X2 AND THE X2/NET DELTA OUTFLOW RELATIONSHIP

prepared for

California Urban Water Agencies
Sacramento, California

by
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NOTICE

This technical report was prepared as a technical document for reference use by California Urban Water Agencies and others considering the U.S. Environmental Protection Agency proposal "Water Quality Standards for Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California, January 6, 1994." This report is not part of the CUWA formal comments to EPA.

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March 10, 1994

California Urban Water Agencies
455 Capitol Mall, #705
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Attention: Lyle N. Hoag, Executive Director

Subject: X2 and the X2/Net Delta Outflow Relationship

Dear Lyle:

This letter report will provide my review of the technical issues involved with the proposed X2 rule.

Concern has been expressed that the abundance of certain biological species within the San Francisco Bay/Sacramento River Delta has been reduced significantly in the past 20 years. The belief is held that this abundance reduction is associated with the intrusion of saline Bay waters into the Delta and a specific indicator of the degree of salinity intrusion has been proposed. This is the location within the Delta of the 2 part per thousand salinity isopleth measured at 1 meter from the channel bottom. In fact a negative correlation has been claimed between species abundance and the distance from Golden Gate of this 2 part per thousand isopleth, a distance which has been designated as X2.

With the goal of increasing the species abundance within the Delta system EPA has proposed that Delta operations be such that there shall be a specified number of days in each year, for each of five different categories of water year, at which the X2 location must be situated west (i.e. downstream) of three specified sites within the Delta. This proposed EPA Rule on Bay/Delta Standards is summarized in Table 1.

Number of days (February - June) 2ppt salinity line must be downstream of:			
Year Type	Roe Island* (Port Chicago)	Chipps Island	Confluence (Collinsville)
Wet	133	148	150
Above Normal	105	144	150
Below Normal	78	119	150
Dry	33	116	150
Critical	0	90	150
*Required only after a storm event pushes 2 ppt line downstream of Roe Island			

Table 1. EPA Proposed X2 water quality standards. (Source: Ref. 3)

The proposed Rule has implicit within it that the position of x2 can be controlled. Which is to say that there must be a predictive relationship between the net Delta outflow (NDO), which is the only Delta variable that can be controlled, and the daily position of X2. Several attempts have therefore been made at providing such a predictive relationship between the X2 location and the NDO (or some index of the NDO).

In this memorandum we discuss these relationships and the underlying scientific support, or lack thereof, for each of the approaches taken. The four approaches considered are those by Kimmerer and Monismith (K&M, Ref. 1). Gartrell, Denton and Sullivan (CCWD, Refs. 2, and 3), California Department of Water Resources (DWR, Ref. 4) and Brown and Yotter (B & Y, Ref. 5). However, before becoming involved with the details of the specific approaches taken to find the relationship between NDO and X2 it is important to be cognizant of several fundamental facts related to the issue, each of which will be discussed in turn.

(1) Measurement of X2

First, it must be understood that it is almost impossible to measure X2 directly. It can only be deduced by interpolation of simultaneous measurements of salinity taken 1 meter from the bottom at a large number of measurement sites along the Delta. While this could be done by installing a large number of telemetering instruments, the practicality of such a scheme has yet to be justified.

(2) Surface and Bottom Salinity

The extant data base relating bottom and surface salinity within the Delta is apparently very small (see DWR, Ref. 4 and K & M, Ref. 1) with data existing from only three sites. These few data make it very clear to see that there is no unique relationship between surface and bottom salinity; nor should one be expected from what is currently known scientifically about the formation and movement of saline wedges in estuaries (see Ref. 6). The importance of this derives from the fact that all of the methods of relating NDO to X2 actually relate NDO (or some index) to surface salinity and then utilize some kind of postulated relationship between surface salinity and bottom salinity. However, as actual field data make abundantly clear, no such definitive relationship actually exists (see Fig. 1). (This will be discussed in more detail subsequently).

(3) Daily Specification of X2 Location

The proposed X2 rule specifies the number of days that X2 must lie downstream of a defined site, despite that the fact that a key variable in defining the location of X2 on any day (if it could be measured) is the tidal range. It is therefore interesting that all of the attempts to relate NDO to X2 almost all use averaged data that specifically excludes tidal effects.

(4) Classification of Water Years

The X2 standard presupposes knowledge regarding the specific type of water year and then establishes, in a discontinuous fashion, the number of days in each category of year that must satisfy the proposed X2 rule. In that the designation of a specific year-type is based on an entirely subjective definition of "dry" versus "wet" versus "normal" etc., the discontinuities introduced into the required number of X2 days will become just as subjective as the definition of the year type.

In summary, the proposed X2 rule contains many of the features of rule making at its worst in that:

(a) The prime variable (X2) can not be measured directly.

(b) The relationship of bottom to surface salinity is quite non-unique.

(c) Compliance is specified on a daily schedule, when in fact daily data are strongly influenced by tides.

(d) The rule includes discontinuities introduced by criteria that categorize specific year types by a subjective measure.

Furthermore, given all of the above, it is difficult to see how a definitive correlation can actually be shown between X2 and abundance since no causal relationship appears to have been directly established between any flow index and species abundance. Thus, the paradoxical state has been established in which X2 is being related to NDO in an attempt to return species abundance levels to 1960-70 levels by controlling NDO, despite the fact that there appears to be no direct relationship between NDO and abundance.

