DELTA RISK MANAGEMENT STRATEGY

INITIAL TECHNICAL FRAMEWORK PAPER

FLOOD HAZARD ANALYSIS

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Flood Hazard Analysis

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Foreword

The purpose of the Delta Risk Management Strategy (DRMS) Initial Technical Framework (ITF) is to guide the analysis of specific technical topics as they relate to assessing potential risks to Delta levees and assets resulting from various potential impacts (e.g., floods, earthquakes, subsidence, and climate change). These ITFs are considered “starting points” for the work that is to proceed on each topic. As the work is developed, improvements or modifications to the methodology presented in this ITF may occur.

Hydrologic events, such as large storms and storm surges, are a common cause of levee failures in the Delta. Additionally, the consequences of a failure caused by something other than a hydrologic event, such as an earthquake, can also be related to hydrologic conditions at the time of the event. Knowledge on the causes of levee failures, the probabilities of various failure scenarios, and the consequences of failures are needed to develop a strategy for management of the Delta.

The purpose of the hydrologic risk analysis is to produce a set of inflows, tides, and wind waves that represent the full range of hydrologic conditions that existed historically and that could occur in the future. The inflows, tides, and wind waves will allow estimates of water surface elevations (WSEs) throughout the study area. These WSEs will be used by the levee vulnerability group to estimate the probability of levee failure at any location within the study area, including a measure of uncertainty in the estimates.

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1.0 INTRODUCTION

1.1 Background

Hydrologic events, such as large storms and storm surges, are a common cause of levee failures in the Delta. The consequences of a failure caused by something other than a hydrologic event, such as an earthquake, can also be related to hydrologic conditions at the time of the event. Knowledge on the causes of levee failures, the probabilities of various failure scenarios, and the consequences of failures are needed to develop a strategy for management of the Delta.

1.2. Purpose

This Initial Technical Framework (ITF) paper describes hydrologic studies that will be completed for the Delta Risk Management Strategy (DRMS) to evaluate levee failure risks. Specifically, this paper describes the analyses that will be made, the outputs that will be developed, and how the output will be used in the DRMS.

The purpose of the hydrologic risk analysis is to produce a set of inflows, tides, and wind waves that represent the full range of hydrologic conditions that existed historically and that could occur in the future. The inflows, tides, and wind waves will allow estimates of water surface elevations (WSEs) throughout the study area. These WSEs will be used by the levee vulnerability group to estimate the probability of levee failure at any location within the study area, including a measure of the uncertainty in the estimates.

1.3 Scope

Historic data on daily inflows into the study area and tide conditions in San Francisco Bay during the inflows will be collected and analyzed. The data analysis is needed to assure the data set is consistent; that the inflows reflect a consistent set of watershed development and reservoir conditions.

Analyses of historic inflow and tide data will be made for the period of historic record. These analyses will provide estimates of inflows and associated tides for average inflow conditions and flood events with average return frequencies of 5, 20, 50, 100, and 200 years (herein referred to as hydrologic events).

Each of the six (6) hydrologic events will be analyzed for four (4) different climate conditions. Changes in climate conditions in the study area that will be analyzed include rise in sea level and changes in the amount, patterns, and timing of precipitation and snow melt that are expected in the future. Climate conditions that will be analyzed are current conditions and conditions that are expected to exist in the years 2050, 2100, and 2200.

For each of the six hydrologic events and four climate conditions, twelve (12) seasonal subsets of the hydrologic database will be analyzed:

- Summer hydrologic conditions will be analyzed for a wet year, dry year, and average conditions during the period of record.
- Fall hydrologic conditions will be analyzed for a wet year, dry year, and average conditions during the period of record.

- Winter hydrologic conditions will be analyzed for a wet year, dry year, and average conditions during the period of record.
- Spring hydrologic conditions will be analyzed for a wet year, dry year, and average conditions during the period of record.

Historic measurements of WSEs at gauging stations throughout the study area will be collected and correlated with the historic inflows and tides. These correlations will allow estimates of WSEs at the gauging stations for the range of hydrologic events, climates, and seasons that are included in the hydrologic hazard analyses. WSEs at the gauging stations can then be interpolated to provide estimates of WSEs at any location in the study area and the level of uncertainty in the estimates.

Wind waves in the study area will increase the potential for levee overtopping and hydrostatic forces imposed upon the levees. Wind waves will also cause erosion of the levees and their vulnerability to failure, particularly to the landside levee slopes after failure of a levee and flooding of the interior island. Estimates of average and extreme wave heights and wave energy in various zones of the study area will be made for the six hydrologic events and twelve hydrologic seasons for each zone of the study area. Estimated wave heights will be added to the WSE estimates developed from inflows and tides. These WSE estimates, which reflect the full range of inflows, tides and wind waves in the study area, will be used by the levee vulnerability group to assess levee failure potential. The estimates of average hydrologic conditions will be used to evaluate hazards associated with earthquakes and other non-hydrologic events.

Duration of water surface elevations during hydrologic events is a factor that needs to be considered in evaluating the potential for levee failure. As part of the hydrologic hazard analysis, estimates of WSE versus duration will be made. Daily WSE estimates will be made for the period of historic record and WSE-durations calculated for the range of hydrologic events, climate conditions, seasons, and locations in the study area.

1.4 Probabilistic Method

The objective of the hydrologic analysis is to provide an estimate of the water surface elevations in the Delta for a distribution of possible hydrologic conditions. The calculation of water surface elevation can be represented by:

$$WSE_{i,j}=f_j(Q_i,t_i) \qquad (1)$$

where:

$WSE_{i,j}$ = the water surface elevation for inflow condition i at location j.

Qi = inflow condition i

t = tidal condition i

f_j = deterministic function that relates inflow condition to water surface elevations. It could be different for each location j or the same for all locations depending upon the type of relationship used.

The uncertainty associated with Equation 1 is often divided into two types: aleatory and epistemic (Daneshkhah 2004). Aleatory uncertainty is the uncertainty due to the natural variability or stochastic nature of the system. This uncertainty cannot be reduced through data collection or an increase in knowledge. For example, collecting more data or gaining a better understanding of the Delta system will not increase the ability to deterministically predict what the flow will be in the Sacramento River next year or in 100 years. Epistemic uncertainty is the uncertainly associated with a lack of knowledge or understanding of the system. This uncertainty can be reduced through more and better data collection and obtaining a better understanding of the system . An example of epistemic uncertainty would be predicting the water surface elevation in the Sacramento River given a flow rate. In concept the uncertainty in the prediction can be reduced to as small a value as desired through better data collection (e.g., river cross-sections and roughness) and the use of appropriate analytical tools (e.g., Mannings equation, one-dimensional hydraulic models, multi-dimensional model).

If U represents the epistemic uncertainty and V the aleatory uncertainty, the uncertainty in Equation 1 can be represented as (Daneshkhah 2004):

$$WSE(U,V)_{i,j}=f_j(Q(V)_i,t(V)_I, U) \tag{2}$$

The primary source of epistemic uncertainty in the analysis is in the relationship $f(Q,t)$, between flows, tides and the water surface elevations in the Delta. Typically, a model would be calibrated/validated and the results of the validation provide a measure of the uncertainty, or error, in the deterministic model. In addition, the choice of distribution to represent the Delta inflows provides another source of epistemic uncertainty.

In the case of predicting water surface elevations, the aleatory uncertainty can, in concept, be estimated by setting the epistemic variables, U, to a fixed value, that is using a selected deterministic relationship for f (and a selected distribution for Q).

$$WSE(U=u,V)_{i,j}=f_j(Q(V)_i,t(V)_I, U=u) \tag{3}$$

where:

u = a selected relationship for f such as the best estimate or mean estimate, the 95 percentile estimate (i.e., there is a 95% chance that the WSE will be lower than predicted).

For the selected relationship for $f(Q,t)$ the uncertainty is primarily due to the natural variability in the model inputs. Using different relationships for f, an estimate of the epistemic uncertainty can be estimated. As described in the discussion on selection of a relationship for water surface elevation (Section 2) a regression relationship will be developed that will include an estimate of the uncertainty in the regression. A value for the best fit plus a high and low value will be used.

The uncertainty or variability in the inflows to the Delta can be estimated using a probability distribution such as the Log-Pearson Type III, Gumbel, or other distribution, which represents extreme values. If sufficient data were available to properly define the distribution, all the distributions would provide similar values for flow rates. It is anticipated that about 50 to 70 years of data will be available to define the distribution used to represent the variability in Delta inflows. This amount of data should be sufficient such that the choice of distribution will not significantly affect the estimates for frequent events, such as the 2-, 5-, 10-, and 20-year events. Estimates of less frequent events, such as the 100- and 200-year events, may be affected by the choice of distribution. To account for this, a sensitivity analysis will be conducted using several commonly used extreme value distributions. If the prediction of extreme event inflows varies between distributions, a composite distribution that represents the average of the distributions will be generated and used for the final analysis.

