# APPENDIX C

# DETAILED DESCRIPTION OF LINKAGE ANALYSIS DESIGN FLOW CALCULATIONS

# INTRODUCTION

This appendix supplements Section 5 of the *Draft Sacramento and Feather River Diazinon Total Maximum Daily Load Report* (TMDL Report). The appendix was written after the TMDL Report and some errors were found and corrected. The TMDL Report will be updated to reflect these corrections, along with any changes based on comments received from the public.

The appendix provides a detailed description of the methodology used to determine the design flow needed for calculation of the loading capacities in the Sacramento and Feather Rivers. A description of the preparation of the data, prior to application of the methodology, is also given.

# METHODOLOGY USED TO ESTABLISH DESIGN FLOWS

## US EPA's Biologically-Based Method for Determining Design Flows

As discussed in Section 5 of the TMDL Report, the method applied below is adapted from the US EPA's biologically-based method of determining design flows (US EPA, 1986). Since the water quality objective is known (or assumed in this case), the "design flow" is then used to calculate a total allowable load:

Equation 1: $$M_{load} = Q_d \times Cwqc \times f$$

where

$M_{load}$ = total allowable load, lbs/day

$Q_d$ = design flow (1-day or 4-day average), cfs

$C_{wqc}$ = water quality criterion for diazinon, ng/L

$f$ = unit conversion factor, 5.39e-06

The design flow derived from the biologically-based method is based directly on the magnitude, frequency, and duration of the water quality criterion or objective being considered. Since the California Department of Fish and Game criteria are being considered, the allowable frequency at which those criteria can be exceeded is once every three years. The total number of allowable "exceedances" or excursions (R) that can occur in a given time period of "S" years is R = (S/3). The magnitude (highest allowable average concentration) for the criterion maximum concentration (CMC) is 80 ng/l over a one-hour duration and the magnitude for the criterion continuous concentration (CCC) is 50 ng/l average over a four-day duration (Siepmann and Finlayson, 2000).

The biologically-based method assumes that the design flow should be calculated for the worst case condition – low flow. Historical flows records are used to predict future flow conditions. All historic flows for a given site are rank ordered from lowest to highest. The lowest flow that will accommodate no more than the allowable number of excursions (R) is chosen as the design flow. For example, if a 30 year flow record is evaluated, the total number of allowable excursions is R=30/3=10. If the $11^{th}$ lowest flow is chosen as the design flow, there will be 10 flows that are lower. The total allowable load ($M_{load}$) is then calculated based on the $11^{th}$ lowest flow. If $M_{load}$ is present in all flows in the flow record, then there will be 10 occasions (i.e. the 10 lowest flows) when the concentration in the water body is greater than the allowable concentration, $C_{wqc}$.

## Adaptation of the US EPA's Biologically-Based Method for Determining Design Flows

The Regional Board adapted this method for calculating the assimilative capacity of the San Joaquin River for selenium (Karkoski, 1994; McCarthy and Grober, 2001). In that case, the Regional Board considered monthly variations in flow and pollutant discharge, as well as the effect of water year type on the assimilative capacity. Rather than developing a single "design" flow, sixteen design flows were calculated that reflected four different seasons and four different water year types. This adaptation allowed the Regional Board to estimate an acceptable pollutant discharge while recognizing variations in both assimilative capacity and pollutant discharge patterns.

In this report, the biologically-based method is adapted to account for the primary time period of concern. As discussed in Section 2 of the TMDL Report, January and February are the times of highest agricultural use of diazinon on orchards and the period with the most frequent exceedances of the California Department of Fish and Game criteria. Since irrigation does not occur during January and February, the primary mechanism for the off-site movement of diazinon is assumed to be rainfall-runoff. The biologically-based method is, therefore, adapted to focus on January and February and to focus on rainfall events that could trigger runoff.

**Method Description**

The method used to select the design flow follows the procedure described below.

