Works Assosication, 2003
In 2003 Cost = $0.35 per 1000 gallons permeate
Using ENR Construction Cost Index History, Aug 2007 calculate cost in present-day dollars

Present Day Cost of O&M for RO=	**$2,100,000 /yr**

Total Cost in Aug 2007 dollars= MBR Facility Cost + RO Equipment Cost + RO Facility Cost

Total Capital Cost of Upgrade (Scenario 4) =	**$94,400,000**

Total O&M Cost of Upgrade (Scenario 4) =	**$15,500,000 /yr**

Treatment/Effluent Quality Scenario	Final Effluent TDS Goal (mg/L)	Representative Area Food Processor Average Flow Rate (MGD)	Design Representative Area Food Processor Flow		Representative Area POTW Influent		Combined (Food Processor + POTW) Average Flow Rate (MGD)	Design Combined (Food Processor + POTW) Influent TDS (mg/L)		Side-stream Flow Rate (MBR + RO) to Meet TDS Goal (MGD)	Treatment Upgrade Capital Costs ($)		Treatment Upgrade O&M Costs ($/yr)		Total Treatment Upgrade Costs		Collection System Costs		Total Treatment Upgrade and Collection System Costs		POTW Effluent TDS Reduction	
			Monthly Peak Flow Rate (MGD)	Flow-weighted Average TDS (mg/L)	Average Flow Rate (MGD)	Maximum TDS (mg/L)		Flow Rate (MGD)	TDS (mg/L)		MBR	RO (equipment + facility)	MBR	RO	Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)	Capital Cost ($)	O&M Cost ($/yr)	Concentration (rounded) (mg/L)	Load (lb/d)
Current Effluent TDS Concentration Limit: Representative Area POTW (Modesto WQCF)	924	4.9	7.2	1570	26	970	30.9	33.2	1100	7.4	$40,800,000	$22,600,000	$5,400,000	$1,100,000	$63,400,000	$6,500,000	$40,000,000	$220,000	$103,400,000	$6,720,000	180	46,400
Background Groundwater TDS in Representative Area + 300 mg/L	620	4.9	7.2	1570	26	970	30.9	33.2	1100	18.5	$50,700,000	$43,700,000	$13,400,000	$2,100,000	$94,400,000	$15,500,000	$40,000,000	$220,000	$134,400,000	$15,720,000	480	123,700
Current Effluent TDS Concentration Average: Representative Area POTW (Modesto WQCF)	502	4.9	7.2	1570	26	970	30.9	33.2	1100	22.3	$61,000,000	$50,000,000	$16,200,000	$2,300,000	$111,000,000	$18,500,000	$40,000,000	$220,000	$151,000,000	$18,720,000	600	154,600
Background Groundwater TDS in Representative Area	320	4.9	7.2	1570	26	970	30.9	33.2	1100	27.6	$75,800,000	$58,500,000	$20,100,000	$2,700,000	$134,300,000	$22,800,000	$40,000,000	$220,000	$174,300,000	$23,020,000	780	200,900

E. Appendix III.5: Review of Urban Water Management Plans

1. Atwater

The City of Atwater is located in Merced County in the San Joaquin Valley. It is situated approximately six miles northwest of Merced, 105 miles south of Sacramento and 65 miles north of Fresno. The 2000 population of the City of Atwater was 23,113. It is expected that population will reach 26,693 in 2005 and expand to 43,877 in 2025. All City water supplies are obtained from City-owned groundwater wells distributed throughout the City and this is expected to continue through 2025. The system facilities include 11 wells of which 9 are active. Two wells are currently on standby as a result of elevated concentrations of the pesticide dibromochloropropane (DBCP.)

The City recognizes that the sub-basin is currently in a state of overdraft and is concerned with protecting its water resources, both in terms of availability and quality. The purchase and delivery of any surface water supplies to the City is not practical at this time since the City has no water treatment facilities. The UWMP states that it is not practical to use surface water on a short-term or emergency basis.

2. Bakersfield

The City of Bakersfield is located 110 miles north of Los Angeles and 271 miles south of Sacramento. Bakersfield is the principle city in Kern County. There are multiple urban water retailers that serve the urban area of Bakersfield, including the Domestic Water System, Cal Water, the Vaughn Mutual Water Company and the East Niles Community Service District. The UWMP submitted to DWR covers the Domestic Water System. The service area’s estimated population was 114,316 in 2005 and is expected to reach 174,000 in 2025. In comparison, Bakersfield had an overall population in excess of 220,000 in 1998; the city’s Planning Department has projected the 2020 population at 365,600. The Domestic Water System expects to deliver 35,668 AF in 2005, increasing to 50,375 AF by 2025.

The Domestic Water System obtains its entire supply from 58 wells. Future water demand will be my by drilling additional wells, along with the construction of surface water purification plant. The Domestic System has recently contracted with the Kern County Water Agency to receive 6,500 AFY from the Improvement District No. 4 (ID4) Water Purification Plant. In addition, a new 10 mgd micro-filtration membrane water purification plant currently being constructed by California Water Service Company will add another 2 million gallons per day to the system supply.

Historically, deep wells have provided water to the city. According to the UWMP, starting in 2010 groundwater will account for 72 percent of water supply with surface and imported water accounting for the remaining 28 percent. In 2025, the plan expects groundwater to account for 65 percent, surface water from the Kern River for 22 percent and imported water from ID4 the remaining 13 percent.

3. Ceres

The City of Ceres is located in central Stanislaus County. The Tuolumne River borders the city on the north, and the City of Modesto lies to the northwest. The service area's estimated population was 39,520 in 2005 and is expected to reach 66,000 in 2025. The sole water-supply source for the City of Ceres is groundwater extracted from the Turlock Groundwater Basin. Over the past five years approximately 10,000 AFY has been extracted annually from City wells. Recently, the City signed an agreement with the Turlock Irrigation District (TID) to acquire 11,000 AFY of surface water beginning 2010 2010. The plan also projected that groundwater supplies will increase to 20,000 AFY in 2015 and remain through 2025.

4. Clovis

The City of Clovis is located in Fresno County, west of the Sierra Nevada foothills and northeast of Fresno. The service area's estimated population was 89,972 in 2005 and is expected to reach 153,382 in 2025. Until July 2004, Clovis obtained all of its drinking water from the groundwater aquifer underlying the community. The City has 40 wells, but three are on standby due to water quality concerns; DBCP and high iron and manganese are the main contaminants in the Clovis area. In 2004, 23,035 AFY was extracted from the Kings sub-basin, which represented 93 percent of the total potable water supply.

Clovis currently has three available sources of water: groundwater, surface water and exchange water. The city's projections show it moving away from groundwater as its sole source of supply in the future in both absolute and relative terms. Groundwater pumping will decline from 18,060 AFY in 2005 (41% of the potable water supply) to 13,092 AFY in 2030 (18% of the potable water supply.) A large part of planned water supplies will come from supplier surface diversions. Clovis is located almost entirely within the Fresno Irrigation District (FID), except for the city center which is excluded from the District. The city has existing agreements with FID for 21,617 AF of Kings River water annually.[185]

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[185] City of Clovis, 2005 UWMP, p.16

Other planned future water sources are recycled water and additional exchange water. In 2004, the city and FID entered into an agreement that will increase surface water supplies whereby the city receives rights to 9,000 AF annually from the Waldron Pond Banking Facility in return for helping finance its construction. Clovis is also planning to construct a wastewater treatment plant producing 8.4 mgd of disinfected tertiary treated water.

5. Coalinga

The City of Coalinga is located in Fresno County, on the west side of the Central San Joaquin Valley in an area known as Pleasant Valley. The service area's population was 14,057 in 2005 and is expected to reach 26,260 in 2025. Coalinga is a rare example of a San Joaquin Valley city that does not rely on groundwater. The groundwater in the Coalinga area is unsuitable for drinking without treatment or blending, and the city has relied solely on treated surface water to meet its potable water needs since 1972.

6. Corcoran

The City of Corcoran is located south of Fresno in Kings County. Corcoran did not make an UWMP available for review; accordingly, projections have been estimated based on California Department of Finance data. In 2000, Corcoran had a population of 14,458. The service area's estimated population was 22,475 in 2005 and is expected to reach 42,625 in 2025.[186] The city's water supply is obtained from groundwater aquifers using seven wells. New wells are planned to accommodate expected development. Assuming Corcoran remains completely dependent on groundwater, they city will demand approximately 11,611 AF in 2025.

7. Delano

The City of Delano is located in Kern County, approximately 30 miles north of Bakersfield and 150 miles north of Los Angeles. The service area's estimated population was 43,391 in 2005 and is expected to reach 70,757 by 2025. The city relies on local groundwater as its sole source of supply. Its 11 groundwater wells have a total supply capacity of 21.0 million gallons per day (mgd), or roughly 23,500 AF/Y.

8. Dinuba

The City of Dinuba is located in the northwestern portion of Tulare County, approximately 14 miles north of Visalia and 32 miles southeast of the Fresno/Clovis metropolitan area. The service area's estimated population was 19,297 in 2005 and is expected to reach 27,933 by 2025. The primary water source is the Kings Groundwater Basin from seven wells. The City of Dinuba is added two new wells in 2006 and expects to add an additional well every five years, indicating that the city plans to continue relying on groundwater in the future. Dinuba also expects 1,120 AF or recycled water to be added to the water supply by 2025.

9. Fresno

The City of Fresno, the sixth largest in the state, is the seat of Fresno County. The Fresno UWMP is currently in development and was not made available for review. According to

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[186] Population forecasts are estimated from California Department of Finance projections.

information obtained from the city, the service area population was 475,061 in 2005. According to the California Department of Finance, the estimated population was 464,324 in 2005 and is expected to reach 650,968 by 2025.[187]

10. Hanford

The City of Hanford is located in Kings County, approximately 30 miles southwest of Fresno and 195 miles north of Los Angeles. The service area's estimated population was 49,550 in 2005 and is expected to reach 83,239 by 2025. The city currently utilizes local groundwater as its sole source of supply, pumping 35.2 mgd (39400 AF/Y) from 19 wells. All future demands are projected to be met with groundwater resources.