1.5 ITF Paper Organization

The hydrologic hazard analyses that will be made for the DRMS studies are described in more detail in the following sections of this ITF paper. Section 2 describes the analyses of study area inflows and tides, water surface elevation estimates for inflows and tides, and WSE-duration estimates.

2.0 INFLOWS, TIDES, AND WATER SURFACE ELEVATIONS

2.1 Physical System/Problem

The Sacramento–San Joaquin Delta is a complicated hydrologic system consisting of 738,000 acres of Delta islands and channels with hundreds of miles of waterways and more than 1,000 miles of levees (DWR 1995). Major inflows into the Delta include Sacramento River and Yolo Bypass, draining over 20,000 square miles (mi^2) north of the Delta; San Joaquin River, draining over 13,000 mi^2 south of the Delta; and East Side streams, such as Mokelumne and Cosumnes Rivers that drain over 1,200 mi^2. In addition there are several smaller streams draining from both the east and west that contribute to flows in the Delta. Table 2-1 provides a summary of some of the major inflows into the Delta.

Table 2-1
Summary of Flows on Major Inflows to Delta

Station	High Flow Months[1]	Mean Flow during High Flow Months (Standard deviation) (cfs)	Peak Flow of Record[2] (second highest) (cfs)	Date of Peak Flow of Record
Sacramento at Freeport (USGS 11447650)	January – March	37,900 (7%)	117,000 (115,000)	Feb 19, 1986 (Jan 3, 1997)
San Joaquin River nr Vernalis (USGS 11303500)	February - June	7,100 (6%)	75,600 (45,100)	Jan 5, 1997 (Mar 7, 1983)
Mokelumne River at Woodbridge (USGS 11325500)	January – June	840 (12%)	5,340 (5,070)	Mar 8, 1986 (Jan 22, 1997)
Cosumnes River at Michigan Bar (USGS 11335000)	January – April	1090 (11%)	93,000 (45,100)	Jan 2, 1997 Feb 17, 1986)
Yolo Bypass nr Woodland (USGS 11453000)	January - February	16,300 (5%)	374,000 (357,000)	Feb 20, 1986 (Jan 3, 1997)

[1] Months that are at least 25% higher than the preceding or following month.
[2] Since construction of New Melones Reservoir in 1979.

cfs = cubic feet per second

High flow runoff patterns vary, with Sacramento River high flows occurring primarily in January and February and San Joaquin River high flows occurring later in the year, from February through June. For the largest events, such as occurred in 1986 and 1997, the same series of rainfall events may cause a peak to occur on all streams flowing into the Delta but the peaks may not occur on or near the same day (note that the peak from the 1986 event on San Joaquin River occurred in mid-March, about one month after the peak on Sacramento River, by which time the Sacramento was at about 65 percent of its peak value).

Levee breaches in the Delta often occur during periods of high tides in the Bay. Herein after, tide is meant to include astronomical tides, storm surges, and other factors, except discharge and waves that influence WSEs. Tides can be normal high tides, such as the spring tides which occur on about a two-week cycle; annual high tides, which occur on about a six month cycle; or storm surges, which are associated with large meteorological events. For a given magnitude and pattern of inflows into the Delta, higher tides result in higher WSEs in the Delta.

Because of the multitude of combinations of inflows and tides that can occur, there is not a unique set of Delta WSEs for a given total inflow into the Delta. For example, a 100-year flow event on the Sacramento River combined with a extreme event on the San Joaquin River and a storm surge in the Bay will not produce the same set of WSEs in the study area as a 100-year flow event on the Sacramento combined with a smaller event on the San Joaquin River and a normal tide in the Bay. For this reason it is essential that a probabilistic method be used to describe the infinite number of possible WSEs in the study area based on the infinite number of possible magnitudes and patterns of inflow and tide.

2.2 Probabilistic Hydrologic Events

2.2.1 Data Gathering, Analysis, and Compilation

Two common causes of levee failures in the Delta are levee overtopping and seepage due to high WSEs. High WSEs are a function of the magnitudes and patterns of Delta inflow and tide levels in the Bay that occurred during the inflows. Thus, important inputs into the DRMS studies will be unbiased representations of the magnitudes and patterns of inflow and concurrent tides that could occur. These estimates, along with consideration of the effects of wind waves, will allow unbiased estimates of WSEs which, in turn, can be used to estimate the likelihood of levee overtopping and/or seepage failures.

For the DRMS studies, we will use historic records of Delta inflows and Bay tides to develop the unbiased representation of hydrologic conditions. Data on inflows into the Delta are available from a number of sources. These sources will be researched to obtain a consistent and reliable record of inflows suitable to the DRMS studies. Figure 2-1 is a plot of daily inflows into the Delta for the 1997 and 1998 water years that illustrates the type of data and tributary inflows that may be obtained and used in the DRMS studies.

Historic inflows into the Delta can be significantly influenced by changes in the watershed that occur during the historic period of record that is analyzed. For example, construction of New Melones Dam in 1979 would reduce flood flows to the Delta and make the record prior to 1979 inconsistent with the more recent record. It is assumed that the available data for daily inflows has not been adjusted to reflect changes in the watershed and that the needed adjustment will be made to the data as part of the DRMS studies. It is assumed that operations of upstream reservoirs will be unchanged in the future. The period of historic record used in the analyses must also be carefully selected so as not to bias the statistical results. For example, the historic records used in the analyses should be as long as possible to include extended droughts or wet years.

Data on Bay tides are available from several gauging stations. The station that will be selected for used in the DRMS studies will be representative of WSEs at the outlet of the study area and have the same period of record as the Delta inflow records. It is anticipated that WSEs in the Bay will be partially correlated with large storm events and associated inflows into the Delta. For smaller storm events, WSEs in the Bay and Delta inflows may be independent. The probability distribution of tide data will be determined such that any correlation between tide and total Delta inflow that exists is preserved. Figure 2-2 illustrates tide data that will be obtained and used in the studies.

Daily records of inflows will be compiled along with the record of daily maximum Bay tides. The inflows will be summed to give a daily record of total inflow into the Delta for the period of record. For the purposes of the DRMS studies, it is assumed that the total inflow into the Delta from all major tributary sources is a measure of the how critical the hydrologic event is to levee failure in the study area.

Once the inflow and tide data have been compiled and reviewed for consistency, it will be divided into the 12 seasonal subsets discussed above:

- Summer hydrologic conditions during a wet year, dry year, and average year.
- Fall hydrologic conditions during a wet year, dry year, and average year.
- Winter hydrologic conditions during a wet year, dry year, and average year.
- Spring hydrologic conditions during a wet year, dry year, and average year.

Dry years may be defined as those years that the total seasonal inflow is less than the inflow exceeded 75 percent of the time and wet years may be defined as those years that the total seasonal inflow is greater than the inflow exceeded 25 percent of the time.

2.2.2 Analysis of Seasonal Inflows and Tides

The records of daily total inflows for each of the 12 seasons will be carefully reviewed to identify and tabulate distinct and relatively infrequent hydrologic events. This tabulation will most likely include more that one event during some years. Thus, a partial series inflow-frequency statistical analysis of the data will be necessary. Several probability distributions will be evaluated, including the Log-Pearson Type III distribution. The Log-Pearson Type III probability distribution is a three-parameter (mean, standard deviation, skew) log distribution that is commonly used for estimating extreme flow events. Since the results of the probability distribution for extreme events may be sensitive to the choice of skew coefficient used in the analysis, several methods of estimating the skew will be used to test sensitivity. Additionally, the magnitude of extreme event values may be sensitive to the probability distribution function that is used (Apel et al. 2004). Uncertainties in the estimates associated with the correct probability distribution function, skew, and other parameters will be determined as part of the analyses. The resulting inflow-frequency distribution for the Delta, which may look something like the illustration in Figure 2-3, can be used to give estimates of extreme hydrologic events that may not have occurred during the period of historic record.

