Winds generate waves can lead to levee erosion and potential breaching. This section presents an analysis of wind and the corresponding wind waves to use in erosion calculations.

8.1 INTRODUCTION

To evaluate the likelihood and severity of winds and wind waves, wind data were collected from multiple locations in the Delta and Suisun Marsh. The wind data were analyzed to estimate the probability of extreme winds and their patterns, seasonal wind occurrences, and a range of wave conditions that may be caused by these winds.

Wind and wind waves pose a hazard to Delta levees. Winds blowing over water in Delta sloughs can generate waves that break on the water-side (outboard) slopes of Delta levees. These waves may runup the levee slope, overtop the levee crest, and cause levee erosion and possibly levee failure, particularly during storm events in which water levels may be high. In the event that a levee surrounding a Delta island may erode and breach along a Delta slough, the island would be flooded and winds blowing over the length of the flooded island would generate waves. These waves have the potential to erode the inner slope (inboard side) of the levee, which is generally not armored. Inboard levee erosion could cause damage to many miles of levees and potential cause breaches. Winds can also elevate the water level near barriers (called wind set up). High water levels are somewhat more likely to occur during high winds, and the combined effect (total water level and associated erosion and flooding) is therefore more likely than the probabilities associated with each of the forcing parameters considered separately (Garrity et al. 2007; FEMA 2005).

This section addresses wind wave hazards and their probabilities. This study did not analyze wind setup, wave transmission past levees due to wave overtopping, the joint probability of high winds/wind waves and high water levels (residuals or storm surges), or the probability of the flood response caused by high wind waves and high water levels (e.g., wave runup, wave overtopping, levee erosion, and levee breaching).

8.2 METHODS

Winds and wind waves were analyzed separately. The wind analysis included both extreme winds that occur infrequently and typical winds that on average occur throughout each season and year. Extreme winds were analyzed using a probabilistic model of extreme wind events and their spatial patterns across the Delta and Suisun Marsh region. For typical winds, the percent occurrence of wind speeds was analyzed in multiple directions (wind roses) for two seasons (fall-winter and spring-summer) and multiple locations. The approach to the wind wave portion of the analysis is deterministic rather than probabilistic. Wind wave height, period, power, and runup were estimated for a range of wind speeds and open-water fetch lengths. Deep water wave conditions were assumed and wave transformations were ignored. Water depth criteria are provided to inform whether deep water or shallow water wave conditions are expected.

8.2.1 Extreme Wind Analysis Method

Wind data are available from National Oceanic and Atmospheric Administration/National Weather Service (NOAA/NWS), DWR, and the California Irrigation Management Information System (CIMIS). Wind stations are shown on Figure 8-1 and available wind data are summarized in Table 8-1. Only a few wind stations are actually located in the Delta and Suisun Marsh and these stations are located on the periphery of the Delta and Suisun Marsh. Each agency uses different data collection and quality control procedures. Gaps in wind data were assessed as part of this analysis and are described in other DRMS documentation. The height of the wind gage at each station and the sampling interval over which winds are measured vary by station and agency. The wind speed data were corrected to a 10-m height using the Coastal Engineering Manual (CEM) (USACE 2003) and a 1-minute averaging period to give a consistent set of regional wind data.

The extreme wind probability model is consistent with the probabilistic approach to the DRMS risk analysis. DRMS requires a probabilistic assessment of regional extreme wind events that can occur over the spatial dimensions of the Delta, rather than the probability of extreme winds at a particular location independent of other locations. Therefore, wind data and synoptic charts were analyzed in terms of regional wind patterns (meteorologies) that cause high winds. Three meteorologies were identified (Pacific Low, Polar Front, and Sea Breeze) that cause high winds based on an assessment of measured wind direction patterns for high wind events and synoptic charts of weather and pressure systems from the National Centers for Environmental Prediction (2006) North American Regional Reanalysis data and NOAA Central Library U.S. Daily Weather Maps Project (2006).

To model the probability of regional high-wind events, events for each meteorology in the measured regional wind data record were identified. These events were ranked by the highest peak wind speed measured at a particular location or wind station. The data generally showed that, during these events, wind speeds were relatively high throughout the Delta and Suisun region. For a given event, regional wind speeds were typically highest at Travis. Travis was selected as the reference station to represent the regional probability of extreme wind events. For each meteorology, an extreme value analysis was performed on peak annual wind speeds measured at Travis (i.e., using high wind events only). The analysis resulted in estimates of extreme “meteorological” wind events and their probabilities for Pacific Lows, Polar Fronts, and Sea Breezes.

To evaluate the wind patterns (speed and direction) throughout the study area, coincident wind data collected at other locations were compared to those collected at Travis. Then, wind data were scaled relative to the Travis data. Winds were estimated at un-gauged locations throughout the study area by interpolation. For each meteorology, spatial scaling patterns for wind speed and direction were developed. Using triangulation, wind speeds were interpolated throughout the region for the highest peak wind events measured in each year. Wind direction for several measured high wind events were interpolated using the Winds on Critical Streamline Surfaces (WOCSS) model (Ludwig et al. 1991). The WOCSS model was also tested for wind speed interpolation, but linear interpolation was selected as a more appropriate scheme. The wind speed and direction fields were interpolated for multiple events to estimate typical (mean) patterns of: (1) (normalized) wind speed and (2) direction. The normalized wind speed patterns and wind direction patterns for each meteorology were used as the spatial scaling patterns. The variability in these patterns was accounted for in the probabilistic model.

Empirical probability distributions were developed for the direction, duration, and month of occurrence of measured high wind events. These distributions were used to characterize these parameters for extreme wind events.

8.2.2 Wind Wave Analysis Methods

Simple parametric equations for wind wave generation and wave runup (USACE 1984, 2003; TAW 2002) were used to develop "look-up tables" for wind wave height, period, power, and runup. Each look-up table is arranged by wind speed and fetch length. The range in wind speed covers seasonal and extreme winds, and the range in fetch lengths covers possible fetches in Delta sloughs and islands and Suisun Marsh. Wind wave conditions are dependent on island shape and fetch orientation, water depth, bed friction, and vegetation. Site-specific assessments to delineate fetches, estimate water depths, or characterize bed and vegetation types were not performed. The look-up tables developed as part of this analysis are based on deepwater conditions, which may be representative of Delta sloughs and deeply subsided flooded islands. Water depth criteria are provided to allow users to determine whether the assumption of deepwater waves is valid, or whether shallow water wave conditions are expected. Shallow water (relative to the wave length) limits wind wave growth (USACE 1984, 2003).

8.3 WIND AND WAVE HAZARD

To model the regional occurrence of extreme wind events, a probabilistic extreme wind probability model (model) was developed. The model was implemented for the Delta and Suisun Marsh region using the collected wind data.

8.3.1 Wind and Wave Hazard Model

The wind model for the Delta is shown below:

$$P(S(\underline{x}) > s(\underline{x}), \theta(\underline{x}), d, t \mid m_i) \qquad (8\text{-}1)$$

where,

$P(\ )$ = annual probability of exceedance distribution

$\underline{x}$ = vector of geographic locations where the wind hazard is defined

$S(\underline{x})$ = wind speed at location $\underline{x}$

$\theta(\underline{x})$ = wind direction at location $\underline{x}$

d = event duration

t = time of year

m_i = meteorological event type (meteorology).

Equation 8-1 calculates the probability of wind events in the Delta and Suisun Marsh occurring in a direction and duration for a given period of the year. Different meteorologies are assumed to be independent.

Reference wind speed distribution. Given the occurrence of a meteorology m_i, a probability distribution of wind speeds for a reference location can be determined. This distribution can be expressed:

$$P(S_R > s \mid m_i) \qquad (8\text{-}2)$$

where,

S_R = the wind speed at a reference location.

Spatial wind speed distribution. An occurrence of a wind event at a reference location will be accompanied by an associated pattern of coincident winds throughout the Delta. These patterns are spatially correlated because they are associated with the same wind event and meteorology. The coincident wind speeds can be expressed:

$$S(\underline{x}, m_i) = S_R(m_i)\, u(\underline{x}, m_i) \qquad (8\text{-}3)$$

where,

$u(\underline{x}, m_i)$ = spatial pattern of normalized wind speeds (with respect to a reference location and wind speed, S_R) in the Delta and Suisun Marsh, and defined as a function of meteorology

Given the occurrence of a wind speed at the reference location, the spatial pattern of wind speed will be random and can be expressed:

$$P(u(\underline{x}, m_i)) \qquad (8\text{-}4)$$

The distribution of this random variability of the spatial wind speed pattern with respect to the reference station is assumed to be lognormal. The distribution parameters are:

$\mu(\underline{x}, m_i)$ = the mean of the natural logarithm of the normalized wind speeds at location $\underline{x}$

$\sigma(\underline{x}, m_i)$ = the standard deviation of the natural logarithm of the normalized wind speeds at location $\underline{x}$; the variability of the spatial wind speed pattern is assumed to be perfectly correlated in space.

The extreme tails of the lognormal distribution of the spatial wind speed pattern variability are truncated to account for the fact that real wind speed values are limited and may not reach extreme values in the distribution tails.

The exceedance probability of wind speeds at locations throughout the Delta (x) is a function of two random variables: the wind speed at the reference location (SR) and the random variability of the spatial wind speed pattern (u). The combination of these two random variables can be used to derive the probability distribution on wind speed at any location in the Delta and Suisun Marsh:

$$P(S(\underline{x}) > s(\underline{x}) \mid m_i) = P(S_R * u(\underline{x}) > s(\underline{x}) \mid u(x), m_i)\, P(u(\underline{x}) \mid m_i) \qquad (8\text{-}5)$$

Spatial wind direction distribution. For each meteorology, a probability mass function (PMF) on wind speed direction was determined from observations. This distribution can be expressed:

$$P(\theta(\underline{x}) \mid m_i) \qquad (8\text{-}6)$$

where,

$\theta(\underline{x})$ = the wind direction for a given event at location $\underline{x}$.

The spatial pattern of wind directions can be denoted:

$$\theta(\underline{x}, m_i) = h(\underline{x}, m_i) + \eta(\underline{x}_m, m_i) \qquad (8\text{-}7)$$

where,

$h(\underline{x}, m_i)$ = mean spatial wind direction pattern in the Delta and Suisun Bay, defined as a function of meteorology, m_i

$\eta(\underline{x}_m, m_i)$ = random variability of wind direction relative to the mean spatial wind direction pattern, represented as a PMF at:

$\underline{x}_m$ = the location of the wind station nearest to $\underline{x}$.

A simplified representation of highly variable data was necessary to develop the spatial wind direction patterns for each meteorology. Wind direction and its variation can be important in determining the appropriate wind fetch, wind wave conditions, and wind wave hazards including levee erosion. The wind direction distributions represent the direction of the peak wind speed (peak wind direction) for a given event, but do not model the temporal variation of wind direction within an event. This simplification can be mitigated somewhat by the way the method is applied. The wind direction distributions (η in Equation 8-7, represented as PMFs) can be applied to give the probability of wind events with peak wind speeds occurring over a range of directions. These distributions represent the variability of the peak wind direction from the mean wind direction at the wind stations. These distributions can also be used to represent the variability of wind direction at other locations near the stations. In this case, the distributions can be applied to the local mean wind direction at another location, as estimated from the mean spatial wind direction patterns (h in Equation 8-7). Additionally, the directional variability of winds and wind waves can be addressed using directional spreading functions (e.g., see Goda (1985). An alternative simplified approach is to select the direction corresponding with the longest fetch for a given location and meteorology if, for example, that wind wave direction might produce the greatest erosion.

The Pacific Low meteorology includes both southeasterly winds (typically pre-frontal winds) and westerly winds (typically following passage of a cold front). Hence, to represent both wind conditions, wind speeds for Pacific Low events should be applied for two wind directions. For Pacific Low wind events, the duration of the wind event, discussed below, can be split between the direction of the prefrontal wind speed and the direction of subsequent winds from the southwest to west. A reasonable assumption is that winds are southeasterly for half the duration and westerly for half the duration.

Wind duration distribution. Observational data can be used to determine a PMF of wind event duration for different meteorological types, which can be expressed as:

$$P(S(\underline{x}), d \mid m_i) \qquad (8\text{-}8)$$

where,

d = wind speed duration above a given threshold (in hours) for a given wind event.

While the analysis of wind event duration showed that wind speed and wind event duration may be partially correlated, wind event duration was characterized independently of wind speed as a simplifying assumption. The simplified PMF of wind event duration can then be denoted:

$$P(d \mid m_i) \qquad (8\text{-}9)$$

Timing of an event within a year. The timing of a wind event (for a given meteorology) within a year can be denoted by a PMF:

$P(t \mid m_i)$ (8-10)

where,

t = the month of occurrence of a wind event.

Probability of wind events. The probability of wind events can be determined from a combination of the various elements identified above. The probability of winds generally in the Delta and Suisun Marsh for events of a given meteorology can be expressed:

$$P(S(\underline{x}) > s(\underline{x}), \theta(\underline{x}), d, t \mid m_i) = P(S(\underline{x}) > s(\underline{x}) \mid m_i)\, P(\theta(\underline{x}) \mid m_i)\, P(d \mid m_i)\, P(t \mid m_i) \qquad (8\text{-}11)$$

Uncertainty. Given epistemic uncertainty exists in the elements of the model, uncertainty exists in the estimate of the probability of wind events, (S(x), θ(x), d). Based on an analysis of these uncertainties and propagating them through the analysis, the uncertainty can be denoted:

$$\{P(S(x) > s(x), \theta(x), d|mi)j, pj\} \qquad (8\text{-}12)$$

where,

pj = the probability weight associated with the jth wind model.