Regardless of this, and despite the clear futility of establishing a regulation for which satisfaction can not be directly determined, we proceed to evaluate the NDO-X2 relationships proposed.

NDO-X2 RELATIONS

It is significant that none of the relationships proposed relate NDO (or any other flow index) directly to X2. They all actually relate NDO to <u>surface conductivity</u> and then attempt to relate surface conductivity to the 1 meter salinity isopleths. The reason for this is obvious: no direct data measurements of X2 exist, or are likely to exist, for reasons previously explained. With this point in mind we consider each of the Delta salinity versus flow index relationships that have been proposed.

However, before proceeding to this discussion one further point deserves emphasis. Measurements of electrical conductivity in micro mhos/cm (μmhos/cm) are neither measurements of total dissolved solids nor salinity. In fact, there appears to be some confusion on the issue. The point has been directly and clearly addressed in the memorandum by Sullivan & Denton (Ref. 4). They show that electrical conductivity is related to practical salinity units (psu) and that the relationship is very temperature dependent (see Figure 2). Temperature corrections are therefore essential, especially as the surface and bottom may have quite different temperatures at the time of measurement (see Appendix A for examples from Carquinez Strait).

In CCWD Figure 2.1.2 (Ref. 4) reproduced here as Figure 3, the relationship of psu to chloride concentration and total dissolved solids is made clear and should be kept in mind when reviewing the results of other studies.

We now discuss the various relationships proposed for X2 and NDO.

1. Contra Costa Water District (CCWD)

Contra Costa Water District (CCWD, Refs. 2 and 3) has attempted to relate conductivity measured at the surface at a fixed site (eg. Port Chicago) to Net Delta Outflow (NDO). This has been accomplished by using a formula that relates salinity measurements to flow in periods antecedent, *i.e.* preceding, the period in question. The basis for the method is to fit the solution of an estuary salt balance equation to the 14 day-averaged salinity and flow records. This can be done from the recognition that the average salt balance along the estuary is fixed by a balance between the NDO and the tidal flushing, as represented by a so-called dispersion coefficient. This is a well-recognized concept that has been widely used throughout the world to characterize estuary salt distributions (Ref. 6). The novel feature of the application of the theory, as implemented by CCWD, is to relate the salinity to the flows in the period preceding the period under consideration. This greatly reduces the scatter in the data and provides a firm estimate of conductivity as a function of flow. With this relationship it is possible to predict with a high degree of reliability the surface conductivity, if the flow rate is known in preceding time periods. Particular examples of these predictions are shown in Figures 4, 5, and 6.

The basic conclusion is that the CCWD approach uses well-recognized relationships to define average surface conductivity in a scientifically defensible manner. Note, however, that the issue of relating surface conductivity to X2 location remains. Thus while the surface salinity can be accurately predicted the bottom salinity can not.

2. Department of Water Resources (DWR)

The relationship of bottom salinity to surface conductivity was addressed in a DWR memorandum dated February 9, 1993 and prepared by F. Chung, R. Finch and C Enright (Ref. 4). Their discussion is based on data from three locations at which top and bottom electrical conductivity has been measured in the Delta: at Martinez and at two locations near Emmaton. These data are plotted in Figure 1. It can be seen that there is no significant trend in the data and, as previously stated, there is a very distinct lack of uniqueness in the relationship between surface electrical conductivity (EC) and bottom salinity. No definitive relationship can be established between the surface and bottom salinity. Despite this lack of coherence DWR decided to state that electrical conductivity at the top is 86 per cent of that at the bottom.

The conversion from top electrical conductivity to top TDS is based on equations developed by DWR in 1986. Effectively they state that for a 2 ppt bottom TDS an equivalent surface EC of 3 micro mhos/cm is required.

The basis for the NDO/salinity relationship is a statistical relationship between running averages of NDO and salinity. Four different schemes were employed involving 14 day flow averages and 1 day or 14 day EC values, or 28 day flow averages and 14 day and 28 day EC averages. The statistical scheme is to order the NDO figures and for each flow the associated conductivity was examined to determine if it exceeded the target EC (eg. 3 micro mhos/cm for 2 ppt at the bottom). The total number of TDS data above and below the target were determined and the probability of the target being exceeded for that flow computed. With these statistical data in hand an attempt was made to find that flow that would lead to 20 per cent probability of the target TDS being exceeded at Mallard Slough. The basic result is that a flow of 12,000 cfs will result in a 20 percent chance that the bottom TDS will exceed 2 ppt.

This analysis has no physical principles; it simply assumes that the prior data contain the physics in a statistical sense, regardless of the fact that the statistics may result from prior flow control practices that may not be continued into the future. The assumption that a conductivity of 3 micro mhos/cm at the surface represents 2 ppt TDS, which in itself clearly has a strong statistical distribution, is not accounted for in the analysis.

