3 Marginal Export Cost and MDO Replacement

A fast, accurate model to estimate salinities in the Sacramento–San Joaquin Delta when given flow inputs is an important tool, but not an easy one to develop. Such a model can be used to estimate Marginal Export Cost (MEC, also known as carriage water); as a replacement for the MDO routine in the statewide planning model DWRSIM; as a realtime flow/salinity estimation model; and in reservoir release optimization studies. Attempts at developing such a model have been made for many years with less than full success. A fairly recent mathematical and programming technique known as Artificial Neural Networks (ANNs) was applied to the problem with considerable success. ANNs offer several advantages over previous methods because they are nonlinear; allow multiple, arbitrary inputs; easily allow "memory" to be incorporated; and are not confined to pre–determined impulse–response function shapes. ANN models are developed by first calibrating the internal coefficients of an ANN with sequences of flows and salinities at a location of interest. After the ANN has been calibrated, new flow inputs are provided and estimated salinities produced.

There is a strong need to "model" a model of the Delta; in other words, to calibrate an ANN on the salinity output of another numerical model such as DSM2, for use in DWRSIM. Ideally, DSM2 would be incorporated into DWRSIM directly, but this is impractical because of tremendous differences in running time between the two models. Instead, a faithful and fast imitation of DSM2 can be developed using ANNs and used in DWRSIM.

A description of ANNs and preliminary investigations of MEC was given in the June 1995 *Annual Report*. Further investigation of MEC was conducted and a draft report prepared, "*Modeling Flow-Salinity Relationships in the Sacramento-San Joaquin Delta Using Artificial Neural Networks*", January 1997, which is available from the Delta Modeling Section. In this annual report, we summarize our findings from that report.

Carriage Water Findings Using Artificial Neural Networks

1. Multiple flow inputs—as opposed to a single, lumped flow parameter such as Net Delta Outflow—provide a significant increase in the accuracy of salinity estimates when given flows (Figure 3–1, 3–2), as well as the sequence of flows to meet a required salinity standard (Figures 3–3, 3–4). It is especially important in the interior Delta to model salinities using separate flows, such as the Sacramento and San Joaquin rivers and Banks and Tracy pumping, instead of lumping them into a single parameter. Furthermore, a single–input model must, by definition, assume the Marginal Export Cost to be zero, which in our opinion can be a significant error.

2. Marginal Export Cost (carriage water) exists and it is not a trivial or negligible quantity. It is highly variable, depending on the controlling salinity location,

duration and quantity of through–Delta flow, and current and past hydrology. It can range from −100% of export increases (Emmaton controlling) to +100% or greater of export increases (Rock Slough and Clifton Court Forebay). Typical ranges would seem to be 10% to 30% at Jersey Point, Rock Slough, and Clifton Court Forebay if they are assumed to be the only controlling stations. In other words, an increase in export pumping causes salinity to change at that station. In order to bring the salinity back to the historical level, the amount of Sacramento flows needed in excess of the increase in pumping were estimated with the ANNs. The Marginal Export Cost is lowest in the western Delta, and increases to higher values in the interior Delta and the export pumps (Figures 3–5 through 3–8).

3. It is difficult to estimate the effect of the Cross Channel gate operation on Delta salinities from historical data, probably because the gate has been operated according to past flow regimes. Historically the gate has been closed during high flows in the Sacramento River and open during low flows. This colinearity between Sacramento flow and gate position confuses a black–box model such as multiple regression or ANNs. Therefore, the impact of gate position must be estimated from a simulation model where inputs can be deliberately decoupled.

This issue is critical, as the ability to simulate internal Delta operations will be important to the use of ANNs with DWRSIM. Therefore, we conducted a separate investigation to see if this bias in historical data could be removed with the use of a numerical model such as DSM1.

Replacement of MDO with ANNs in DWRSIM

Historic flow data, along with DSM1–simulated Total Dissolved Solids (TDS), was used to train Artificial Neural Networks (ANNs) to model water quality as a function of input flows and Delta Cross Channel (DXC) gate position. ANNs were developed to estimate water quality, which is measured in TDS at various locations in the Delta.

These networks were tested using a Java–based simulator for varying flows and DXC operation. The ANNs' output for different scenarios revealed some problems with these historically–trained TDS networks.

Opening the DXC gate allows fresh water from the Sacramento River to flow into the interior Delta, which should result in better water quality in the interior Delta. Western Delta locations like Pittsburg should be relatively insensitive to DXC operation. The initial ANNs developed at Contra Costa Canal and at Pittsburg did not give the expected results (Figures 3–9 and 3–10).

Figure 3–9 illustrates several problems with the initial TDS ANN at Contra Costa Canal. At some points keeping the DXC closed seems to result in lower TDS than historic operation and at other points keeping the DXC gate open seems to increase TDS values, when compared to the historic case.

Similarly, Figure 3–10 shows that the ANN–simulated TDS at Pittsburg is highest when the DXC gate is open, and TDS is much lower when the DXC is closed, which should not be the case.

This unanticipated behavior can be attributed to bias in the data used to prepare our ANNs. Historically, the Delta Cross Channel has been opened during periods when TDS values were relatively high. An ANN may then associate higher TDS values with the opening of the DXC gate. The historic correlation between DXC operation and high TDS values keeps the neural network from accurately modeling the effects of DXC operation.

Training our ANNs using DSM1-modeled TDS allowed us to create additional training data to negate the bias present in the historic data. In order to develop an unbiased training set, we used an additional DSM1 run to augment our original training set. The first half of the new training set was the original historic flows and DXC position with DSM1-simulated TDS. The second half of the new training set also used historic rimflows; however the DXC position was inverted, resulting in different daily TDS values.

Whenever the gate was closed in the original training set, the gate was set open in the second half of the training set, and vice versa. This was done in an attempt to "cancel out" the correlated operation of the gate in the original, unaugmented training set.

The results of this experiment appear to be successful (Figures 3–11 and 3–12).

The new Contra Costa Canal ANN (Figure 3–11) shows that when DXC was kept closed for the entire simulation period, the TDS was generally higher than the baseline case (historic operation). Similarly, when DXC was kept open lower TDS values than the baseline case resulted.

The new Pittsburg ANN (Figure 3–12) shows that TDS is relatively insensitive to DXC operation, as expected.

