DRAFT TECHNICAL MEMORANDUM NO. 3
MASS LOADING METHODOLOGY
CALIFORNIA URBAN WATER AGENCIES
STUDY OF DRINKING WATER QUALITY IN DELTA TRIBUTARIES

June 28, 1994

One objective of Phase I of the Study of Drinking Water Quality in Delta Tributaries is to determine if it is possible to calculate mass loads of key drinking water constituents at the benchmark locations and from various discharges to the Delta tributaries so that the impact of the discharges on drinking water quality can be assessed. Based on the mass loading analysis, alternatives for improving drinking water quality will be developed in Phase 2.

Proposed Mass Loading Methodology

The mass loading methodology proposed at the January 19, 1994, Project Advisory Committee (PAC) meeting consists of developing a series of frequency distribution graphs showing the loads of the constituents of concern versus their percent occurrence at the benchmark locations during both dry and wet years. These graphs could be used for comparison of the frequency distributions of contaminant loads from various discharges (e.g. Sacramento Regional Wastewater Treatment Plant, Colusa Basin Drain) to the contaminant loads at the benchmark locations. This tool could then be used to assess the likelihood that removing a discharge completely, partially, or seasonally would improve drinking water quality.

At the January PAC meeting, the project team proposed that loads for total dissolved solids (TDS) and total organic carbon (TOC) or dissolved organic carbon (DOC) be evaluated at three benchmark locations; Greene's Landing on the Sacramento River, Vernalis on the San Joaquin River, and the State Water Project (SWP) Banks Pumping Plant. TOC or DOC was selected for mass loading computations since organic carbon is a key constituent of concern because it affects water treatment control of disinfection by-products. TDS was selected because there is an extensive database on electrical conductivity (EC) extending from 1982 to the present. DWR has determined the statistical relationships between TDS and EC at numerous locations in

the Delta. Table 1 shows the conversion equations that were used to calculate TDS from EC measurements. (Tables and figures are located at the end of the text.) The calculated TDS concentrations provide an 11 year database encompassing the range of water year types from critical to wet years. The PAC directed the project team to proceed with this analysis and determine the suitability of this methodology for more detailed mass loading analyses.

Data Selected For Analysis

A review of the extensive data collected for this project showed that the best data for evaluation of the mass loading methodology was collected by the Municipal Water Quality Investigations (MWQI) program conducted by the Department of Water Resources (DWR). The MWQI sampling locations are shown on Figure 1. TOC and DOC data have been collected since 1989 by the MWQI program. DOC rather than TOC was selected due to the greater amount of available data. Two MWQI data sets were used:

1. Monthly surface water grab samples - Monthly data on EC extends from 1982 to 1993 and DOC data extend from 1987 to 1993. Occasionally, samples are collected every two weeks but this data set is referred to as the monthly data.

2. Daily DOC data collected in 1993 by automated sampling devices. There are no daily EC data.

Comparison of Monthly Grab Samples to Daily Samples. The 1993 daily DOC results were compared to the 1993 monthly DOC results to assess how well the monthly data represent water quality conditions. There are monthly data available for the three benchmark locations as well as other Delta locations. However, the daily data are limited to one benchmark location (Greene's Landing) and a Delta location near the Banks Pumping Plant (Middle River at Borden Highway). To make a more complete comparison between the monthly and daily data, the Middle River data were also examined.

Figure 2 presents a summary of the monthly DOC data collected between 1989 and 1993 at the three benchmark locations. This figure shows:

1. There is more variability and higher DOC concentrations during the winter and early spring wet weather period.

2. The DOC concentrations at Vernalis and Banks are roughly double the Greene's Landing concentrations.

Figure 3 presents a summary of the daily results for DOC, ultraviolet absorbance (UVA_{254}), and specific absorbance at Greene's Landing in 1993. This figure shows:

1. The daily DOC data for 1993 have the same pattern as the five year period of monthly grab samples.

2. The UVA_{254} data show the same pattern as the DOC data.

3. The specific absorbance, which is the ratio of UVA_{254} to DOC, is relatively constant throughout the year.

Figure 4 presents the 1993 monthly DOC concentrations. A comparison of the summary of daily samples presented on Figure 3 to the monthly data shown on Figure 4 indicates:

1. The daily DOC data show that monthly data are representative of summer water quality conditions at Greene's Landing in 1993. During the dry months, the average monthly grab sample results were about the same (within 1 mg/L) as the median and mean of the daily results at Greene's Landing.

2. Monthly or biweekly samples do not always depict sudden DOC changes during the wet weather period (January to May) as do the daily data. This is because DWR MWQI field sampling crews are unable to sample during peak runoff and

storm periods for safety reasons and because of poor levee road conditions. For example, in February 1993, the daily data recorded a peak DOC concentration of 6.8 mg/L and median value of 4 mg/L at Greene's Landing, as shown on Figure 3. The highest DOC concentration collected in a monthly sample was 4 mg/L, as shown on Figure 4

Figures 5 and 6 present the daily and monthly data, respectively, for the Middle River at Borden Highway, near the Banks benchmark location. These figures show:

1. The DOC and UVA_{254} concentrations are higher and more variable in the winter and early spring months, as they are at Greene's Landing. However, there is a steady decline in concentrations from January to August, which does not occur at Greene's Landing.

2. The monthly DOC data adequately characterize water quality conditions during the dry months.

3. Monthly data do not depict the peak concentrations seen in the daily data during the wet months. Daily data showed a peak DOC of 13 mg/L in January and February, 1993, as shown on Figure 5. The highest monthly data were 8.2 and 8.5 mg/L DOC in January and February, respectively, as shown on Figure 6.

The data were reviewed to determine which data should be used to conduct the mass loading estimates. At issue were which data best represented water quality conditions at the sites, how much data were available, how should the data be combined or treated, and how should the mass loading estimates be presented. Based on the comparison of monthly and daily data, described previously, the daily data were used to compute 1993 DOC mass loadings at Greene's Landing. Monthly data were used to compute DOC mass loads at the Vernalis and Banks benchmark locations since daily data are not available for these two locations.

Flow Data. Mean daily river and diverted flows were obtained from the DWR DAYFLO database. DAYFLO computed Delta outflow, Sacramento River flow at Freeport, and estimated precipitation for 1982 through 1993 are shown on Figures 7a through 7l. The Decision 1485 classification for each water year (October 1 to September 30) is shown on each figure. A better indication of the year to year variability in flow is shown on Figure 8. Measured flows for the Sacramento River at Freeport, San Joaquin River near Vernalis, and SWP exports were used in the mass loading calculations for TDS and DOC at Greene's Landing, Vernalis, and Banks, respectively. SWP export values were also used for the mass loading estimates at Middle River. This results in an unavoidable overestimation as it assumes the SWP is exporting all water from Middle River. However, there are no DAYFLO values at Middle River. The use of the SWP export values does not affect the comparison of daily versus monthly load estimates at Middle River.

Relationship Between Flow and Concentration. The relationships between flow and DOC and flow and EC were investigated to determine if these relationships could be used to extrapolate DOC and TDS (calculated from EC) concentrations to extend the database to cover periods when limited data were collected (i.e., monthly samples) or to cover water year classifications that are not well represented in the existing database (i.e., wet years).

Figure 9 shows DOC concentration versus flow at Greene's Landing, Vernalis, and Banks. The monthly data were used since they extend back to 1982. There are clearly no useful relationships between DOC concentrations and flow at these three locations. Figure 10 presents EC versus flow at the three benchmark locations. There is no relationship between EC and flow at the Banks location, as expected. There is scatter in the Greene's Landing data but the EC to flow relationship at Vernalis is clear. During high flows, San Joaquin River water is less saline that during low flow periods. For this initial set of mass loading estimates it was decided not to interpolate or extrapolate DOC or TDS data based on flow for unsampled time periods.

Preliminary Mass Loading Results

The mass loads of DOC and TDS at Greene's Landing, Vernalis, Banks, and Middle River were calculated using the following equation:

Mass loading calculations used the following equation:

Mass load (lbs. per day) = Q (mgd) x concentration (mg/L) x 8.34 lbs. per gal.

where Q, the flow in million of gallons per day (mgd) = Q (cfs) x 0.64632

Example:

Q = 20,000 cfs per day and DOC = 3.7 mg/L

Mass loading = (20,000 cfs/day)x(0.64632)x(3.7 mg/L DOC)x(8.34 lbs/gal)
= 399,000 lbs. per day of DOC

Frequency distributions of the mass loads of DOC and TDS were determined for the three benchmark locations and Middle River based on the available data to determine if the proposed methodology would prove suitable for more detailed analysis.

DOC Mass Loads. Figure 12 shows the frequency distribution of the 1993 DOC mass loading (pounds per day) computations at each of the four sites. During the period of record for the DOC data, 1993 represents the only wet (wet or above normal) year. The curves are much smoother and continuous for Greene's Landing and Middle River than at Banks and Vernalis because there are over 200 daily samples taken at Greene's Landing and Middle River whereas the Banks and Vernalis plots were constructed with monthly samples. Figure 13 presents the mass loading frequency distributions for the dry (critical, dry, or below normal) years between 1989 and 1992. The dry years were generally similar with the exception of some periods of

heavy rainfall (e.g., March, 1991), which differentiated some years from others. A review of Figures 12 and 13 shows:

1. If it is assumed that the total riverine load to the Delta comes from the Sacramento and San Joaquin Rivers (i.e., the eastside streams are negligible), then during the 1993 wet year the median DOC load at Greene's Landing (250,000 lbs/day) represented 78 percent of the riverine load and Vernalis (median load of 70,000 lbs/day) represented 22 percent of the total. The DOC concentrations at Vernalis are roughly double the Greene's Landing concentrations (Figure 2) but the Sacramento River flow is substantially higher than the San Joaquin River flow.

2. During dry years, the median DOC load at Greene's Landing (125,000 lbs/day) represents 83 percent of the total riverine load and Vernalis represents 17 percent.

3. A comparison of the median DOC loads shows that alternatives to control DOC in the San Joaquin Basin will have a minimal impact on the total loading to the Delta (and due to Delta hydrology, a minimal impact at the Banks pumping plant).

4. During the 1993 wet year, 80 percent of the DOC load measurements at Greene's Landing were lower than 500,000 lbs/day, whereas the maximum load was 3 million lbs/day. During the dry years, 80 percent of the DOC load measurements at Greene's Landing were less than 200,000 lbs/day, whereas the maximum load was 1.5 million lbs/day. This indicates that a large load of DOC enters the Delta during a short period of time. It may be possible to identify the sources during the high loading periods and construct alternatives that would reduce the DOC load.

TDS Mass Loads. Monthly EC data extending back to 1982 were used to compute TDS mass loads by water year type. Data from water years 1982, 1983, 1984, 1986, and 1993 were grouped together because they were classified as wet years. The results of the wet year TDS

mass loads are shown on Figure 14. Figure 15 presents the mass loading frequency distributions for the dry years of 1985 and 1987 through 1992. A comparison of Figures 14 and 15 shows:

1. Comparison of the wet years median TDS load values shows that Greene's Landing contributes 66 percent of the TDS load (median of 9.5 million lbs/day) and Vernalis contributes 34 percent of the load (median of 5 million lbs/day). Vernalis contributes a greater percentage of the TDS load than the DOC load.

2. Comparison of the dry year median TDS load values shows that Greene's Landing continues to contribute two thirds and Vernalis contributes one third of the total load. The contribution from Vernalis does not decrease during dry years as it does for DOC.

3. Although Greene's Landing represents the largest percentage of the TDS load, the Vernalis load is significant enough to have an effect on east Delta TDS concentrations.

4. During the wet years, 80 percent of the TDS load measurements at Greene's Landing were lower than 26 million lbs/day compared to the maximum of 40 million lbs/day. During the dry years, 80 percent of the TDS load measurements at Greene's Landing were lower that 9 million lbs/day, whereas the maximum was 30 million lbs/day. This indicates that a large load of TDS enters the Delta during a short period of time but the short term load is not as significant a percentage of the total load as it is for TOC.

Conclusions on the Use of the Mass Loading Methodology

The mass loading methodology described in this technical memorandum is a useful tool for comparing mass loads of constituents of concern at benchmark locations. It will also be a useful tool for comparing various alternatives for improving drinking water quality, provided there are sufficient flow and concentration data. An assessment of the data on constituents of

concern, other than DOC and TDS, and flow at the benchmark locations and for the preliminary alternatives identified at the beginning of this study will be presented for discussion at the July 7 PAC meeting.

Table 1. EC to TDS Conversion Equations[a]

Sacramento River at Greene's Landing (RSAC139)		
Wet water years	TDS = 35.58 + (0.385575 x EC)	EC limits 64 - 308
Normal water years	Insufficient data	
Dry water years	Insufficient data	
All water years	**TDS = 38.97 + (0.375404 x**	**EC limits 64 - 356**

Table 1. EC to TDS Conversion Equations[a]

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All water years	**TDS = 38.97 + (0.375404 x EC)**	EC limits 64 - 356
Middle River at Borden Highway		
Wet water years	**TDS = -32.8 + (0.223407 x EC)**	EC limits 157 - 947
Normal water years	TDS = -35.1 + (0.248671 x EC)	EC limits 172 - 730
Dry water years	**TDS = -43.2 + (0.259561 x EC)**	EC limits 211 - 941
All water years	TDS = -38.0 + (0.244047 x EC)	EC limits 157 - 947
Banks Headwords (used Clifton Court intake - West Canal CHWST0		
Wet water years	**TDS = 8.5 + (0.539136 x EC)**	EC limits 153 - 1320
Normal water years	Insufficient data	
Dry water years	**TDS = 23.1 + (0.525874 x EC)**	EC limits 179 - 1480
All water years	TDS = 19.2 + (0.528851 x EC)	EC limits 153 - 1480
San Joaquin River near Vernalis (RSAN112)		
Wet water years	**TDS = 6.69 + (0.550722 x EC)**	EC limits 217 - 1740
Normal water years	TDS = 2.53 + (0.576392 x EC)	EC limits 153 - 843
Dry water years	**TDS = 5.52 + (0.583542 x EC)**	EC limits 263 - 1850
All water years	TDS = -2.67 + (0.583793 x EC)	EC limits 140 - 1850

[a]The conversion formulae were statistically developed by DWR (P. Lee, memorandum dated September 4, 1986, Salinity Conversion Equations). The equations used in this study are shown in bold face.