The distribution illustrated in Figure 2-3 will give the magnitude and confidence limits of total inflows into the Delta. We will then determine an array of hydrologic events that includes all possible patterns of inflows and tides for any given total inflow event. This array of events is illustrated by the event tree shown in Figure 2-4. The high, medium, and low values of tide and Delta inflows from each of the contributors to the Delta will be determined from the daily flow values during the period of record being analyzed. Figures 2-5a through 2-5f illustrate how the high, medium, and low values shown in the hydrologic event tree (Figure 2-4) may be determined for the studies. The high, medium, and low values may be the value exceeded 5 percent of the time, the mean value, and the value exceeded 95 percent of the time, respectively, for a given total Delta inflow event. It should be noted that the mean and 5% and 95% exceedance limits shown in Figures 2-5a through 2-5f are not calculated values and are for illustration purposes only.

As shown in Figure 2-4, for each value of total Delta inflow, such as the mean 100-year return period inflow event, there are 243 different patterns of inflow, each coupled with 3 different tides, to give 729 different hydrologic events. Including a high and low estimate of the 100-year total inflow will give 2,187 hydrologic events for each return period total inflow event. If 6 total inflow events are to be evaluated, such as the average and the 5-, 20-, 50-, 100-, and 200-year return period events, the total number of hydraulic events to be evaluated is 13,122.

2.2.3 Analysis of Water Surface Elevations

Once the tide and inflow from each tributary to the Delta is determined for the array of hydrologic events, it is then necessary to calculated WSEs throughout the Delta for each hydrologic event. It is assumed that the water surface elevations can be estimated by use of regression equations developed from historic WSE measurements at existing gauging stations located throughout the study area.

Several existing gauging stations at key locations throughout the study area will be identified. For each of these stations, maximum WSE measurements will be compiled for the period of record that cover the full range of inflow magnitudes for each of the tributaries to the study area.

Using the data on tide and inflow from the various streams and rivers and the data on measured WSE at the gauging stations, a multiple regression analysis of the data will be made for each WSE measuring station to give an equation that can be used to predict WSE for any combination of inflows and tide. The general form of this equation is:

$$WSE_i = aT^{a'} + b(Q_{Sac})^{b'} + c(Q_{Yolo})^{c'} + d(Q_{SJ})^{d'} + e(Q_{Cos})^{e'} + f(Q_{Mok})^{f'} + g(Q_{misc})^{g'} \qquad (4)$$

where

WSE_i = water surface elevation at station “i”

T = tide elevation

Q_{Sac} = Sacramento River inflow

Q_{Yolo} = Yolo Bypass inflow

Q_{SJ} = San Joaquin River inflow

Q_{Cos} = Cosumnes River inflow

Q_{Mok} = Mokelumne River inflow

Q_{misc} = miscellaneous inflow

The coefficients a–g and a’–g’ are determined from the regression analysis.

As an example, a multiple regression analysis of WSE data for San Joaquin River at the Venice Island station (VNI) for the period October 1, 1996, through January 1, 1997, was made for illustration purposes. The result of this analysis is presented in Figure 2-6. Note that the 5% and 95% exceedence limits shown on Figure 2-6 are not calculated, they are estimated for illustration purposes only. As shown in Figure 2-6, predicted WSEs will also have a level of uncertainty that will be determined from the regression analyses.

Once equations are developed for each of the measuring stations, these equations can be used to calculate maximum WSEs, and the uncertainty in the elevations, at each gauging station for each hydrologic event developed from the inflow and tide data. These WSEs will have the same probability of occurrence, and uncertainty, as the tide and inflow events discussed in Section 2.2.2 plus the uncertainty associated with the regression equations. Assuming a low, medium, and high estimate of WSE will be calculated at 12 gauging stations in the study area, the total number of WSEs will be 472,392.

The 472,392 calculated WSEs would be developed for each of the 12 seasons described above and each of the 4 climate conditions discussed above. This will result in a total of 22,674,816 WSEs that will be given to the levee vulnerability group for use in evaluating potential levee failure. It is not likely that all critical levee sections will be located at or near the gauging stations, in which case it is assumed that WSEs at locations between gauging stations can be interpolated. To aid in the interpolation intermediate values of WSE will be calculated using the hydrodynamic model described in the hydrodynamics ITF paper.

The WSEs estimated from inflows and tides do not consider wind waves. Wind wave heights and run up should be added to the estimated WSEs to determine levee freeboards and the potential for levee overtopping by waves. Procedures for estimating wind wave heights and run up are discussed in the wind-wave action ITF paper. Because wind wave heights and run up are a function of wind direction, fetch, and water depth and may vary during a given season, the contribution to high WSEs from wind waves should be considered on a case by case basis when evaluating the potential for failure of any given levee segment.

2.2.4 Analysis of Flow Duration

The longer high WSEs persist in the study area, the greater the likelihood of a levee failure. This factor needs to be considered by the levee vulnerability group. Relationships of historical WSE versus duration will be developed to assist the levee vulnerability group in considering the probability of levee failures.

Using the historic record of daily inflows and tides discussed above and the equation presented above for WSE_i, a daily record of WSE at each of the gauging stations discussed in Section 2.2.3 will be calculated and plotted for each of the seasons discussed above. An illustration of calculated WSE versus time is presented as Figure 2-7 for Venice Island for the period October 1 through December 29, 1996. As shown by Figure 2-7, short- and long-term durations of WSE can be read from the plotted data. Figure 2-7 only illustrates one season (Fall) of WSEs at one location (Venice Island). Assuming 50 years of historical record are available, probabilities of various durations for selected maximum WSEs, and their uncertainty, can be calculated in a manner similar to that used to calculate probabilities of total inflow into the study area. It is expected that durations of high WSEs will be greater during extreme hydrologic events that during less extreme events and any correlation that exists will be preserved.

2.3 Assumptions

1. It is assumed a database of adjusted Delta inflows that reflects a consistent and current set of watershed conditions exists and will be available for the DRMS studies. Unadjusted historic inflow records are available but start before significant changes in the watershed occurred,

such as construction of New Melones Dam and reservoir in 1979. To adjust a historic record to reflect current conditions as part of the DRMS studies would require additional effort that is not included in the anticipated effort. Alternatively, a shorter period of historic record that does not include any major watershed changes and reflects current conditions could be used for the DRMS studies.

2. It is assumed that the total inflow into the Delta from all major tributary sources is a measure of the how critical the hydrologic event is to levee failure in the study area.
3. It is assumed that WSEs at locations between gauging stations can be interpolated.
4. It is assumed that the record of Delta inflows reflect levee failures and flood plain storage outside the study area that routinely occurs during major flood events and that these failures and storage of floodwaters will continue into the future.
5. It is assumed that future operation of the dams and reservoirs will be similar to past operation.
6. It is assumed that the water surface elevations can be accurately estimated by use of regression analysis equations developed from historic WSE measurements at existing gauging stations throughout the study area and that the WSE data set will include several days of high, medium, and low total inflow into the Delta. It may be necessary to supplement the data set with selected hydrodynamic modeling runs. At some locations in the Delta the length of record may not be long, these will be artificially lengthen when possible.

2.4 Engineering/Scientific Models

It is anticipated that some of the data needs can be obtained from the Internet. Most of the analyses can be completed with simple spreadsheet-type models.

2.5 Data Requirements

1. Records of mean daily inflows into the study area from all significant contributors to inflow.
2. Daily maximum tidal measurements in San Francisco Bay for the same period of record as the mean daily inflow data for the study area.
3. Daily maximum water surface elevation data at key locations throughout the study that are concurrent with data on total inflow and tide data for the study area.
4. Estimates of future mean daily inflow for all significant tributaries to the study area for the years 2050, 2100, and 2200 (discussed in the climate change ITF paper).
5. Estimates of the increase in sea level elevations for San Francisco Bay for the years 2050, 2100, and 2200 (discussed in climate change ITF paper).

2.6 Work Products

The work products for this task will be estimates of water surface elevations throughout the study area for the full range of total inflows, patterns of inflows, and tide conditions at the outlet of the study area. These work products will be produced for existing climate conditions and estimated future climate conditions.

The work products of this subtask, along with the estimates of wind wave heights, will be provided to the levee vulnerability group to use is estimating levee freeboards that are available under various flood conditions and the probability of levee failure.

All analyses and work products will be documented in a study report that will include descriptions of the analyses, supporting data and calculations, and study findings.

