Salinity of Tile Drainage Effluent[1]

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Abstract. A four-year study of drainage effluent obtained from 15 tile drainage systems located in the arid San Joaquin Valley of California showed that the concentration of salts and the various ions discharged in the tile effluent decreased, logarithmically, from the time that the tile systems were installed. Regression equations and correlation coefficients are presented for total salts, boron, sodium, calcium plus magnesium, chloride and sulfate ions, versus time from 0 to 12 years of tile drainage system age. The relationships presented could change with more intensive drainage and more liberal use of irrigation water, providing a more rapid trend toward equilibrium.

INTRODUCTION

Under irrigated agriculture, the soil root zone represents the location where a significantly large portion of applied water is lost by evapotranspiration, leaving essentially all of the dissolved constituents, i.e. salts, behind. Tile drainage systems placed immediately beneath this zone provide a means of egress for the salts, which are leached from the soil profile and added to the groundwater. The prevention of degradation of water quality for downstream uses and downstream groundwater basins is best achieved by exporting brackish agricultural waters collected at the subsurface tile drainage outlets.

The Firebaugh area of the San Joaquin Valley has been rather extensively irrigated for about 35 years with San Joaquin River water delivered through large canals. Water imported into the area through the Delta-Mendota Canal of the Central Valley Project is now delivered as a substitute for the San Joaquin River water originally used [*California Water Plan,* 1957]. Upon importation of the new water, the irrigable area was substantially increased. The need for drainage in the Firebaugh area soon followed importation of the water, and the first tile drains were installed during 1951. Since 1951, tile installations have increased steadily.

Now the U. S. Bureau of Reclamation is constructing the San Luis Unit of the Central Valley Project and the State of California, Department of Water Resources, is constructing the California State Water Project. These projects will import more water and result in large increases in the irrigated areas on the west side of the San Joaquin Valley. The areas with expanded irrigation application and newly irrigated land will have similar climate, similar soils, and irrigation water similar to those of the Firebaugh area where the study reported in this paper was conducted.

As irrigation agriculture throughout the whole region becomes intensified, and as more water and salt are imported, over and above the water and salt naturally flowing into the basin, the need to achieve salt balance becomes important. Achieving salt balance requires the separation of degraded water with a minimum possible dilution and the deportation of that water to some point outside the basin. The salt balance of the basin, as contrasted with the salt balance of the root zone, tends to be something that can be put off to the future and there are many advocates of such a policy. However, the fact is that highly saline drainage water can now go only into downstream irrigation supplies,

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and these downstream supplies are becoming seriously degraded. This situation emphasizes the urgency of separation and a by-pass. The need for a master by-pass is well recognized and is being planned by the state as a joint endeavor with the Bureau of Reclamation.

The studies reported herein are part of a cooperative research project developed to make possible better design criteria for tile drainage and to provide a better evaluation of principles for agricultural waste water management.

CLIMATE AND SOILS

The region is essentially arid. Rainfall at Firebaugh averages 7.65 in/yr and occurs only during the winter months. Summer temperatures are generally high, with 100° to 110°F common. However, diurnal fluctuations are sufficient, and the nights are usually pleasant. The drained soils are relatively heavy textured, sedimentary rock alluvium, represented by the Panoche, Oxalis, and Lethent series [*Harradine*, 1950]. The area to be irrigated by the San Luis Unit of the Central Valley Project, now under construction, will be somewhat southeast and peripheral to the land now supplied with Sacramento River water through the Delta Mendota Canal of the Central Valley Project, but will also be largely within the area of the same Western Fresno County soil survey. Table 1 shows that the soils now irrigated and tile drained reasonably represent the major soil types found in the new land. The soils are classed as alluvial fan, basin rim, and basin soils. All are calcareous and before being irrigated contained slight to strong alkali accumulations. Average hydraulic conductivity rates in fields studied varied from 0.17 (Oxalis) to 0.91 (Panoche) ft/day [*Johnston et al.*, 1963].

METHODS AND PROCEDURES

Along with other information still being analyzed, water and salt balance data for 15 farms with tile drainage systems located in the Firebaugh area of the San Joaquin Valley were collected from 1959 to 1962 inclusive [*Pillsbury and Johnston*, 1965]. The tile-drained farms ranged from 36 to 170 acres in size. Tile spacings ranged from 200 to 1300 ft, and these rather minimal systems averaged only about 92.5 ft of tile/acre. Average tile depth was about 6 ft. Cotton, rice, alfalfa, and barley were the common crops grown but were not necessarily under any rotation system. In certain cases the same crop was grown on a field every year during the study.