Figure 1. IDHAMP Monitoring Stations

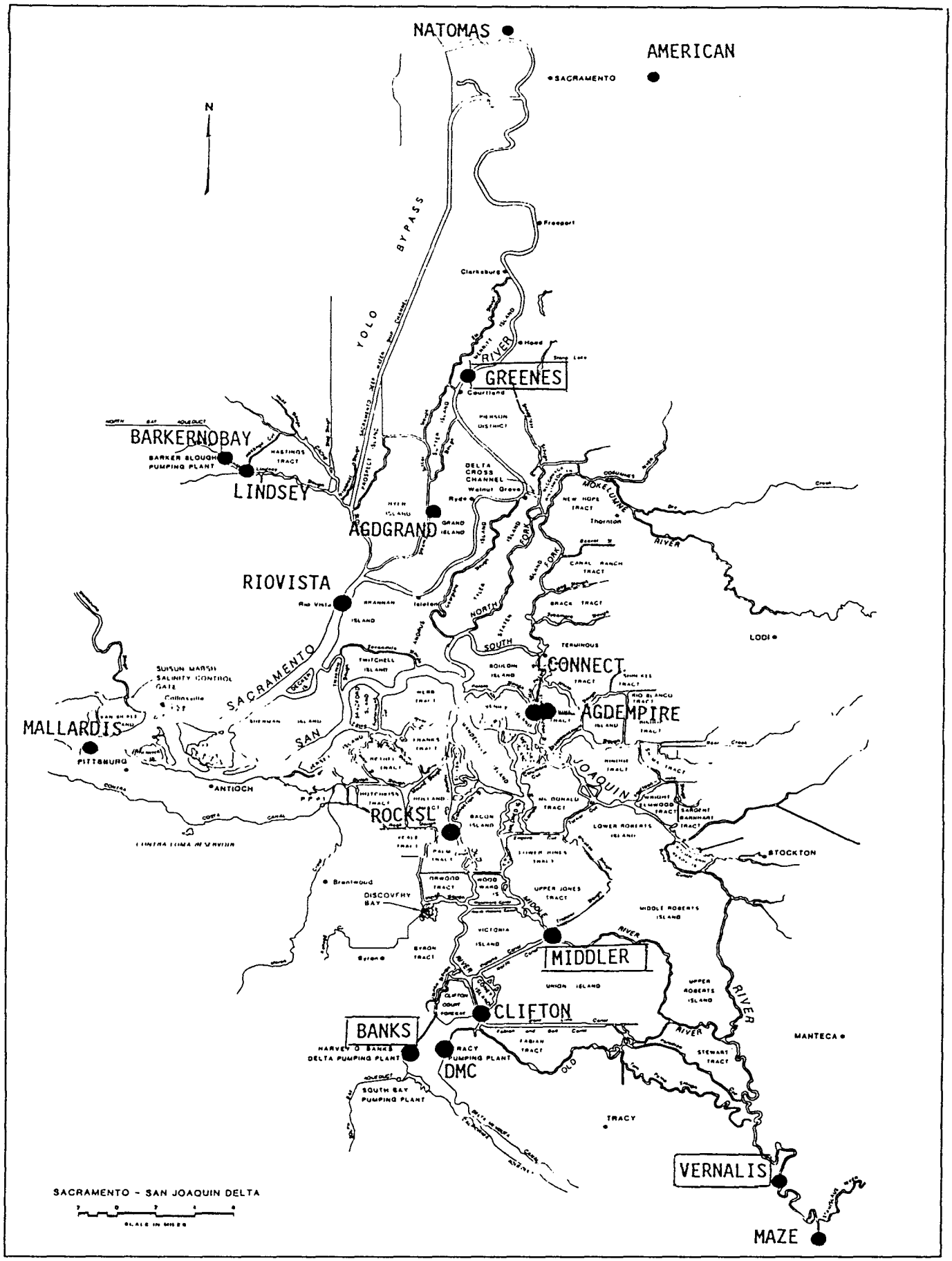
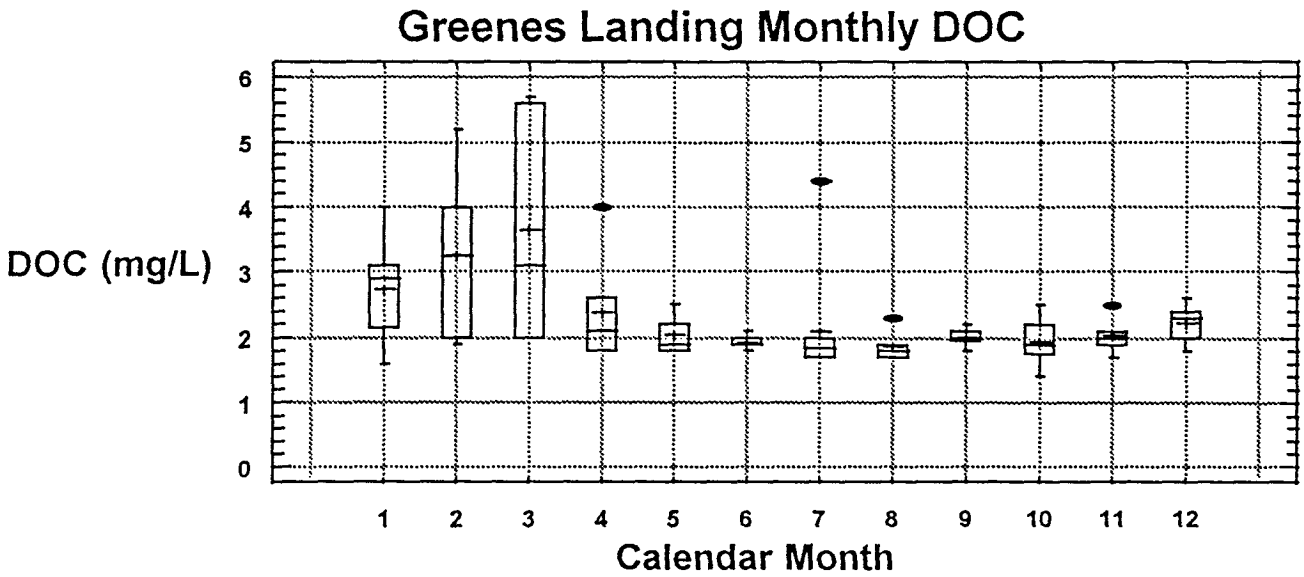
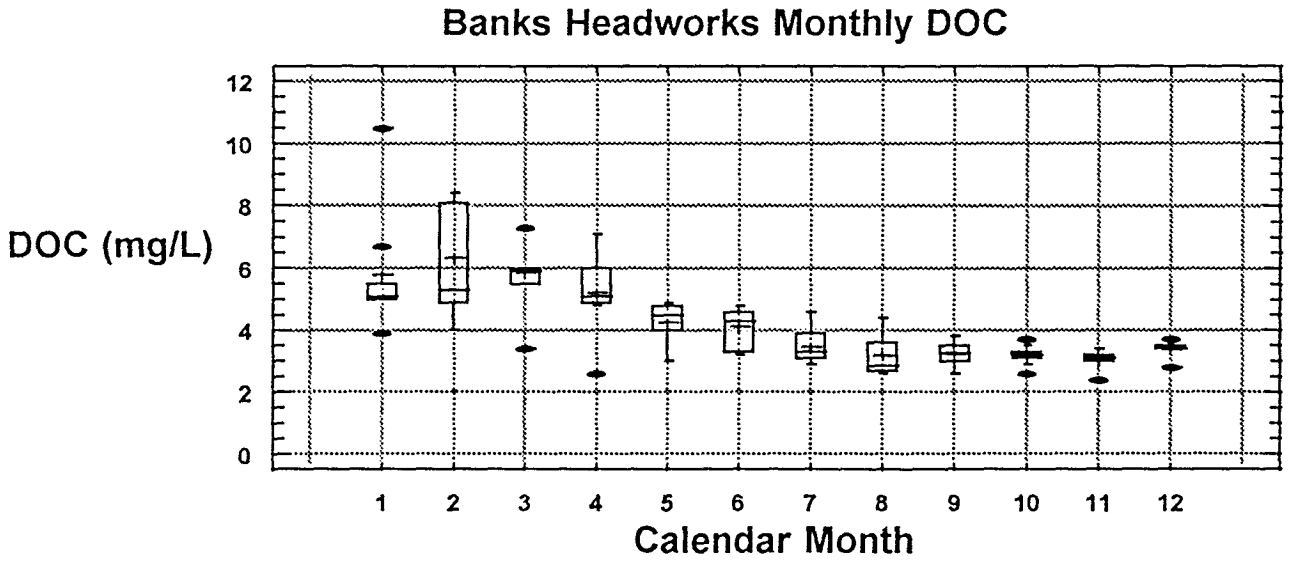


Figure 2. MWQI Monthly Grab Sample DOC 1989-93





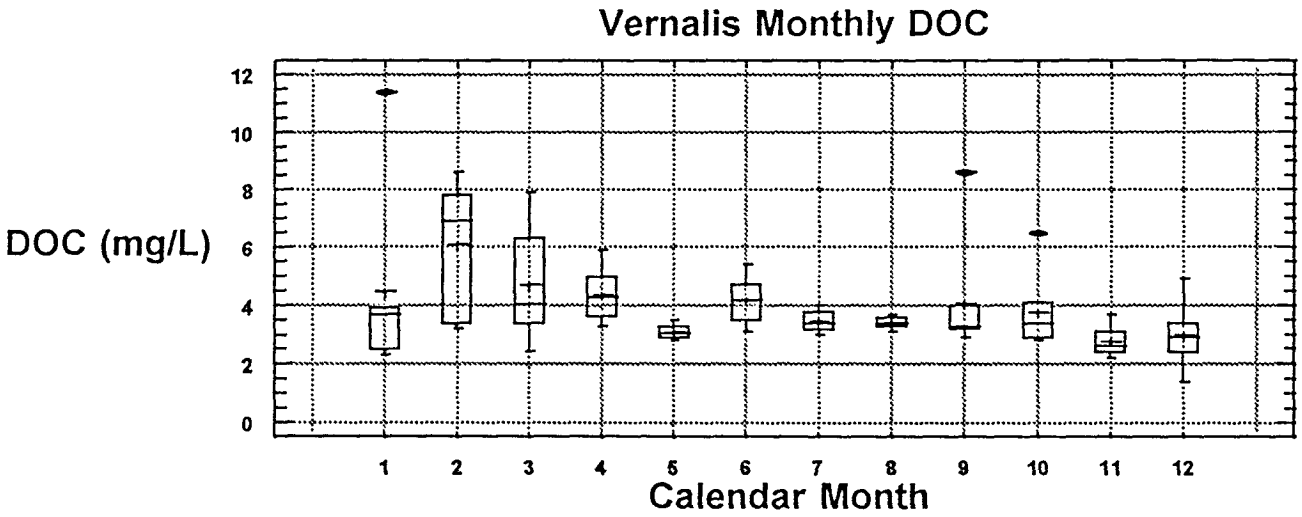


Figure 3. Sacramento River at Greenes Landing 1993 Autosampler results by calendar month

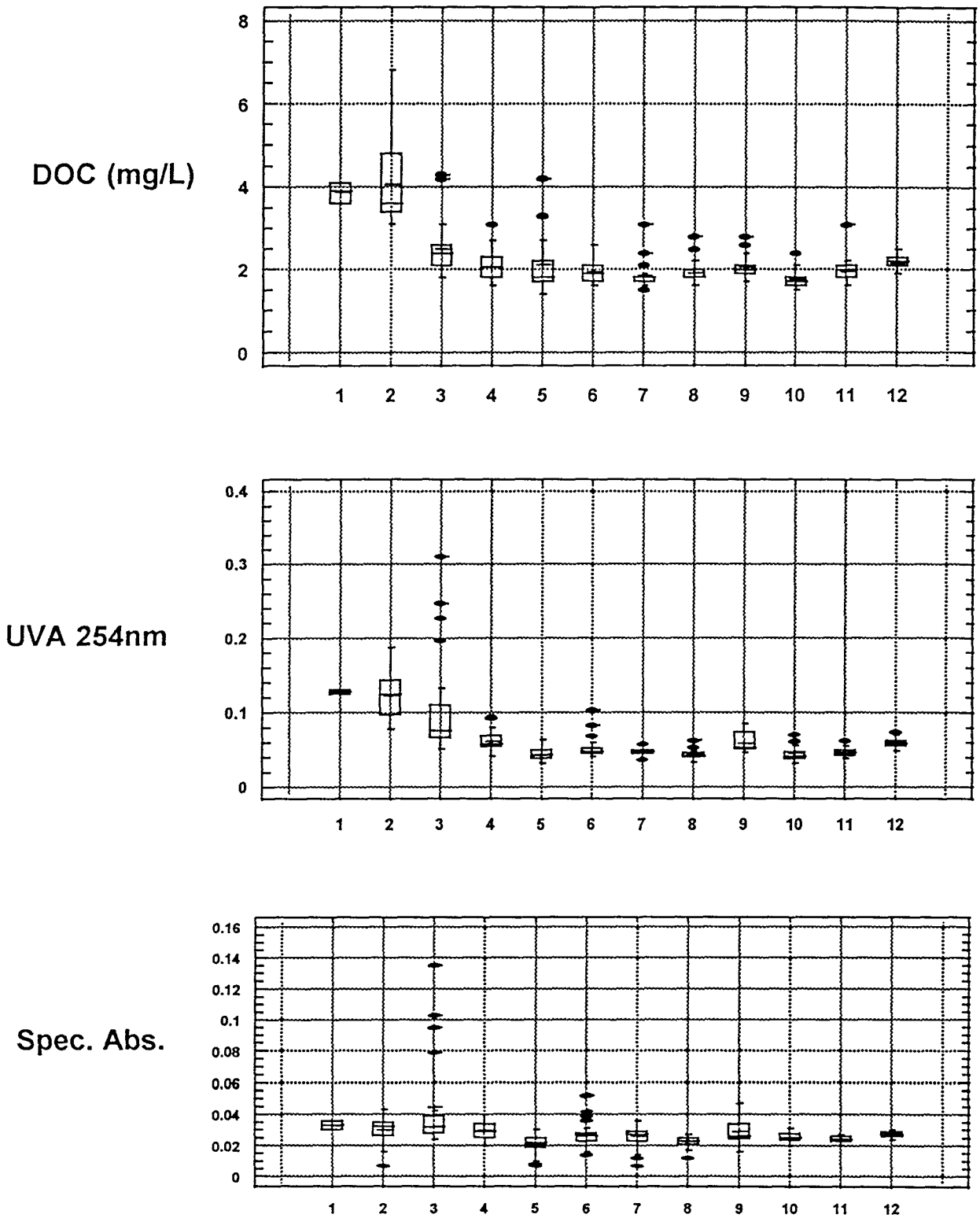


Figure 4. MWQI Grab Samples Greenes Landing 10/92-9/93

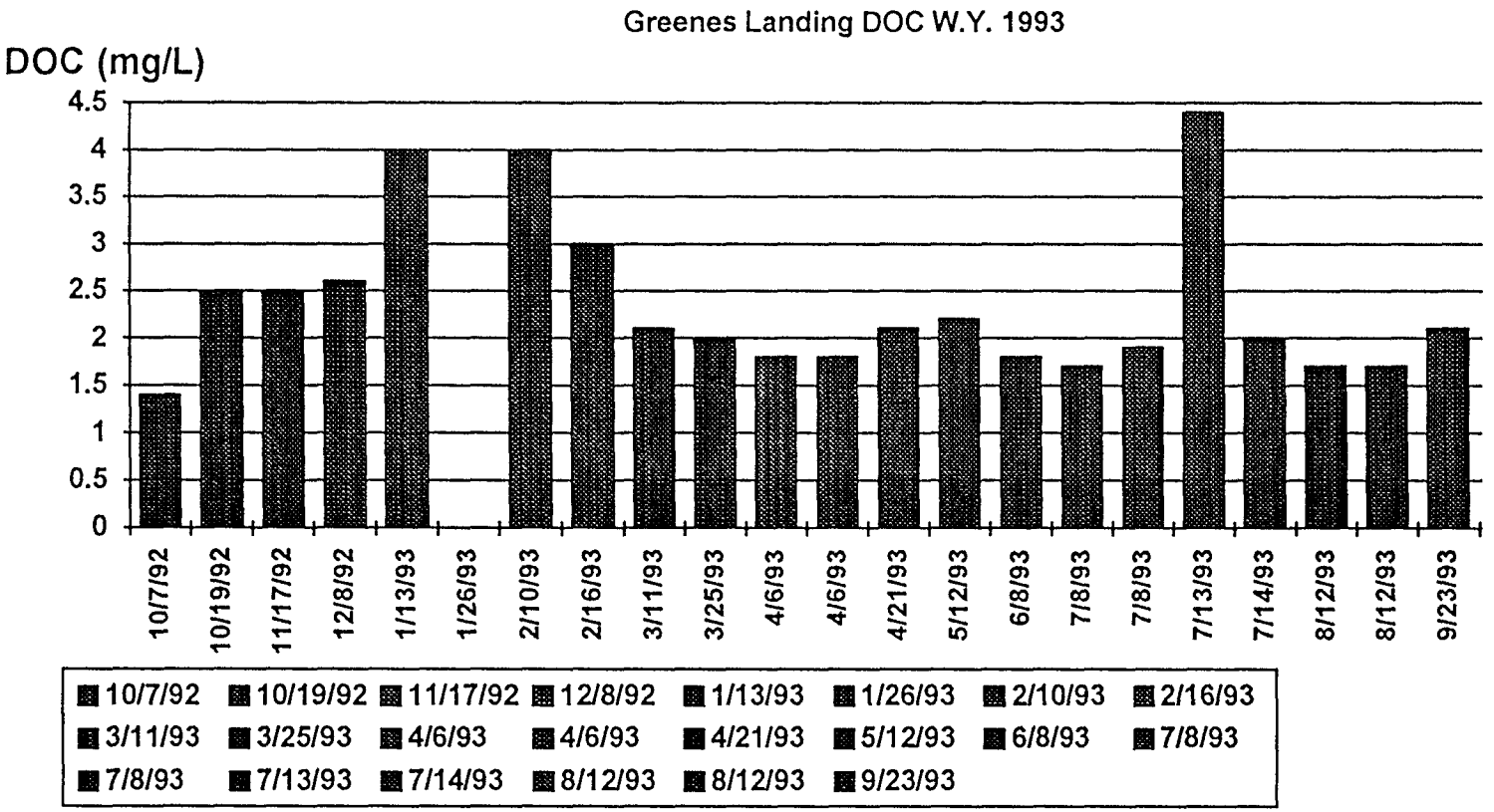


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Figure 5. Middle River at Borden Hwy. 1993 Autosampler results by calendar month

