A SLIDING SCALE FOR THE EPA SALINITY STANDARD

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NOTICE

This technical report was prepared as a technical document for reference use in 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 or NHI formal comments to EPA.

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Background The proposed EPA salinity standard consists of the number of days during February-June on which salinity is less than 2 ppt at three control points: Roe Island at 64 river kilometers, Chipps Island at 74 km, and the river confluence at 81 km. This standard is intended to approximate various mean values of X_2, the longitudinal position of 2 ppt salinity 1 meter off the bottom. The standard is set differently for each of 5 water year types to reflect interannual variability in availability of water to the system.

The selection of numerical values for the standard was based on a reconstruction of the historical record of salinity. The historical time series of salinity at the three control points was reconstructed by EPA using the Dayflow estimates of delta outflow and the Kimmerer-Monismith X_2 equation to estimate the number of days in February-June when salinity was less than 2 ppt at these points. The purpose of this reconstruction was to determine an appropriate frequency of exceedance of 2 ppt at these points, under the assumption that this frequency gave adequate protection to the estuary in times past but not in the last 15-20 years.

Variability in the number of days' exceedance is governed by two factors: the amount of unconstrained flow, and the level of development of water projects. Both of these depend on the years selected as the reference period, i.e. the time period over which the number of days' exceedance is determined. Although there is general agreement that a wide range of hydrologies is needed, there is disagreement over the range of years to use because of the issue of level of development.

The standard proposed by EPA is widely perceived as too rigid in its use of water years, each of which encompasses a wide range of actual water availability. At the recent workshop on salinity standards held at Stanford University, several speakers objected to the selection of water years and of reference periods for determining standards. In addition, George Barnes from the Department of Water Resources presented an analysis demonstrating that level of development (as indexed by calendar year) had a substantial influence on the relationship between total unconstrained flow and X_2. This is no surprise, but it has led to debate over the proper selection of reference years to use in setting the standards.

Objective The main objective of this study was to devise a sliding scale taking into account the natural variability of availability of water, and to separate the issues of level of development and natural variability in hydrology. A secondary objective was to explore alternative methods of averaging to determine their effect on achievement of the standard.

Averaging methods As originally conceived, the proposed EPA standards set the minimum number of days in February-June when salinity at each control point must be no greater than 2 ppt. This standard was considered operationally impracticable, so EPA modified this to use a 14-day running mean starting on February 1. Thus, the salinity at each control point would be calculated as a running mean for the period from the current date to the date 14 days earlier, but not before February 1.

EPA requested suggestions for alternatives to this scheme that would achieve protection at greater operational ease. Contra Costa Water District suggested that a day be considered as meeting the standard if one of three conditions were met: the actual salinity on that day, or the running mean, was under 2 ppt, or the calculated net delta outflow was sufficient to achieve the standard under steady-state conditions.

David Fullerton of NHI suggested simply averaging days slightly above and below 2 ppt to allow, for instance, a day at 2.5 and a day at 1.5 ppt to be counted as two days at 2, thereby achieving the standard. Days with salinity greater than 4 ppt would not be included. To calculate this standard, the salinities in the month (for this analysis; if applied this scheme would be used across the 5-month period) are ranked in increasing order. The mean of all days from the lowest to the highest value less than 4 ppt is calculated; if over 2 ppt, the next highest is used, and then the next until the mean of *n* days is not over 2 ppt. This number *n* is the number of days on which the standard was met in this month. Operationally, this standard would be met by trading off days in different parts of the season. It has the advantage over the running mean that operators can take advantage of periods of high flow and are not hurt excessively by brief periods when the daily mean salinity is well over 2 ppt. It appears to be operationally workable (Jim Snow and Paul Fujitani, pers. comm., March 1994).