3. **Kimmerer and Monismith**

K & M (Ref. 1) again attempt to relate surface salinity to flow rate by using an auto-regressive model with time lags. They recognize the inherent difficulty of relating surface conductivity measurements to bottom salinity. As a result of an analysis showing this inherent difficulty they elected to simply use the "median value of surface salinity for 2 ppt at the bottom". Presumably this means that where the bottom TDS was measured at 2 ppt the median value of the corresponding surface salinities was used as the indicator of a bottom TDS of 2 ppt. The actual location of X2 was estimated then from the surface salinity by using an interpolation formula relating the logarithm of salinity to distance from Golden Gate, with some adjustment for tidal flushing at each location considered. With these data an auto-regressive model was used to relate X2 at any date to X2 at a previous date and the flow at the current date.

The error in the estimate of the X2 location from the auto-regressive interpolation formula and grab sample data is shown in Figure 7 (from K & M, Figure 17). As can be seen errors of +- 20 km in the location of X2 are not uncommon.

4. **Brown and Yotter Estimates**

Brown and Yotter (Ref. 5) have plotted surface salinity and NDO data for the years 1968-1992 (for an example, see Figure 8). The electrical conductivity data are from Benecia, Port Chicago, Pittsburgh, Collinsville and Emmaton, ranging in distance from 56 km to 92 km from Golden Gate. By interpolating these daily averaged electrical conductivity data the location of any surface isopleth of electrical conductivity can be located. Then, by relating the surface conductivity to bottom TDS the estimated position of X2 can be found. These interpolated data are shown in Figure 9 for 1968 together with the surface location of the 1, 3, 5, 7 and 9 ppt isopleth of surface electrical conductivity.

These data clearly show the surface manifestation of the saline wedge within the estuary. Obviously they can only indicate the approximate position of the bottom TDS concentration isopleths since the shape of the saline wedge is not known.

DISCUSSION

As the above presentation should have made clear, the basic flaw in the X2 concept as a Delta flow regulator, is that it is very difficult, if not impossible, to define the actual X2 with any significant degree of accuracy. The rationality of establishing a deterministic rule that can not be properly enforced, or that is open to serious statistical error, must be questioned. To emphasize the point, the regulation gives a specific number of days (eg. 133, for a wet year, 105 for a dry year, see Table 1) with no recognition of the level of error involved in the determination of the X2 location. In fact, given the error implicit in any biological abundance index and the error involved in the determination of X2, one must also seriously doubt that there is a significantly better correlation of the abundance index with X2, rather than with either the location of the surface 2 ppt isopleth, or a flow index.

In order to choose such a difficult index (X2) as the basis for a rule making surely there should be a **very strong** indication that it is a much better biological indicator than any other flow or salinity index. There does not appear to be such evidence to support this conclusion as Walker (Ref. 7) points out. In fact, since the X2 data are derived almost directly from the surface conductivity measurements the logical route seems to have been surface conductivity → bottom salinity → biological index → bottom salinity → surface conductivity → flow. The logic of it all does seem rather circular. As the CCWD (Refs. 2, 3) analysis and Brown and Yotter (Ref. 5) graphs make clear, the Delta salinity and flow are strongly related, as they are for almost all estuaries (Ref. 6). If the biological index is actually salinity related then why not prepare a rule that can be directly monitored with data that is currently being collected, such as surface salinity or flow. If it is so imperative to use salinity as the predictor then it seems that the CCWD antecedent flow approach has the strongest scientific basis.

REFERENCES

1. Kimmerer, W. and Monismith, S. An estimate of the historical position of the 2ppt salinity in the San Francisco Bay Estuary. Issue Paper for the Fourth Technical Workshop on Salinity, Flows, and Living Resources of the San Francisco Bay/Delta Estuary, August 1992.

2. Denton, R.A. and Sullivan, G.D. Antecedent flow-salinity relations: Application to Delta Planning Models. CCWD Report, December 1993.

3. Sullivan, G.D. and Denton, R.A. Report on Clean Water Act X2 Water Quality Standards, CCWD Report, February 1994.

4. Chung, F. Finch, R. and Enright, C. Appendix V Historical Flow Versus Salinity at Mallard Slough: Flow Needed to Maintain 2.0, 3.0, 4.0, and 5.0 PPT Bottom Salinity. DWR Report.

5. Brown, R. and Yotter, S. Sacramento-San Joaquin Delta Daily Electrical Conductivity and outflow and Location of Salinity Gradient and Estimated X2 Position for Water Years 1968-1992. Jones and Stokes Associates Inc., January 1994

6. Savenije, H.H.G., Rapid Assessment Technique for Salt Intrusion in Alluvial Estuaries, Delft Hydraulics Laboratory, 1992.

7. Walker, W. Preliminary Comments on Proposed Delta Salinity Standards. Prepared for MWD of Southern California, February 7, 1994.

We appreciate the opportunity to provide these comments. Please feel free to call if you have any questions.