The model was implemented by sorting data for high wind events by wind meteorology, fitting extreme value probability distributions to the reference wind speed data, developing spatial wind patterns and distributions, and developing empirical probability distributions of wind event duration and month of occurrence.

8.3.2 Wind Characterization

Three meteorologies cause winds with relatively consistent seasonal and directional patterns. The following meteorologies were identified:

- Pacific Low: an extra-tropical low pressure storm system moving from the Pacific through or to the north of the San Francisco Bay-Delta region, generally causing high winds from the southeast before frontal passage (and also from the southwest to west after frontal passage and sometimes prior to southeast frontal winds) in the Delta.
- Polar Front: a high pressure cold front extending from the polar region and Canada coupled with a low pressure system over the southern Great Basin, generally causing high winds from the north in the Delta.
- Sea Breeze: thermal pressure gradient between a cold high pressure area over the Pacific and a warm low pressure area inland. Sea breezes generally cause high winds from the west through the straits and over the coastal range and diverge to the northeast and southeast in the Delta.

The meteorology classification of each peak annual event was checked against wind speed and direction patterns at Travis, Sacramento, and Stockton and the time of year of each event. For events in which this information did not conform to the general pattern for the meteorology, synoptic charts were checked to confirm or re-classify the event meteorology. The peak wind speed and direction for certain events appeared to be erroneous. These wind events were not included in the extreme wind data sets as a quality control measure.

The time series of wind directions and wind event duration for Pacific Lows are complex. Wind directions during Pacific Low events may shift from southeast to west at a given location as the storm front moves through the region. During Pacific Low wind events, high wind speeds typically occur for a duration of approximately 12 hours. A Pacific Low storm system may have multiple storm fronts or may be a series of storms. Thus, these 12-hour wind events may be preceded or followed by wind events of similar duration in which the peak wind speed is less. Analyzing the time series of wind events and series of multiple events was not evaluated in this study.

Wind data were characterized by the following parameters:

Reference Wind Speed Distribution

Travis was selected as the reference wind station because it has the longest data record and the wind speed at Travis is often the highest during high wind events (i.e., winds speeds at Travis are higher than at other stations for more than 80 percent of the peak annual wind events from 60 years of data record). As the spatial wind speed patterns are normalized, any station could be chosen as the reference station and the results are not expected to vary significantly due to which station is chosen.

Two different probability distributions were tested for the reference wind speed:

1. Gumbel (Extreme Value Type I) Distribution
2. Generalized Extreme Value Distribution (GEV)

The distributions were fit to annual maximum wind speed data for each meteorology.

Spatial Wind Distribution

The WOCSS model was tested as a method for spatially interpolating wind speed and direction for this study. Triangulation was selected as a wind speed interpolation method over the WOCSS model. The WOCSS model results were used to interpolate wind direction patterns and develop a spatial wind direction pattern.

The WOCSS model interpolates wind speed and direction in space using an inverse distance interpolation scheme between data points (wind stations) and imposes physical constraints on the interpolation to account for the effects of topography and atmospheric layering (Ludwig et al. 1991; Ludwig and Sinton 1998). The physical principles of the WOCSS model are intended primarily to account for complex physical terrain and atmospheric stratification. The physical principles are based on a two-dimensional nondivergence constraint to force flow interaction with topography and atmospheric layers. The WOCSS model is not an atmospheric model and does not solve differential equations for the conservation of momentum.

Spatial Wind Speed Distribution

Wind speed exceedance probability distributions were developed at selected locations throughout the Delta and Suisun Marsh region using normalized spatial wind speed patterns, applying these patterns to scale the reference wind speed distributions in space, and accounting for the variability in the spatial wind speed patterns.

Spatial Wind Direction Distribution

Wind direction exceedance probability distributions were developed at locations throughout the Delta and Suisun Marsh region using mean spatial wind direction patterns and PMFs of wind direction at each NWS station.

For each wind event modeled with WOCSS (9 hours modeled per event), the wind direction results were averaged to give a spatial map of wind direction for each event. For the five events modeled for each meteorology, the wind event direction maps were averaged to give mean spatial wind direction patterns for each meteorology. For each meteorology and each NWS station, PMFs of wind direction corresponding to the peak wind speed for peak annual wind events were developed.

Duration

The duration of wind speeds above 11 m/s were plotted against wind speed for the peak annual wind events from each meteorology. Wind event duration and wind speed appear to be partially correlated for Polar Fronts and Sea Breezes, but not for Pacific Lows. This difference could be explained by the fact that Polar Fronts and Sea Breezes may be characterized by meteorological conditions (i.e., pressure systems) that persist for more than a day, whereas Pacific Low storm systems may tend to move through the region within a day.

PMFs of wind event duration were calculated for each meteorology using wind data from the reference station (Travis), without consideration of wind speed. If the potential correlation with wind speed is not included as a simplifying assumption, the wind event duration PMFs could be applied to wind speed exceedance distributions at any location to give distributions of wind event duration and wind speed exceedance. This application may tend to underestimate the probability of longer duration events associated with higher wind speeds, and overestimate the probability of longer durations for lower, bur more frequent wind speeds.

The wind event durations could be applied by assuming wind speeds increases from 11 m/s to the estimate peak wind speed, and then decreases back to 11 m/s over the event duration. For Pacific Lows, this assumption may not account for multiple storm fronts or a series of storm fronts, as the analysis approach only represents peak annual wind events and does not model stochastic processes involving multiple storms. Seasonal wind data include the full series of winds throughout the year. Additional discussion of the duration of Pacific Low events is included above.

Month of Occurrence

PMFs for the month of occurrence of peak annual wind events from each meteorology were calculated using wind data at the reference station (Travis). The wind speed exceedance distributions (or other distributions) at a particular location can be multiplied by the probability of occurrence for a month to give the probability of a wind event (wind of a given speed) occurring during a given month.

Seasonal Winds

WRPLOT was used to create seasonal wind roses for the fall-winter season (October to March), spring-summer season (April to September), and the entire year for the period from 1997 to 2005 at each wind data station. The wind roses give the percent occurrence of wind speeds (from low to high) in eight compass directions. For other DRMS analyses using the seasonal wind rose data at a given location, the wind rose for the nearest NWS station can be used, as the NWS data are consistent and are expected to provide the most reliable data.

8.4 WIND WAVE ANALYSIS

Wind wave calculations were performed to develop look-up tables for wind wave height and period, wave power, and wave runup. These look-up tables can be used to estimate deepwater wind-wave heights and periods, power, and runup for seasonal or extreme winds and any fetch of interest in other DRMS analyses.

8.4.1 Wind Wave Generation

Wind wave heights and periods were calculated for a range of fetch lengths and wind speeds using the procedures and parametric deepwater wave equations for fetch-limited wave growth from the Shore Protection Manual (USACE 1984).

Wind speeds estimated in the wind analysis are based on wind speed data measured over land (and are corrected to a 10-m wind gage height and 1-minute averaging period). The over-land wind speeds were increased by a factor of 1.2 to estimate wind speeds over water, based on corrections provided in the CEM. The CEM recommends a correction factor of 1.2 for fetches less than 10 miles (16,000 m). For longer fetches, the CEM gives this correction factor as a function of wind speed based on a Great Lakes study and provides additional correction factors for air-sea temperature difference and the stability of the atmospheric boundary layer. The factor of 1.2 was used for all fetches for consistency and simplicity.

For fetch-limited wave growth conditions in sheltered waters, the wind blows steadily in a constant direction for a sufficient amount of time to achieve steady-state fetch-limited wave conditions. Wind wave generation requires a sustained input of wind energy. The adjusted 1-minute average wind speeds represent sustained winds with durations of 1 minute. The duration of the sustained wind speed that gives steady-state fetch-limited wave conditions may be longer (or shorter) than 1 minute. For each 1-minute wind speed estimate, wind speeds corresponding to a range of durations using Shore Protection Manual equations were calculated and these combinations of wind speed-duration were tested in the wave growth equations.

An automated computer code was used to find the wind-speed duration combination giving fetch limited conditions. The code calculates the duration for the highest wind speed-shortest wind duration combination to see if the calculated duration is sufficient to develop a fetch limited condition. If not, the code selects the next wind speed and repeats the calculation. When the calculated duration for a given wind speed and fetch length is greater than the corresponding wind duration, the corresponding wind stress factor is used to calculate deep-water wave heights and periods, considered to be the largest fetch limited condition. The results are included in tables found in Appendix A of the Wind Wave Analysis TM for wind speeds above the highest estimated wind speed of interest (35 m/s, which has an exceedance probability of less than 0.002 for all meteorologies and fetch lengths beyond the longest fetch length, 21 km from east to west across Suisun Marsh).

8.4.2 Wave Power

Wave power is a measure of the rate of wave energy transmitted to a surface, such as a coastal structure or levee. As defined in the CEM, wave power refers to "the average wave energy flux per unit wave crest width transmitted across a vertical plane perpendicular to the direction of wave advance." Wave power is an indicator of potential work done toward levee erosion and generally provides an indication of intensity. Given that waves are dissipated over time and space, the actual work done on a surface depends on the shape of that surface and hence the antecedent wave conditions. Erosion is affected by the sequence of wave power, water levels, and event duration and is more accurately modeled in terms of a time series of waves and erosion.

8.4.3 Wave Runup

Potential wave runup height is the height above the still water level that a wave breaking on a structure slope will reach as it travels up the slope, assuming the slope extends above the runup height. The actual wave runup height or elevation depends on the water level and structure crest elevation, which may limit runup height. However, potential wave runup is an indicator of water velocity on the structure slope, wave overtopping of the structure, and the potential for erosion of both the outboard levee slope and inboard levee slope (due to wave overtopping and head-cutting).

For each combination of wave height and period in the wind wave generation look-up table, potential wave runup heights were calculated using the TAW method (2002) as described in the *Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States* (FEMA 2005).

The TAW method and other wave runup methods give the wave runup height that is exceeded 2 percent of the time during a given wave event. This 2 percent wave runup height was calculated for each wind wave height and period. The 2 percent wave runup height is otherwise not related to the probability of a given wind speed or wind wave condition. Wave runup height calculated from the TAW method includes the super-elevation of the still water level due to wave setup (static and dynamic) caused by the wave conditions input into the equation. Note that in real situations, larger waves can break farther offshore of the slope and induce greater setup, which can in-turn increase the local wave height and wave runup height elevation. The analysis accomplished here assumes the hindcast wave impinges on the slope and the wave runup includes all wave setup.

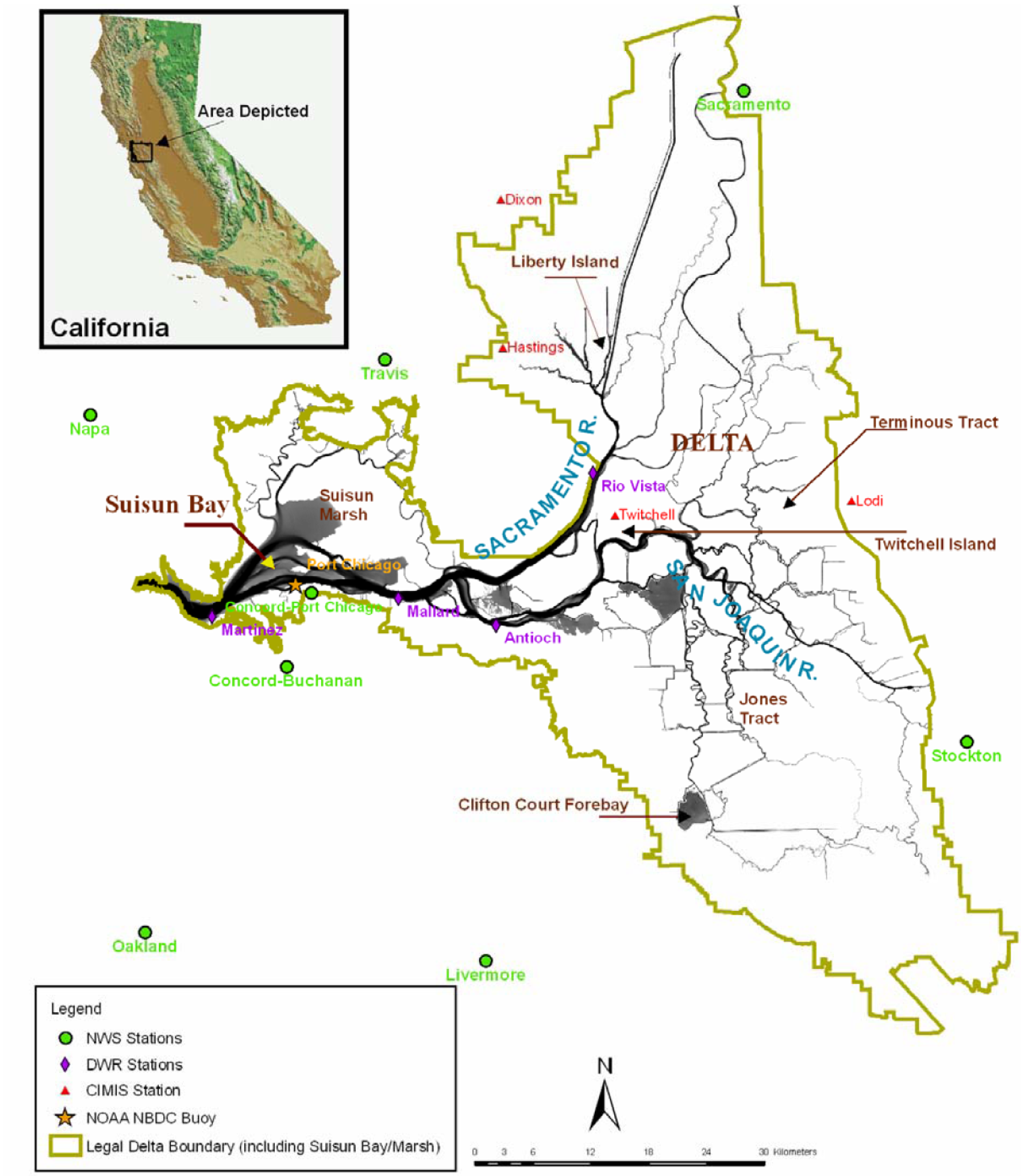
Wave runup heights were calculated for two structure slopes:

- 1 vertical to 1.5 horizontal (1:1.5) to represent relatively steep upper slopes of outboard and inboard levees that typically result in relatively high wave runup heights
- 1 vertical on 5 horizontal (1:5) to represent less steep lower slopes or average (composite) slopes of inboard levees

The TAW method includes wave runup reduction factors for surface roughness, the influence of a berm, oblique wave incidence, and structure permeability. FEMA (2005) and TAW (2002) provide guidance on estimating wave runup reduction factors. These reduction factors were not included in wave runup calculations, and assumed smooth levee surfaces, the absence of a berm, perpendicular wave attack, and an impermeable structure (i.e., all reduction factors equal to one). For armored levees, a roughness reduction factor of 0.55 to 0.6 can be applied for levees with one layer of rock armoring, where the rock diameter (D) is one to three times the significant wave height (H_s / D = 1 to 3) (FEMA 2005).