11. Lathrop

The City of Lathrop is located in the San Joaquin County south of Stockton and west of Manteca. The service area's estimated population was 22,800 in 2005 and is expected to reach 68,779 in 2025. In the past the city has relied completely on groundwater. Future water supply for the City will consist of treated surface water delivered through the South County Water Supply Program (SCWSP) and groundwater extracted within the City. Surface water deliveries are projected to start in 2005 with 5,200 AFY and expand to 11,791 AFY in 2025. Groundwater pumping is expected to continue to increase to meet the total supply needed, but surface water deliveries will provide the majority. The SCWSP will supply up to 16,400 AFY to the city during Phase I of its operation (see **Error! Reference source not found.**, above.) Phase II will increase the SCWSP supply to the City's total allocation of 23635 AFY.

12. Lemoore

The City of Lemoore is located in Kings County, approximately 200 miles north of Los Angeles and 210 miles south of San Francisco. The service area's estimated population was 23,983 in 2005 and is expected to reach 52,484 in 2025. Currently the City utilizes local groundwater as its sole source of supply, with nine wells extracting from aquifers below the city and in a well field to its north. Total well capacity is 21,500 AF/Y.

13. Livingston

The City of Livingston is located in north central Merced County, approximately 115 miles southeast of San Francisco and 290 miles northwest of Los Angeles. The service area's estimated population was 14,135 in 2005 and is expected to reach 79,490 in 2025. The City of Livingston's current source of water supply is groundwater extracted from underground aquifers using seven wells. Supplied water in 2005 totaled 16,578 AFY and this is expected to increase to 51,302 AFY by 2030. The city plans to expand the number of wells to accommodate the large increase in supply capacity that is expected. Since the city lies within the MID service area, surface water supplies may also be available.

14. Lodi

The City of Lodi is a large urban area located in San Joaquin County. The service area's estimated population was 62,467 in 2005 and is expected to reach 84,134 in 2025. The

[187] Estimated from California Department of Finance projections.

City currently uses groundwater as its sole source of water supply, which is produced from 26 groundwater wells; groundwater production in 2004 was 17,011 AFY. In May 2003, the City entered into an agreement with Woodbridge Irrigation District (WID) to purchase 6,000 acre-feet per year (AFY) of surface water for a period of 40 years. Thus, although historically groundwater pumping has provided for the city's total supply, surface water is expected to comprise a significant portion of the urban water supply in the future. Groundwater pumping is projected to stay constant at 15,000 AFY from 2010 and to 2030 as total water demand increases to roughly 30,000 AFY. Remaining demand will be met by WID surface water, as well as recycled water, which is expected to supply 10,380 AFY by 2030.

15. Los Banos

The City of Los Banos is located in western Merced County. The service area's estimated population was 32,380 in 2005 and is expected to reach 70,949 by 2025. The city relies solely on groundwater extracted from the Delta-Mendota sub-basin using 13 city-owned wells. In 2005, groundwater pumping was 7,598 AFY. This number is expected to increase to 16,640 AFY in 2025 and will still account for 100% of supplies. The city currently has no surface water entitlements, although its most recent UWMP notes it is pursuing a surface water supply due to the limited availability of groundwater meeting domestic water quality standards.

16. Madera

The City of Madera is located in Madera County northwest of Fresno. The service area's estimated population was 51,845 in 2005 and is expected to reach 105,172 by 2025. The City is completely reliant on groundwater that is extracted from 16 water wells. According to the most recent urban water plan, in 2004 the City pumped 12,886 AFY from the Madera sub-basin, accounting for 100 percent of total supply. Future supply will continue to rely solely on groundwater, increasing to 27,081 AFY by 2025. There are currently no efforts to purchase long-term surface water supplies.

17. Manteca

The City of Manteca is located in south San Joaquin County, approximately 10 miles south of Stockton and 15 miles north of Modesto. The service area's estimated population was 61,500 in 2005 and is expected to reach 119,950 by 2025. The city is completely reliant on groundwater, pumping 14,933 AF in 2004.

Contributions from the SCWSP are expected to eventually reduce groundwater withdrawal to below the safe aquifer yield of 1 AFY per acre. Since the primary urban service area of Manteca measures 13,790 acres, this effectively limits groundwater extraction to 13,790 AFY. By 2025, groundwater is expected to provide 47 percent of overall supply, with surface water making up the balance.

18. Merced

The City of Merced is located in eastern Merced County, approximately 110 miles southeast of San Francisco and 310 miles northwest of Los Angeles. The service area's estimated population was 74,487 in 2005 and is expected to reach 118,562 in 2025.[188] Groundwater is currently the only source of supply, with 19 production wells. In 2005, groundwater production was 30,118 AFY. By 2025, demand is expected to increase approximately 85 percent to 55,677 AFY, due mainly to growth from UC Merced. Surface water will contribute a negligible fraction of overall supply by 2025: 200AFY (.36%)

19. Modesto

Refer to <<XREF to Representative Area discussion>> for a discussion of the Modesto UWMP.

20. Oakdale

The City of Oakdale is located in Stanislaus County, approximately 15 miles northeast of Modesto. The UWMP for the City of Oakdale was not made available for review. The service area's estimated population was 17,438 in 2005 and is expected to reach 29,897 in 2025.[189] Future groundwater extraction rates were estimated using known extraction rates from communities that rely completely on groundwater in the San Joaquin Valley, and population projections from the California Department of Finance. Assuming Oakdale is completely reliant on groundwater, ccording to the results, it is expected Oakdale will require approximately 7,720 AF in 2025.

21. Patterson

The City of Patterson is located in Stanislaus County, 92 miles south of Sacramento and 89 miles southeast of San Francisco. The service area's estimated population was 16,150 in 2005 and is expected to reach 34,000 by 2025. Water demand in 2005 was 3,250 AFY and is expected to grow to 8,176 AFY by 2030. Currently, the city uses groundwater to meet all of its municipal and industrial water demands, using with six wells producing a total of 6,700 GPM. Available yields are sufficient to service anticipated expansion, but salinity concentrations in the groundwater might require Patterson to provide treatment at some time in the future.

22. Porterville

The City of Porterville is located midway in Tulare County. Porterville's UWMP was not made available for review. The service area's estimated population was 44,555 in 2005 and is expected to reach 102,263 by 2025.[190] Assuming the city continues to rely completely on groundwater, its estimated 2025 demand is 29,842 AF.

23. Reedley

The City of Reedley is located in Fresno County, south of Sanger and north of Dinuba. The service area's estimated population was 24,500 in 2005 and is expected to reach

[188] According to the UWMP, the City population is combined with the UC Merced Campus population and then approximately 90 percent is served by the City water system. This same process was carried out to calculate the service area population for 2025.
[189] Estimated from California Department of Finance projections.
[190] Estimated from California Department of Finance projections.

38,500 by 2020.The city depends entirely on groundwater pumping for water, using seven deep wells and one well reserved for standby. Reedley extracted 5,003 AFY in 2000 and expects pumping to increase to 9,424 in 2020.

24. Ripon

The City of Ripon is located in southern San Joaquin County just north of Modesto and approximately 75 miles east of San Francisco, 70 miles south of Sacramento and 20 miles south of Stockton. The service area's estimated population was 14,600 in 2005 and is expected to reach 35,000 by 2025. The city relies completely on groundwater pumped from seven wells. Groundwater production in 2005 totaled 5,860 AFY and is expected to grow to 14,470 AFY by 2025.

25. Riverbank

The City of Riverbank is located in Stanislaus County along the Stanislaus River south of Modesto. Riverbank's UWMP was not made available for review. The service area's estimated population was 19,986 in 2005 and is expected to reach 47,485 by 2025.[191] Assuming the city continues to rely completely on groundwater, its estimated 2025 demand is 13,097 AF in 2025.

26. Sanger

The City of Sanger is located in the center of the Central Valley at the base of the Sierra Nevada Mountains' foothills in Fresno County. The service area's estimated population was 22,105 in 2005 and is expected to reach 41,503 in 2025. Groundwater, extracted from eight wells, is the major water supply source for the city. In 2004, Sanger extracted 5,364 AFY of groundwater and expects this number to more than double to 10,045 AFY by 2025. The city expects to remain fully reliant on groundwater in the future.

27. Selma

The City of Selma is located in Fresno County, approximately 20 miles southeast of Fresno and 90 miles north of Bakersfield. The service area's estimated population was 23,500 in 2005 and is expected to reach 84,920 in 2025. Selma is served by the Cal Water through the Selma Water District. Customers of the Selma District are completely reliant on groundwater. There are 13 active wells located throughout the service area. In 2005, groundwater extraction was 6,648 AFY. Demand is expected to grow to 24,417 AFY by 2025.[192]

28. Shafter

The City of Shafter is located approximately 15 miles northwest of Bakersfield and 100 miles north of Los Angeles, in Kern County. The service area's estimated population was 14,000 in 2005 and is expected to reach 94,415 in 2025. Shafter currently receives 100 percent of its water supply from the Kern County Sub-basin of the San Joaquin Valley

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[191] Estimated from California Department of Finance projections.

[192] Based on maintaining annual growth at City projected rate of 2.5% per year and current tract information and average demand per service (Demand Scenario 2A), California Water Service Company, 2006 UWMP, Selma District, December 15, 2006.

Groundwater Basin. In 2005, it extracted roughly 5,000 AF. This number is expected to grow to 34,549 AFY by 2025.

29. Stockton

The City of Stockton is located in north central California, approximately 70 miles east of the San Francisco Bay Area and 50 miles south of Sacramento. Stockton is located in San Joaquin County and is the 4th largest City in the Central Valley. The service area's estimated population was 279,513 in 2005 and is expected to reach 415,011 in 2025. Before 1978, groundwater was the sole source of retail water supply for the Stockton Area. Since 1978, the urban area has been treating and supplying surface water from New Hogan Dam and other surface water supplies from the Calaveras and Stanislaus Rivers.

