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A Mass Balance Approach to Evaluate Salinity Sources in the Turlock Sub-Basin, California

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DEFINITION OF TERMS

μS/cm	microsiemens per centimeter
acre-ft	acre feet
ANR	University of California, Division of Agriculture and Natural Resources
applied water	Amount of water from any source needed to meet the demand of the user. Applied water includes the volume of water delivered to the intake to a city water system or manufacturing facility, and a farm headgate or other point of measurement. Precipitation and seepage from the water supply system prior to reaching the intended user are not included in the volume of applied water.
bgs	below ground surface
CAFO	concentrated animal feeding operation
CASTNET	Clean Air Status and Trends Network
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region
CV-SALTS	Central Valley Salinity Alternatives for Long Term Sustainability
CVSC	Central Valley Salinity Coalition
Durbin	Timothy J. Durbin, Inc.
DWR	California Department of Water Resources
EC	electrical conductivity
EKI	Erler & Kalinowski, Inc.
EWD	Eastside Water District

DEFINITION OF TERMS

FDS	fixed dissolved solids
ITRC	Irrigation Training and Research Center
mg/L	milligrams per liter
MID	Merced Irrigation District
NADP	National Atmospheric Deposition Program
POTW	publicly owned treatment works
salt and salinity	Minerals that dissolve in water. Salt and total dissolved solids are used interchangeably to refer to conservative salt components that do not readily transform in the environment.
TDS	total dissolved solids
TGBA	Turlock Groundwater Basin Association
TID	Turlock Irrigation District
tons/yr	tons per year
USGS	United States Geological Survey

1 EXECUTIVE SUMMARY

Human activity is increasing the salinity of surface water and groundwater in California's Central Valley. Identified salt sources include concentrated animal feeding operations (CAFOs), irrigated agriculture, municipalities, food processors, septic tank systems, and mineral dissolution caused by water recharge.

The California Department of Water Resources (DWR) divides the Central Valley into three groundwater basins, which in turn are partitioned into 40 groundwater sub-basins. Erler & Kalinowski, Inc. (EKI) performed a preliminary salt mass balance on one of these sub-basins, the Turlock Sub-basin. The objectives of this study were:

- Evaluate the feasibility of completing a preliminary salt mass balance to identify and quantify salt sources in a Central Valley sub-basin using publicly-available information, and

- Recommend means for improving the preliminary salt mass balance on sub-basins in the Central Valley.

The preliminary salt mass balance involved estimating salt quantities contributed to surface water and groundwater by identified sources in the Turlock Sub-basin. The salt mass balance was checked by comparing the predicted rate of increase of groundwater salinity with the observed rate of increase. The predicted rate of salinity increase was found to approximate the observed rate.

Further studies using additional or updated data sources may find that salt loads for individual sources are higher or lower than those estimated herein. However, this preliminary salt mass balance indicates that salt quantities added to the Turlock Sub-basin do not require exact determination to understand how individual sources are contributing salt to the sub-basin on a regional basis and to help identify effective salt management strategies. This salt mass balance approach can provide a sensible framework for sub-basin salt management because it focuses on the Central Valley's core salinity challenge — more salt is imported than is exported.

Publicly-available data were found sufficient to identify and quantify the major salt sources for this sub-basin. Available data also may be sufficient to develop salt mass balances on other Central Valley sub-basins without collecting extensive new data.

This preliminary salt mass balance for the Turlock Sub-basin could be refined. Major stakeholders have extensive knowledge of their respective operations and would be key contributors to an improved mass balance. Further work could include:

- Detailed water and salinity mass balances at representative food processors, CAFOs, and municipalities,

- Mineral dissolution studies to quantify the effects of local soil and water types on salt loading, and

- Evaluation of the local estimated salt contribution of fertilizers and soil amendments.

2 INTRODUCTION

The Sacramento Valley and San Joaquin Valley comprise the Central Valley of California. With more than 250 different crops grown in an area covering 20,400 square miles, the Central Valley is one of the world's most productive agricultural regions.

The salinity of Central Valley surface water and groundwater supplies is steadily increasing. This increase threatens the region's agricultural productivity, and impairs the urban and industrial economic output and quality of wildlife and aquatic habitats. The University of California Davis (2009) estimates that by 2030 the costs associated with increased salinity could amount to $8.7 billion per year in today's dollars if the rate of salinity increase in water supplies remains unabated.

Surface water and groundwater salinity in the Central Valley results from both natural and manmade sources. As described in Box A, these source contributions must be understood on a quantitative basis if solutions to the salinity challenge are to be developed and implemented. A mass balance approach to quantifying sub-basin salt inflows and outflows is a key step toward effective regional salinity management.

Box A - Salt and its Measurement

The terms "salt" and "salinity" refer to minerals that readily dissolve in water, including but not limited to sodium chloride, also called common table salt. When salts dissolve in water, they dissociate into positively-charged ions (cations) and negatively-charged ions (anions). The most prevalent cations are calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}). Important anions include chloride (Cl^{-}), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^{-}). Potassium (K^{+}), carbonate (CO_3^{2-}), nitrate (NO_3^{-}), fluoride (F^{-}), and silicate (SiO_3^{2-}) also exist in water supplies, but concentrations of these ions are comparatively low (University of California, Division of Agriculture and Natural Resources, 2002).

Salt concentrations in water are most often quantified by measuring total dissolved solids (TDS) or electrical conductivity (EC). TDS represents the solids that remain after evaporating water to dryness at 180°C. TDS, reported as milligrams per liter (mg/L), increases as the salinity of the water increases. EC represents the ability of salt ions in water to conduct electricity. EC, reported as microsiemens per centimeter (μS/cm), also increases as the salinity of the water increases.

TDS can be calculated directly from cation and anion concentrations as follows (American Public Health Association et al., 2005):

$$\text{TDS} = 0.6\,(\text{alkalinity as } CaCO_3) + Na^{+} + K^{+} + Ca^{2+} + Mg^{2+} + Cl^{-} + SO_4^{2-} + SIO_3^{2-} + NO_3^{-} + F^{-}$$

TDS measurements reported by a laboratory can be considerably higher than TDS calculated from the above expression due to organic matter present in water. For this reason, TDS concentrations that reflect high levels of organic matter, such as certain food processor wastewaters, should be adjusted because organic matter does not persist in the environment in the same fashion as mineral salts. Brown and Caldwell and Kennedy/Jenks Consultants (2007) state that TDS in food processor wastewater is typically 40 to 70 percent organic matter that decomposes over time due to microbial action. With certain exceptions, inorganic dissolved solids are "conservative" in nature, in that they do not readily transform in the environment.

These conservative salt components are sometimes reported as "fixed dissolved solids," or "FDS." The FDS concentration is determined by further heating the solids obtained from TDS testing to 500°C. The solids lost due to this further heating are called "volatile solids." Determinations of FDS and volatile solids do not distinguish precisely between inorganic and organic matter because heating to high temperatures can decompose or volatilize certain mineral salts. The American Public Health Association et al. (2005) recommend that supplemental tests, such as direct measurement of total organic carbon, can more directly characterize dissolved organic matter.

Box A - Salt and its Measurement (continued)

In this preliminary salt mass balance report, the terms "salt" and "TDS" are used interchangeably to refer to conservative salt components. Where appropriate, as in the case of food processor wastewater, TDS concentrations have been adjusted to remove the contributions of organic matter that do not persist in the environment. Although nitrogenous compounds, such as ammonia (NH_3) and nitrate, appear in water, their influence on TDS is small because these ions are present at much lower concentrations than mineral salts. As a consequence, TDS and FDS can be considered equivalent if the water does not contain high concentrations of organic matter.

TDS and EC are related. The observed ratio of TDS (in terms of mg/L) to EC (expressed in units of µS/cm) ranges from 0.55 to 0.7 (Metcalf & Eddy, Inc., 2003; Tchobanoglous and Schroeder, 1985). A ratio of 0.6 is a common rule-of-thumb to convert EC measurements to TDS concentrations.

3 OBJECTIVES

The idea of a salt mass balance is simple to grasp. Salt loadings can often be estimated straightforwardly, allowing quantification of salinity sources. This study evaluated the feasibility of completing a salt mass balance to identify and quantify salt sources in a Central Valley sub-basin using readily-available information. The study also sought to identify major data gaps and recommend areas for further consideration. A mass balance approach was identified as a straightforward means of evaluating salt sources and quantifying the observed import-export imbalance in sub-basin groundwater salinity.

The root cause of this increasing salinity is widely recognized. DWR (2009) compares the dynamics of salt accumulation with sweeping dust in a room: "Unless sufficient dust is picked up and taken out of the room at some point, it will continue to accumulate and redisperse, ultimately making the room unfit for use." DWR (2001) calculated that imported surface water alone adds 2.45 million tons of salt to the San Joaquin Valley annually.

Further study was done by the California Regional Water Quality Control Board, Central Valley Region (CVRWQCB), which completed initial salt mass balances to assess the magnitude of the salinity problem confronting the Central Valley and to establish water quality objectives for the San Joaquin River at Vernalis (CVRWQCB, 2006, 2004). The Central Valley Salinity Coalition (CVSC), in conjunction with the Central Valley Salinity

Alternatives for Long Term Sustainability (CV-SALTS) initiative, conducted a recent pilot study of procedures designed to quantify Central Valley salt and nitrate sources.

4 TURLOCK SUB-BASIN

The Turlock Sub-basin is located on the eastern side of California's San Joaquin Valley (Figure 1). The sub-basin, which lies between the Tuolumne and Merced Rivers, is bounded on the west by the San Joaquin River and on the east by the Sierra Nevada foothills. Portions of Stanislaus and Merced Counties are included within the sub-basin boundaries.

4.1 Land Use

The Turlock Sub-basin encompasses 347,000 acres (540 square miles), including approximately 245,000 acres of irrigated land and 20,000 acres of urban development. The remaining land is described as foothills and riparian habitat.[1] An aerial photograph taken in 2009 shows irrigated land use throughout the sub-basin (Figure 2).

Both surface water and groundwater are used to meet the sub-basin's agricultural, residential, commercial, and industrial demands. Surface water is diverted from the Tuolumne River by the Turlock Irrigation District (TID) and from the Merced River by the Merced Irrigation District (MID). Groundwater supplies are managed by the Turlock Groundwater Basin Association (TGBA), which includes TID, MID, the Eastside Water District (EWD), and the Ballico-Cortez Water District (Figure 3).

4.2 Sub-basin Geology

The Turlock Sub-basin is comprised of six water-bearing geologic formations that rest upon marine sandstone and shale and upon the bedrock of the Sierra Nevada foothills. The Ione, Valley Springs, and Mehrten units, the deepest formations, consist predominantly of sedimentary rocks. Overlying these rock formations are the Turlock Lake, Riverbank, and Modesto formations. The United States Geological Survey (USGS) indicates these upper formations consist largely of overlapping unconsolidated alluvial fan deposits or other sediments that resulted from stream flow (USGS, 2009, 2007).

[1] Riparian habitats are natural ecosystems that occur along water courses or water bodies.

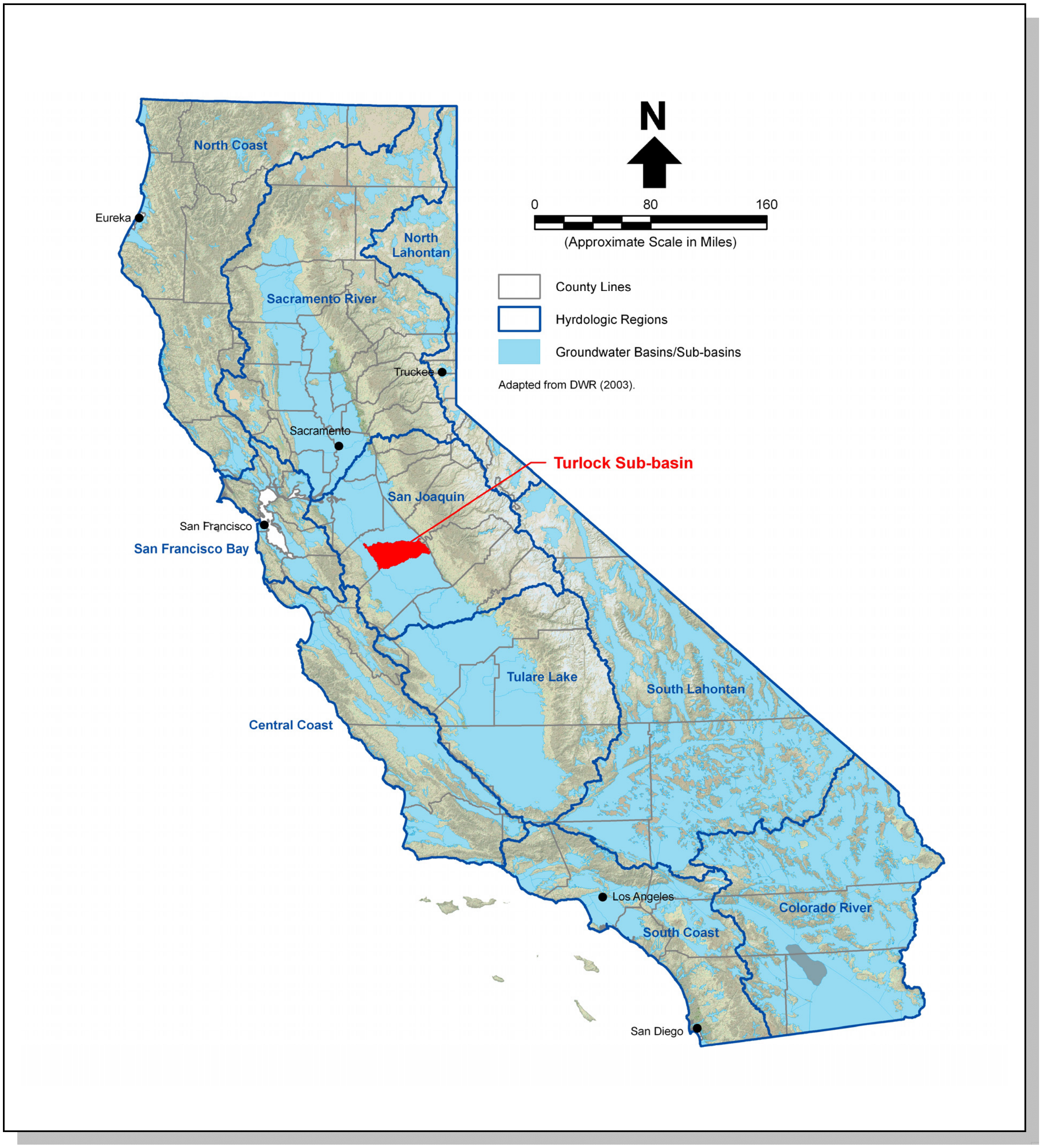


FIGURE 1 - TURLOCK SUB-BASIN

The California Department of Water Resources (DWR) divides the Central Valley into three major surface water basins, or hydrologic regions, consisting of the Sacramento River, San Joaquin River, and Tulare Lake Basins. Within these hydrologic basins, DWR has delineated 40 sub-basins. As noted in DWR (2003), these sub-basin boundaries are not precise and local study should be performed to determine if a specific area lies within the boundaries of a given sub-basin.

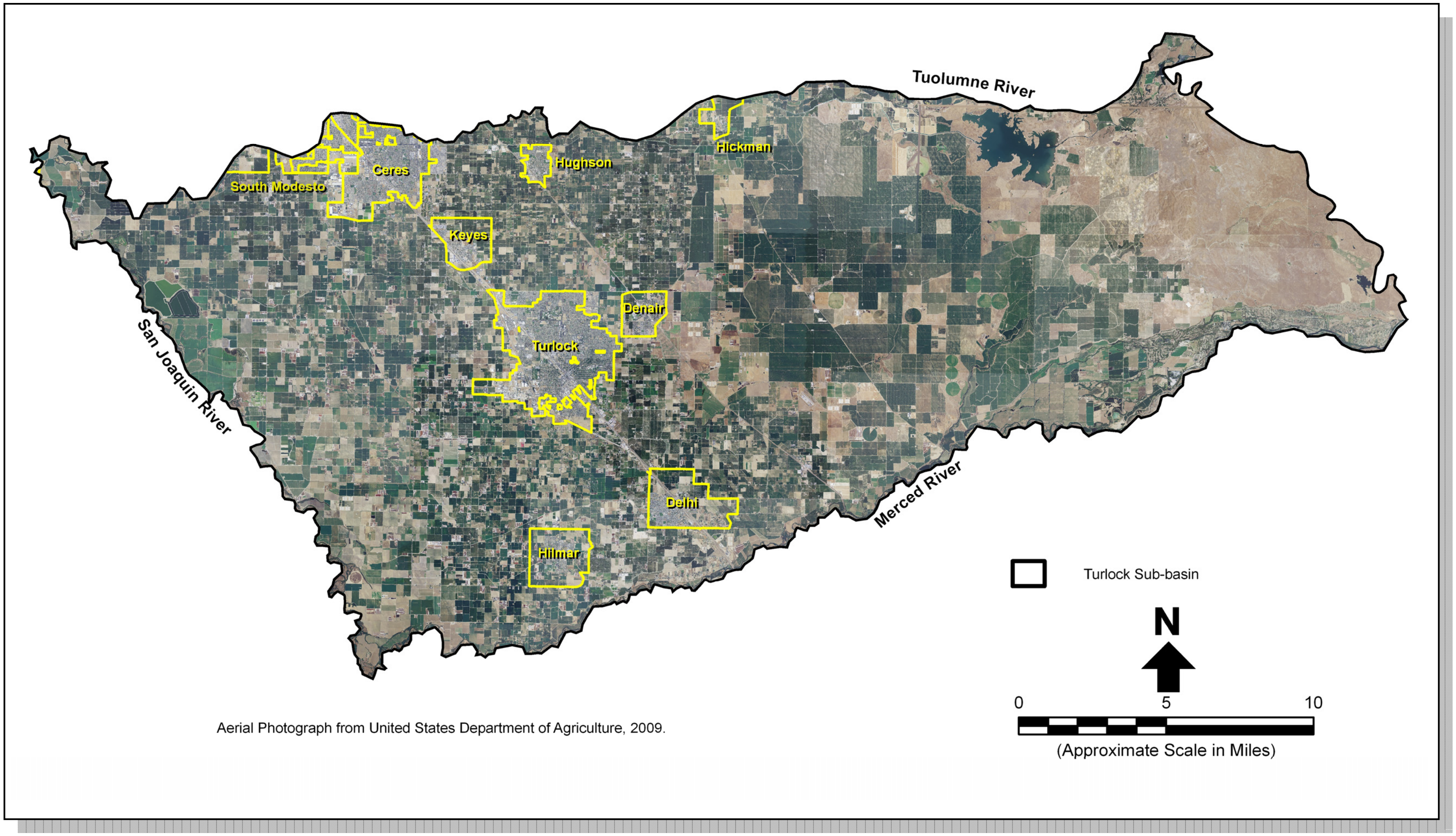


FIGURE 2 - TURLOCK SUB-BASIN 2009 AERIAL PHOTOGRAPH

United States Department of Agriculture photograph of the Turlock Sub-basin shows the predominant irrigated land use throughout the sub-basin.

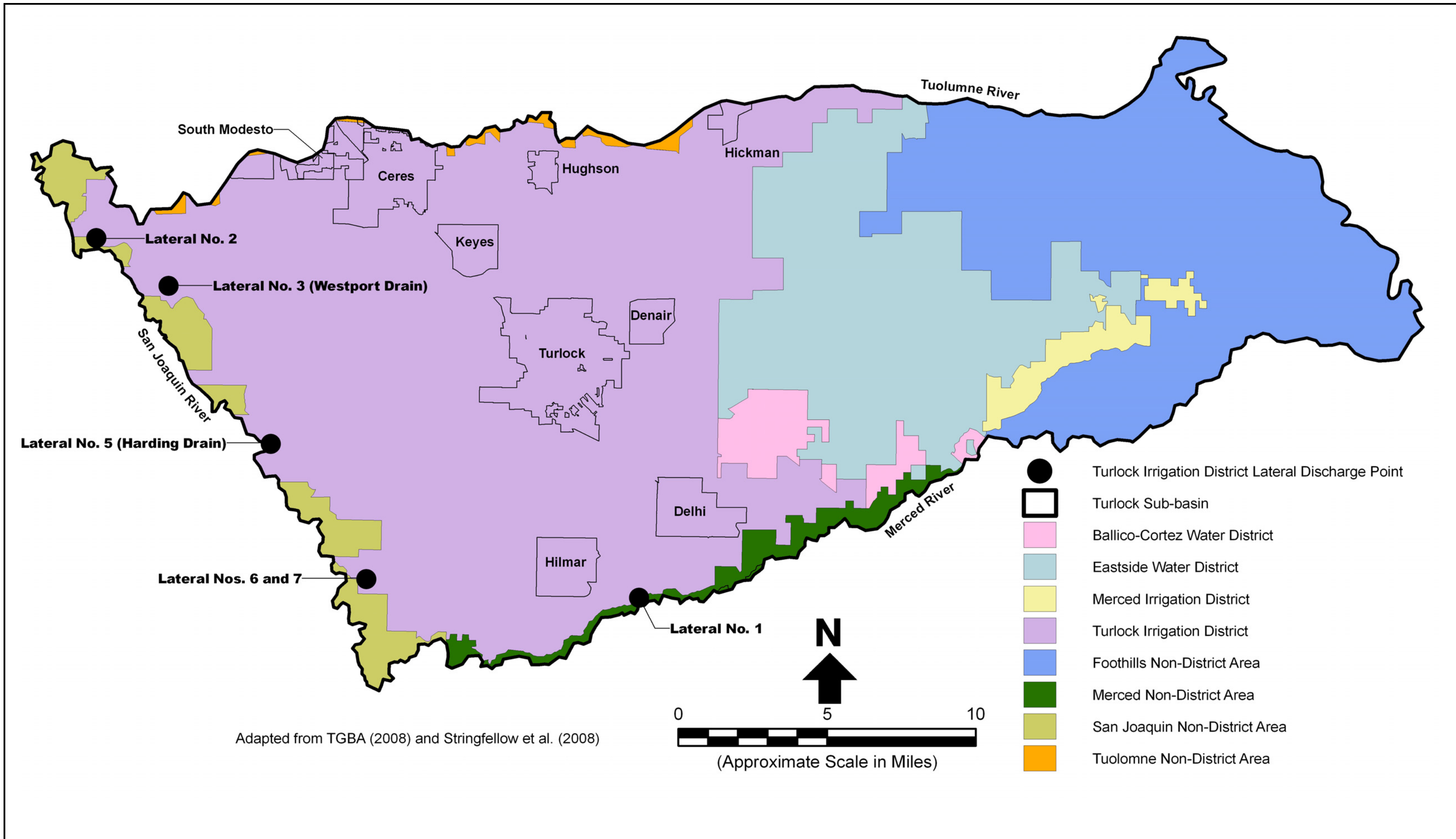


FIGURE 3 – TURLOCK SUB-BASIN IRRIGATION DISTRICTS

Irrigation districts manage surface water and groundwater to meet the demands of the sub-basin. Irrigation drainage, return flows, and storm water are conveyed through laterals that discharge to surface water. The discharge points of main laterals owned and operated by the Turlock Irrigation District are shown.