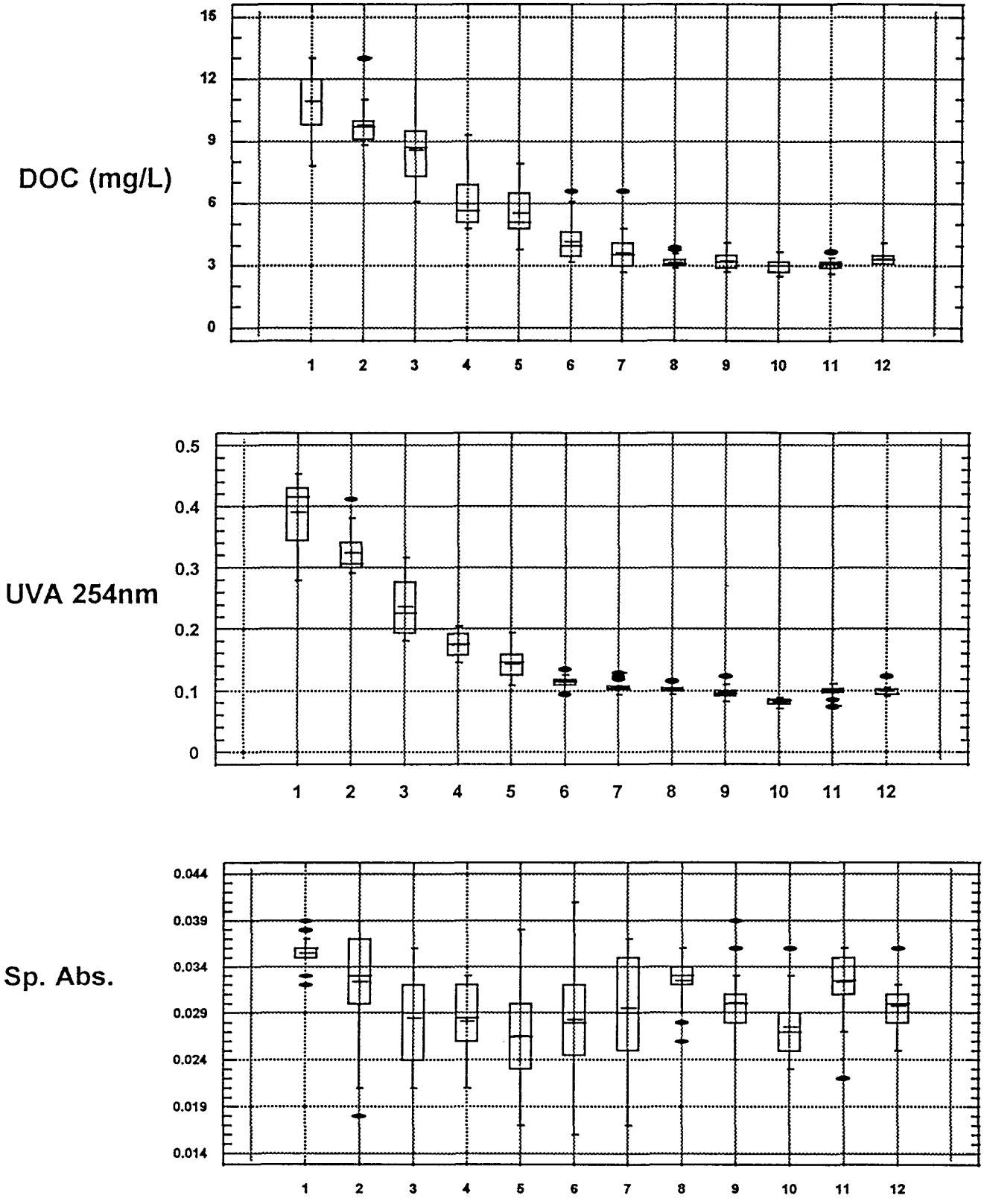

Figure 6. MWQI Grab Samples Middle River 10/92-9/93

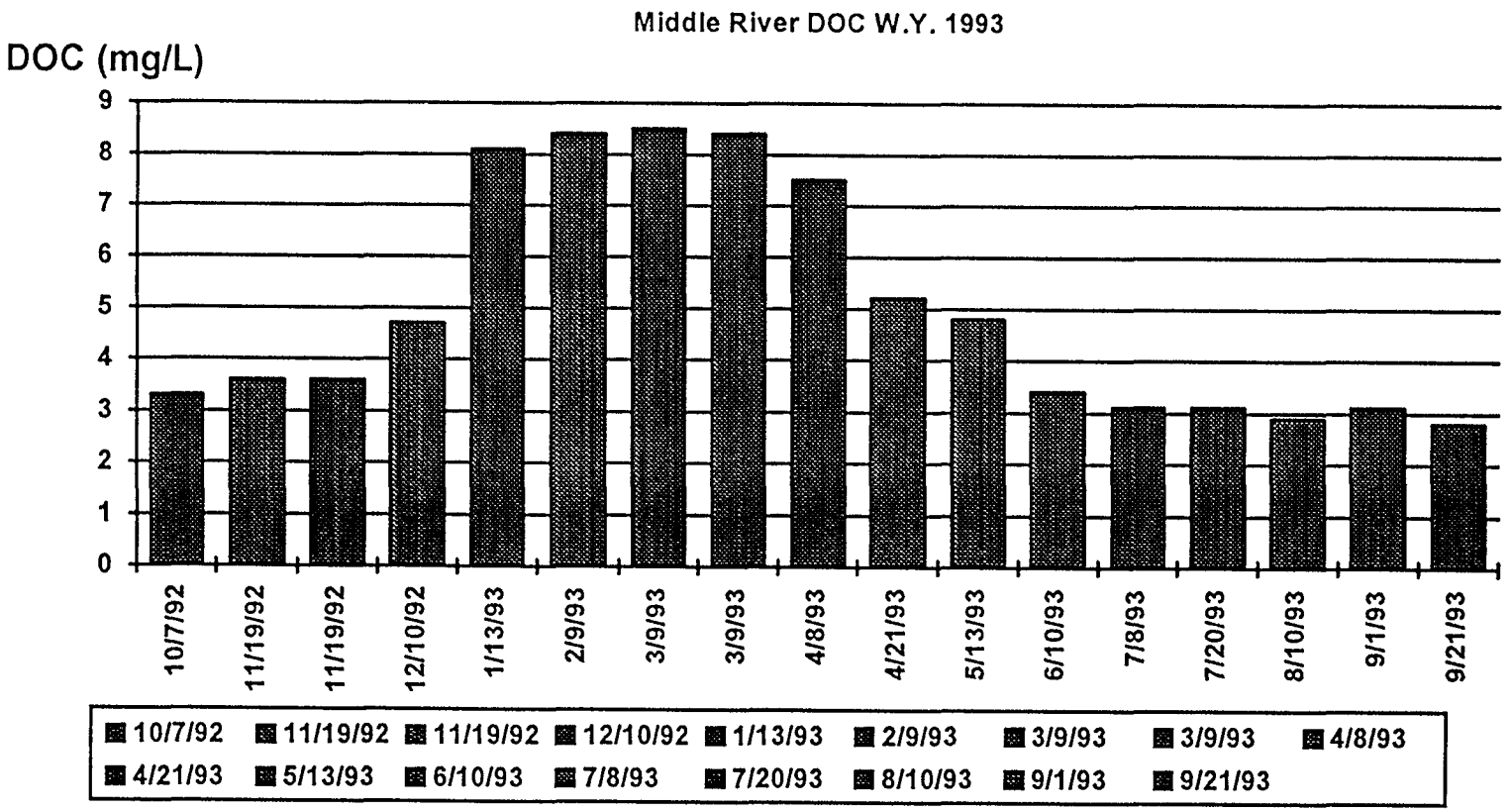

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Figure 7a

Water Year 1982 DAYFLO Flows

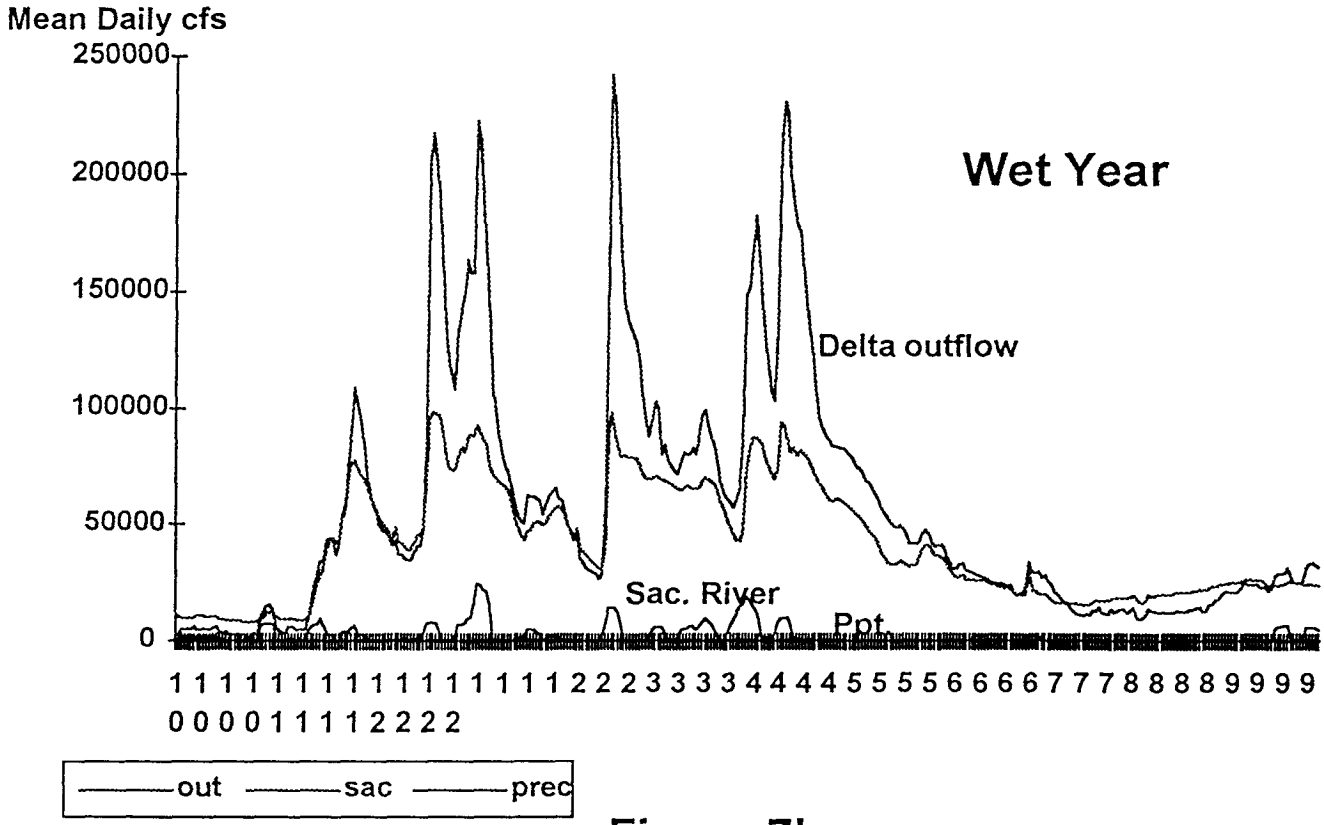

Figure 7b

Water Year 1983 DAYFLO Flows

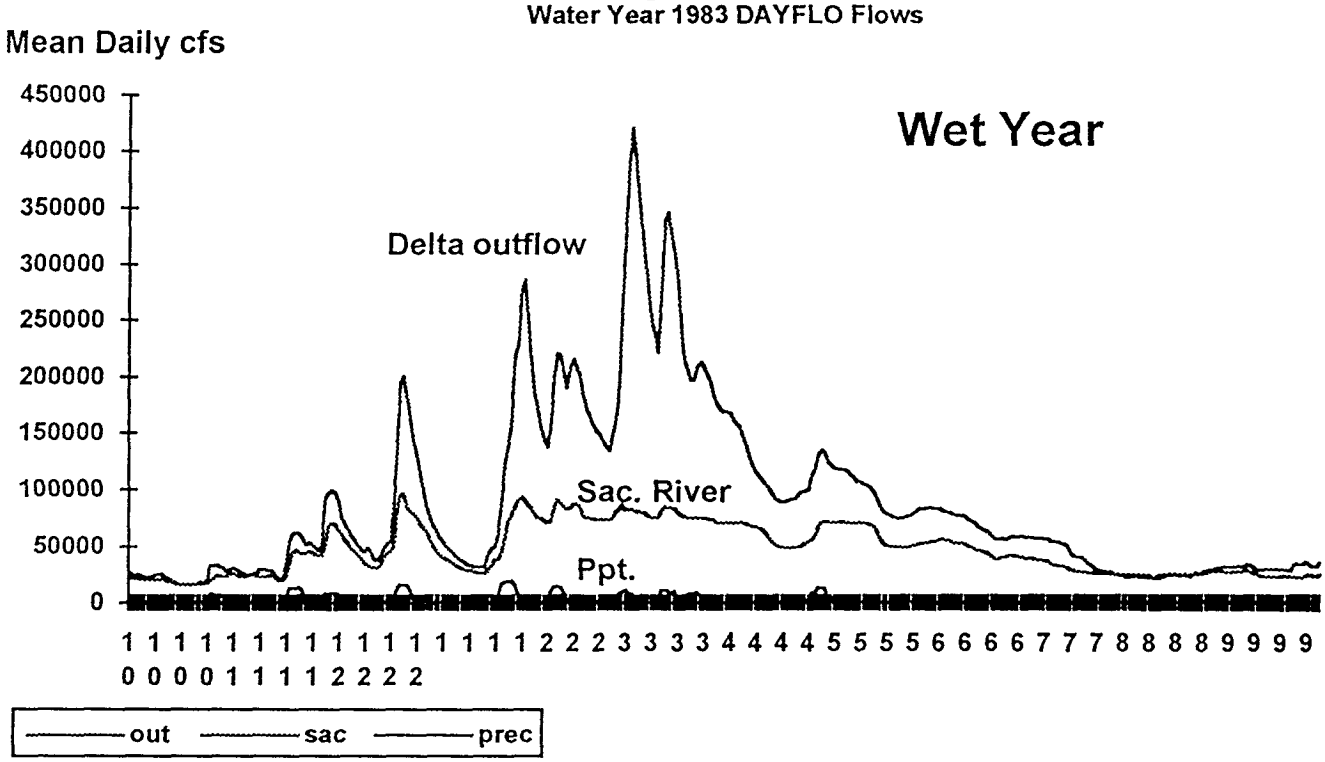

Figure 7c

Water Year 1984 DAYFLO Flows

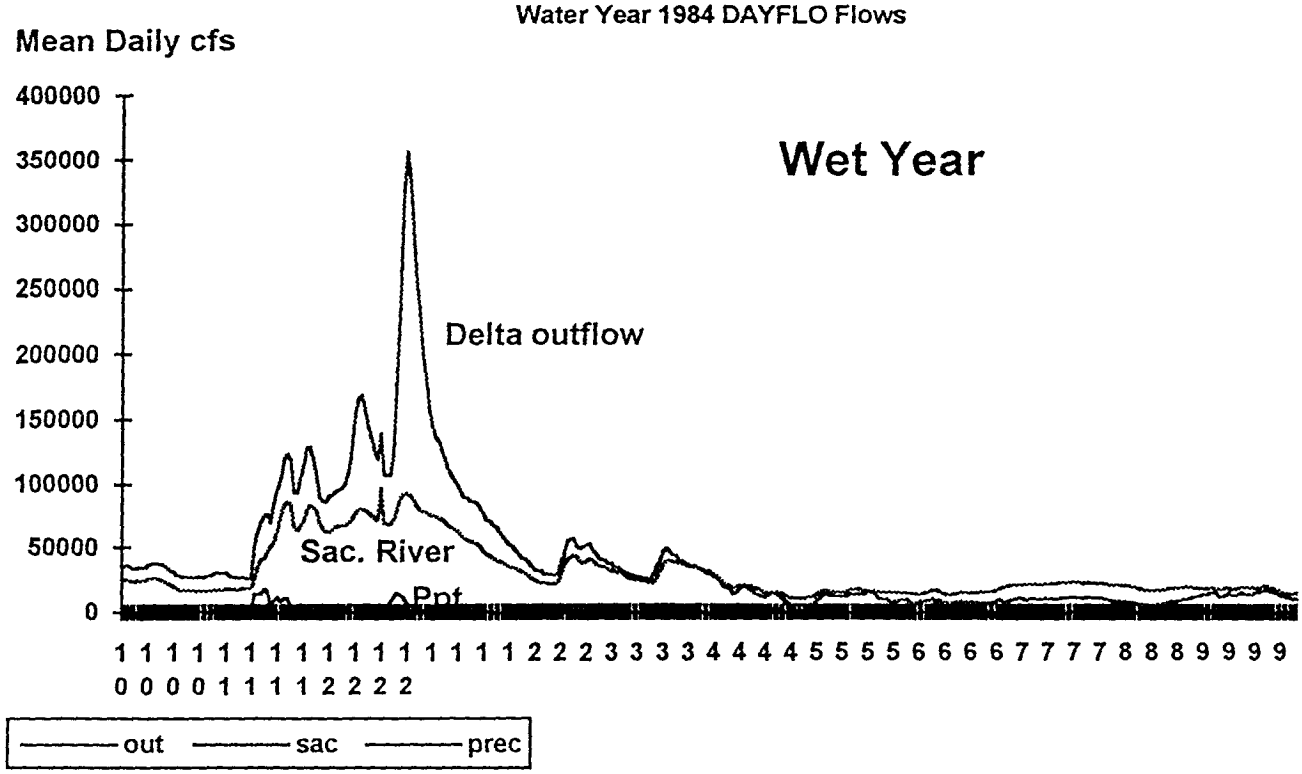

Figure 7d

Water Year 1985 DAYFLO Flows