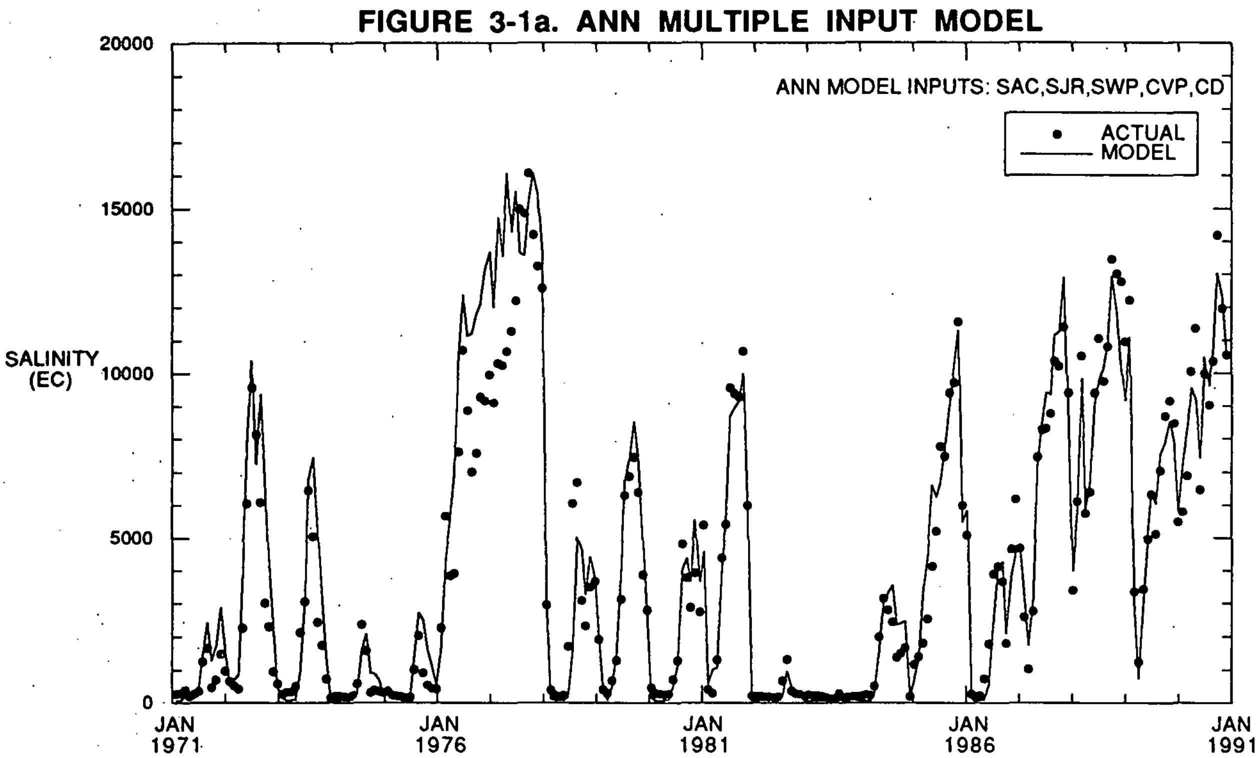
The approach of combining ANN technology with a physically-based model like DSM1 or DSM2 seems to be a promising one. Once trained and calibrated, ANNs are much faster than the comparable physically-based numerical model; however, the predictive ability of our ANNs is directly related to the quality of our training sets. Using DSM1 or DSM2 output, we can continue to optimize ANN performance to combine the reliability of calibrated, physically-based models with the speed and ease of ANN-based models.

Future Directions

In the next year, we anticipate the use of a multiple-input ANN module within DWRSIM to replace the current MDO or G model routine. Models which use only Net Delta Outflow have more difficulty than multiple-input models in handling the non-historical operation of the Delta as proposed in various planning studies.

We also plan to calculate historical Marginal Export Costs during periods of through-Delta water transfers. This would involve estimating which water quality station was controlling flows and the amount of water transferred; then the ANN and reverse-solver would estimate the MEC penalty incurred for the water transfer. Confirmation of the estimated MEC could be performed by a traditional numerical model such as DSM2.