Also present is the Corcoran Clay layer that underlies the western half of the Turlock Sub-basin at depths ranging between 50 and 200 feet below ground surface (bgs). This dark greenish-gray clay, often referred to locally as “blue clay,” results from lake (lacustrine) deposits that formed over 1.5 million years ago (TGBA, 2008; DWR, 2006; USGS, 2004). Figure 4 depicts a geologic cross-section through the Turlock Sub-basin.

4.3 Groundwater Occurrence and Movement

Fresh groundwater exists on top of saline groundwater within the Turlock Sub-basin. This saline groundwater, containing greater than 2,000 mg/L TDS, is present in the Ione and Valley Springs formations (TGBA, 2008; USGS, 1973). Saline groundwater is found at depths of about 400 feet bgs in the western portion of the sub-basin and at over 800 feet bgs in the eastern portion (TGBA, 2008; USGS, 1998). Timothy J. Durbin, Inc. (Durbin, 2003) attributes this saline groundwater to upward flows, called “upwells,” that originate from marine sandstone and shale that were once covered by oceans. Groundwater in the marine sandstone and shale may contain as much as 50,000 mg/L TDS (Durbin, 2003).

Fresh groundwater is naturally recharged at the upper parts of the alluvial fan deposits near the foothills, where the Tuolumne and Merced Rivers enter the Turlock Sub-basin. Groundwater in the alluvial fan deposits flows west toward the San Joaquin River. The groundwater flow has been altered by pumping and irrigation and by artificial recharge from lagoons and percolation ponds. As shown on Figure 5, groundwater extraction has formed a cone of depression in the sub-basin groundwater table, creating a groundwater divide. Groundwater located east of the divide flows toward the cone of depression created by extraction from wells, while groundwater located west of the divide moves along its natural flow paths to the San Joaquin River (TGBA, 2008; USGS, 2007, 2004, 1991a, 1991b).

The Eastside Water District (EWD) was formed in 1985 to address declining groundwater elevations caused by pumping (EWD, 2002). Shifts in irrigation technologies and crop types, combined with surface water purchases from TID and MID during wet years, have reduced the volume of groundwater extracted within the EWD. TGBA (2008) and Durbin (2008) indicate that the groundwater cone of depression in this portion of the sub-basin has generally stabilized.

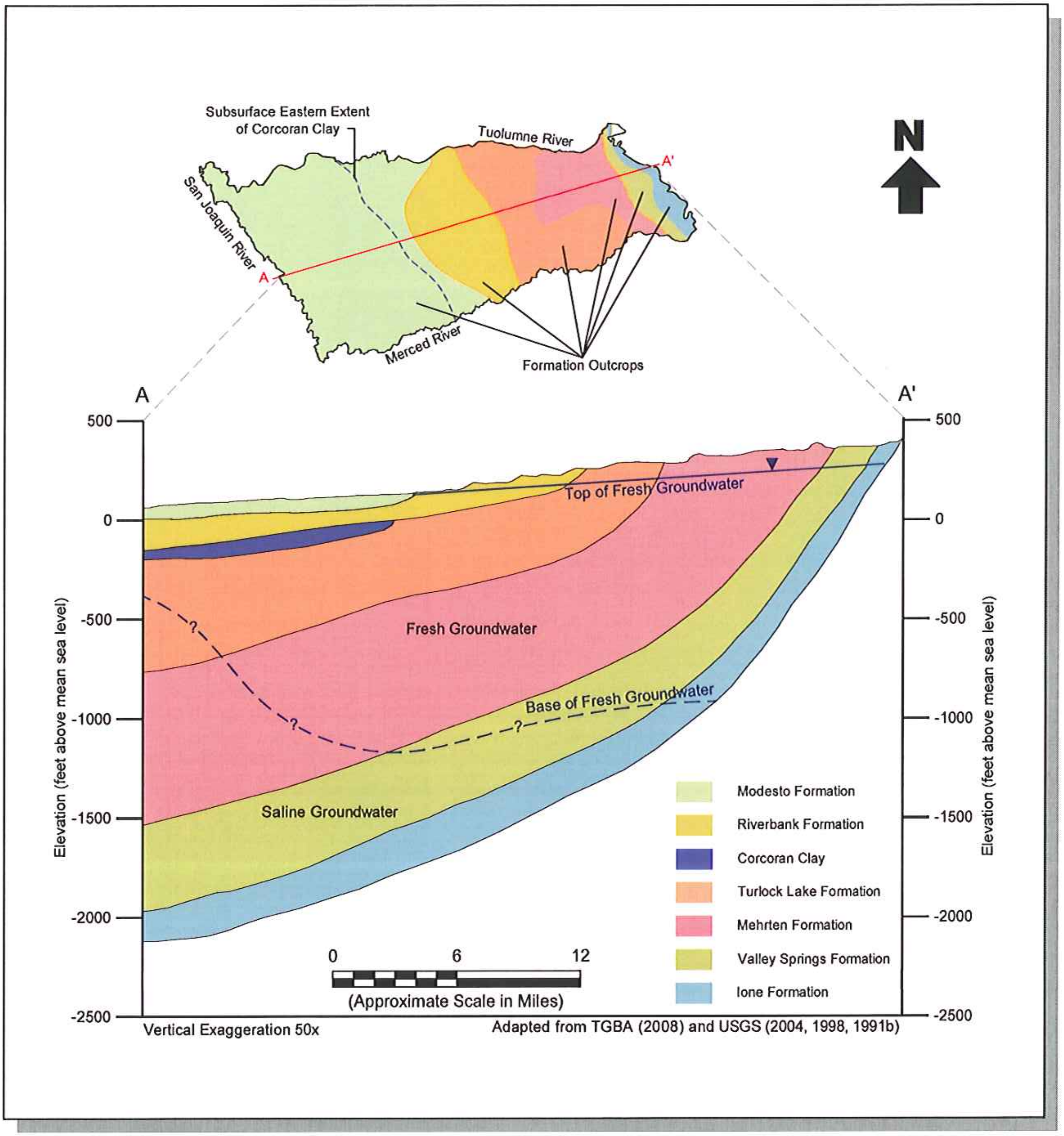


FIGURE 4 - GEOLOGIC CROSS-SECTION THROUGH TURLOCK SUB-BASIN

The Turlock Sub-basin consists of six water-bearing geologic formations that rest upon marine sandstone and shale, and the bedrock of the Sierra Nevada foothills. The Ione, Valley Springs, and Mehrten are the deepest formations and consist predominantly of sedimentary rocks. Overlying these rock formations are the Turlock Lake, Riverbank, and Modesto formations, which consist largely of overlapping unconsolidated alluvial fan deposits or other sediments. A notable exception to the alluvial fan deposits is the Corcoran Clay that underlies the western half of the sub-basin.

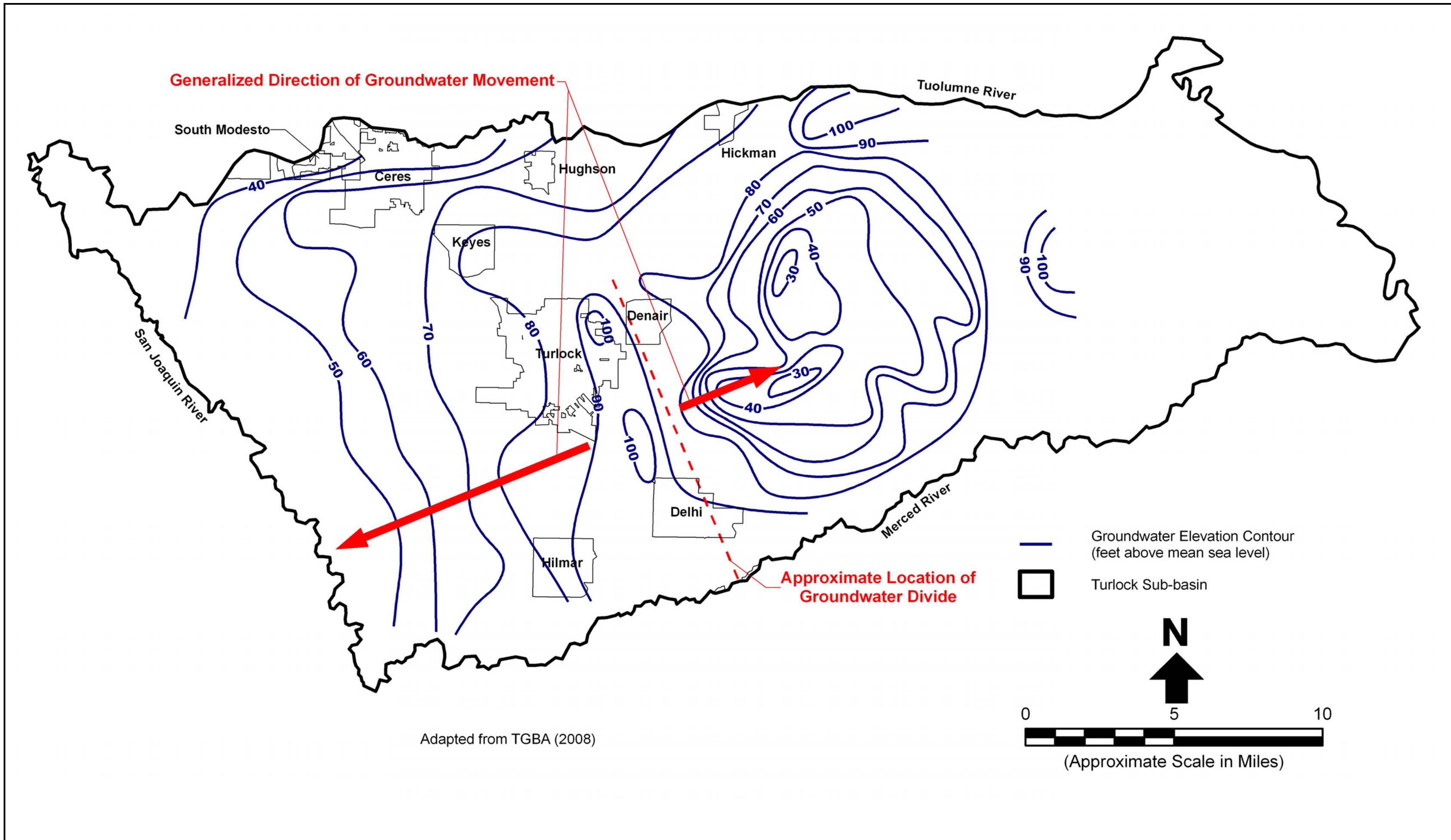


FIGURE 5 – TURLOCK SUB-BASIN GROUNDWATER ELEVATION CONTOURS MEASURED IN 2005

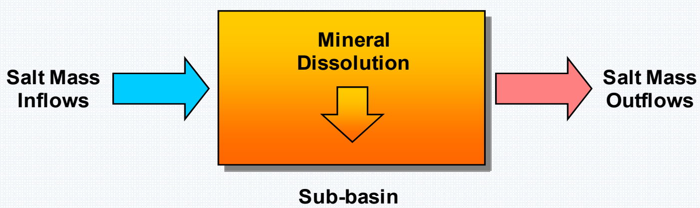
The natural groundwater flow has been altered by pumping, irrigation, and artificial recharge. Groundwater extraction from wells in the eastern portion of the sub-basin has produced a cone of depression, creating a groundwater divide. Groundwater east of the divide flows toward the extraction wells, while groundwater west of the divide moves along its natural flow paths to the San Joaquin River.

5 METHODOLOGY

As described in Box B, the mass of salt in a given water flow is the product of the flow volume and its TDS concentration. The preliminary salt mass balance for the Turlock Sub-basin focuses on the volume of fresh groundwater. This groundwater volume is defined laterally by the sub-basin boundaries and vertically from the groundwater table down to the lowest depth at which fresh groundwater is found. DWR (2006) and USGS (1989) estimate the total volume of fresh groundwater stored in the sub-basin at 23 million acre feet (acre-ft).[2]

Box B - Salt Mass Balance

Conservation of mass is a fundamental principle that recognizes mass can be transformed (changed from one form to another), but cannot be created or destroyed. The salt mass balance, which assumes the conservation of mass, is an accounting of the salt mass that flows into and out of the sub-basin system, and the changes in inventory of the material within the system, illustrated as follows:



Expressed as a mathematical formula, the mass balance becomes:

$$\text{Change in Salt Mass} = \sum \text{Salt Mass Inflows} - \sum \text{Salt Mass Outflows} + \text{Mineral Dissolution}$$

where:

$$\text{Salt Mass} = \text{Flow (Q)} \times \text{Concentration (C)}$$

Inflows include rainfall, irrigation, artificial recharge from lagoons and percolation ponds, seepage from canals, rivers, and lakes, and groundwater flow into the sub-basin. Outflows include groundwater extraction, discharge to rivers, and groundwater flow out of the sub-basin.

[2] The volume of groundwater stored in the Turlock Sub-basin is subject to interpretation. Durbin (2008), which studied groundwater availability in the Turlock Sub-basin by applying a groundwater flow model, concluded “For the eastern region of the Turlock basin, the sparse available data limit the ability to characterize the geologic formations, and that translates into highly uncertain model predictions.” Durbin encountered difficulty in evaluating specific-yield and specific-storage values that affect groundwater volume estimates.

As an initial step taken toward a regional salt mass balance,[3] water balances were developed for the sub-basin's unsaturated and saturated zones. Each water flow was then multiplied by the estimated representative TDS concentration of the flow to derive the flow's associated salt mass. Certain salt masses represent inflows to the sub-basin, and other masses are outflows from the sub-basin. The salt mass balances were completed by considering dissolved salts resulting from mineral dissolution.

5.1 Data Uncertainty

EKI's preliminary salt mass balance on the Turlock Sub-basin relied upon publicly-available water flow and TDS data that were accessible on-line. This approach was followed to evaluate whether a reasonable salt mass balance could be constructed using publicly-available information. This capability is important because it can be difficult or infeasible to obtain proprietary or other source-specific data.

EKI found that much of the uncertainty in the resulting salt mass balance was associated with the water balance for the saturated zone, as discussed in Box C.

Box C - Uncertainty in Saturated Zone Water Balance

Appendix A compiles supporting tables that compare the reported values of certain parameters needed to perform the sub-basin salt mass balance. These parameter values often differ among references.

Not all surface water and groundwater flows are directly assessed and groundwater level data are often lacking, which results in an incomplete understanding of groundwater movement in the Turlock Sub-basin. As a consequence, judgment must be exercised to resolve or "close" the water balance for the saturated zone.

This situation is not limited to the Turlock Sub-basin. USGS (2009) states: "Like many areas, the Central Valley needs better data, better access to existing data, and data-management tools to produce useful and integrated information." In recognition of these needs, Senate Bill 6 (SB 6) was passed into California law on 9 November 2009. SB 6 requires systematic monitoring of groundwater levels in the state's basins and sub-basins, with this data to be made readily available.

[3] The zone between ground surface and the water table is termed the unsaturated zone, also called the "vadose" zone. The unsaturated zone also may include localized perched groundwater. The saturated zone is the zone below the water table, in which the pores of Valley sediments are filled with water.

DWR (2003) explains that incomplete data hinders the preparation of detailed water balances (i.e., "groundwater budgets") for most basins in California:

> Groundwater budgets can be useful tools to understand a basin, but detailed budgets are not available for most groundwater basins in California. A detailed knowledge of each budget component is necessary to obtain a good approximation of the change in storage. Absence or inaccuracy of one or more parameters can lead to an analysis that varies widely from a positive to a negative change in storage or vice versa. Since much of the data needed requires subsurface exploration and monitoring over a series of years, the collection of detailed field data is time-consuming and expensive.

The Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo has completed several water balances for regions or water districts within the San Joaquin Valley. In each case, ITRC (1999) found that "the greatest unknown component for the water balance is subsurface flows."

These data limitations must be kept in mind when interpreting the preliminary salt mass balance for the Turlock Sub-basin. In spite of these limitations, insights into salt source contributions can be gained from reviewing the salt mass balance constructed from publicly-available information.

5.2 Water Balance

EKI's water balance relied on publicly-available data compiled between 1997 and 2006, representing a range of wet, normal, and dry conditions. The saturated zone component of the water balance made the simplifying assumption that all groundwater exiting the sub-basin discharges to the San Joaquin River.

Differing views have been expressed regarding the interaction of groundwater with the San Joaquin River. For instance, TGBA (2008) states that groundwaters from opposite sides of the San Joaquin Valley meet at the San Joaquin River. In contrast, USGS (2007, 1991a) indicates that, depending on the water-bearing zone, some groundwater may flow beneath the San Joaquin River channel and toward pumping wells located on either the east or west sides of the San Joaquin River, rather than discharge into the river and its associated sediments (Figure 6). These differing views arise because groundwater

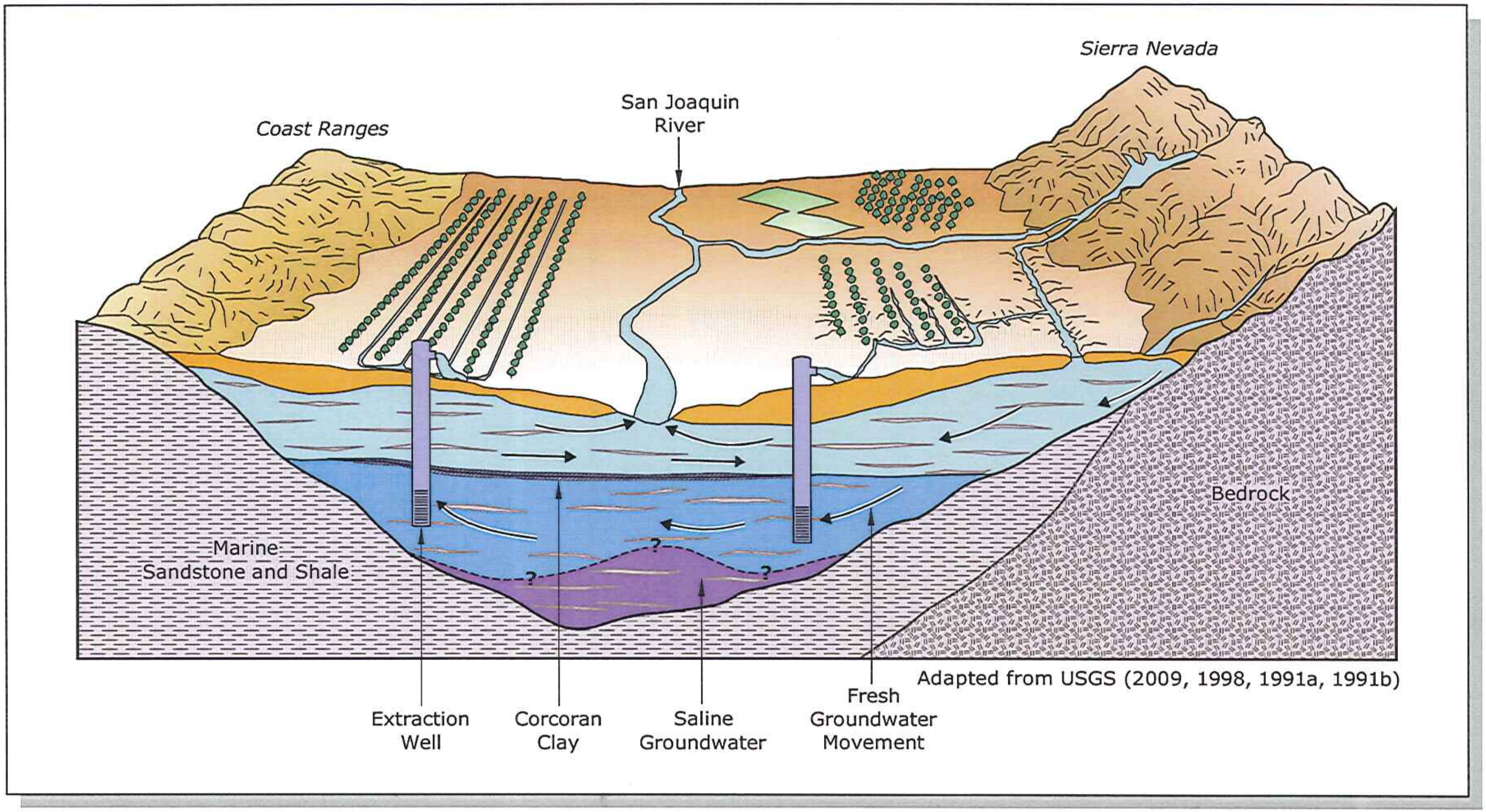


FIGURE 6 – SCHEMATIC OF GROUNDWATER FLOW IN VICINITY OF TURLOCK SUB-BASIN

Groundwater flow patterns near the San Joaquin River are incompletely understood. Depending upon the water-bearing formation, some groundwater may flow beneath the San Joaquin River toward pumping wells on either the east or west sides of the San Joaquin Valley rather than discharge to the river (USGS, 2007, 1991a).

elevation data are limited, leading to incomplete understanding of groundwater flow patterns near the river.

EKI's water balance for the Turlock Sub-basin was completed by assuming that the difference between the total volumes of groundwater flowing into and out of the sub-basin is equal to the change in the sub-basin's volume of fresh groundwater. As shown on Figure 7 and summarized in Table 1, the EKI water balance incorporates a decrease in groundwater storage of approximately 14,000 acre-ft per year.