Table 2 gives the average of irrigation water quality analyses for the period of study. The quality of applied water degrades as the irriga-

TABLE 1. Recent Alluvial Fan, Basin Rim, and Basin Soils As Listed in the Western Fresno County Soil Survey* and Acreage under Tile Drainage Systems Observed in the Firebaugh Area

Description of Soils	Approx. Total Acreage†	Acreage under Tile Systems Observed
Recent Alluvial Fan Soils		
Medium textured, deep permeable subsoils (A1)		
Panoche series	250,800	377
Sorrento and Panhill series	30,925	0
Fine textured, deep permeable subsoils (A3)		
Panoche series	209,300	580
Sandy soils, deep permeable subsoils (A5)		
Panoche series	1,900	0
Basin Rim Soils		
Fine textured, moderately dense subsoils (A4)		
Panoche series	5,750	0
Oxalis series	115,500	670
Fine textured, moderately dense subsoils (B4)		
Levis (29,500 ac) and Temple series	34,050	0
Basin Soils		
Medium textured, moderately dense subsoils (N2)		
Temple series	12,600	0
Medium to fine textured dense clay subsoils (B9, B10)		
Lethent series	46,700	280

* Omitted are all soils not in profile groups I, II, and III, and river flood plain soils, sandy, gravelly, and rocky soils with permeable subsoils, terrace soils, and upland soils, as these probably will not be drainage problem soils.

† Acreage as given in soil survey, which is bounded on the west by the 1000-ft contour. Initial area of the San Luis Project needing drainage may be bounded on the west by about the 250- to 260-ft contour.

TABLE 2. Average of Irrigation Water Analyses, Firebaugh Area, 1959–1962*

Cations (m.e./l)		Anions (m.e./l)		Total Salts† (m.e./l)
Ca + Mg	3.2	HCO_3	1.6	6.8
Na	3.4	SO_4	2.3	
		Cl	2.7	
(B = 0.4 ppm)				

* Irrigation water is designated as class AA 121 water using the system developed by the University of California, Agricultural Water Quality Conference.

† Computed from electrical conductivity.

tion season progresses, since considerable quantities of drainage effluent are discharged into the irrigation canals. Generally, the electrical conductivity (*EC*) increases from about 0.3 mmhos/cm at 25°C in May to 0.8 mmhos/cm at 25°C in August. The *EC* of the irrigation water is also relatively high in the spring when the canals are first filled. The sodium adsorption ratio (*SAR*), which affects the rate of water movement in the soil, increases as *EC* increases. The two increases tend to offset each other as to their effects on soil permeability. In general, the water quality is good [*University of California,* 1964].

The *EC* of the effluent from each tile system studied was determined weekly. Generally, effluent samples for complete analysis were obtained monthly except when changes in *EC* indicated a need for greater frequency. Standard methods of analysis were used [*American Public Health Association,* 1960].

The data were programmed for analysis on a digital computer using a number of different equations, and the best fit was obtained with the logarithmic equations reported. Field salinity data are always extremely variable, and high correlation coefficients cannot be expected.

RESULTS AND DISCUSSION

In correlating time with salt concentration (*EC*) of the drainage effluent, time periods of 0–2, 0–3, 0–6, and 0–12 years were used. Best correlation coefficients were for the 0–12 year period, and equations for that period are given in Table 3. Equations are also presented for several individual ions. The data for the individual ions were obtained from analyses of the effluent samples collected monthly, whereas the data for the *EC* curve were obtained from analyses of the effluent samples collected weekly. Since the shape of each curve was similar, the discussion will be limited to the *EC* curve directly related to total salts. Analyses were also made for bicarbonates, but no correlation of concentration with time was found. This lack of correlation is not surprising considering the low solubility of the ion, and the fact that the soils were calcareous.

The *EC* data and curve are also shown in Figure 1, which illustrates the variance that must be expected with such field collected data because there is so much variation in the salinity of the root zone and of the groundwater from field to field at time 0, and because the rate of reclamation is so variable from field to field. However, variations do decrease with time, and time, on the average, becomes the dominant factor affecting the quality of drainage effluent, although the crop and some of the other field variables are also important.

