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DIVISION S-6—SOIL AND WATER MANAGEMENT AND CONSERVATION

Salt and Water Balance in Imperial Valley, California[1]

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ABSTRACT

Salt balance ($SB = V_{\mathrm{eff.w}} \cdot C_{\mathrm{eff.w}} - V_{\mathrm{inf.w}} \cdot C_{\mathrm{inf.w}}$) of the Imperial Valley (IV) has been determined annually since 1943 by the Imperial Irrigation District. Salinity trends in the valley are assessed from biweekly measurements of the volume, *V*, and concentration, *C*, of influent, inf.w, and effluent, eff.w, waters. In this paper we summarize the SB data, evaluate their significance, and suggest approaches for assessing salinity trends in the soils of the valley.

The SB data reflected the cropping and water use patterns in the valley. However, the data were insufficient to distinguish origin of water and salt in effluent waters or to provide information about changes in root zone salinity. In 1973 total evapotranspiration (ET) by crops in the valley was estimated to be 229 × 10^3 ha-m, equivalent to 70% of the water delivered to the farmers. Deductions as to Cl^- composition of influent and effluent during 1973 suggest that the Cl^- load in the effluent water was contributed as follows: 54.7% from ground water, 35.0% from root zone drainage water, and 10.3% from tail water (runoff).

A more definitive interpretation of the salt balance data would require more accurate evaluation of volume of tail and consumptive use waters and volume and concentration of root zone percolate. If this information cannot be obtained on a valley-wide basis, then an alternative approach is to establish a representative number of soil salinity monitoring plots through the valley and assess their root zone salinity periodically.

Additional Index Words: **influent water, effluent water, root zone salinity, ground water salinity, surface run-off.**

SALT BALANCE was defined by Scofield (12) as "the relation between the quantity of dissolved salts delivered to an irrigated area with the irrigation water and the quantity removed from the area by the drainage water". The relation was expressed as:

$$\text{salt output } (V_{\mathrm{eff.w}} \times C_{\mathrm{eff.w}}) - \text{salt input } (V_{\mathrm{inf.w}} \times C_{\mathrm{inf.w}}) = \text{salt balance (SB)}$$

where $V_{\mathrm{eff.w}}$ and $V_{\mathrm{inf.w}}$ are the volumes of effluent (drainage) and influent (irrigation) water, and $C_{\mathrm{eff.w}}$ and $C_{\mathrm{inf.w}}$ are the soluble salt concentration in effluent and influent water, respectively. Sometimes the salt balance is reported as the ratio of output to input salts, which is referred to as the salt balance index (13). Scofield (12) acknowledged the limitations of the SB concept, since the drainage output "may be in error by the amount of quantities (of salt) absorbed (by the plant), precipitated, or decomposed". Similarly, "outflowing drainage water may represent largely water displaced from the subsoil reservoir, and under these conditions there may long continue for the area as a whole a favorable salt balance, and yet with inadequate root zone leaching there may be progressive and harmful accumulation of salts in the root zone". In spite of these limitations salt balance calculations are frequently advocated for indicating the trends in salinity in irrigated projects (1, 13). Since 1943, the Imperial Irrigation District (IID) has published annual SB reports following the procedures suggested by Scofield (11, 12). From 1953 through 1958, the SB reports included only the total salts. Since 1959, the anion and cation content of the irrigation and drainage waters have also been included.

This paper summarizes and evaluates the SB reports of the Imperial Valley District in the light of present knowledge of the soil properties of the valley, soil salinity, and existing water management practices.

PHYSIOGRAPHY, SOIL PROPERTIES, AND IRRIGATION AND DRAINAGE SYSTEMS OF IMPERIAL VALLEY

The Imperial Valley is in extreme southern California and occupies most of the northern arm of the Colorado River Delta. It extends for about 64 km (40 miles) along the USA-Mexico International boundary on the south, where the elevation is about sea level, to the southern end of the Salton Sea on the north where the elevation is about 70 m (230 feet) below sea level. The valley is roughly bowl-shaped, with a fall ranging from 0.19–0.75% toward the center and in the direction of the Salton Sea. Irrigation was begun in the valley in 1901 by importing Colorado River water; before that the valley was a desert. The irrigated area in the valley comprises about 178,000 ha (440,000 acres), and is from 25 to 48 km (16–30 miles) wide in the east-west direction (Fig. 1).