This analysis compares the relationships between the monthly mean X_2 and the number of days' exceedance of 2 ppt under four schemes: no averaging, a 14-day running mean, CCWD's scheme, and Fullerton's scheme. Data used for this analysis included the daily salinity data from the USBR monitoring stations, used in initial calculation of X_2, and the monthly mean best estimates of X_2 from the same series. For each control point, running mean salinity was calculated starting on February 1. For each month in the series (1968-91), the station closest to X_2 was selected and the number of days on which salinity was not over 2 ppt was calculated under each of the 4 schemes.

To take into account the different positions of the stations, the number of days' compliance with the standard was plotted against *Delta* X_2, the difference in km between X_2 and the nominal position of the station. This allowed all data to be combined in a single analysis, under the assumption that the relationship between

Delta X_2 and number of days' compliance would be the same for each station. Examination of residuals from the analyses suggested that this was the case.

Figure 1 shows the relationship between the proportion of days' compliance and Delta X_2 for each of the four schemes. The line fit to the data is a logistic function, appropriate for a relationship between a dichotomous variable (i.e. compliance or no compliance) and a continuous variable (Delta X_2). The value of Delta X_2 at which the line crosses 50% compliance should be close to zero. In Figure 1, it can be seen that this line moves further from 0 for the four averaging schemes. With no averaging it is not zero because the relationship between X_2 and salinity at any point is nonlinear. With more averaging this crossover point shifts to the right, or to a higher mean X_2, because an increasing number of higher salinity values are allowed to represent compliance with the standard. However, it is useful to note several features of these graphs. First, all of the averaging schemes result in more values at the extremes, either 0 or 100%, because salinity does not vary much within most months. Second, the variability around the line is highest for the CCWD scheme, lower for the 14-day running mean, and lowest for the Fullerton scheme. Thus, this latter scheme would give the greatest certainty that achieving a given number of days' exceedance would also achieve a certain value of X_2.

Effects of hydrology and level of development Data used in this analysis were daily estimates of X_2 either from the 1968-91 series or estimated from Dayflow using the Kimmerer-Monismith equation. Note that this equation and the CCWD antecedent conditions equation give roughly the same values for number of days at each control point.

I had data for 1930-1991, but selected 1930-1975 for analysis because flow standards in 1976-91 altered the relationship between X_2 and unconstrained flow. Mean X_2 and number of days on which salinity was less than 2 ppt at each of the three control points was determined for the February-June period of each year without averaging.

The analysis proceeded in two stages which were then combined. First, an equation predicting mean X_2 from flow and year was determined; next a logistic function for days of compliance as a function of X_2 was determined in a similar manner to that described above; and third, the two equations were combined and parameters redetermined in an overall regression analysis.

For periods when it is not measured, X_2 is linearly related to log of delta outflow. Thus the log of unconstrained flow was chosen as a predictor variable. Preliminary analysis revealed that unconstrained flows from rivers in the Sacramento and San Joaquin basins and eastern Delta were highly correlated. Based on principal component analysis, there appeared to be no major mode of variability in these data that was not incorporated in their total, and that explained any of the variation in X_2. Thus, the total unconstrained flow, averaged over February-June, was used in the analysis.

Table 1 shows the results of this multiple regression analysis. The R^2 value of 0.97 indicates that this analysis captures all but 3% of the variation in X_2 (Figure 2A).

In the second analysis, data from all control stations were combined and plotted against Delta X_2 as described in the previous section. The data were then fitted to a logistic regression, which had an adjusted R^2 of 0.94 (Table 2, Figure 2B).

The combined analysis expressed the percent of days at or below 2 ppt as a function of year, log of total unconstrained flow, and position of the station in kilometers. As with the previous analysis, this allowed all three stations to be used in the same analysis. This analysis gave an R^2 of 0.92 (Table 3). In Figure 2C, the data for the entire period (1930-1991) are plotted and it becomes clear that the later years deviate considerably from the relationship. This is also apparent in Figure 2D, where residuals are plotted separately for each control point. Before the mid-1970s, the residuals are similar for each point, and rather small with a standard deviation of 8% of days (i.e. 12 days). After that time, the residuals for Chipps Island and especially the confluence generally are positive and those for Roe Island negative, probably because D-1485 standards protected flows at the upstream locations.