This estimated decrease is close to the decrease in storage of 21,500 acre-ft per year between 1997 and 2006 that TGBA estimated by determining the change in groundwater elevations in the sub-basin, multiplied by the sub-basin's area and specific yield (TGBA, 2008). TGBA (2008) notes that this decrease is subject to uncertainty:

> Recent reductions in the California Department of Water Resources (DWR) monitoring network have introduced uncertainty in the measurement of groundwater levels. Uncertainty in the estimated groundwater elevation translates into uncertainty in storage estimates. Therefore, the magnitude and direction of changes in groundwater storage cannot be fully characterized through an analysis based solely on the groundwater contours.

The decreases in fresh groundwater storage estimated by EKI and TGBA are well under the reported ranges of individual flow components. For example, reported irrigation recharge values (see Table A-4) range from 343,000 to 407,200 acre-ft/yr, and roughly 1,400,000 acre-ft of water flows into and out of the sub-basin annually. Thus, EKI's estimated net storage decrease is well under the variability in the water balance's flow components, such that it is unclear if overdraft of the sub-basin is occurring. Durbin (2008) states: "the groundwater system has been in a near-equilibrium state with the water use since about 1990."

5.3 Salt Mass Balance

Table 2 summarizes the overall preliminary salt mass balance for the Turlock Sub-basin. The mass balance is shown graphically on Figure 8. Salt sources in the Central Valley identified by DWR (2009), CVRWQCB (2006), and others include CAFOs, irrigated agriculture, municipalities, food processors, septic tank systems, mineral dissolution,

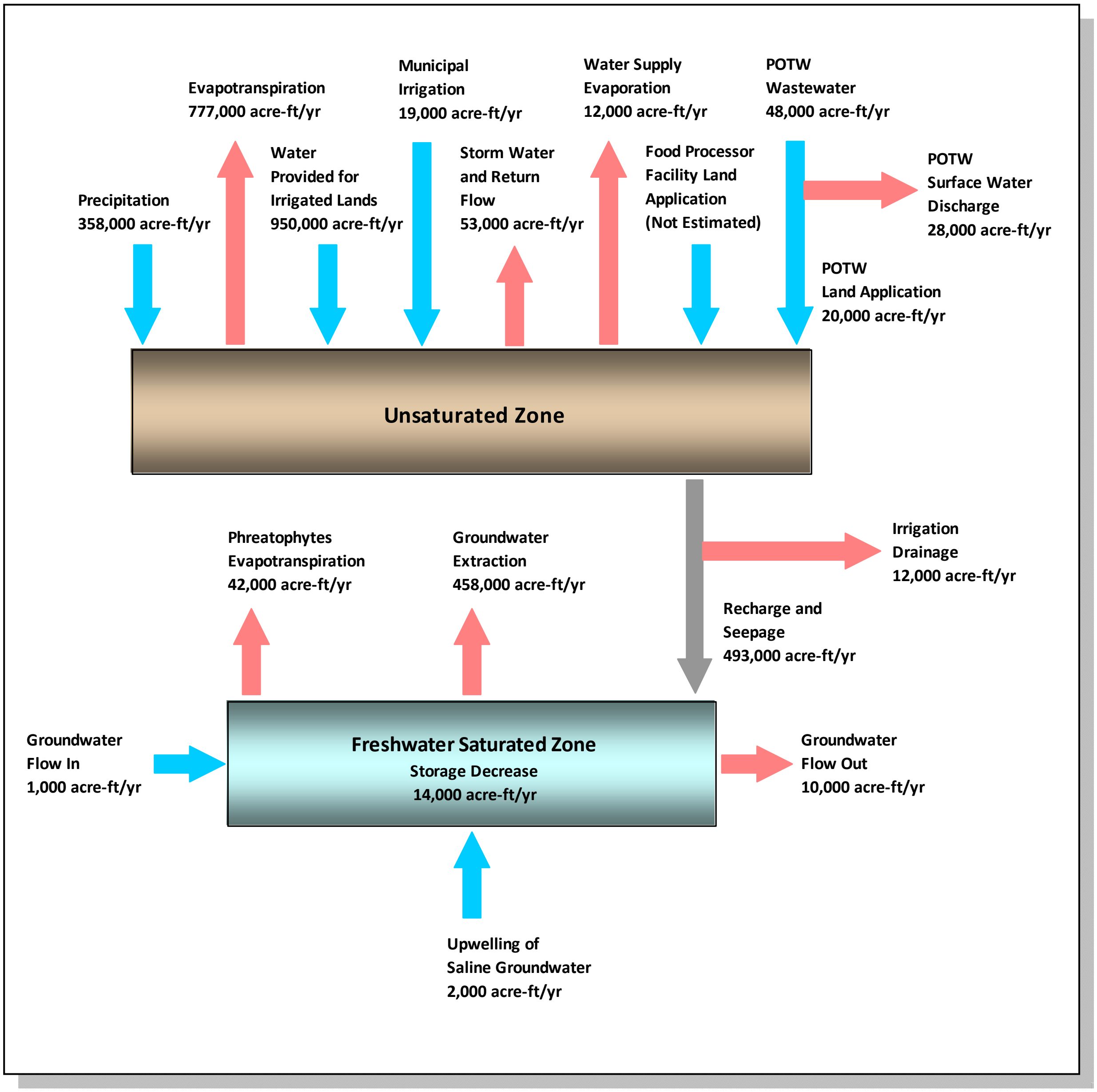


FIGURE 7 - TURLOCK SUB-BASIN WATER BALANCE IN ACRE-FEET PER YEAR

Several references were consulted to complete the water balance for the Turlock Sub-basin. Most flows are based upon data compiled between 1997 and 2006, representing a range of wet, normal, and dry conditions experienced in the sub-basin instead of conditions associated with a particular year. The water balance shows a decrease in groundwater storage of approximately 14,000 acre-feet per year. This deficit is within the margin of error of the flow estimates used to complete the water balance and it is unclear if overdraft of the sub-basin is occurring.

TABLE 1
SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE WATER BALANCES
Turlock Sub-basin, California

Flow Description	Subtotal Inflow (acre-ft/yr)	Total Inflow (acre-ft/yr)	Subtotal Outflow (acre-ft/yr)	Total Outflow (acre-ft/yr)	Reference
Unsaturated Zone					
● Water Provided for Irrigated Lands					
Extracted Groundwater	410,000				TGBA, 2008; See Note (q)
Surface Water Diversions	540,000				TGBA, 2008; See Table A-3
		950,000			
● Municipal Irrigation		19,000			Calculated; See Note (b)
● POTW Wastewater (c)		48,000			See Table 5 for breakdown
● Food Processor Facility Land Application		-			Rubin et al., 2007; See Note (d)
● Precipitation		358,000			Calculated; See Note (e)
● Evapotranspiration					
Muncipalities			22,000		Calculated; See Notes (f) and (g)
POTW Land Application			14,000		Calculated; See Table 5
Irrigated Lands			680,000		DWR (2000); See Table A-2
Native Vegetation			61,000		Calculated; See Notes (h) and (i)
				777,000	
● Water Supply Evaporation					
Turlock Lake (j)			10,000		DWR (2002)
Irrigation Canals			2,000		Calculated; See Note (k)
				12,000	
● POTW Surface Water Discharge				28,000	TGBA, 2008
● Storm Water and Return Flow					
Storm Water Runoff			7,000		Calculated; See Note (l)
Return Flow			46,000		Calculated; See Note (m)
				53,000	
● Irrigation Drainage				12,000	TGBA, 2008
● Recharge and Seepage					
Irrigation Recharge					
Irrigated Lands			353,000		Calculated
Muncipalities			6,000		Calculated; See Note (n)
POTW Land Application Recharge			6,000		Calculated; See Note (g)
Water Supply Seepage					
Turlock Lake			62,000		TGBA, 2008
Irrigation Canals			38,000		TGBA, 2008
Precipitation Recharge					
Municipalities			5,000		Calculated; See Note (o)
Native Vegetation			23,000		Calculated
				493,000	
Unsaturated Zone Totals: (a)		**1,375,000**		**1,375,000**	

TABLE 1 (continued)
SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE WATER BALANCES
Turlock Sub-basin, California

Flow Description	Subtotal Inflow (acre-ft/yr)	Total Inflow (acre-ft/yr)	Subtotal Outflow (acre-ft/yr)	Total Outflow (acre-ft/yr)	Reference
Saturated Zone					
● Recharge and Seepage		493,000			
● Groundwater Flow Into Sub-basin		1,000			TGBA, 2008
● Upwelling of Saline Groundwater		2,000			TGBA, 2008
● Groundwater Extraction					
Total Water District Pumping			83,000		TGBA, 2008; See Table A-3
Total Private Pumping			327,000		TGBA, 2008; See Table A-3
Total Municipal Pumping			48,000		TGBA, 2008; See Table A-3
				458,000	
● Phreatophytes Evapotranspiration (i)				42,000	TGBA, 2008
● Groundwater Flow Out of Sub-basin				10,000	CVRWQCB, 2004; See Table A-5
● Storage Decrease		14,000 (p)			Calculated
Saturated Zone Totals: (a)		**510,000**		**510,000**	

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Notes:

(a) Totals may not sum exactly due to rounding.

(b) Water used for urban landscape irrigation is estimated as the difference between the volume of groundwater extracted for municipal water supply and the volume of municipal wastewater conveyed to publicly owned treatment works (POTWs). See Table A-6 for breakdown of POTW wastewater flows.

(c) Wastewater treated at POTWs for discharge to surface water and land application. Flow includes wastewater conveyed to POTWs from food processors and communities (e.g., Modesto, Empire, and unincorporated areas) that is generated outside the sub-basin.

TABLE 1 (continued)
SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE WATER BALANCES

Turlock Sub-basin, California

Notes:

(d) Information on volumes of wastewater applied to land at food processor facilities within the Turlock Sub-basin was not reviewed as part of this study.

(e) Precipitation amounts based upon TGBA (2008) land use areas summarized in Table A-1 and an average annual rainfall of 12.39 inches calculated by TGBA (2008) from precipitation data for the Turlock area for 1952 to 2006.

(f) Evapotranspiration related to municipalities (e.g., parks, athletic fields, residential and commercial landscaping) is assumed to account for 40 percent of incident precipitation on urban development plus 70 percent of municipal water supply applied for landscape irrigation.

(g) The volume of applied water utilized by vegetation is assumed to be 70 percent based upon the application efficiencies of irrigation systems summarized by Center for Irrigation Technology (1988). The remaining 30 percent of the water volume is assumed to be lost to deep percolation or recharge to the saturated zone.

(h) Evapotranspiration of native vegetation was estimated using the USGS linear regression for San Joaquin Valley relating excess precipitation (PPT_{ex}) to annual precipitation (PPT): $PPT_{ex} = 0.64 \times PPT - 6.2$ (USGS, 1989). The volume of excess precipitation is estimated to be 10,000 acre-ft/yr based upon an average annual rainfall amount of 12.39 inches and 69,000 acres of foothills (Table A-1). Excess precipitation is assumed to recharge the saturated zone. The volume of precipitation that does not recharge the saturated zone is assumed to be lost due to evapotranspiration of native vegetation.

(i) Phreatophytes, plants that live along a river system with their roots below or near the groundwater table, extract water directly from the saturated zone. Approximately 13,000 acres of native phreatophytes are assumed to grow in riparian habitat along the Tuolumne, Merced and San Joaquin Rivers. Consequently, no evapotranspiration of incident rainfall on riparian habitat is assumed to occur. Phreatophyte evapotranspiration from the saturated zone is presumed to occur.

(j) Water diverted from the Tuolumne River is conveyed to Turlock Lake before the water is distributed to irrigated lands (TGBA, 2008). Therefore, Turlock Lake serves as a reservoir for imported surface water supply and evaporation and seepage losses from the lake must be accounted for in the water balance.

(k) Turlock Irrigation District (TID) owns and operates approximately 230 miles of irrigation canals and laterals, 90 percent of which are reported to be concrete-lined (TGBA, 2008). Merced Irrigation District owns and operates approximately 26 miles of open earthen channels within the Turlock Sub-basin (TGBA, 2008). Evaporation from canals was estimated assuming 250 miles of canals with an average width of 10 feet and evaporation of 60 inches of water per year based upon studies of evaporative demands in the Central Valley by DWR (2004b, 1975).

(l) Storm water runoff from urban development is assumed to consist of 35 percent of incident rainfall on cities in the Turlock Sub-basin.

(m) Volume of return flow conveyed to TID laterals is the volume of flows through these laterals reported by Stringfellow et al. after subtracting the volumes of irrigation drainage (TGBA, 2008) and treated wastewater discharged by the City of Turlock (2005) to TID laterals. Return flows are described in Table A-8.

(n) Recharge is assumed to consist of 30 percent of water used for irrigation.

(o) Municipalities within the Turlock Sub-basin manage storm water by discharging a portion of collected runoff to the Tuolumne, Merced, or San Joaquin Rivers, and allowing the remaining volume to percolate to the saturated zone through storm water detention basins (City of Ceres, 2003; City of Turlock, 2003). The volume of incident precipitation on urban developments (Table A-3) that recharges the saturated zone is assumed to be 25 percent based upon the percentage of rainfall that is conveyed to detention basins by the City of Ceres.

(p) The water balance for the Turlock Sub-basin was completed ("or closed") by assuming that the difference between the total estimated volumes of groundwater flowing in and out of the sub-basin is equal to the net change in the volume of groundwater stored in the sub-basin. Using this appoach, the water balance shows a decrease in groundwater storage of approximately 14,000 acre-feet per year. This deficit is within the margin of error of the flow estimates used to complete the water balance and it is unclear if overdraft of the sub-basin is occurring.

(q) Value cited is the total reported groundwater extraction of 458,000 acre-ft/yr minus the total municipal pumping of 48,000 acre-ft/yr. EKI assumed the resulting value of 410,000 acre-ft/yr includes groundwater extracted at dairies for drinking by dairy cattle, cleaning of dairy cows and equipment before milking, sprinkling cows for evaporative cooling, and flushing manure to storage lagoons.

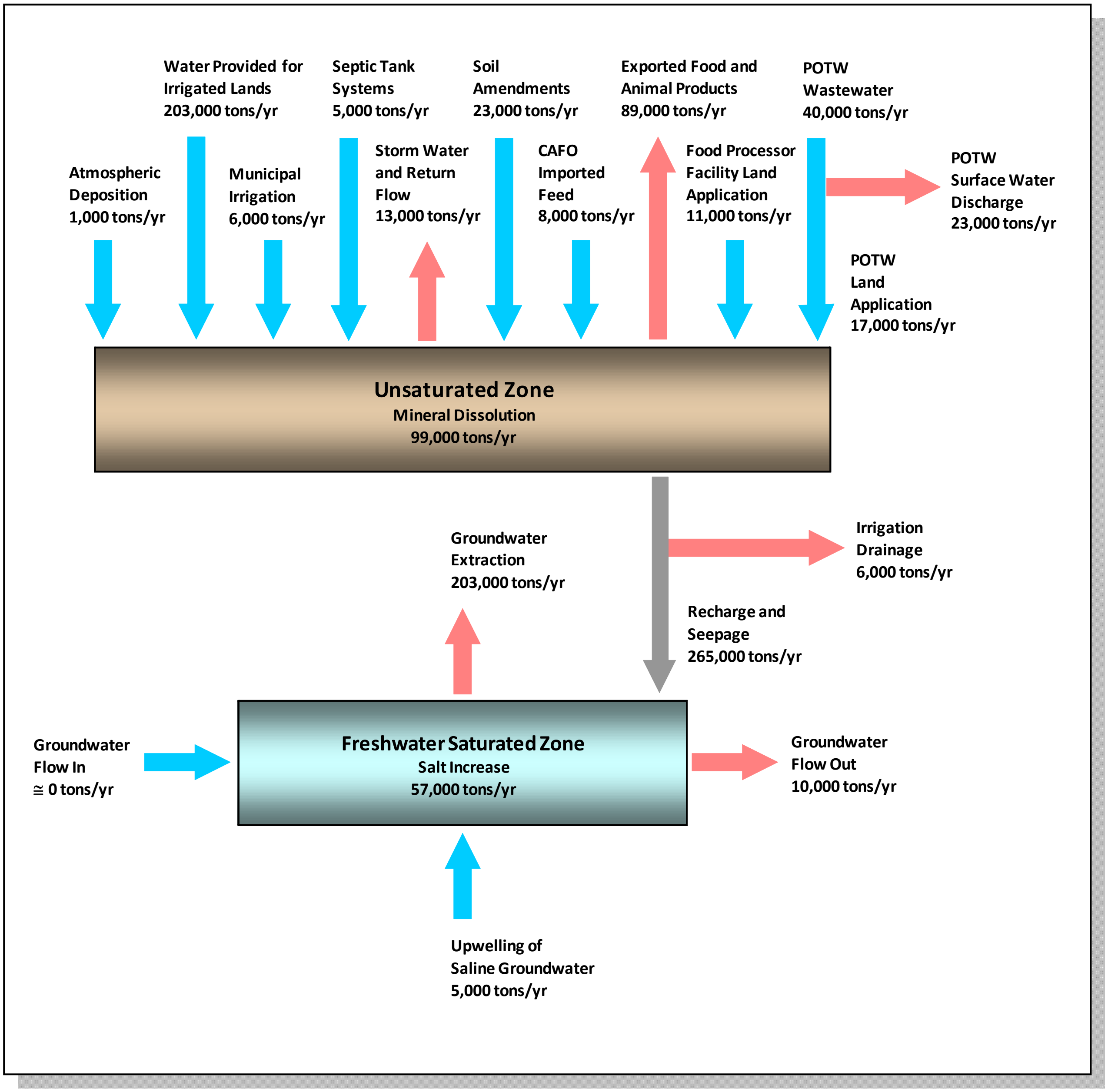

FIGURE 8 - TURLOCK SUB-BASIN SALT MASS BALANCE IN TONS PER YEAR

The salt mass balance indicates that salt inflows and outflows are not equal. As a result, salt is estimated to be accumulating in the saturated zone at a rate of 57,000 tons/yr. Sources contributing to this salt imbalance include concentrated animal feeding operations (CAFOs), irrigated agriculture, municipalities, food processors, and mineral dissolution by water recharge. This rate of salt increase is an estimate that is subject to the uncertainties of the data upon which the mass balance is based.

TABLE 2

SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE SALT MASS BALANCES

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Unsaturated Zone								
● Water Provided for Irrigated Lands								
Extracted Groundwater	410,000	335 (b)	187,000					
Surface Water Diversions	540,000	22 (c)	16,000					
				203,000				
● Municipal Irrigation	19,000	250 (d)		6,000				
● POTW Wastewater	48,000	614 (e)		40,000				
● Septic Tank Systems	-	-		5,000				
● Food Processor Facility Land Application	-	-		11,000				
● CAFO Imported Feed	-	-		8,000				
● Soil Amendments								
Agriculture Food Crops	-	-	7,000					
CAFO Forage Crops	-	-	16,000					
				23,000				
● Imported Fertilizers	-	-		≅ 0 (f)				
● Exported Food and Animal Products								
Agriculture Food Crops					-	-	70,000	
CAFO Animal Products					-	-	19,000	
								89,000
● Atmospheric Deposition								
Wet Deposition	358,000	1	500					
Dry Deposition	-	-	500					
				1,000				

TABLE 2 (continued)
SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE SALT MASS BALANCES

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Unsaturated Zone								
● Evapotranspiration					777,000	≅ 0		≅ 0
● Water Supply Evaporation					12,000	≅ 0		≅ 0
● POTW Surface Water Discharge								
Municipal Wastewater					22,000	530 (e)	16,000	
Food Processor Wastewater					6,000	860 (e)	7,000	
								23,000
● Storm Water and Return Flow								
Municipal Storm Water Runoff					7,000	≅ 0	≅ 0	
CAFO Return Flow					21,000	220 (e)	6,000	
Agriculture Return Flow					25,000	220 (e)	7,000	
								13,000
● Irrigation Drainage								
CAFO Irrigation Drainage					5,000	460 (e)	3,000	
Agriculture Irrigation Drainage					7,000	280 (e)	3,000	
								6,000

TABLE 2 (continued)

SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE SALT MASS BALANCES

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
● Recharge and Seepage to Groundwater								
CAFO Lagoon Seepage					2,000	1,500 (e)	4,000	
CAFO Irrigation					157,000	500 (e)	107,000	
Agriculture Irrigation					194,000	310 (e)	82,000	
Muncipal Irrigation					6,000	450 (e)	8,000	
Septic Tank Systems					-	-	5,000	
POTW Land Application of Municipal Wastewater					4,500	2,100 (e)	13,000	
POTW Land Application of Food Processor Wastewater					1,500	2,500 (e)	5,000	
Food Processor Facility Land Application					(g)	-	11,000	
Water Supply Seepage					100,000	170 (e)	23,000	
Precipitation Recharge					28,000	150 (e)	6,000	
Atmospheric Deposition (h)					-	-	1,000	
								265,000
● Mineral Dissolution Due to Recharge and Seepage								
Municipal Irrigation	-	-	1,000					
POTW Land Application	-	-	1,200					
Agriculture Irrigation	-	-	39,000					
CAFO Lagoon Seepage	-	-	200					
CAFO Irrigation	-	-	32,000					
Water Supply Seepage	-	-	20,000					
Precipitation Recharge	-	-	6,000					
				99,000				
Unsaturated Zone Totals: (a)	**1,375,000**			**396,000**	**1,375,000**			**396,000**

TABLE 2 (continued)

SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE SALT MASS BALANCES

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Saturated Zone								
● Groundwater Flow Into Sub-basin	1,000	≅ 0		≅ 0				
● Upwelling of Saline Groundwater	2,000	2,000 (i)		5,000				
● Recharge and Seepage to Groundwater	493,000	-		265,000				
● Groundwater Extraction								
Groundwater for Irrigated Lands					410,000	335	187,000	
Groundwater for Municipalities and Food Processors					48,000	250	16,000	
								203,000
● Phreatophytes Evapotranspiration					42,000	≅ 0		≅ 0
● Groundwater Flow Out of Sub-basin					10,000	698 (j)		10,000
● Storage Decrease	14,000 (k)	-		-				
● Salt Increase					-	-		57,000 (l)
Saturated Zone Totals: (a)	**510,000**			**270,000**	**510,000**			**270,000**

TABLE 2 (continued)

SUMMARY OF UNSATURATED ZONE AND SATURATED ZONE SALT MASS BALANCES

Turlock Sub-basin, California

References:

California Regional Water Quality Control Board, Central Valley Region (CVRWQCB). March 2010. *Draft San Joaquin River Basin Rotational Sub-basin Monitoring: Eastside Basin: January 2003 – April 2004 (Stanislaus, Tuolumne, and Merced River Watersheds and Farmington and Valley Floor Drainage Areas.*

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Notes:

(a) Totals may not sum exactly due to rounding.