1. Select the water quality criteria of interest. Identify the duration, magnitude, and frequency.
2. Define the sites, events, and time periods of interest.
3. Assemble the flow record for the time period and sites of interest (i.e. January/February)
   a. Estimate flow where data gaps exist.
   b. Calculate flow (e.g. four-day average) for the criteria duration
4. Select flows that occur during events of interest (i.e. "storm" events)
5. Rank order flows from lowest to highest
6. Determine the allowable number of exceedances
7. Pick the $(R+1)^{th}$ ranked flow as the design flow (if R+1 is not an integer it is rounded down to the nearest integer)
8. Calculate the total allowable load using equation 1

**1. Selection of the Water Quality Criteria of Interest. Identification of the Duration, Magnitude, and Frequency.**

As discussed above, the water quality criteria of interest are the California Department of Fish and Game criteria for diazinon. As suggested by the US EPA guidance (1986), the one-hour average criterion can be assumed to be equivalent to a one-day average for purposes of calculating the design flow. To calculate a design flow for the CCC or chronic criterion, four-day average flows will need to be calculated. The allowable frequency of excursions above the criteria is no more than once every three years.[1]

**2. Definition of the Sites, Events, and Periods of Interest.**

Since the method is based on the historical data set, the length of the available historical flow record is critical to site selection. The Sacramento River watershed has many gage stations that measure stage, but few of those stations have a long historic flow record. The sites used were the Feather River near its outlet near the city of Nicolaus, the Sacramento River at the I street bridge in the city of Sacramento (where the Sacramento River enters Sacramento-San Joaquin Delta), and the Sacramento River at the city of Colusa.

The Feather River near its outlet was used to determine the design flows and loading capacity for all sources of diazinon to the lower Feather River. The Sacramento River at the City of Sacramento was used to determine the design flows and loading capacity for the all sources of diazinon to the lower Sacramento River. Elevated diazinon

[1] The allowable frequency of exceedance (or excursions) expresses the frequency at which the criteria can be exceeded over time. More than one excursion can occur in a given three year period as long as over a long period of time (S years), the ratio of excursions (R)/years (S) is less than 1/3.

concentrations have been observed in the Sacramento River as far north as Red Bluff (Holmes et al., 2000). The gage station on the Sacramento River at the city of Colusa is located approximately halfway between Red Bluff and the city of Sacramento. Significant diazinon concentrations and loads have been observed in the Sacramento River at the city of Colusa (Holmes et al., 2000). There is a long historical flow record for this site, and flows in the Sacramento River at this location are significantly different than the flows at the city of Sacramento. Therefore, the Sacramento River at Colusa is an appropriate location to establish maximum loading capacities.

#### a. Minimum Storm Event Determination

As discussed above, the period of interest is January and February. The events of interest are rainfall-runoff events, which are assumed to cause diazinon to runoff into streams. Not all rainfall events will trigger runoff, so it was necessary to define a "storm" event that would cause diazinon runoff. It was assumed that the effect of a storm event may last for several days while diazinon runoff from the upper part of the watershed travels to downstream sites. Once a minimum "storm" event is defined, only those historical rainfall events that are equal to, or larger than the minimum "storm" event would produce significant diazinon runoff, hence, only flows that occur during these "storm" events need be considered.

To determine what type of minimum "storm" event would result in runoff of diazinon at levels of concern, the historic water quality data available for the three sites was evaluated. Several different storm events were defined and, based on these definitions, the frequencies of exceedances of various diazinon concentration levels were evaluated.

A minimum "storm" event was defined as the day that at least a given level of precipitation fell, plus a defined number of days after the rainfall event. For example, a "storm" event could be defined as a day in which at least 0.5 inches of rain fell, plus the following two days. The water quality data available for those three days would be compared to different concentration levels and the frequency at which given concentration levels were exceeded was determined.

The observed effect of a rainfall-runoff event (i.e., the concentration at a particular site) is a complex cumulative effect of what occurs upstream of that site. Therefore, precipitation measurements taken upstream of the sites of interest were used to define "storm" events. For the Sacramento River at Colusa, rainfall measurements at Red Bluff were used. For both the Feather River site and the Sacramento River at the city of Sacramento, Marysville rainfall measurements were used.

The time it takes water to flow from one site to another (travel time) was also taken into consideration. Since the travel times of water from Red Bluff to Colusa and from Marysville to the city of Sacramento are both about one day, the minimum "storm" definition was adjusted accordingly. For example, if 0.5 inch of rain fell on Red Bluff on January 15, the concentration of diazinon at the Colusa site on January 16 would be "selected" as the first day of the "storm" event.

The results from the evaluation of different definitions of "storm" event are presented below.