On the basis of the above results, we have a model that gives the number of days not exceeding 2 ppt as a function of year, unconstrained flow, and location. The model is illustrated in Figures 3 and 4. In Figure 3, the combined effects of flow and year can be seen for each control point. As expected, in any year the number of days under 2 ppt increases with increasing flow and is highest upstream, but the relationship has shifted over the years as water has been increasingly used and impounded.

The effects of selecting alternative reference years are given in Figure 4, which show slices through the surfaces in Figure 3 for 1940, 1958, 1968, and 1975. The different years cause considerable difference in the number of days ≤ 2 ppt at each station, especially over the range at which X_2 is near that station and the number of days changes rapidly.

Table 4 presents the days at or below 2 ppt for several flow values assuming a 1975 level of development. In contrast to the EPA standards, the number of days at the confluence does not reach 150 except under high-flow conditions.

Figure 5 shows the February-June flow as a cumulative frequency distribution for

1930-75 and 1976-91 separately. This figure illustrates that the flows in the historical period used are representative of the full range, except that the later period included both the highest- and lowest-flow years. The later period had, as expected, more drought years and more high-flow years than the historical period, but since nearly the entire range is included in the historical period, it can be used without excessive extrapolation.

Table 1. Results of multiple regression analysis of X_2 vs. the log of total unconstrained flow (February to June) and year. The model for this regression is:

$$X_2 = A + B \times \text{Year} + C \times \text{LOG}_{10}(\text{Unconstrained flow, MAF}) + \text{Error}$$

Parameter	Degrees of Freedom	Value	p value
R-squared		0.97	<0.0001
A	1	114.57	<0.0001
B	1	0.16959	<0.0001
C	1	-50.396	<0.0001
Error	43	-	-

Table 2. Results of logistic regression analysis of percent of days when salinity at a control point was 2 ppt or less vs. Delta X_2, the difference between X_2 and the control point location. The model for this regression is:

$$Prop = 1 - \frac{1}{(1 + e^{(A + B \times DeltaX_2)})}$$

where Prop is the proportion of days at or below 2 ppt.

Parameter	Degrees of Freedom	Value	p value
R-squared		0.94	<0.0001
A	1	-0.2596	<0.0001
B	1	0.18279	<0.0001
Error	136	-	-

Table 3. Results of overall model in which the proportion of days not over 2 ppt at a control point, Prop, is predicted from year, log of unconstrained flow, and control point position X_c. The equation, using the symbols in previous tables, is:

$$Prop=1-\frac{1}{(1+e^{(A+B\times Year+C\times LogQ+D\times X_c)})}$$

Parameter	Degrees of Freedom	Value	p value
R-squared		0.92	<0.0001
A	1	-19.7529	<0.0001
B	1	-0.04731	<0.0001
C	1	9.54710	<0.0001
D	1	0.176863	<0.0001
Error	134	-	-

Table 4. Days of salinity ≤ 2 ppt for several flow values using 1975 level of development.

Unconstrained	Days of salinity ≤ 2 ppt		
Flow, MAF	Roe Is.	Chipps Is.	Confluence
5	1	4	14
10	12	51	96
15	48	110	136
20	91	135	145
25	119	144	148
30	134	147	149
35	141	148	150

Figure 1. Effect of averaging period on percent days < 2 ppt in a month, vs. Delta X_2 (Difference between X_2 and station location): A, No averaging; B, 14-day running average; C, CCWD scheme; D, cumulative average of increasing values up to 2 ppt