Table 8-1 Summary of Delta and Suisun Bay Wind Data

Agency	Data Type/QC	Station	Years of Record
NOAA/NWS	Wind Speed & Direction (daily)	Concord Buchanan	1973-2006
		Concord	1973-2006
		Livermore	1978-2006
		Sacramento	1948 - 2006
		Stockton	1941-1946, 1948-1955, 1963-2006
		Travis	1943-1970, 1973-2006
		Oakland	1943 only
NOAA NDBC	Wind Speed, Direction & Gust (hourly)	Port Chicago	1994-present
DWR	Wind Direction & Velocity	Antioch	1983 - 2006
		Mallard	1984 - 2006
		Martinez	1983 - 2006
		Rio Vista	1983 - 2006
CIMIS	Wind Speed & Direction (hourly)	Dixon	1994-2006
		Hastings	1995-2006
		Lodi	2000-2006
		Twitchell	1997-2006


California
Area Depicted
Sacramento
Dixon
Liberty Island
Hastings
Travis
Napa
DELTA
SACRAMENTO R.
Terminous Tract
Lodi
Rio Vista
Suisun Bay
Suisun Marsh
Twitchell
Twitchell Island
Port Chicago
Concord-Port Chicago
Martinez
Mallard
Antioch
SAN JOAQUIN R.
Concord-Buchanan
Jones Tract
Stockton
Clifton Court Forebay
Oakland
Livermore
Legend
NWS Stations
DWR Stations
CIMIS Station
NOAA NBDC Buoy
Legal Delta Boundary (including Suisun Bay/Marsh)
N
0 3 6 12 18 24 30 Kilometers

Historic data were used to estimate the rate of levee breaches during nonflood and nonseismic conditions “sunny day failures”. The frequency of historical failures that occurred in the Delta and Suisun Marsh were determined from the 6 recorded sunny day failures in Delta and the 2 sunny day breaches in Suisun Marsh. Assuming 911 miles of Delta levees within the MHHW boundary, a failure rate of $1.18x10^{-4}$ /year/levee mile or 0.107 failure/year was estimated. Assuming 75 miles of Suisun Marsh exterior levees within the MHHW boundary, a failure rate of $4.76\ x10^{-4}$ /year/levee mile or 0.036 failure/year was estimated. Each failure rate will be applied to all levees for its area within the MHHW boundary, assuming a uniform probability of occurrence.

The methodology uses the historical sunny day levee failures that have occurred in the Delta to estimate future failure rate. In the last 56 years, 8 levee failures occurred during summer that resulted in island flooding. Sunny day, or summer time, is defined as the period between June and October. Data prior to 1950 were not used because the information is sparse and lacks the necessary details, and also the levee configuration is not comparable to today’s levees. The information associated with the summer island flooding is summarized in Table 9-1. The water levels in the nearby sloughs were obtained from gage station historic records operated and maintained by the California CDEC. Levee crest elevations were obtained from the IFSAR data in the GIS files provided by DWR. The descriptions of the failure modes are not complete and very anecdotal. No post-failure investigation reports providing detailed descriptions of the causes of levee failures were available. The information provided in Table 9-1 is conjectural and relates to few available data and communication with DWR personnel and the reclamation district’s engineers. It seems like well engineered levees may be less vulnerable to failure than older non-engineered levees. However sufficient data are not available to determine failure rates by levee classes.

Figure 9-1 shows the levee crest elevations versus the water stage (NAVD-88) for the eight levee breaches at the time of failure; Figure 9-2 shows the approximate locations of the breaches. A close examination of the data indicates that failures occurred during an unusually high tide conditions. At Simmons-Wheeler, the water stage rose above the crest of the levee at Suisun Marsh and may have caused failure of the levees by overtopping. Other reports also indicate the levee failure at Simmons-Wheeler may have been caused by rapid drawdown during the period of receding stage. These summer time failure events may be the result of the combination of high tide and pre-existing internal levee and foundation weaknesses (i.e., burrowing animals, internal cumulative erosion of the levee and foundation), and other human interventions (dredging at the toe of the levee). The unusual high tide could be the result of offshore storm surges arriving in the Delta, astronomic conditions resulting in higher gravitational pull from the concurrent alignment of the sun and the moon, or a combination of the two. Higher tides caused by astronomic gravitational pull occur twice a year. Post-failure reports indicate the failure of Brannan Andrus Island may have been caused by excavation activities at the land side toes of the levee. At MacDonald Island, the levee may have been breached as a result of dredging on the water side toe (information not confirmed).

Whether the failures occurred during a high tide condition or not, rodent activities and pre-existing weaknesses in the levees and foundation seem to have contributed considerably to the levee failures. It is believed by most practicing engineers, scientists, and maintenance personnel in the Delta and Suisun Marsh that rodents are prolific in the Delta and use the levees for borrowing and, hence, causing undo weaknesses by creating a maze of internal and interconnected galleries. Underseepage is a process that tends to work through time by removing fines from the foundation material during episodes of high river stage. The cumulative deterioration through the years, can lead to foundations that would ultimately fail by uncontrollable internal erosion leading to slumping and cracking of the levee.

Four out of the eight levee failures occurred during unusual high tide. Because of the incomplete information on the exact causes of the sunny day levee failures, the recurrence model of sunny day failures assumes that the probability of levee failure represents all the above failure modes and that occurrences are uniformly distributed throughout the Delta and Suisun Marsh.

Table 9-1 Sunny Day Failures

Island/Tract	Year	Month	Day	Failure Mode	Water Level (NAVD-88)	Levee Crest (NAVD-88)
Webb Tract	1950		2	High Tide, Stability	6.1	10.8
Brannan-Andrus Is.	1972	June	22	Excavation at Landside Toe	6.2	10.8
Lower Jones Tract	1980	Sept.	26	Seepage & Rodents Activities	6	11
McDonald Island	1982	August	23	Seepage from Dredging at Waterside Toe?	5.48	11.5
Little Mandeville	1994	August	2	High Tide, abandoned	6.1	11.5
Upper Jones Tract	2004	June	3	High Tide, Underseepage & Rodent Activity	6.85	11
Simmons-Wheeler	2005	July	20	High Tide, breach occurred between two water control structures. Beaver activities suspected	7.51	7.3
Sunrise Duck Club	1999	July	NA	High tide and possible beaver activities	NA	5 to 6

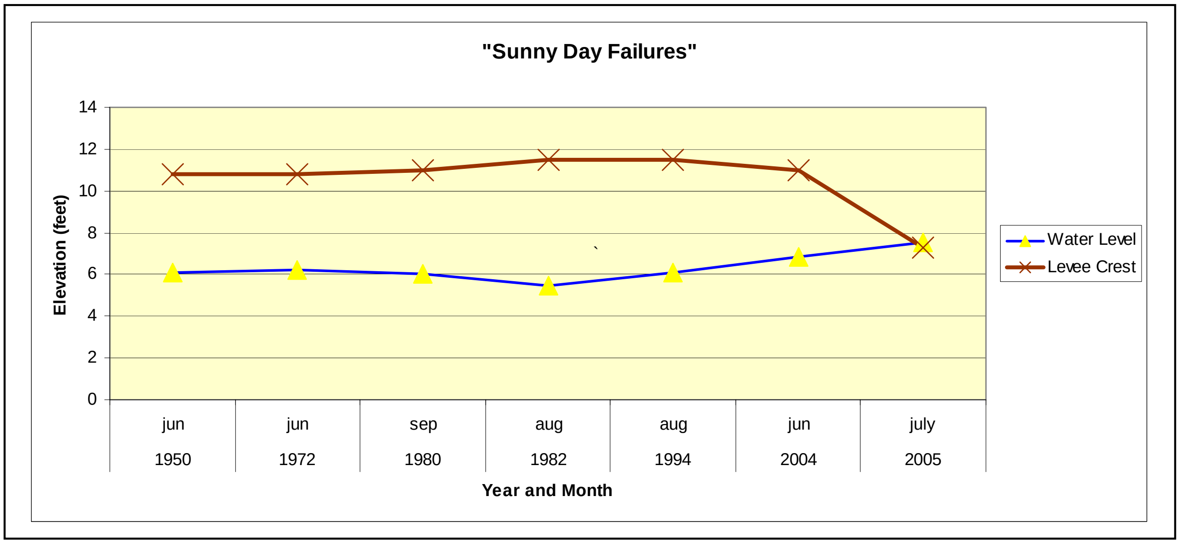
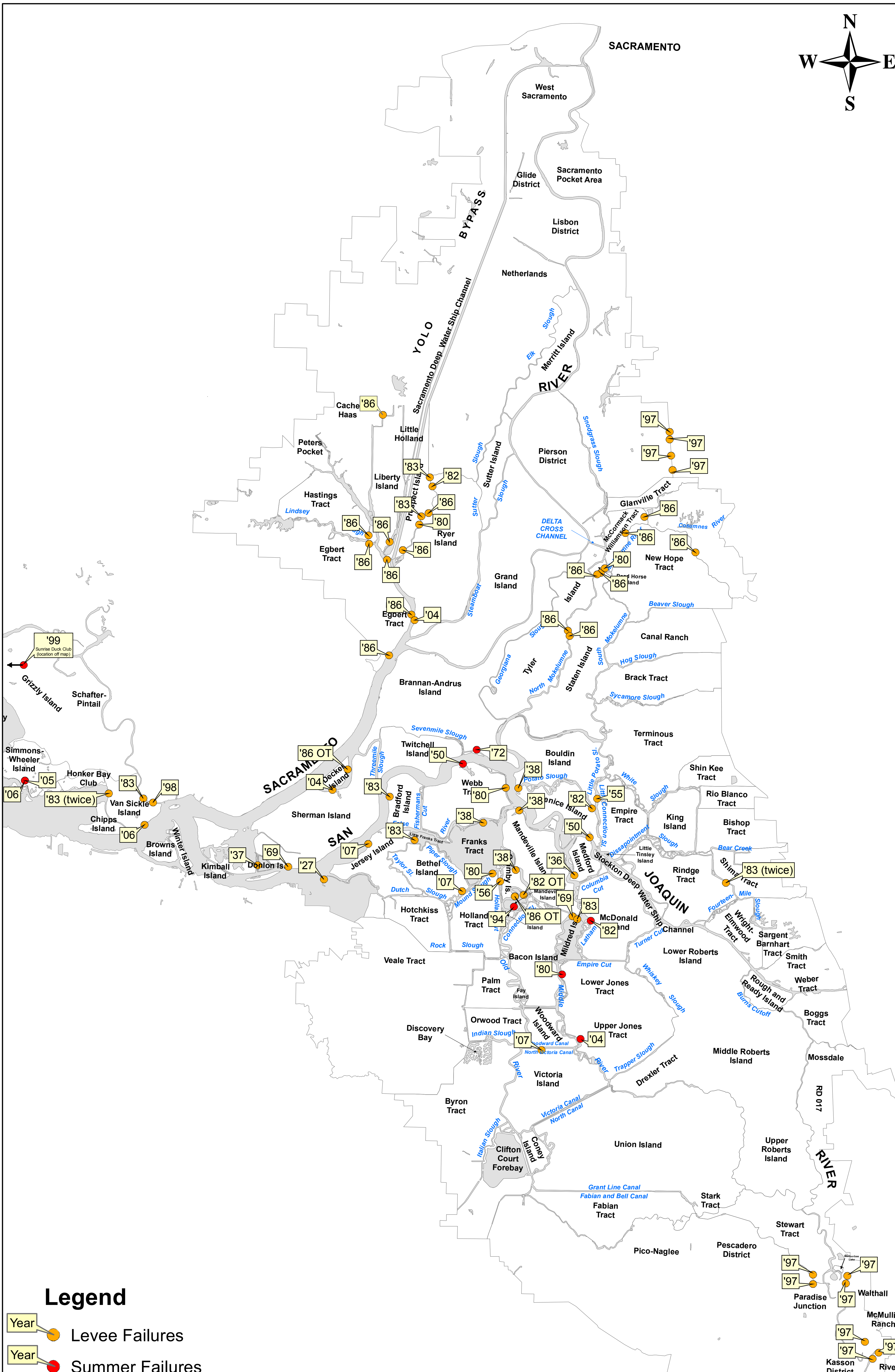


Figure 9-1 Water Stage versus Crest Elevation at Breach Locations



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Locations of Levee Failures

Figure 9-2

The objective of this part of the risk analysis is to estimate the time and material required, and the associated costs, to stabilize damaged levee sections, prevent further damage, close breaches, and dewater flooded islands following an event. The Emergency Response and Repair Technical Memorandum presents more detailed information on emergency response and repair (ER&R) analysis.