The Stockton Metropolitan Area receives its urban water supply from three urban water retailers: the City of Stockton Municipal Utilities Department (COSMUD), Cal Water, and the County of San Joaquin. In 2004, it was estimated that Cal Water provided 47 percent of total demand.[193] The City of Stockton provided 50 percent and the County provided the remaining three percent. According to the city's 2005 UWMP, the Stockton Municipal Utilities Department used 14,960 AF of groundwater in 2005, which was 46 percent total supply. This number is expected to significantly drop to 409 AF in 2025, just one percent of total water supplies. Water demand was 32,399 AF in 2005 and is expected to climb to 43,830 AF by 2025. The water district plans to increase supply accordingly through the acquisition of rights to 30,000 AFY from the Stanislaus River watershed from neighboring irrigation districts.

Cal Water provides the Stockton District customers with a combination of groundwater and treated surface water. Due to overdraft conditions, a conservative assumption for groundwater extraction was set at 0.06 AFY/acre. Cal Water's estimated 2006 supply to the Stockton District was 15,000 AF of groundwater and 22,500 AF of surface water. By 2025 the company expects to delivery equal amounts of ground and surface water.

30. Tracy

The City of Tracy is located 68 miles south of Sacramento and 60 miles east of San Francisco in San Joaquin County. The service area's estimated population was 78,300 in 2005 and is expected to reach 109,000 by 2025. Tracy derives most of its water supply from multiple surface water sources through contracts with the federal government and surrounding irrigation and water districts. Groundwater extraction is expected to decline from 4,000 AFY in 2010 to 2,500 AFY by 2015 and continue at this level through 2025. As a percent of total water supply, groundwater is expected to fall to seven percent by 2015, making it one of the least groundwater-dependent communities in the San Joaquin Valley. In the event that the city is unable to secure additional high quality surface water supplies in the future, groundwater remains a viable water supply at up to 9,000 AFY.

[193] Mariposa Lakes Specific Plan Project Draft, California Water Service Company, November 17, 2006

31. Tulare

The City of Tulare is located 45 miles south of Fresno and 60 miles north of Bakersfield in Tulare County. The most recent UWMP for the City of Tulare was not made available for review. The service area's estimated population was 49,545 in 2005 and is expected to reach 104,160 in 2025.[194] In 1995, the year of the most recent available UWMP, the city relied completely on groundwater, using 27 wells to extract 11,832 AF. Assuming Tulare continues to rely solely on groundwater, pumping is estimated to equal 30,422 AF in 2025.

32. Turlock

The City of Turlock is located in Stanislaus County, 15 miles south of Modesto and 20 miles north of Merced. The service area's estimated population was 65,970 in 2005 and is expected to reach 128,256 in 2025. Historically, the city has relied solely on groundwater; extractions totaled 25,465 AF in 2004. The city plans to substantially decrease its groundwater demand substantially over the coming decades. Pumping in 2010 is estimated at 10,201 AF, or 35 percent of total supply. By 2025 the city expects this number to fall even further, to 8,811 AF (17 percent of total supply.) The decrease in groundwater use is made possible by increasing surface water purchases from the Turlock Irrigation District and increased wastewater recycling.

33. Visalia

The City of Visalia is located in Tulare County. Visalia is served by the Cal Water. The Visalia District lies approximately 42 miles southeast of Fresno and 75 miles north of Bakersfield. The service area's estimated population was 95,424 in 2005 and is expected to reach 162,953 in 2025.[195] Groundwater is the sole source of water furnished to customers in the Visalia District. In 2005, the amount of groundwater pumped was 30,124 AFY and is expected to increase to 48,408 AFY in 2025.[196]

34. Wasco

The City of Wasco is located in the southern San Joaquin Valley about 25 miles northwest of Bakersfield, in Kern County. The area's estimated population was 23,765 in 2005 and is expected to reach 33,585 in 2025.[197] The number of urban water customers is actually slightly lower, since those figures include Wasco State Prison; the most recent estimate is 18,254 people receiving city water service.[198] Wasco obtains all of its water from the Poso Creek Aquifer in the Tulare Lake basin; pumping totaled 4,451 AF in 2005, a 12-percent increase from a decade ago.

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[194] Estimated from California Department of Finance projections.

[195] Population figures were estimated from the UWMP using residential service estimates and a density of 3.24 persons per residential service.

[196] Based on maintaining constant annual growth at the ten year average and average demand per service (Demand Scenario #2), See Appendix A, California Water Service Company, UWMP for the Visalia District, June 2004.

[197] Estimated from California Department of Finance projections.

[198] Infrastructure Rehabilitation Water Feasibility Study for the City of Wasco, Helt Engineering, Inc., May 8, 2007.

The Wasco UWMP does not forecast groundwater consumption, but does signal that groundwater will remain the primary source of supply in the future. Assuming Wasco remains solely reliant on groundwater, its estimated pumping in 2025 is 8,848 AF.[199]

[199] This estimate likely overstates groundwater demand, since it is based on California Department of Finance projections which include the prison population.

III.13 Appendix: Peer Reviewer and Stakeholder Comments

As required, the comments of the following four peer reviewers and our responses are included in this Appendix:

Dennis Corwin, USDA-ARS George E. Brown, Jr. Salinity Laboratory
Erik Lichtenberg, Department of Agricultural and Resource Economics, University of Maryland
Hugo Loaiciga, Department of Geography, University of California, Santa Barbara
Tom Young, Department of Civil and Environmental Engineering, University of California, Davis

In addition, the comments of Kennedy/Jenks Consultants on behalf of the Wine Institute are included because they are extensive and raise some important issues. Comments received by other stakeholders including Rob Neenan of the California League of Food Processors, Ron Crites of Brown & Caldwell and Burt Fleischer of Hilmar Cheese were incorporated where possible in the final report.

Review of Hilmar Supplemental Environmental Project (SEP) – October 17, 2007

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In general, the draft report for the Hilmar Environmental Supplemental Project (SEP) is nicely prepared, reasonably sound, and professional. The important findings appear predicated on a sound technical understanding of the problem. The participants on the project are to be commended on the comprehensiveness of the report in addressing an extremely complex problem within such a short time frame. That said, there are some areas where improvements could be made that would add to the clarity, credibility, and level of impact of the report. These areas will be discussed in order of importance.

Volume I of the draft report covers an area that is outside my area of expertise, so this volume is not included in my review. However, I did enjoy reading this section and felt that I gained considerable knowledge and insight into areas with which I am familiar, but certainly not an expert. The authors have done a thorough job of presenting a very useful compilation of food processing industry waste discharges on land and into public owned treatment works (POTWs) in the Central Valley, the regulatory framework within which the food processing industry falls, water use and economic impacts of environmental regulation in the San Joaquin Valley, and alternatives for management of salinity discharge to ground and surface water resources.

Volume II lies more within my area of understanding and knowledge; therefore, this is where I have focused my efforts in the hope of providing constructive recommendations specifically intended to help the authors develop the best possible report based on technically sound findings. Before I make any recommendations I would like to commend the modeling group for their outstanding modeling effort. The parameterization and input data compilation was first rate.

Salt accumulation within and just below the root zone is primarily a consequence of the process of evapotranspiration (ET) and will be determined largely by the amount of ET and the root water uptake distribution. The model used in the study, MIN3P, does not appear to have a very sophisticated root water uptake routine since it has no apparent feedback between plant growth and salt accumulation nor does it appear to have a root water uptake routine that is based on combined matric and osmotic stresses, but rather assumes a uniform uptake through the root zone regardless of the matric or osmotic potential. This maybe a major weakness since salt accumulation and leaching, which results in salt loading, is so closely tied to ET and plant water uptake distributions. In cases where salinity is accumulating in the root zone, osmotic stress will determine where water uptake by the root will occur. In areas of the root zone where higher levels of salt have accumulated and higher osmotic stress occurs, the plant will withdraw water from areas where the osmotic stress is lower and continue to withdraw water from this portion of the root zone until the matric and/or osmotic stresses reach a point where the plant is expending too much energy to uptake water. In essence, the plant will withdraw water from that portion of the root zone that requires the least expenditure of energy. In addition, it is important to account for the impact of salt accumulation within the root zone on plant growth, which directly influences ET. If root zone salinity reaches a level where plant growth is affected, then the ET will be reduced. As ET diminishes due to less plant growth, less water is being taken up by the plant, so more water is available to leach salts. A feedback mechanism is needed within the model that decreases the ET when salt accumulation reaches the salinity threshold that affects plant growth. The relationship between salinity and plant yield has been well established by Maas and Hoffman (1977). The influence of salt accumulation on root water uptake and plant growth is an important factor influencing the accumulation and leaching of salts. Salt loads will not be simulated correctly if a sophisticated plant water uptake routine is not included in the model. The lack of a sophisticated plant water uptake model will also result in unreasonably predictions of NO_3 loads in situations where salt accumulation effects plant growth. Diminished plant growth will result in reduced uptake of NO_3, making more NO_3 available for leaching. At the beginning of the SEP when I was asked for my input on the modeling approach, I had inquired as to why MIN3P was being used over other models more applicable to salt transport, such as UNSATCHEM. It is because of the aforementioned reasons that I made this inquiry.

Another weakness in the modeling study is the limited uncertainty analysis performed (i.e., Monte Carlo simulations or first-order uncertainty analysis). Monte Carlo simulations were performed for effective conductivity, but were not performed for other parameters found to hold a significant role in the fate and transport of salinity, NO_3, and NH_3. Monte Carlo simulations performed with distribution functions assigned to each variable and parameter or at least the most significant variables and parameters would be valuable in light of the fact that no field measurements were taken, due to the short project duration, to compare to simulated results. Without uncertainty analysis the interpretation of the simulated results is less credible since the reliability of the simulated results is unknown. Monte Carlo simulations could be run for each case study using distribution functions for model parameters and variables that are present in the literature or by assuming a normal distribution. Uncertainty analysis should not be confused with the case study approach that was used to bracket variability in site conditions. The uncertainty analysis will provide an indication of the reliability of the model simulations due to inherent uncertainty in model input data and the subsequent effect of this uncertainty on model predictions.