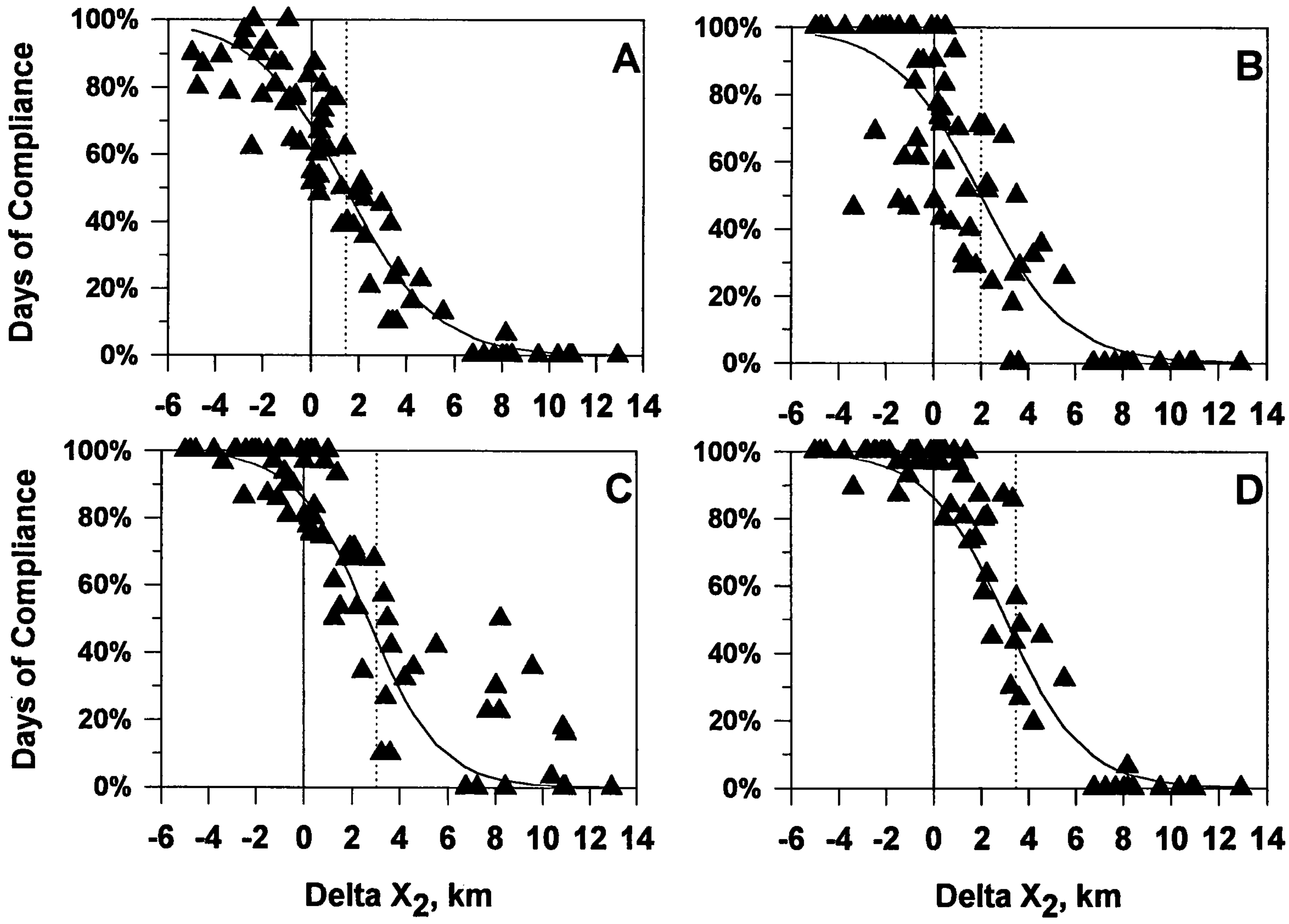

Figure 2. Calculation of model predicting number of days < 2 ppt: A, X_2 predicted from year and log flow; B, Percent of days < 2ppt vs. distance from station to X_2 C, Percent of days < 2 ppt predicted from model; D, Residuals from model.