The average quantity of water applied to the land and discharged from the tile drainage systems for four different crops is shown in Table 4. Continuously flooded rice produces the highest average depth of leaching, but irrigation of cotton and barley seems to be more efficient (relative to water applied) in terms of water and salt removal. However, with barley receiving only one irrigation, not much total water or salt is removed. The situation in regard to alfalfa is interesting. The practical amount that can be applied during a summer is generally inadequate to provide leaching, and in some cases it may even be inadequate for the evapotranspirational needs of the crop. Irrigation during the balance of the year remains basically

TABLE 3. Regression Equations and Correlation Coefficients for Total Salts and Individual Ions

Electrical Conductivity or Ion and Units	Regression Equation* 0–12 years	Correlation Coefficient (r)
EC (mmhos/cm) at 25°C	$y = 11.74\ x^{-0.30}$	0.57
B (ppm)	$y = 34.65\ x^{-0.59}$	0.65
Na (ppm)	$y = 2289\ x^{-0.19}$	0.56
Ca + Mg (m.e./l)	$y = 49.04\ x^{-0.19}$	0.55
Cl (ppm)	$y = 1115\ x^{-0.39}$	0.54
SO_4 (ppm)	$y = 6014\ x^{-0.33}$	0.60

* x = time in years; y = concentrations in units shown.

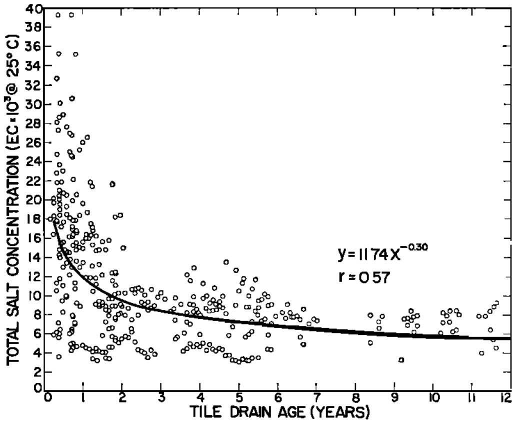

Fig. 1. Total salt concentration expressed as $EC \times 10^3$ @ 25°C versus tile drainage system age in years.

inadequate, so that alfalfa irrigation usually brings about no net salt reduction.

Curves with shapes similar to those shown in Figure 1 were also obtained in the Coachella Valley [*Reeve et al.*, 1955], although they were based on reduction of salinity in the soil profile in the absence of a water table. Since the data reported here refer to the dissolved constituents in the drainage water from land with a water table, other comparisons would not be valid. The depth of drainage water removed from the land has been averaging about 0.7 ft/yr. This amount of water is not sufficient to provide for a very rapid reclamation of the root zone soil, or to provide very rapid freshening of the groundwater around and below the tile. Eventually, an equilibrium condition will develop, assuming the continuation of the same irrigation, drainage, and cropping practices, but it is not unrealistic to assume that the same logarithmic decline in concentration will continue for possibly 50 years. Under ultimate equilibrium conditions, with a healthy intensive agriculture, the ratio of salt concentration in the drainage water to salt concentration in the irrigation water ($ECdw/ECiw$) should be expected to range in the neighborhood of 4–6, and would certainly not be higher than 8 or less than 2. This ratio is a matter of surmise that involves some crystal-ball gazing into the future and certainly cannot be extrapolated from the data presented. However, for about the next 10 years there should be enough new tile drainage systems coming into use every year so that no 'equilibrium' should be anticipated. Assuming that effluents with $EC < 3$ are not by-passed, the average effluent to be by-passed might well remain in the range of EC 5 to 7 for some time.

CONCLUSIONS

The concentration of total salts and the various ions discharged in the tile drainage effluent of the Firebaugh area has been decreasing somewhat logarithmically from the time that the tile systems were installed. This decrease indicates a gradual freshening of the shallow groundwater bodies, but the data cannot be extrapolated yet to indicate the quality of drainage effluent very far into the future.

With more intensive drainage systems and more liberal use of irrigation water, the relationships found would change, providing a more rapid trend toward an equilibrium condition. On the other hand, the result might well be a lower salinity equilibrium value, taking equally as long to reach.

TABLE 4. Average Annual Water and Salt Balance

	Average Annual Application			Average Annual Discharge through Drains			Salt
Crop	Average Number of Irrigations	Water (acre-ft/acre)	Salt (tons/acre)	Water (acre-ft/acre)	Salt (tons/acre)	Per Cent of Application*	Balance† (tons/acre)
Rice	Continuous	7.3	3.72	1.09	8.62	15	4.90
Cotton	4	2.9	2.10	0.50	4.64	17	2.54
Alfalfa	10	6.0	3.12	0.18	1.17	3	−1.95
Barley	1	1.0	0.82	0.18	1.32	18	0.50

* Ddw (depth of drainage water removed)/Diw (depth of irrigation water applied), expressed as a per cent.
† Salt balance is negative if more salt is added than is removed.

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