PITTSBURG TIME SERIES PLOT
HISTORICAL DATA



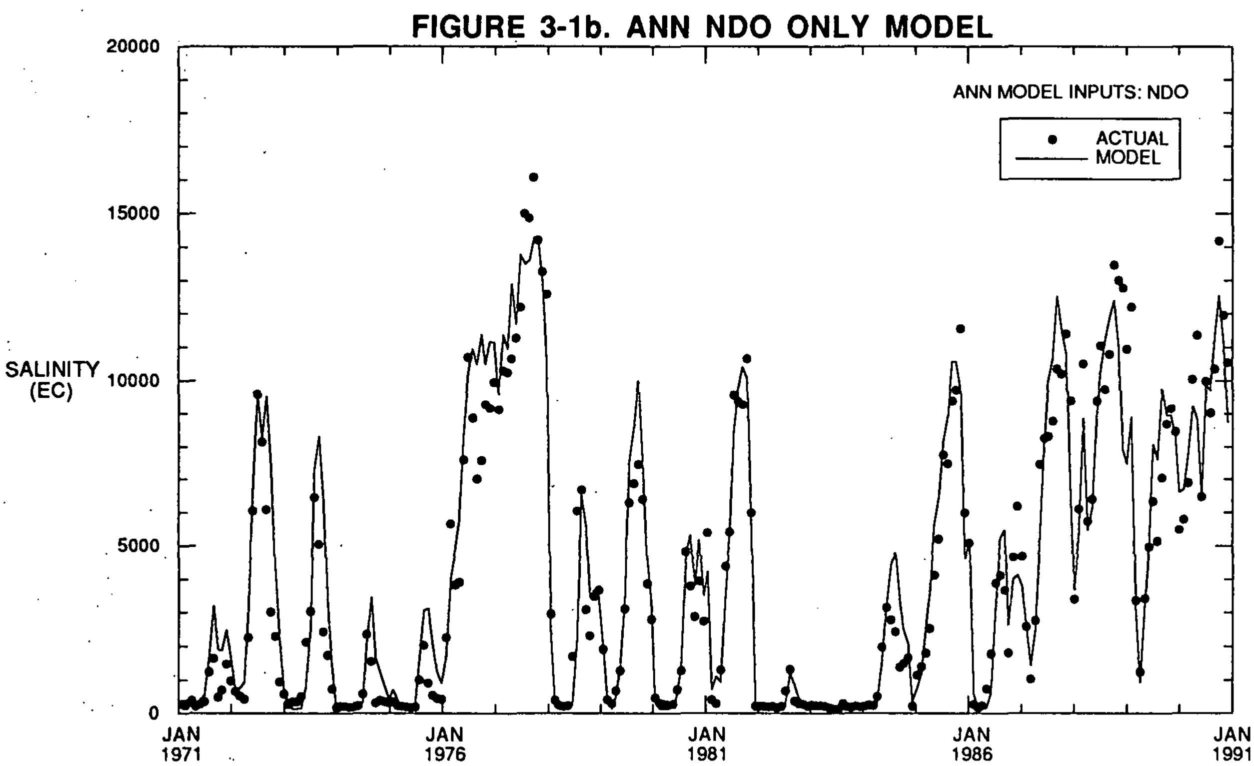


Figure 3-1

CONTRA COSTA CANAL TIME SERIES PLOT
HISTORICAL DATA

FIGURE 3-2a. ANN MULTIPLE INPUT MODEL

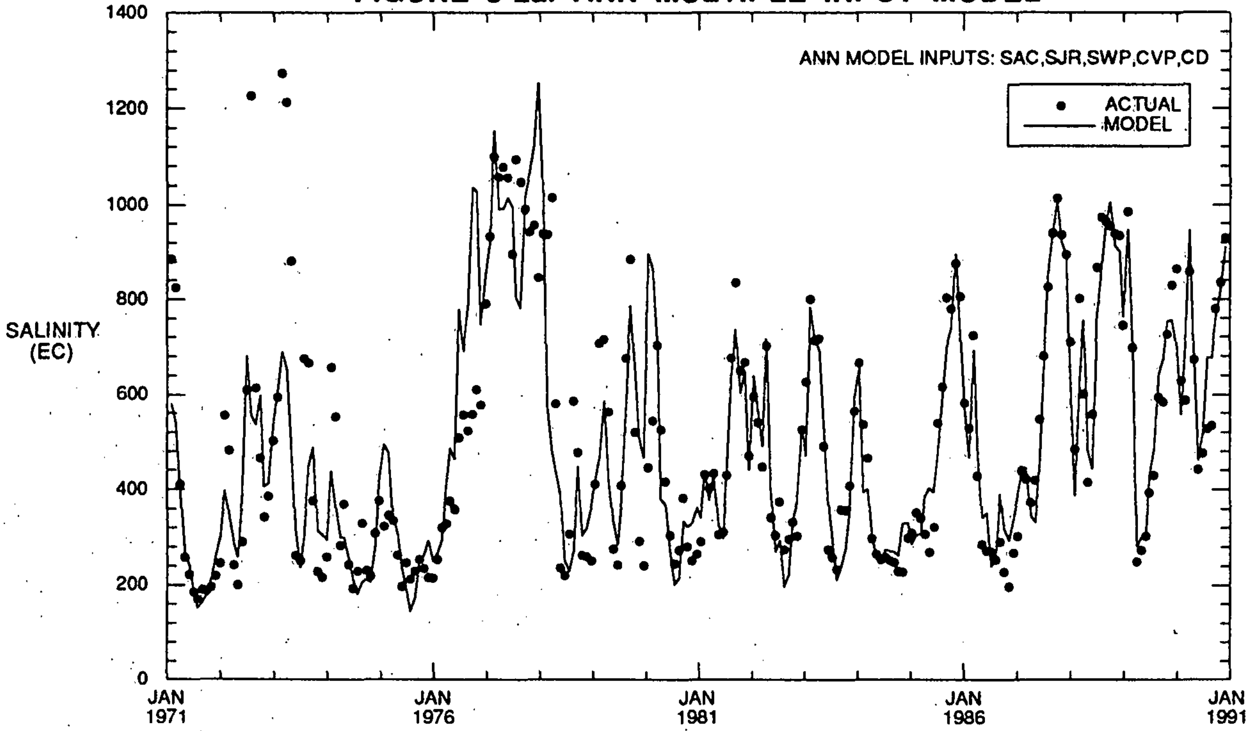


FIGURE 3-2b. ANN NDO ONLY MODEL

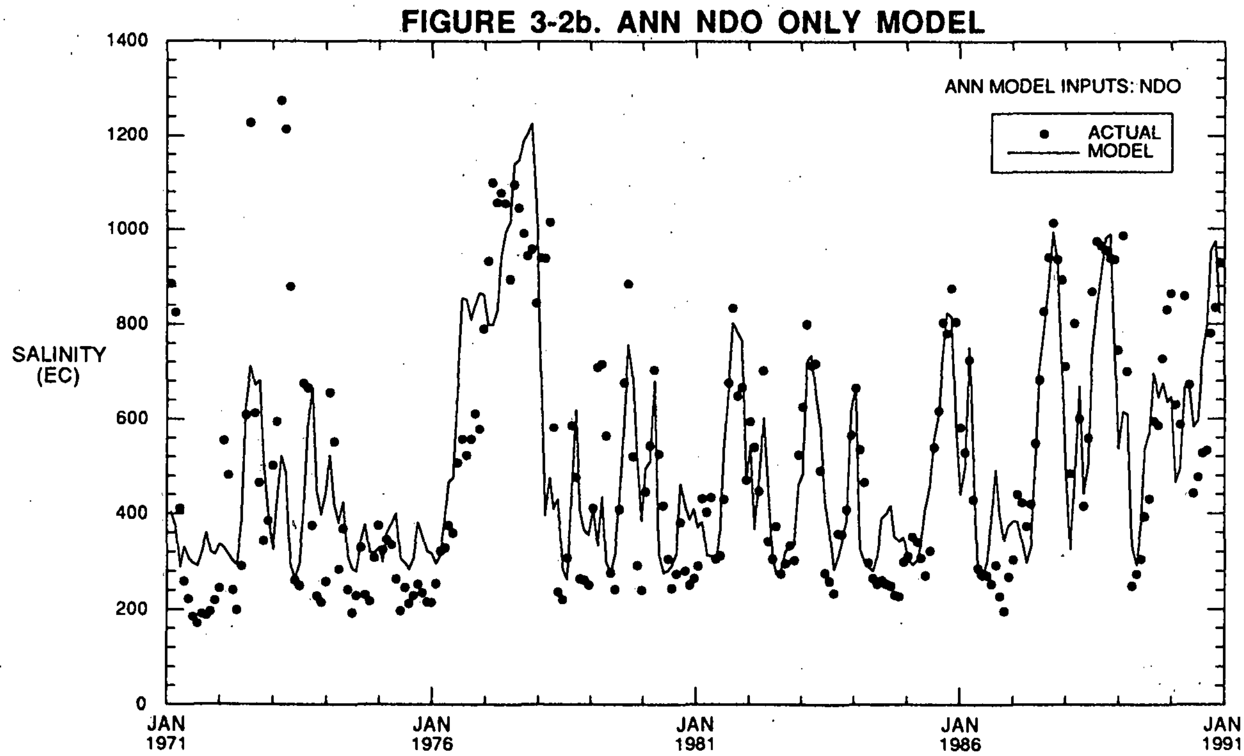


Figure 3-2

SAC PREDICTIONS FROM PITTSBURG SALINITY HISTORICAL DATA

FIGURE 3-3a. ANN MULTIPLE INPUT MODEL

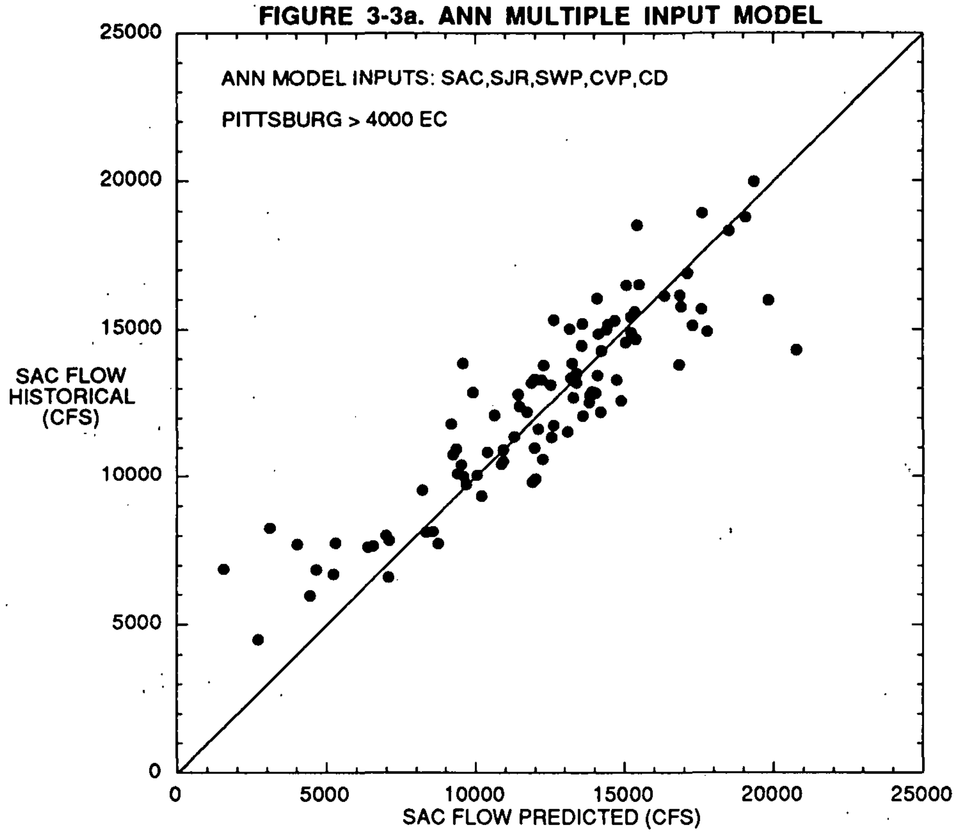


