IMPACT OF SAN JOAQUIN RIVER QUALITY ON CROP YIELDS IN THE SOUTH DELTA

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INTRODUCTION

The agricultural productivity of lands within the South Delta Water Agency is dependent upon both the quantity of water that enters the Delta at Vernalis and its quality. It is also determined in part by the nature of soils, i.e. their permeabilities and leaching requirements to avoid excessive accumulation of salinity during the growing season. In general, fine textured soils such as those that comprise the major part of South Delta lands have lower permeabilities, and thus require higher quality of applied water to assure optimal crop growth without loss of yield.

To demonstrate the nature and dependence of agricultural productivity in the South Delta on San Joaquin River quality, it is necessary to consider the following factors:

1. Soil characteristics, i.e. permeabilities and field leaching fractions, and variability of these over the lands of the South Delta,

2. Crop yields in relation to water quality, soil characteristics, and crop type,

3. Quality of water available in South Delta channels during the growing season, and

4. Cropping pattern and crop value for the South Delta.

SDWA EXHIBIT NO. 114

Combining these factors in a quantitative framework results in estimates of the sensitivity of the South Delta area to water quality at Vernalis.

SOIL CHARACTERISTICS

Soils of the South Delta, identified in the most recent soil survey of the area, have been organized into five groups according to field permeabilities. These are depicted on the general soil map for the South Delta area (SDWA Exhibit 106), and for a smaller representative area in the vicinity of Old River between the San Joaquin River and Salmon Slough (SDWA Exhibit 107). Characteristics of these soil groups, which are considered indicative of *between-field* variability in the South Delta, are given in Table 1.

Table 1. Soil Groups in the South Delta

Group	Map Color Code	Percent of area	Permeability description in/hr
A	brown	40	slow < 0.2
B	blue	34	mod. slow 0.2 - 0.6
C	yellow	17	moderate 0.6 - 2
D	green	6	mod. rapid 2 - 6
E	red	3	rapid > 6

Leaching characteristics of South Delta soils were derived from the 1976 South Delta Salinity Status Study (SDWA Exhibit 104), using observed EC_es and applied water EC_ws for 51 sites at 10 different locations. Leaching fractions (LF) were calculated for both spring and fall EC_e profiles at all sites (102 determinations) according to the relation

$$LF = \frac{EC_w}{2(EC_e)_d} \quad (1)$$

where

EC_w = electrical conductivity of applied water, mmhos/cm (dS/m)

$(EC_e)_d$ = electrical conductivity of soil solution extract at drainage horizon (assumed to be the maximum in the EC_e profiles) mmhos/cm (dS/m)

Mean leaching fractions ($\overline{LF}$) and standard deviations from the mean (σ) were determined for each location (up to 15 observations in some cases). It was found that σ ranged widely, from about 25 to 65 percent of $\overline{LF}$. An average of about one-third, i.e. $\sigma = \overline{LF}/3$, was adopted as representative of *in-field* variation in leaching during the growing season.

Soil permeabilities and leaching fractions were related to one another by identifying specific locations (Salinity Study, SDWA Exhibit 104) with permeability groups (Soil Permeability Map, SDWA Exhibit 106). Calculated LFs were plotted against permeabilities as shown in Figure 1. While some scatter is apparent, owing largely to in-field variation, there appears to be a fairly consistent relationship between permeability and leaching fraction.

In subsequent calculations, values of $\overline{LF}$ and standard deviations of the distributions shown in Figure 1 are identified with the various soils as they are actually classified for the South Delta (SDWA Exhibit 106). These values for the moderate to slow permeability soils are:

Group	$\overline{LF}$	σ
A	0.053	0.0177
B	0.093	0.0310
C	0.188	0.0627

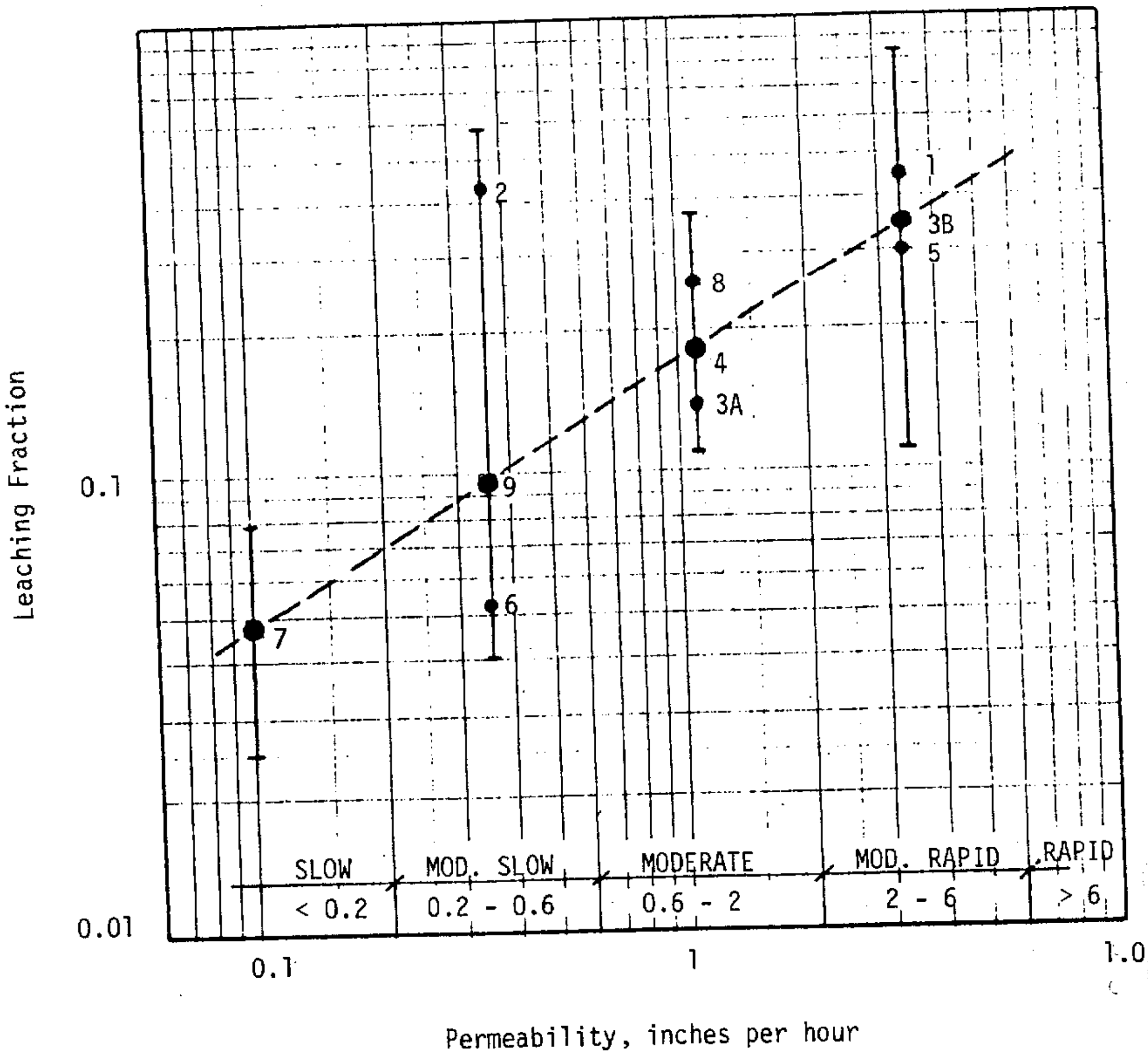

Figure 1. RELATIONSHIP BETWEEN LEACHING FRACTION AND FIELD PERMEABILITY, SOUTH DELTA SOILS

CROP YIELD VS WATER QUALITY

The relationship between yield decrement, leaching fraction, and applied water quality is given by

$$\Delta Y = S(EC_w \{ \frac{1 + LF}{5LF} \} - B) \qquad (2)$$

where

ΔY = yield decrement, percent

S = unit decrement, percent/mmho/cm

B = threshold EC_e, mmhos/cm

and other terms are as previously defined. Values of S and B for various crops are found in FAO Irrigation and Drainage Paper 29 as revised (SDWA Exhibit 105) and were supplemented by the Water Quality Advisory Panel for the South Delta Salinity Status Study (SDWA Exhibit 103).