(b) Average value of total dissolved solids (TDS) concentrations in 71 production wells monitored by the California Department of Health Services (DWR, 2006).

(c) CVRWQCB (2010) reports that the median electrical conductivity (EC) value for the Tuolumne River at La Grange is 37 μS/cm. A value of 22 mg/L TDS was assumed for surface water diversions, using a ratio of 0.6 to convert EC measurements to TDS concentrations.

(d) TDS concentration is the geometric mean of TDS values reported for municipal supply wells in the Turlock Sub-basin in 2006 (USGS, 2008b).

(e) Value calculated by dividing total salt load by flow.

(f) Fertilizers are considered to be insignificant net salt sources. Nitrogenous, phosphate, and potassium fertilizers were assumed to be largely taken up by plants.

(g) Information on volumes of wastewater applied to land at food processor facilities within the Turlock Sub-basin was not reviewed as part of this study.

(h) Salt due to atmospheric deposition is assumed to recharge groundwater.

(i) Groundwater with TDS concentrations greater than 2,000 mg/L is defined to be saline (TGBA, 2008; USGS, 1973).

(j) TDS concentration in shallow groundwater reported by CVRWQCB to discharge into the San Joaquin River from the east side of the river (CVRWQCB, 2010).

(k) The water balance for the Turlock Sub-basin was completed ("or closed") by assuming that the difference between the total estimated volumes of groundwater flowing in and out of the sub-basin is equal to the net change in the volume of groundwater stored in the sub-basin. Using this appoach, the water balance shows a decrease in groundwater storage of approximately 14,000 acre-feet per year. This deficit is within the margin of error of the flow estimates used to complete the water balance and it is unclear if overdraft of the sub-basin is occurring.

(l) The salt mass balance indicates that salt inflows and outflows are not equal. As a result, salt is estimated to be accumulating in the saturated zone at a rate of 57,000 tons/yr. This rate of salt increase is an estimate that is subject to the uncertainties of the data upon which the mass balance is based.

atmospheric deposition, and upwelling of saline groundwater. EKI evaluated each of these sources to arrive at our preliminary salt mass balance for the Turlock Sub-basin.

The balance indicates that salt inflows and outflows are not equal, such that salt is accumulating in the saturated zone at a rate of about 57,000 tons per year (tons/yr). Sources of these salt loadings to the sub-basin are discussed below.

CAFOs

CAFOs bring feed to large numbers of animals in a defined area instead of in pastures or on rangeland. CAFOs include poultry, swine, veal, beef cattle, and milk cow farms.

Dairies comprise the majority of CAFOs in the Turlock Sub-basin. U.S. EPA (2009) mapped the distributions of dairy herds in the Turlock Sub-basin in 2009, as shown on Figure 9. Analysis of the contours on Figure 9 indicates about 194,000 equivalent animal units are present within the sub-basin. The salt loading from CAFOs presented herein is based upon 194,000 animal units.

Dairy production areas consist of milk barns, corrals (exercise yards and holding pens), and free stalls (resting and feeding facilities). Water is used in the milk barns, corrals, and other production areas for livestock watering, cleaning of dairy cows and equipment before milking, sprinkling cows for evaporative cooling, and flushing manure to storage lagoons. Water used for flushing, cleaning, and cooling is assumed to be extracted groundwater. Intermittent rainfall runoff from the corrals is captured and stored in the lagoons, but the mass of salt associated with rainfall runoff flows to the storage lagoons is considered negligible (ANR, 2005). Diluted liquid manure from the lagoons is eventually applied to forage crops that are grown on local fields (Meyer, Garnett, and Guthrie, 1997).

Based on water budgets for Florida dairy farms, the total water volume for cleaning, cooling, and flushing is approximately 150 gallons per day per cow (Bray et al., 2008). For this study, TDS in groundwater from dairy production wells was assumed to be 335 mg/L based upon average TDS concentrations in 71 production wells in the Turlock Sub-basin monitored by the California Department of Health Services (DWR, 2006). Production wells at dairies are typically drilled to a depth of approximately 130 to 200 feet (Harter et al., 2002). Production well water quality was found to be significantly better than that observed in shallow monitoring well networks at the dairies and comparable to levels in production wells of other California dairy regions (Harter et al., 2002).

EKI's CAFO salt mass balance assumes a salt intake in feed of 2.3 pounds per day for each animal unit and an assumed salinity excretion rate of 1.9 pounds per day based upon data reported by the University of California, Division of Agriculture and Natural Resources (ANR) in its study of the California dairy industry (ANR, 2005). Anecdotal information indicates that 3 to 10 percent of animal feed is imported into the San Joaquin Valley (ANR, 2005), with the remaining quantity of animal feed grown locally. EKI's salt mass balance assumes that 10 percent of feed is imported.

CAFO salt loadings are estimated to be approximately 9,000 tons/yr to surface water and 111,000 tons/yr to groundwater, as shown on Figure 10 and summarized in Table 3. These salt loadings are based upon dairies, which comprise the majority of CAFOs in the Turlock Sub-basin. A more complete understanding of CAFO salt loadings could be obtained if other types of CAFOs also were incorporated into the mass balance. Salt loading rates for individual CAFO facilities and individual forage crop fields may vary significantly depending on the feed rations, manure and nutrient management, and irrigation practices used by the CAFO. Soil properties also will vary, which suggests naturally-occurring salinity levels in forage crop fields should be considered (ANR, 2005).

EKI estimated TDS in groundwater beneath CAFO irrigated fields to be approximately 500 mg/L, derived by dividing the total salt load in irrigation recharge by the recharge volume (see Table 3). This estimated TDS concentration was compared with reported TDS concentrations to assess the reasonableness of the corresponding CAFO salt loading to groundwater.

Brown, Vence & Associates (2003) studied Central Valley CAFOs, reviewing groundwater monitoring data for 10 dairies located in Madera, Fresno, Kings, and Tulare Counties. TDS data were available for groundwater beneath forage crop fields at 6 of the 10 dairies. TDS in groundwater beneath the irrigated fields ranged from 620 to 690 mg/L at four of the dairies, and were measured at 1,650 and 18,000 mg/L at the remaining two dairies studied. Harter et al. (2002) reported an average EC of 1,600 μs/cm, corresponding to about 960 mg/L TDS, in groundwater beneath fields at five San Joaquin Valley dairies. EKI's estimated TDS concentration in underlying groundwater of 500 mg/L is less than the TDS concentrations measured in groundwater beneath forage crop fields reported by Brown, Vence & Associates and Harter et al.

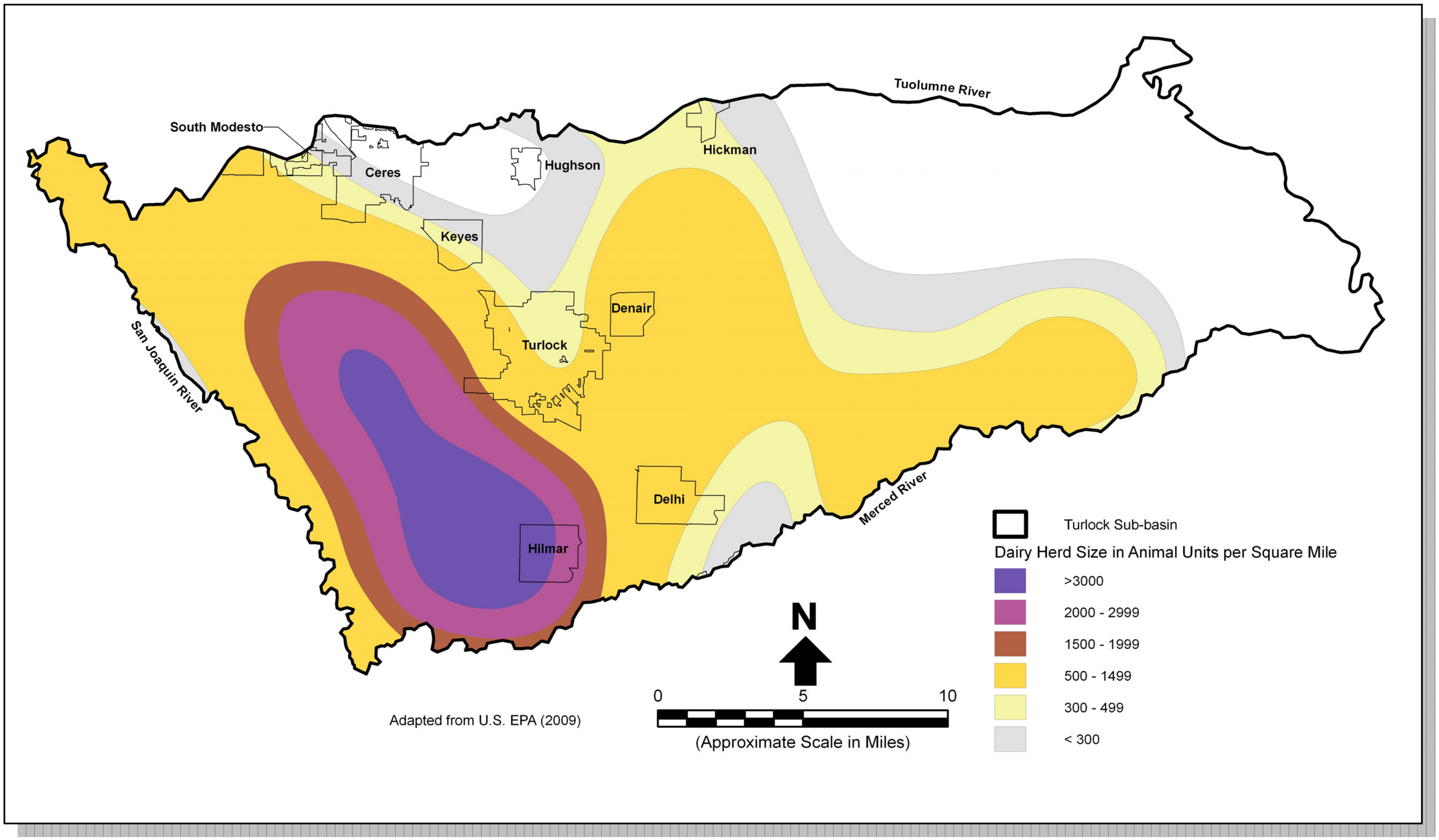

FIGURE 9 – DISTRIBUTIONS OF DAIRY HERDS WITHIN TURLOCK SUB-BASIN IN 2009

Dairies represent the majority of concentrated animal feeding operations (CAFOs) in the Turlock Sub-basin. Analysis of the contours indicates 194,000 animal units are present within the sub-basin.

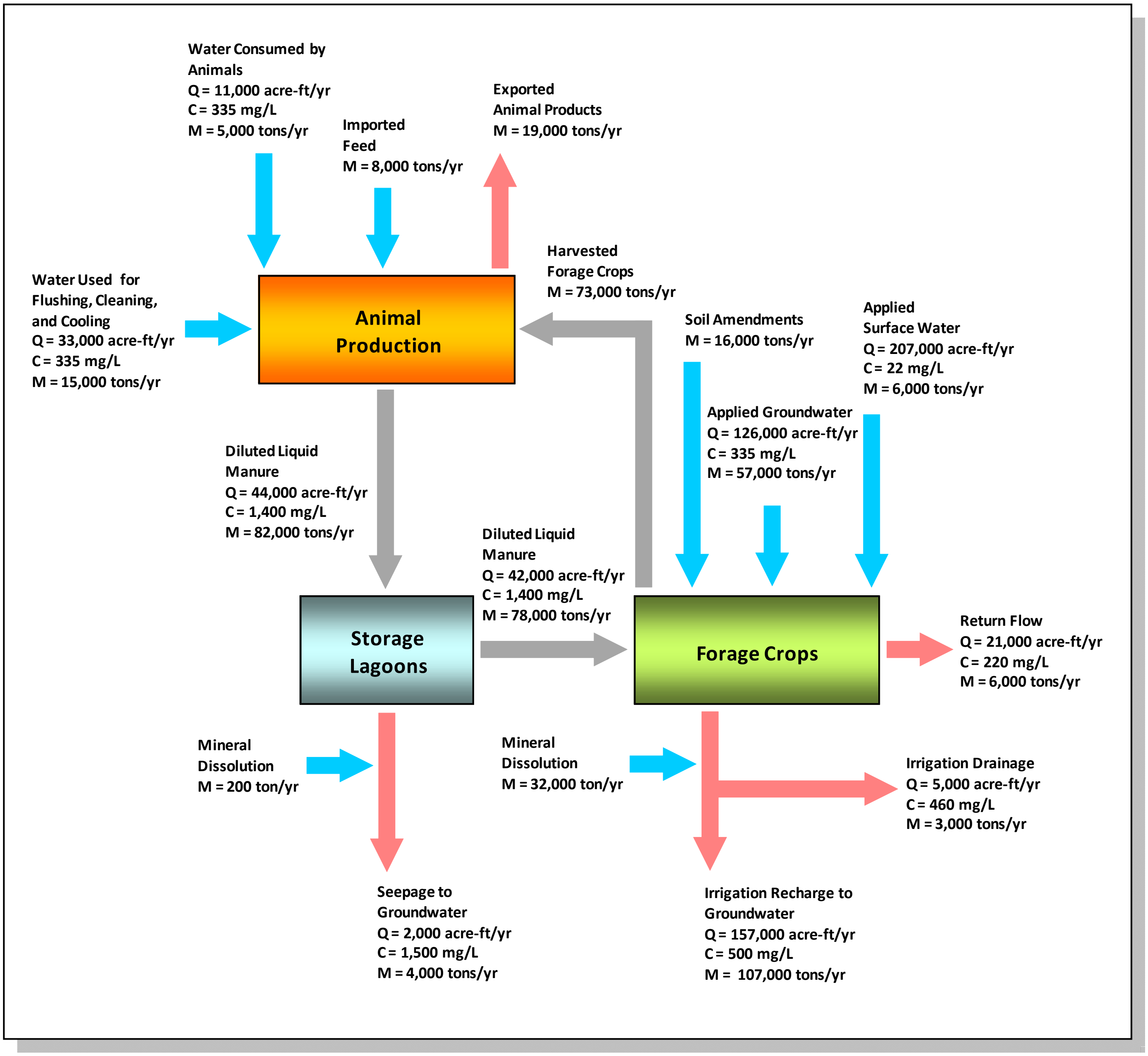

FIGURE 10 - CAFOs SALT MASS BALANCE IN TONS PER YEAR

The salt mass balance for concentrated animal feeding operations (CAFOs) is based upon dairies in the Turlock Sub-basin because dairies comprise the majority of CAFOs in the sub-basin. An enhanced understanding of the salt loadings to surface water and groundwater could be obtained if all types of CAFOs were considered in the salt mass balance.

TABLE 3

CONCENTRATED ANIMAL FEEDING OPERATIONS (CAFOs) SALT MASS BALANCE

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Animal Production Areas and Storage Lagoons (b)								
● Salt in Water Consumed by Animals	11,000 (c)	335 (e)		5,000				
● Salt in Water Used for Flushing, Cleaning, and Cooling	33,000 (d)	335		15,000				
● Salt in Imported Feed (f)	-	-		8,000				
● Salt in Harvested Forage Crops	-	-		73,000 (g, h)				
● Salt in Exported Animal Products					-	-		19,000
● Diluted Liquid Manure Applied to Land					42,000	1,400 (m)		78,000 (i)
● Seepage from Storage Lagoons					2,000	1,500 (m)		4,000 (i)
● Mineral Dissolution Due to Seepage	-	-		200				
Animal Production Area Totals: (a)	**44,000**			**101,000**	**44,000**			**101,000**
Forage Crops								
● Water Applied to Forage Crops (j)								
Salt in Groundwater Supply	126,000	335	57,000					
Salt in Surface Water Supply	207,000	22 (k)	6,000					
				63,000				
● Soil Amendments Added to Forage Crops	-	-		16,000 (l)				
● Diluted Liquid Manure Applied to Land	42,000	1,400 (m)		78,000	-	-		
● Salt in Harvested Forage Crops					-	-		73,000
● Applied Water Evapotranspiration					192,000	≅ 0		≅ 0
● Irrigation Return Flow					21,000	220 (m)		6,000
● Irrigation Drainage					5,000	460 (m)		3,000
● Irrigation Recharge					157,000	500 (m)		107,000
● Mineral Dissolution Due to Irrigation Recharge	-	-		32,000				
Forage Crop Totals: (a)	**375,000**			**189,000**	**375,000**			**189,000**

TABLE 3 (continued)

CONCENTRATED ANIMAL FEEDING OPERATIONS (CAFOs) SALT MASS BALANCE

Turlock Sub-basin, California

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Notes:

(a) Totals may not sum exactly due to rounding.

(b) Salt loads associated with animal production areas are based upon 194,000 animal units assumed to be present in the Turlock Sub-basin (U.S. EPA, 2009; United States Department of Agriculture, 2008; Stanislaus Economic Development and Workforce Alliance, 2006).

(c) Flow is based upon a water intake of 50 gallons per day for each animal unit in the sub-basin (ANS, 2005).

(d) Flow is based upon a water intake of 150 gallons per day for each animal unit in the sub-basin (Bray et al., 2008).

(e) Average value of total dissolved solids (TDS) concentrations in 71 production wells monitored by the California Department of Health Services (DWR, 2006).

(f) Anecdotal information indicates that 3 to 10 percent of animal feed is imported into the San Joaquin Valley (ANR, 2005). The remaining quantity of animal feed is grown locally. Salt loading assumes that 10 percent of feed for CAFOs is imported.

(g) Salt loading is based upon an assumed salt intake in feed of 2.3 lb per day for each animal unit in the sub-basin (ANR, 2005).

TABLE 3 (continued)

CONCENTRATED ANIMAL FEEDING OPERATIONS (CAFOs) SALT MASS BALANCE

Turlock Sub-basin, California

Notes:

(h) Value corresponds to approximately 1,300 pounds of salt per acre of harvested forage crops assuming 111,900 acres are used for forage crops (See Table A-2). This value is within the range of salt quantities removed by various crops reported by Brown and Caldwell and Kennedy/Jenks Consultants (2007). According to studies reviewed by Brown and Caldwell and Kennedy/Jenks Consultants, can remove 759 to 2,093 pounds of salt per acre of forage crops.

(i) Salt loading due to animal waste is based upon an assumed salinity excretion rate of 1.9 pounds per day for each animal unit in the sub-basin (ANR, 2005).

(j) Water flow volumes are allocated based upon the percentage of irrigated lands in the Turlock Sub-basin that are used for forage crops. See Table A-2 for a breakdown of food and forage crops grown.

(k) CVRWQCB (2010) reports that the median electrical conductivity (EC) value for the Tuolumne River at La Grange is 37 μS/cm. A value of 22 mg/L TDS was assumed for surface water diversions, using a ratio of 0.6 to convert EC measurements to TDS concentrations.

(l) Surface water from the Tuolumne and Merced Rivers is low in salinity. Gypsum (calcium sulfate, or $CaSO_4 \bullet 2H_2O$) is often added as a soil amendment during farm operations to improve infiltration of low salinity irrigation water (USGS, 2008a; University of California Cooperative Extension, Tulare County, 1998). Infiltration can be increased by directly adding gypsum to irrigation water at a rate of 250 to 1,000 pounds per acre-ft of applied water (University of California Cooperative Extension, Tulare County, 1998; Ayers and Westcot, 1985). Soil amendment quantity is based upon an addition of 300 pounds of gypsum per acre-ft of surface water applied to forage crops. It is assumed that gypsum is applied on 66 percent of the acreage used for forage crops.

(m) Value calculated by dividing total salt load by flow.

Irrigated Agriculture

Salt loadings caused by irrigation of food crops are estimated to be approximately 10,000 tons/yr to surface water and 82,000 tons/yr to groundwater, as shown on Figure 11 and summarized in Table 4. Significant streams that result from applied water to agricultural fields consist of irrigation drainage, return flow, and irrigation recharge.

Irrigation drainage is shallow groundwater removed by perforated subsurface pipes, which are designed to lower the groundwater table below the crop root zones. Return flow is surface water that leaves irrigated lands following application. Irrigation drainage and return flow are conveyed through laterals that discharge to surface water. Figure 3 depicts the discharge points of laterals owned and operated by TID.

Irrigation recharge is water that percolates past the root zones of plants and infiltrates to the saturated zone. An excess of water is applied to leach salts accumulating in topsoil. This accumulated salt must be leached; otherwise, crop yields fall as plants become unable to extract sufficient water from the salty topsoil (Ayers and Westcot, 1985).

Our study allocated groundwater and surface water supplies provided for irrigated lands among food and forage crops based upon the acreages of these crop types in the Turlock Sub-basin (see Table 1). We assumed that harvested crops uptake salt at 1,000 pounds per acre per year, with this salt mass leaving the sub-basin. Imported fertilizers were assumed to be negligible salt sources, as nitrogenous compounds, such as ammonia (NH_3) and nitrate, are present in groundwater at much lower concentrations than mineral salts.[4] Furthermore, nitrogenous, phosphate, and potassium fertilizers were assumed to be largely taken up by plants.