FIGURE 3-3b. ANN NDO ONLY MODEL

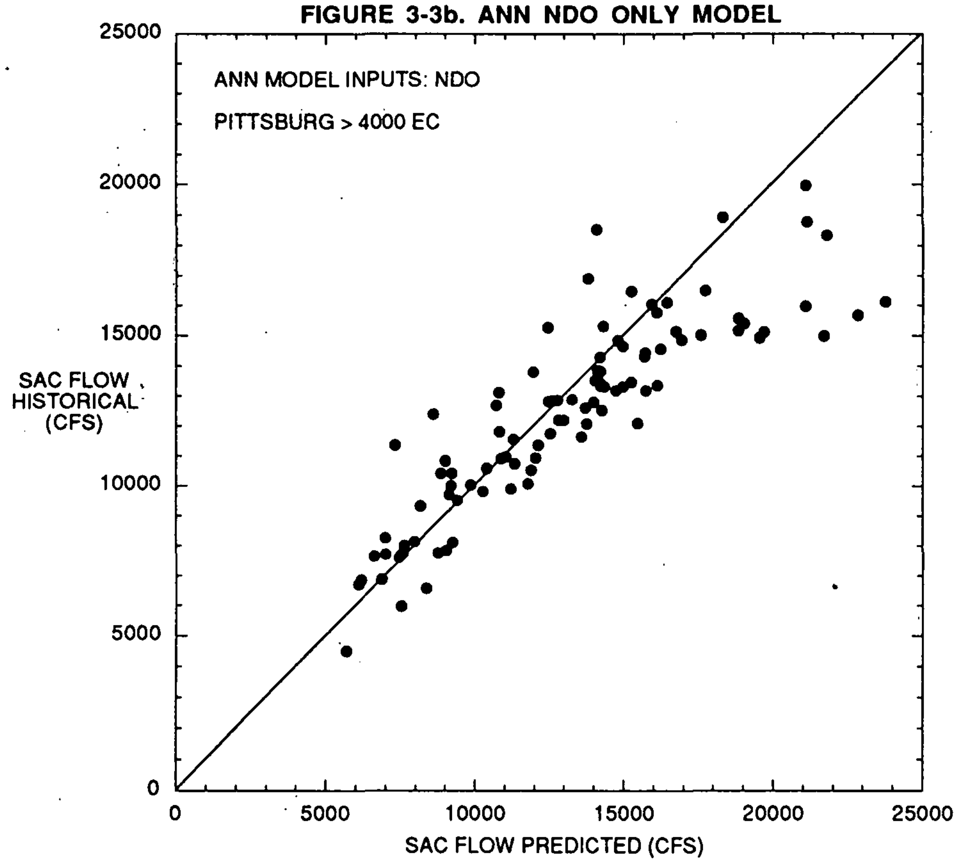


Figure 3-3

SAC PREDICTIONS FROM CONTRA COSTA CANAL SALINITY HISTORICAL DATA

FIGURE 3-4a. ANN MULTIPLE INPUT MODEL

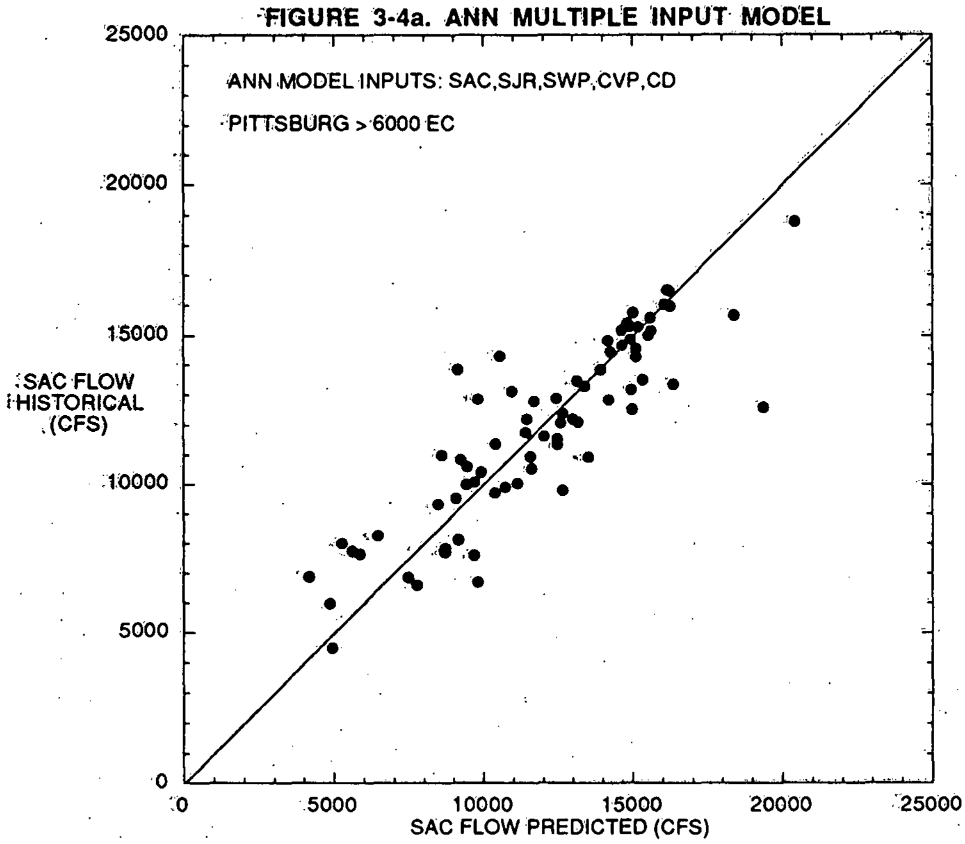


FIGURE 3-4b. ANN NDO ONLY MODEL

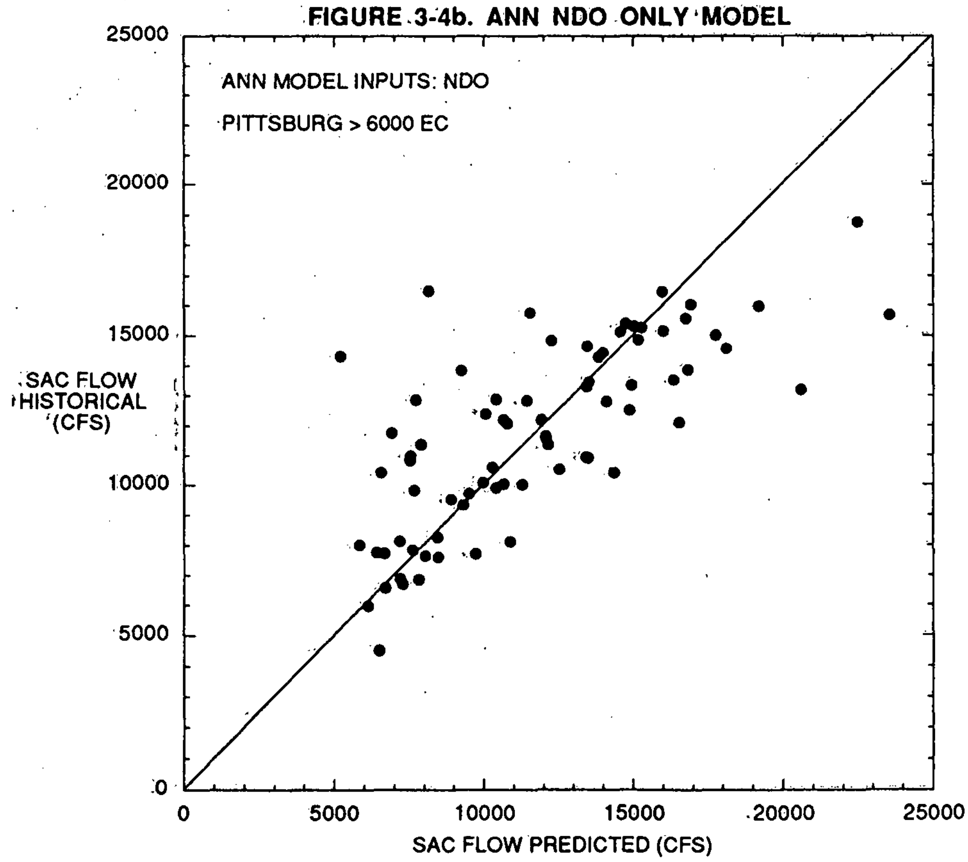


Figure 3-4

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT PITTSBURG

HISTORICAL DATA - ANN MULTIPLE INPUT MODEL