The yield decrement for a field with variable LF is determined by combining equation (2) with the probability density function for LF and integrating from 0 to LF_c, a fraction above which no decrement in yield occurs.

$$\Delta Y = \int_{o}^{LF_c} S \, [\, EC_w \, \{\frac{1 + LF}{5 \, LF}\} - B \,] \, \frac{\exp}{\sigma \sqrt{2\Pi}} \left(- \frac{1}{2} \, \frac{(LF-\overline{LF})^2}{\sigma^2} \right) dLF \qquad (3)$$

where all terms are as previously defined.

A yield decrement--quality relationship for a particular soil, e.g. Group A, is obtained by carrying out the integration of equation (3) over the range of EC_w that is of interest. In the case of the South Delta, this was 0.7 to 1.3 mmhos/cm, corresponding to a range of TDS of roughly 450 to 825 mg/L. The properties of the soil are given by $\overline{LF}$ and σ and the susceptibility of the crop by S and B. Representative yield decrement--quality relationships used in this study are summarized for the six most sensitive crops and the three soil groups in Table 2.

Table 2. Yield Decrement at Function of
Water Quality, Soil Type, and Crop

EC_w, dS/m	Yield Decrement, Δy, percent Beans	Corn	Alfalfa	Tomatoes	Fruit & Nuts	Grapes
	Soil Group A, $\overline{LF}$ = 0.053, σ = 0.0177					
0.4	19	4	-	-	10	3
0.7	42	18	9	8	34	16
1.0	68	34	19	21	61	29
	Soil Group B, $\overline{LF}$ = 0.093, σ = 0.0310					
0.4	6	-	-	-	2	-
0.7	18	4	2	2	10	4
1.0	33	12	6	4	24	12
	Soil Group C, $\overline{LF}$ = 0.188, σ = 0.0627					
0.4	-	-	-	-	-	-
0.7	3	1	-	-	2	-
1.0	9	2	1	1	4	2

REVENUE LOSS DUE TO QUALITY DEGRADATION

The dollar value of potential crop losses for a given water quality and soil is estimated from the known acreage of specific crops, the market value per acre, and the decrement calculated by equation (3), and is given by

$$C_T = \frac{1}{100} \sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij}\, c_{ij}\, \Delta Y_{ij} \qquad (4)$$

where

C_T = total potential loss, \$

A = area, acres

c = value of crop, \$/acre

ΔY = yield decrement, percent

i = crop, 1 to n

j = soil group, 1 to m

A representative cropping pattern for the South Delta Water Agency, i.e. values of A_{ij}, is derived from a survey of the San Joaquin County Agricultural Department for the period 1971-1975. Typical unit values of crops, i.e. values of C_{ij}, were derived from the 1980 San Joaquin Agricultural Report. These data are summarized in Table 3.

Table 3. Cropping Pattern for the South Delta Water Agency

Crop	Percent of total area	Area acres	Crop Value $/acre[1]
Beans	8	9,840	656
Corn	9	11,070	563
Alfalfa	26	31,980	732
Tomatoes	14	17,220	2110
Fruit and Nuts	5	6,150	2154[2]
Grapes	0.8	1,000	1358
Grains	16	19,680	426
Asparagus	7	8,610	1434
Sugar beets	10	12,300	1235
Other	4.2	5,150	-
Total	100	123,000	

Source: San Joaquin County Agricultural Department survey data within the SDWA for the 1971-75 period

[1]1980 values

[2]average of peaches and walnuts

CASE STUDY EXAMPLE

To illustrate the application of the procedure for estimation of potential crop losses due to water quality degradation, two scenarios are considered.

1. Actual conditions of water quality prevailing in the South Delta during 1976, and

2. 1976 conditions modified by the assumption of New Melones Project operation to maintain 500 mg/L TDS at Vernalis.

The procedure entails the following steps:

a. Simulation of hydrodynamics and water quality for the South Delta for the agricultural season, using the mathematical models of the estuarial system (SDWA Exhibit 82),

b. Estimation of the average quality of water supplied to each of 10 subareas of the South Delta, as identified in Figure 2,

c. Calculation of the yield decrement ΔY expected for each soil type (3), crop (6), and subarea(10) by application of Equation 3.

d. Summation of incremental costs due to loss of yield, by application of Equation 4,

e. Comparison of cost differences attributed to water quality control by New Melones.