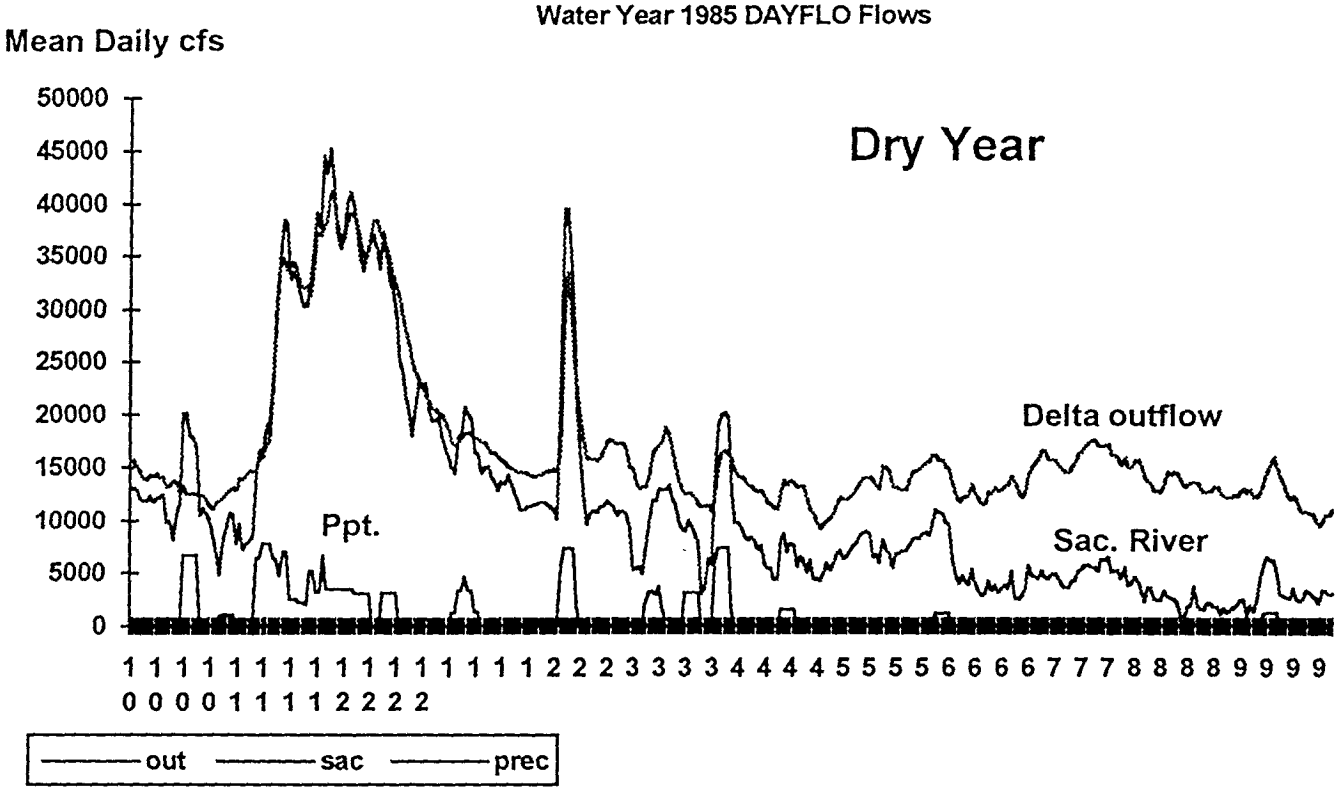

Figure 7~~d~~e

Water Year 1986 DAYFLO Flows

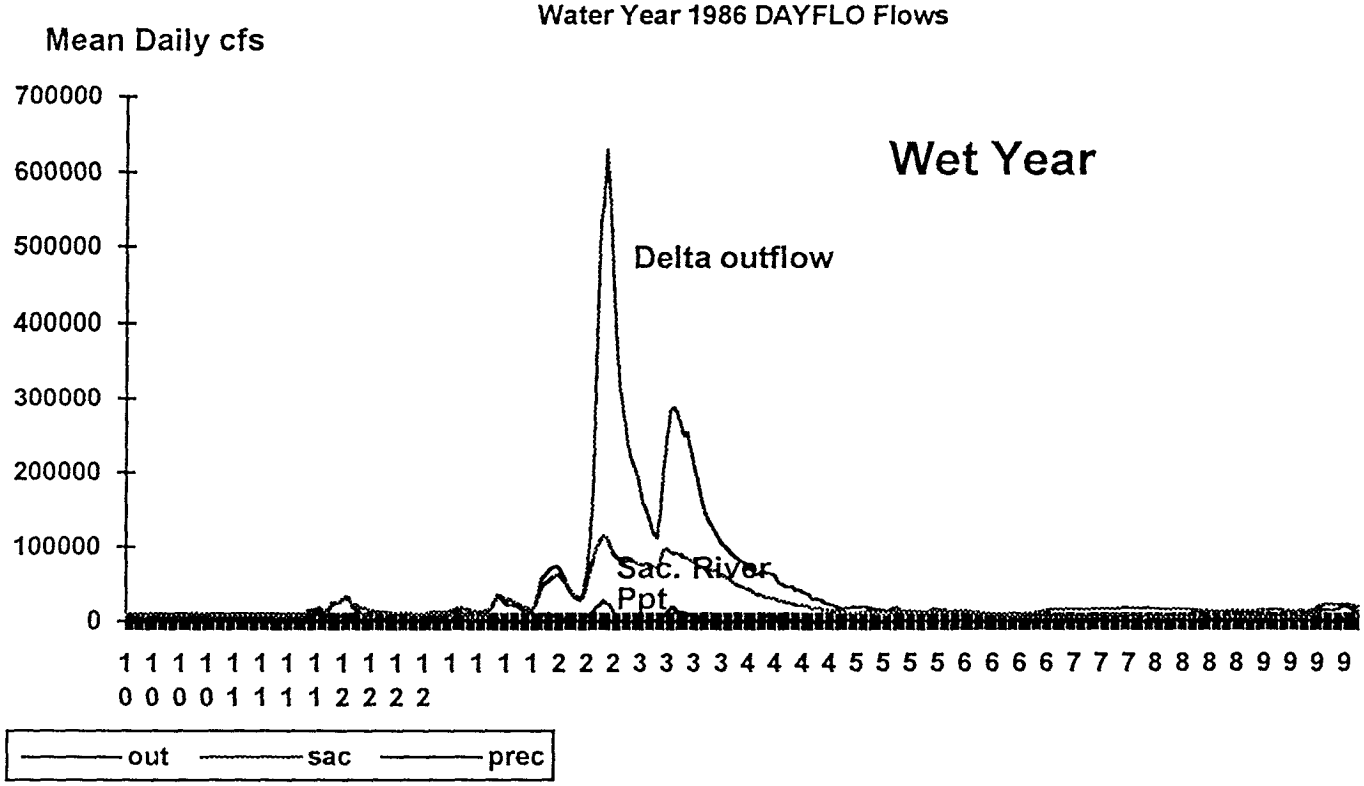

Figure 7~~e~~f

Water Year 1987 DAYFLO Flows

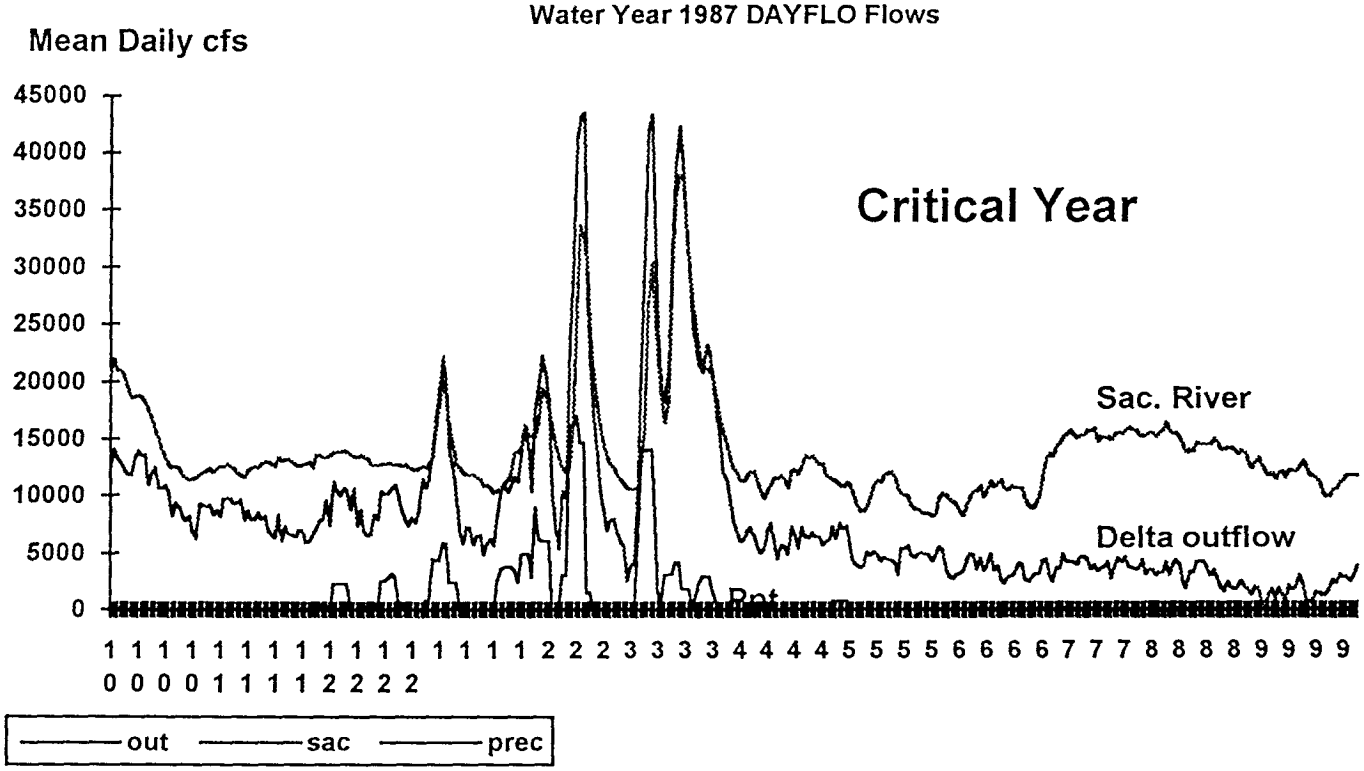

Figure 7g

Water Year 1988 DAYFLO Flows

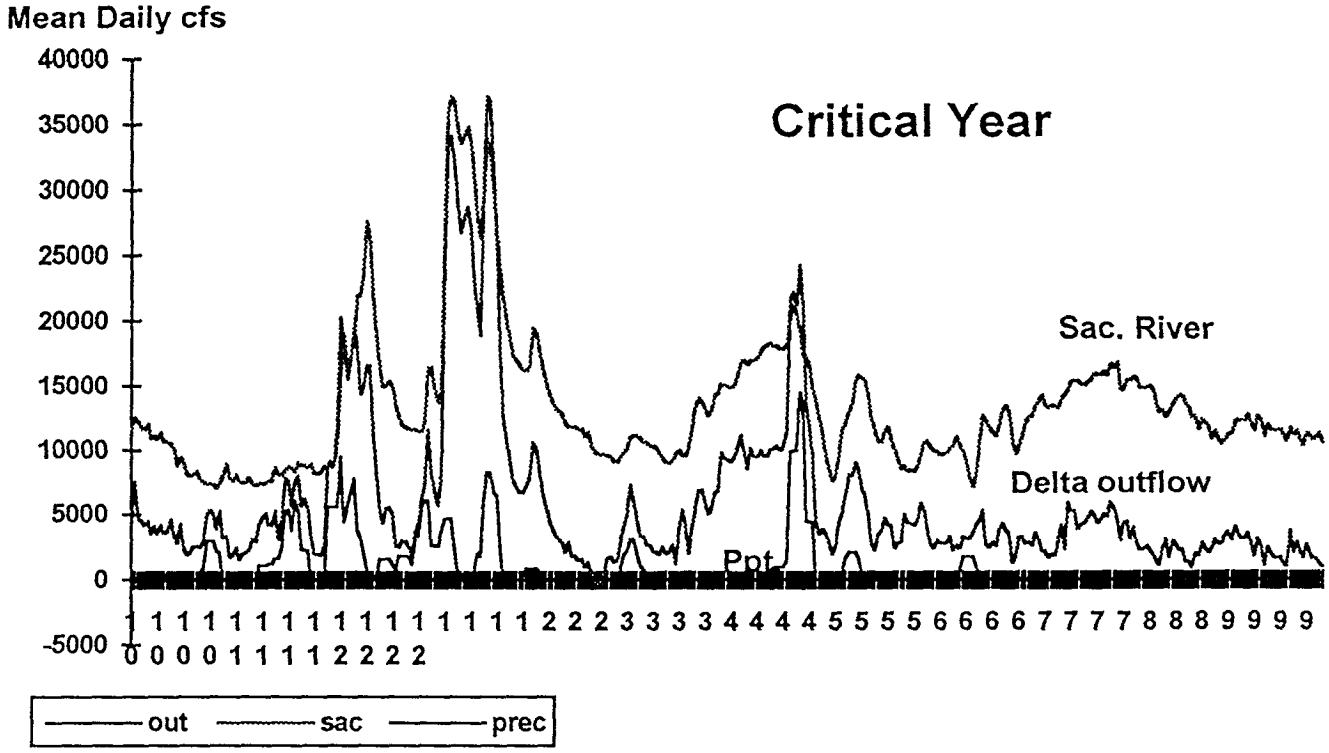

Figure 7h

Water Year 1989 DAYFLO Flows

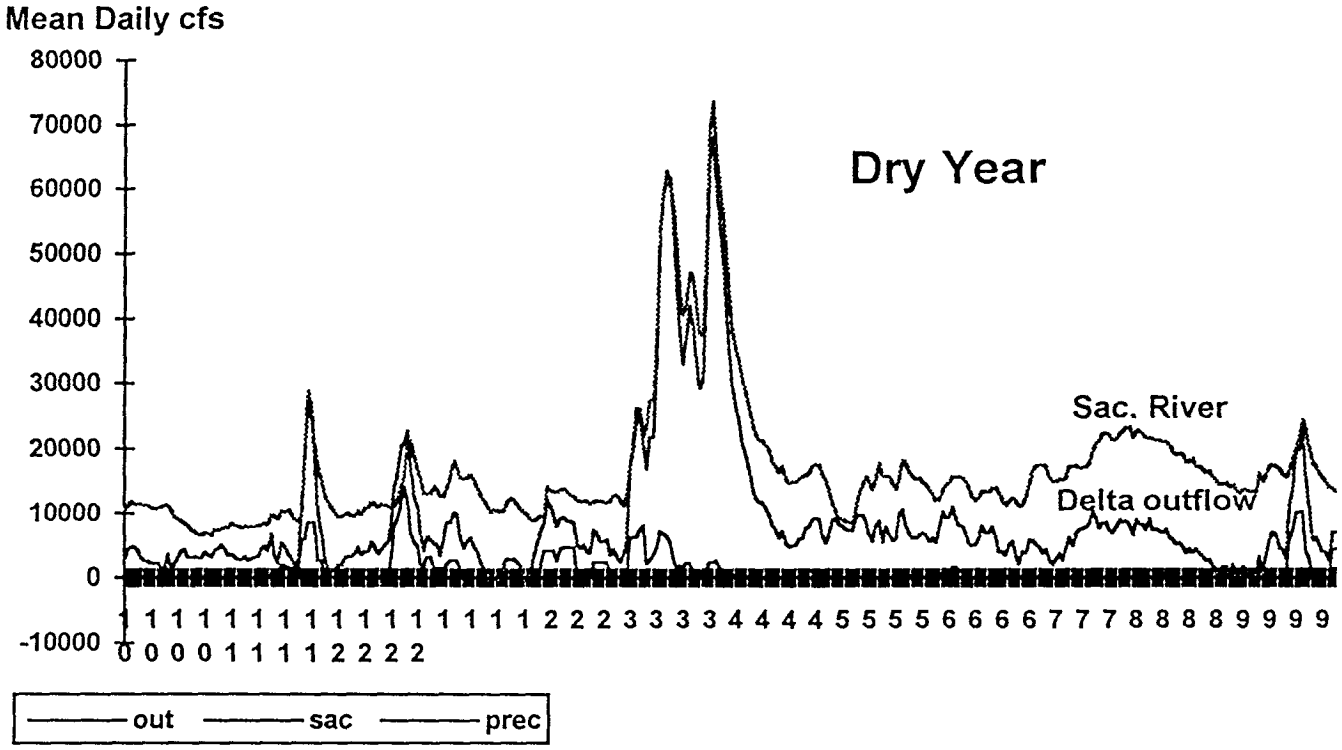

Figure 7i

Water Year 1990 DAYFLO Flows

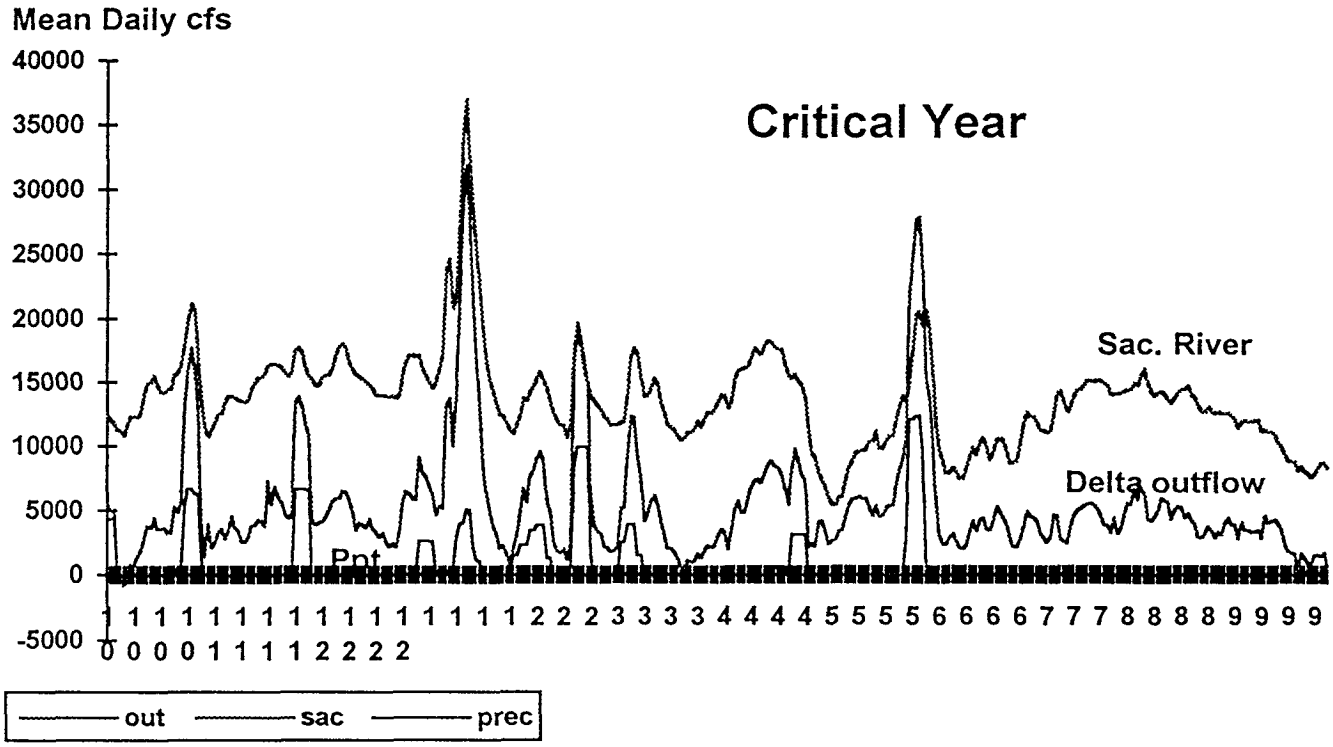

Figure 7j