Sincerely,

E. John List, Ph.D., P.E.
Principal Consultant

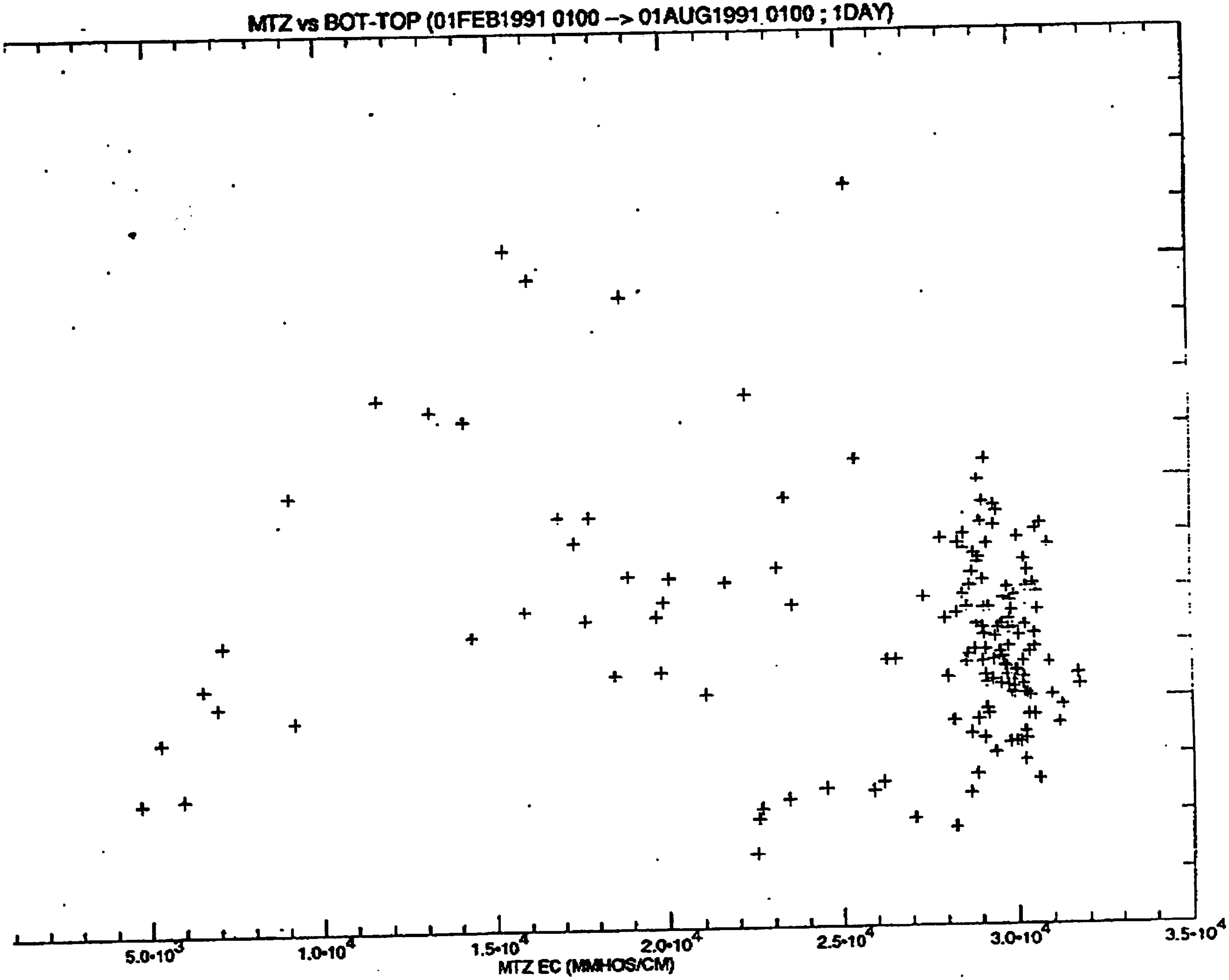


Figure 1

(Source: Ref. 4)

Figure 2

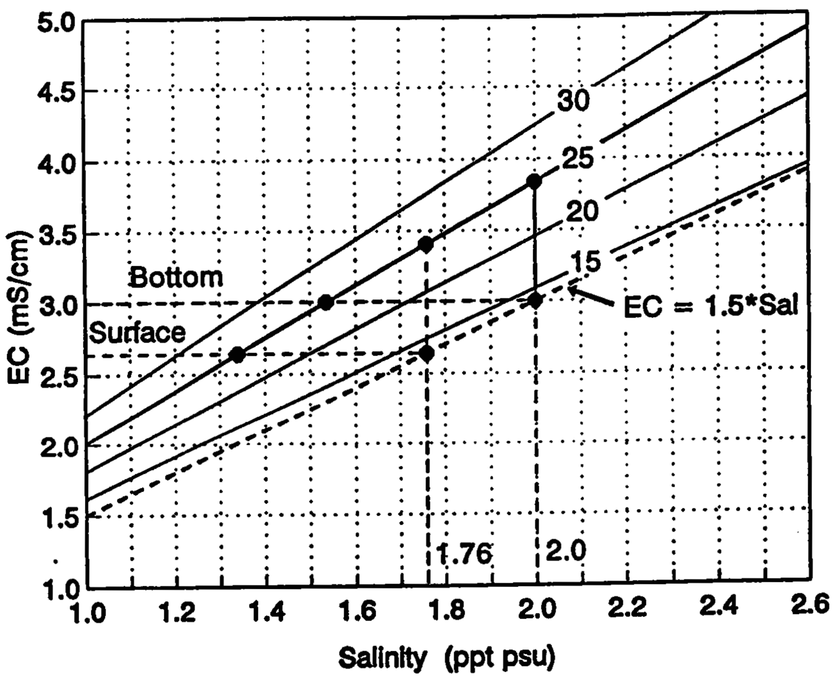


Figure 2.1.1. Conversion from electrical conductivity (EC) to practical salinity using the Accerboni-Mosetti equation. The conversions are shown for four temperatures: 15, 20, 25, and 30 °C.