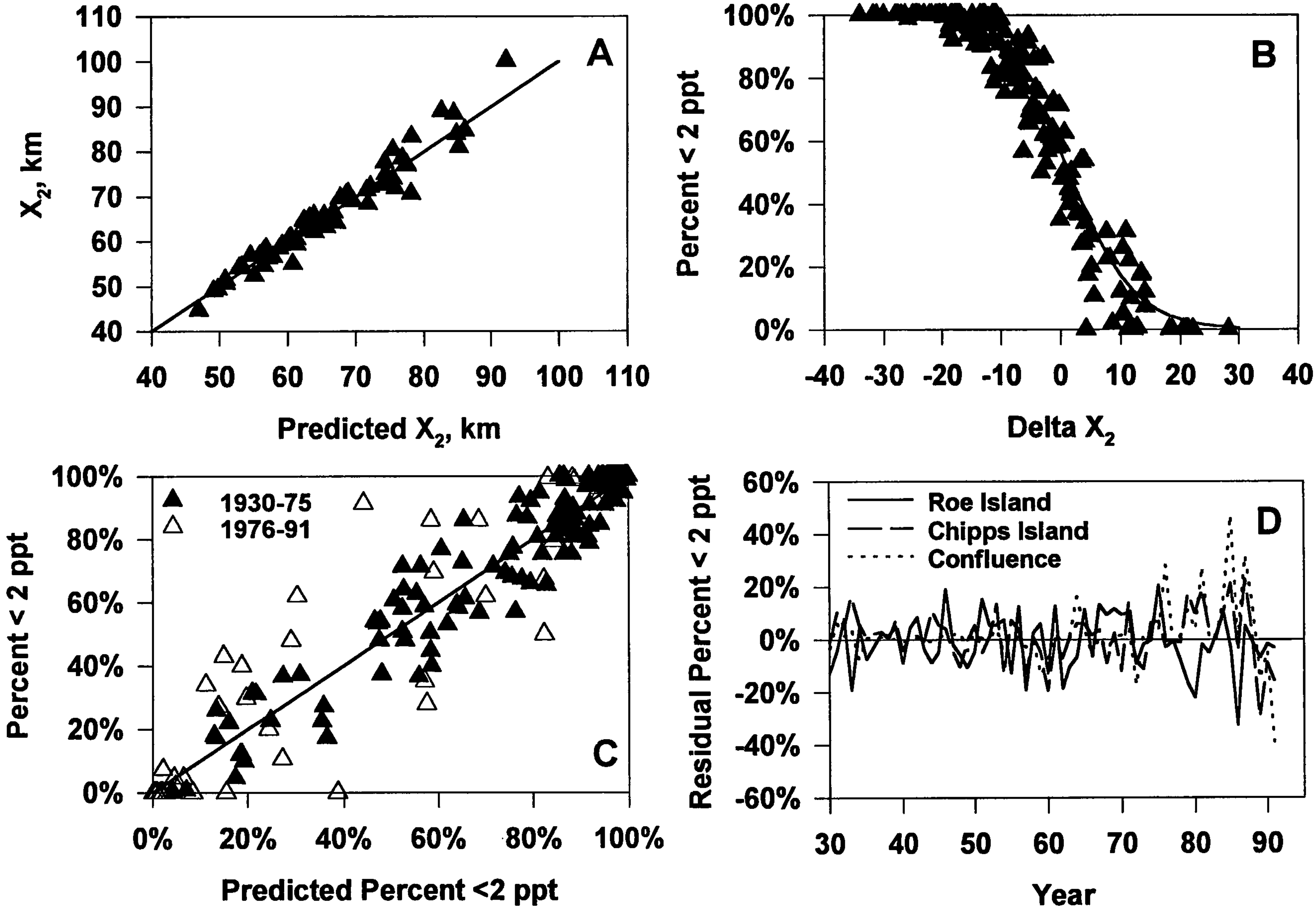

Figure 3. Predicted percent days < 2 ppt showing effects of year and flow