Table 1. Evaluation of Diazinon Concentration Data for Different "Storm" Events for the Feather River near Nicolaus. A total of 54 samples were collected in January and February 1994-2001.

| | "Storm" Event = the day that at least "x" inches of precipitation or more fell at Marysville + the following "y" days | | | |
|---|---|---|---|---|
| | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| % of samples > 30 ng/l occurring during "storm" | 79% | 83% | 63% | 71% |
| % of samples > 50 ng/l occurring during "storm" | 88% | 94% | 76% | 88% |
| % of samples > 80 ng/l occurring during "storm" | 90% | 90% | 80% | 80% |

Sources: Holmes et al., 2000; Larry Walker Associates, 2002; Dileanis et al., 2000; Dileanis, 2002.

Table 2. Evaluation of Diazinon Concentration Data for Different Defined "Storm" Events for the Sacramento River at Colusa. A total of 52 samples were collected in January and February 1994-2001.

| | "Storm" Event = the day after at least "x" inches of precipitation or more fell at Red Bluff + the following "y" days | | | |
|---|---|---|---|---|
| | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| % of samples > 30 ng/l occurring during "storm" | 100% | 100% | 94% | 100% |
| % of samples > 50 ng/l occurring during "storm" | 100% | 100% | 100% | 100% |
| % of samples > 80 ng/l occurring during "storm" | 100% | 100% | 100% | 100% |

Sources: Holmes et al., 2000 ; Dileanis et al., 2000 ; Dileanis, 2002.

Table 3. Evaluation of Diazinon Concentration Data for Different Defined "Storm" Events for the Sacramento River at I Street. A total of 67 samples were collected in January and February 1992-2001.

| | "Storm" Event = the day after at least "x" inches of precipitation or more fell at Marysville + the following "y" days | | | |
|---|---|---|---|---|
| | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| % of samples > 30 ng/l occurring during "storm" | 67% | 76% | 56% | 68% |
| % of samples > 50 ng/l occurring during "storm" | 81% | 86% | 64% | 78% |
| % of samples > 80 ng/l occurring during "storm" | 90% | 100% | 70% | 90% |

Sources: Holmes et al., 2000; MacCoy et al., 1995; Larry Walker Associates, 2002; Dileanis et al., 2000; Dileanis, 2002.

### 3. Assembly of the Flow Record for the Period and Sites of Interest

The Sacramento River at Colusa site has a complete flow record from 1921 to 2000; the Feather River at Nicolaus has a complete flow record from 1951 to 1983; and the Sacramento River at I Street has a complete flow record from 1948 to 1979. Since the operation of major dams could affect the flow regime, completion of dam construction was considered when evaluating the historic record

The major dams controlling releases to the middle and lower Sacramento River are Shasta and Keswick Dams. Shasta Dam was constructed from 1938 to 1945, and all facilities at the dam were finished in 1950. Keswick Dam was constructed from 1941 to 1949. Since Shasta and Keswick dams both were completed by 1950, the data from 1951 through 2000 are used for the hydrologic analysis for the Sacramento River sites. The major dam controlling releases into the lower Feather River is Oroville Dam, which was constructed from 1961 to 1968. Therefore, flows from 1969 through 2000 are used for the hydrologic analysis for the Feather River site.

#### a. Estimation of Flow Where Data Gaps Exist

The Feather River at Nicolaus site has flow data available from 1969 through 1983. For 1984 through 2000, the daily flow rates for the Feather River at Nicolaus are estimated by summing the major contributing flows as gaged at the Feather River at Gridley, the Yuba River at Marysville, and the Bear River at Wheatland. These sites account for most of the total flow in the Feather River. A regression analysis was performed between the measured January and February flows at the Nicolaus site and the estimated January and February flows for 1969 through 1983 in order to more accurately extrapolate the daily

flow rate at Nicolaus from the major contributing gaged flow sites. The results of the regression analysis are shown in Figure C1, below. The resulting equation for estimating the flow in the Feather River near Nicolaus is:

Equation 2: $Q_{\text{Feather-Nicolaus}} \cong 1.12*(Q_{\text{Feather-Gridley}} + Q_{\text{Yuba}} + Q_{\text{Bear}})$

Where:
$Q_{\text{Feather-Nicolaus}}$ = Flow rate in the Feather River at Nicolaus for a particular day.
$Q_{\text{Feather-Gridley}}$ = Flow rate in the Feather River at Gridley
(the previous day's flow rate is used to account for travel time from Gridley to Nicolaus)
$Q_{\text{Yuba}}$ = Flow rate in the Yuba River at Marysville for particular day
$Q_{\text{Bear}}$ = Flow rate in the Bear River at Wheatland for a particular day

Equation 2 was used to develop the flow record for the Feather River at Nicolaus from 1984 through 2000.