Low salinity water, such as that from the Tuolumne and Merced Rivers, tends to leach calcium and other salts from surface soil. The loss of these minerals can cause finer soil particles to disperse, filling soil voids and leading to the formation of a crust. This soil crust can restrict plant emergence and reduce water infiltration rates, lowering

[4] Krauter et al. (2001) found that fertilizer quantities applied in the Central Valley were not available from any public source and therefore estimated fertilizer usage by questioning farmers, fertilizer industry members, county farm advisors, and other crop specialists. Based upon the work performed by Krauter et al. (2001), nitrogen fertilizers used on food and forage crops grown in the Turlock Sub-basin appear to consist predominately of anhydrous nitrogen, UAN-32 (i.e., urea/ammonium nitrate solution), and ammonium nitrate. These nitrogen fertilizers do not contain conservative salt components.

agricultural crop yields (Ayers and Westcot, 1985). Ayers and Westcot (1985) state: "very low salinity water (less than EC_w = 0.2 ds/m) almost invariably results in water infiltration problems."[5]

To maintain favorable soil infiltration, gypsum (calcium sulfate, or $CaSO_4 \bullet 2H_2O$) is often applied to improve infiltration of irrigation water (USGS, 2008a; University of California Cooperative Extension, Tulare County, 1998). Infiltration can be increased by directly adding gypsum to applied irrigation water at a rate of 250 to 1,000 pounds per acre-ft (Cooperative Extension, Tulare County, 1998; Ayers and Westcot, 1985). Given this range, our estimated salt loadings from irrigated agriculture and CAFOs assume that, when gypsum is employed, 300 pounds are added per acre-ft of surface water applied to sub-basin food and forage crops. Gypsum is more commonly used in areas of finer-grained soil, predominantly in the western portion of the sub-basin, where most of the sub-basin's forage crops are grown. Based on the reported distribution of food and forage crops in the sub-basin, it is assumed that gypsum is applied to 25 percent of the sub-basin acreage used for food crops and 66 percent of the acreage used for forage crops.

USGS (2008a) reported that groundwater beneath an agricultural field in Modesto contained 486 mg/L TDS. Harter et al. (2002) reported an average EC value of 810 μS/cm, which corresponds to about 490 mg/L TDS, for groundwater samples collected between 1995 and 1998 from five monitoring wells in the San Joaquin Valley. Three of these wells were near agricultural fields consisting of almond orchards, vineyards, and forage crops. The other two wells were near dairies both with and without manure-treated fields. For our salt balance, EKI estimates TDS in groundwater beneath irrigated agriculture fields to be 310 mg/L, obtained by dividing the total salt load in irrigation recharge by the volume of irrigation recharge (see Table 4). This concentration is less than the TDS concentrations measured in groundwater beneath Central Valley agricultural fields reported by USGS and Harter et al.

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[5] An EC of 0.2 ds/m is equivalent to 200 μS/cm, or about 120 mg/L TDS assuming a TDS to EC ratio of 0.6. TDS concentrations in the Merced and Tuolumne Rivers are less than this threshold, suggesting the potential for mineral dissolution and crust formation over time. CVRWQCB (2010) reports that the median EC value for the Tuolumne River at La Grange is 37 μS/cm, which is equivalent to 22 mg/L TDS assuming a TDS to EDC ratio of 0.6. CVRWQCB (2004) reports that the flow-weighted average TDS values for the Merced and Tuolumne Rivers near their confluences with the San Joaquin River are 65 and 68 mg/L, respectively, for 1977 to 1997.

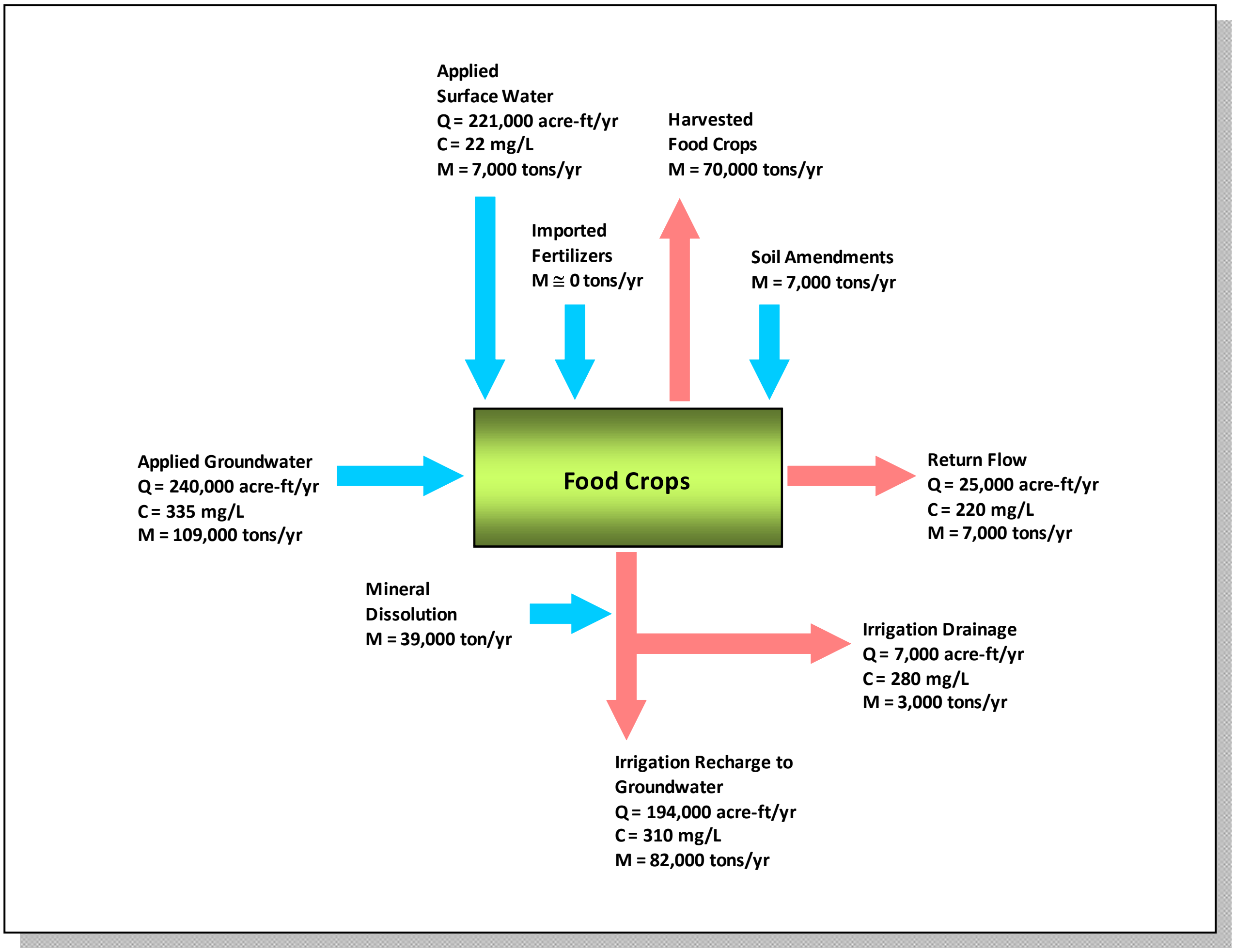

FIGURE 11 - IRRIGATED AGRICULTURE SALT MASS BALANCE IN TONS PER YEAR

Salt mass balance on irrigated agriculture assumes that gypsum is applied as a soil amendment to improve water infiltration. The quantities of salts in imported fertilizers added to agricultural fields are considered to be insignificant.

TABLE 4

IRRIGATED AGRICULTURE SALT MASS BALANCE

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Food Crops								
● Water Applied to Food Crops (b)								
Salt in Groundwater Supply	240,000	335 (c)	109,000					
Salt in Surface Water Supply	221,000	22 (d)	7,000					
				116,000				
● Soil Amendments Added to Food Crops	-	-		7,000 (e)				
● Imported Fertilizers Added to Food Crops				(f)				
● Salt in Exported Harvested Food Crops					-	-		70,000 (g)
● Applied Water Evapotranspiration					235,000	≅ 0		≅ 0
● Irrigation Return Flow					25,000	220 (h)		7,000
● Irrigation Drainage					7,000	280 (h)		3,000
● Irrigation Recharge					194,000	310 (h)		82,000
● Mineral Dissolution Due to Irrigation Recharge	-	-		39,000				
Food Crop Totals: (a)	**461,000**			**162,000**	**461,000**			**162,000**

References:

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U.S. Geological Survey (USGS). 2008a. *Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California* . Scientific Investigations Report 2008-5156.

Notes:

(a) Totals may not sum exactly due to rounding.

(b) Water flow volumes are allocated based upon the percentage of irrigated lands in the Turlock Sub-basin that are used for food crops. See Table A-2 for a breakdown of food and forage crops grown.

(c) Average value of total dissolved solids (TDS) concentrations in 71 production wells monitored by the California Department of Health Services (DWR, 2006).

(d) CVRWQCB (2010) reports that the median electrical conductivity (EC) value for the Tuolumne River at La Grange is 37 µS/cm. A value of 22 mg/L TDS was assumed for surface water diversions, using a ratio of 0.6 to convert EC measurements to TDS concentrations.

(e) Surface water from the Tuolumne and Merced Rivers is low in salinity. Gypsum (calcium sulfate, or $CaSO_4 \bullet 2H_2O$) is often added as a soil amendment during farm operations to improve infiltration of low salinity irrigation water (USGS, 2008a; University of California Cooperative Extension, Tulare County, 1998). Infiltration can be increased by directly adding gypsum to irrigation water at a rate of 250 to 1,000 pounds per acre-ft of applied water (University of California Cooperative Extension, Tulare County, 1998; Ayers and Westcot, 1985). Soil amendment quantity is based upon an addition of 300 pounds of gypsum per acre-ft of surface water applied to forage crops. It is assumed that gypsum is applied on 25 percent of the acreage used for food crops.

(f) Imported fertilizers are considered to be insignificant net salt sources. Nitrogenous, phosphate, and potassium fertilizers were assumed to be largely taken up by plants.

(g) An annual salt uptake rate of 1,000 pounds per acre was assumed to estimate the salt quantity in harvested food crops.

(h) Value calculated by dividing total salt load by flow.

Municipalities

The Turlock Sub-basin includes the communities of Ceres, Delhi, Denair, Hickman, Hilmar, Hughson, Keyes, and Turlock, plus the south side of Modesto. Turlock is the largest community located entirely within the sub-basin, growing in population from approximately 14,000 people in 1970 to over 70,000 people in 2009 (City of Turlock, 2009). Most of the urbanization in the sub-basin has taken place in Turlock, and in other communities and unincorporated urban areas within the TID district boundaries. Lands within the EWD, Ballico-Cortez Water District, and MID have not seen the urbanization that has occurred in the TID (TGBA, 2008).

Except for customers within the Ballico-Cortez Community Services District, urban wastewater is conveyed to municipal wastewater treatment plants, also called publicly owned treatment works or "POTWs." Ballico-Cortez Community Services District customers use septic tank and leachfield systems for wastewater disposal. Table A-6 summarizes wastewater flows reported by each community. After POTW treatment, these flows are discharged to either surface water or applied to land.

Salt loadings added by municipal use are estimated to be approximately 23,000 tons/yr to surface water and 26,000 tons/yr to groundwater, as shown on Figure 12 and summarized in Table 5. These salt loadings include food processor wastewater that is sent to POTWs, with the remaining loading contributed by the municipalities themselves at an estimated 16,000 tons/yr to surface water and 21,000 tons/yr to groundwater.

The total wastewater flow of 48,000 acre-ft/yr treated by sub-basin POTWs exceeds the total groundwater flow of 42,000 acre-ft/yr extracted for municipal water supply. This is in part because food processors and communities such as Modesto, Empire, and unincorporated areas located outside of the Turlock Sub-basin send wastewater to POTWs within the sub-basin. Several food processors also have their own water supply wells. Water supply volumes associated with food processor wells or obtained from outside the sub-basin have not been included in the municipal water supply volume for the sub-basin.

Our assumed TDS in the municipal water supply is based upon testing by USGS, which is authorized "to provide a statistically unbiased, spatially distributed assessment of the quality of groundwater resources used for public drinking water supply" (USGS, 2008b).

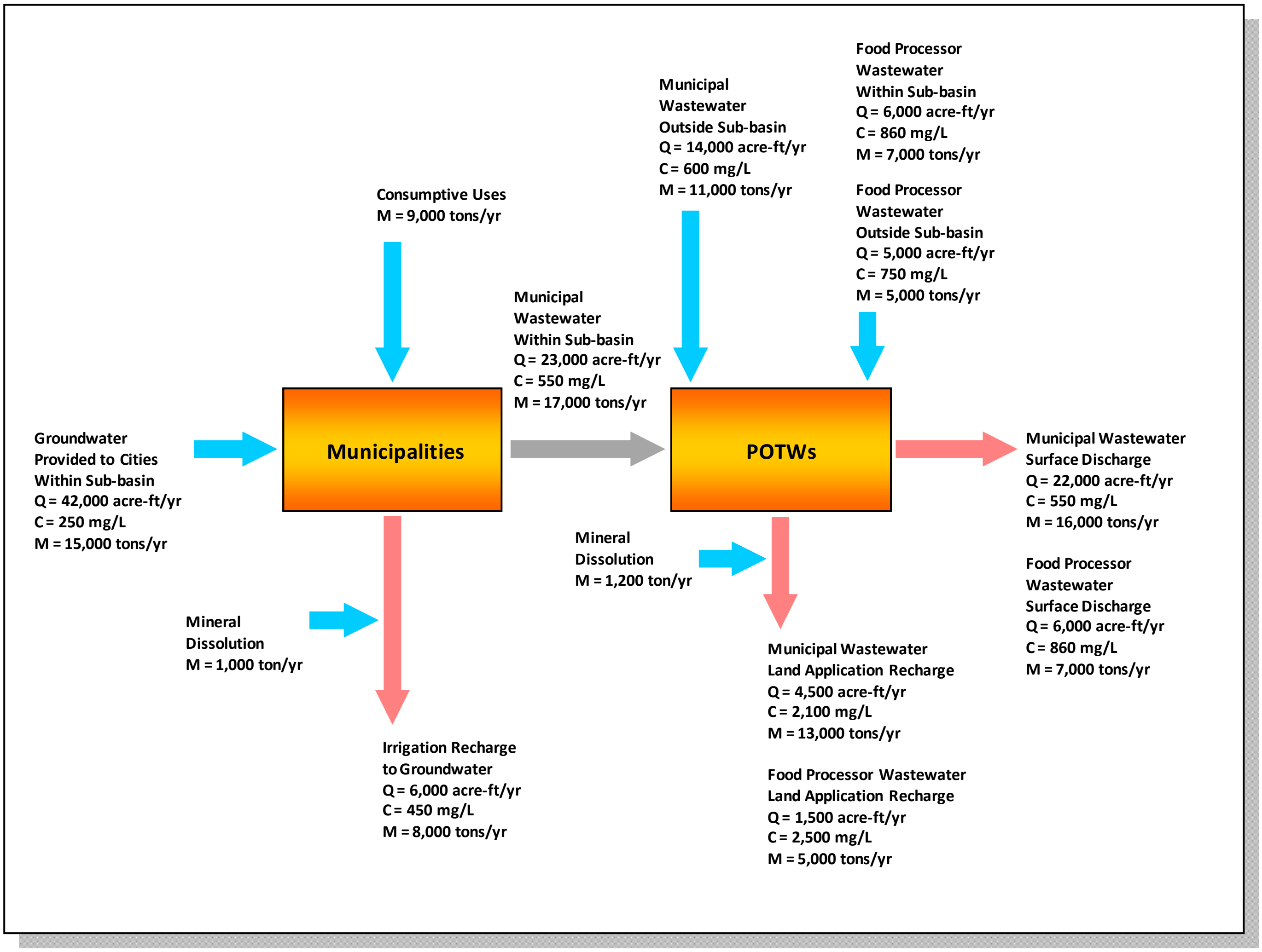

FIGURE 12 - MUNICIPALITIES SALT MASS BALANCE IN TONS PER YEAR

Publicly owned treatment works (POTWs) manage wastewater from cities within the Turlock Sub-basin as well as wastewater conveyed to the POTWs from food processors and from the City of Modesto, which is partially situated outside the sub-basin.

TABLE 5

MUNICIPALITIES SALT MASS BALANCE

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
Municipalities Within Sub-basin								
● Extracted Groundwater Provided to Cities	42,000							
Salt in Groundwater Supply		250 (b)	15,000					
Salt Added Due to Consumptive Uses		300 (d)	9,000					
				24,000				
● Municipal Irrigation								
Municipal Irrigation Evapotranspiration					13,000 (e)	≅ 0	≅ 0	
Municipal Irrigation Recharge					6,000 (e)	450 (c)	8,000	
								8,000
● Municipal Wastewater					23,000			
Salt in Groundwater Supply						250	8,000	
Salt Added Due to Consumptive Uses						300	9,000	
								17,000
● Mineral Dissolution Due to Irrigation Recharge	-	-		1,000				
Municipalities Totals: (a)	**42,000**			**25,000**	**42,000**			**25,000**

TABLE 5 (continued)
MUNICIPALITIES SALT MASS BALANCE

Turlock Sub-basin, California

Flow Description	Salt Mass Inflow				Salt Mass Outflow			
	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)	Flow (acre-ft/yr)	TDS Concentration (mg/L)	Subtotal Salt Load (tons/yr)	Total Salt Load (tons/yr)
POTWs								
● Municipal Wastewater Within Sub-basin	23,000 (i)	550	17,000					
● Municipal Wastewater Outside Sub-basin	14,000 (f)	600 (g)	11,000					
				28,000				
● Food Processor Wastewater Within Sub-basin	6,000 (h)	860 (h)	7,000					
● Food Processor Wastewater Outside Sub-basin	5,000 (f, h)	750 (h)	5,000					
				12,000				
● Surface Water Discharge								
Municipal Wastewater					22,000 (i)	550	16,000	
Food Processor Wastewater					6,000 (h)	860	7,000	
								23,000
● Land Application								
Municipal Wastewater Evapotranspiration					10,500 (e, i)	≅ 0	≅ 0	
Food Processor Wastewater Evapotranspiration					3,500 (e, i)	≅ 0	≅ 0	
Municipal Wastewater Recharge					4,500 (e)	2,100 (c)	13,000	
Food Processor Wastewater Recharge					1,500 (e)	2,500 (c)	5,000	
								18,000
● Mineral Dissolution Due to Land Application Recharge								
Muncipal Wastewater	-	-	900					
Food Processor Wastewater	-	-	300					
				1,200				
POTW Totals: (a)	**48,000**			**41,000**	**48,000**			**41,000**

TABLE 5 (continued)

MUNICIPALITIES SALT MASS BALANCE

Turlock Sub-basin, California

References:

Carollo Engineers (Carollo). March 2007. *City of Modesto, Wastewater Master Plan, Phase 2 Update, Master Plan Report, Final.*

Center for Irrigation Technology. January 1988. *Irrigation System Selection* . Irrigation Notes, California State University, Fresno.

EOA, Inc. (EOA). November 2005. *City of Modesto, Update of Modesto Ranch Salt Study* .

Metcalf & Eddy, Inc. 2003. *Wastewater Engineering: Treatment and Reuse* . 4th Ed. The McGraw-Hill Companies, Inc.

USGS. 2008b. *Ground Water Quality Data in the Central Eastside San Joaquin Basin 2006: Results from the California GAMA Program* . Data Series 325. Report prepared in cooperation with California State Water Resources Control Board.

Notes:

(a) Totals may not sum exactly due to rounding.

(b) Total dissolved solids (TDS) concentration is the geometric mean of TDS values reported for municipal supply wells in the Turlock Sub-basin in 2006 (USGS, 2008b).

(c) Value calculated by dividing total salt load by flow.

(d) Metcalf & Eddy, Inc. (2003) reports that TDS in water can be expected to typically increase between 150 to 380 mg/L due to municipal use. A TDS concentration increase of 300 mg/L is assumed in wastewater generated by cities within the Turlock Sub-basin and conveyed to publicly owned treatment works (POTWs).

(e) The volume of applied water utilized by vegetation is assumed to be 70 percent based upon the application efficiencies of irrigation systems summarized by Center for Irrigation Technology (1988). The remaining 30 percent of the water volume is assumed to be lost to deep percolation or recharge to the saturated zone.

(f) Flow consists of wastewater from the City of Modesto that is generated outside the sub-basin. See Table A-6 for breakdown of municipal and food processor wastewater from City of Modesto.

(g) Assumed concentration based upon TDS values reported for City of Modesto municipal wastewater (Carollo, 2007; EOA, 2005).

(h) See Table 6 for description of food processor wastewater.

(i) See Table A-6 for breakdown of POTW surface water discharge and POTW land application.

The geometric mean is 250 mg/L for TDS concentrations in sub-basin municipal supply wells tested by USGS.[6]

The incremental salt concentration added to extracted groundwater by residential, commercial, and industrial uses was assumed to be 300 mg/L TDS, within the typical range of 150 to 380 mg/L reported by Metcalf & Eddy, Inc. (2003). Adding 300 mg/L TDS to the assumed initial concentration of 250 mg/L TDS in the municipal water supply yields an estimated wastewater TDS concentration of 550 mg/L. This assumed concentration is similar to the average of 580 mg/L TDS calculated from City of Turlock POTW effluent data for 1995 to 2002 (CVRWQCB, 2004).

Food Processors

Information on food processors was obtained from (1) publicly-available studies performed on behalf of the City of Modesto (Carollo Engineers, 2007; EOA, Inc., 2005; Black and Veatch, 2003) and from (2) the Hilmar Supplemental Environmental Project (Hilmar SEP) conducted by Rubin et al. (2007). Wastewater generated by food processors is either applied directly to land or is conveyed to POTWs.

Figure 13 depicts the entities that land-apply wastewater at their facilities pursuant to Waste Discharge Requirements issued by the CVRWQCB. Table 6 summarizes these food processing operations and associated salt loadings.

According to Rubin et al. (2007), salinity data are not always reported for land-applied wastewater. Their 2007 report did "gap filling" to compensate for incomplete data, noting that "There is no unique method of gap filling, making it somewhat speculative, and as such it is subject to uncertainty." Salt loadings associated with land application presented by EKI in Table 6 reflect arithmetic averages of loadings, with gap filling for 2003, 2004, and 2005 as reported in the Hilmar SEP. The accuracy of these values is thus not fully known.