Water Year 1991 DAYFLO Flows

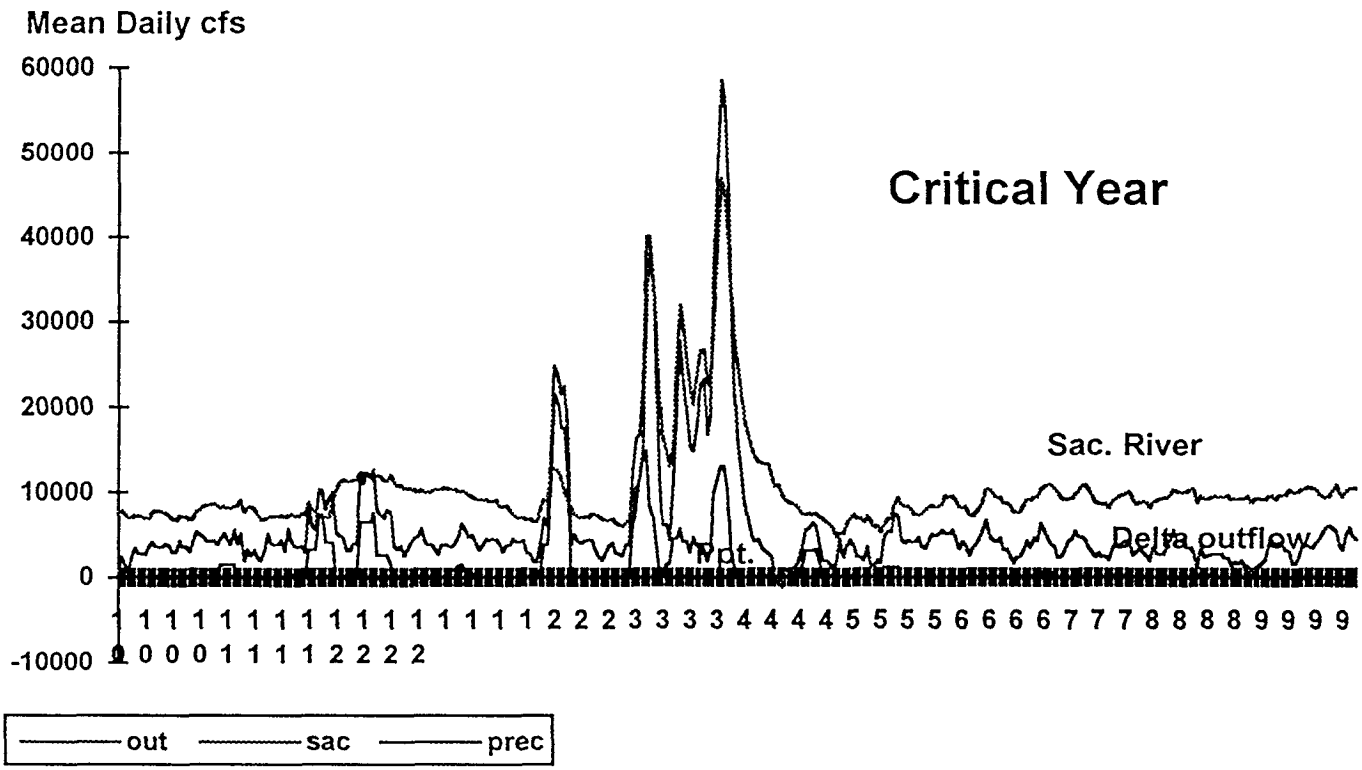

Figure 7k

Water Year 1992 DAYFLO Flows

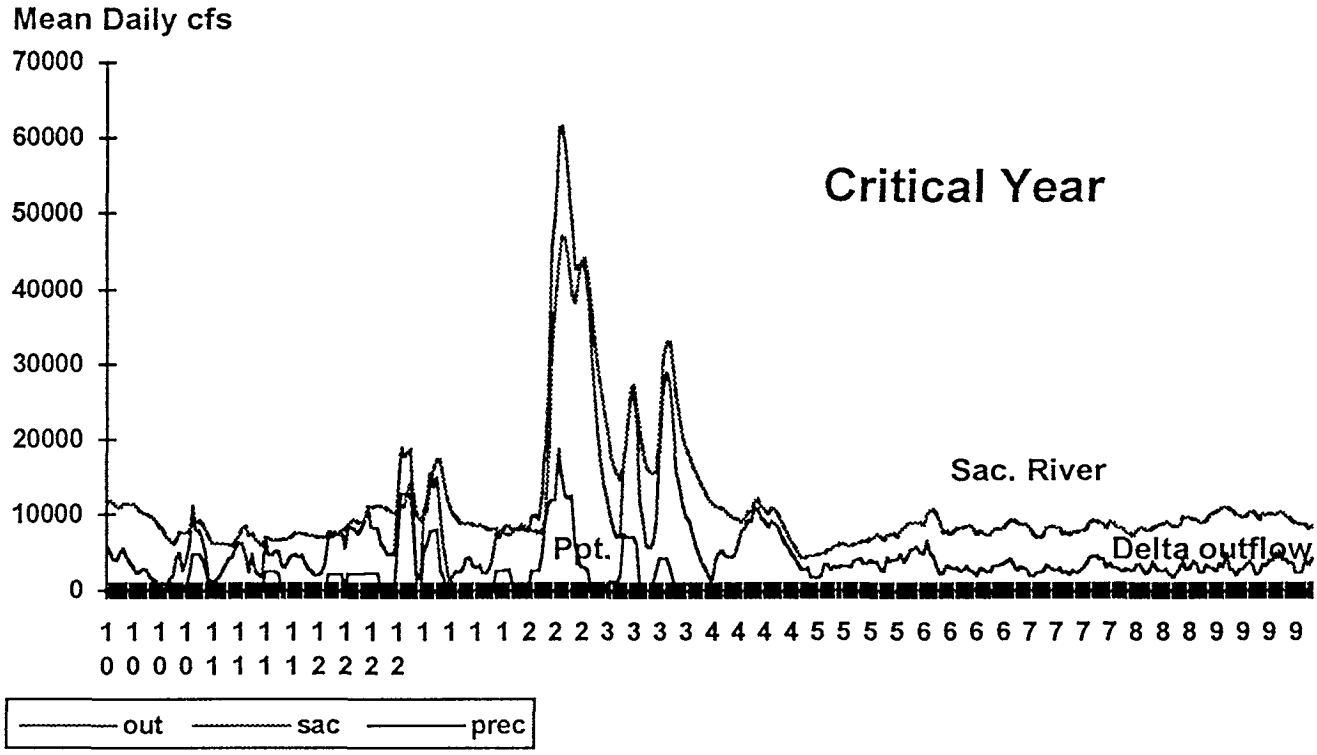

Figure 7l

Water Year 1993 DAYFLO Flows

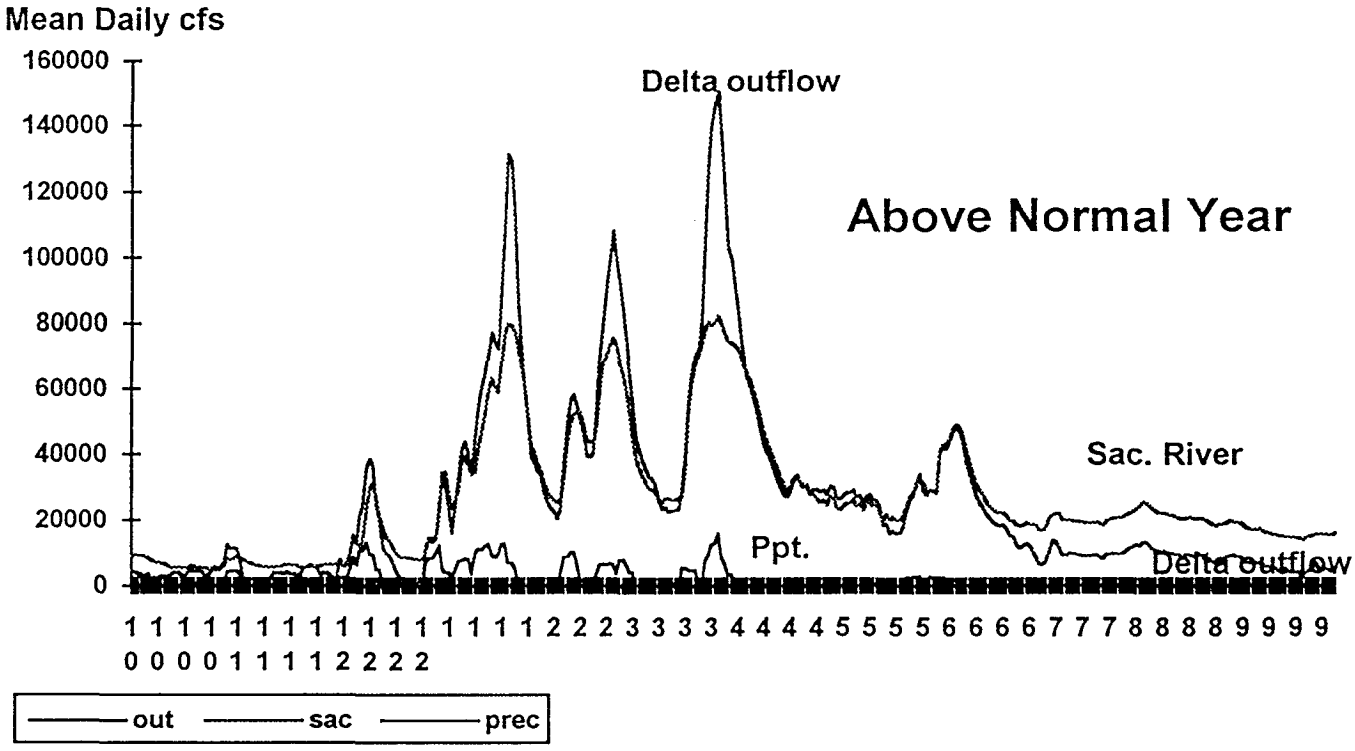

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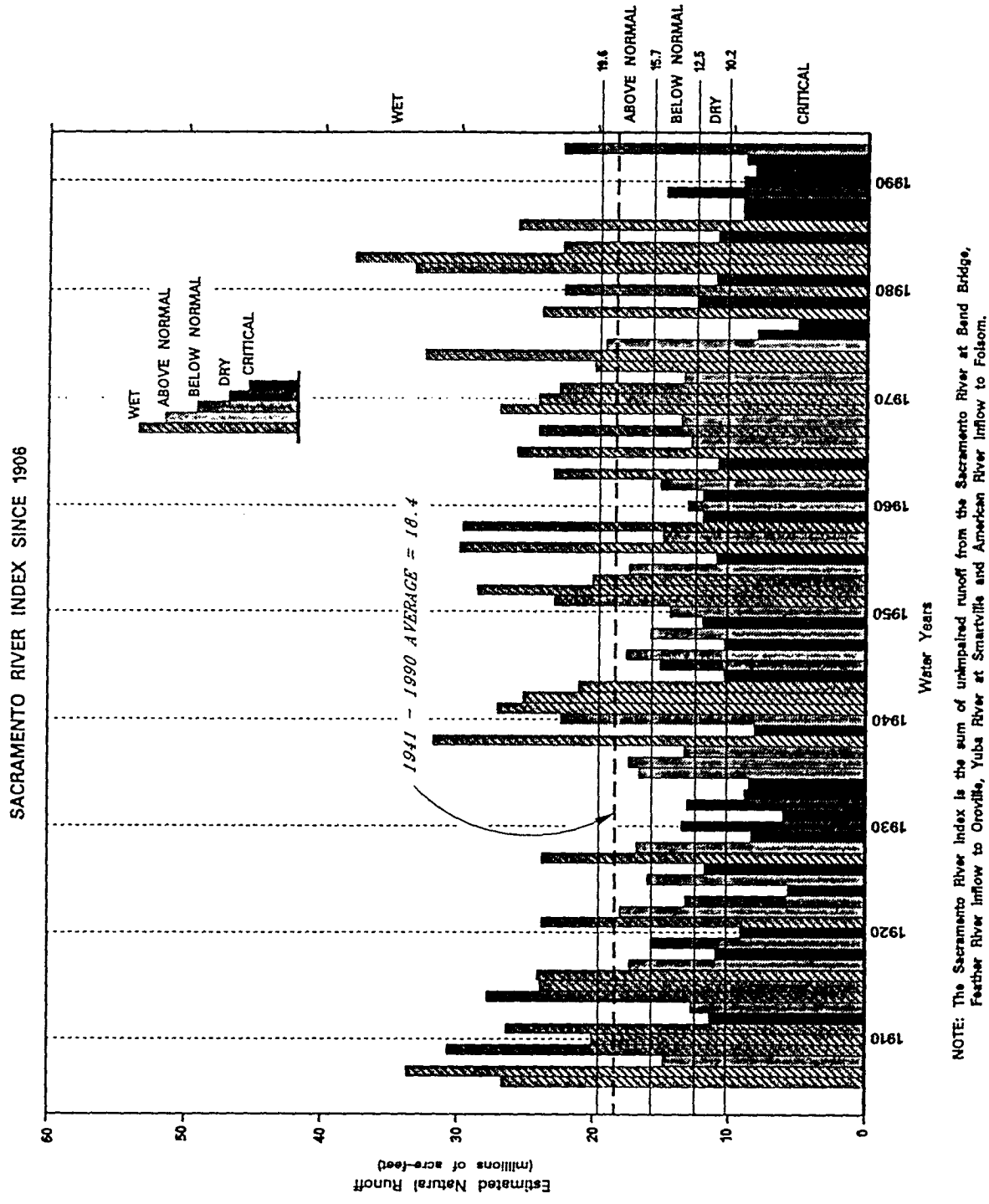
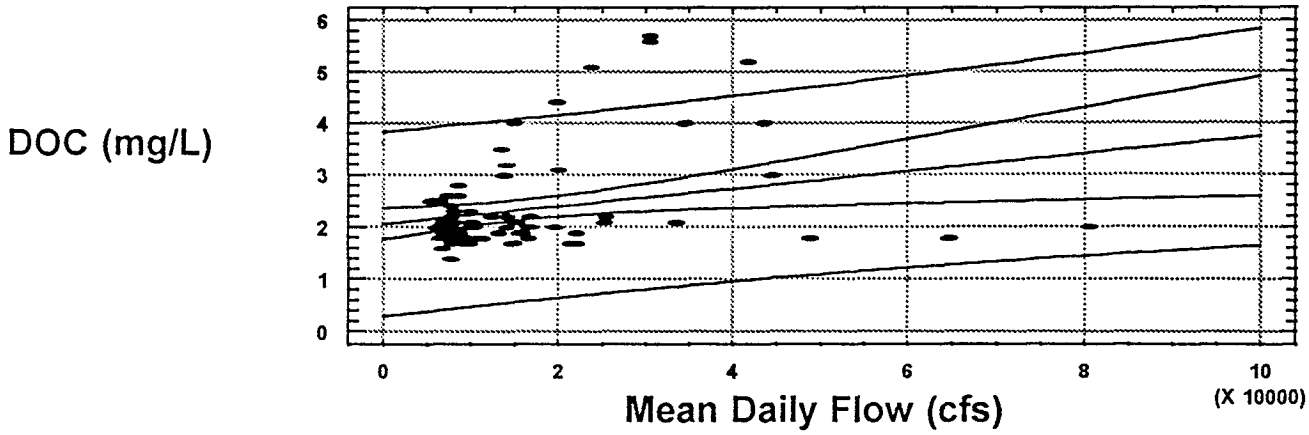
FIGURE 8. SACRAMENTO RIVER INDEX SINCE 1906



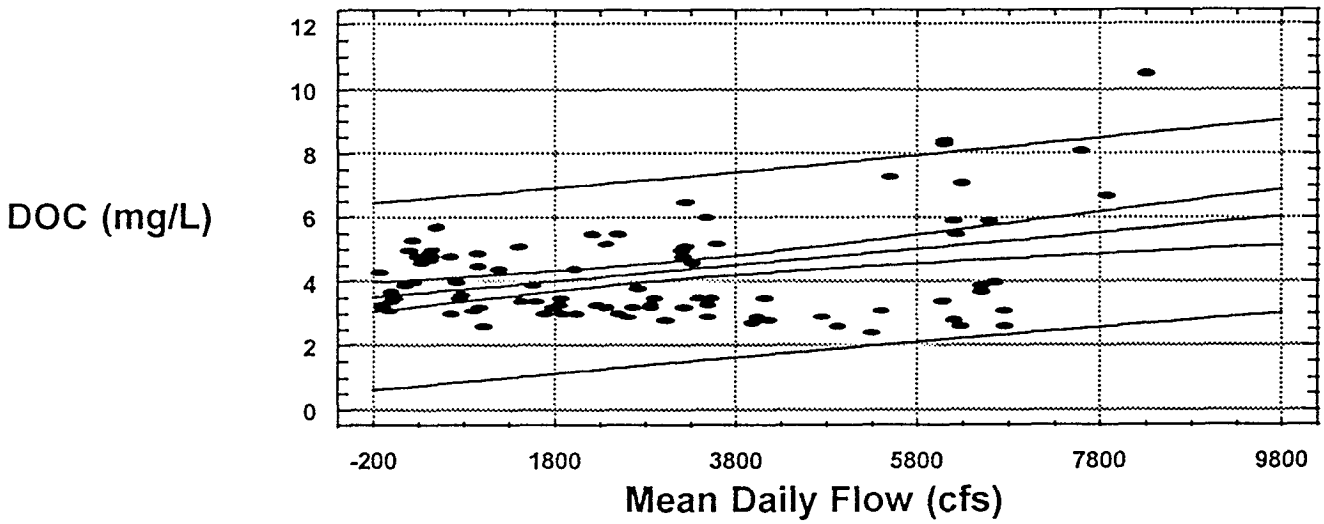