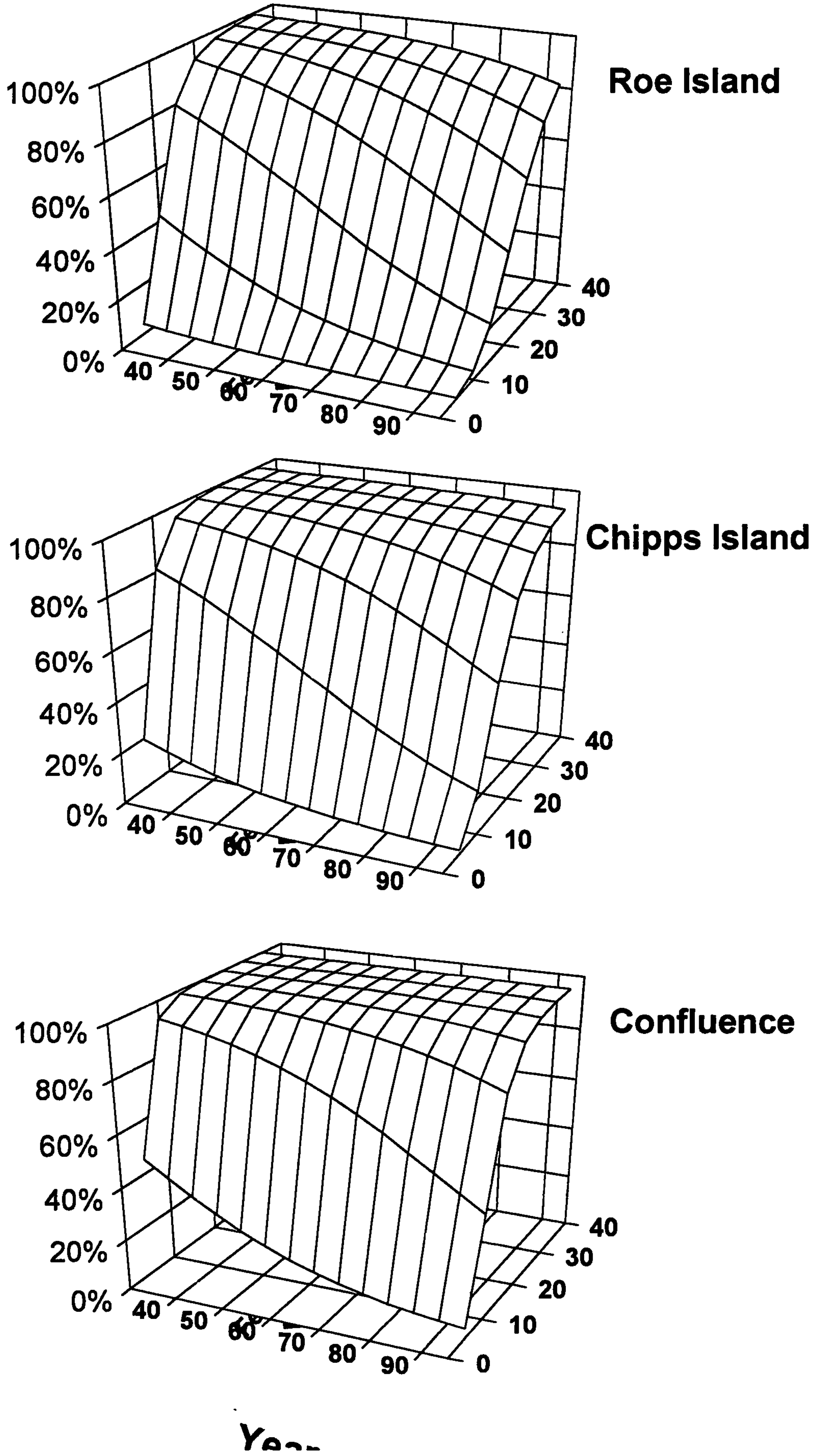

Figure 4. Predicted days < 2 ppt vs. unconstrained flow for 4 reference years