10.1 LEVEE FAILURE SCENARIOS

Damages in the Delta could result from earthquakes, floods, subsidence, animal burrowing activity, and other natural events. Extreme hydrologic or seismic events could result in major damages throughout the Delta.

10.2 EMERGENCY RESPONSE

It is assumed that rock placement will be exclusively utilized as the means of stabilizing damaged levees and closing breaches, as has been done in the past. This approach, based on past experience includes capping of breach ends to stabilize the breach before attempts are made to close it, as well as placement of erosion protection on the interior levee slopes of flooded islands.

It is assumed that the San Rafael Rock Quarry (SRRQ) is the primary source of material and the only source of material for marine-based activities. Currently, the SRRQ, located in San Rafael, California, and owned by The Dutra Group, is the primary supplier of quarry products for the Delta. The SRRQ is the only quarry located in Northern California with direct loading access to barges. Consequently, the quarry possesses a significant advantage over competing quarries in its ability to directly load barges with product for delivery to the Delta and the economy of scale this advantage offers. Placement of erosion protection and repair of erosion damage can be carried out from land, if access permits. In this case, material is sourced from local quarries. Although BAU practices are summarized above, it is recognized that no failure of many islands (20 or more) at the same time has yet occurred to provide actual experience. Alternative rock sources for marine placement will be considered in Phase 2 as a potential approach for enhanced emergency response.

Other assumptions for emergency response include:

- Within days of a sequence of levee breaches, local regulations will be eased or set aside to allow the SRRQ to operate on a 24-hour basis.
- Sufficient transportation equipment (i.e., deck barges, scows, and tugs) can be made available immediately to support initial material production rates, so that material supply capacity remains the constraint. This assumption is based on the modeler’s familiarity with Dutra’s fleet and with other marine equipment generally active in the Bay Area. It also considers equipment available from other West Coast locations, given a mobilization period, to support increased production rates later in the repair period.
- Resources (i.e., materials, equipment, and trained labor) are assumed to be available and will not be compromised by demands outside the Delta that occur as a result of the same seismic or flood event. Damage that occurs to assets other than levees will not put a demand on resources required to support levee breach repairs.
- Additional damage resulting from earthquake aftershocks is not considered.

- No constraints exist for dewatering resources.

10.3 IMMEDIATE RESPONSE

Following an event, any, or all of the following tasks may be undertaken, depending on the repair prioritization scheme:

- Stabilization of damaged levee sections to prevent further breaches
- Protection of the levee's interior slope against erosion from exposure to wind-driven wave action on flooded island
- Stabilization of wind-eroded interior slopes on flooded islands
- Capping of breach ends
- Breach closure
- Island dewatering

The model assumes an effective emergency preparedness status is in place. As the magnitude of damage increases, it is believed the effect of emergency preparedness on overall repair durations diminishes. Therefore, the model does not quantitatively account for such emergency preparedness preparations beyond the assumption that such preparations enable the model to meet the ER&R production rates presumed within.

10.4 ONGOING DAMAGE

Prevention of ongoing damage (such as remediation of damaged sections of levee, capping of breached levee ends, and interior levee protection) is an important part of an emergency response strategy.

10.4.1 Exterior Damage

In the case of slumped levee sections on a flooded island, overtopping from the exterior (from an episodic storm) will not result in further breaches, since equal heights of water occur on both sides of the levee. However, exterior damage could occur as a result of waves breaking on the crest instead of on the riprap, as a result of an exterior episodic event. This type of damage would be eroding (similar to interior slope erosion) over a short period of time, since it is episodic. Thus, it is likely not an important factor (it adds a little more to the material requirement of the already damaged levee section) and is, therefore, not included in the model.

10.4.2 Breach Growth

Breached sections will grow in length over time. The breach growth that occurs after the island has flooded/equalized is modeled as random, lognormal distribution with a mean and a standard deviation equal to 10 percent of the mean value.

10.4.3 Wind Wave Erosion

Wind wave erosion on the levee's interior slopes will act on the intact and damaged levee sections throughout the repair period. This erosion manifests itself as additional (continuing) damage on initially intact and damaged levee sections of flooded islands, resulting in larger quantities of rock required when the repair of that section proceeds.

Levee interior slope erosion is modeled as follows:

- Sets of erosion curves, or parametric equations (time vs. erosion), are defined for each island sector (each island is subdivided into eight sectors, each consisting of 45 compass degrees).
- With each day that passes following flooding of the island, erosion damage is accumulated on the intact and damaged levee sections of each island sector, based on wind and wave forces as generated by the wind/wave module (see Section 8).
- Erosion occurs at an equal rate along the entire levee perimeter of each island sector.
- The additional erosion acts on the levee width at MHHW (which is different for intact vs. damaged/slumped levee sections). When the levee's width has been eroded down to a threshold level of 6 feet (to be confirmed), it is assumed that the remaining portion of the levee fails, and the entire levee cross section above MLLW collapses and must be replaced for that specific levee segment.
- Accumulation of erosion damage stops when failure (as defined above) occurs or when laying of rock for protection of the levee interior is commenced. The amount of rock laid is based on the amount required for the layer of protection plus the amount required to replace the eroded section that has been accumulated to that point.

10.4.4 Secondary Breaches on Nonflooded Islands

Sections of levee on nonflooded islands may have been damaged and could fail at a later time, as a result of a storm event that causes overtopping and subsequent breach.

10.5 PRIORITIZING REPAIRS

Deciding on the relevant factors and relative priorities for allocating scarce resources to levee repairs in an emergency situation depends on the location and magnitude of the failure(s). Risk Analysis must incorporate some structure for making these decisions. This document identifies various factors included and establishes a BAU approach to use in the initial version of the risk analysis. Although an attempt has been made to realistically describe the factors that would be weighed in setting priorities under present (BAU) conditions, the results are the judgment of the analyst. Actual priorities set in a real emergency will undoubtedly prove to be different considering the situation that must be addressed.

Purpose – The purpose of the prioritization approach is to allocate marine repair resources. Some types of damage and locations do not require marine transportation of materials and marine construction equipment. Repairs that can be made from land approaches should be allocated to land-based contractors and are not addressed by this priority system.

Objective – The objective that has been established for this priority system is very broad. The system is to allocate marine resources to island repairs in a way that best responds to the interests of the State of California (given BAU). The system developed attempts to be responsive as well as clear, unambiguous, and workable.

Factors – The factors incorporated into the priority system include the following:

- Flooded state – i.e., is an island or tract already flooded or is it in imminent danger of flooding?
- Population – What is the population of the island or tract?
- Infrastructure – What infrastructure is flooded (or threatened) and what are the impacts?
- Export Salinity Impact – What is the relative impact of this island or tract (or group of areas) on salinity at the export pumps and on the ability to export?

For each of these factors, the islands (analysis zones) were ordered going from most important to least important. The order for a factor is fixed; it does not vary from sequence to sequence.

Repair Types and Business-as-Usual – The process of responding to levee damage and breaching in the Delta is divided into a series of repair types:

- RT1 – repair nonbreach damage on nonflooded island
- RT2 – protect the levee interior slopes on a flooded island against wind wave damage, or repair damage if it has already occurred
- RT3 – repair nonbreach damage on a flooded island
- RT4 – stabilize breached levees by capping the levee ends at the breach
- RT5 – breach closure
- RT6 – island dewatering

As part of the ER&R analysis, these repairs can be prioritized, eliminated, etc. from one island to the next.

Repairs for Flooded Islands – The repairs for flooded islands are of particular importance. Under BAU (prior to DRMS) the sequence of repairs is:

- Cap all breach ends (all islands, in priority order)
- Control ongoing interior damage (all islands, in priority order)
- Repair each flooded island (in priority order)
- Close the breach
- Repair nonbreach damage
- Finalize repairs (to the point necessary for levee stability adequate to pump out)
- Pump out the island

The basis for setting this type of repair structure is the perception that pre-DRMS, the most important activity was thought to be controlling ongoing damage. Thus, marine repair resources are allocated to capping and interior protection first on all islands (as long as they can be used effectively). Then they move on to breach closure and island pump out on an island priority basis.

Repairs for Nonflooded Islands – Repairs are made on damaged nonflooded islands as the top priority. Thus, RT1 is the top priority for all "significant" islands.

Significant Islands – "Significant" islands are listed based on population, infrastructure, and flooding volumes/locations that impact salinity relative to water export. The list of "significant" islands (or analysis areas) is provided in Table 10-1. All "significant" islands are addressed by this priority system in Categories A and B, as explained below.

Prioritization of Levee Repairs – Three high-level Priority Categories are established as follows:

- A – Islands/areas threatened but not yet flooded
- B – Islands/areas already flooded
- C – All islands/areas not addressed by Categories A or B (less significant Delta and Suisun Marsh islands or areas)

For a given sequence involving a series of flooded and/or damaged islands, each island is placed in one of the above categories. The highest priority is given to Category A, then B, then C.

Within a group, islands are ranked based on the factors identified above (e.g., population, etc.). This ordering is used to define the island priority and the work order that is input to the ER&R module. The scheduler looks through each island/area group (as defined by A1 through A12; see Table 10-2 for the list of priorities) in the order specified to find the next assignment. If no assignment is found in Priority Category A (threatened but not flooded) the search continues in Priority Category B (islands already flooded). Finally the scheduler goes on to Priority Category C (islands that were not included in A or B).

Population – The population categories were established only based on estimated 2005 population. Where population data were not readily available, estimates were based on the number of households as estimated by the Economics Team. Four groups were defined: 10,000 or more, 5,000 but less than 10,000, 1,000 but less than 5,000, and 500 but less than 1,000. Areas with less than 500 were not considered to have population preference. Island priorities based on population are given in Table 10-3. Within each group, islands are listed in priority order.

Infrastructure – In the case of islands that have flooded, much of the critical infrastructure can be put back into service before an island is repaired and pumped out. This situation is true for interstate highways, electrical transmission lines, the Mokelumne Aqueduct, and the railroad. Thus, the only infrastructure items that enter into a decision on which flooded island should be repaired next are:

- The state highways (12, 4, and 16)
- Natural gas storage and retrieval (McDonald Tract)

Since traffic can be rerouted around the impassable area, the state highways generally do not get a high priority (for flooded islands). For nonflooded islands, the presence of a state highway is considered with higher priority.

Loss of gas storage and retrieval on McDonald Tract does not appear to have a crippling regional impact, so it does not receive a high priority except where flooding might be prevented.

When an island has not yet been flooded but is under imminent threat of flooding, the infrastructure priority is based on preventing damage to:

- Mokelumne Aqueduct
- State Highways
- Railroads
- MacDonald Island's natural gas storage and retrieval facility

Infrastructure priority groups are listed in Table 10-4. Within each group, islands are listed in priority order.

Salinity – The salinity priority categories are based on the current understanding by the project's hydrodynamics modeler (as of the time at which a priority system had to be set) of which islands, when flooded with saline waters, are most disruptive to water exports. The fundamental precept is that salinity intrusion deep into the southern Delta must be avoided if possible by defending threatened south Delta islands. This idea is based on an earlier project (Jack R. Benjamin & Associates 2005) in which the south Delta islands were found to be the dominant interference for water exports. If intrusion occurs, affected islands must be repaired as the top salinity priority. The south Delta islands are addressed as Old River first, then Middle River, and then San Joaquin River, based on the hydrodynamic modeler's judgment. Then the islands in the western Delta are important. Lastly, islands in the eastern and northern Delta may have adverse impacts on salinity and export, but it is believed they will freshen while the southern, central, and western Delta islands are repaired. The salinity priority groups are listed in Table 10-5. Within each group, islands are listed in priority order. Ideally, this priority system would be derived from multiple model runs to rigorously establish the relative importance of islands to salinity impacts in a whole collection of breach scenarios. Such an approach was not feasible within the project schedule.

Within the three factors considered (population, infrastructure, and salinity), population and infrastructure were thought to warrant somewhat higher priority when an area is unflooded and damage might be prevented than would be the case when the flooding has already occurred.

Within each priority category (A and B) the relative position given to population versus infrastructure versus salinity is based on a subjective evaluation of the groups' overall "interest to the state." When flooding might be prevented on a threatened (damaged island), the highly populated areas deserve a high priority. Thus, areas with 5,000 or more residents get highest consideration. At the same time it is important to avoid disrupting the state's water supply and also to prevent damage to other infrastructure. Thus, these factors dominate (and compete for resources) where the goal is to prevent flooding. A salinity group comes next, then an additional population group, an infrastructure group and so forth.

When flooding has already occurred, a shift in the "state's interest" is believed to warrant more priority toward repairs that restore the state's water supply. Still, it seems unreasonable to ignore the plight of high population areas that have been flooded. Thus, a portion of the marine-based repair resources is allocated to areas with populations of 5,000 or more. Otherwise, full attention is devoted to repair of islands important to restoration of water exports in priority order.

Table 10-6 presents the island/area priority order that results for unflooded (Category A) and flooded (Category B) islands/areas addressed as “significant.”

Priorities have not been specified for the Category C islands and tracts, but a simple algorithm can be established if necessary. For example, these zones might be addressed based on acreage.