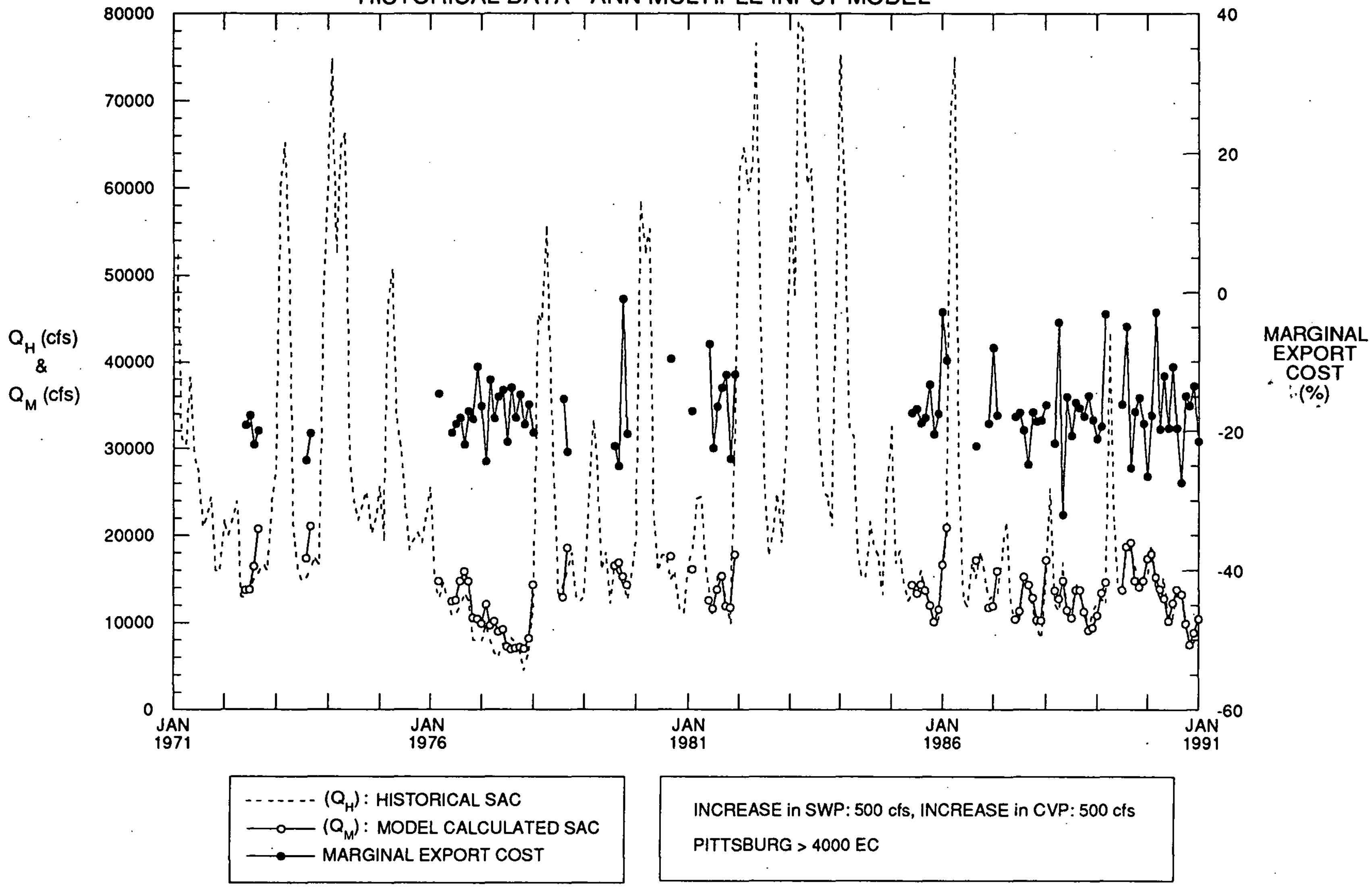


Figure 3-5

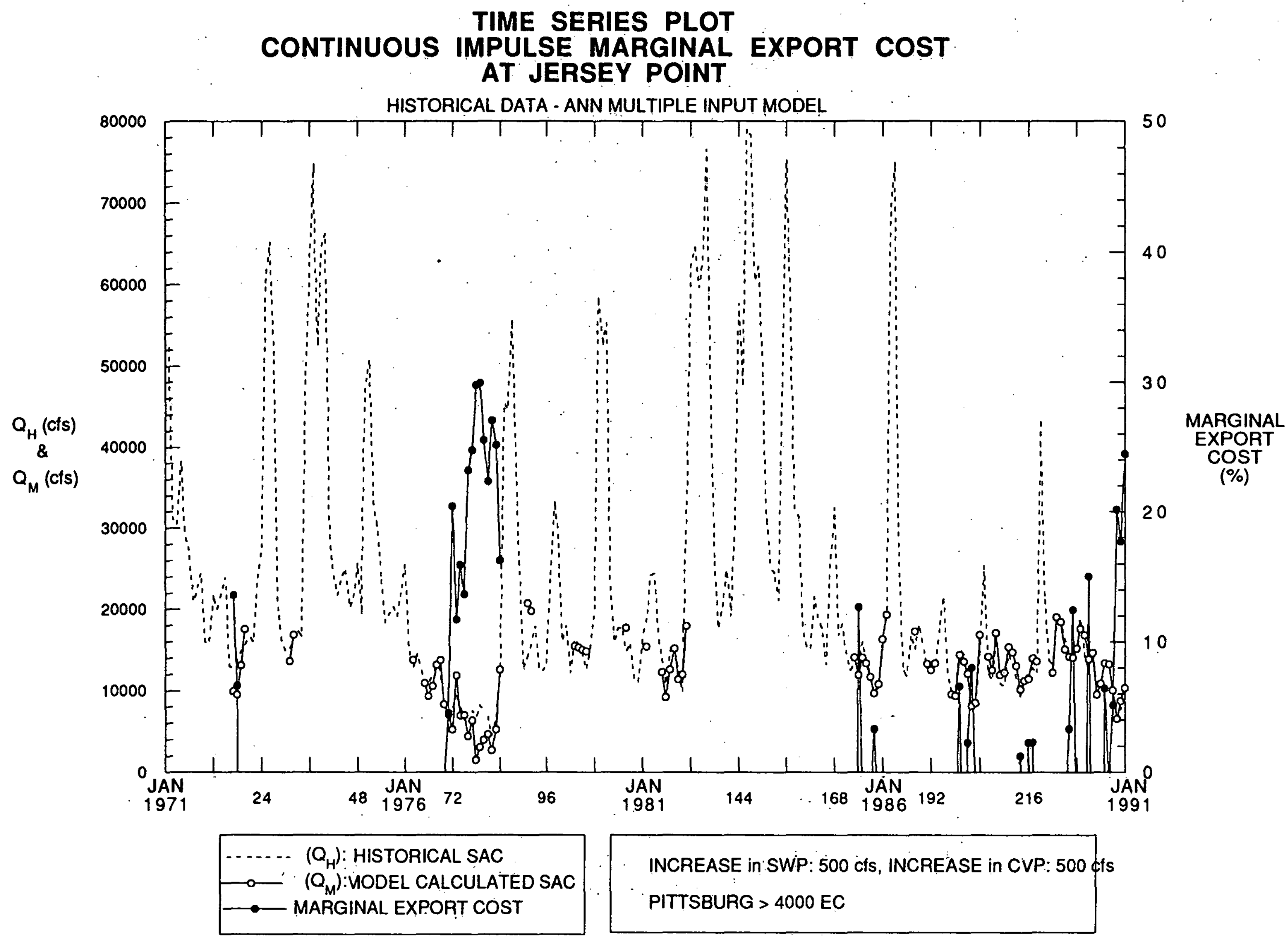

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT JERSEY POINT
HISTORICAL DATA - ANN MULTIPLE INPUT MODEL
Q_H (cfs) & Q_M (cfs)
MARGINAL EXPORT COST (%)
JAN 1971
24
48
JAN 1976
72
96
JAN 1981
144
168
JAN 1986
192
216
JAN 1991
(Q_H): HISTORICAL SAC
(Q_M): MODEL CALCULATED SAC
MARGINAL EXPORT COST
INCREASE in SWP: 500 cfs, INCREASE in CVP: 500 cfs
PITTSBURG > 4000 EC