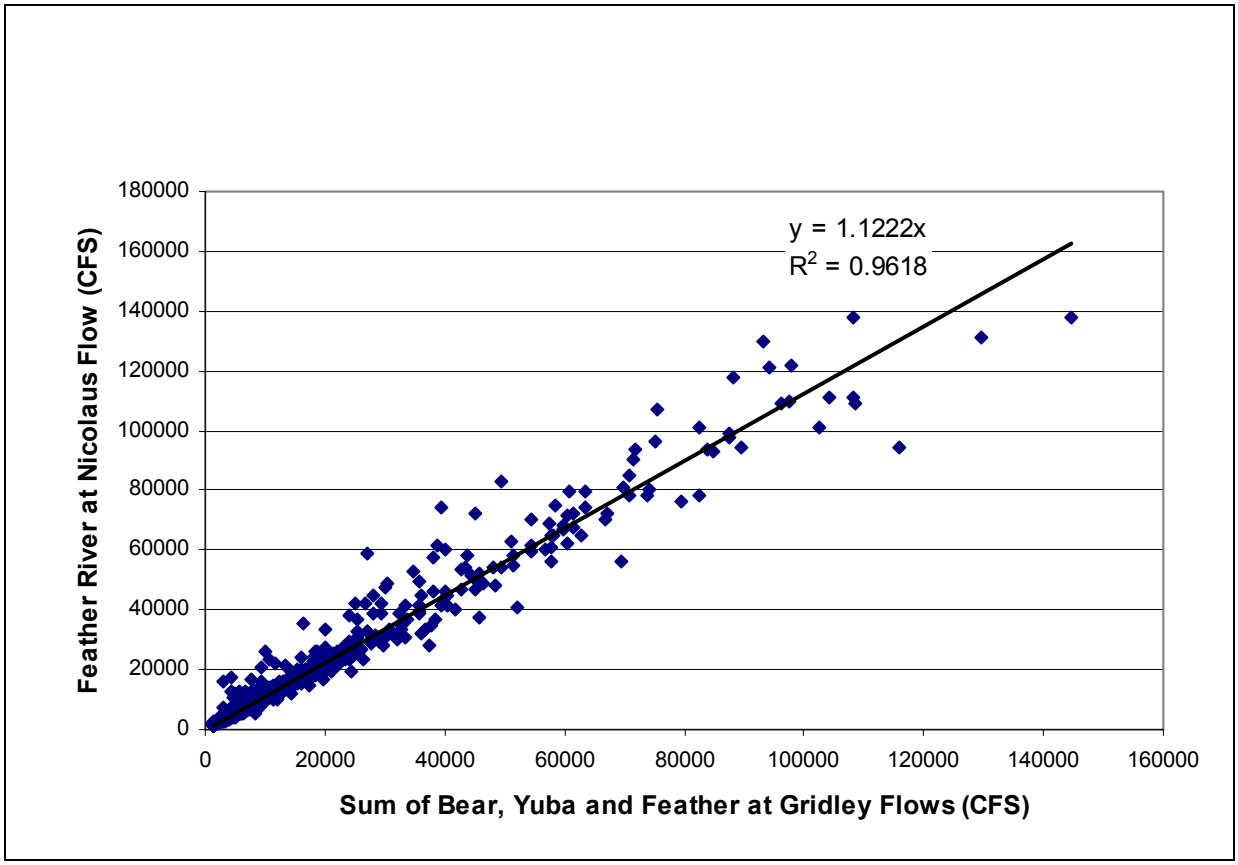


**Figure C1: 1969 - 1983, January and February Feather River Basin Flow Relationship Regression**

The Sacramento River at I Street has flow data available from 1951 to 1979. For the period of 1980-1983, flows from the Sacramento at the city of Freeport were utilized to

represent the flows at I Street because there are no significant inflows between the I street bridge and Freeport and the two sites are relatively close together.

#### b. Calculation of Four Day Average Flows

The daily flow record is used directly to estimate the design flow for the acute criterion. Four-day average flows are used to estimate the design flow for the chronic criterion. The four-day average flow for a given day was found by averaging the mean daily flow for that day and the subsequent three days.