NOTE: The Sacramento River Index is the sum of unimpaired runoff from the Sacramento River at Bend Bridge, Feather River Inflow to Oroville, Yuba River at Smartville and American River Inflow to Folsom.

Figure 9. DOC versus Flow Relationships

Greenes Landing DOC vs. Sacramento River Flow



Banks Headworks DOC vs. SWP Exports



San Joaquin River nr. Vernalis DOC vs. SJR Vernalis Flow

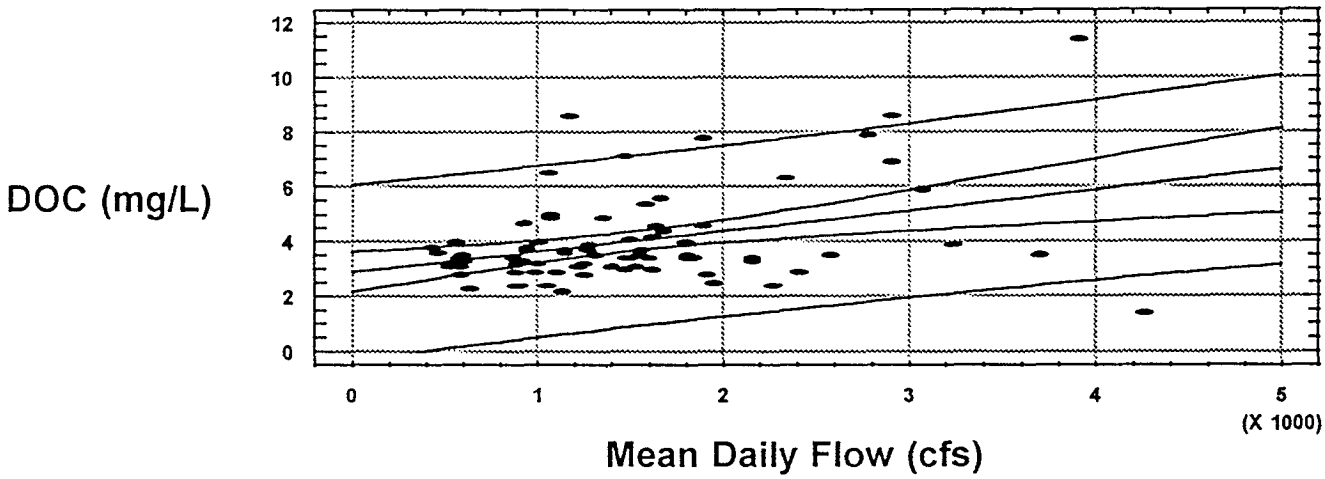
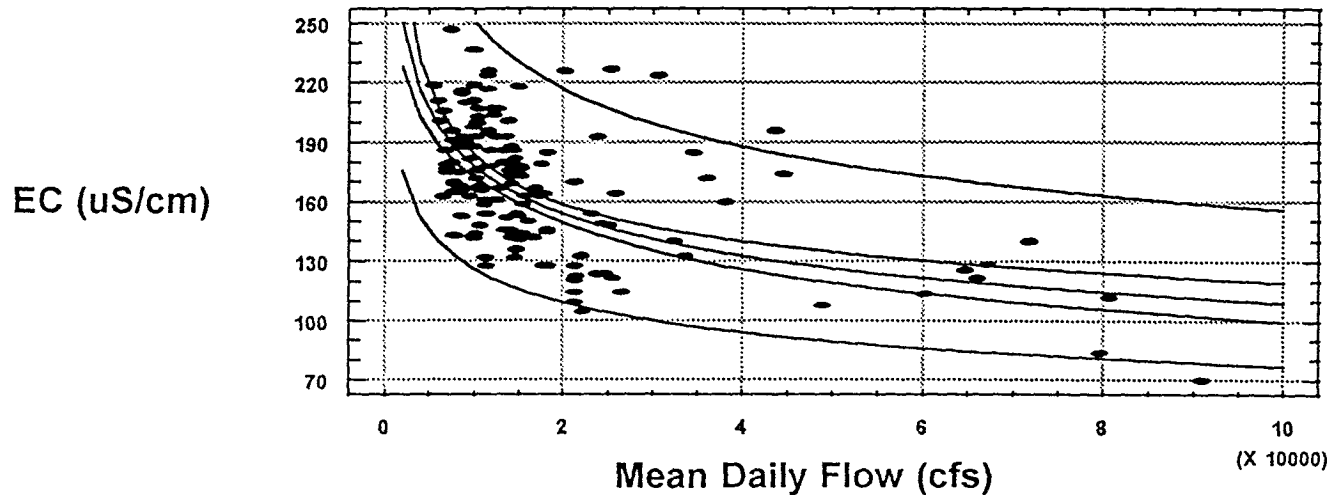
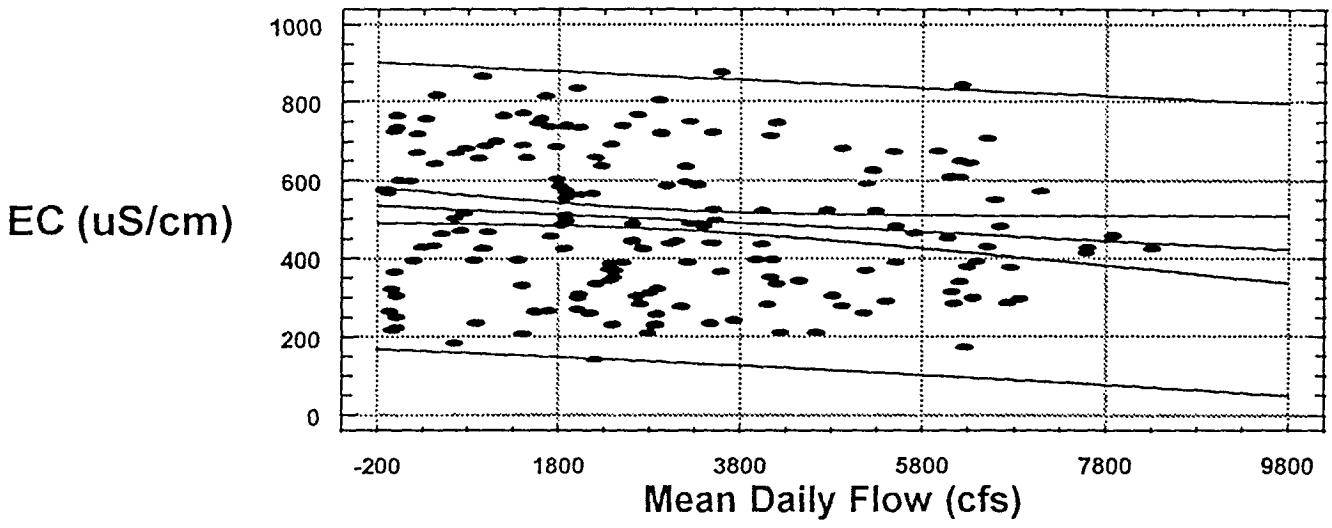