Figure 3-6

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT CONTRA COSTA CANAL

HISTORICAL DATA - ANN MULTIPLE INPUT MODEL

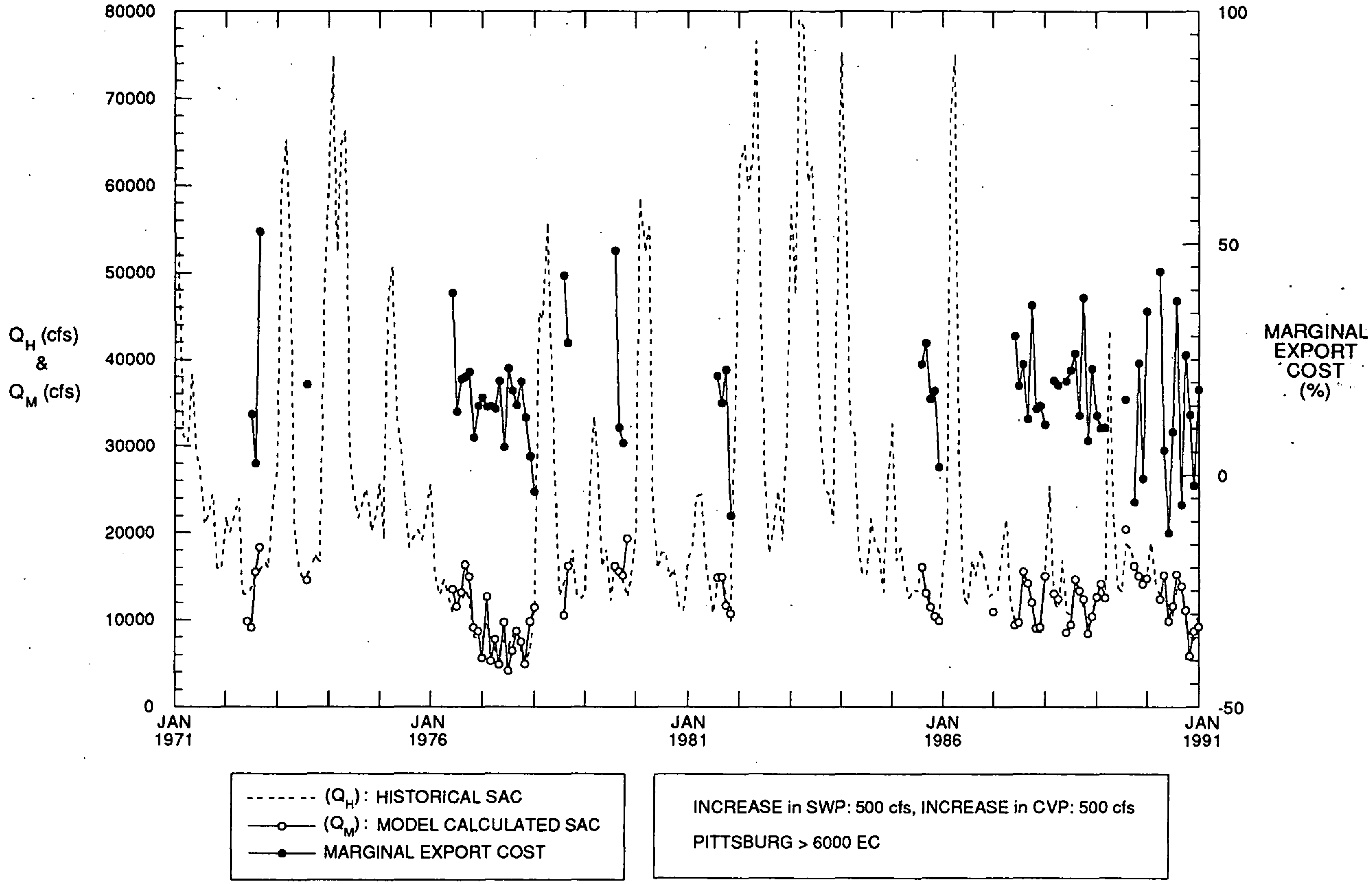


Figure 3-7

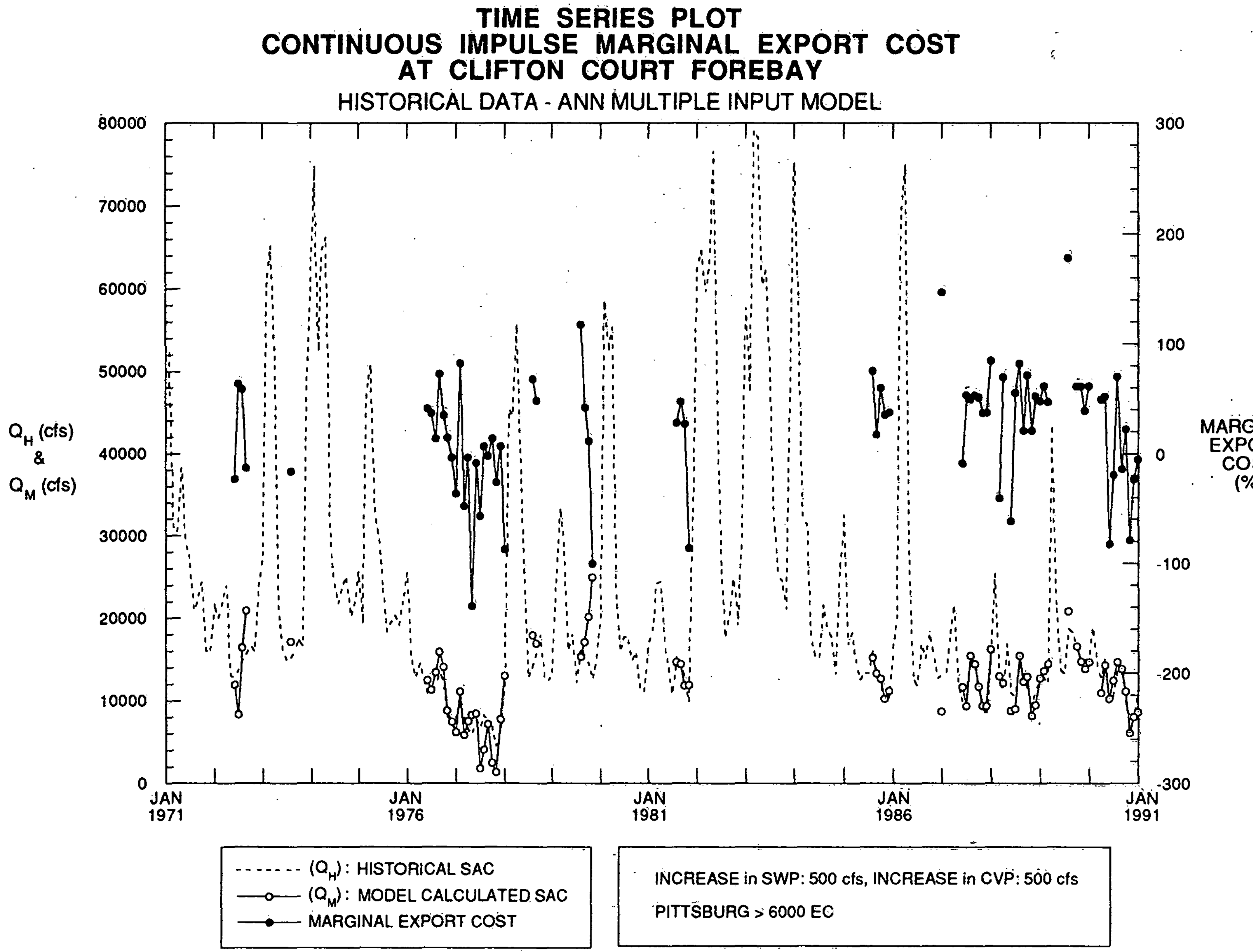
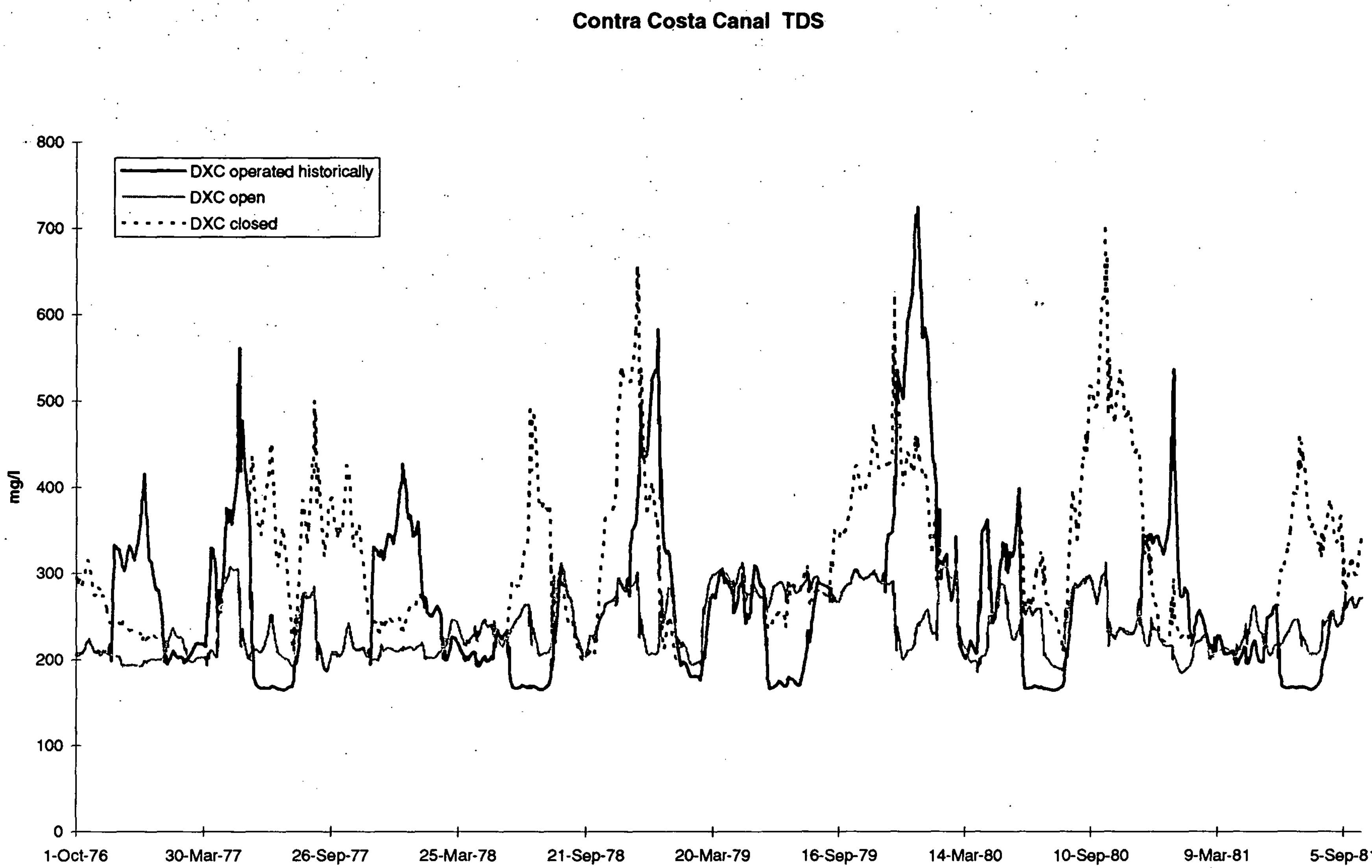
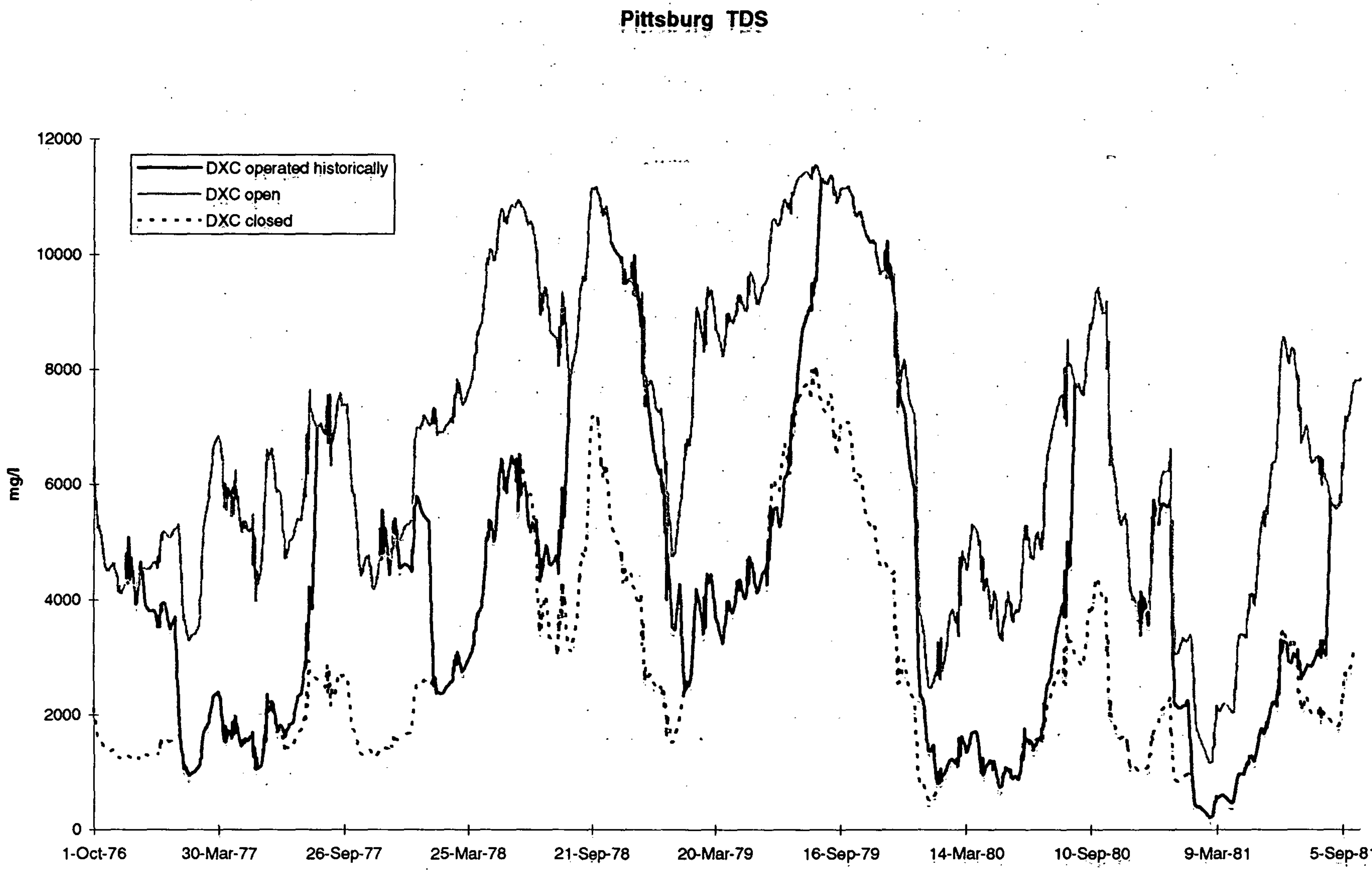

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT CLIFTON COURT FOREBAY
HISTORICAL DATA - ANN MULTIPLE INPUT MODEL
80000
70000
60000
50000
40000
30000
20000
10000
0
Q_H (cfs) & Q_M (cfs)
300
200
100
0
-100
-200
-300
MARGINAL EXPORT COST (%)
JAN 1971
JAN 1976
JAN 1981
JAN 1986
JAN 1991
(Q_H): HISTORICAL SAC
(Q_M): MODEL CALCULATED SAC
MARGINAL EXPORT COST
INCREASE in SWP: 500 cfs, INCREASE in CVP: 500 cfs
PITTSBURG > 6000 EC