### 4. Selection of Flows that Occur During Events of Interest (i.e. "Storm" Events)

After the "storm" events have been defined and the flow record assembled, the daily flows (for the acute criteria design flow) and four-day average flows (for the chronic criteria) that occurred during the "storm" events during January and February are selected for evaluation.

### 5. Ranking Flows from Lowest to Highest

The daily flows selected in Step 4 are then sorted from lowest flow to highest flow.

### 6. Determination of the Allowable Number of Exceedances

The allowable number of excursions (R) is calculated based on the allowable excursion rate (E) and the total number of years (S) of historical record being evaluated (R = S/E). The historical record being evaluated for the Sacramento River sites extends from 1951 to 2000 (50 years), therefore, R=16.7. The historical record being evaluated for the Feather River site extends from 1969 through 2000 (32 years), therefore R=10.7.

### 7. Selection of the $(R+1)^{th}$ Lowest Ranked Flow as the Design Flow

From the flows selected in Step 4, the $(R+1)^{th}$ lowest ranked flow is picked as the design flow. If R+1 is not an integer it is rounded down to the nearest integer. In this case, the $17^{th}$ lowest flow for the scenario being evaluated is chosen for the Sacramento River at the city of Sacramento and for the Sacramento River at Colusa, and the $11^{th}$ lowest flow is chosen for the Feather River near Nicolaus.

The adjustment suggested by the US EPA methodology to account for drought conditions was also considered. This adjustment limits the number of days in which flows are below the design flow to no more than five in a given year. If there were more than five low flows in a given year, the lowest flows for that year were removed from the flow record until there were only five low flows from that year.

## 8. Calculation of the Total Allowable Load from Equation 1

The results of the design flow calculations and resulting diazinon loads that are obtained using equation 1 are shown in the tables below. Limitations on the number of flows below the design flow are compared to results with no limitations

Table 4. Design flows and total allowable diazinon loads based on California Department of Fish and Game acute criterion (80 ng/l) for the Feather River near Nicolaus. Loads (lbs/day) and flows (cfs) are expressed as a daily average.

| | | "Storm" Event = the day that at least "x" inches of precipitation fell at Marysville + the following "y" days | | | |
|---|---|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| No limits | 1,480 | 1,875 | 1,810 | 2,008 | 1,897 |
| No more than 5 low flows | 1,801 | 1,991 | 1,897 | 2,008 | 1,930 |
| **Total Allowable Load (lbs/day)** | | | | | |
| No limits | 0.64 | 0.80 | 0.78 | 0.87 | 0.82 |
| No more than 5 low flows | 0.78 | 0.86 | 0.82 | 0.87 | 0.83 |

Table 5. Design flows and total allowable diazinon loads based on California Department of Fish and Game chronic criterion (50 ng/l) for the Feather River near Nicolaus. Loads (lbs/day) and flows (cfs) are expressed as a four-day average.

| | | "Storm" Event = the day that at least "x" inches of precipitation fell at Marysville + the following 3 days (for the 4-day average flow). | |
|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" | 0.50" |
| No limits | 1,483 | 2,256 | 2,853 |
| No more than 5 low flows | 1,826 | 2,256 | 2,853 |
| **Total Allowable Load (lbs/day)** | | | |
| No limits | 0.40 | 0.61 | 0.77 |
| No more than 5 low flows | 0.49 | 0.61 | 0.77 |

Table 6. Design flows and total allowable diazinon loads based on California Department of Fish and Game acute criterion (80 ng/l) for the Sacramento River near Colusa. Loads (lbs/day) and flows (cfs) are expressed as a daily average.

| | | "Storm" Event = the day after at least "x" inches of precipitation fell at Red Bluff + the following "y" days | | | |
|---|---|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| No limits | 4,560 | 5,400 | 5,240 | 5,920 | 5,510 |
| No more than 5 low flows | 4,630 | 5,420 | 5,350 | 6,190 | 5,910 |
| **Total Allowable Load (lbs/day)** | | | | | |
| No limits | 1.97 | 2.33 | 2.26 | 2.55 | 2.38 |
| No more than 5 low flows | 2.00 | 2.34 | 2.31 | 2.67 | 2.55 |