3.0 REFERENCES

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Figures

FIGURE 2-1: ILLUSTRATION OF DELTA INFLOW DATA (W.Y. 1997-98)

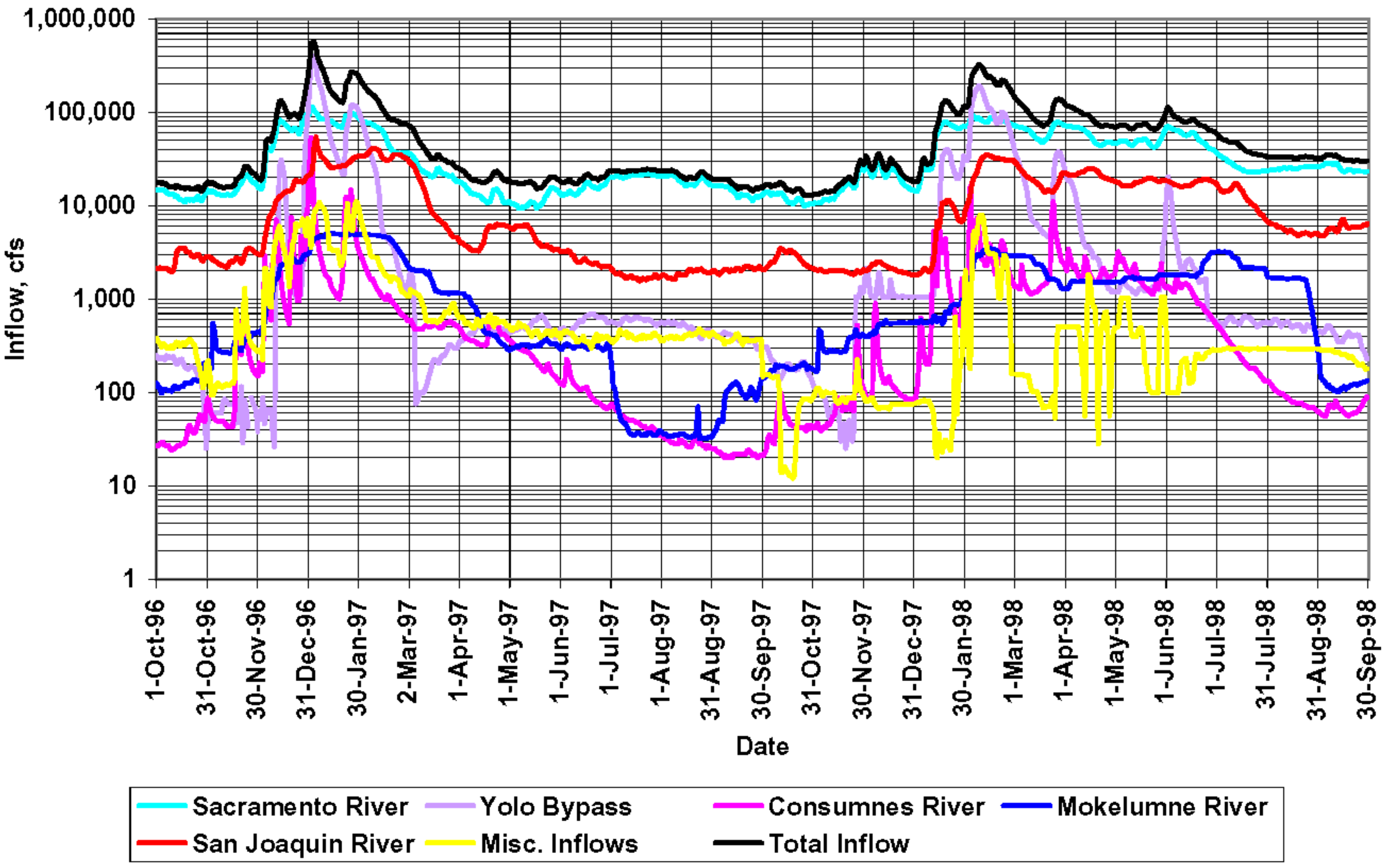


FIGURE 2-2: ILLUSTRATION OF SAN FRANCISCO BAY TIDE DATA (W.Y. 1997-98)

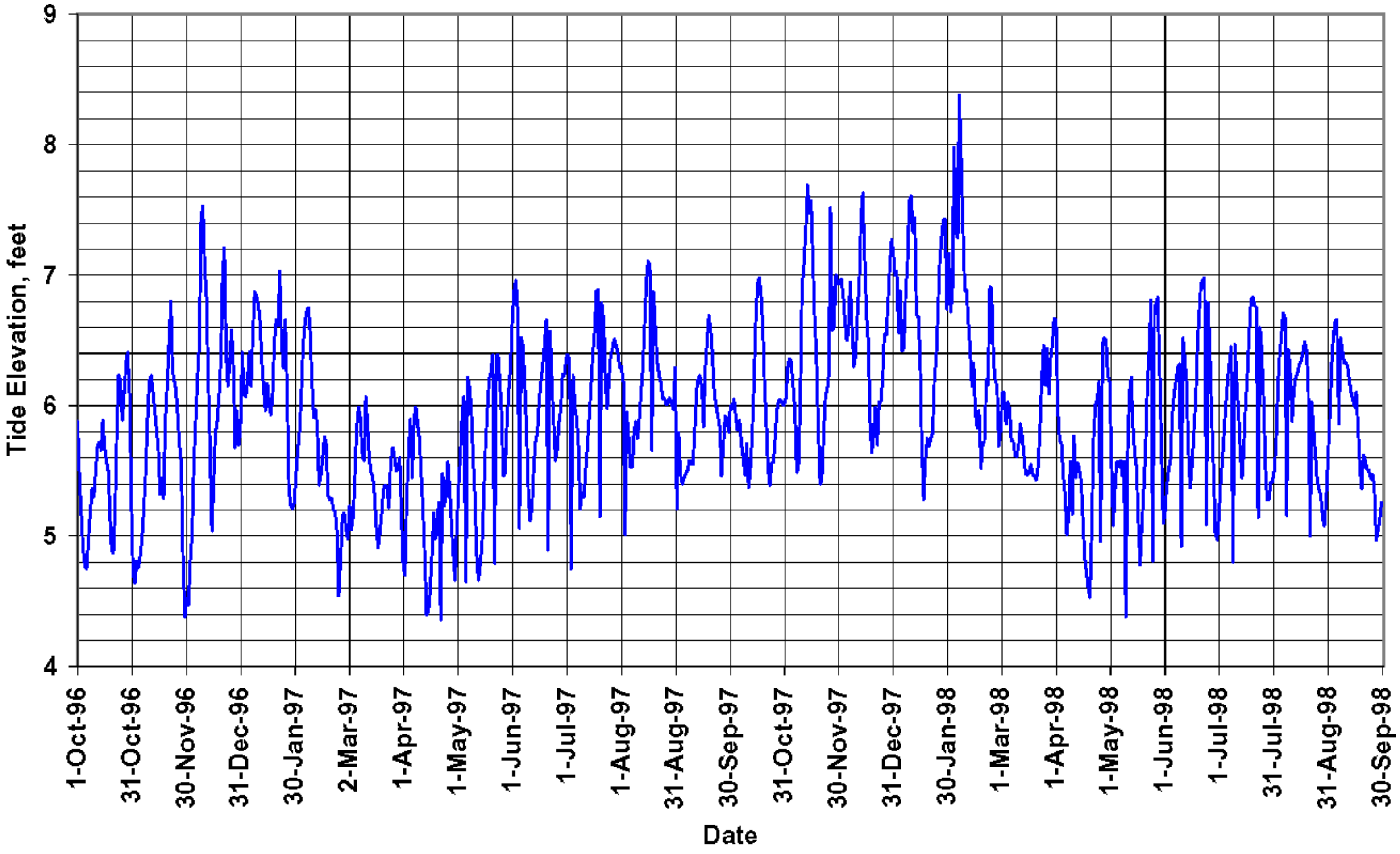


FIGURE 2-3: ILLUSTRATION OF PROBABILITY DISTRIBUTION OF TOTAL INFLOWS INTO DELTA

(Data On Chart Is Assumed - Chart Is For Illustration Purposes Only)