Figure 3-8



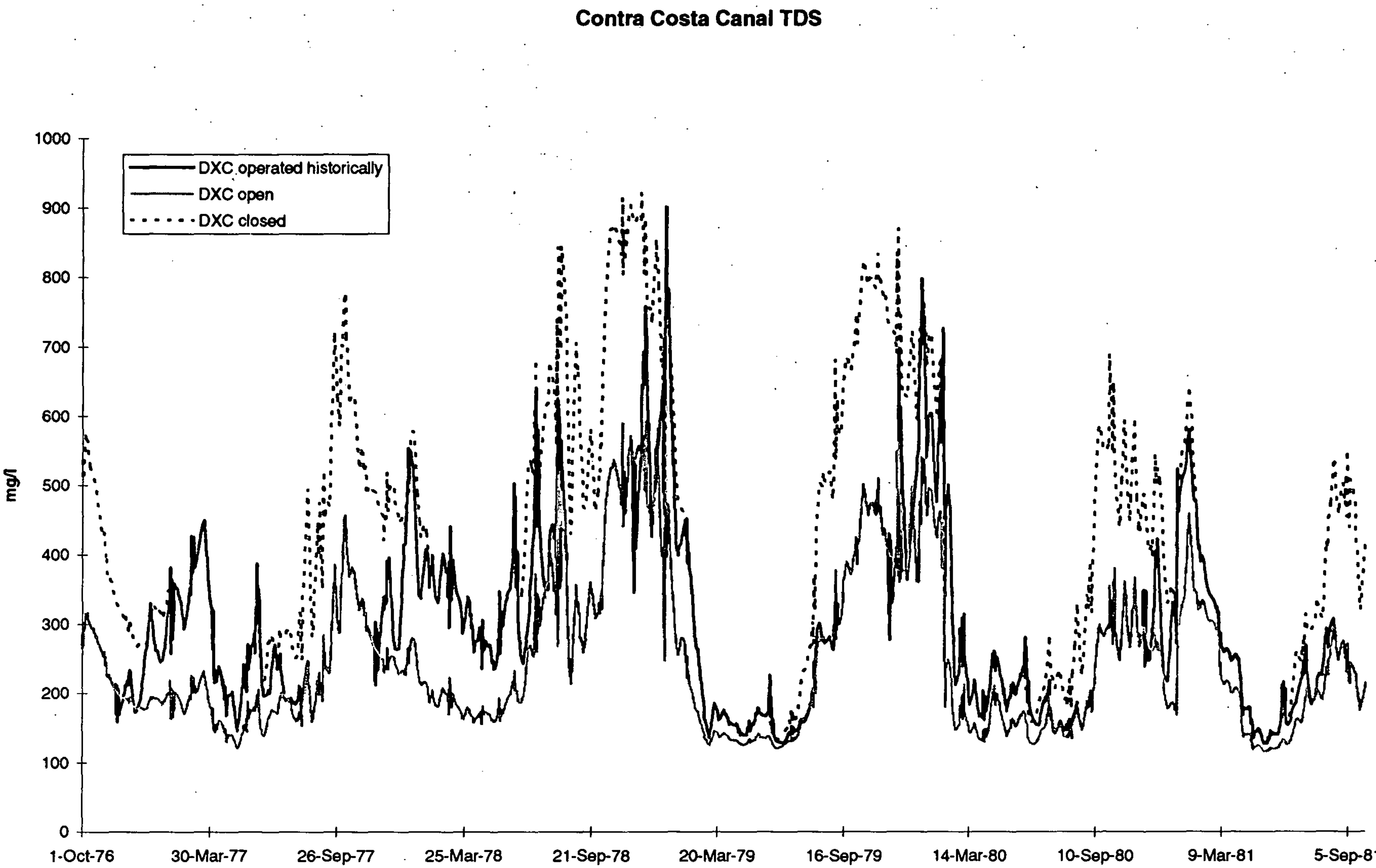
TDS at Contra Costa Canal (ANN trained with historic DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-9



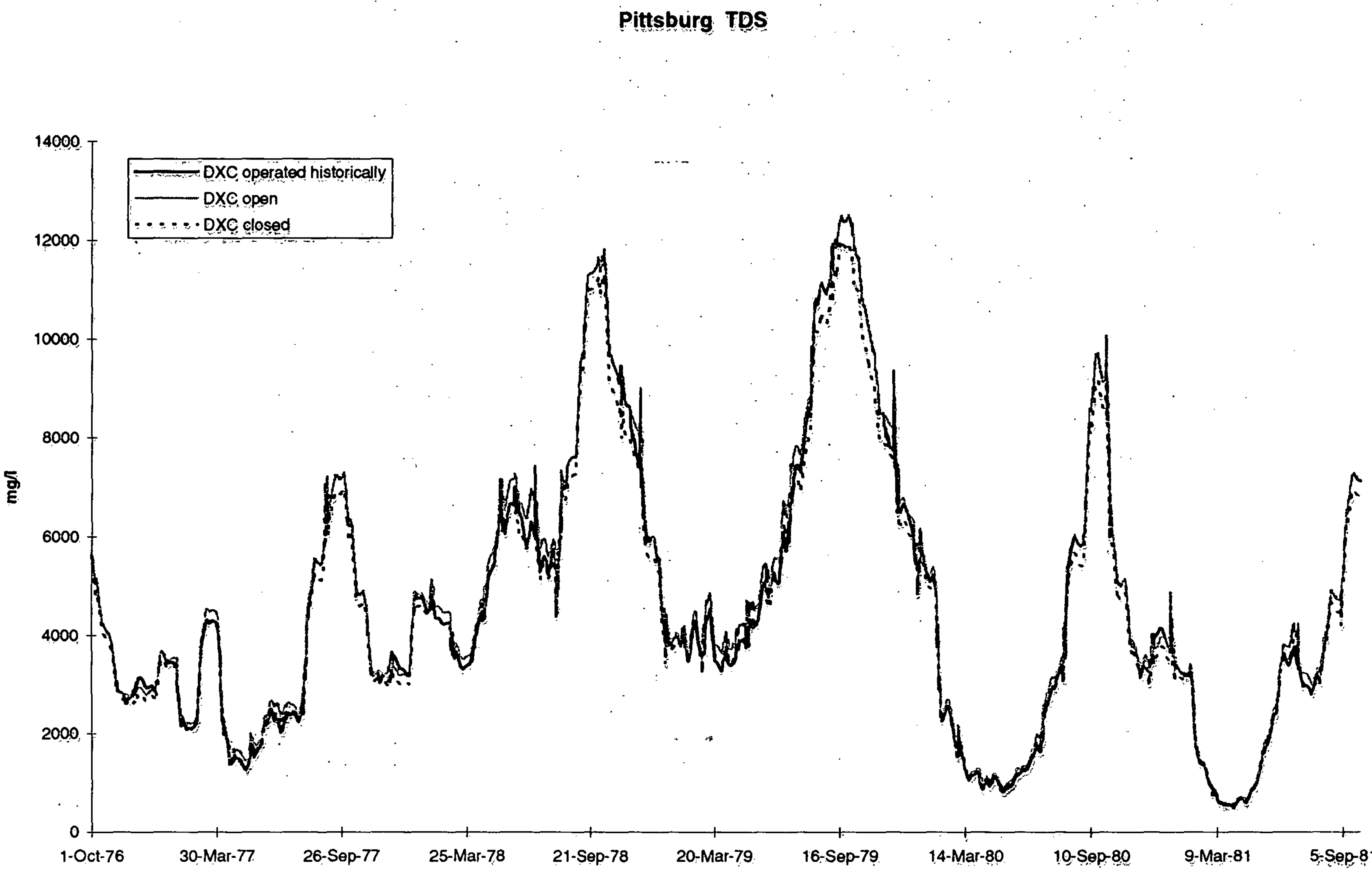
TDS at Pittsburg (ANN trained with historic DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-10



TDS at Contra Costa Canal (ANN trained with historic and inverted DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-11



TDS at Pittsburg (ANN trained with historic and inverted DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-12

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