10.6 SCHEDULING/LIMITS TO PROGRESS

The Emergency Response and Repair Technical Memorandum presents development of a model (ER&R model) that can be used to estimate the time and material required to recover from levee failure(s). It estimates the time and associated costs to stabilize damage levee section, prevent further damage, close breaches, and dewater flooded islands following levee failure(s). Given a sequence that identifies a set of levee breaches and/or damage throughout the Delta, the ER&R model makes an assessment of the ability to respond. Some limits to progress are:

- After a seismic event in the Bay Area, access constraints for the barges may occur if bridges have collapsed, but no access constraints have been assumed.
- The time required to put contracts into place may be significant and will vary from event to event.
- It may not be possible for The Dutra Group to obtain permits to build a second loading facility in within 90 days. State/federal officials may need to step in to waive the typical permitting process (California Environmental Quality Act/National Environmental Policy Act). Additionally, SRRQ neighbors may hold up the process if they do not see events in the Delta as an impact on them.
- It may take longer than 180 days to bring other sources of material on line. The State will probably have to make the decision when to call in help from nonlocal sources, such as Catalina Island, Canada, or Mexico.
- After a seismic event numerous projects may compete for the same resources. The State may have to make the call on prioritization of competing projects.

Actual results for repair times and repair costs are presented in Section 13, which addresses specific cases that are used to develop risk results from several different levee breach events.

Table 10-1 Significant Islands for Repair Prioritization

(Based on Population, Infrastructure, and Volume/Salinity)

Bacon Island	Rough & Ready Island
Bethel Island	Ryer Island
Bishop Tract	Sacramento Pocket Area (196)
Bouldin Island	Sargent-Barnhart Tract 2 (188)
Brack Tract	Sherman Island
Bradford Island	Shima Tract
Brannon-Andrus Island	Shin Kee Tract
Byron Tract 1 (127)	SM-124 (Suisun Marsh, Southwest of Suisun City)
Byron Tract 2 (128)	Staten Island
Canal Ranch	Sutter Island
Coney Island	Terminous Tract 2 (87)
Discovery Bay	Twitchell Island
Empire Tract	Tyler Island 1 (Walnut Grove; 62)
Fabian Tract	Tyler Island 2 (63)
Grand Island	Union Island 1 (117)
Hastings Tract 2	Veale Tract 2 (129)
Holland Tract	Venice Island
Hotchkiss Tract 1 (108)	Victoria Island
Jersey Island	Webb Tract
Jones Tract (Upper and Lower)	West Sacramento North
King Island	West Sacramento South 1
Mandeville Island	Woodward Island
McDonald Tract	Wright Elmwood Tract (190)
Medford Island	Wright-Elmwood/Sargent-Barnhart Tract (191)
Netherlands 3 (142)	Zone 126 (Pico Naglee, north Tracy)
New Hope Tract	Zone 148 (E of Sac River near Hood)
Orwood Tract (20)	Zone 157 (Smith Tract, West Stockton)
Palm Tract (16)	Zone 158 (Weber Tract, West Stockton)
Pierson District 1 (149)	Zone 159 (Boggs Tract, West Stockton)
Quimby Island	Zone 185 (Northwest Stockton)
RD 17 Mossdale (Lathrop Area)	Zone 197 (E of Sac River N of Hood)
Ringe Tract	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Rio Blanco Tract	Zone 68 (Little Egbert Tract)
Roberts Island (Middle, 154/Lower, 106)	Zone 70 (Egbert Tract)
	Zone 76 (Freeport-Franklin)

Table 10-2 Priority Group Order for Unflooded and Flooded Islands

Priority Group Order – Islands That Are Threatened But Not Yet Flooded	Priority Group Order – Flooded Islands
A1 – Population A (>/= 10,000)	B1 – Flooded Population Areas A & B
A2 – Population B (>/= 5,000)	B2 – Salinity 1
A3 – Salinity 1	B3 – Salinity 2
A4 – Infrastructure A	B4 – Salinity 3
A5 – Population C (>/= 1,000)	B5 – Salinity 4
A6 – Salinity 2	B6 – Salinity 5
A7 – Infrastructure B	B7 – Infrastructure B
A8 – Population D (>/= 500)	B8 – Population C
A9 – Salinity 3	B9 – Population D
A10 – Salinity 4	B10 – Infrastructure D
A11 – Infrastructure C	B11 – Salinity 6
A12 – Infrastructure D	B12 – Salinity 7
A13 – Salinity 5	B13 – Salinity 8
A14 – Salinity 6	
A15 – Salinity 7	
A16 – Salinity 8	

Table 10-3 Population Priority Groups (Islands/Areas in Priority Order)

Population A (>/= 10,000) Zone 196 (South Sacramento/pocket) ***Population B (>/= 5,000 but < 10,000)*** West Sacramento North Zone 157 (Smith Tract, West Stockton) Wright-Elmwood Tract/Sargent-Barnhart Tract (West Stockton) Zone 76 (Freeport-Franklin) Sargent-Barnhart Tract 2 (West Stockton) Discovery Bay ***Population C (>/= 1,000 but < 5,000)*** RD 17 Mossdale (Lathrop Area) Shima Tract (Northwest Stockton) Zone 159 (Boggs Tract, West Stockton) Zone 185 (Northwest Stockton) West Sacramento South 1	***Population C (cont.)*** Zone 158 (Weber Tract, West Stockton) Bethel Island Brannon-Andrus Island SM-124 (Suisun Marsh, SW of Suisun City) Grand Island New Hope Tract Netherlands ***Population D (>/= 500 but < 1,000)*** Hotchkiss Tract Zone 126 (Pico Naglee, north Tracy) Zone 37 (North Shore Suisun Bay near Benicia) Roberts Island (Middle, 154/Lower, 106) Pierson District Terminous Tract Tyler Island 1 Union Island

Table 10-4 Infrastructure Priority Groups (Islands/Areas in Priority Order)

Infrastructure A (Mokelumne Aqueduct, if island is not already flooded)	***Infrastructure B (cont.)***
Orwood	*Hwy 160* (cont.)
Woodward	Brannon-Andrus Island
Jones Tract	Grand Island
Roberts (Middle/Lower)	Sutter Island
Wright-Elmwood/Sargent-Barnhart	Pierson District
Infrastructure B (State Highways)	Zone 148
Hwy 12	Zone 197
Brannon-Andrus	Sacramento Pocket Area (196)
Bouldin	***Infrastructure C (Railroad, if island is not already flooded)***
Terminous	
Hwy 4	
Byron	Boggs Tract (159)
Victoria	***Infrastructure D (Natural Gas Storage and Retrieval)***
Roberts (Middle/Lower)	McDonald Tract
Hwy 160	
Sherman Island	

Table 10-5 Salinity Priority Groups (Islands/Areas in Priority Order)

Salinity 1 (Old River Corridor, South to North)	***Salinity 4 (West Delta)***
Union	Twitchell
Victoria	Bradford
Fabian	Jersey
Coney	Sherman
Byron 2	***Salinity 5 (San Joaquin River – Upstream*** South to North)
Byron 1	Rough & Ready
Woodward	Wright Elmwood
Orwood	Wright Elmwood / Sargent Barnhart
Palm	RD17 Mossdale
Bacon	***Salinity 6 (North Delta)***
Veale	Terminous
Holland	Staten
Hotchkiss	Tyler 2
Bethel	Grand
Quimby	Ryer
Salinity 2 (Middle River Corridor, South to North)	Little Egbert
Roberts (Middle/Lower)	Egbert
Jones	Hastings 2
McDonald	Pierson
Mandeville	Sutter
Salinity 3 (San Joaquin Corridor, Southeast to Northwest)	Netherlands
Ringe	***Salinity 7 (East Delta A)***
King	Brack
Empire	Canal Ranch
Medford	New Hope
Venice	***Salinity 8 (East Delta B)***
Bouldin	Shima
Brannon-Andrus	Bishop
Webb	Rio Blanco
	Shin Kee

Table 10-6 Resulting Island/Area Prioritization

Category A – Unflooded	Category B – Flooded
Sacramento Pocket Area (196)	Sacramento Pocket Area (196)
West Sacramento North	West Sacramento North
Zone 157 (Smith Tract, West Stockton)	Zone 157 (Smith Tract, West Stockton)
Wright-Elmwood/Sargent-Barnhart Tract (191)	Wright-Elmwood/Sargent-Barnhart Tract (191)
Zone 76 (Freeport-Franklin)	Zone 76 (Freeport-Franklin)
Sargent-Barnhart Tract 2 (188)	Sargent-Barnhart Tract 2 (188)
Discovery Bay	Discovery Bay
Union Island 1 (117)	Union Island 1 (117)
Victoria Island	Victoria Island
Fabian Tract	Fabian Tract
Coney Island	Coney Island
Byron Tract 2 (128)	Byron Tract 2 (128)
Byron Tract 1 (127)	Byron Tract 1 (127)
Woodward Island	Woodward Island
Orwood Tract (20)	Orwood Tract (20)
Palm Tract (16)	Palm Tract (16)
Bacon Island	Bacon Island
Veale Tract 2 (129)	Veale Tract 2 (129)
Holland Tract	Holland Tract
Hotchkiss Tract 1 (108)	Hotchkiss Tract 1 (108)
Bethel Island	Bethel Island
Quimby Island	Quimby Island
Jones Tract (Upper and Lower)	Roberts Island (Middle, 154/Lower, 106)
Roberts Island (Middle, 154/Lower, 106)	Jones Tract (Upper and Lower)
RD 17 Mossdale (Lathrop Area)	McDonald Tract
Shima Tract	Mandeville Island
Zone 159 (Boggs Tract, West Stockton)	Ringe Tract
Zone 185 (Northwest Stockton)	King Island
West Sacramento South 1	Empire Tract
Zone 158 (Weber Tract, West Stockton)	Medford Island
Brannon-Andrus Island	Venice Island
SM-124 (Suisun Marsh, Southwest of Suisun City)	Bouldin Island
Grand Island	Brannon-Andrus Island
New Hope Tract	Webb Tract
Netherlands 3 (142)	Twitchell Island
McDonald Tract	Bradford Island
Mandeville Island	Jersey Island
Bouldin Island	Sherman Island
Terminous Tract 2 (87)	Terminous Tract 2 (87)
Sherman Island	Grand Island
Sutter Island	Sutter Island
Pierson District 1 (149)	Pierson District 1 (149)
Zone 148 (E of Sac River near Hood)	Zone 148 (E of Sac River near Hood)
Zone 197 (E of Sac River N of Hood)	Zone 197 (E of Sac River N of Hood)
Zone 126 (Pico Naglee, north Tracy)	Rough & Ready Island
Zone 37 (North Shore Suisun Bay near Benicia Bridge)	Wright Elmwood Tract (190)
Tyler Island 1 (Walnut Grove; 62)	RD 17 Mossdale (Lathrop Area)
Ringe Tract	Shima Tract
King Island	Zone 159 (Boggs Tract, West Stockton)
Empire Tract	Zone 185 (Northwest Stockton)

Category A – Unflooded	Category B – Flooded
Medford Island	West Sacramento South 1
Venice Island	Zone 158 (Weber Tract, West Stockton)
Webb Tract	SM-124 (Suisun Marsh, Southwest of Suisun City)
Twitchell Island	New Hope Tract
Bradford Island	Netherlands 3 (142)
Jersey Island	Zone 126 (Pico Naglee, north Tracy)
Rough & Ready Island	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Wright Elmwood Tract (190)	Tyler Island 1 (Walnut Grove; 62)
Staten Island	Staten Island
Tyler Island 2 (63)	Tyler Island 2 (63)
Ryer Island	Ryer Island
Zone 68 (Little Egbert Tract)	Zone 68 (Little Egbert Tract)
Zone 70 (Egbert Tract)	Zone 70 (Egbert Tract)
Hastings Tract 2	Hastings Tract 2
Brack Tract	Brack Tract
Canal Ranch	Canal Ranch
Bishop Tract	Bishop Tract
Rio Blanco Tract	Rio Blanco Tract
Shin Kee Tract	Shin Kee Tract

One or more Delta levee breaches that result in island flooding may impact Delta water quality (most obviously salinity) and water operations. A substantial amount of saline water may be drawn in from the Bay – depending on the initial salinity of the river/Delta/Bay system, river inflows at the time of the breach event, and the number, size and locations of the breaches and flooded islands. Subsequently, salinity may be dispersed and degrade Delta water quality for a prolonged period due to the complex interrelationship between ongoing Delta inflows, tidal mixing, and the breach repair schedule. Other water quality measures, such as organic carbon, are also important. However, the essential first step in characterizing Delta water quality, in context of a levee breach event, is to characterize salinity.

Tracking of any contaminant in the Delta waterway system is dependent on first being able to accurately simulate the movement and mixing of Delta waters – that is, Delta hydrodynamics. Salinity is the obvious marker for tracking the movement and mixing of Delta waters. It is ubiquitous, easily measured, and exhibits strong variations due to the low salinity of fresh water inflow, the high salinity of Bay waters, and the strong tidal hydrodynamic movement and mixing. Unless salinity movement, mixing and resulting concentration gradients can be accurately represented, a model will not be able to track the movement, mixing, and concentration variations of any other contaminant. Modeling salinity is the essential first step and is the parameter used for the Phase 1 analysis.