One case study that has been overlooked and may have a significant impact in the management of FDS and N loads, particularly FDS loading, is one in which food-processing waste is applied in low volumes but at high frequencies. The wastewater is applied at a frequency that would assure a downward water flux to prevent any upward movement of salts into the root zone, but in sufficiently low volumes to exceed slightly the ET demands by the plant, resulting in a low leaching fraction (i.e., volume of drainage water/volume of irrigation water). This low leaching management would result in substantial precipitation of salts just below the root zone that would reduce FDS loads to the groundwater by 20-30%. The leaching of NO_3 would be minimized allowing maximum uptake by plants, while the fate of NH_3 would depend on maintaining aerobic conditions, which may or may not be a challenge depending on the soil texture. This means of managing salt and NO_3 loads has great potential for the long-term attenuation of salinity and is a case study scenario that could be explored with modest effort. Although this is more of a management scenario, the simulated results could be extremely valuable as a means of managing those sectors of the food-processing industry with the highest potential FDS loads.

Spatial variability has been addressed to evaluate the effects of large-scale heterogeneity on salt concentration by investigating the influence of buried paleo-channels. However, some estimate of the effect of within-field variation of other fate and transport related parameters (e.g., spatial variations in clay content and ET) on simulation results is valuable to add credence to the final representative simulations for the different case scenarios. The spatial variation of ET can be particularly valuable since salt accumulation within and just below the root zone is highly dependent on ET and the root water uptake distribution. Even though the simulated results are being used to understand the significant interactions of mechanisms influencing the fate and transport of salinity, NH_3, and NO_3, the influence of within-field variability provides a more realistic understanding of field-scale ranges than the three selected case studies, which are intended more to provide a range of conditions encountered in the San Joaquin River and Tulare Lake Basins. Since land application of food-processing wastewater is largely done on tracts of land comparable to agricultural field sizes (e.g., 40 to 160 ac), simulations run using the spatial variability encountered in a typical field would add another level of understanding, a level that is more applicable to variation in field-scale conditions.

The issue of sensitivity analysis for the model should be addressed beyond what was presented in Sections II.3.D.3 and II.4.G. Sensitivity analysis is needed for all parameters to establish those parameters that are most significant in their effect on simulated outputs. This is a minor undertaking and is recommended just to provide a point of general reference. A table of results is sufficient indicating the most and least sensitive inputs and parameters. If a sensitivity analysis has already been performed for MIN3P in the literature, then the table can be created from the literature data. It is important to know the parameters to which the model output is most sensitive to understand those parameters that need to be measured or estimated mostly accurately. It can then be evaluated if the most sensitive parameters have been measured or estimated with sufficient accuracy and if not to what extent this may or may not influence the simulated results.

The Executive Summary can be improved. First, a paragraph is needed that discusses the distinction between Volume I and II and how they go together to meet the objectives of the project. This will help orient the reader as to what is contained in each volume and how each volume contributes to the overall objective. Second, explicitly state in the

Executive Summary the rationale for conducting the modeling study. The modeling effort is designed more to understand the interaction of the mechanisms that are influencing the fate and transport of salinity, NO_3, and NH_3, rather than predicting actually amounts of these solutes that will reach ground and surface waters. It would help to have this explicitly stated from the start.

Finally, the draft report needs to be proofread more closely. There are typographical mistakes throughout, particularly in Volume II. As a quick example, the figure numbers indicated in the main text do not coincide with the actual figures (see page 24 of Volume II.1.C just as an example), there are figures with 2 sets of numbers (see pages 25 and 27 Volume II.1.C), there is redundant information (e.g., an explanation of FDS is given at least 3 different places when all that is needed is to define and discuss the acronym when first mentioned and to make certain that a separate page is provided in the appendix listing and defining all abbreviations), and some of the figure captions need to be more complete in their description. A close proof reading of Volume II would eliminate these problem areas. Also, the numbering system used to organize the report into volumes, sections, subsections, etc. should be consistent throughout the report (i.e., Volume I use a strictly numerical system whereas Volume II mixes a numerical and alphabetical system). These are very minor things but they definitely help, especially when trying to review a report, and will help remove any potential confusion by future readers of the report.

I have a question concerning the simulation results: was there an instance where pH changes occurred to the point where modeling of trace elements, such as B, are warranted due to increased mobility and subsequent increased potential for impacts on groundwater? I believe that the removal of fruit peel is often done using sodium hydroxide. The sodium hydroxide appears in the food-processing waste water. Does the presence of sodium hydroxide sufficiently raise pH to levels that would influence adsorption and thereby increase the mobility of trace elements? Or are the pH changes too small to affect the adsorption process to any significant extent? Is this a potential scenario that should have been considered? Or is this an insignificant concern?

Comments on the Hilmar Supplemental Environmental Project Draft Report of September 21, 2007

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October 15, 2007

General Comments

My comments on this report will be restricted to the economic analysis, my own area of expertise.

Overall, this report contains a very impressive piece of regulatory economic analysis. Two aspects are particularly noteworthy: (1) the integration of hydrologic, engineering, and economic modeling into a unified analytical framework and (2) the use of sophisticated spatial modeling in that integrated interdisciplinary framework. It is increasingly recognized that spatial heterogeneity is a hallmark of environmental quality problems, especially those associated in some way with agriculture (Lichtenberg 2002, Smith, Sanchirico, and Wilen 2007). But to date relatively few applied economic analyses performed for regulatory purposes have incorporated spatial heterogeneity. This study has done so in a very thorough manner.

Also noteworthy is the report's treatment of the incidence of regulatory costs and the implications of likely forward and backward shifts of those costs for industry location decisions and thus economic activity in the San Joaquin Valley. The conceptual framework is not new; for example, the Just, Hueth, and Schmitz 1982 text on applied welfare economics contains a thorough treatment of the appropriate measurement of benefits and costs in vertical market chains like those considered in this report. Nevertheless, very few applied economic analyses have actually applied such a rigorous analytical approach.

The key results of the economic analysis flow directly from the findings of the hydrological analysis. That analysis indicates that the effects of saline wastewater applied to land remain highly localized, implying strongly that any damage incurred will tend to be low. Moreover, the integrated spatial hydrologic/economic analysis indicates that the effects of land application of saline wastewater are for the most part limited to land owned by food processors discharging that wastewater, implying that there is little economic justification for regulation. As the report notes, public intervention to limit pollution is justifiable on welfare-theoretic grounds only when pollution has negative external effects, that is, only when it causes damage to agents other than the polluter. In the absence of external effects, polluters bear the full costs of their own actions and presumably act to balance the negative impacts of their waste discharges against benefits of those discharges (e.g., lower costs of waste treatment or production more generally). In the case at hand, food processors own most of the land to which they apply wastewater. Most of that land is currently in agricultural uses. If processors operate that land themselves, they suffer damage in the form of lower profits due to lower yields and/or higher production costs. For example, the profits of dairy operators growing forage next to a cheese manufacturing plant discharging saline wastewater will suffer due to lower yields and/or higher costs due to the need to blend irrigation water. Similarly, land leased to other farm operators will command lower rents due to those lower profits while land sold for development will command a lower price if wastewater discharges result in higher costs of obtaining clean water for residential use. In sum, the extent of market failure in this instance seems to be highly limited, which suggests little justification for regulatory action.[1]

The economic methodology used in this report is, by and large, state-of-the-art and substantially more sophisticated than is usual in analyses of this kind. There are, however, a few ways in which the analysis could be improved. Three areas in which technical improvements seem warranted are discussed below: (1) the model used to predict conversion of agricultural land to urban uses; (2) the model used to estimate yield effects of irrigation water salinity; and (3) the model used to calculate the costs of shortened lifetimes of residential plumbing and appliances.

It should be noted, however, that the fact that the external costs of wastewater discharges are so small suggests that the results of the economic analysis are likely to be highly robust to any technical adjustments, at least in a qualitative sense. That caveat includes the adjustments discussed below. While improvements in these areas might be desirable from the perspective of analytical rigor, they will likely have little or no effect on the results obtained or on the policy recommendations implied by those results.

The Land Use Model

The component of the analysis most in need of improvement is the model used to predict conversion of agricultural to urban land uses. The report uses cross-sectional GIS data to estimate a logit Markov model of the probability that land in agricultural use in 1984 had been converted to urban use by 2004. The estimated coefficients of this logit model are then used to predict the probability that land in agricultural use in 2004 would be converted to urban use by 2024. The use of a sophisticated GIS-based approach is highly laudable. Nevertheless, improvements in the discussion of the model and the modeling approach more generally would be desirable.

The report discusses the signs and magnitudes of these estimated coefficients but lacks any discussion of the reliability of the model's predictions. Since the model's principal purpose is forecasting, an assessment of its in-sample predictive accuracy is absolutely necessary. The report should definitely include a discussion of measures of predictive accuracy such as the improvement in prediction from using the covariates rather than the raw sample average probability of conversion.

[1] The report could and should make this point more strongly. The draft discusses the importance of determining the extent to which an externality is present in general terms but does not relate those generalities strongly enough to the case at hand, e.g., by citing the kinds of examples noted above.

It also seems to me that newer, better modeling approaches are available and applicable to the data used in the report. Specifically, a panel data approach like that developed by Irwin and Bockstael (2002, 2004) offers a number of advantages. Panel data methods afford greater control for unobserved heterogeneity, which is probably substantial given that the data contain only observations on a limited number of parcel characteristics. Letting the dependent variable be the probability that land is in, say, agricultural use (rather than limiting the analysis to land initially in agriculture in 1984) would make fuller use of the data by including data on land in urban uses in 1984 (and 2004). The cross-section approach employed in this report may also be subject to bias due to endogeneity of the initial land use; the Irwin/Bockstael approach removes this problem. Finally, spatial correlation due to unobserved common characteristics shared by neighboring parcels likely influences land use patterns. Irwin and Bockstael discuss means of controlling for spatial correlation as well. While I recognize that the time series component of this panel is quite limited (only two years are available), it seems to me that panel data methods still have the potential for significant improvements in modeling land use.

The Crop Salinity Response Model

The report discusses two possible approaches to modeling crop response to irrigation water salinity: the linear spline model of Maas and Hoffman and a sigmoidal response function. The discussion in the text seems to indicate that the sigmoidal response function is more valid from an agronomic perspective. Despite the seeming advantages of a sigmoidal response model, the analysis itself uses the linear spline model. It would be instructive to see a sensitivity analysis with agricultural yield losses calculated using the sigmoidal model, assuming that existing data make it possible to calibrate the latter for the crops grown on the land affected by wastewater discharges.