The soils of the valley have been deposited under lacustrine, semilacustrine, and deltaic conditions within the valley and alluvial fan formations at the outer margins of the valley. They are highly stratified Entisols, and are divided into eight soil series according to the texture of the main soil section (25–100 cm depth). Soils having control sections of (i) clay and silty clay—Imperial soil series; (ii) silty clay loams, clay loams and sandy clay loams—Glenbar series; (iii) silt loams, loams, and very fine sandy loams—Indio series; (iv) fine sandy loams and loamy fine sands—Antho series; and (v) fine sands—Rositas series. Three soil series contains two major strata of contrasting textures. Soils with fine textures such as silty clay overlying loamy textures, such as sandy and silt loam fall into the Holtville series. Soils with an inverse stratification of coarse loamy over fine textures belong to the Meloland series. Local overwash of sand or gravelly sand underlain by clay textures is called the Niland series. The Imperial series belong to the Typic Torrifluvent Subgroup, the Rositas series belong to the Typic Torripsamment Subgroup, and the rest of the series belong to the Typic Torrifluvent Subgroup. The acreage percentages of the various series in the irrigated land of Imperial Valley are estimated as 44, Imperial; 15, Glenbar; 15, Holtville; 8, Meloland; 8, Antho; 6, Indio; 2, Niland; and 2, Rositas.

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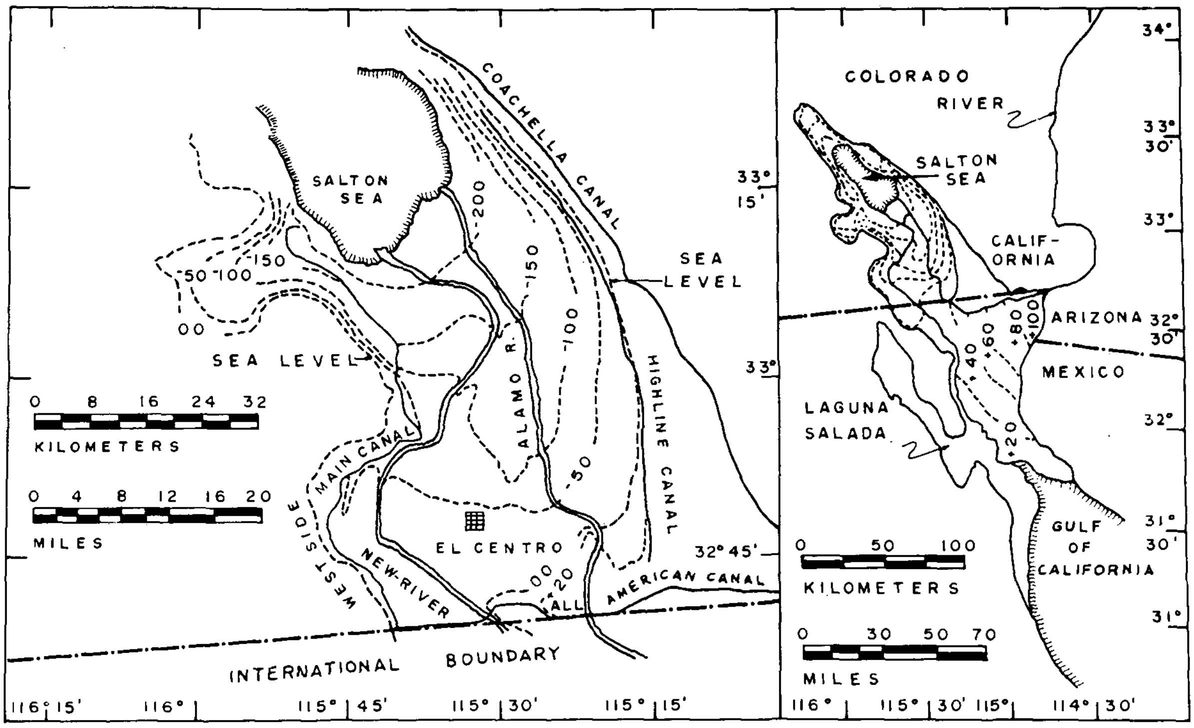

Fig. 1—Colorado River delta *(right)* and Imperial Valley *(left)*. Dashed lines represent contour intervals in feet.

The valley is intersected by an elaborate system of distributary canals and open drains constructed and maintained by the IID. These canals and drains are generally 0.8 km (0.5 miles) apart. The All American Canal, which diverts water from the Colorado River at the Imperial Dam provides all the water needed for irrigation and domestic purposes. Three branches of the All American Canal—East Highline, Central Main, and West Highline—feed the gravity-flow irrigation system through distributary canals that run parallel to open drains.

The open drains provide outlets for surface and subsurface drainage water. Except for some drains in the north that discharge into Salton Sea directly, the open drains discharge into the Alamo and New rivers, which in turn discharge by gravity-flow into the Salton Sea. Open drain construction began about 1921 to alleviate the waterlogging and salinity problems that had developed in the valley. The system was only partially successful and the need for more field subsurface drains became urgent. Farmers began to install tile drains on their land as early as 1928. Now about 156,000 ha (385,000 acres) or about 88% of the irrigated area in the valley has tile or plastic tube subsurface drains installed 1.5–1.8 m (5–6 feet) deep at spacings of 15–75 m (50–250 feet).