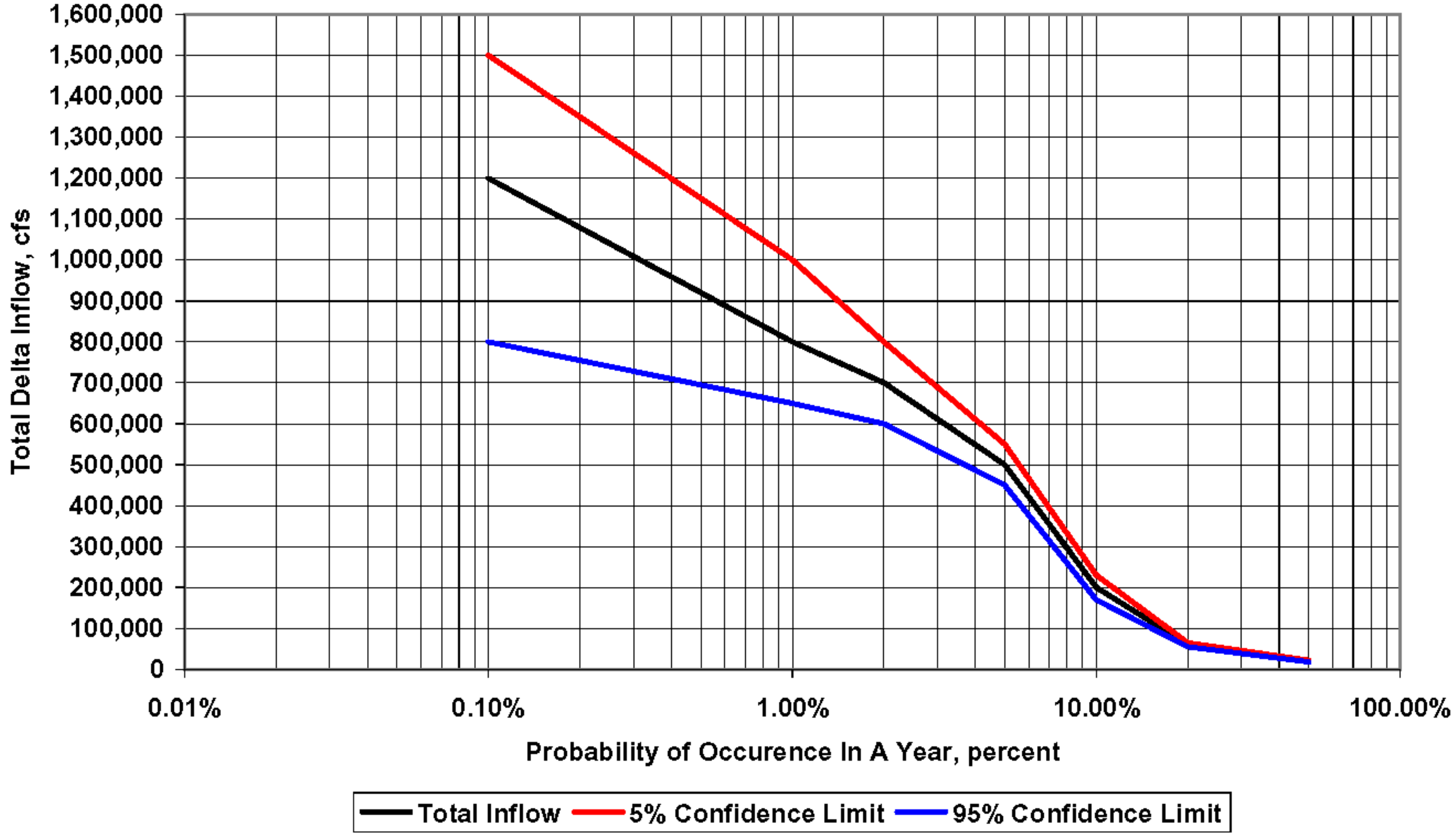
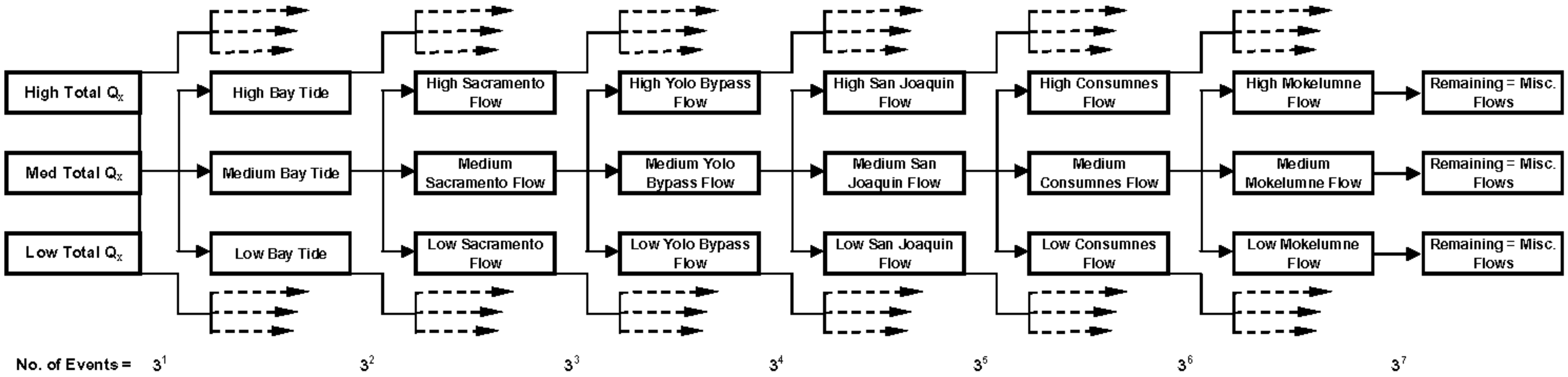


Figure 2-4: Hydrologic Events Tree



Q_x = Total inflow with return frequency x, x = avg., 5, 20, 50, 100, & 200 = 6
Total number of combinations of inflow patterns and tides = $6x3^7$ = 13,122
Assume a low, med. & high WSE @ 12 gauging station = $12x3x6x3^7$ = 472,392
Calculations will be repeated for each of 12 seasons = $12x12x3x6x3^7$ = 5,668,704
Calculations will be made for current year, 2050, 2100 &2200 = $4x12x12x3x6x3^7$ = 22,674,816

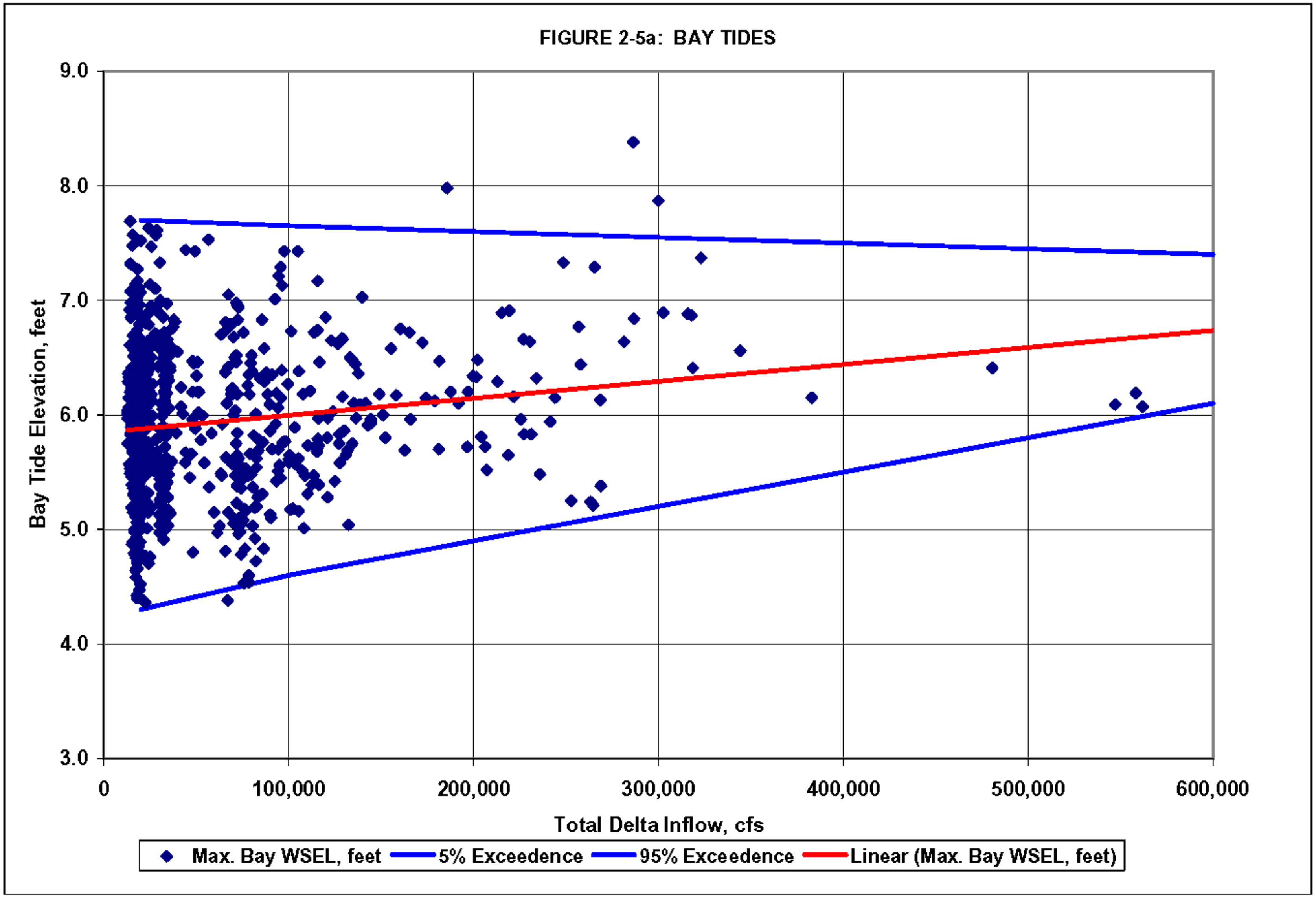


FIGURE 2-5a: BAY TIDES
Bay Tide Elevation, feet
9.0
8.0
7.0
6.0
5.0
4.0
3.0
0
100,000
200,000
300,000
400,000
500,000
600,000
Total Delta Inflow, cfs
◆ Max. Bay WSEL, feet
5% Exceedence
95% Exceedence
Linear (Max. Bay WSEL, feet)