Table 7. Design flows and total allowable diazinon loads based on California Department of Fish and Game chronic criterion (50 ng/l) for the Sacramento River near Colusa. Loads (lbs/day) and flows (cfs) are expressed as a four-day average.

| | | "Storm" Event = the day after at least "x" inches of precipitation fell at Red Bluff + the following 3 days (for the 4-day average flow). | |
|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" | 0.50" |
| No limits | 4,583 | 7,235 | 9,345 |
| No more than 5 low flows | 4,665 | 7,235 | 9,345 |
| **Total Allowable Load (lbs/day)** | | | |
| No limits | 1.23 | 1.95 | 2.52 |
| No more than 5 low flows | 1.26 | 1.95 | 2.52 |

Table 8. Design flows and total allowable diazinon loads based on California Department of Fish and Game acute criterion (80 ng/l) for the Sacramento River at I Street. Loads (lbs/day) and flows (cfs) are expressed as a daily average.

| | | "Storm" Event = the day after at least "x" inches of precipitation fell at Marysville + the following "y" days | | | |
|---|---|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" + 2 days | 0.25" + 3 days | 0.50" + 2 days | 0.50" + 3 days |
| No limits | 7010 | 9,870 | 9,600 | 10,600 | 10,300 |
| No more than 5 low flows | 7650 | 9,980 | 9,870 | 10,600 | 10,400 |
| **Total Allowable Load (lbs/day)** | | | | | |
| No limits | 3.02 | 4.26 | 4.14 | 4.57 | 4.44 |
| No more than 5 low flows | 3.30 | 4.30 | 4.26 | 4.57 | 4.48 |

Table 9. Design flows and total allowable diazinon loads based on California Department of Fish and Game chronic criterion (50 ng/l) for the Sacramento River at I Street. Loads (lbs/day) and flows (cfs) are expressed as a four-day average.

| | | "Storm" Event = the day after at least "x" inches of precipitation fell at Marysville + the following 3 days (for the 4-day average flow). | |
|---|---|---|---|
| **Design Flow (cfs)** | All Flow Data | 0.25" | 0.50" |
| No limits | 7,030 | 11,875 | 16,425 |
| No more than 5 low flows | 7,790 | 11,875 | 16,425 |
| **Total Allowable Load (lbs/day)** | | | |
| No limits | 1.89 | 3.20 | 4.43 |
| No more than 5 low flows | 2.10 | 3.20 | 4.43 |

# REFERENCES


Dileanis, P., J.L. Domagalski and K.P. Bennett. 2001. Occurrence and Transport of Diazinon in the Sacramento River and its Tributaries During Three Winter Storms, January-February 2000. USGS Water Resources Investigation Draft Report. 2000.

Dileanis, P. 2002. Data from 2001 dormant spray season water quality monitoring performed by the US Geological Survey and the California Department of Pesticide Regulation (Report is in preparation). US Geological Survey. Sacramento, CA.

Holmes, R., V. de Vlaming and C. Foe. 2000. Sources and Concentrations of Diazinon in the Sacramento Watershed During the 1994 Orchard Dormant Spray Season. Central Valley Regional Water Quality Control Board Staff Report. Sacramento, CA.

Karkoski, J. 1994. A Total Maximum Monthly Load Model for the San Joaquin River. Central Valley Regional Water Quality Control Board Staff Report. Sacramento, CA.

Larry Walker Associates, 2002. Sacramento River Watershed Program (SRWP) Water Quality Database. Larry Walker Associates, April 2002.

MacCoy, D., K.L. Crepeau and K. M. Kuivila. 1995. Dissolved Pesticide Data for the San Joaquin River at Vernalis and the Sacramento River at Sacramento, California, 1991-1994. USGS Open File Report 95-110.

McCarthy, M. and L. Grober. 2001. Total Maximum Daily Load for Selenium in the Lower San Joaquin River. Central Valley Regional Water Quality Control Board Staff Report. Sacramento, CA.

Siepmann, S., and B. Finlayson. 2000. Water Quality Criteria for Diazinon and Chlorpyrifos. California Department of Fish and Game. Office of Spill Prevention and Response. Administrative Report 00-3. 2000.

US EPA (US Environmental Protection Agency). 1986. Technical Guidance Manual for Performing Wasteload Allocations Book VI, Design Conditions: Chapter 1 – Stream Design Flow for Steady-State Modeling. US EPA. Washington, D.C.