A given levee breach scenario considered in the DRMS risk analysis is identified and specified by the modules discussed in previous sections – seismic or flood hazard, levee vulnerability and emergency response. The Water Analysis Module (or WAM) receives the specifics of the breach event as input and simulates direct, salinity-related consequences of the event. Specifically, WAM incorporates:

- Initial island flooding
- Upstream reservoir management response
- Delta water operations
- Salinity disruption of Delta irrigation
- Delta net water losses (or net consumptive water use)
- Hydrodynamics
- Delta water quality (initially represented by salinity)
- Water exports as impacted by salinity

The module is central to the risk analysis, receiving the description of each breach scenario (e.g., resulting from a seismic or other event) and details of the levee repair process from the emergency response and repair part of the analysis. The model produces hydrodynamic, water quality, and water supply consequences for use in the economic and ecosystem modules. The water quality consequences of levee failures in the Delta are dependent, not only on the initial state of the Delta at the time of failure, but also on the time series of tides, inflows, exports, other uses, and on the water management decisions that influence these factors. Thus, WAM is the model that tracks water management and the Delta's water quality response starting before the initial breach event and proceeding through the breach, emergency operations, repair, and recovery period. The model is a key link in facilitating assessment of ecosystem and economic consequences and associated risks.

The WAM Technical Memorandum presents more detailed information on the WAM and its use to estimate salinity impacts. Note that available schedule has not allowed incorporation of other water quality parameters into WAM. Additional parameters, such as organic carbon, can be incorporated during a subsequent model development phase. Since organic carbon is important to urban water agencies, a preliminary analysis of potential organic carbon increases due to contact of waters with flooded island organic soils has been provided in the WAM TM, Appendix I. The results of the preliminary analysis indicate that increased organic carbon concentrations are potentially very significant, that organic carbon should be modeled in more detail, and that island dewatering should be managed to minimize organic carbon impacts. This effort requires extensions of both WAM and the Emergency Response and Repair Module.

11.1 OVERVIEW

Because a complex interrelationship exists between reservoir operations upstream of the Delta, hydrodynamics and water quality within the Delta, and the ability to use or export water from the Delta, these features of WAM within the risk analysis framework are combined into a single module. When an emergency occurs, decisions will be made to manage ongoing reservoir releases and Delta exports based on the water quality of the Delta, so it is not possible to set release or export strategies without simultaneously evaluating the evolution of Delta water quality. In WAM, water quality conditions are initially represented by salinity; other measures of water quality can be added later, if desired.

The decision submodels incorporated into WAM calculate Delta water operations, upstream reservoir releases, and exports immediately following a breach event and throughout the repair/recovery period. The decision submodels are based, to the extent possible, on operating rules included in existing models of the California water system, water rights and water quality standards, contractual requirements, and operating guidelines. CalSim is an example of an existing model that includes operations components. However, because it does not consider levee breach emergencies, different operating rules than are currently included in CalSim are required to manage water operations in response to such an emergency. Considerable input was required from operators and policy makers responsible for managing the state and federal water systems to develop the decision submodels. The initial versions of the models reflect this input, but the amount of input was constrained by the limited schedule. Additional input is needed and will be reflected in future versions of the models.

The overall simulation of a levee breach scenario has been subdivided into three phases to reflect the dramatically different hydrodynamic and water management situations that define each phase. The phases in WAM simulation are:

- **Island Flooding –** The rush of water filling an island(s) immediately following a levee breach dominates Delta water flow or hydrodynamics (especially after multiple, approximately simultaneous levee breaches). Island flooding may take up to several days. The water needed to fill the islands comes mainly from adjacent Delta channels, but the effect will be felt at an ever-expanding spatial scale. Ultimately, the total volume required to fill the islands and restore overall balance will come from river inflows and/or flow from Suisun Bay. The hydrodynamics submodel considers the initial flow and salinity conditions in the Delta (as obtained from CalSim results for the selected event initiation time); calculates the sources, amounts and distribution routes of the required inflows; and characterizes the resulting Delta salinity distribution at the time a stable flow situation reestablishes (post flooding). The "flooding" phase of WAM accomplishes this modeling task.

- **Flushing –** During the flushing period, WAM's focus is on the Delta fresh water inflows, tidal mixing, dispersion and dilution of salinity, and the gradual movement or reestablishment of a fresh water / saline water interface at a more normal downstream location. Upstream reservoir management and flushing releases are primary considerations, and the hydrodynamics and water quality submodel is focused on characterizing the distribution and timing of water quality improvements that result from flushing. Pumping for export during the flushing period may exacerbate the situation by drawing saline water into the Delta. Specifically, the south Delta can be very strongly impacted by salinity intrusion. Previous modeling (Jack R. Benjamin and Associates 2005) suggests the south Delta may experience a degraded water quality condition and prolonged disruption. Under such conditions, adverse results would include prolonged noncompliance with water quality standards for environmental (in channel) conditions, local (Delta area) uses and exports.
- **Limited Pumping –** When Delta water quality is sufficient to allow export pumping, the WAM focus shifts to maintenance of the Delta's water quality and deciding how much upstream reservoir water can be used in support of export pumping. These decisions are not straightforward. Maintaining Delta water quality when several islands are still flooded requires more than the usual inflow of fresh water because of the extra volume of tidal inflow and outflow under breach conditions (due to inflow into and out of flooded islands) and the resultant increased mixing. Additionally, the amount of water required, over and above the amount of pumping to prevent quality degradation (i.e., carriage water), will also increase. If poorly planned decisions are made, the upstream reservoir storage may be significantly depleted or opportunities for additional export could be missed. The WAM calculator simulates these upstream reservoir operation and pumping decisions until Delta levee repairs are completed and both pumping and reservoir storage return to normal. Obviously, these decisions and the resulting Delta water quality impact in-Delta uses and the ecosystem as well as exports.

WAM simulates the water-quality consequences of the levee breach occurrence, repair and water management responses, Delta inflows, Delta hydrodynamics, and water quality through time – in some cases, through an extended period of time. To avoid iteration – a computationally intensive approach – WAM calculations for the current time step rely only on the previous calculation period results. WAM is designed to operate overall on a monthly time step. Internally, several processes (such as flooding and flushing) must be addressed on a daily basis. However, the overall results of Delta water quality, changes in reservoir storage, exports, and other actions are reported monthly.

At all time steps, the model includes tidal averaging simplifications as an approach to achieve computational efficiency. This approach is made possible by using dispersion coefficients to capture the impacts of tidal mixing, as required for accuracy. More spatially and temporally detailed three-dimensional models (TRIM and UnTRIM) and two-dimensional models (the RMA Bay-Delta Model) have been used to calibrate the dispersion coefficients for the simpler tidally averaged one-dimensional model that is central to WAM. Details of calibration and verification are provided in the WAM TM, Appendices D and E.

11.2 DELTA WATER OPERATIONS

In the event of a Delta levee breach resulting in island flooding, Delta water operations may be substantially altered – gate positions may be changed (including the Delta Cross Channel gates and the South Delta barriers), export pump operations may be curtailed (e.g., emergency shutdowns), in-Delta diversions may cease (for Delta island irrigation) and, potentially, upstream reservoir releases may occur to counteract salinity intrusion during island flooding. The purpose of the Delta Water Operations Submodel is to represent these operations as they are expected to occur in a BAU response to a Delta levee breach incident. This effort is necessary because they will impact Delta hydrodynamics and salinity concentrations.

The operations submodel is subdivided into three phases in coordination with the hydrodynamics and upstream reservoir management submodels. The phases for Delta Water Operation actions are: 1) immediate response (during flooding), 2) flushing, and 3) limited pumping.

The operations submodel reflects the standard project operating procedures that existed in 2005 together with additional details that could be inferred from discussions with operators. In general, operations are tightly controlled by the water quality standards established by the State Water Resources Control Board and set forth in their Water Rights Decision 1641 (2000). Under BAU, WAM assumes that the projects would not intentionally violate a requirement of D-1641.

To the extent the projects can be operated with discretion, such actions often require consultation with federal and state fish and wildlife agencies under their respective Endangered Species Act provisions. These consultations require some time to formulate a request, discuss conditions and concerns, and agree on an action. Thus, the operations submodel assumes that any action requiring consultation will not be immediately available (within hours), but will require several days for formulation of a proposed action, discussion, agreement, and implementation. Consequently, such actions will typically occur during the flushing phase. Another assumption is that consultation will generally not allow compromises of intended protections for endangered species. During the limited pumping phase, normal D-1641 provisions are assumed to be in force.

In-Delta water use is assumed to be affected only by salinity conditions at the Delta island irrigation intakes. Delta water users generally have riparian or senior water rights and are therefore not obliged to respond to requests to suspend withdrawals, though they may cooperate voluntarily. Their responses to emergency orders are not predictable –no plan exists to issue and enforce such orders, so they are not part of the BAU scenario for base-case analysis.

Since the analyses for future years are to be for BAU, 2005 Delta water operations approaches and rules will remain unchanged. The one potential exception (included in the 2030 California Water Plan) is inclusion of the proposed operable south Delta barriers. It is not clear that barrier operation in a levee breach emergency would be substantially different than that assumed for the 2005 case with temporary barriers.

11.3 NET DELTA AREA CONSUMPTIVE USE

Within WAM the net Delta area consumptive water use or Net Delta Area Losses submodel (referred to herein as NDAL) determines the return flow, return flow salinity and net channel withdrawals for each island and/or groupings of islands. Net consumptive use is total consumptive use minus precipitation. NDAL and net channel withdrawals are the same as net consumptive water use, because consumptive use is supplied by either precipitation or water from Delta channels.

To represent NDAL within WAM, the Delta is divided into groups. Initially the Delta is divided into five groups representing each of the major Delta flow paths as defined by the hydrodynamics (HD) submodel. Each of the 142 subareas (defined by DWR for tabulating Delta net evapotranspiration) is assigned to a group and these groupings are used to report the NDAL output to the HD calculator. Each of the subareas is assigned to an evapotranspiration group, an evaporation group, and a precipitation group.

NDAL assesses in-Delta water demands based on normal irrigation net consumptive use, breach event details, islands flooded, channel salinity, and repair progress. If an island is flooded, irrigation demand ceases, as does seepage, and return flow. No evapotranspiration occurs, but evaporation occurs instead. When an island is repaired, seepage and return flow are restarted. Irrigation can commence as well, if adjacent channel salinity is of appropriate quality. For an unbreached or a repaired island, NDAL checks channel salinity calculated by the HD submodel and determines whether water quality conditions are sufficient to provide irrigation water. If water quality is unsatisfactory, irrigation does not occur until water quality conditions become satisfactory.

The NDAL submodel includes the ability to read and incorporate climate changes in the form of Delta area precipitation changes, temperature increases and carbon dioxide concentration increases. Precipitation increases result in a corresponding decrease in NDAL. The opposite is true for precipitation decreases. Temperature increases would increase evaporation and plant transpiration. Carbon dioxide increases, on the other hand, are believed to decrease water use for transpiration (DWR 2006) and will thus dampen the effect of future temperature increases.

11.4 UPSTREAM RESERVOIR OPERATIONS, TARGET EXPORTS, AND DELIVERIES

Depending on the severity of the levee breach scenario, the management of upstream and south of Delta reservoirs may be substantially altered. A small event, like Jones Tract, may require only slight modifications. But in a larger event, a prolonged period may occur of reduced or no pumping with an associated need to ration south of Delta supplies. Managed Delta inflows will also be needed to provide flushing and the additional Delta outflow to maintain water quality. After adequate flushing is achieved, the quantity of inflow required (simply to maintain water quality) will include normal Delta outflow and an increased amount based on the larger tidal prism due to tidal flow into and out of unrepaired, flooded islands. Finally, when limited export pumping can be reestablished, additional Delta inflow will be needed to provide the water that is to be pumped plus both the normal and increased carriage water needed to maintain water quality.

The reservoir management submodel makes emergency reservoir operating decisions related to the levee breach to balance the amount of water released for Delta inflow while the emergency and repairs progress with the need to conserve water for other and future uses. For reservoirs south of Delta, this effort means balancing deliveries to respond to water users' needs with the need to conserve water in south of Delta reservoirs in case the disruptions last longer than expected or encounter dry or critical years. For reservoirs north of Delta, this effort means balancing releases to reestablish through-Delta conveyance with the need to conserve in upstream reservoirs, so that other needs can be served, drought protection is provided and, when export pumping is reestablished, water is available to pump.

The basic approach used north of Delta is to receive daily requests from the HD submodel indicating the amounts of Delta inflow needed to reestablish or maintain required water quality. Separately, the HD submodel indicates the extra amount required to facilitate any given amount of pumping. These requests are then considered in light of the time of year, stored water available, the quantity requested and the projected duration of the incident (with its anticipated future requirements for extra water). A set of decision rules is incorporated into the submodel to make reasonable releases while saving enough water in storage to get through the incident and be in a position to recover toward normal operations, even encountering dry years. These daily decisions are accumulated to report monthly amounts of releases, Delta exports, and end of month storage.

The approach is similar for south of Delta storage. Releases may be made for CVP and SWP contractors after considering and balancing available stored water, anticipated incident duration, normal allocations, anticipated limited pumping during the rest of the incident, and the intensity of needs from the earlier cuts that are part of the incident. These water contractor deliveries are apportioned in full conformance with existing contracts. Again, the decision rules are crafted to get through the incident without implementing even more drastic cuts (due to running out of water) and then being able to rebuild deliveries in a reasonable way when pumping from the Delta is reestablished.

WAM produces time-series output for Delta exports, south of Delta water deliveries, south and north of Delta storage, and north of Delta flow and delivery changes. The following figures contain output from a sample WAM simulation – a preliminary version of a multi-island breach case beginning in August 1992. Note that the only purpose of this simulation and the results presented is to illustrate the way WAM may react to a breach scenario and to indicate the types of water flow and storage output information that will be generated.

The figures below contain traces of Delta exports for a baseline (without disruption) and for a preliminary multi-island breach case. Figures 11-1 and 11-2 show Delta exports for each month for the WAM simulation. Both CVP and SWP exports are halted during the flooding and flushing period after the breach and resume after 7 months.