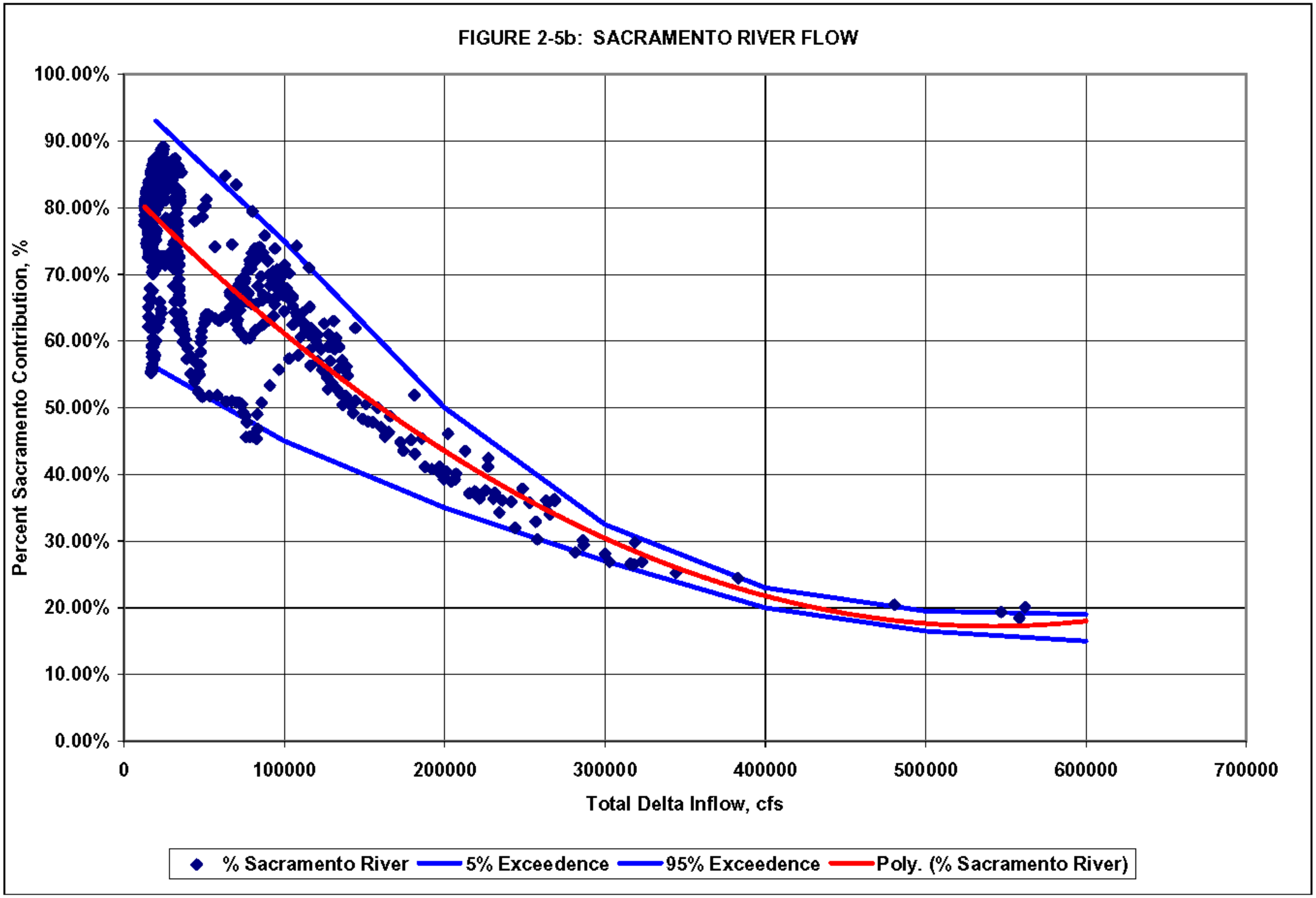


FIGURE 2-5b: SACRAMENTO RIVER FLOW
Percent Sacramento Contribution, %
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0
100000
200000
300000
400000
500000
600000
700000
Total Delta Inflow, cfs
◆ % Sacramento River
5% Exceedence
95% Exceedence
Poly. (% Sacramento River)