Results of water quality simulations are presented in Figures 3 and 4. Conditions shown are for mid-July, considered to be representative of the quality of water available at the peak of the irrigation season. From the results of the two simulations, the average quality of water available to the 10 subareas may be estimated as that of the most accessible channel serving the area. These are summarized in Table 4.

Yield decrements were estimated from the relationships summarized in Table 2. These were then weighted by subarea and soil group in relation to the entire SDWA area, and summed to obtain the aggregate decrement for each crop type. These were then applied to the total value of the crop to obtain the decrement in revenue. Table 5 summarizes the calculations.

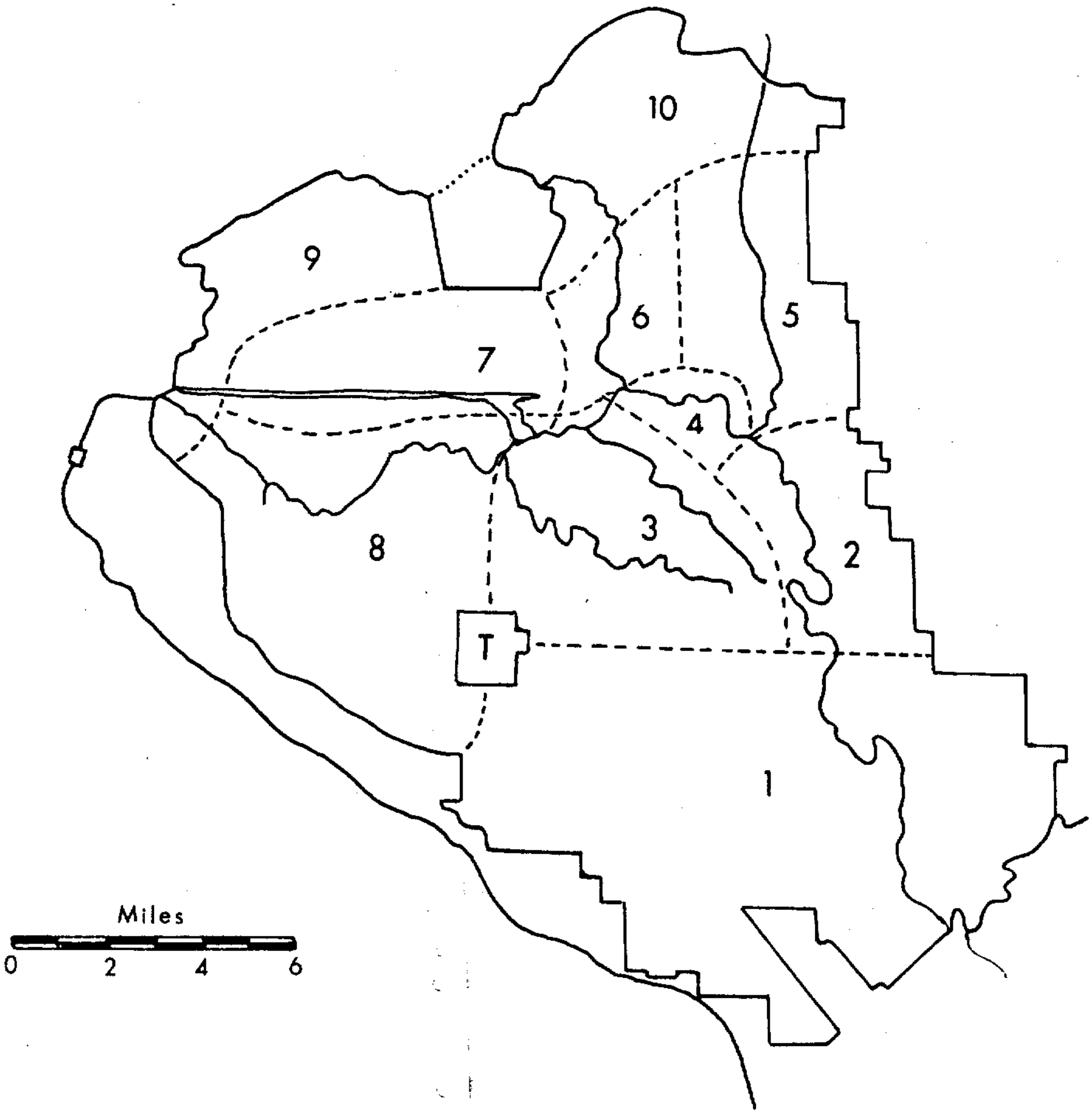

Figure 2. AGRICULTURAL SUBAREAS, SOUTH DELTA WATER AGENCY

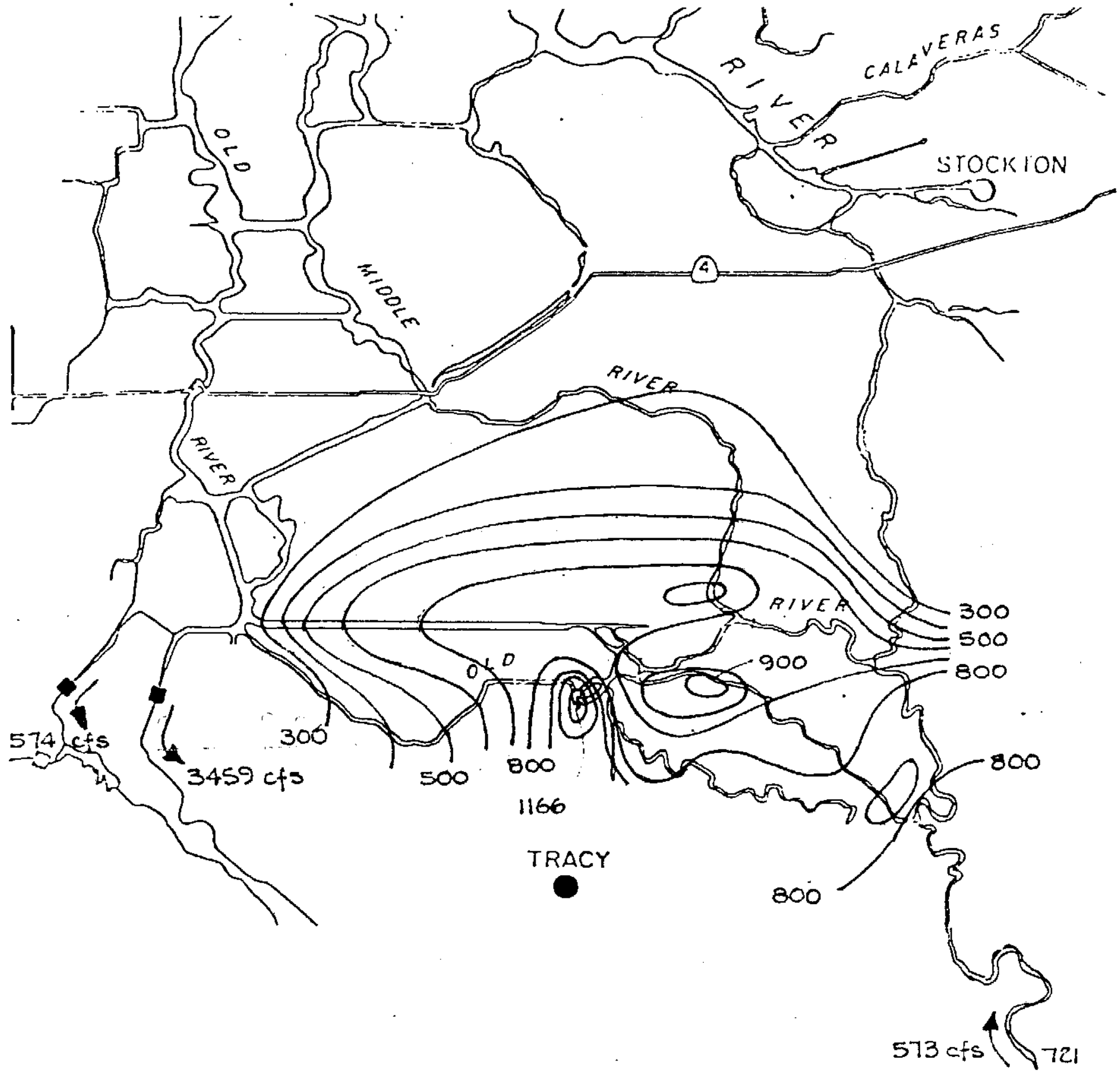

Figure 3. SIMULATED WATER QUALITY IN SOUTH DELTA CHANNELS, MID-JULY 1976, ACTUAL HYDROLOGY
(Contours are of equal TDS, mg/L)