Figure 11-3 provides plots of total (SWP and CVP) south of Delta deliveries with and without the breach and total delivery reductions due to the disruption. WAM allocates water to each group of contractors of the SWP and CVP based on contract priority. The total reduction in delivery is about 2.8 million acre-feet.

Figure 11-4 shows plots of storage south of the Delta. During this model simulation, south of Delta storage dropped by approximately 2 million acre-feet.

WAM is designed to provide these types of data for each levee breach scenario that is considered. Additional example plots and more detailed discussion of the reservoir management submodel of WAM are provided in the TM.

Refinements of the upstream reservoir management submodels for future years will generally be avoided in the spirit of providing a BAU analysis. Operating rules will be altered as necessary in the CalSim runs (used as input) to develop reasonable base cases. The objective will be to ensure that reservoirs are not unrealistically drawn down in the "no breaches" case used as a baseline. Follow up refinements of WAM operating rules may be required to avoid similarly unrealistic drawdowns in levee breach events. Operating rules are discussed in more detail in Appendix C of the WAM TM.

The hydrologic input to WAM may change quite dramatically for future years. WAM is designed to use CalSim input and output as the basic source of hydrologic information. For present (2005) conditions it uses the CalSim Common Assumptions 2005 LOD simulation. For future years, WAM will need to have available future year CalSim runs reflecting changes in level of development and climate change induced modifications to the hydrologic regime. Although little information is available beyond 2030 regarding level of development, substantial work has been performed to assess the impacts of climate change on the input hydrology for CalSim and the resulting impacts on amounts of water available for water supply. This work is described and summarized in the WAM Technical Memorandum.

11.5 HYDRODYNAMICS AND WATER QUALITY

The challenge for the hydrodynamics and water quality has been somewhat different – it has not been to balance decisions, but to have a working interaction with the water management decisions to calculate the Delta salinity resulting from the water management decisions in the context of the specific levee breach scenario. Very sophisticated models are already available for doing this calculation – e.g., the Delta Simulation Model 2 (DSM2), or the RMA Bay-Delta Model. However, it takes hours to days of real time for these models to simulate a large-scale levee breach event, so it is not feasible to use it in a fully interactive mode or for each of several thousand scenarios. A simplified hydrodynamics/water quality submodel has therefore been developed as part of the WAM. The following approach has been implemented:

- Use existing physically based numerical models (RMA Bay Delta Model and TRIM/UnTRIM 3D models) to explicitly evaluate hydrodynamic, salinity, and other water quality impacts for a limited number of specific breach events as well as to characterize the dynamics of the system.
- Analyze scenario simulations conducted using existing multidimensional models to estimate dispersion coefficients that quantify the strength of salt intrusion processes.
- Create a new tidally averaged flow and salinity transport model using a one-dimensional network approximation reaching from the central San Francisco Bay to the upstream limits of the Delta to rapidly evaluate salinity impacts of levee breach events and interact with the water management decision-making component of WAM.

The primary challenge in developing the simplified hydrodynamic/water quality model has been to represent enough of the physics to provide sufficient accuracy while maintaining the computational speed needed to simulate many thousands of levee breach events. The primary outputs of the WAM are monthly average quantities including export volumes and salinity, and in-Delta salinity at selected locations. Therefore, it is not necessary for the simplified model to explicitly represent the flow and transport on the tidal time scale or variations in flow velocity or salinity concentrations across a channel cross section. The simplified model is therefore a one-dimensional, tidally averaged transport model. This type of model considers net flow and tidal mixing (tidal dispersion, turbulent diffusion, and vertical stratification and mixing) relations derived from full dynamic models of the system. The simplified model then interacts with the water management component of WAM during the course of simulation, both providing input to the water management decision making component and receiving calculated inflows and exports. Figure 11-5, illustrates the basic conceptual structure of the simplified model.

Figures 11-6 and 11-7 provide samples of daily outputs from the HD model for an example of a multi-island levee breach event occurring in various years (assuming July 1 in each year) and in various months (for 1993). The figures indicate that the WAM HD submodel is capable of showing dramatic increases in salinity (at Jersey Point) as expected from an event of substantial magnitude. It also shows that the HD submodel will respond to the different Delta inflows and salinity conditions that prevail with different types of water years and different months during a year. More details on the calibration and performance of the HD submodel are provided in the WAM Technical Memorandum.

The hydrodynamics and water quality model will reflect future changes in two substantial ways. First the sea level rise attributed to the analysis year will be incorporated. This will change Delta hydrodynamics and may require recalibration of the dispersion coefficients used in the simplified hydrodynamics model. Secondly, when a levee breach with island flooding occurs, a larger volume will be flooded due both to the higher flood water level (higher sea level) and due to lower island surfaces where subsidence has occurred.

11.6 OTHER WATER QUALITY IMPACTS

In WAM, water quality conditions are represented by salinity; other water quality measures can potentially be modeled in future versions. As with salinity, other water quality parameters have concentrations that are influenced by the volume of water required to fill the islands, tidal mixing, dispersion, dilution, fresh water inflows, flushing, water exports, and management decisions. These conditions are already modeled by WAM.

One of the potential water quality impacts for water exports is from increased treatment costs due to organic carbon released from flooded island with predominately organic soil. Organic carbon can act as a disinfection byproduct precursor. As part of the water treatment process, excess organic carbon can be removed prior to chemical disinfection.

In contrast to salinity, sources for potential water quality pollutants can include water inputs from the river/Delta/Bay system as well as benthic sediments, suspended sediments, island stockpiles, or accidental contaminate releases from the Delta islands. Chemical pollutants have the potential to impact in-Delta water use, ecosystems, and water exports. The location, quantities, and chemical composition of potential toxics located on Delta islands are not extensively inventoried.

The location of some of the potential sources of toxics can be seen on Figures 11-8 and 11-9. Figure 11-8 shows toxic sources in the Delta complied from EPA Envirofacts database, from the

Department of Toxic Substances Control EnviroStor database, and from narrative information included in the Land Use and Resource Management Plan for the Primary Zone of the Delta (Delta Protection Commission 2002). Envirofacts contains the toxic release inventory and a list of facilities that are hazardous waste generators, transporters, or NPDES permit holders. EnviroStor inventories cleanup sites including federal superfund sites, state response sites, and voluntary cleanup sites. Figure 11-9 shows the location of all of the oil and gas wells and production fields in the Delta. Although safeguards and controls exist for toxic material storage containers and oil and gas extraction wells, these controls are not necessarily designed for an extended submergence after a period of stress. Additional information regarding potential water quality pollutants on Delta islands is located in Section 12.1, Ecosystem Impacts.

Potentially, future versions of the WAM can use transport modeling and particle tracking to model the dispersion of known sources of toxic chemicals.