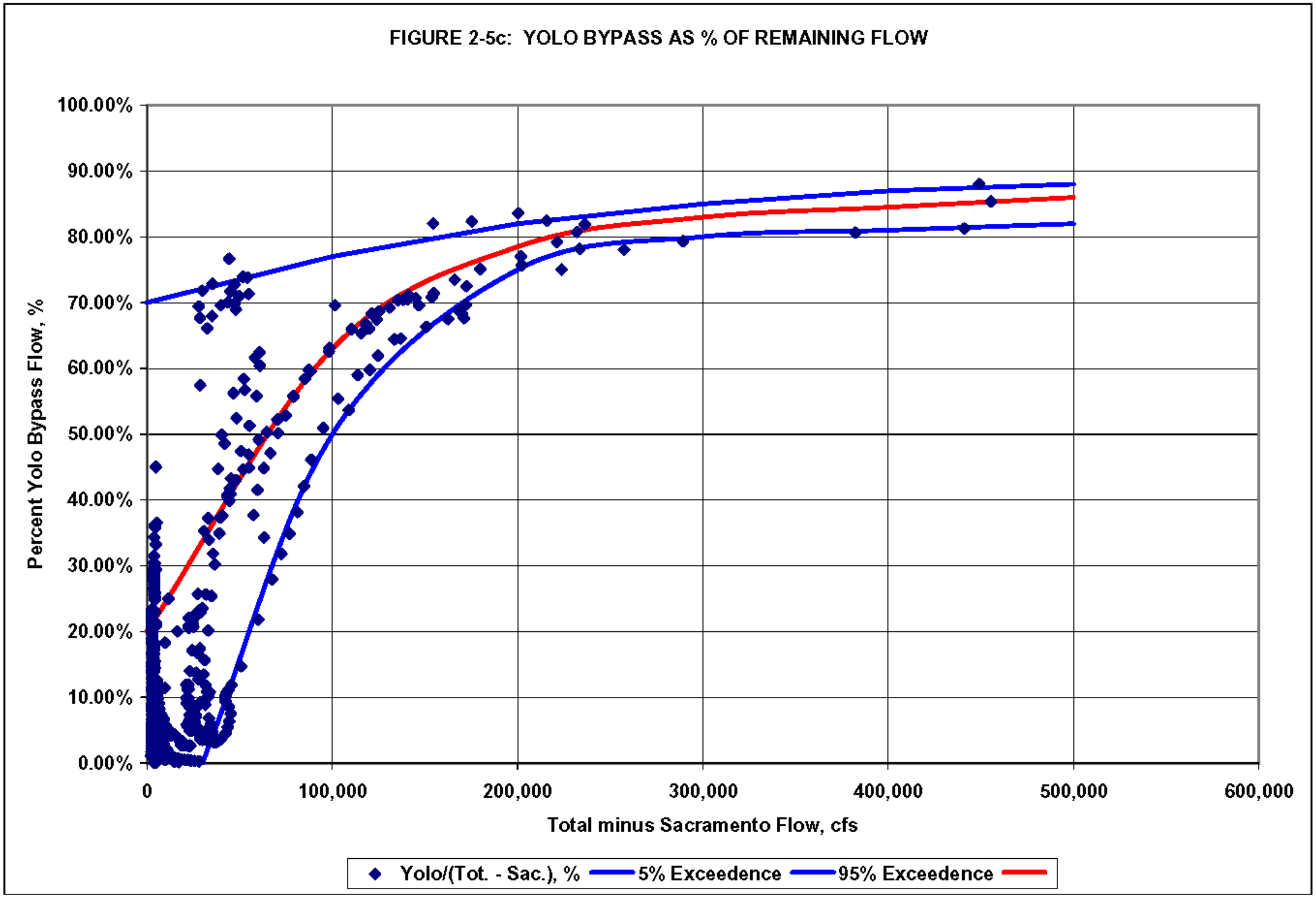
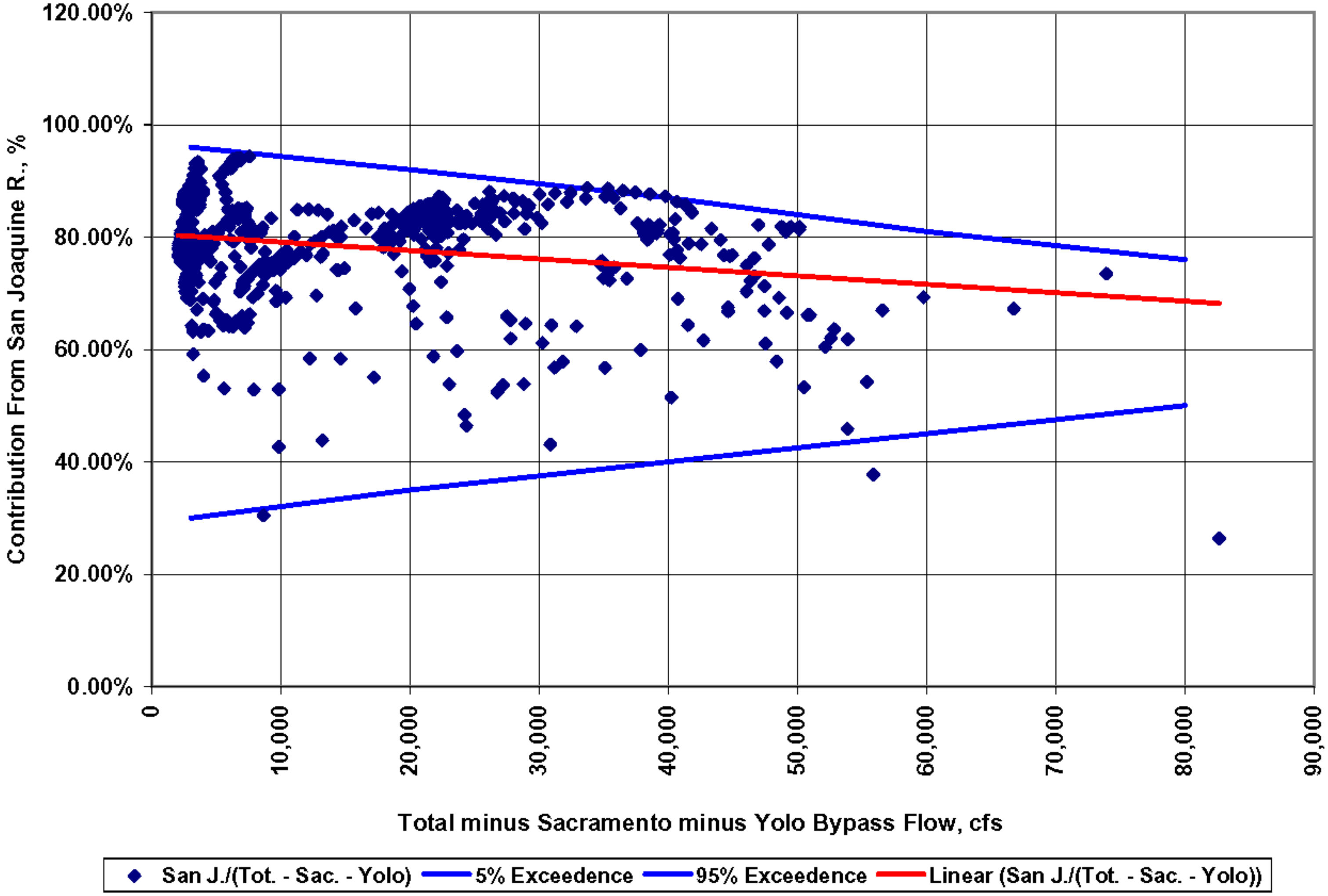


FIGURE 2-5c: YOLO BYPASS AS % OF REMAINING FLOW
Percent Yolo Bypass Flow, %
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0
100,000
200,000
300,000
400,000
500,000
600,000
Total minus Sacramento Flow, cfs
◆ Yolo/(Tot. - Sac.), %
5% Exceedence
95% Exceedence