(Source: Ref. 3)

Figure 3

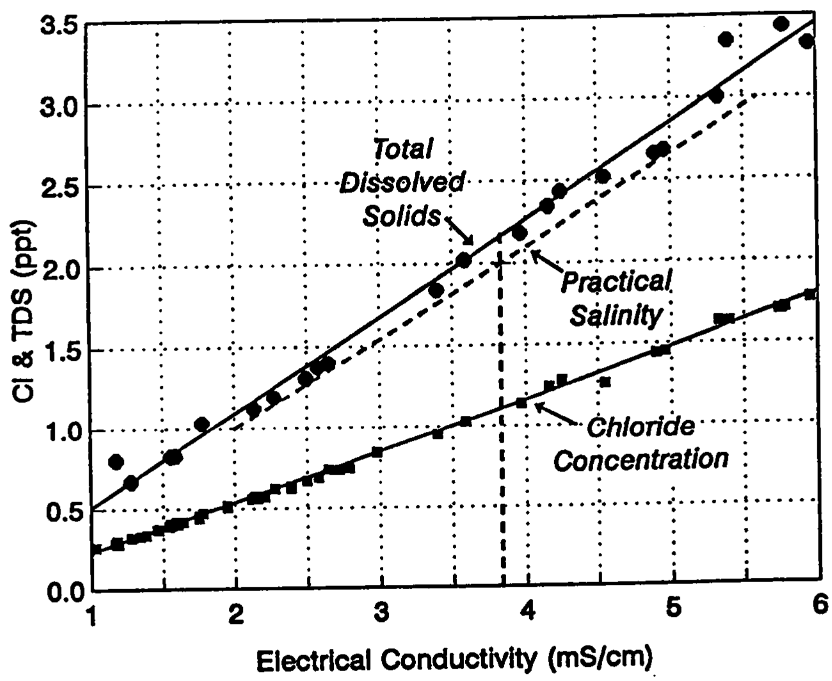


Figure 2.1.2. Total dissolved solids and chloride concentration from DWR grab samples. The dotted line indicates the practical salinity relation of Accerboni- Mosetti referenced to 25°C. The solid lines represent "best-fit" curves.

(Source: Ref. 3)

Figure 4

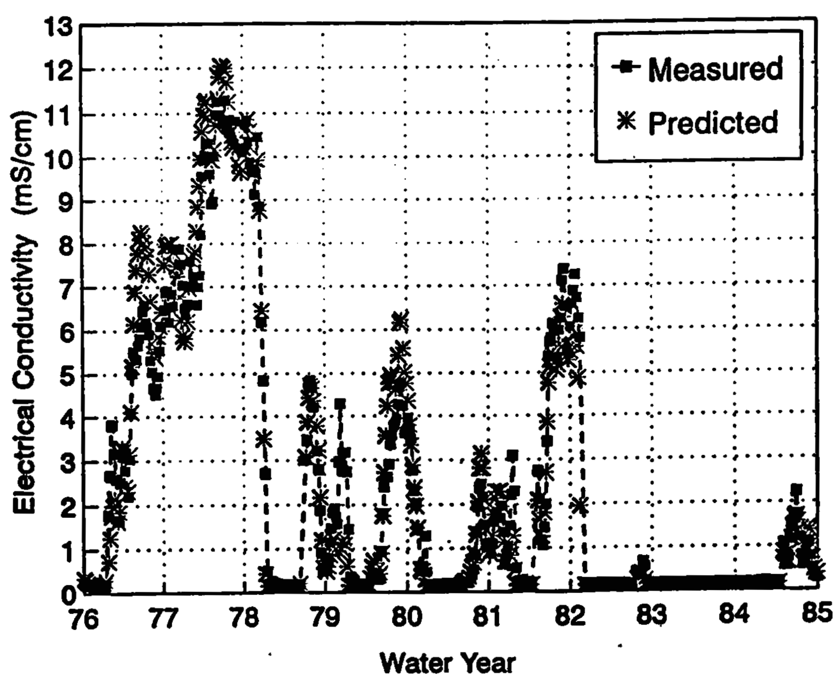


Figure 4.4. Measured and predicted 14-day average salinity at Collinsville for the period, 1976-1985. The stars represent predictions using Denton's antecedent flow model. The squares joined by dashed lines represent field-measured salinities.