Intensive soil water table investigations were started in 1920 when the IID installed observation wells in roughly a 1.609-km (1-mile) grid over most of the irrigated area. Observations were made at each well every 4 months. For years 1940 and 1943 the Sept. readings showed the following distribution of water table depths (3).

	Percentages	
Depth, cm	1940	1943
0–180	43.7	30.0
180–240	20.5	28.9
below 240	35.8	41.1

The readings of the wells have been taken periodically three times a year since 1943 but no analyses or summaries of the data are available. However, general observations indicate that the percentages of areas with water tables at the 0–180 cm depth tends to decrease gradually as more areas are provided with subsurface tube drains, and concrete-lined irrigation ditches.

WATER AND SALT BALANCE MEASUREMENTS

The IID measures the amounts of water and salt, and the composition of the salt load (i) entering the valley from the All American Canal and from the Alamo and the New rivers at the USA-Mexico border and (ii) leaving the valley into the Salton Sea from the Alamo and New rivers. They also measure the amounts of water discharged directly from northern open drains into the Salton Sea; concentration of salts in these latter drains is taken as the average of the concentration in the Alamo and New rivers. Underground waters entering the south or from eastern and western borders of the valley are not measured for any salt balance calculations.

Water samples are analyzed weekly for total dissolved solids (TDS). Before 1970, TDS were determined by evaporation and drying to constant weight at 105C. Since 1970, TDS have been determined by evaporation and drying to constant weight at 180C. Samples are analyzed biweekly for HCO_3, Cl, SO_4, Ca, and Mg. These ions have been determined as follows: HCO_3, titration with $0.05N$ H_2SO_4 to methyl orange end point; Cl^-, titration with $AgNO_3$ (Mohr's method); Ca, precipitation as oxalate and titration with $KMnO_4$; SO_4, precipitation and weighing $BaSO_4$; Mg precipitation as $MgNH_4PO_4$ and weighing as $Mg_2P_2O_7$. Sodium and K are estimated by the difference between the sum (in meq) of HCO_3, Cl, and SO_4 anions and the sum of Ca and Mg cations. Because K is generally $< 5\%$ of Na, a value of Na + K has been used as a measure of Na.

RESULTS AND DISCUSSION

Water Balance

A water balance for the Imperial Valley may be calculated according to the relation:

Input = output ± change in soil and ground water storage

$$V_{\text{inf.w}} + V_{\text{rw}} = V_{\text{cw}} + V_{\text{eff.w}} \pm \Delta V_{\text{sw}} \pm \Delta V_{\text{gw}} \quad [1]$$

where input consists of the volumes of the influent, $V_{\text{inf.w}}$,

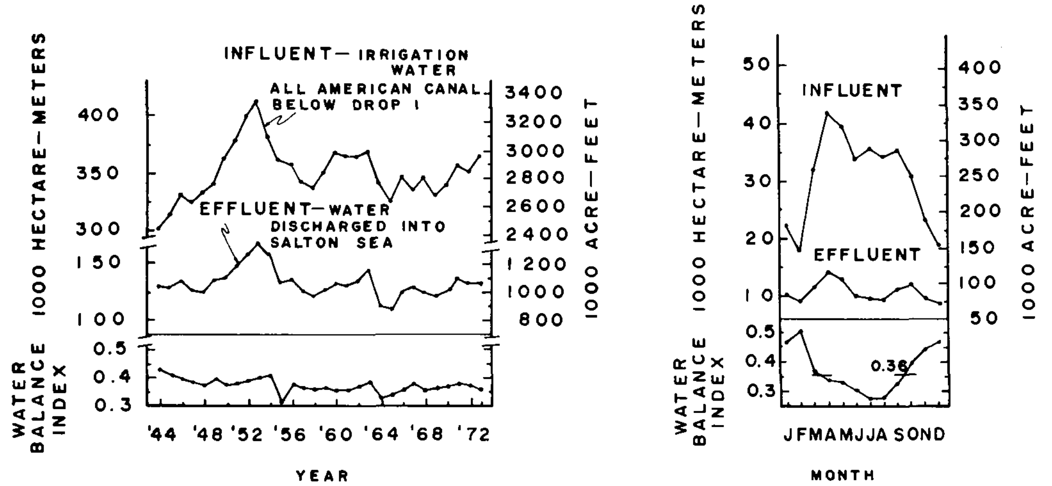

Fig. 2—Influent water (diverted to Imperial Valley), effluent water (discharged into Salton Sea from Imperial Valley), and the respective WBI years 1944 to 1973 *(left)* and months of 1973 *(right)*. Water balance index of 0.36 is the weighted average WBI for 1973.