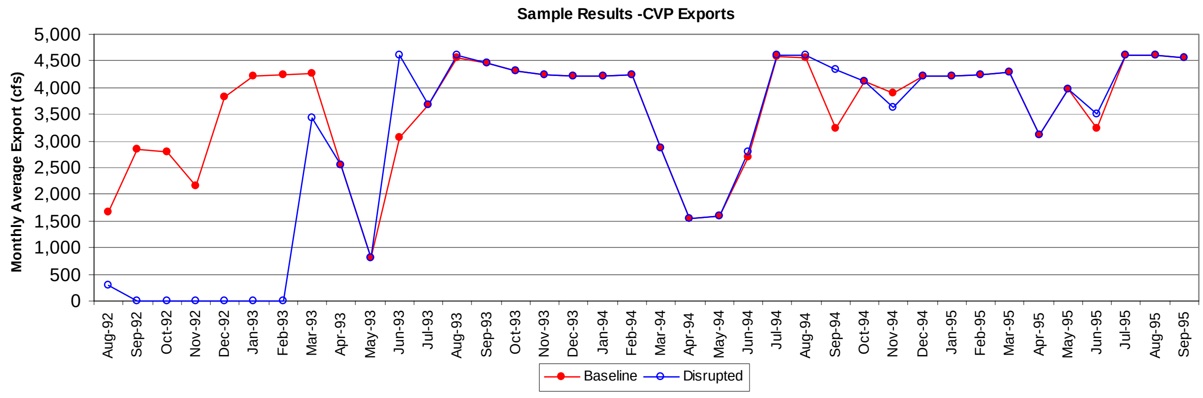


Figure 11-1 CVP Exports

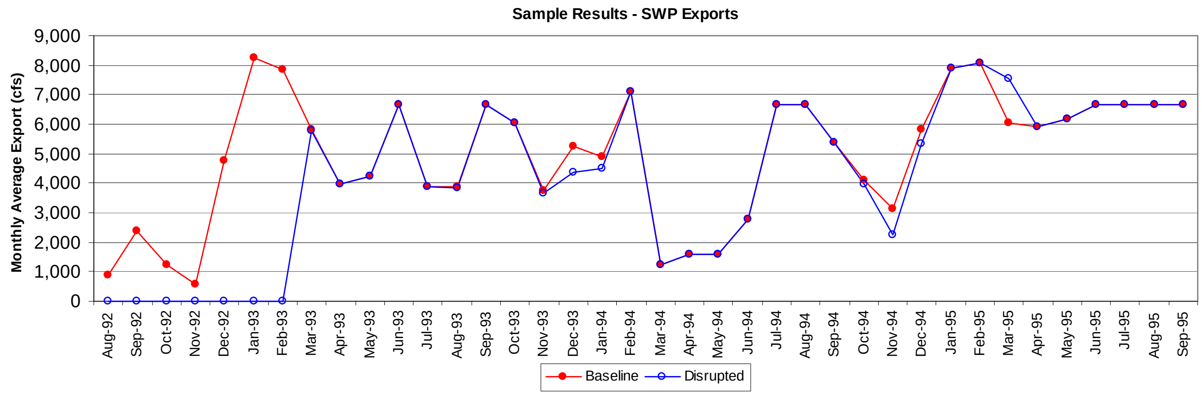


Figure 11-2 SWP Exports

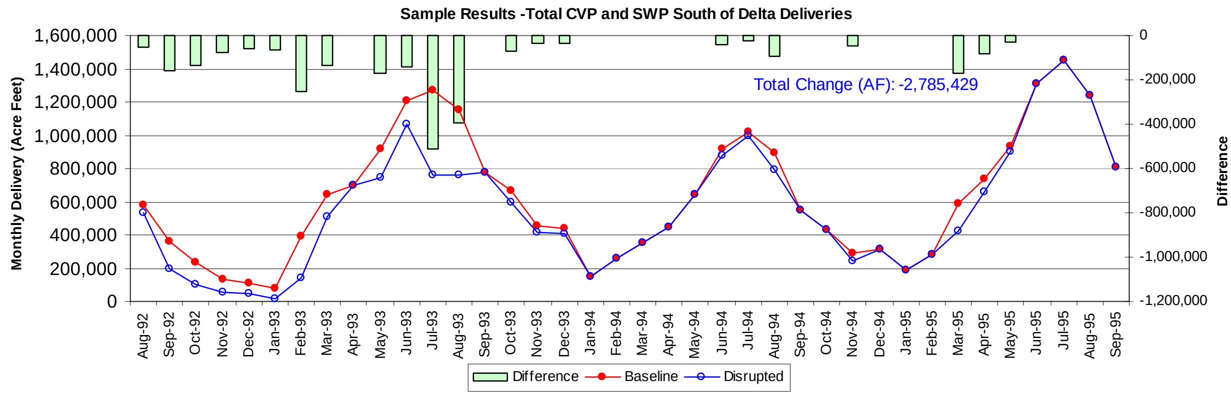


Figure 11-3 Total South of Delta Deliveries

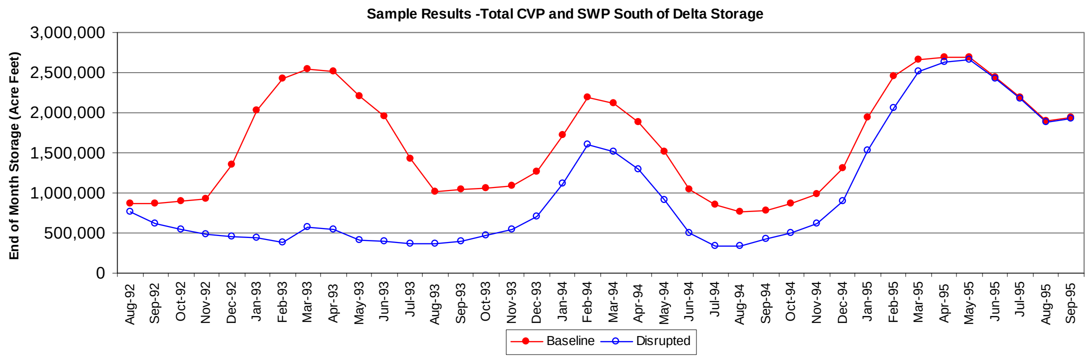


Figure 11-4 Total South of Delta Storage

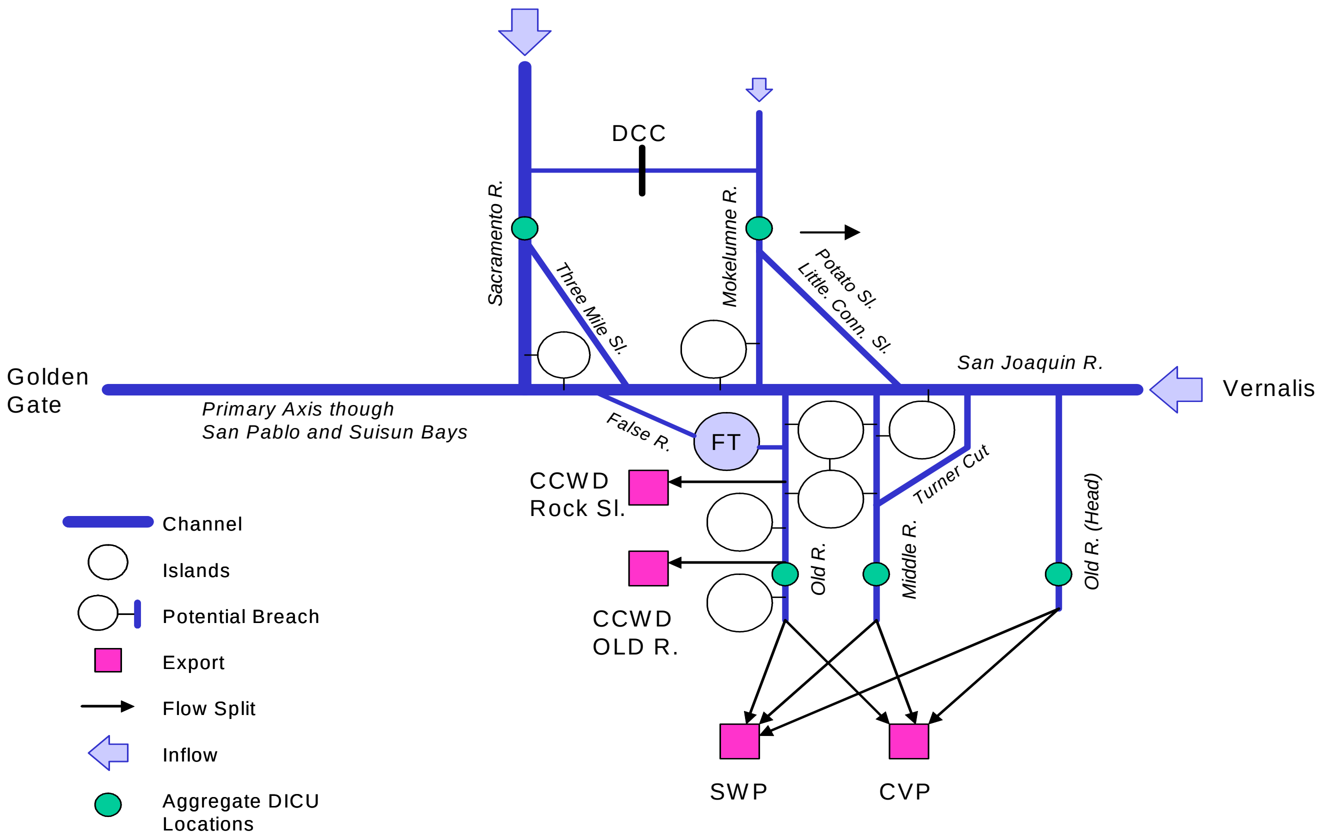


Figure 11-5 Simplified Hydrodynamic/Water Quality Submodel Schematic (showing example islands only)

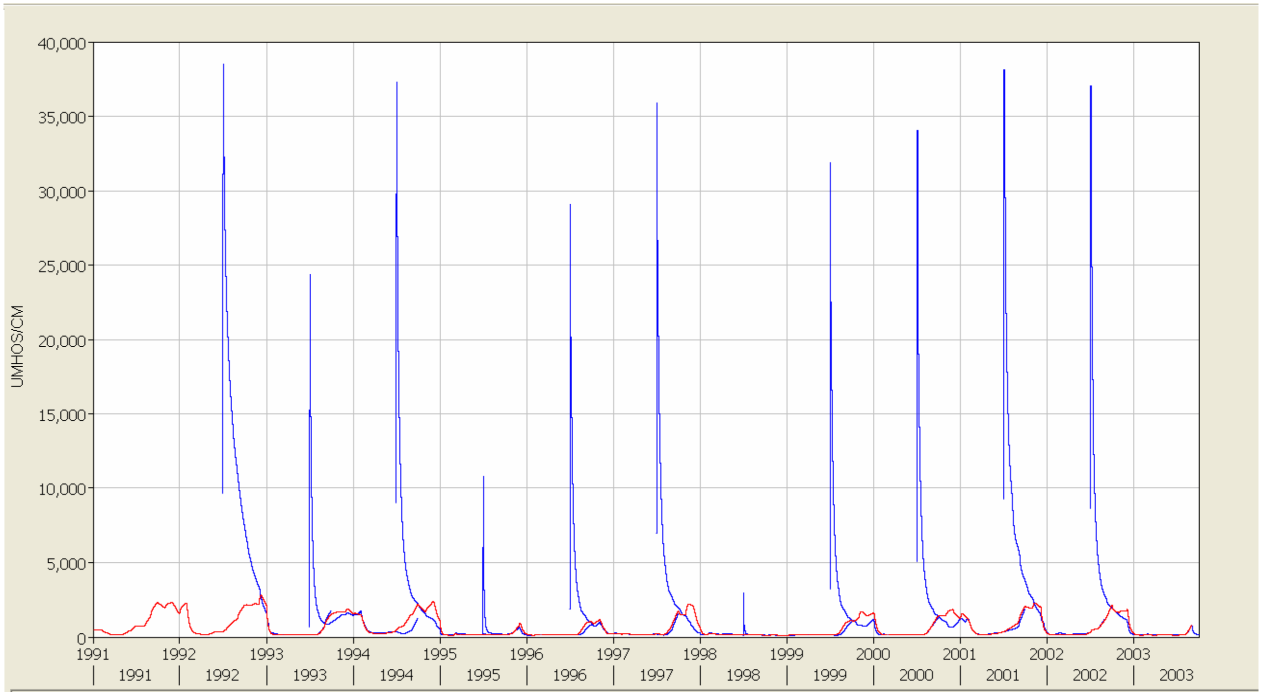


Figure 11-6 WAM HD Calculation of the Jersey Point Salinity Response to a Multi-Island Levee Breach Event Occurring on July 1 in Various Years

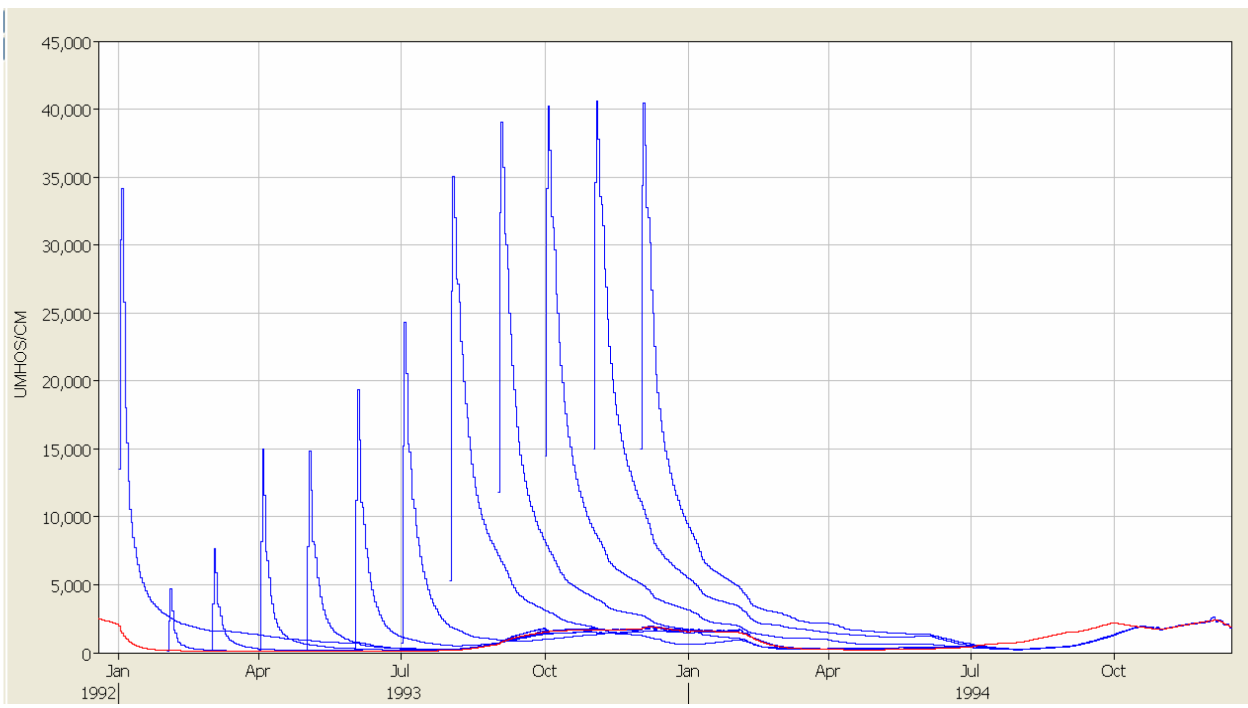


Figure 11-7 WAM HD Calculation of Jersey Point Salinity Response to a Multi-Island Levee Breach Event Occurring (Alternatively) on the First of Each Month During 1993

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Toxics\DRMS_toxics_map.mxd Date: 3/6/2007 5:55:39 PM Name: akkeele0

Type of Toxic Area

- Chemical Storage
- Clean-up
- NPDES
- Small Generator
- Superfund
- Toxic Release
- Transporter

Wastewater and Biosolids Disposal

Dredge Materials Disposal

Analysis Zone

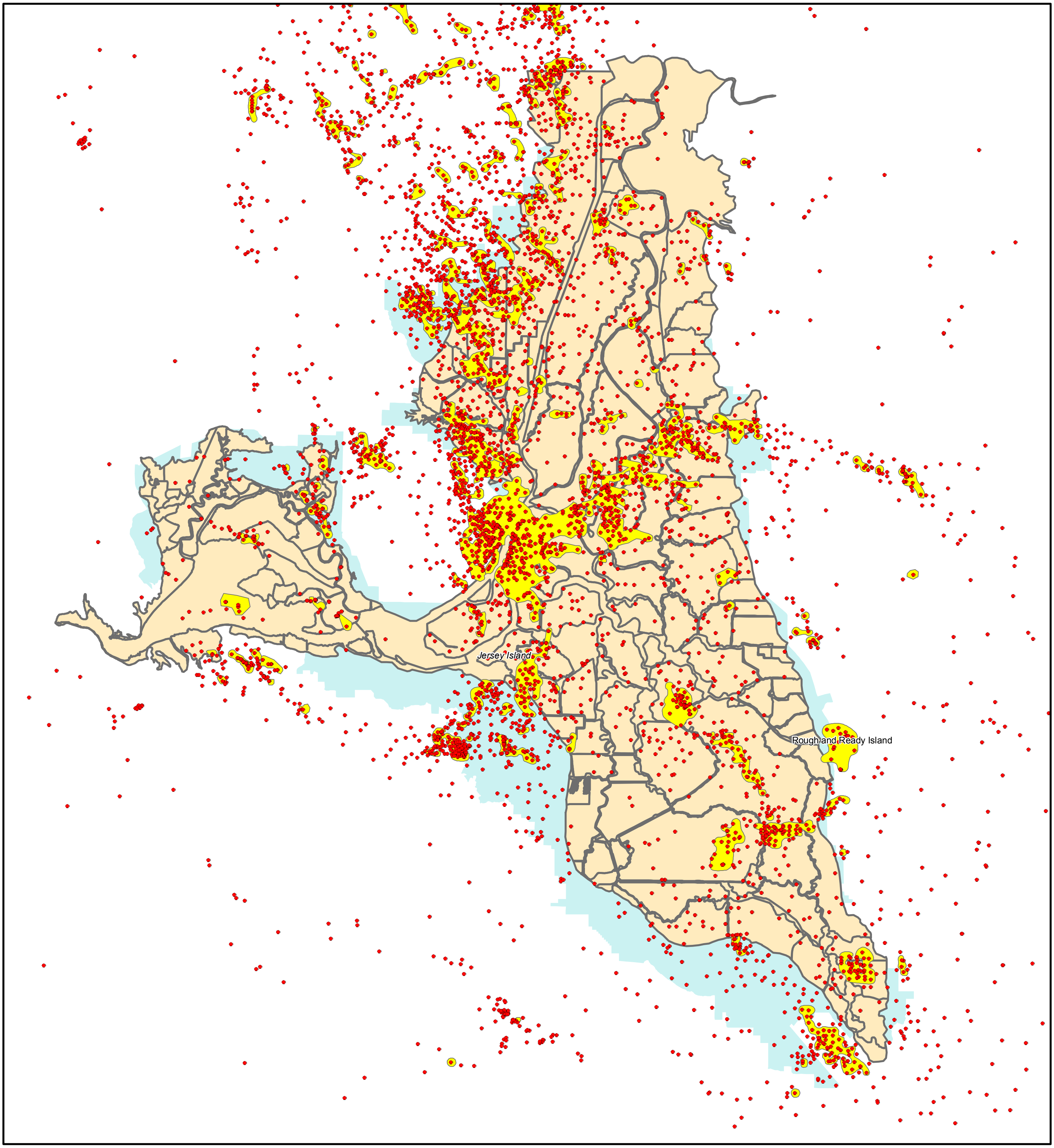
FEMA 100-year Floodplain

Legal Delta and Suisun Boundary

0 2 4 8 Miles

N

URS	DRMS 26815621	Toxics Known in the Delta	Figure 11-8



Analysis Zone

FEMA 100-year Floodplain

Legal Delta and Suisun Boundary

Gas and Oil Production Fields

Gas and Oil Wells

0 2 4 8 Miles

N

URS

DRMS	Gas and Oil Facilities in the Delta	Figure 11-9
26815621		

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