The effect of using sigmoidal response functions is not clear. A sigmoidal response curve might have a higher salinity threshold than the linear spline models used in the report and thus predict smaller yield losses. At the same time, a sigmoidal response function might predict greater marginal losses once the threshold is crossed, which would tend to increase predicted yield losses.

The sections of the report need significant editorial attention as well.

- The chapter on salinity damage in agriculture begins with discussions of the DAP and DRMS models. Neither model is actually used in the final analysis, either to calculate damages or as a means of cross-checking the estimates obtained from the linear spline model. No reasons are given for not using them, making at least this reader wonder why they were included in the report.

- The section discussing the final analysis of salinity damages in agriculture (p. 112) mentions that these damages were calculated as a weighted average of crops from each county but does not specify how the weights themselves were obtained. More detail is needed here.

- Brief summary of the costs of reducing saline discharges under each possible remediation option.

- Brief comparison of benefits and costs of potential regulatory actions, including a discussion of the implications of the ways and extent to which current damage is internalized by food processors.

Such an overview chapter would be followed by separate chapters discussing each of the methodologies used in detail, much as has been done so far. But an overview chapter would give the reader a sense of the context for each of the separate components as well as how they fit together.

A final note. A cap-and-trade system works for dischargers using a common discharge site (or a set of linked discharge sites). It might be workable for food processors discharging to a municipal waste treatment system or similar common disposal site. In such cases thin markets due to a small number of agents might be a problem. Given the localized nature of the effects of wastewater applied to land, a cap-and-trade system wouldn't be workable for processors currently using land application for disposal.

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M.D.Smith, J.N. Sanchirico and J.W. Wilen. 2007. The economics of spatial-dynamic processes: applications to renewable resources. Presented at the Frontiers of Environmental Economics Conference, Washington, DC. February 2007.

Dave,

Here are my comments about the Hilmar Supplemental Environmental Project Report:

1. The study was aimed at reporting general findings on water demand and the benefits of water quality regulations in the San Joaquin Valley, and to examine five alternative ways to manage salinity stemming from food processing effluents. I found that the economic valuation of benefits and costs for each of the five alternatives was not fully pursued to the point that they could have been ranked based on a benefit/cost basis. Perhaps the study was not intended to be as complete as to have a B/C ranking of the alternatives.

2. There is a lot of water use data for the San Joaquin Valley, something that appears to be contradicted by statements written in the Report. The best source is the California Department of Water Resources (DWR), which in its California Water Plan subsumes water use/water supply for all of California, in great detail.

3. Dennis McLaughlin, now at MIT, produced with Resources Management Consultants (an extinct consultancy formerly based in Walnut Creek California) a finite-element ground water model for the San Joaquin Valley, something which is overlooked in the Report. The model might still be available from DWR.

These are my comments,

Hugo A. Loaiciga

November 1, 2007

Dave: here are my ground water comments about the Hilmar Supplemental Environmental

Project report:

1. I reviewed the entire project report and

sent you comments about the issues that stood out most prominently tome. Those concerned benefit/cost analysis for the five alternatives to cope with waste effluents from the food processing industry in the study area. These were the "red flags" so to speak that I identified, and I do not doubt that you can answer those. See my previous email concerning my review of this project report.

2. As for ground water data, ground water modeling, and solute transport modeling of fixed dissolved solids (FDS) using a coupled MODFLOW/MT3DMS: my opinion is that the study investigators used state-of-the art modeling techniques that are widely used and standard in the United States, and that their findings are reasonable. That is, FDS concentrations in subsurface waters are high near the disposal sites and they are diluted away from the application areas.

3. The ground water monitoring data used in the study and the conceptual model used to describe the input and attenuation of compounds applied overland through the vadose zone are as good as one can reasonably expect from a study emanating from a settlement agreement. In other words, this was not a focused research project on the fate and transport of food-processing wastes through soils,

air, and water; instead, it appears to me that it involved site characterization and reconnaissance investigations to determine whether or not food-processing wastes are an imminent threat to the environment in the study area. In this respect, I found the data, methods ,and results written in the report to be appropriate. Section II.5 of the report cites environmental impacts of food-processing wastes in the San Joaquin Valley.
I found the identified environmental impacts to be well-supported by the Hilmar Environmental Study.

4. The various alternatives to land application of food-processing wastes suggest that there are ways to minimize impacts to water quality and sensitive ecosystems in the San Joaquin Valley. The project report, as far as I can tell, did not recommend any specific alternative or combination of alternative to land application of food-processing wastes.

Hugo A. Loaiciga

Review of Hilmar Supplemental Environmental Project
Y. Rubin, D. Sunding, M. Berkman
September 21, 2007 Draft Report

Prepared by: Thomas M. Young
Professor
Civil & Environmental Engineering
University of California, Davis

30 October 2007

Overview

The subject report attempts to consider the benefits of and the costs associated with the control of salinity associated with wastewater from the food processing industry in the Central Valley of California. More specifically, most of the detailed cost and benefit analysis focuses on a "Representative Area" surrounding Modesto. Although this decision compromises the complete generality of the results, I support the production of useful, detailed and quantitative information for a specific, relatively large, heterogeneous area over the production of much more qualitative information for a larger geographic area. Although the authors rightly caution against the application of their conclusions to other sub-areas within the Central Valley, I suspect that, with careful attention to the similarities and differences between some other sub-area and their "representative area" that the major qualitative conclusions of their work regarding costs and benefits would be transferable. Overall, the report is impressive in its scope and detail. I find both the estimates of the costs and benefits persuasive and in line with my professional judgment regarding both sets of issues. This is important because it is often the case, in my experience, that apparently careful application of benefit and cost estimation tools at the micro-scale can produce results that are counter-intuitive at the macro-scale because of the omission of non-obvious but critical costs and/or benefits.

As my own expertise is in physical/chemical methods for treatment of water and wastewater, water quality and environmental policy, I restricted my detailed review of the report to sections I.VIII, I.IX, I.X, I.XI, I.XII, I.XIII, and I.XIV. My review of the remainder of the document was more cursory, particularly regarding the methods used in the estimation of economic benefits and the details of the hydrogeologic model, which are mostly outside the scope of my expertise.

Salinity Management Options and Costs

The authors do a fine job of identifying and outlining the treatment options for salinity control which, briefly summarized, are prevention, concentration or export. These three choices are approximately aligned with the "in-plant measures", "treatment" in a POTW or newly constructed centralized facility, and "brine line" discussed in the report. In a "big picture" sense, these options are not equivalent since prevention and export "remove" the salinity from the Central Valley water system while concentration via membrane treatment or otherwise, does not, unless the concentrated stream is managed in a way that completely dewaters it or subsequently transports it from the system. The authors clearly recognize this (see especially statements on page 239 last paragraph and page 253 first paragraph) but given the likely wide distribution of this report to people not intimately familiar with water treatment technology and the report's potentially large role in shaping opinions and decisions on these issues it seems worth making the point as directly as possible both when the individual options are discussed and when the final conclusions are generated. The phrase "requires additional desalination reject stream management" is unlikely to be translated by most non-engineers as "the salt removed from the main part of the treated water is now confined at higher concentration within a smaller volume of water which we now need to do something with." Precisely how the brine from a reverse osmosis or other salt concentrating process is handled makes all the difference in whether that "treatment" system actually removes salinity from the basin and improves water quality or whether it simply redistributes the impact from the food processing plants to the centralized treatment facility. Efforts to prevent negative water quality impacts by properly managing the concentrate stream are included in the cost estimates presented, but the nature of those efforts is not fully specified. This is appropriate in the conceptual level cost analysis being presented but it is important that the stakeholders in this problem (industry, regulators and the public) understand the basic nature of what they are getting for the large investments of resources being contemplated under many of the salinity management options described in the report.

Because of the "preventive" nature of in-plant measures that keep the salt from entering the process water in the first place or that treat such streams while they are still highly concentrated and small in volume, such measures are preferred in principle over treatment of larger volumes at lower concentrations. However, as is obvious from the report, sufficient information to predict the impacts and costs of particular in-plant measures is generally lacking. In particular, salt budgets are lacking or are incomplete for most of the food processing sectors considered (see for example statements about milk processing on page 192). Consequently, I believe that the cost estimates for the in-plant measures are substantially less certain than those for the construction and operation of centralized treatment facilities for which industry-wide data compilations are available. I would emphasize that further investment in identifying and quantifying the sources of salt to process water streams in varied food processing operations is well worth the effort and might lead to control options with substantially smaller cost per ton of TDS removed (although likely for relatively small total amounts of salt removed).

I must admit that my comments favoring in-plant measures of salinity control largely stem from my dislike of the centralized treatment options, in principle. Despite the relatively favorable cost numbers per ton of TDS removed presented in Table 116, which I do not dispute at the conceptual level at which they were generated, I would have trouble telling citizens and industries in this region that they collectively needed to spend between \$100 and \$175 million to construct and \$6 to \$23 million per year to operate the infrastructure to pump salty water over significant distances to a facility where a treatment system would make some of the water saltier while the resulting clean water would (most likely) be discharged to the environment where it would mix with water that was probably saltier. Each of these steps (construction, operation, and maintenance of both the collection system and the treatment system) consume significant amounts of energy and other resources. The authors do a good job of expressing this concern on page 160 (second to last paragraph) but this aspect of the regional treatment alternatives are not reiterated in either the executive summary or the comparison of alternatives sections. The fact that virtually all of the salt abatement strategies are significantly more costly than the economic benefits to be derived may make the comparison among those strategies less critical, but if policy makers choose to tackle this problem anyway, then providing them with a clear understanding of which alternative way of addressing the problem is "lowest cost" is critical.