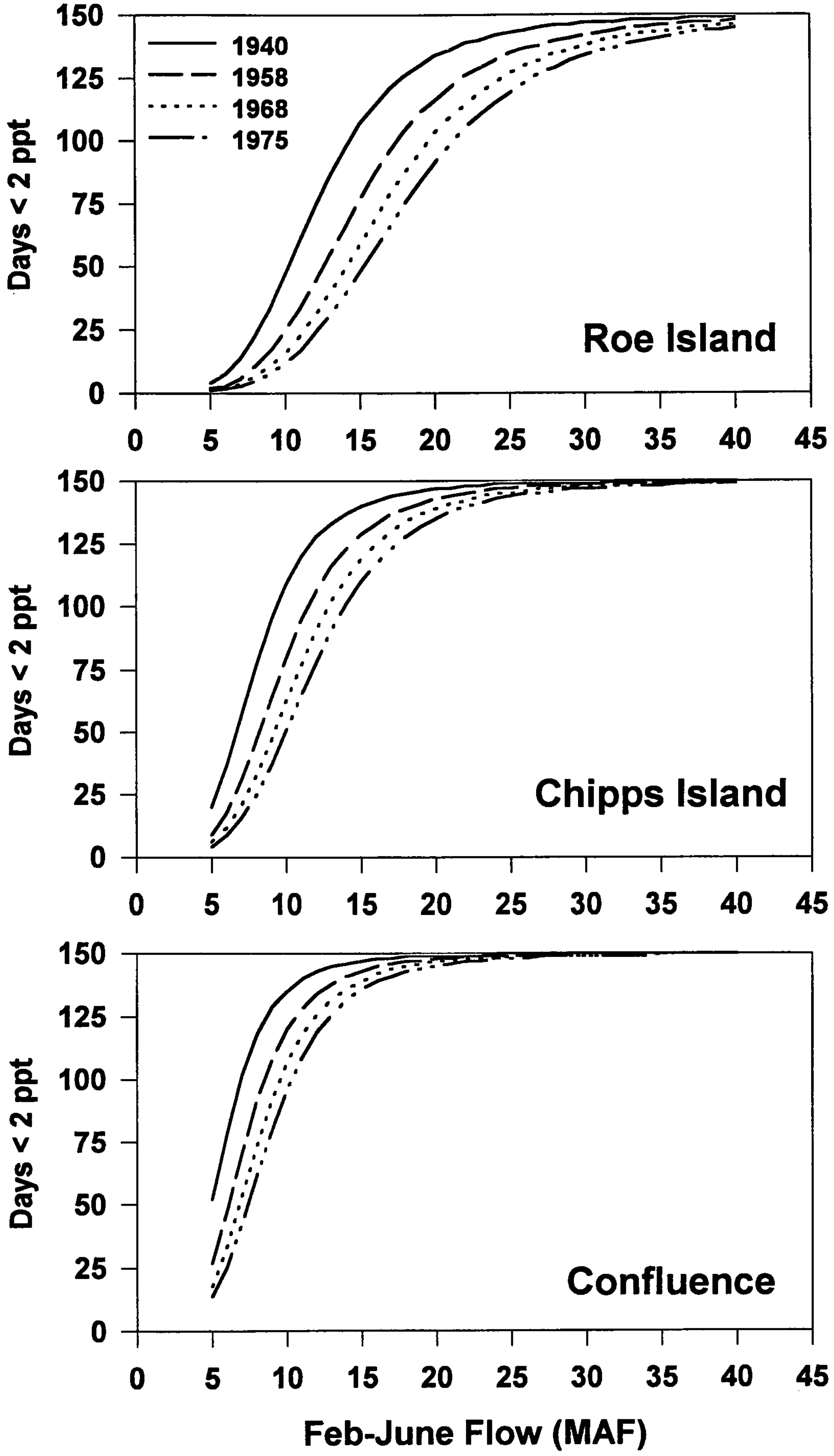

Figure 5. Frequency distribution of historical unconstrained flows for two time periods