[6] The geometric mean was selected as the representative TDS concentration in groundwater because distributions of environmental data are often asymmetrical or log-normally distributed. Log-normal data typically have a single "mode," which is the value that occurs the most frequently in a data set, plus a "tail" of higher-value data points extending to the right on a graphical plot. The geometric mean attempts to describe the central tendency of log-normally distributed data, moderating the influence of higher-value "outlier" data points. The more familiar arithmetic mean is better suited to data sets that are more symmetrical.

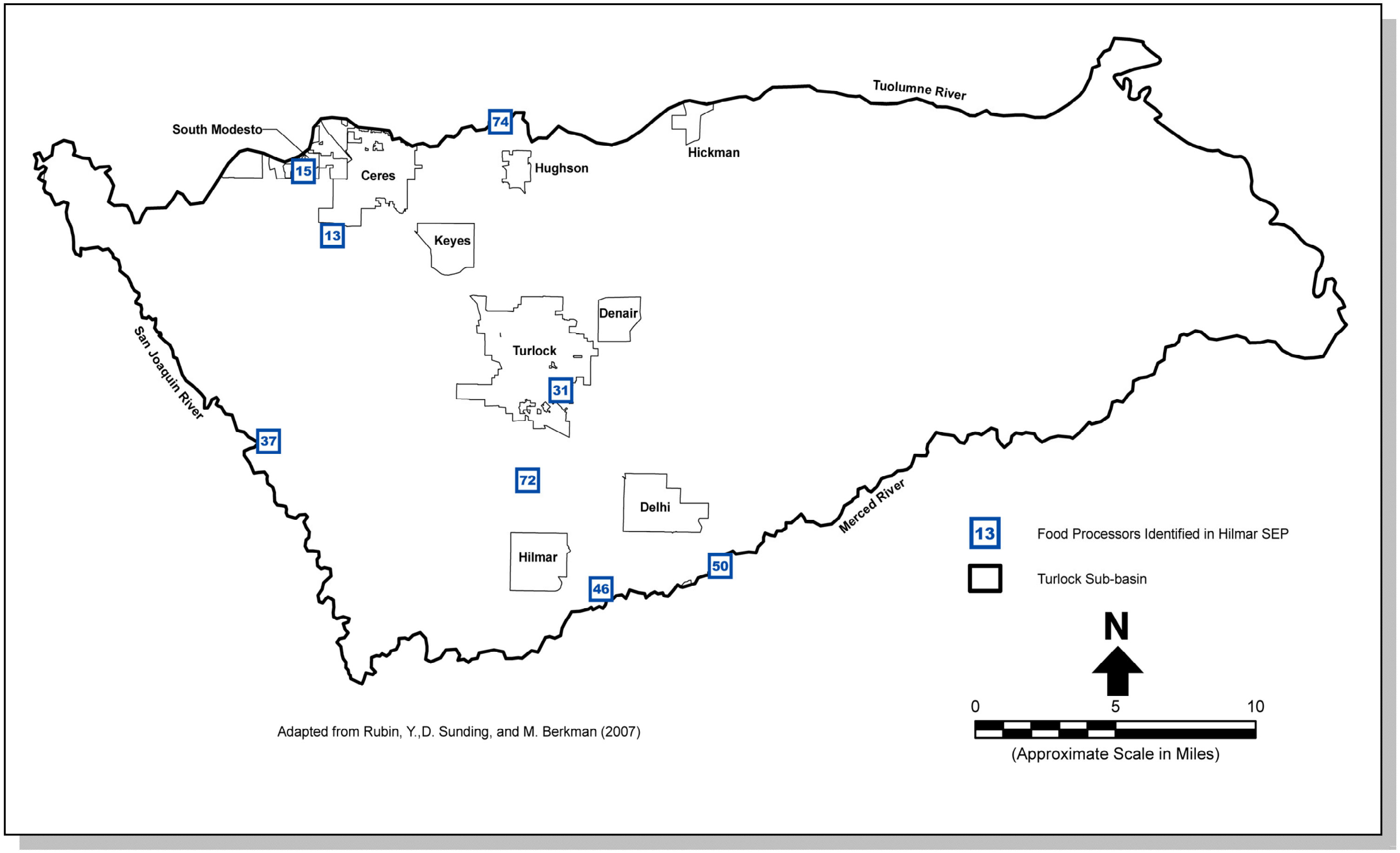

FIGURE 13 – FOOD PROCESSORS WITHIN TURLOCK SUB-BASIN

Food processors within the Turlock Sub-basin are taken from the Hilmar Supplemental Environmental Project (Hilmar SEP) study prepared by Rubin, Sunding, and Berkman (2007). Food processors shown are authorized by the California Regional Water Quality Control Board, Central Valley Region to apply wastewater to land at their facilities. Besides land application at food processor facilities, food processor wastewater also is conveyed to and managed at publicly owned treatment works (POTWs) within the sub-basin. Food processor wastewater managed by POTWs includes wastewater generated outside the sub-basin.

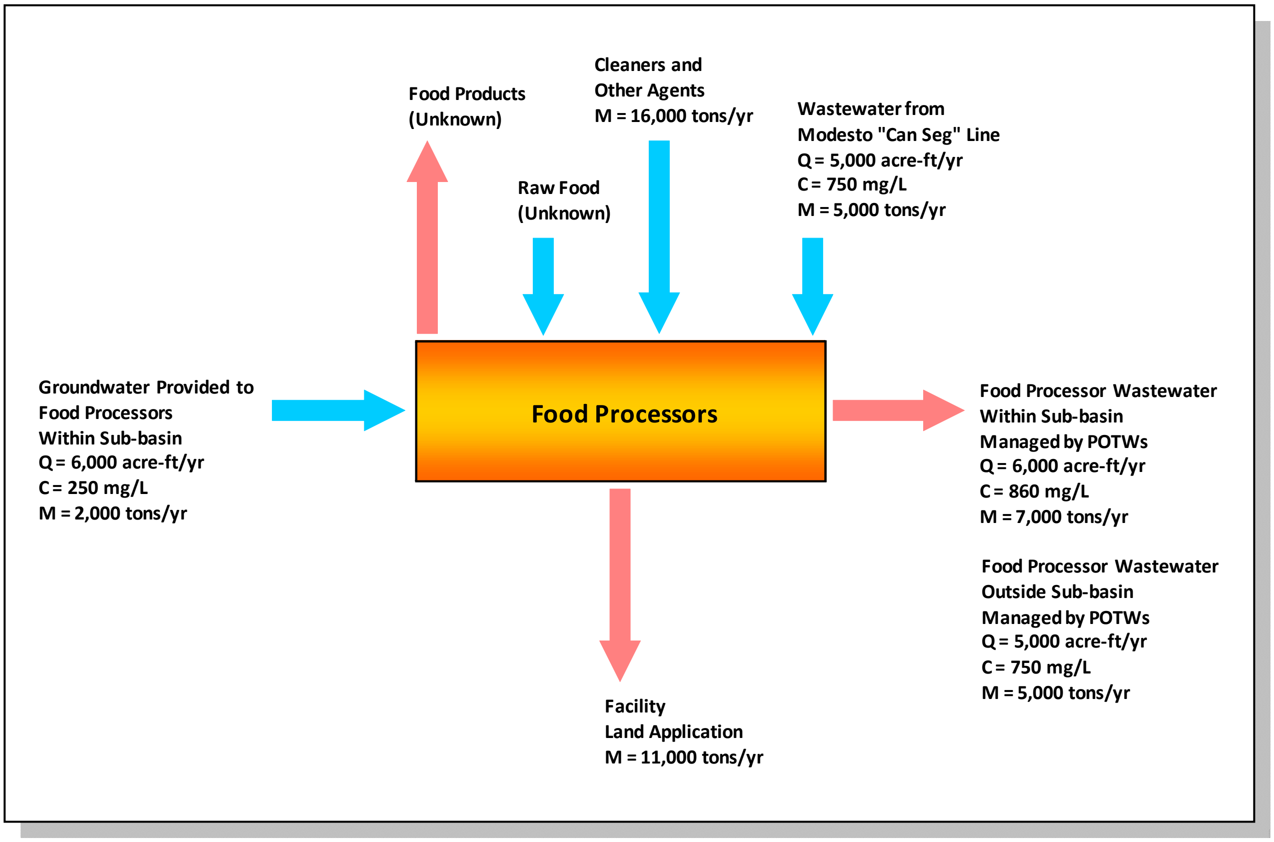

FIGURE 14 - FOOD PROCESSORS SALT MASS BALANCE IN TONS PER YEAR

Wastewater generated by food processors is either applied directly to land at food processor facilities or conveyed to publicly owned treatment works (POTWs) for management. The determination of food processor salt loadings could be enhanced by more frequent testing of wastewater generated at food processor facilities and through auditing the quantities of salt that are added to wastewater as a result of process operations.

TABLE 6
FOOD PROCESSORS SALT MASS BALANCE
Turlock Sub-basin, California

Flow Description	Salt Mass Inflow Flow (acre-ft/yr)	Salt Mass Inflow TDS Concentration (mg/L)	Salt Mass Inflow Subtotal Salt Load (tons/yr)	Salt Mass Inflow Total Salt Load (tons/yr)	Salt Mass Outflow Flow (acre-ft/yr)	Salt Mass Outflow TDS Concentration (mg/L)	Salt Mass Outflow Subtotal Salt Load (tons/yr)	Salt Mass Outflow Total Salt Load (tons/yr)
Food Processors Within Sub-basin								
● Salt in Groundwater Supply	6,000 (e)	250	2,000					
● Salt in Harvested Food Crops	-	-	(b)					
● Salt in Cleaners and Other Agents	-	-	16,000					
				18,000				
● Salt in Exported Food Products					-	-		(b)
Food Processor Wastewater from Modesto								
● Wastewater Discharge to "Can Seg" Line	5,000 (c, d)	750 (f)		5,000				
Wastewater Managed by POTWs								
● Food Processor Wastewater Within Sub-basin					6,000	860 (f)	7,000	
● Food Processor Wastewater Outside Sub-basin					5,000	750	5,000	
								12,000
Facility Land Application Within Sub-basin (g)								
● Food Processors Permitted to Discharge to Land								
13 - Winery					-	-	500	
15 - Fruits and Vegetable Canning					-	-	3,400	
31 - Animal Slaughtering and Processing					-	-	0	
37 - Rendering					-	-	0	
46 - Winery					-	-	1,000	
50 - Waste and Miscellaneous					-	-	2,200	
72 - Dairy Product Manufacturing					-	-	4,000	
74 - Nuts and Peanut Butter					-	-	20	
								11,000
Food Processor Totals: (a)	**11,000**			**23,000**	**11,000**			**23,000**

TABLE 6 (continued)

FOOD PROCESSORS SALT MASS BALANCE

Turlock Sub-basin, California

References:

Rubin, Y., D. Sunding, and M. Berkman. 16 November 2007. *Hilmar Supplemental Environmental Project* . Report prepared in compliance with California Regional Water Quality Control Board, Central Valley Region Order No. R5-2006-0025.

Notes:

(a) Totals may not sum exactly due to rounding.

(b) Salt mass balance was completed without information on these flows. Evaluation of these flows and associated salt concentrations would enhance the understanding of these flows on the salt mass balance.

(c) Cannery process flows from City of Modesto are routed through the cannery segregated, or "Can Seg" pipeline to publicly owned treatment works (POTWs) within the Turlock Sub-basin for land application.

(d) See Table A-6 for breakdown of food processor wastewater conveyed to and managed by POTWs.

(e) Rubin, Sunding, and Berkman (2007) state food processor wastewater comprises 44 percent and 50 percent of wastewater managed by POTWs operated by City of Turlock and City of Hughson, respectively. See Table A-6 for breakdown of municipal wastewater flows.

(f) Assumed total dissolved solids (TDS) concentration is based upon fixed dissolved solids (FDS) or adjusted TDS values for wastewater generated by food processors in the Central Valley (see Table A-7). TDS concentrations in Table A-7 are values that have been adjusted to remove contributions of decomposable organic matter to TDS in food processor wastewater.

(g) Descriptions of food processing entities and identification numbers were assigned by Rubin, Sunding, and Berkman (2007). These facilities are located in the Turlock Sub-basin and apply wastewater to land pursuant to Waste Discharge Requirements issued by the California Regional Water Quality Control Board, Central Valley Region. Salt loadings are the arithmetic averages of loadings with gap filling for 2003, 2004, and 2005, as reported by Rubin, Sunding, and Berkman (2007).

Food processor total salt loading is estimated to be approximately 23,000 tons/yr, as shown on Figure 14 and summarized in Table 6. Of this loading, 7,000 tons/yr are estimated to be discharged to surface water and 16,000 tons/yr to groundwater.

Confidence in food processor salt loadings could be improved by more frequent TDS and other mineral testing of food processor wastewater and through auditing the quantities of salt added to wastewater during processing operations, covering sources such as water softeners, odor control chemicals, sanitizers, cooling tower blowdown, flavoring, and peeling and pickling solutions. Salt also will enter in harvested food and will leave as finished food products.

Data on TDS concentrations in groundwater beneath food processors was obtained from Rubin et al. (2007) and from a report prepared by the CVRWQCB that evaluated 331 Central Valley food processors (CVRWQCB, 2005). Of those food processors, 223 entities were authorized by the CVRWQCB to discharge treated wastewater to land or surface waters, with 107 facilities compiling groundwater data (Rubin et al., 2007; CVRWQCB, 2005). Upon review of this information, Rubin et al. concluded that 70 food processors had impacted groundwater or were suspected of doing so.

TDS concentrations in groundwater underlying food processors varied owing to differing compositions of discharged wastewaters. Rubin et al. (2007), examining the groundwater data for 19 facilities, found that TDS was greater than 500 mg/L in groundwater beneath 90 percent of them. Rubin et al. (2007) and CVRWQCB (2005) have cited TDS concentrations ranging between 500 to 2,700 mg/L in groundwater underlying such facilities.

Food processor wastewater also is applied to land by POTWs. TDS data were reviewed for 14 groundwater monitoring wells constructed in fields where the City of Modesto POTW applies food processor wastewater. TDS concentrations measured in these wells in 2003 and 2004 averaged from 651 to 5,457 mg/L (EOA, Inc., 2005). For our salt mass balance, EKI estimated a TDS concentration of 2,500 mg/L in shallow groundwater beneath fields where food processor wastewater is land-applied (see Table 5).

Septic Tank Systems

A septic tank and its associated leach field is a common small-scale sewage treatment system outside of municipal service areas such as small communities and rural housing.

Most of the Turlock Sub-basin, about 94 percent, is rural or unincorporated without sewage collection and treatment services.

Conservative salt components in septic tank discharges, such as sodium and chloride, will eventually reach underlying groundwater. In this way, septic tank systems represent a salt source to sub-basin groundwater.

The number of septic tank systems operating in the Turlock Sub-basin is unknown.[7] Using available U.S. census data on rural and other non-city populations in the sub-basin, EKI estimated the salt loading from septic tanks by multiplying the rural population by an assumed per capita salt loading.

EKI applied two approaches to estimate a per capita salt loading. For the first approach, we assumed rural residents generate salt loadings similar to those of urban residents and divided the estimated salt loading from municipal wastewater generated within the sub-basin, 17,000 tons per year, by an estimated urban population of 140,000 individuals, yielding a per capita salt load of 0.12 tons per year.[8] For the second approach, we used a typical wastewater generation rate of 75 gallons per person per day (Metcalf & Eddy, 2003), multiplied by our assumed wastewater TDS concentration of 550 mg/L, yielding a per capita salt load of 0.06 tons per year.[9] Given a per capita salt loading of 0.12 tons per year and a sub-basin rural population of 40,000 individuals, the salt loading from septic tank systems is estimated to be roughly 5,000 tons per year.

<u>Mineral Dissolution Due to Irrigation and Land Application</u>

Dissolution of naturally-occurring calcium carbonate ($CaCO_3$) minerals, such as calcite, contributes salt to groundwater. While calcium carbonate is sparingly soluble in distilled

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[7] Stanislaus County health inspectors do not track the number of septic tank systems in the county.

[8] Using Year 2000 U.S. Census data for Stanislaus County, average population densities were calculated for urban areas (i.e., south side of Modesto, Ceres, Hughson, Newman, Oakdale, Patterson, Riverbank, Turlock, and Waterford) and the remaining, non-urban (rural) areas in Stanislaus County. The average urban and rural population densities for Stanislaus County were assumed to be representative of population densities in the Turlock Sub-basin. The population densities were then multiplied by the estimated urban and rural acreage in the Turlock Sub-basin of 20,000 acres and 327,000 acres respectively, to estimate the urban and rural populations in the Turlock Sub-basin.

[9] Wastewater TDS concentration is assumed to consist of an average water supply concentration of 250 mg/L and 300 mg/L of salt added due to consumptive uses.

water, higher calcium ion (Ca^{2+}) concentrations are typically observed in the environment due to the influence of gaseous carbon dioxide (CO_2) in the subsurface.

Water infiltrates into soil and reacts with carbon dioxide, becoming slightly acidic. These acidic conditions promote dissolution of calcium carbonate. Higher TDS concentrations in water result from calcium carbonate's dissolution into calcium and bicarbonate ions (HCO_3^-), as indicated by the following reaction (Stumm and Morgan, 1996; USGS, 1985):

$$CO_2 + H_2O + CaCO_3(s) \Leftrightarrow Ca^{2+} + 2HCO_3^-$$

Stimulation of plant and soil respiration by irrigation and fertilizer application creates carbon dioxide that can further dissolve calcium carbonate.

The actual processes in the unsaturated zone that govern groundwater TDS concentrations are complex, involving ion exchange, mineral dissolution-precipitation, microbial mediated reactions, and the quality of the applied water. Rubin et al. (2007), evaluating mineral dissolution as part of the Hilmar SEP, stated the following:

> The large number of simultaneously-occurring processes taking place under a wide range of site conditions suggests that hundreds of site-specific analyses may be required in order to quantify the complete range of expected impacts.

Given the goals of our preliminary salt mass balance study, EKI applied a simplified approach to account for mineral dissolution as part of the overall salt mass balance. The large contribution of mineral dissolution to the salt mass balance suggests that a more detailed approach to modeling mineral dissolution should be assessed.

As a preliminary step toward assessing the contribution of mineral dissolution, EKI estimated the salt loading to groundwater that occurred prior to the current intensive development of the sub-basin. This pre-development salt loading was then multiplied by the ratio of the current to pre-development rates of groundwater recharge to estimate the total current salt loading to the sub-basin attributable to mineral dissolution.

In 1910, USGS (1916) collected groundwater samples from wells and analyzed these samples for mineral constituents. The eastern portion of the Turlock Sub-basin was not being irrigated at that time and TDS was about 150 mg/L in groundwater, assumed to be in rough equilibrium with the TDS level in the recharge water.[10]

Before development, recharge to groundwater was primarily from precipitation, plus seepage from rivers and streams (USGS, 2009, 2008a, 1998, 1989). USGS (2009, 1989) estimates that pre-development recharge was 2,000,000 acre-ft/yr throughout the 20,400 square miles that comprise the Central Valley. The Turlock Sub-basin encompasses 540 square miles, or roughly 2.6 percent of the Central Valley. Assuming pre-development recharge was proportional to surface area, then recharge to groundwater was approximately 2.6 percent of 2,000,000 acre-ft/yr, or 53,000 acre-ft/yr, before intensive agricultural development of the sub-basin occurred.

The salt loading to groundwater prior to development was almost exclusively from mineral dissolution.[11] On this basis, EKI estimates pre-development mineral dissolution to have been 11,000 tons/yr, calculated by multiplying the recharge of 53,000 acre-ft/yr by the pre-development groundwater TDS concentration of 150 mg/L obtained from the 1910 data.

EKI's water balance for current sub-basin conditions indicates that recharge and seepage to groundwater, at about 493,000 acre-ft/yr, is approximately nine times greater than the pre-development recharge rate of 53,000 acre-ft/yr. Multiplying the pre-development mineral dissolution rate of 11,000 tons/yr by a similar factor of nine gives 99,000 tons/yr.

EKI included mineral dissolution as a component of salt loadings resulting from recharge or seepage of water to the saturated zone. Salt originating from mineral dissolution was allocated to CAFOs, irrigated agriculture, municipalities, and food processors based upon the percentages of total recharge and seepage volumes that the flows from these sources represent.

<u>Mineral Dissolution Due to Water Supply Seepage</u>

Water diverted from the Tuolumne River by TID is conveyed to Turlock Lake before the water is distributed to irrigated lands (TGBA, 2008). TID operates approximately

[10] Widespread irrigation of the western portion of the sub-basin commenced around 1900, when TID began operations (USGS, 1989, 1916; Harding, 1960).

[11] The salt contributions from rainfall and river flows are assumed to be negligible.

230 miles of irrigation canals and laterals, 90 percent of which are reported to be concrete-lined (TGBA, 2008), with 26 miles of open earthen channels located within the Turlock Sub-basin.

Water seepage is reported to be 62,000 acre-ft/yr from Turlock Lake and 38,000 acre-ft/yr from irrigation canals in the sub-basin (TGBA, 2008). Mineral dissolution associated with this seepage related to water supply is estimated to be 20,000 tons/yr in addition to the 3,000 tons/yr of salt contained in the water supply itself. Therefore, the total salt loading associated with water supply seepage is 23,000 tons/yr.

Mineral Dissolution Due to Precipitation

Rainfall that percolates to groundwater dissolves naturally-occurring calcium carbonate minerals as it migrates through the unsaturated zone. Mineral dissolution can be estimated based upon the percentage of total recharge and seepage to the saturated zone that infiltrating precipitation represents.

Rainfall can infiltrate to the saturated zone if the precipitation does not run off to surface water, evaporate from soil, or transpire from vegetation.[12] EKI assumed that 40 percent of incident rainfall on municipalities is lost to evapotranspiration and 35 percent is lost as storm water runoff to surface water based upon typical values for urban areas reported by the Federal Interagency Stream Restoration Working Group (2001). The remaining 25 percent (5,000 acre-ft/yr) of rainfall on municipalities is assumed to recharge groundwater.

Excess precipitation on foothills and riparian habitat is the only rainfall associated with native vegetation that is able to infiltrate to the saturated zone. USGS (1989) defines excess precipitation to be the amount of rainfall greater than potential evapotranspiration.[13] Excess precipitation for the foothills was estimated using the USGS linear regression for San Joaquin Valley relating excess precipitation (PPT_{ex}) to annual precipitation (PPT): $PPT_{ex} = 0.64 \times PPT - 6.2$ (USGS, 1989). The volume of excess precipitation is estimated to be 10,000 acre-ft/yr based upon an average annual rainfall

[12] The combined processes of evaporation and transpiration are referred to as evapotranspiration.