Editorial Comments

page	***Paragraph or other identifier***	***Comment***
All		It is confusing to have roman numeral section headings (e.g., I.X.) and then refer to these sections in the text in a mixed roman-arabic manner (e.g., I.10).
161	3	FDS-TDS should be FDS and TDS
161	4	Reference for TDS=.75EC?
162	3	Change "indifferent" to "in different"
162	Table 56	Reference source of information
163	Table 58	Reference source of information
164	Figure 25	Source of this figure? Referenced?
164	3	Figure 1 ????
165	3	Figure 2 ?????
165	Fig 26	The text seems to indicate a comparison of two system configurations but only one flow diagram is provided.
167	1	Table 60 should be Table 61
175	1	Table 12 should be table 67
176	2	"present boiler water system"? Does this refer to a particular system? Where?
181	1	"CIP" define upon first use.
183	Bullet list	Are these costs realistic for the system size contemplated here? It seems they were "scaled down" from larger systems but then their unit costs would likely, in practice, be higher than the numbers listed.
186	Table 74	Source of the data on TDS, FDS, etc.? If the data were collected for this study, the measurement methods and number of replicates should be specified. The meaning of the italicized vs. non-italicized Added FDS values is not clear until the assumptions are reported on page 211. Footnote indicating the assumptions used in calculations in all tables reporting the "Added FDS" result would be helpful.
187	5	"This plant" -- antecedent was unclear.

188	1	"Costs were obtained"
189	1	"This plant is already." Fragment.
189	1	"sensitive processes" definition or examples
189	2	"it also" should be "it is also"
189	5	Should be "making [is] processed"
191	2	Table 78 should be Table 80 in text.
196	Table 85	Source of this information?
198	2	Sentence beginning "Meat processing" is not at all clear.
199	1	"tomato and milk 33 is limited to supply"—not clear.
204	2	Water splitting not water slitting.
206	1	"The leading developer of …" seems a bit like a commercial endorsement. None of the other technologies come with such a direct or glowing reference to the vendor.
207	2	Point A to Point [B]?
209	1	Reverse osmosis listed twice.
209	2	"An integral part of the study was [estimating the] cost of"
211	Assumption 3	Form should be from
224	Table 96	Shaded area in flow column is illegible.
244	Item 2.	Depicted [are] a result
255	Item 5.	The lower unit cost of TDS removal in the POTWs is also due to the fact that you are removing some salt from the combined food processing and municipal streams that would not be removed by the dedicated food processing treatment facility. This suggests that there may be benefits to the POTW upgrade scenario in terms of generally improved effluent quality that may be missed in the analysis.
260	1	Any "no treatment" option on the brine line would surely require the food processors to at a minimum segregate their wastes and likely pretreat them to remove, for example, BOD. It does not seem that these facility-level costs are included in the analysis. See also comment on p. 261, paragraph 2.
265	Issue 4.	Everything about the scale-up scenario is driven by the assumption about the density of food processing operations along Highway 99. The assumptions lead directly to the essentially constant average cost of TDS removal reported in Table 116. I see little justification for the detail in this subsection since it provides the appearance of greater detail in the estimates than is justified.
270	5	Wastewater as measure[d]
271	3	Les[s]
271	4	urbanized tha[n] was
271	5	help [p]reserve
273	Item 6.	Perhaps I missed the discussion of deep well injection, but I could find no reference to it in any earlier portion of the report. It seems to be introduced from nowhere at this point in the report.

	Section II	This section is much more disjointed than section I and it is very hard to find information within this section. There needs to be a single table of contents and uniform, continuous pagination similar to that in section I.

Kennedy/Jenks Consultants

Engineers & Scientists

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17 October 2007

Dr. Mark Berkman
Hilmar SEP Study Administrator
CRA International
5335 College Avenue, #21
Oakland, CA 94618

Subject: Comments on Draft Report, Hilmar Special Environmental Project
K/J 020112.03

Dear Dr. Berkman:

On behalf of the Wine Institute, Kennedy/Jenks Consultants (Kennedy/Jenks) has reviewed the Draft Report for the Hilmar Supplemental Environmental Project (SEP), dated September 2007, and has prepared this comment letter for your consideration in finalizing the document. Due to the complexity of the document and the relatively short review period, our comments are necessarily limited to a few key areas. These areas were identified based on a review of the draft document, as well as our understanding of the study methodology that was outlined in meetings with the SEP Stakeholder Committee.

Section II.2. Model Formulation and Development:

- **Boundary Conditions and Wastewater Application Rates** (pages 20, 22 and 33). The steady-state flow boundary condition specified for the model is inconsistent with best practices for land application that are typically employed by wineries. As detailed in the Wine Institute's draft guidance document, *Land Application of Winery Stillage and Non-Stillage Process Water, Study Results and Proposed Guidelines* (August, 2004), an alternating sequence of wetting and drying cycles is used to maximize treatment effectiveness in high-rate spreading basins. We assume this document was available to the study team, since it was previously submitted to the Regional Water Quality Control Board and is part of the public record; thus, we were disappointed to find it was not leveraged in development of your approach for wineries. For your reference, a copy of the document has been provided by e-mail. However, even for slow-rate irrigation, as prescribed in CLFP's *Manual of Good Practice for Land Application of Food Processings/Rinse Water*, an intermittent application approach is employed to allow time for crop uptake. Thus, the model would need to account for periods when there is no inflow from either wastewater or precipitation.

- **Carbonate Chemistry Assumptions** (pages 6 and 7). The conceptual model assumes that the gas phase in the root and unsaturated zone is in equilibrium with carbon dioxide in the atmosphere (about 330 ppm), while typical values of carbon dioxide in root zones, due to microbial respiration, is on the order of 0.1 to 0.2 atmospheres. In addition, it is unclear whether charge balance is being properly accounted for in the model wastewaters used in the model runs.

- **Vadose Zone Definition and Validation** (pages 6 and 15). The vadose zone, as described in the report and illustrated by the conceptual model, is a single, continuous layer of homogeneous soil. A more representative vadose zone would include layers of varying permeability materials. These heterogeneities inhibit direct downward flow to groundwater, and are a significant factor in the ultimate effectiveness of land application treatment. The report does not provide or discuss validation of the vadose zone model and breakthrough curves.

- **Table 19, Components of Concern in Winery and Grape Processing Wastewater.** Could the maximum concentration of each constituent be shown without attributing it to a specific facility? The benefit to the reader from seeing the facility name is not clear, and it could pose a liability for the named facilities.

Section II.3. Model Application and Results

- **Breakthrough Curves.** The organic matter (representing BOD) breakthrough curves for Case 1 and Case 3 project very high organic matter concentrations at the water table. For example, the Case 1 results (Figure 1 and Table 1 on page 6) indicate that the organic matter concentration is several thousand mg/l, which is more than twice as high as the applied concentrations in three of the four industries. We are unaware of any groundwater data that support such concentrations. We note that in section B, Comparison of Baseline Results with Groundwater Data (pages 25-27), no mention is made of how the organic matter results compare with groundwater data. This suggests there may be problems with how the conceptual model handles organic matter.

- **Sensitivity Analysis for BOD Removal.** The sensitivity analysis for pretreating wastewater for BOD removal prior to land application suggests that for Case 2, the greatest nitrate level occurs when 100 percent of the BOD has been removed (pages 50-51). It is unclear what the mechanism is for the ammonia conversion to nitrate, as no carbon source appears to be present under this scenario. Case 3 shows similar results for nitrate. These results suggest there may be problems with how the model handles the nitrification process.

Appendix II.2:

- **Potentially Environmentally Sensitive Areas within 3 Miles of Central Valley Food Processors.** Given that the results of the study do not suggest lateral migration of groundwater is occurring, the purpose of this table is not clear. We recommend that information on the intended application of the table be incorporated.

In general, the Wine Institute remains concerned that misuse of vadose zone modeling results to develop site specific conclusions could lead to significant misinterpretation of the impact of land application on groundwater. We understand that the study team is aware of this issue, yet any additional language that can be incorporated to further caveat data interpretation would be appreciated. In spite of these concerns, we do strongly agree with the overall conclusion from the study that winery wastewater does not pose a significant threat to groundwater quality or the Central Valley economy. We will continue to evaluate the document, and we look forward to the peer review comments and further discussion at that time.

Very truly yours,

KENNEDY/JENKS CONSULTANTS

Robert S. Chrobak

Robert S. Chrobak, P.E.
Vice President

cc: Chris Savage, E. & J. Gallo Winery
Bob Calvin, Constellation Wines U.S.

Response to Comments from the Wine Institute

Comment 1

Boundary Conditions and Wastewater Application Rates (pages 20, 22 and 33). The steady-state flow boundary condition specified for the model is inconsistent with best practices for land application that are typically employed by wineries. As detailed in the Wine Institute's draft guidance document, *Land Application of Winery Stillage and Non-Stillage Process Water, Study Results and Proposed Guidelines* (August, 2004), an alternating sequence of wetting and drying cycles is used to maximize treatment effectiveness in high-rate spreading basins. We assume this document was available to the study team, since it was previously submitted to the Regional Water Quality Control Board and is part of the public record; thus, we were disappointed to find it was not leveraged in development of your approach for wineries. For your reference, a copy of the document has been provided by e-mail. However, even for slow-rate irrigation, as prescribed in CLFP's *Manual of Good Practice for Land Application of Food Processings/Rinse Water*, an intermittent application approach is employed to allow time for crop uptake. Thus, the model would need to account for periods when there is no inflow from either wastewater or precipitation.

Response 1

When we requested the document o numerous occasions, we were told that this document was still being finalized and would not be made available to us. As of March 15, 2007, the study results and guidelines were still under discussion by the California Regional Water Quality Control Board Central Valley Region. According to the Board's March 15, 2007 Executive Report (available at http://www.swrcb.ca.gov/rwqcb5/monthly_board_report/0703eo.pdf):

> The Wine Institutes' Land Application of Winery Stillage and Non-Stillage Process Water Study Results and Guidelines continues to be the subject of discussion during monthly meetings between State Board staff, Regional Board staff, and the Wine Institute. The State Board's 2005 peer review of the study raised numerous substantive concerns, and State Board staff is spearheading a comprehensive literature review focusing on the ten main issues. State Board staff intends to release a draft summary document later this summer.