Figure 10. EC versus Flow Relationships

Greenes Landing EC vs. Sacramento River Flow



Banks Headworks EC vs. SWP Exports



Vernalis EC vs. SJR Vernalis Flow

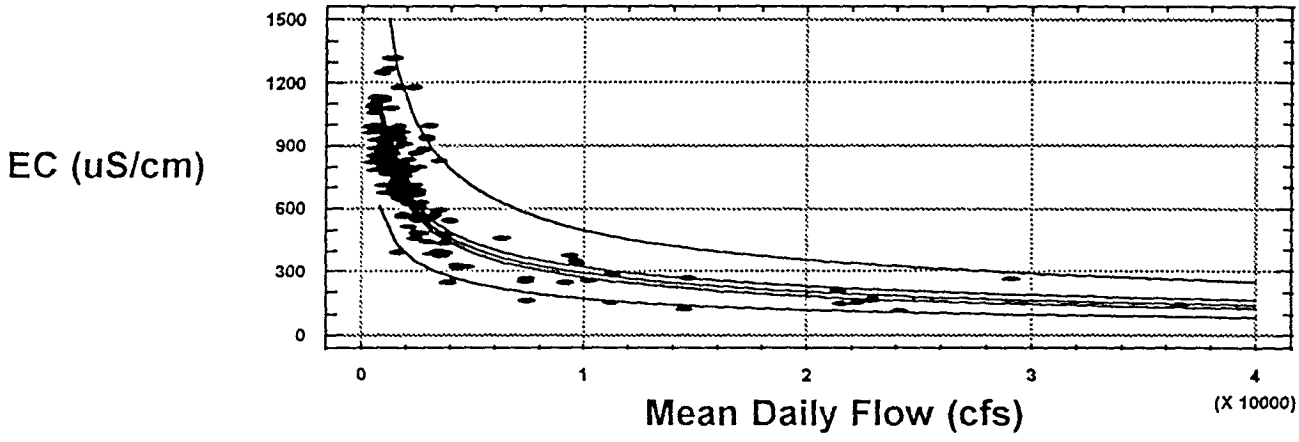
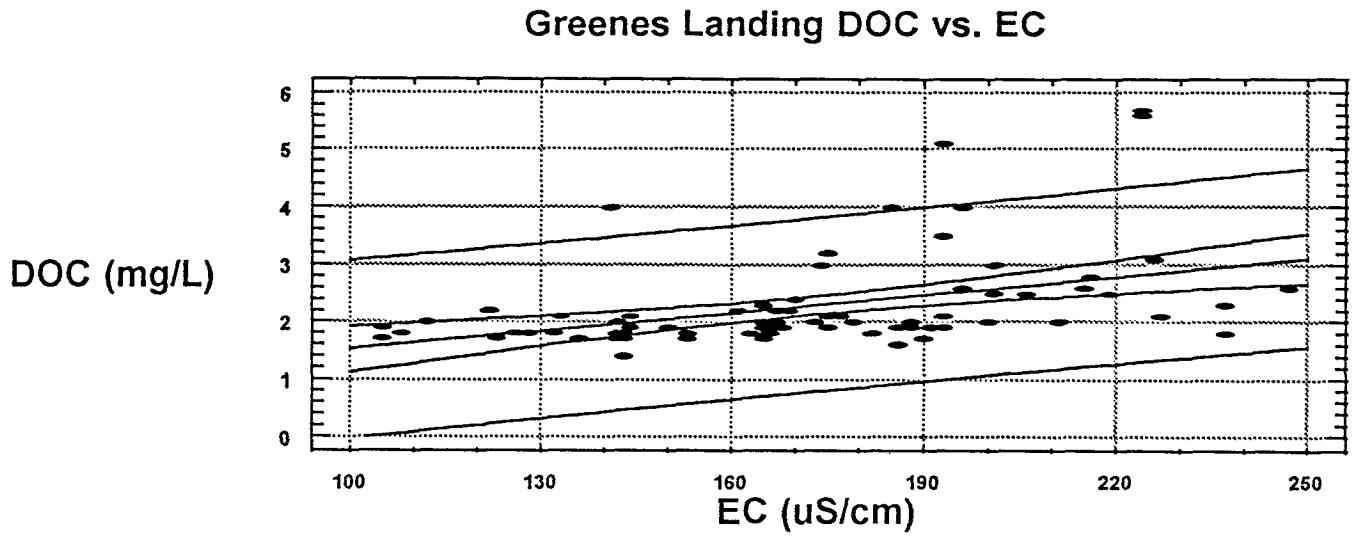
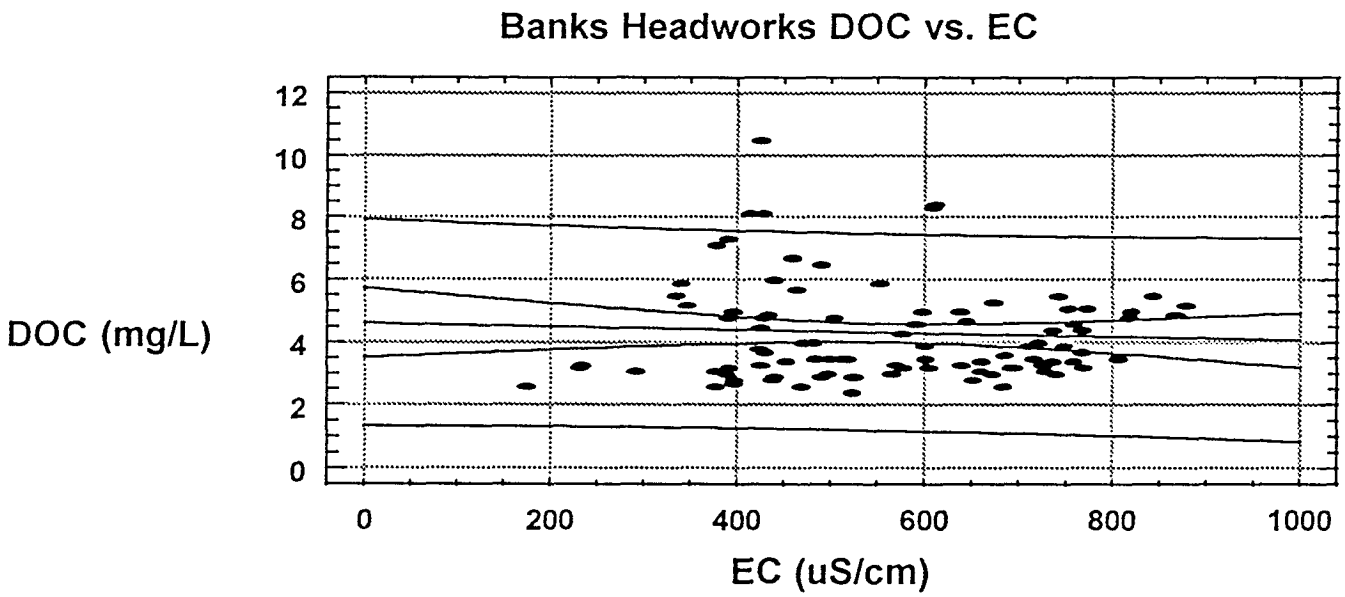


Figure 11. DOC versus EC Relationships





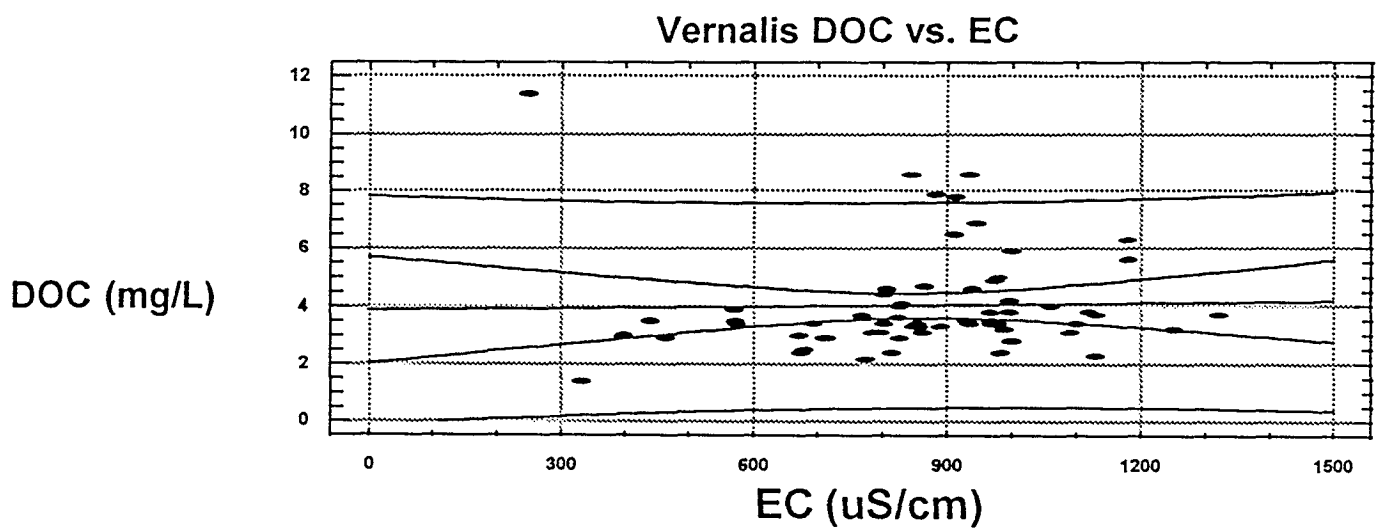
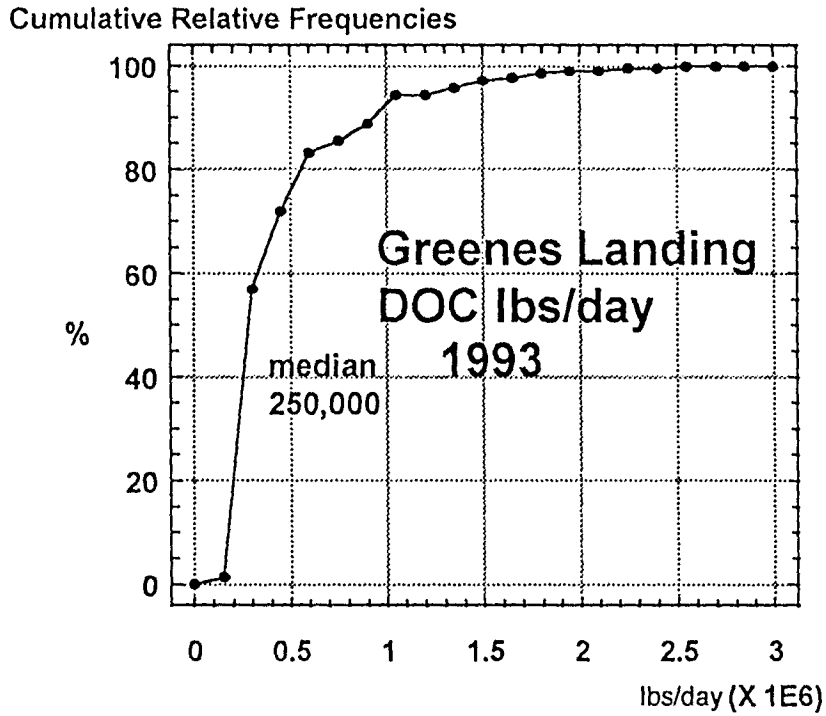
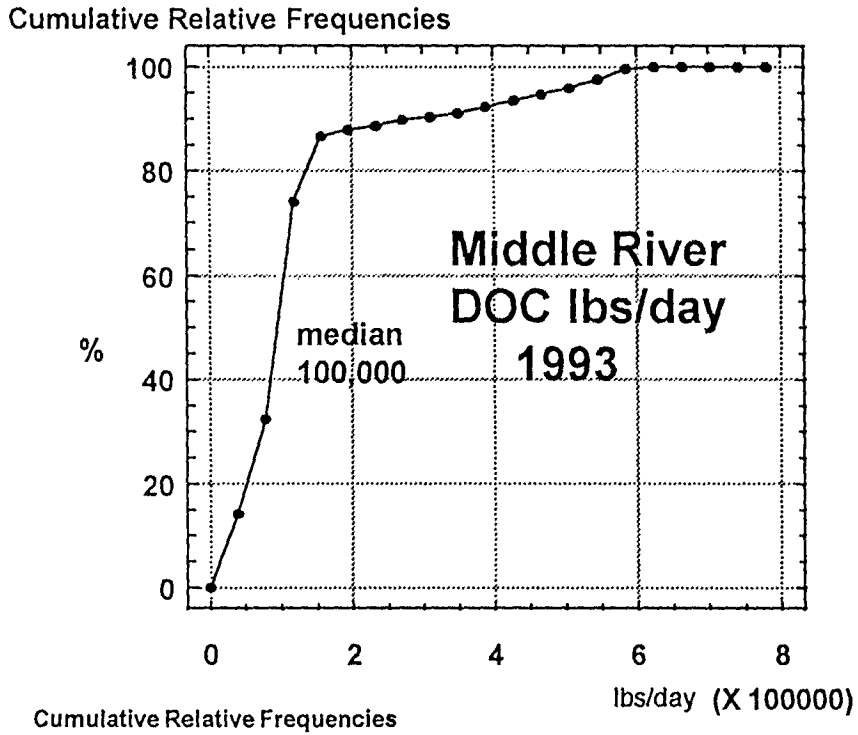
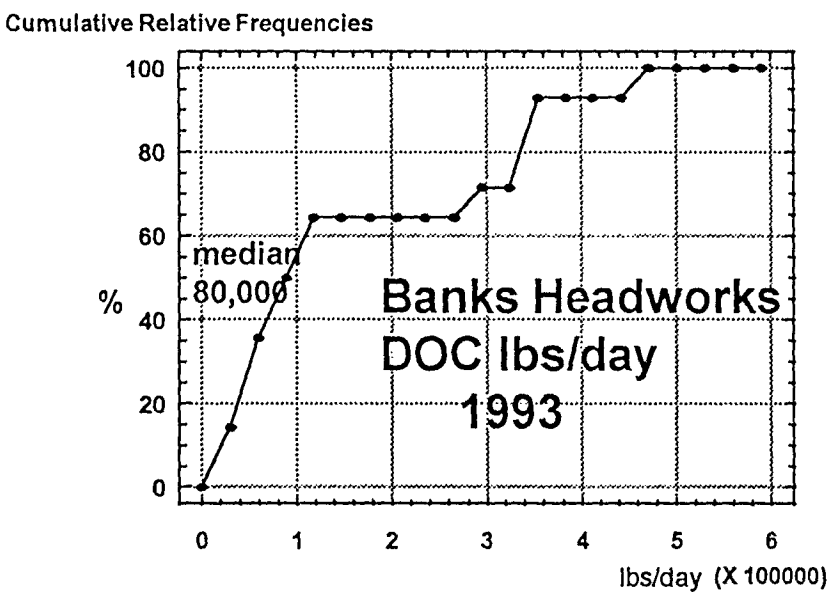