[13] No excess precipitation is assumed to result from irrigated lands since the amount of incident rainfall is less than the evapotranspiration of food and forage crops grown on these lands.

amount of 12.39 inches and 69,000 acres of foothills (Table A-1). All excess precipitation is assumed to recharge the saturated zone.

No appreciable evapotranspiration of rainfall is presumed to occur on riparian habitat because phreatophytic plants grow on this land type.[14] All incident rainfall is assumed to be excess precipitation that recharges the saturated zone. The volume of recharge is estimated to be 13,000 acre-ft/yr based upon an average annual rainfall amount of 12.39 inches and 13,000 acres of riparian habitat (see Table A-1).

Total precipitation recharge is 28,000 acre-ft/yr, which is the sum of 5,000 acre-ft/yr from municipalities, 10,000 acre-ft/yr from the foothills, and 13,000 acre-ft/yr from riparian habitat. Precipitation recharge accounts for approximately 6 percent of the total sub-basin recharge and seepage (492,000 acre-ft/yr). Therefore, mineral dissolution associated with rainfall infiltration is similarly estimated to be 6 percent of 99,000 tons/yr (see Table 2), or 6,000 tons/yr.

Atmospheric Deposition

Atmospheric deposition is the process whereby airborne compounds settle on the earth's surface by wet and dry deposition. “Wet deposition” removes compounds from the air and transports them to land in precipitation. “Dry deposition” entails settling of particulates and gases in the absence of precipitation.

Wet deposition data are compiled through the National Atmospheric Deposition Program (NADP).[15] The only NADP monitoring site in the Central Valley is located in Davis. The precipitation-weighted mean salt concentration was approximately 1 mg/L at this site in 2008 (NADP, 2009). Multiplying this concentration by the total rainfall on the Turlock Sub-basin (358,000 acre-ft; see Table 1) yields a wet deposition salt loading of roughly 500 tons/yr.

[14] Phreatophytes are plants that live along a river system with their roots below or near the groundwater table. Phreatophytes extract water directly from the saturated zone.

[15] NADP is a cooperative research program involving federal, state, and private organizations.

Dry deposition data are compiled through the Clean Air Status and Trends Network (CASTNET).[16] Dry deposition data pertaining to salts are limited to sulfate measurements. Review of the CASTNET annual report for 2007 indicates that approximately 50 percent of sulfate atmospheric deposition in California is associated with dry deposition (MACTEC Engineering and Consulting, Inc., 2008). Therefore, EKI multiplied the wet deposition salt loading of 500 tons/yr by a factor of two to obtain a total atmospheric deposition salt loading of 1,000 tons/yr for the sub-basin.

Upwelling of Saline Groundwater

The salt loading associated with upwelling of saline groundwater was estimated to be 5,000 tons/yr assuming a flow of 2,000 acre-ft/yr and TDS concentration of 2,000 mg/L.

6 RESULTS

Section 6.1 summarizes the salt added to surface water and groundwater by sources in the Turlock Sub-basin. Section 6.2 compares the preliminary salt mass balance results to available data.

6.1 Salt Source Contributions

Table 7 summarizes the salt quantities contributed by identified sub-basin sources to surface water and groundwater. The quantities of salt that CAFOs, irrigated agriculture, municipalities, and food processors contribute to surface water and groundwater were derived from assessment of representative sources (see Tables 3 through 6).

Detailed evaluations of key sources, potentially including auditing of representative facilities from each source type, would improve the mass balances. Despite this potential improvement, the mass balances developed in this study are sufficiently comprehensive such that groundwater TDS concentrations calculated from the mass balances generally agree with reported TDS concentrations in shallow groundwater beneath Central Valley CAFOs, irrigated agriculture, and fields where food processor wastewater is land applied.

[16] CASTNET is a regional long-term environmental monitoring program operated by U.S. EPA. The program is designed to measure concentrations of air pollutants involved in acidic deposition affecting regional ecosystems and rural ambient ozone levels.

TABLE 7
SALT SOURCE CONTRIBUTIONS

Turlock Sub-basin, California

Salt Source (b)	Discharge to Surface Water		Discharge to Fresh Groundwater		Total Discharge to Sub-basin	
	Weight Percent	Salt Loading (tons/yr)	Weight Percent	Salt Loading (tons/yr)	Weight Percent	Salt Loading (tons/yr)
• Concentrated Animal Feeding Operations	21%	9,000	41%	111,000	38%	120,000
• Irrigated Agriculture	24%	10,000	30%	82,000	29%	92,000
• Municipalities	38%	16,000	8%	21,000	12%	37,000
• Food Processors	17%	7,000	6%	16,000	7%	23,000
• Septic Tank Systems	-	-	2%	5,000	2%	5,000
• Mineral Dissolution Due to Water Supply Seepage	-	-	9%	23,000	7%	23,000
• Mineral Dissolution Due to Precipitation	≅ 0	≅ 0	2%	6,000	2%	6,000
• Atmospheric Deposition	≅ 0	≅ 0	0.4%	1,000	0.3%	1,000
• Upwelling of Saline Groundwater	-	-	2%	5,000	2%	5,000
Totals: (a)	**100.0%**	**42,000**	**100.0%**	**270,000**	**100.0%**	**312,000**

<u>**Notes**</u>:

(a) Totals may not sum exactly due to rounding.

(b) See Tables 1 through 6 for derivations and assumptions regarding salt loadings.

As summarized in Table 2, EKI estimates that the total salt loading to surface water in the sub-basin is approximately 42,000 tons/yr, comparable to the 39,322 tons/yr of salt that the CVRWQCB estimates is discharged by sources directly to surface water in the East Valley Floor Subarea (CVRWQCB, 2004). The East Valley Floor Subarea defined by the CVRWQCB encompasses roughly the same area as the Turlock Sub-basin. EKI estimates that the salt loading to sub-basin groundwater is approximately 270,000 tons/yr (Table 7). Section 6.2 discusses the verification of this estimated loading to groundwater.

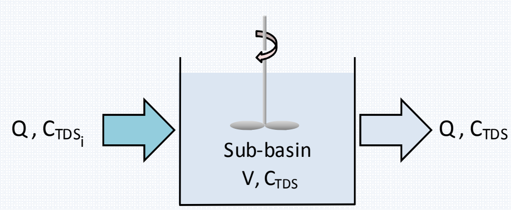
6.2 Comparison of Salt Balance Results with Available Data

The salt mass balance on Turlock Sub-basin groundwater was checked by evaluating the predicted rate of increase of groundwater salinity with the observed rate of increase. The predicted rate of salinity increase was estimated by modeling the saturated zone in the Turlock Sub-basin as a complete-mix system. Box D illustrates this complete-mix approach.

Salt entering the complete-mix system is assumed to instantaneously and uniformly disperse throughout the system. Further, salt concentrations leaving the sub-basin are assumed to also reflect this basin-wide TDS concentration.

Box D - Complete-Mix System Model

The following diagram illustrates the Turlock Sub-basin modeled as a complete-mix system, such that TDS concentrations are the same throughout the sub-basin saturated zone, and assuming there are no TDS-destroying reactions:



The salt mass balance for the sub-basin is given by the following equation:

$$\frac{dC_{TDS}}{dt}V = QC_{TDS_i} - QC_{TDS}$$

Change in Salt Mass = Salt Mass Inflow - Salt Mass Outflow

The complete-mix system is an idealized model representing hypothetical steady-state conditions and does not reflect local groundwater movement and mixing of salt mass. Such a model is useful to predict overall, steady-state salt average concentrations in the sub-basin. In actuality, groundwater moves along flow paths that are determined by the pore and crack structure in sediments. Spatial variations in salt concentrations arise because groundwater moves along different flow paths. Incomplete mixing may lead to distinct salt plumes that could merit management separately from the overall sub-basin to protect beneficial uses of local groundwater.

Model TDS Concentration Trend to Year 2050

Modeling the Turlock Sub-basin as a complete-mix system allows a simplified and direct understanding of the potential effect that continued salt addition has on groundwater quality. Starting with available groundwater TDS data from 1956 and 1957, Figure 15 depicts the model TDS concentration trend to 2050 assuming a salt loading of 270,000 tons per year to sub-basin groundwater (Table 7).

The 1956 start date was selected for checking the EKI salt balance model because the overall salt loading at that time was likely comparable to the current salt loading of 270,000 tons/yr that EKI estimated based on flow data for 1997 to 2006. The advent of sprinkler technology in the 1950s made irrigation practical in the higher-elevation, eastern portion of the Turlock Sub-basin, expanding the amount of land used for irrigated agriculture (EWD, 2002).

The TDS concentration predicted by the complete-mix system model does not represent the amount of dissolved salt in groundwater at a given location in the sub-basin, but the concentration that would be obtained if the total mass of salt in fresh groundwater could be uniformly mixed with all of the fresh groundwater in the sub-basin. A geometric mean TDS concentration of 330 mg/L was calculated from mineral data compiled in 1956 and 1957 as presented in Davis and Hall (1959).[17] This mean concentration gave an initial value for checking against the salt balance's projections of TDS concentration increases in groundwater.

The projected TDS concentration trend based on EKI's preliminary salt balance model (Figure 15) indicates that sub-basin groundwater is a sink for excess salt loading. If the estimated salt loading derived from the salt mass balance is representative of actual

[17] Statistical analysis shows the data to be log-normally distributed.

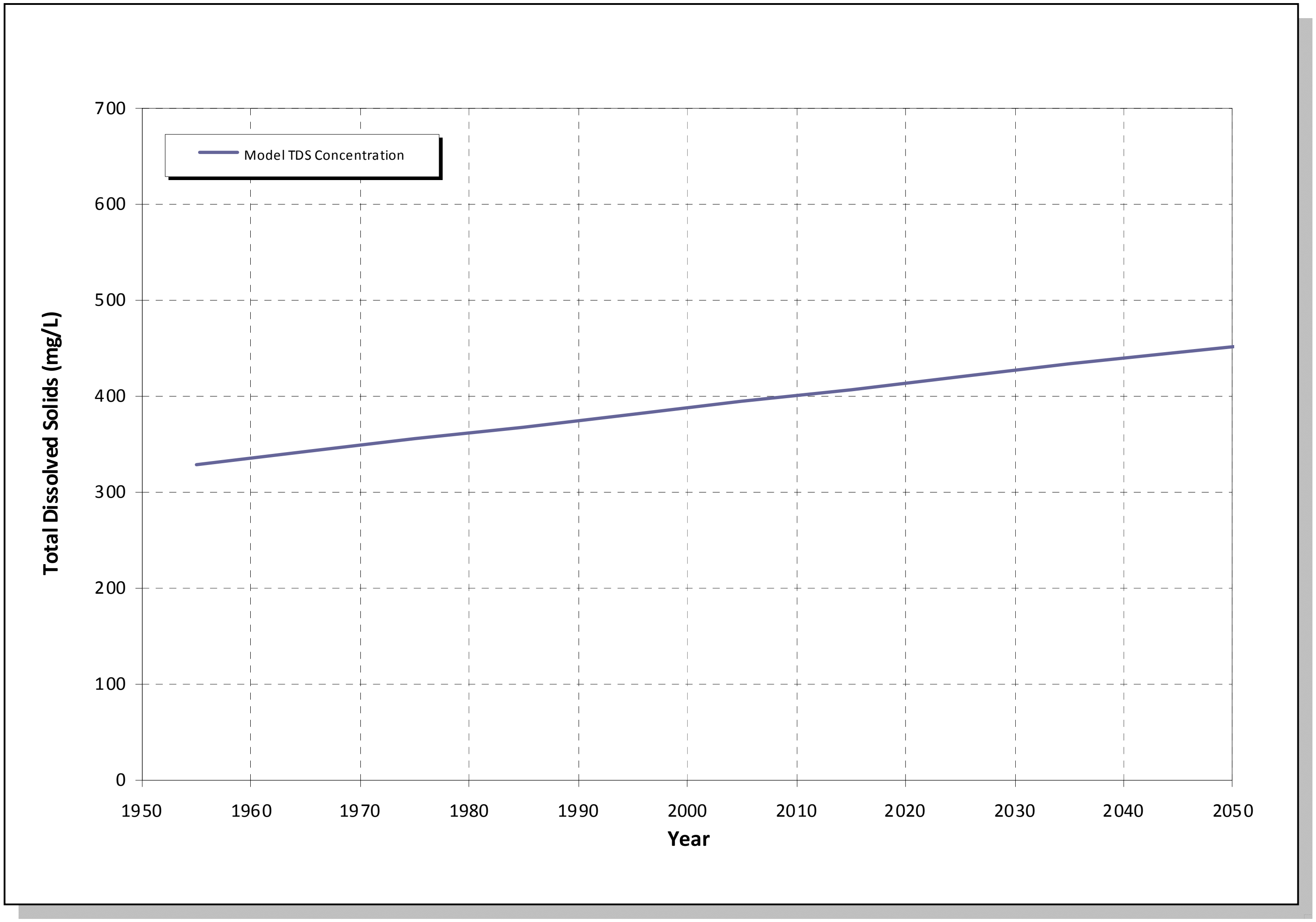


FIGURE 15 – MODEL GROUNDWATER TDS CONCENTRATION TREND TO YEAR 2050

Figure depicts the model total dissolved solids (TDS) concentration trend from 1956 to 2050 assuming a salt loading of 270,000 tons/yr to sub-basin groundwater. Groundwater quality will continue to degrade if with this salt loading is maintained.

conditions, sub-basin groundwater quality will continue to degrade due to a salt loading of roughly 270,000 tons annually, which adds a net excess of 57,000 tons per year to the saturated zone.

Comparison of Model TDS Concentration Trend to Available Data

Figure 16 focuses on the model TDS concentration trend from 1956 to 2010. For comparison, the 1910 TDS data set also is shown on this figure. The salt loading of 270,000 tons/yr is projected to result in an annual increase of 1.3 mg/L in the average TDS concentration in sub-basin groundwater. The plausibility of this projection was assessed by comparing the modeled TDS concentration trend with actual TDS concentration data sets available for Turlock Sub-basin wells.

Figure 16 shows the geometric mean TDS concentrations in Turlock Sub-basin groundwater for the log-normally distributed data sets obtained in 1910 (USGS, 1916), 1956/1957 (Davis and Hall, 1959), 1973 (USGS, 1973), and 2006 (USGS, 2008b). Along with the plotted TDS concentration trend line, this figure also plots the 95 percent confidence intervals for the geometric means.

The geometric mean TDS concentration for sub-basin groundwater has increased to 370 mg/L from 329 mg/L between 1956/1957 and 2006, which corresponds to an increase of roughly 1 mg/L per year. Considerable uncertainty exists in this rate of increase given the scatter in measured TDS concentrations for individual wells. The modeled TDS concentrations of 1.3 mg/L approximates the geometric means of Turlock Sub-basin TDS concentration data for the years 1956/1957, 1973, and 2006, suggesting that the model salt loading of 270,000 tons per year used in the model predictions is plausible.

7 CONCLUSIONS

EKI performed a preliminary salt mass balance on the Turlock Sub-basin to evaluate if salt source contributions can be assessed using a mass balance approach. The salt mass balance involved estimating salt quantities contributed to surface water and groundwater by identified sources located within the sub-basin.

The resulting mass balance was checked by evaluating the predicted rate of increase of groundwater salinity concentrations with the observed rate of increase. The predicted rate of salinity increase is generally consistent with available data, indicating that the

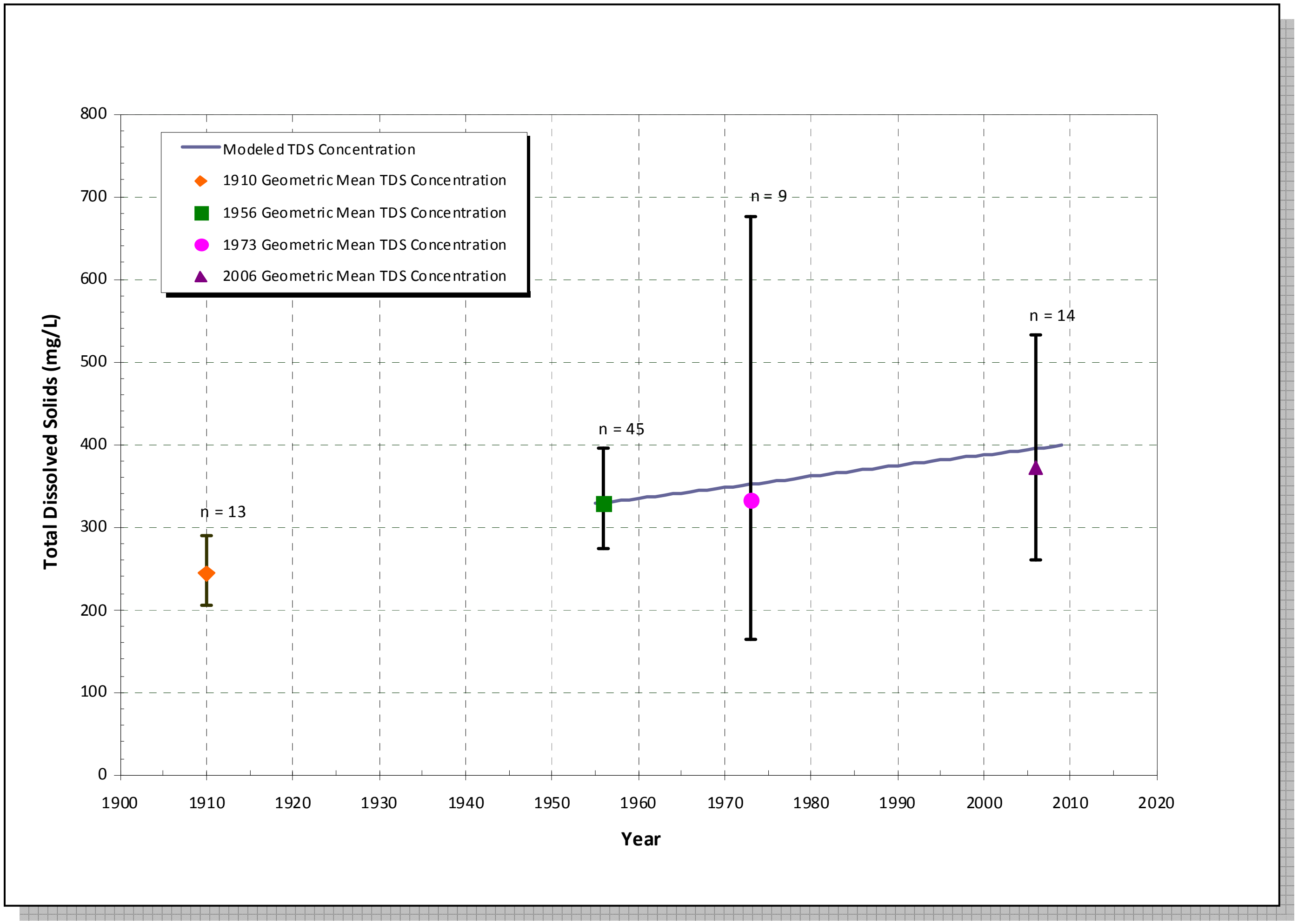


FIGURE 16 – COMPARISON OF MODEL TDS CONCENTRATION TREND TO AVAILABLE DATA

The model total dissolved solids (TDS) concentration trend approximates the geometric means of Turlock Sub-basin TDS concentration data for the years 1956/1957, 1973, and 2006.

major salt sources have been accounted for and that a reasonable salt mass balance for groundwater was achieved.

This finding suggests that publicly-available data may be sufficient to perform similar salt mass balances on other Central Valley sub-basins without collection of extensive new data. The salt mass balance approach can provide a sensible framework for sub-basin salt management because it focuses on the Central Valley's core salinity challenge—more salt is imported into the Central Valley than is exported.

Further work using additional or updated data sources may find that salt loads for individual sources are higher or lower than those estimated herein. However, exact predictions of salt concentrations in surface water and groundwater may not be needed to identify salt sources and their relative impacts on water quality and to develop effective salt management strategies.

This preliminary salt mass balance for the Turlock Sub-basin could be refined. Major stakeholders have extensive knowledge of their respective operations and would be key contributors to an improved mass balance. Further work could include:

- Detailed water and salinity mass balances at representative food processors, CAFOs, and municipalities,
- Mineral dissolution studies to quantify the effects of local soil and water types on salt loading, and
- Evaluation of the local estimated salt contribution of fertilizers and soil amendments.

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APPENDIX A

TABLE A-1
REPORTED LAND USES

Turlock Sub-basin, California

Land Use	Area (acre)	Reference	Area (acre)	Reference	Area (acre)	Reference	Area (acre)	Reference
Urban Development	20,000	TGBA, 2008			7,000 (d)	USGS, 2004		
Foothills	69,000	TGBA, 2008			56,000 (e)	USGS, 2004		
Riparian Habitat	13,000 (a)				17,000 (f)	USGS, 2004		
Irrigated Lands	245,000	TGBA, 2008	251,000 (b), (c)	DWR, 2000	231,000 (g)	USGS, 2004	234,500	ICF, 2008
Total Land in Sub-basin	**347,000**		**347,000**		**311,000**		**347,000**	

References:

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Notes:

(a) Calculated as the difference between total acreage in the Turlock Groundwater Sub-basin and acreage used for urban development, irrigated lands, and native vegetation in foothills reported by TGBA (2008).

(b) Value cited is the equivalent irrigated crop land, which includes multi-cropped land. DWR (2000) reports that the actual land area irrigated for the purpose of growing crops was 231,000 acres in 2000.

(c) Refer to Table A-2 for DWR (2000) breakdown of irrigated land by crop types.

(d) Urban development reported as Ceres urban subarea.

(e) Native vegetation calculated as the Foothills north of Merced River subarea plus the difference between the total areas and irrigated crop lands of TID, EWD, and MER-N subareas.

(f) Riparian habitat calculated as the difference between the total areas and irrigated crop lands of RIP-T, RIP-M, and RIPSJ-TS subareas.