(Source: Ref. 3)

Figure 5

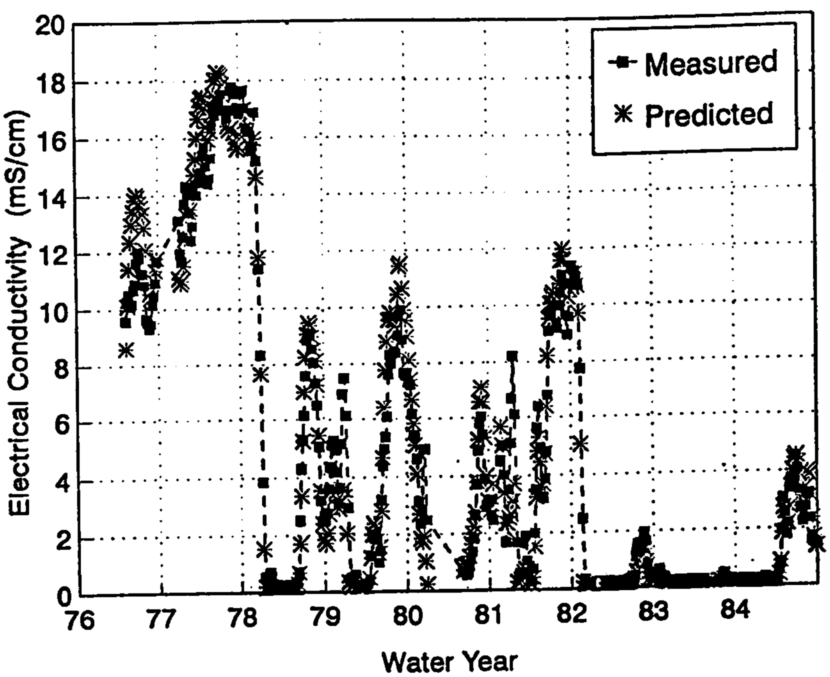


Figure 4.5. Measured and predicted 14-day average salinity at Chipps Island for the period, 1976-1985. The stars represent predictions using Denton's antecedent flow model. The squares joined by dashed lines represent field measured salinities.

(Source: Ref. 3)

Figure 6

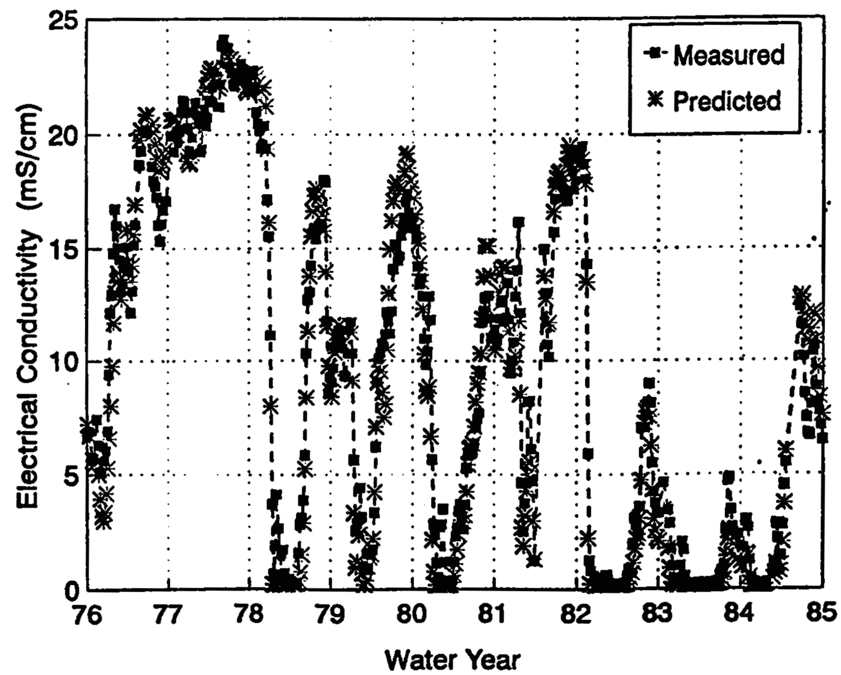
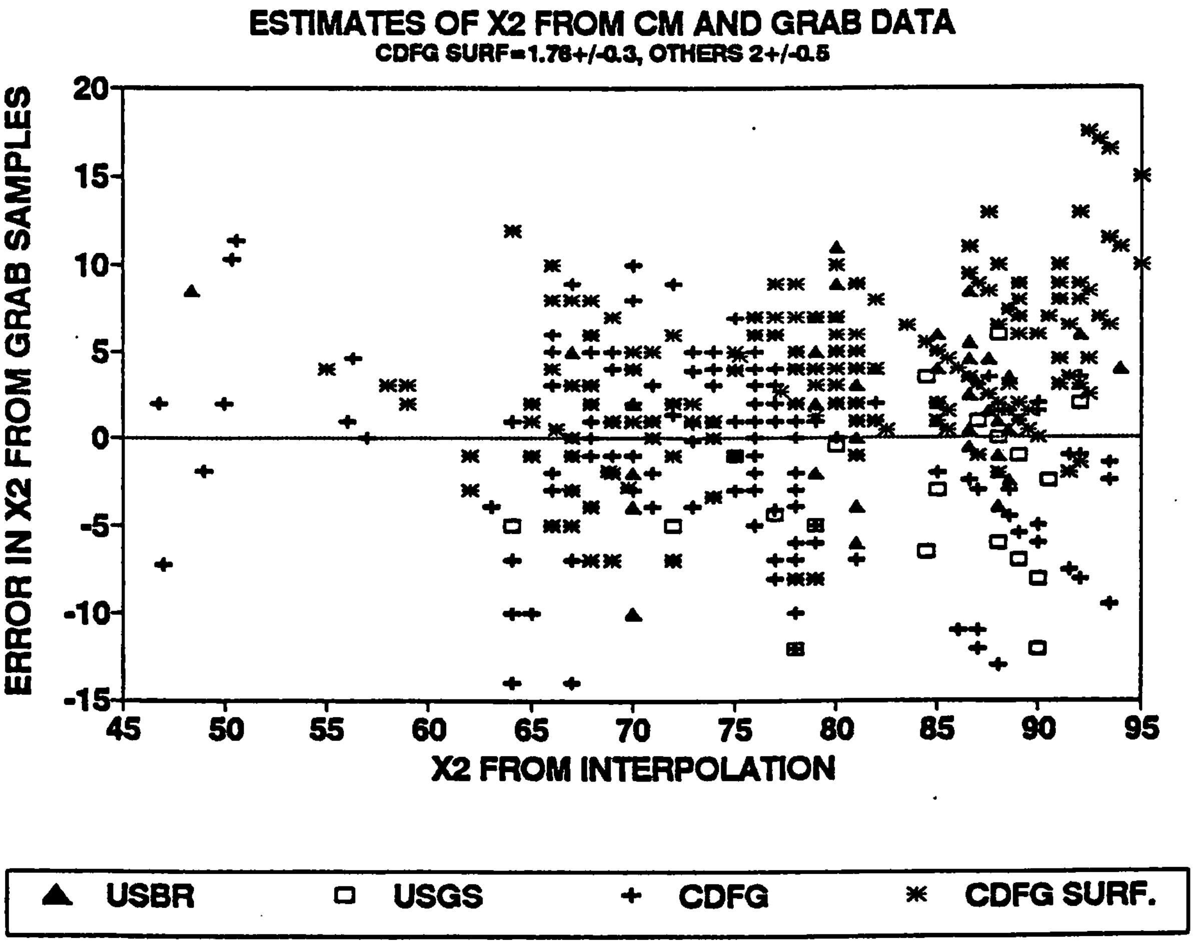