The "spreading basin" approach described in the Wine Institute Report appears to be distinctly different from the current practices for land application, and thus it was clearly not appropriate for inclusion in the "baseline" scenarios presented. The most recent staff report on the land application of food-processing wastewater noted that only a small minority of wineries currently use this method (Central Valley Regional Water Quality Control Board, 2006):

Wine Institute Study. Staff had previously commented on both the study design and drafts of the Wine Institute's *Land Application of Winery Stillage and Non-Stillage Process Water Study Results and Proposed Guidelines*. During 2005, the document underwent a peer review facilitated by the State Water Board. The peer review was critical of the study, and the Wine Institute has recently prepared a response. Staff is continuing to meet with State Water Board staff and the Wine Institute to follow-up on the peer review. While staff supports the objectives of the study, it should be pointed out that only a small number of the largest wineries dispose of waste in the manner studied by the Wine Institute. Staff's main concerns with the *Guidelines* are that (a) intensive monitoring and feedback are necessary to maximize the treatment of wastewater by fallow land and, more importantly, (b) the study shows that land treatment methods are not sufficient to prevent elevated levels of salt and decomposable waste constituents from moving through the vadose zone and into the underlying groundwater. In recognition of the salt issue, the Wine Institute is now conducting a wastewater salt loading study, in which the waste streams from individual winemaking processes will be analyzed and management practices will be proposed to reduce the quantity of salt in the wastewater applied to land.

Spreading basins could have been included as a management strategy, however, it would have required the modification of the model presented in order to adequately describe the above-ground processes associated with this application method. For example, the Wine Institute Report notes, "Organic constituents in process water (characterized by 5-day biochemical oxygen demand, BOD5) are treated primarily by oxidation at the spreading basin surface and in the surface soil horizons." Such changes to the model to investigate non-standard practices were out of the scope of this study.

Comment 2

Carbonate Chemistry Assumptions (pages 6 and 7). The conceptual model assumes that the gas phase in the root and unsaturated zone is in equilibrium with carbon dioxide in the atmosphere (about 330 ppm), while typical values of carbon dioxide in root zones, due to microbial respiration, is on the order of 0.1 to 0.2 atmospheres. In addition, it is unclear whether charge balance is being properly accounted for in the model wastewaters used in the model runs.

Response 2

The conceptual model only assumes that the initial, pre-waste, carbon dioxide concentration is in equilibrium with the atmosphere. The production of CO_2 by microbes and its diffusion through the vadose zone is included in the model. The model typically produces subsurface CO_2 concentrations between 0.1 and 0.3 atm for Cases 1 and 3, and 0.02 atm for Case 2 (Figure). The large difference is caused by the lower saturation levels in Case 2, which allow for the diffusion and release of CO_2 to the atmosphere.

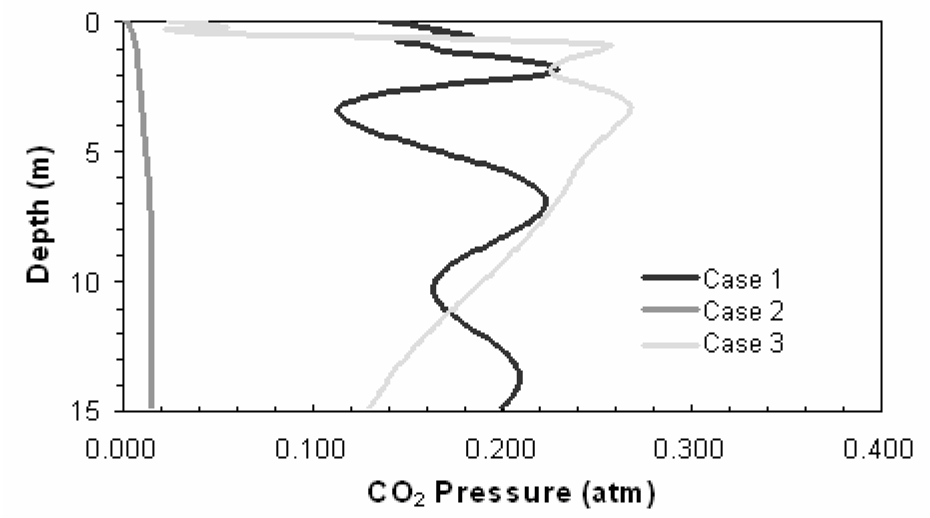

Figure 1: Modeled CO2 pressure at Year 30 for Winery simulations.

The modeled wastewater inputs where charged balanced by adjusting the fraction of Na^+ to Cl^-, as necessary. We chose this approach due to the absence of specific data about the relative concentrations of these compounds in most wastewaters.

Comment 3

Vadose Zone Definition and Validation (pages 6 and 15). The vadose zone, as described in the report and illustrated by the conceptual model, is a single, continuous layer of homogeneous soil. A more representative vadose zone would include layers of varying permeability materials. These heterogeneities inhibit direct downward flow to groundwater, and are a significant factor in the ultimate effectiveness of land application treatment. The report does not provide or discuss validation of the vadose zone model and breakthrough curves.

Response 3

Heterogeneity does not act to inhibit direct downward flow. It can act in different ways, including enhancement of downward flow through macropores. Heterogeneity can imply large and small conductivity, and should not be viewed as an "inhibitor". It is well known in the literature that heterogeneous media can be modeled as a homogeneous one, like we did here, under certain conditions. We discussed this amply in the draft report and in numerus briefings. Let us repeat the main point here. The use of effective properties to homogenize the flow domain is expected to produce average concentrations, such as the concentrations measured at pumping wells. It does not intend to produce concenration values measured over support volumes of small scale.

We have acknowledged throughout the report the difficulties with model validation, due to the lack of appropriate vadose zone data. We have also confirmed (Section II.3.B) that the vadose zone model is producing reasonable concentrations at the groundwater table. As land application is studied futher, sufficient vadose zone data should become available, at which time the model can be rigoursly validated, and biodegradation and crop uptake parameters can be calibrated as appopriate.

Comment 4

Table 19, Components of Concern in Winery and Grape Processing Wastewater. Could the maximum concentration of each constituent be shown without attributing it to a specific facility? The benefit to the reader from seeing the facility name is not clear, and it could pose a liability for the named facilities.

Response 4
The facility names have been removed, consistent with the practice of making processors anoynomous thoughout the rest of the document.

Comment 5

Breakthrough Curves. The organic matter (representing BOD) breakthrough curves for Case 1 and Case 3 project very high organic matter concentrations at the water table. For example, the Case 1 results (Figure 1 and Table 1 on page 6) indicate that the organic matter concentration is several thousand mg/l, which is more than twice as high as the applied concentrations in three of the four industries. We are unaware of any groundwater data that support such concentrations. We note that in section B, Comparison of Baseline Results with Groundwater Data (pages 25-27), no mention is made of how the organic matter results compare with groundwater data. This suggests there may be problems with how the conceptual model handles organic matter.

Response 5
Unfortunately, in the data made available to us, we could find only two wineries providing any groundwater data for organic carbon (as BOD, COD, or TOC), which prevented us from conducting a comparison as was done with nitrate and dissolved solids. In many cases, the concentration of organic carbon reaching the water table is higher than that applied because it is being concentrated in the vadose zone. Plant uptake does not remove organic carbon, but ET reduces the amount of water present, leading to higher concentrations of solutes in the pore water. However, the reaction rates for processes such as microbial respiration, while in line with the literature, are very uncertain due to the lack of studies on these processes in unsaturated conditions with very high organic carbon concentrations such as those present in the wastewater.

Comment 6

Sensitivity Analysis for BOD Removal. The sensitivity analysis for pretreating wastewater for BOD removal prior to land application suggests that for Case 2, the greatest nitrate level occurs when 100 percent of the BOD has been removed (pages 50-51). It is unclear what the mechanism is for the ammonia conversion to nitrate, as no carbon source appears to be present under this scenario. Case 3 shows similar results for nitrate. These results suggest there may be problems with how the model handles the nitrification process.

Response 6

Ammonia/ammonium conversion to nitrate, known as nitrification, occurs through microbe mitigated reactions, shown in Equation 4 of Section II.2.9.a. Nitrifying bacteria are autotrophs, which do not require an organic carbon source, unlike the heterotrophic bacteria responsible for several of the other biodegradation mechanisms mentioned (Asano et al., 2007). Thus, the conversion of ammonia to nitrate in the absence of organic carbon is entirely appropriate. The reaction formulation used in this study is common and is well supported in the literature (Langergraber and Simunek, 2005; MacQuarrie and Sudicky, 2001).

Comment 7

Potentially Environmentally Sensitive Areas within 3 Miles of Central Valley Food Processors. Given that the results of the study do not suggest lateral migration of groundwater is occurring, the purpose of this table is not clear. We recommend that information on the intended application of the table be incorporated.

Response 7
See Final Report

References

Central Valley Regional Water Quality Control Board. 2006. Staff report: Update regarding the regulation of food processing waste discharges to land. Cal. Dept. Water Resources, Rancho Cordova, CA.

Langergraber, G., and J. Simunek. 2005. Modeling variably saturated water flow and multicomponent reactive transport in constructed wetlands. Vadose Zone J. 4:924-938.

MacQuarrie, K.T.B., and E.A. Sudicky. 2001. Multicomponent simulation of wastewater-derived nitrogen and carbon in shallow unconfined aquifers: I. Model formulation and performance J. Contam. Hydrol. 47:53-84.

Response to Peer Review Comments

November 15, 2007

Prof. Tom Young, UC Davis

Prof. Young notes that in some sense the alternatives selected are not fully comparable since some involve the complete removal of salts from the basin and others do not. This observation is correct, of course, and we have modified the text to make sure this point comes through more clearly.

We also agree with his observation that the report could have been clearer about some of the disadvantages of regional treatment systems. In particular, the large capital expenditures required to implement these approaches combined with the questionable environmental benefits would make such an alternative hard to justify. The draft report contained some language to this effect and we have added more text in this regard.

Prof. Young also had a number of detailed textual and editorial suggestions that have been incorporated in the final report.

Prof. Erik Lichtenberg, University of Maryland

Prof. Lichtenberg raises a few substantive questions with respect to the land use forecasting model and the framework for measuring agricultural yield losses. He also observes that the report could be improved to make it more readable. We address these points in turn.