FIGURE 2-5d: SAN JOAQUIN AS % OF REMAINING FLOW



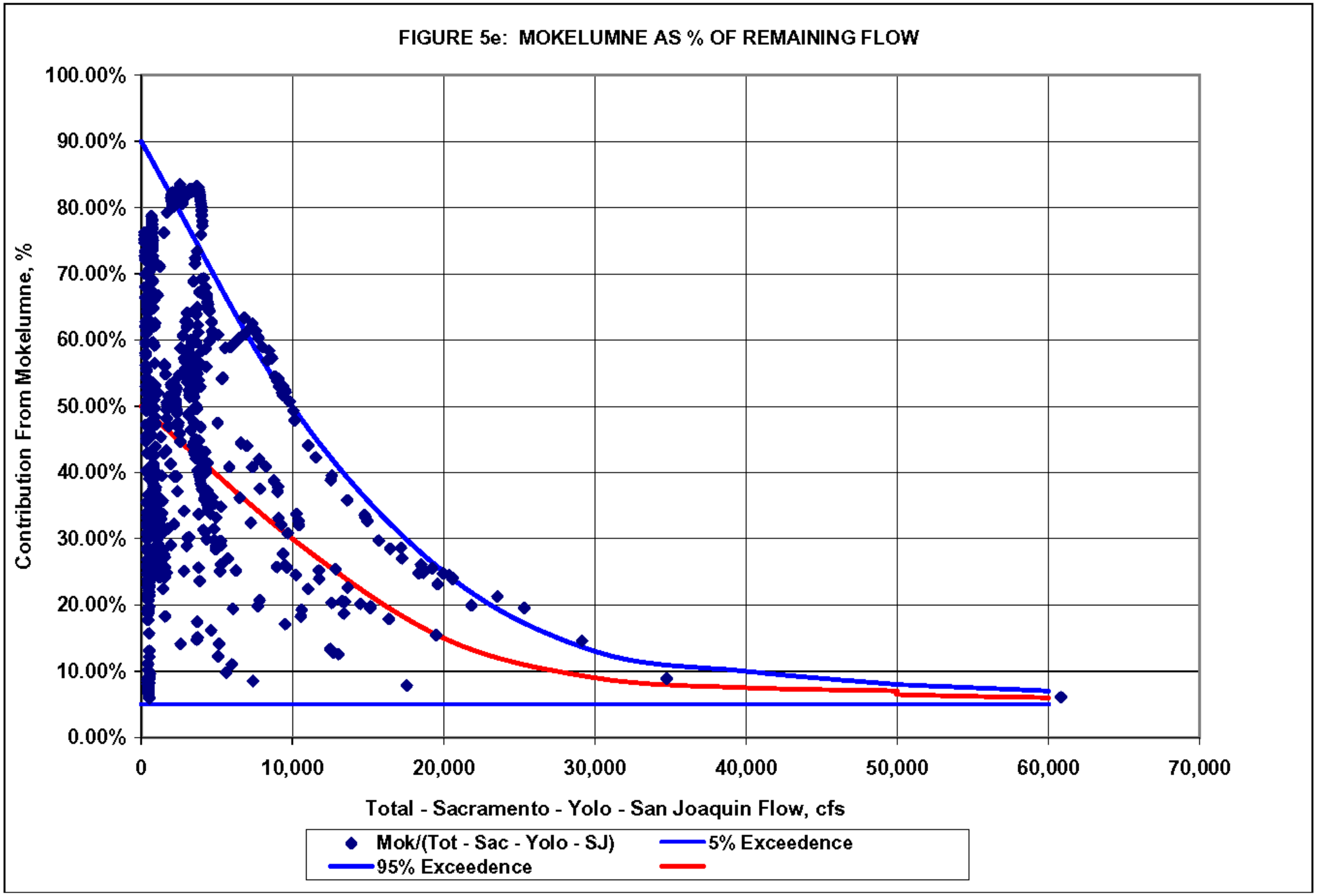


FIGURE 5e: MOKELUMNE AS % OF REMAINING FLOW

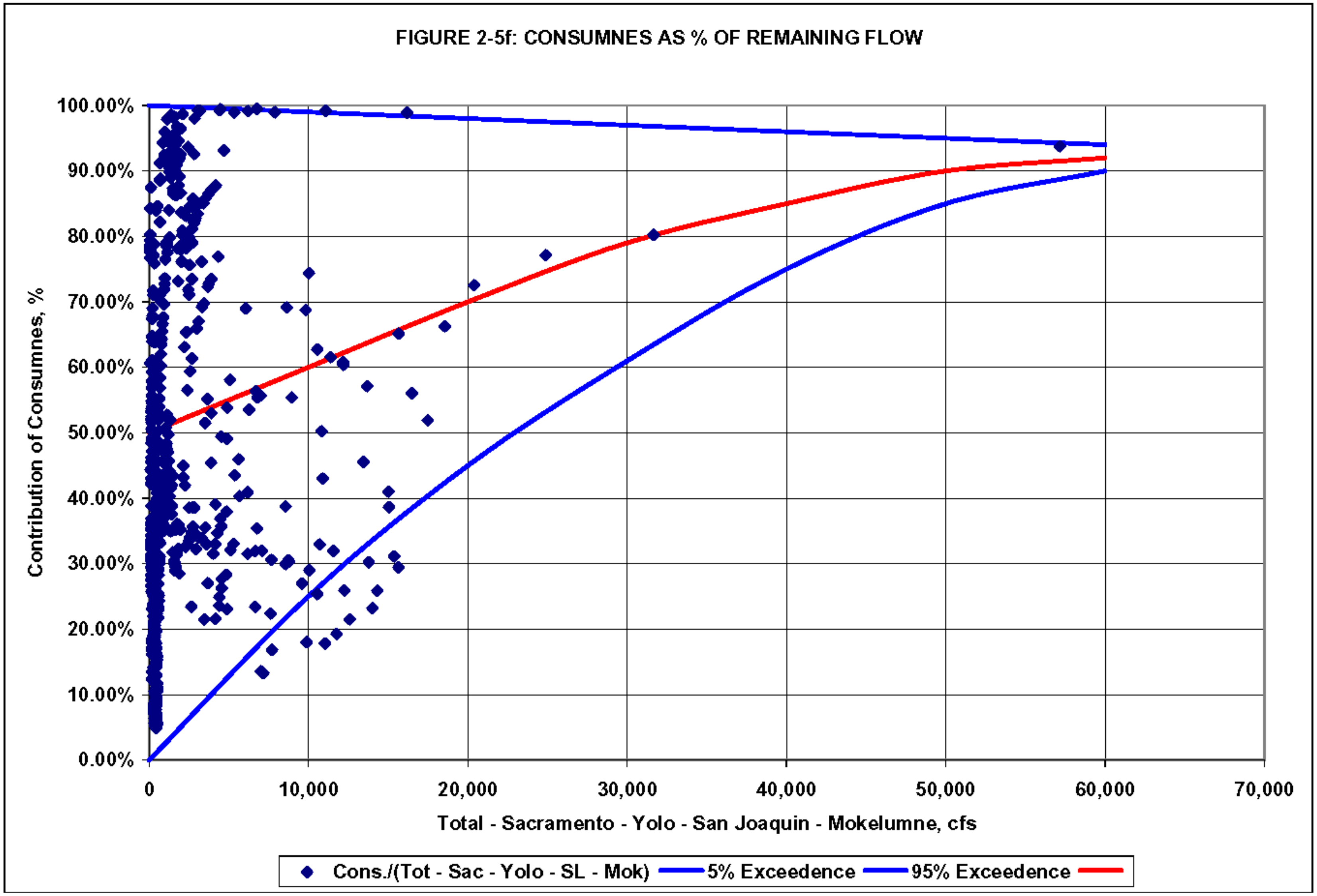


FIGURE 2-5f: CONSUMNES AS % OF REMAINING FLOW
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Contribution of Consumnes, %
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
Total - Sacramento - Yolo - San Joaquin - Mokelumne, cfs
◆ Cons./(Tot - Sac - Yolo - SL - Mok)
5% Exceedence
95% Exceedence

FIGURE 2-6: MEASURED vs CALCULATED WSE
[WSE = 0.532(Tide)+1/114(QSac)-9.567(QYolo)+1.165E-05(QCon)-0.000346(QMok)+8.176E-05(QSJ)+6.312E-06Qmisc)+2.756]

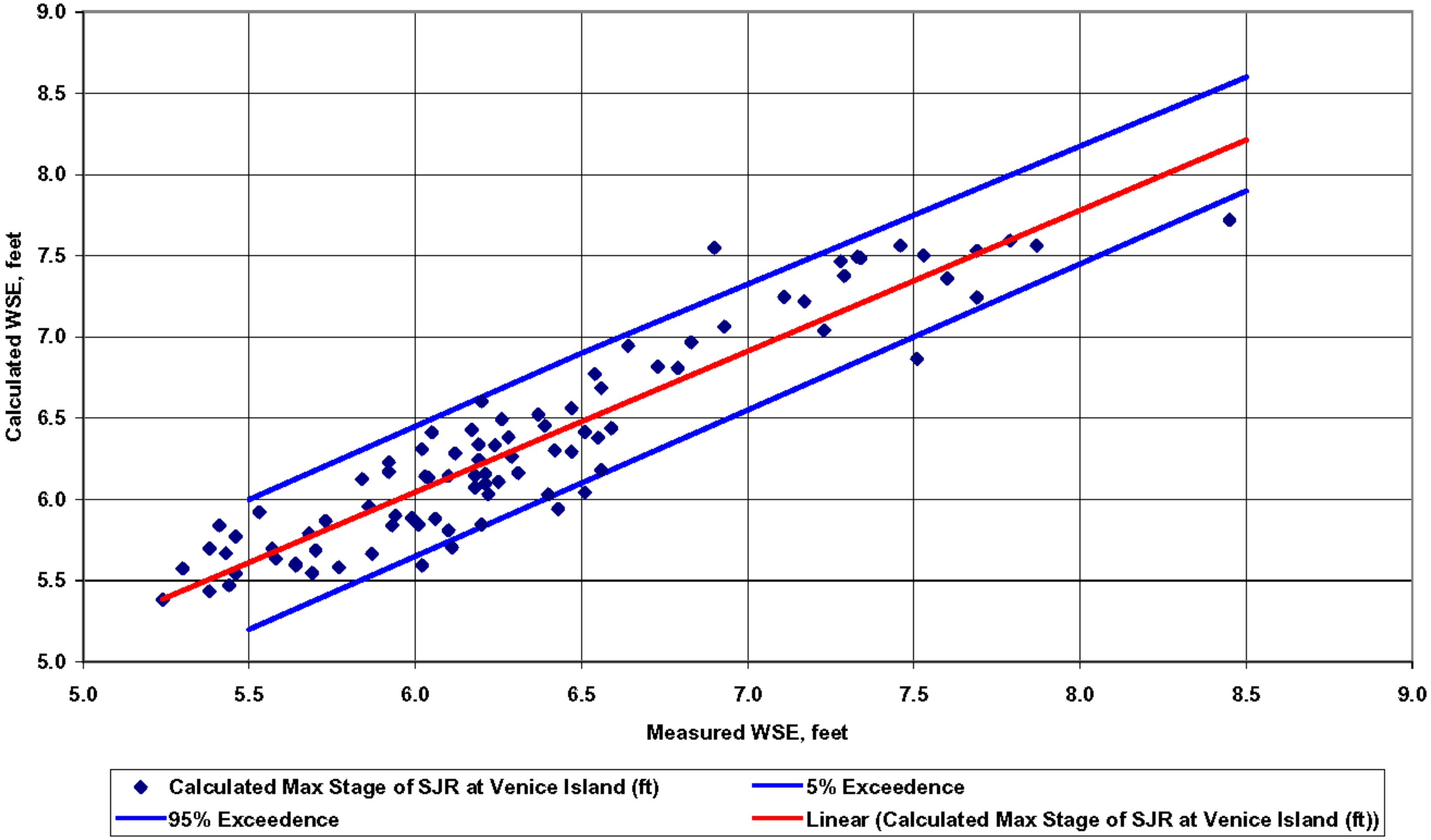


FIGURE 2-7: WSE versus DURATION - VENICE ISLAND, OCT. 1 TO DEC. 29, 1996