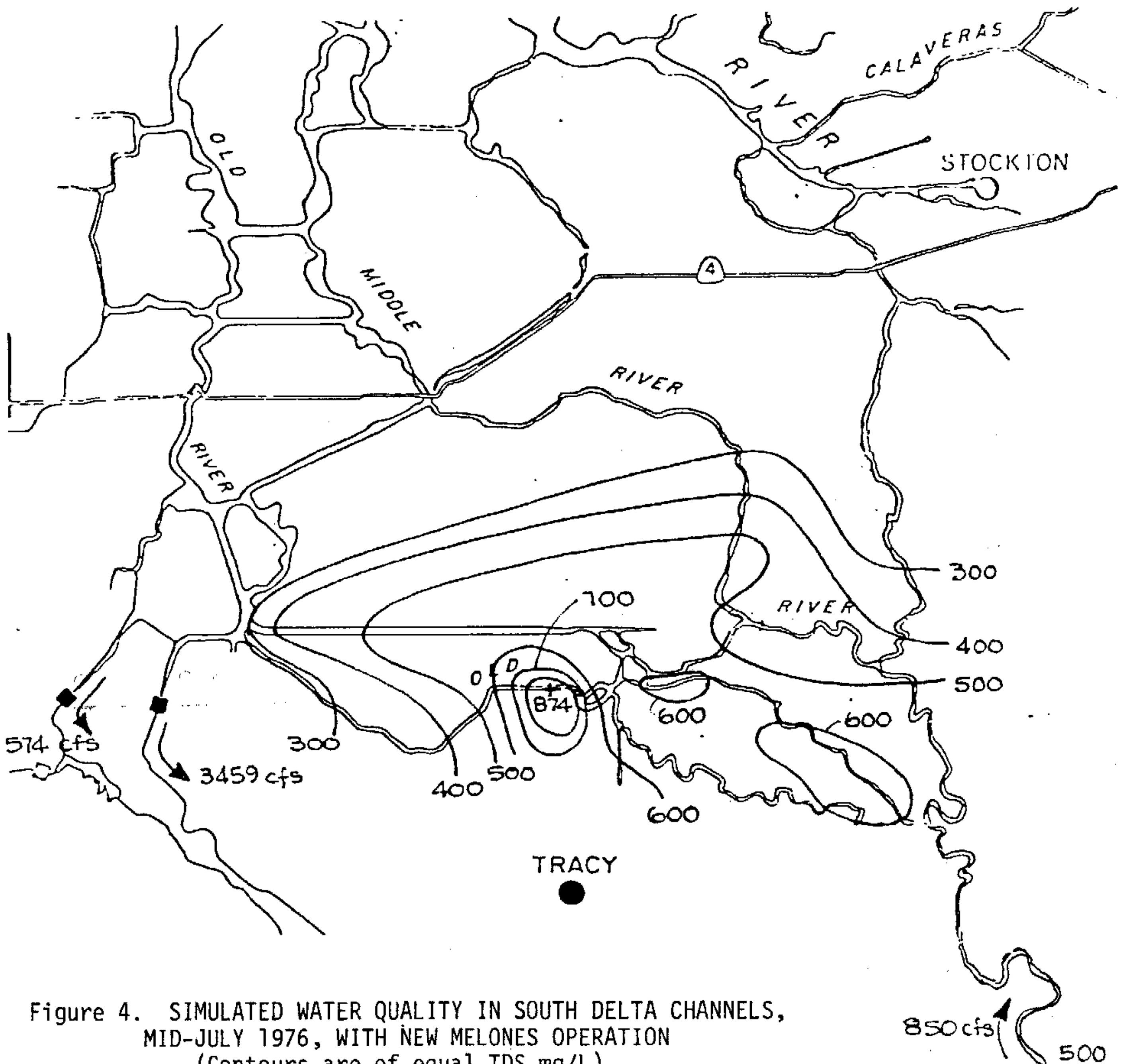

Figure 4. SIMULATED WATER QUALITY IN SOUTH DELTA CHANNELS, MID-JULY 1976, WITH NEW MELONES OPERATION
(Contours are of equal TDS mg/L)