Figure 4.6. Measured and predicted 14-day average salinity at Port Chicago for the period, 1976-1985. The stars represent predictions using Denton's antecedent flow model. The squares joined by dashed lines represent field measured salinities.

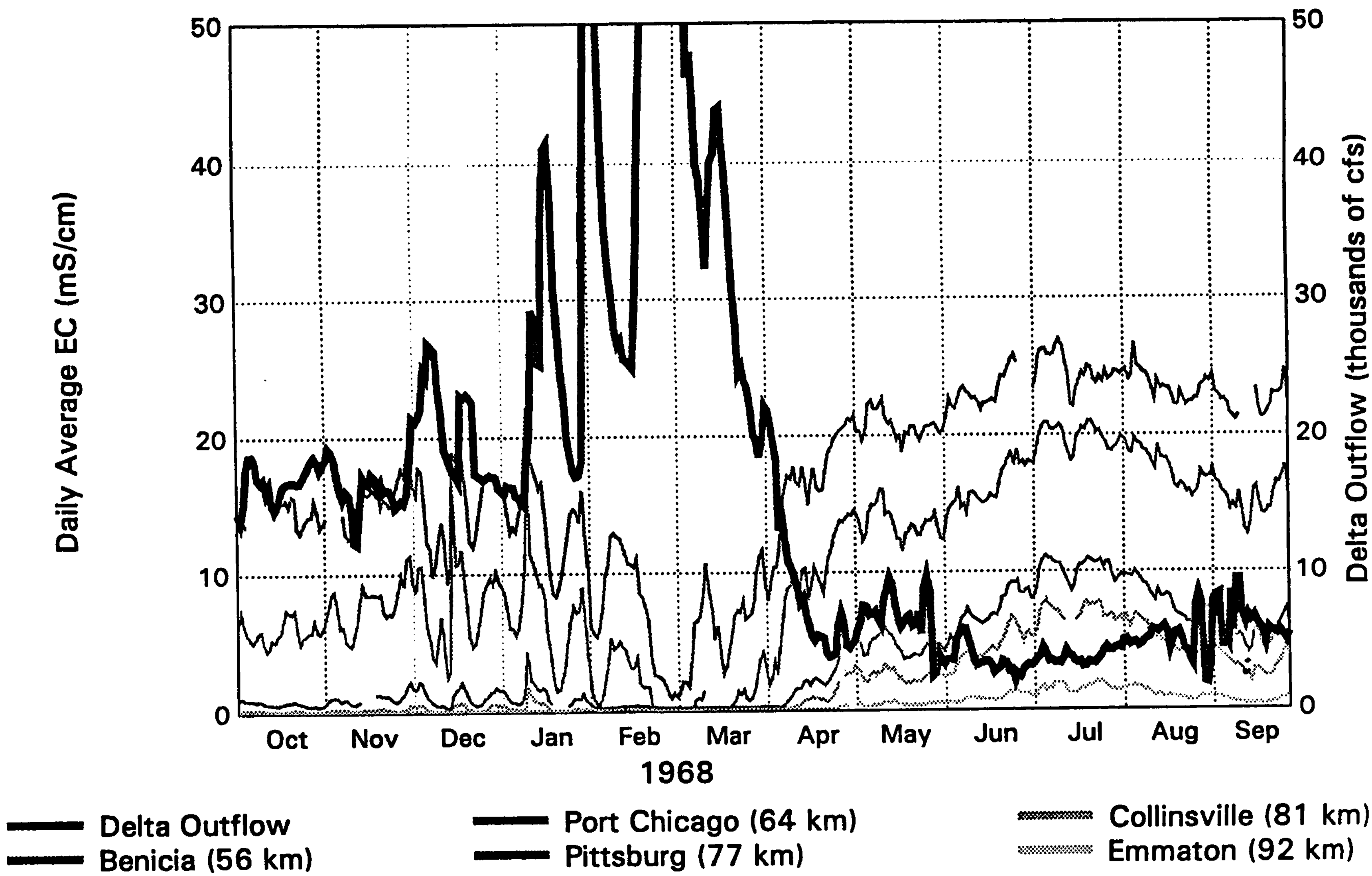
(Source: Ref. 3)