The SEP study presents a logit estimation of the parameters of a Markov transition model. Prof. Lichtenberg notes that the report would benefit from a more thorough presentation of the statistical estimation, and particularly from the inclusion of standard measures of predictive accuracy. These changes have been made. Further, he notes correctly that a panel method such as that developed by Irwin and Bockstael (2002, 2004) is better suited to the problem. Again, we agree with this comment generally, although we note that with only two years of data to compare land use changes, it is unlikely that a panel approach would be successful or would result in different outcomes than those presented. In a setting with more time-variant data, however, we agree that the panel approach is superior.

Prof. Lichtenberg also raises questions about the crop loss functions used in the report. With respect to how they relate to the DAP and DRMS models, we note that the loss functions are part of these larger models. The DAP and DRMS models are calibrated to conditions in the Sacramento-San Joaquin Delta and are thus not directly applicable to the representative area. However, the yield loss functions used in these models are general. With respect to the use of a spline function as opposed to a sigmoidal function, we note again that the alpine formulation was taken directly from the earlier work on Delta agriculture. In any case, the results from the two approaches should be approximately equal since the functions have a similar shape.

Dr. Corwin, U.S. Department of Agriculture

Comment 1:

Salt accumulation within and just below the root zone is primarily a consequence of the process of evapotranspiration (ET) and will be determined largely by the amount of ET and the root water uptake distribution. The model used in the study, MIN3P, does not appear to have a very sophisticated root water uptake routine since it has no apparent feedback between plant growth and salt accumulation nor does it appear to have a root water uptake routine that is based on combined matric and osmotic stresses, but rather assumes a uniform uptake through the root zone regardless of the matric or osmotic potential. This maybe a major weakness since salt accumulation and leaching, which results in salt loading, is so closely tied to ET and plant water uptake distributions. In cases where salinity is accumulating in the root zone, osmotic stress will determine where water uptake by the root will occur. In areas of the root zone where higher levels of salt have accumulated and higher osmotic stress occurs, the plant will withdraw water from areas where the osmotic stress is lower and continue to withdraw water from this portion of the root zone until the matric and/or osmotic stresses reach a point where the plant is expending too much energy to uptake water. In essence, the plant will withdraw water from that portion of the root zone that requires the least expenditure of energy. In addition, it is important to account for the impact of salt accumulation within the root zone on plant growth, which directly influences ET. If root zone salinity reaches a level where plant growth is affected, then the ET will be reduced. As ET diminishes due to less plant growth, less water is being taken up by the plant, so more water is available to leach salts. A feedback mechanism is needed within the model that decreases the ET when salt accumulation reaches the salinity threshold that affects plant growth. The relationship between salinity and plant yield has been well established by Maas and Hoffman (1977). The influence of salt accumulation on root water uptake and plant growth is an important factor influencing the accumulation and leaching of salts. Salt loads will not be simulated correctly if a sophisticated plant water uptake routine is not included in the model. The lack of a sophisticated plant water uptake model will also result in unreasonably predictions of NO_3 loads in situations where salt accumulation effects plant growth. Diminished plant growth will result in reduced uptake of NO_3, making more NO_3 available for leaching. At the beginning of the SEP when I was asked for my input on the modeling approach, I had inquired as to why MIN3P was being used over other models more applicable to salt transport, such as UNSATCHEM. It is because of the aforementioned reasons that I made this inquiry.

Response 1:
An additional section discussing soil salinity buildup and its potential impacts on plant water uptake (ET) and reduced crop yields has been added. It can be found in Section

II.3.D.2: Salinity Buildup in the Root Zone. Discussion on the selection of the numerical modeling code and a comparison between MIN3P and UNSATCHEM has been added to Section II.2.C.1.

Comment 2:
Another weakness in the modeling study is the limited uncertainty analysis performed (i.e., Monte Carlo simulations or first-order uncertainty analysis). Monte Carlo simulations were performed for effective conductivity, but were not performed for other parameters found to hold a significant role in the fate and transport of salinity, NO_3, and NH_3. Monte Carlo simulations performed with distribution functions assigned to each variable and parameter or at least the most significant variables and parameters would be valuable in light of the fact that no field measurements were taken, due to the short project duration, to compare to simulated results. Without uncertainty analysis the interpretation of the simulated results is less credible since the reliability of the simulated results is unknown. Monte Carlo simulations could be run for each case study using distribution functions for model parameters and variables that are present in the literature or by assuming a normal distribution. Uncertainty analysis should not be confused with the case study approach that was used to bracket variability in site conditions. The uncertainty analysis will provide an indication of the reliability of the model simulations due to inherent uncertainty in model input data and the subsequent effect of this uncertainty on model predictions…The issue of sensitivity analysis for the model should be addressed beyond what was presented in Sections II.3.D.3 and II.4.G. Sensitivity analysis is needed for all parameters to establish those parameters that are most significant in their effect on simulated outputs. This is a minor undertaking and is recommended just to provide a point of general reference. A table of results is sufficient indicating the most and least sensitive inputs and parameters. If a sensitivity analysis has already been performed for MIN3P in the literature, then the table can be created from the literature data. It is important to know the parameters to which the model output is most sensitive to understand those parameters that need to be measured or estimated mostly accurately. It can then be evaluated if the most sensitive parameters have been measured or estimated with sufficient accuracy and if not to what extent this may or may not influence the simulated results.

Response 2:
The rationale behind not including a Monte Carlo analysis in the vadose zone study has been further discussed in Section II.2.B and Section II.4.A.

Comment 3:
One case study that has been overlooked and may have a significant impact in the management of FDS and N loads, particularly FDS loading, is one in which food-processing waste is applied in low volumes but at high frequencies. The wastewater is applied at a frequency that would assure a downward water flux to prevent any upward movement of salts into the root zone, but in sufficiently low volumes to exceed slightly the ET demands by the plant, resulting in a low leaching fraction (i.e., volume of drainage water/volume of irrigation water). This low leaching management would result

in substantial precipitation of salts just below the root zone that would reduce FDS loads to the groundwater by 20-30%. The leaching of NO_3 would be minimized allowing maximum uptake by plants, while the fate of NH_3 would depend on maintaining aerobic conditions, which may or may not be a challenge depending on the soil texture. This means of managing salt and NO_3 loads has great potential for the long-term attenuation of salinity and is a case study scenario that could be explored with modest effort. Although this is more of a management scenario, the simulated results could be extremely valuable as a means of managing those sectors of the food-processing industry with the highest potential FDS loads.

Response 3:
Although we have not added such a scenario to our tests of potential management strategies, some discussion of leaching fraction management has been added to Section II.3.D.2.

Comment 4:
Spatial variability has been addressed to evaluate the effects of large-scale heterogeneity on salt concentration by investigating the influence of buried paleo-channels. However, some estimate of the effect of within-field variation of other fate and transport related parameters (e.g., spatial variations in clay content and ET) on simulation results is valuable to add credence to the final representative simulations for the different case scenarios. The spatial variation of ET can be particularly valuable since salt accumulation within and just below the root zone is highly dependent on ET and the root water uptake distribution. Even though the simulated results are being used to understand the significant interactions of mechanisms influencing the fate and transport of salinity, NH_3, and NO_3, the influence of within-field variability provides a more realistic understanding of field-scale ranges than the three selected case studies, which are intended more to provide a range of conditions encountered in the San Joaquin River and Tulare Lake Basins. Since land application of food-processing wastewater is largely done on tracts of land comparable to agricultural field sizes (e.g., 40 to 160 ac), simulations run using the spatial variability encountered in a typical field would add another level of understanding, a level that is more applicable to variation in field-scale conditions.

Response 4:

This issue is addressed in II.2 Subsection A.2. There is no data about field scale variability, to our knowledge. Such variability is important for modeling the small scale variability of the concentration field. Our modeling approach does not intend to capture this variability. Instead, it s focused on averages of large areas, and for such averages, we believe that the small scale variability is not consequential. Our modeled concentrations are in line with those observed (see Section II.2 Subsection B), which provides support for our modeling decisions.

Comment 5:

The Executive Summary can be improved… Finally, the draft report needs to be proofread more closely...

Response 5:
The document made available to the reviewers was a draft. The Executive Summary has been expanded. The section numbering system has been completely reformatted, and the document has undergone additional proofreading.

Comment 6:
I have a question concerning the simulation results: was there an instance where pH changes occurred to the point where modeling of trace elements, such as B, are warranted due to increased mobility and subsequent increased potential for impacts on groundwater? I believe that the removal of fruit peel is often done using sodium hydroxide. The sodium hydroxide appears in the food-processing waste water. Does the presence of sodium hydroxide sufficiently raise pH to levels that would influence adsorption and thereby increase the mobility of trace elements? Or are the pH changes too small to affect the adsorption process to any significant extent? Is this a potential scenario that should have been considered? Or is this an insignificant concern?

Response 6:
In a survey of Waste Discharge Requirement (WDRs), we have found that most processors are required by their permits to discharge wastewater to the land at pH levels between 6.4 and 8.5 (Section II.2.E), and thus we assumed that the pH of any wastewater applied to land was below 8.5. In most cases, the simulations produced near neutral pH values in the root zone and at the groundwater table, between 6.2 and 7.8. While high or low pH values were not noted in the simulations, they may develop if applied wastewater falls outside of the required range.

Prof. Loaiciga, UC Santa Barbara

The main issues addressed in this comment are the lack of identification of “preferred” alternative for salt management, and the fact that the cost-benefit comparison among alternatives is incomplete. With respect to the former, the SEP study was not intended to identify a preferred management strategy. Indeed, during the settlement leading to the SEP study, the parties agreed that the study should not recommend a salt management strategy, but rather present information to the Regional Board and other stakeholders that would assist in analyzing a range of regional salinity objectives and policies. With respect to the incomplete cost-benefit comparison, we have two responses. First, since land application causes so little apparent damage over the study period, alternatives to the status quo cannot cause much less damage, and may cause significantly more. They may also be more expensive. Second, budget constraints prevented the study team from conducting a groundwater quality analysis for all alternatives. This circumstance prevented us from performing such a cost-benefit comparison for every alternative, even if it is clear what would have been the end result of such a comparison.

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