Table 4. Comparison of Crop Loss for 1976 Conditions in South Delta With and Without New Melones Water Quality, Mid-July (Day 195)

Subarea	1976		1976 w/N.M.	
	TDS	EC*	TDS	EC*
1	753	1.19	496	0.77
2	812	1.28	492	0.76
3	777	1.22	559	0.87
4	675	1.06	487	0.77
5	244	0.36	264	0.40
6	684	1.07	486	0.75
7	710	1.12	521	0.81
8	673	1.06	575	0.90
9	227	0.34	226	0.34
10	297	0.45	282	0.43

* EC = (TDS - 18)/620, mmhos/cm

DISCUSSION

Results of this case study illustrate the potential impacts of water quality degradation on the agricultural productivity of lands within the South Delta Water Agency. These impacts are likely to be most severe in areas served by channels in which circulation is not sufficient for uni-directional transport of salt loads entering the Delta at Vernalis. Such was the case in 1976, the case investigated. It is noted that while the area is estimated to have suffered a substantial loss of productivity in this period--as much as 18 percent of the value of salt sensitive crops--this loss could be diminished by improving quality and flow at the upstream boundary at Vernalis. The apparent loss with New Melones operation, i.e. with a maximum TDS of 500 mg/L maintained by releases from the reservoir, would have been reduced by about one half, to roughly 10 percent of the total value of salt sensitive crops.

Table 5. Estimated Loss of Crop Revenue Due to Water Quality Degradation, Case Study: 1976 and 1976 With New Melones Operation

Crop	Area[1]	Unit Value[2]	Mkt. Value	Loss of Crop Revenue, 10^6 \$ — Actual 1976: $\Delta Y/100$	Actual 1976: ΔC	1976 w/N.Melones: $\Delta Y/100$	1976 w/N.Melones: ΔC
	acres	\$/acre	10^6 \$		\$		\$
Beans	9,840	656	6.46	0.406	2.62	0.331	2.14
Corn	11,070	563	6.23	0.201	1.25	0.105	0.65
Alfalfa	31,980	732	23.41	0.102	2.81	0.051	1.19
Tomatoes	17,220	2110	36.33	0.111	4.03	0.052	1.89
Fruit & Nuts	6,150	2154	13.25	0.359	4.76	0.199	2.64
Grapes	1,000	1358	1.36	0.169	0.23	0.093	0.13
TOTALS	72,260[3]		87.04		15.70		8.64

1 1971-75 average

2 1980 San Joaquin County Agriculture Department

3 Does not include 50,740 acres of salt tolerant crops

It should be noted, however, that the presumption that the target quality could be assured by New Melones releases is conditioned by the availability of water in storage for quality control. In some years, the entire volume allocated for this purpose may be released before the critical period of crop growth, as early as mid-April in the case of 1987. With the expectation of increased yield of salinity from the San Joaquin Basin, it will be increasingly difficult to achieve quality control at Vernalis, and in the South Delta, under the present mode of operation and with the current limitations imposed on storage for water quality control.

Another important factor which is illuminated by this example is the increased sensitivity of crops to damage when they are grown in soils of only moderate permeability, less than necessary to achieve optimum leaching during irrigation. A high proportion of South Delta soils are of this type; more than a third are classified as having "slow" permeabilities, less than 0.2 inches per hour. These soils have inherently poor leaching characteristics, with leaching fractions averaging 10 percent or less. Moreover, the wide variability in permeabilities in South Delta soils, over the entire area and even within the same field, exacerbates the leaching problem. Significant fractions of an irrigated area may be comparatively less permeable than the average, requiring higher quality water to avoid potential crop damage due to salinization in sensitive zones.

In summary, soils of the South Delta are found to be more sensitive than normal because of their lower average permeabilities and natural heterogeneity. Crops normally grown in the area are impacted adversely when water quality is not sufficient to preclude buildup of salinity in the soil profile during the irrigation season. Obvious solutions to this problem lie in enhanced water quality in South Delta channels and reductions in the salt load carried into the estuary by the San Joaquin River.