Figure 7

Figure 17. Analysis of residual of grab sample data vs. X_2 from interpolation. Grab samples were taken at salinity of 1.5-2.5, except for CDFG surface samples which were at salinities of 1.76 ± 0.3.



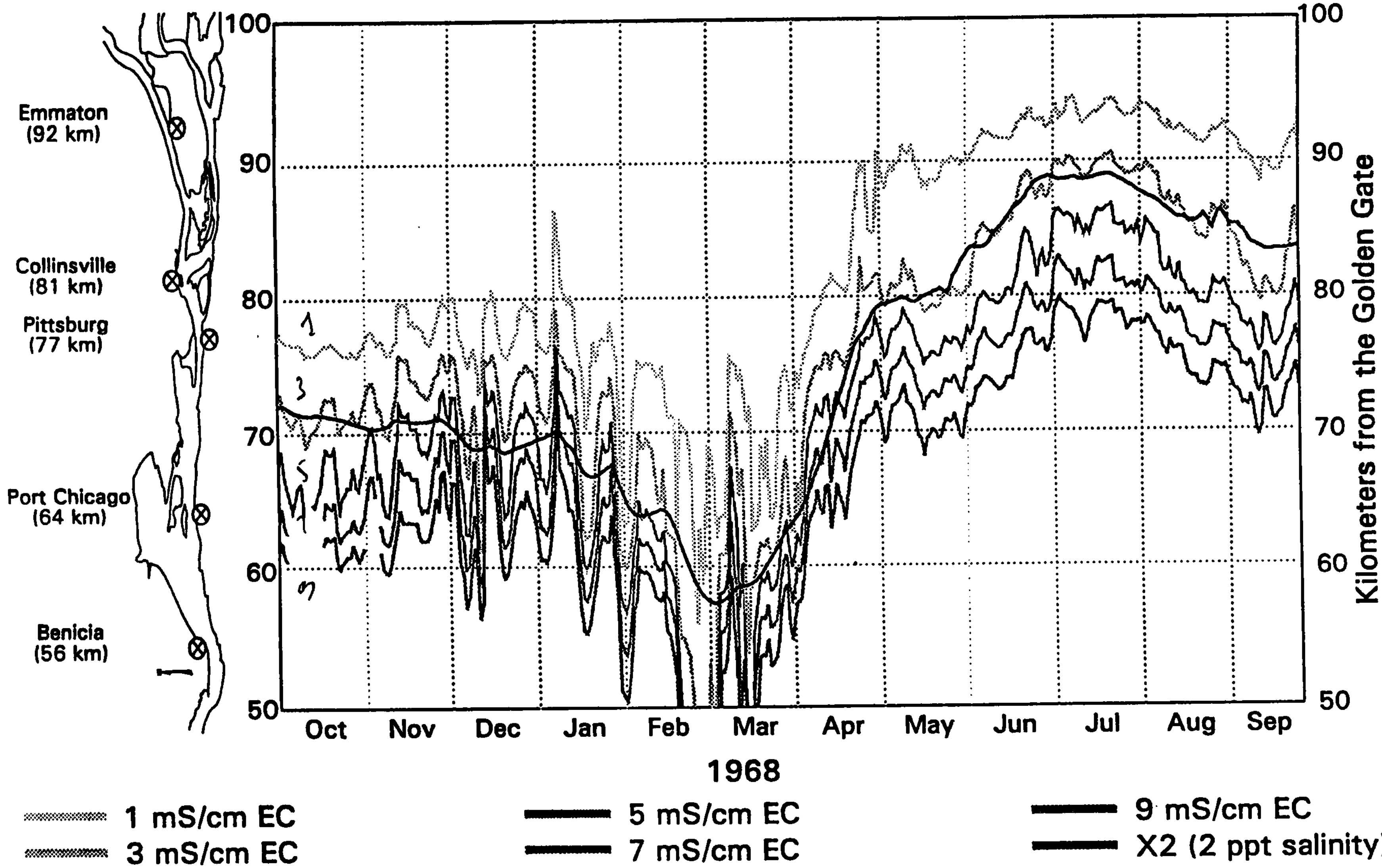
(Source: Ref. 1)



DAILY AVERAGE EC AT SELECTED STATIONS AND DELTA OUTFLOW FOR 1968

Figure 8

(Source: Ref. 5)



LOCATION OF SALINITY GRADIENT INTERPOLATED FROM DAILY AVERAGE EC MEASUREMENTS AND ESTIMATED X2 POSITION FOR 1968

Figure 9

(Source: Ref. 5)