Figure 12. Wet Year 1993 DOC Mass Load







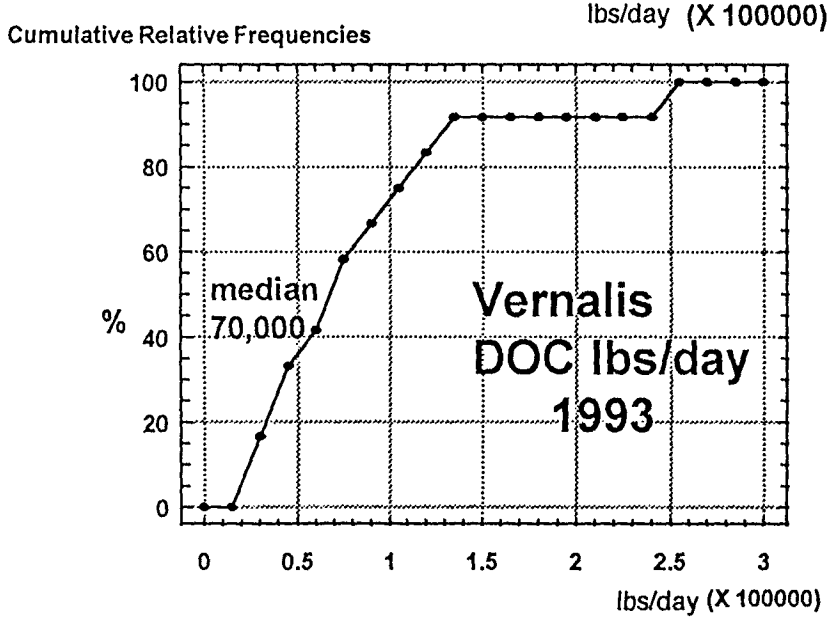


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Figure 13. Dry Water Years DOC Mass Load (lbs/day) 1989,90,91, and 92

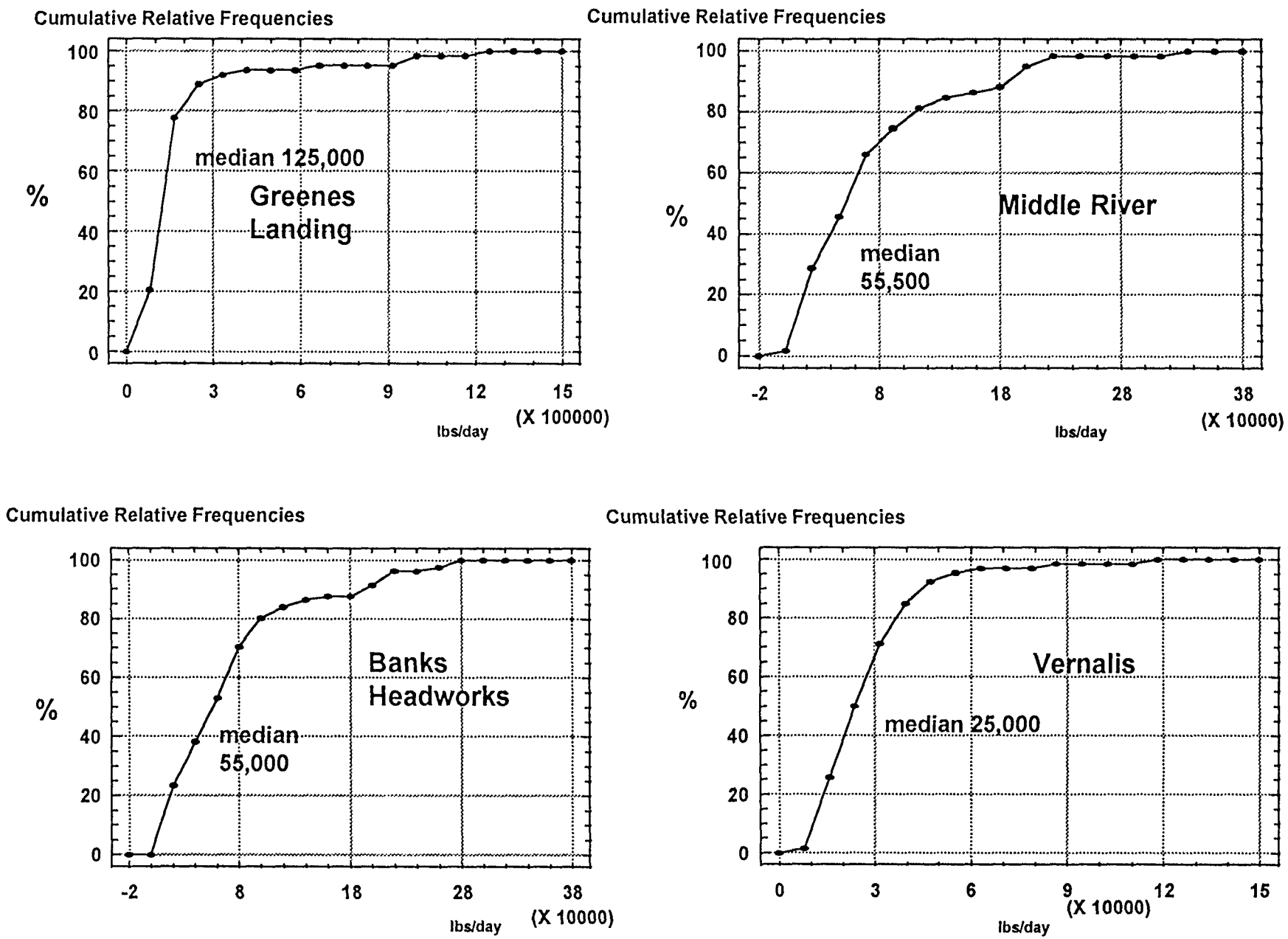

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Figure 14. Wet Years TDS Mass Load (lbs/day) 1982,83,84,86, and 93

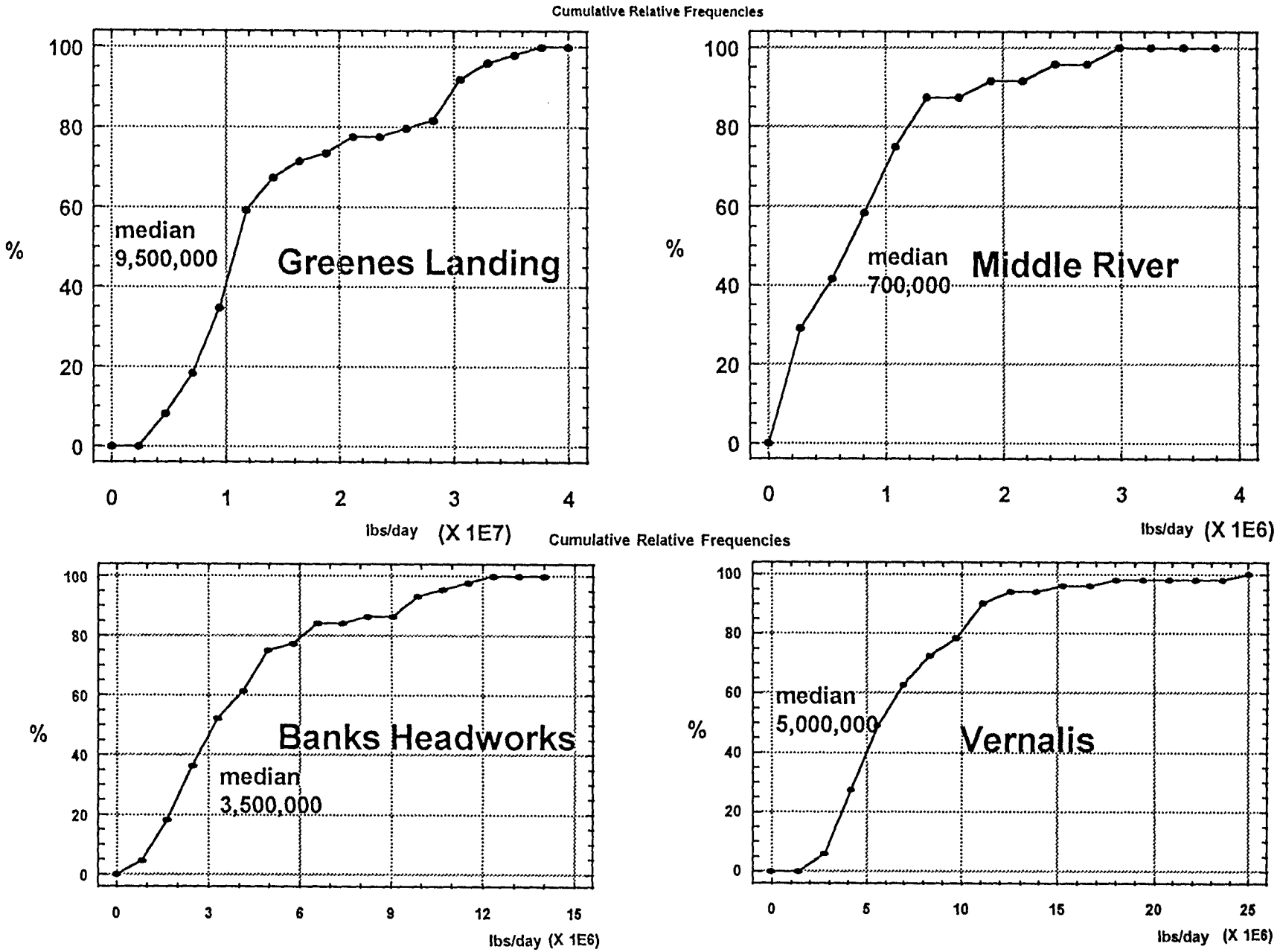

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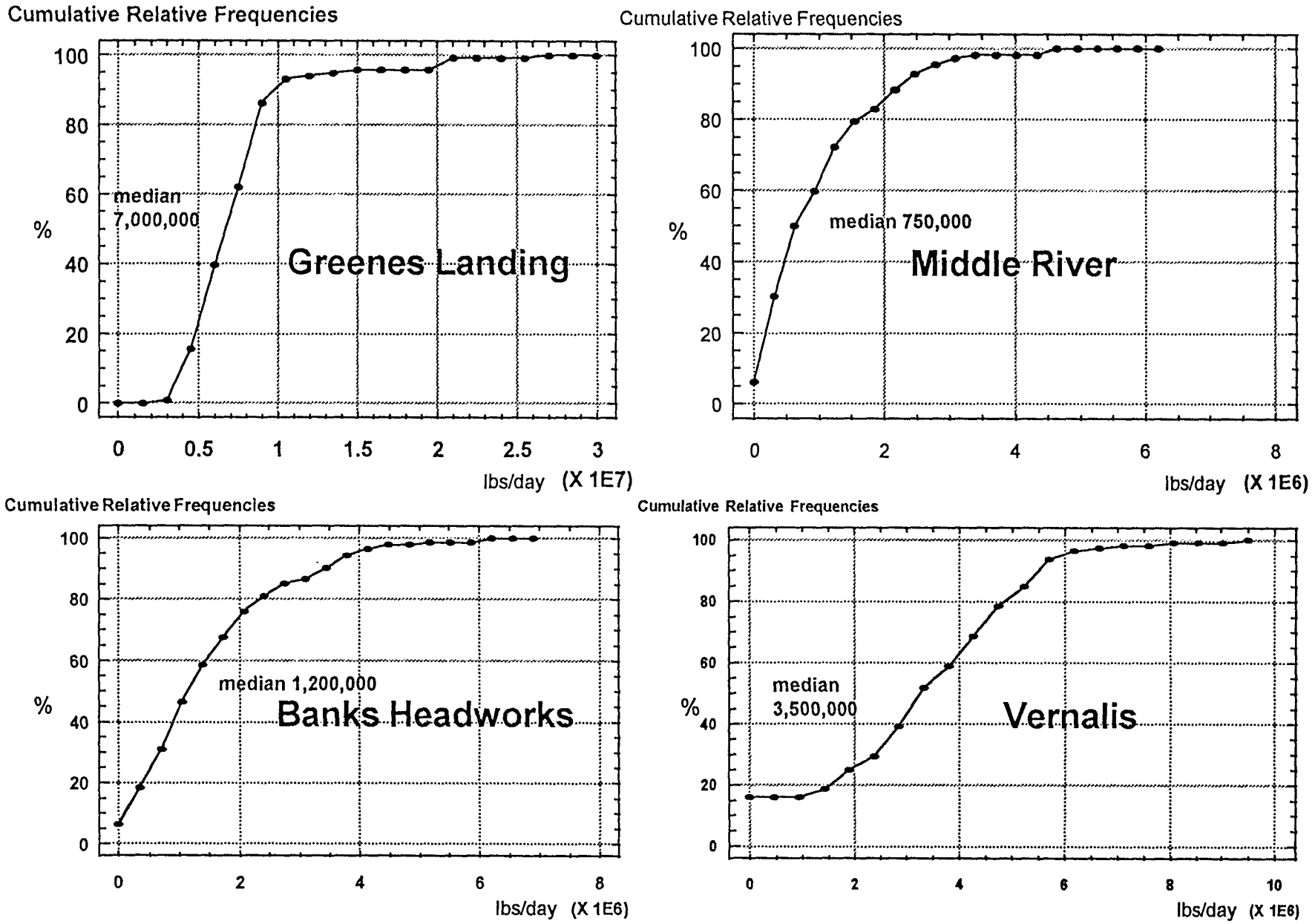
Figure 15. Dry Water Years TDS Mass Load (lbs/day) 1985,87,88,89,90,91, and 92



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