(g) Total irrigated crop area, including multi-cropped land, for Turlock Irrigation District (TID), Eastside Water District (EWD), Merced Irrigation District north of the Merced River (MER-N), Tuolumne River riparian (RIP-T), Merced River riparian (RIP-M), and San Joaquin River riparian south of Tuolumne River (RIPSJ-TS) subareas.

TABLE A-2
DEPARTMENT OF WATER RESOURCES DERIVATION OF EVAPOTRANSPIRATION OF APPLIED WATER TO IRRIGATED LANDS

Turlock Sub-basin, California

Crop Type	Area (acre)	Effective Precipitation (ft/yr)	Effective Precipitation (acre-ft/yr)	Applied Water (a), (b) (ft/yr)	Applied Water (a), (b) (acre-ft/yr)	Evapotranspiration (ft/yr)	Evapotranspiration (acre-ft/yr)	Evapotranspiration of Applied Water (ft/yr)	Evapotranspiration of Applied Water (acre-ft/yr)
Food Crops									
Sugar beet	100	0.7	100	1.89	200	2.2	200	1.5	200
Dry bean	2,400	0.3	700	2	4,800	1.8	4,300	1.5	3,600
Other field crops (e.g., flax, hops, sorghum, sunflowers, and millet)	6,500	0.4	2,600	2.4	15,600	1.9	12,400	1.5	9,800
Fresh tomatoes (i.e., tomatoes for market)	300	0	0	2.4	700	1.8	500	1.8	500
Cucurbits (e.g., melons, squash, and cucumbers)	1,000	0	0	2.4	2,400	1.6	1,600	1.6	1,600
Onions and garlic	100	0	0	3.82	400	2.9	300	2.9	300
Other truck crops (e.g., artichokes, asparagus, spinach, and berries)	11,900	0	0	1.25	14,900	0.9	10,700	0.9	10,700
Almonds and pistachios	84,400	0.55	46,400	3.18	268,400	3.15	265,900	2.55	215,200
Other deciduous crops (e.g., apples, apricots, cherries, and walnuts)	17,700	0.6	10,600	3.55	62,800	3.3	58,400	2.7	47,800
Subtropical crops (e.g., oranges, lemons, pears, dates, and olives)	200	0.6	100	2.82	600	2.7	500	2.1	400
Wine, table, and raisin grapes	14,500	0.7	10,200	1.94	28,100	2.2	31,900	1.6	23,200
Total Food Crops	139,100		70,700		398,900		386,700		313,300
Forage Crops									
Grain (e.g., wheat, barley, oats, grain, and hay)	17,300	0.7	12,100	1.32	22,800	1.6	27,700	0.9	15,600
Corn (e.g., field and sweet corn)	49,800	0.4	19,900	2.44	121,500	2.1	104,600	1.7	84,700
Alfalfa (e.g., alfalfa and alfalfa mixtures)	21,500	0.6	12,900	4.5	96,800	3.6	77,400	3	64,500
Pasture (e.g., clover, turf farms, and bermuda, rye and klein grasses)	23,300	0.5	11,700	4.5	104,900	3.6	83,900	3.2	74,600
Total Forage Crops	111,900		56,600		346,000		293,600		239,400
Total Irrigated Lands (c)	**251,000**		**127,000**		**744,900**		**680,000**		**553,000**

TABLE A-2
DEPARTMENT OF WATER RESOURCES DERIVATION OF
EVAPOTRANSPIRATION OF APPLIED WATER TO IRRIGATED LANDS

Turlock Sub-basin, California

References:

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Notes:

(a) DWR (1998) defines applied water as the amount of water from any source needed to meet the demand of the user. Applied water includes the volume of water delivered to the intake to a city water system or manufacturing facility, and a farm headgate or other point of measurement. Precipitation and seepage from the water supply system prior to reaching the intended user are not included in the volume of applied water.

(b) Applied water is the sum of surface water diverted by water districts, and groundwater extracted by water districts and private entities, as summarized in Table A-3.

(c) Value cited is the equivalent irrigated crop area, which includes multi-cropped acres. DWR (2000) reports that the actual land area irrigated for the purpose of growing crops was 231,000 acres in 2000.

TABLE A-3
REPORTED WATER SUPPLY FLOWS

Turlock Sub-basin, California

Flow Description	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference
Groundwater Extraction						
Pumping by Water Districts						
Turlock Irrigation District	83,000	TGBA, 2008	77,000	USGS, 2004		
Total Water District Pumping	83,000		77,000			
Pumping by Private Entities						
Ballico-Cortez Water District	23,000	TGBA, 2008				
Eastside Water District	157,000	TGBA, 2008	195,000	USGS, 2004		
Merced Irrigation District	100	TGBA, 2008	10,000	USGS, 2004		
Turlock Irrigation District	32,000	TGBA, 2008	167,000	USGS, 2004		
Non-District Areas	115,000	TGBA, 2008				
Total Private Pumping	327,000		372,000		204,700 (e)	DWR, 2005a
Pumping by Municipalities						
Ceres	11,000	TGBA, 2008				
Delhi	1,700	TGBA, 2008				
Denair	1,400	TGBA, 2008				
Hickman	300	TGBA, 2008				
Hilmar	1,300	TGBA, 2008				
Hughson	1,400	TGBA, 2008				
Keyes	1,400	TGBA, 2008				
South Modesto	2,500	TGBA, 2008				
Turlock	23,000	TGBA, 2008				
Rural Residential Areas	4,000	TGBA, 2008				
Total Municipal Pumping	48,000		7,000 (b)	USGS, 2004	76,300	DWR, 2005a
Total Groundwater Extraction	**458,000**		**456,000**		**281,000**	DWR, 2005a
Surface Water Diversion						
Merced Irrigation District	20,000	Durbin, 2008; TGBA, 2008	9,000	USGS, 2004		
Turlock Irrigation District	520,000	Durbin, 2008; TGBA, 2008	449,000	USGS, 2004		
Non-district areas			111,000 (c)	USGS, 2004		
Total Surface Water Diversion	**540,000**		**569,000**		**742,400**	DWR, 2005a
Precipitation						
Urban Development	21,000 (a)	TGBA, 2008				
Foothills	71,000 (a)	TGBA, 2008				
Riparian Habitat	13,000 (a)	TGBA, 2008				
Irrigated Lands	253,000 (a)	TGBA, 2008				
Total Precipitation	**358,000**		**384,000 (d)**	USGS, 2009	**426,100**	DWR, 2005b

TABLE A-3
REPORTED WATER SUPPLY FLOWS

Turlock Sub-basin, California

References:

Department of Water Resources (DWR). 1 December 2005a. S*an Joaquin River Hydrologic Region - Middle Valley East Side* Planning *Area (PA 608), Water Use and Distribution of Dedicated Supplies* . http://www.waterplan.water.ca.gov/planningareas/sjr/index.cfm. Accessed 5 October 2009.

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USGS. 2009. *Groundwater Availability of the Central Valley Aquifer, California* . Professional Paper 1766.

Notes:

(a) Precipitation amounts based upon TGBA (2008) land use areas summarized in Table A-1 and an average annual rainfall of 12.39 inches calculated by TGBA (2008) from precipitation data for the Turlock area for 1952 to 2006.

(b) Value cited is groundwater extraction for Ceres urban (URB-C) subarea.

(c) Value cited is the sum of groundwater extraction for Tuolumne River riparian (RIP-T), Merced River riparian (RIP-M), and San Joaquin River riparian south of Tuolumne River (RIPSJ-TS) subareas. These subareas consist of land that is not included within water districts serving the Turlock Groundwater Sub-basin.

(d) Precipitation amounts based upon the average annual rainfall for 1962 to 2003.

(e) Value cited is total volume of groundwater extracted in 2000. USGS (2005a) did not break down the volume by amounts pumped by water districts and private entities.

TABLE A-4
REPORTED WATER LOSS FLOWS

Turlock Sub-basin, California

Flow Description	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference
Evapotranspiration						
Urban Development					26,200	DWR, 2005
Foothills and Native Vegetation						
Riparian Habitat	41,500	TGBA, 2008	70,000	USGS, 2004		
Irrigated Lands			597,000	USGS, 2004	541,700	DWR, 2005
Total Evapotranspiration	**41,500**		**667,000**		**567,900**	
Water Supply Evaporation						
Irrigation Canals					48,300	DWR, 2005
Turlock Lake						
Total Evaporation					**48,300**	
Irrigation Recharge						
Urban Development	18,000	TGBA, 2008	4,000	USGS, 2004		
Riparian Habitat			41,000	USGS, 2004		
Irrigated Lands	375,000	TGBA, 2008	298,000	USGS, 2004		
Total Irrigation Recharge	**393,000**		**343,000**		**407,200**	DWR, 2005
Precipitation Recharge						
Urban Development			2,000	USGS, 2004		
Foothills and Native Vegetation	22,000	TGBA, 2008	13,000	USGS, 2004		
Riparian Habitat			33,000	USGS, 2004		
Irrigated Lands			184,000	USGS, 2004		
Total Precipitation Recharge	**22,000**		**232,000**			
Water Supply Seepage						
Turlock Lake	62,000	TGBA, 2008	900	USGS, 2004		
Irrigation Canals	38,000	TGBA, 2008	800	USGS, 2004		
Total Seepage	**100,000**		**1,700**			

References:

Department of Water Resources (DWR). 1 December 2005. S*an Joaquin River Hydrologic Region - Middle Valley East Side* Planning *Area (PA 608), Water Use and Distribution of Dedicated Supplies* . http://www.waterplan.water.ca.gov/planningareas/sjr/index.cfm. Accessed 5 October 2009.

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TABLE A-5
REPORTED GROUNDWATER DISCHARGE TO SAN JOAQUIN RIVER

Turlock Sub-basin, California

Flow Description (a)	Reference		
	J&S, 2005; USGS, 1991	CVRWQCB, 2004	TGBA, 2008
Merced River to Crows Landing			
Segment Length (River Mile)	9.6 (b)		
Normalized Groundwater Flow Along Segment (ft^3/s-mi); (c), (d)	0.23 to 0.65		
Total Groundwater Flow Along Segment (acre-ft/yr)	1,600 to 4,500		
Crows Landing to Patterson			
Segment Length (River Mile)	9.2 (b)		
Normalized Groundwater Flow Along Segment (ft^3/s-mi); (c), (d)	0.1 to 0.5		
Total Groundwater Flow Along Segment (acre-ft/yr)	700 to 3,300		
Patterson to Tuolumne River			
Segment Length (River Mile)	15.6 (b)		
Normalized Groundwater Flow Along Segment (ft^3/s-mi); (c), (d)	0.4 to 0.8		
Total Groundwater Flow Along Segment (acre-ft/yr)	4,500 to 9,000		
Total Flow to San Joaquin River			
Segment Length (River Mile)	34.4	50 (e)	
Normalized Groundwater Flow Along Segment (ft^3/s-mi); (c)		0.29 (f)	
Total Flow to San Joaquin River	**6,800 to 16,800**	**10,498**	**30,000**

References:

California Regional Water Quality Control Board, Central Valley Region (CVRWQCB). July 2004. *Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Salt and Boron Discharges into the Lower San Joaquin River, Draft Final Staff Report, Appendix 1: Technical TMDL Report.*

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Timothy J. Durbin, Inc. (Durbin). December 2003. *Turlock Groundwater Basin Water Budget 1952-2002.*

U.S. Geological Survey (USGS). 1991. *Quantity and Quality of Ground-water Inflow to the San Joaquin River, California* . Water-Resources Investigations Report 91-4019.

Notes:

(a) According to Durbin (2003), groundwater inflow occurs along the lower reaches of the Tuolumne and Merced Rivers, and along the entire reach of the San Joaquin River. Groundwater flow from the Turlock Sub-basin is assumed to be equal to the inflow to the San Joaquin River.

(b) Lengths estimated based upon locations of San Joaquin River segments presented in J&S (2005).

(c) Normalized groundwater flow is cubic feet per second (ft^3/s) per each river mile (mi) along segment.

(d) Groundwater flow from the Turlock Sub-basin along each segment is the estimated percentage of groundwater that enters the San Joaquin River from the portion of the shallow unconfined saturated zone situated east of the River. USGS (1991) reports average groundwater flows at Newman, Crows Landing, and Patterson, California are 1.8 to 5 ft^3/s-mi, 1 to 5 ft^3/s-mi, and 2.5 to 5 ft^3/s-mi, respectively, of which 13, 10, and 16 percent of the flows at these locations are attributable to groundwater movement from the shallow unconfined saturated zone east of the San Joaquin River.

(e) Length of San Joaquin River along East Valley Floor Subarea as defined by CVRWQCB (2004).

(f) CVRWQCB (2004) derived flow based upon its review of USGS (1991) study.

TABLE A-6
REPORTED PUBLICLY OWNED TREATMENT WORKS (POTW) EFFLUENT FLOWS

Turlock Sub-basin, California

Flow Description	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference
POTW Surface Water Discharge								
City of Modesto	14,300	TGBA, 2008	12,100	EOA, 2005			14,700	CVRWQCB, 2004
City of Turlock (a), (b)	13,300	TGBA, 2008	11,700	City of Turlock, 2005	11,600	Tulloch, 2002	11,000	CVRWQCB, 2004
POTW Land Application								
Ballico Community Services District (c)								
City of Ceres	2,200	TGBA, 2008						
City of Delhi	700	TGBA, 2008	400	B&V, 2003				
City of Hilmar	500	TGBA, 2008						
City of Hughson	800	TGBA, 2008	1,000	B&V, 2003	900	Quad Knopf, 2007		
City of Turlock Domestic Wastewater	100	TGBA, 2008	570	City of Turlock, 2005				
City of Modesto Domestic Wastewater	11,300	TGBA, 2008	11,100	EOA, 2005	14,600	B&V, 2003		
City of Modesto Food Processor Wastewater (d)			4,700	EOA, 2005	4,500	B&V, 2003	4,300	Carollo, 2007

References:

Black and Veatch (B&V). 25 September 2003. *Water and Wastewater Capacity Needs (Task 2.3)* . Memorandum to William Wong, City of Modesto from Phil Gittens.

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Turlock Groundwater Basin Association (TGBA). 18 March 2008. *Turlock Groundwater Basin, Groundwater Management Plan* .

TABLE A-6
REPORTED PUBLICLY OWNED TREATMENT WORKS (POTW) EFFLUENT FLOWS

Turlock Sub-basin, California

Notes:

(a) Keyes and Denair Community Service Districts and the City of Ceres contract with the City of Turlock for wastewater treatment and disposal. Wastewater generated by these entities is included in the quantity of wastewater discharged by the City of Turlock to surface water.

(b) City of Turlock discharges treated effluent to the Turlock Irrigation District Lateral No. 5, which is also known as the Harding Drain.

(c) Customers within the Ballico Community Services District use septic tank systems for wastewater disposal. No information on the numbers of septic tank systems in Ballico or other areas of the Turlock Sub-basin was located as part of this study performed by Erler & Kalinowski, Inc.

(d) City of Modesto separates cannery process flows from domestic flows. Cannery process flows are routed through the cannery segregated, or "Can Seg" pipeline for land application.

TABLE A-7
REPORTED ELECTRICAL CONDUCTIVITY (EC) AND TOTAL DISSOLVED SOLIDS (TDS)
IN PUBLICLY OWNED TREATMENT WORKS (POTW) EFFLUENT FLOWS

Turlock Sub-basin, California

Flow Description	EC (mS/cm)	TDS Concentration (mg/L)	Reference	EC (mS/cm)	TDS Concentration (mg/L)	Reference	EC (mS/cm)	TDS Concentration (mg/L)	Reference
POTW Surface Water Discharge									
City of Modesto		700 (a)	CVRWQCB, 2004	1,069	502	Carollo, 2007	1,072	732	B&V, 2003
City of Turlock		580 (b)	CVRWQCB, 2004						
POTW Land Application									
Ballico Community Services District									
City of Ceres									
City of Delhi									
City of Hilmar									
City of Hughson	804	559	Quad Knopf, 2007	970	650	B&V, 2003			
City of Modesto Domestic Waste		620	EOA, 2005						
City of Modesto Food Processor Waste		710 (c)	EOA, 2005		852 (c)	Rubin et al., 2007	1,596	680 (d)	B&V, 2003

References:

Black and Veatch (B&V). 25 September 2003. *Water and Wastewater Capacity Needs (Task 2.3)* . Memorandum to William Wong, City of Modesto from Phil Gittens.

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TABLE A-7
REPORTED ELECTRICAL CONDUCTIVITY (EC) AND TOTAL DISSOLVED SOLIDS (TDS) IN PUBLICLY OWNED TREATMENT WORKS (POTW) EFFLUENT FLOWS

Turlock Sub-basin, California

Notes:

(a) TDS concentration was calculated by dividing 13,971 tons of salts by 14,730 acre-ft of water that CVRWQCB (2004) reports is discharged by the City of Modesto POTW to the San Joaquin River, which equates to an effective TDS concentration of 700 mg/L.

(b) TDS concentration was calculated by dividing 8,650 tons of salts by 11,032 acre-ft of water that CVRWQCB (2004) reports is discharged by the City of Turlock POTW to Turlock Irrigation District Lateral No. 5, which equates to an effective TDS concentration of 580 mg/L.

(c) Brown and Caldwell and Kennedy/Jenks Consultants (2007) state that TDS in food processor wastewater is comprised of typically 40 to 70 percent organic matter that decomposes in soil, as contrasted with inorganic dissolved solids, or fixed dissolved solids (FDS), which are conservative in nature. FDS concentrations for food processor wastewater are reported where available and estimated as 50 percent of TDS when only TDS data have been provided.

(d) FDS concentration estimated based upon an average reported TDS concentration of 1,357 mg/L from 2000 to 2002.

TABLE A-8
REPORTED IRRIGATION DRAINAGE AND RETURN FLOWS

Turlock Sub-basin, California

Flow Description (a), (b)	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference	Flow (acre-ft/yr)	Reference
TID Lateral No. 1	9,400	Stringfellow et al., 2008				
TID Lateral No. 2	3,100	Stringfellow et al., 2008				
TID Lateral No. 3 (Westport Drain)	19,900	Stringfellow et al., 2008				
TID Lateral No. 5 (Harding Drain); (c)	25,300	Stringfellow et al., 2008	23,481	CVRWQCB, 2004		
TID Lateral Nos. 6 and 7	11,800	Stringfellow et al., 2008				
Total Flow Through All Laterals	**69,500**		**73,041**	CVRWQCB, 2004 (d)	**12,000 (e)**	TGBA, 2008

References:

California Regional Water Quality Control Board, Central Valley Region (CVRWQCB). July 2004. *Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Salt and Boron Discharges into the Lower San Joaquin River, Draft Final Staff Report, Appendix 1: Technical TMDL Report.*

Stringfellow, W. et al. May 2008. *San Joaquin Valley Drainage Authority, San Joaquin River Up-Stream DO TMDL Project ERP-02D-P63, Task 4: Monitoring Study, Final Task Report.*

Turlock Groundwater Basin Association (TGBA). 18 March 2008. *Turlock Groundwater Basin, Groundwater Management Plan* .

Notes:

(a) Irrigation drainage and return flows consist of water removed from perforated subsurface pipes, which are designed to lower the groundwater table below the root zones of crops grown on irrigated lands, water (i.e., return flow) that leaves irrigated lands following application of water, and storm water run off from urban development.

(b) Irrigation drainage and return flow exit the Turlock Groundwater Sub-basin through Turlock Irrigation District (TID) drains that discharge to the San Joaquin River.

(c) Flow through Harding Drain includes the flow of treated effluent discharged from the City of Turlock publicly owned treatment works to Harding Drain.

(d) Surface water discharge from entire East Valley Floor Subarea as defined by CVRWQCB (2004).

(e) Value cited consists solely of irrigation drainage. TGBA (2008) does not estimate return flow and storm water volumes discharged to the San Joaquin River.

TABLE A-9
REPORTED ELECTRICAL CONDUCTIVITY (EC) AND TOTAL DISSOLVED SOLIDS (TDS)
IN IRRIGATION DRAINAGE AND RETURN FLOWS

Turlock Sub-basin, California

Flow Description	EC (µS/cm)	TDS Concentration (mg/L)	Reference	EC (µS/cm)	TDS Concentration (mg/L)	Reference	EC (µS/cm)	TDS Concentration (mg/L)	Reference
TID Lateral No. 1	40	26	Stringfellow et al., 2008	750	450 (a)	DWR, 2004			
TID Lateral No. 2	131	85	Stringfellow et al., 2008	400	240 (a)	DWR, 2004			
TID Lateral No. 3 (Westport Drain)	668	434	Stringfellow et al., 2008	650	390 (a)	DWR, 2004			
TID Lateral No. 5 (Harding Drain); (c)	694	451	Stringfellow et al., 2008	870	520 (a)	DWR, 2004		380 (b)	CVRWQCB, 2004
TID Lateral Nos. 6 and 7	641	417	Stringfellow et al., 2008	700	420 (a)	DWR, 2004			

References:

California Regional Water Quality Control Board, Central Valley Region (CVRWQCB). July 2004. *Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Salt and Boron Discharges into the Lower San Joaquin River, Draft Final Staff Report, Appendix 1: Technical TMDL Report.*

Department of Water Resources (DWR). 3 September 2004a. *DSM2-San Joaquin River Extension over the 1990 - 1999 Period* . Memorandum to Tara Smith, Chief, Delta Modeling Section, from Jim Wilde, Engineer, WR, and Bob Suits, Senior Engineer, Delta Modeling Section.

Stringfellow, W. et al. May 2008. *San Joaquin Valley Drainage Authority, San Joaquin River Up-Stream DO TMDL Project ERP-02D-P63, Task 4: Monitoring Study, Final Task Report* .

Notes:

(a) A TDS (in mg/L) to EC (in µS/cm) ratio of 0.6 is frequently used to convert from EC to TDS. Calculated TDS concentrations presented herein were derived by multiplying measured EC values by 0.6.

(b) TDS concentration was calculated by dividing 12,003 tons of salts by 23,481 acre-ft of water that CVRWQCB (2004) reports flows through TID Lateral No. 5 annually, which equates to an effective TDS concentration of 380 mg/L.

(c) EC and TDS data pertaining to the Harding Drain includes effects of treated effluent discharged from the City of Turlock publicly owned treatment works to Harding Drain.