(diverted) to the Valley, and the rain V_{rw} waters; and output consists of the volumes of consumptive use V_{cw}, and effluent water discharged into the Salton Sea $V_{eff.w}$; and ΔV_{sw} and ΔV_{gw} represent the changes in the volumes of soil water in the root zone and in the ground water, respectively. The water volumes can also be expressed as water depths (volume/acre).

The following sources contribute to the total effluent water, $V_{eff.w}$, discharged into the Salton Sea:

1) Surface water brought from Mexico through the Alamo and New rivers.
2) V_{tw}—tail water (surface runoff).
3) V_{dw}, intercepted root zone percolation water.
4) V_{gw}, ground water below the root zone.
5) $V_{sp.w}$, seepage from canal, which is incorporated into both V_{dw}, V_{gw}.
6) Miscellaneous sources such as sewage effluents and canal spillage.

The volumes of water and salt contents brought from Mexico through the Alamo and New rivers are measured at the USA-Mexico boundary and are subtracted from their respective discharges into the Salton Sea. During 1973 the total discharge of the Alamo and New rivers and the northern channels that drain directly into Salton Sea were 79, 53, and 14 thousand ha-m (639, 429, and 116 thousand acre-feet), respectively.

Contributions from Mexico to the Alamo and New rivers were 0.2 and 14.4 thousand ha-m (1.4 and 117 thousand acre-feet). According to IID, waters delivered to the farmers, $V_{app.w}$ (volume of water applied at farm fields) constitute about 90% of the total $V_{inf.w}$ diverted to the Valley. The difference between $V_{inf.w}$ and $V_{app.w}$ is the water delivered for urban uses and seepage from canals. Tail water is generally estimated by IID to constitute about 75% of the effluent water. The contributions by the miscellaneous sources of sewage effluents and canal spillage were estimated to be about 5–10% of the total $V_{eff.w}$ (7). More work is needed to determine the contribution of both V_{dw} and V_{gw}.

The volumes, of V_{sw} and V_{gw} for a long period, say 1 year, are fairly constant. Precipitation water V_{rw}, is received from scattered showers. It averages only about 7 cm annually and most of it evaporates before it infiltrates into the soil. Thus V_{rw}, ΔV_{sw}, ΔV_{gw} may be considered negligible and the water balance equation may then be reduced to

$$V_{inf.w} = V_{cw} + V_{eff.w}. \qquad [2]$$

Figure 2 shows the annual (1944–1973) and the monthly (1973) values of $V_{inf.w}$, $V_{eff.w}$ and water balance index (WBI) ($V_{eff.w}/V_{inf.w}$) for the Imperial Valley. The annual volumes of influent water ranged from 301 × 10^3 to 413 × 10^3 ha-m (2,445 × 10^3 to 3,352 × 10^3 acre-feet). Values of $V_{inf.w}$ were highest during 1951 to 1954 as a result of the increase in cotton acreage. Changes in $V_{eff.w}$ paralleled changes in $V_{inf.w}$. From 1944 to 1954 WBI's ranged from 0.37 to 0.43 with an average of 0.40, whereas the WBI's from 1955 to 1973 ranged from 0.31 to 0.39 with an average of 0.36.

The monthly flow variations of inf.w and eff.w (Fig. 2) appear to reflect the irrigation practices and cropping patterns. Inflow peaks in Sept. and April: this is the time when winter and summer crops are planted. WBI's are highest during Oct. to Feb.; increased areas are being irrigated at this time under conditions of decreased evapotranspiration (ET) demand (winter crops being grown). As shown in Fig. 2, the WBI during 1973 ranged from 0.51 (Feb.) to 0.28 (July) with a weighted average of 0.36.

In 1973 the total volume of inflow irrigation water and the volume of irrigation water delivered to the farmers were reported as 364 × 10^3 ha-m (2,956 × 10^3 acre-feet) and 329 × 10^3 ha-m (2,670 × 10^3 acre-feet), respectively (IID records). An estimate of ET for the crops grown in the valley in 1973 is shown in Table 1. The estimate was calculated by the Blaney-Criddle formula using semimonthly consumptive use crop coefficients K, as reported by Erie et al. (4). Values of ET determined with lysimeters at the Imperial Valley Conservation Research Center for sugarbeets, cotton, alfalfa, sorghum, barley, and wheat were within ± 5% of the values calculated by the Blaney-Criddle formula. The ET value of alfalfa in Table 1 is 183 cm and it is 88% of the calculated value. The lower value of ET was chosen because farmers generally underirrigate alfalfa. In most alfalfa fields, the low infiltration rates, the frequent cuttings (7–9 cuttings a year), and the frequent use

Table 1—Estimated annual evapotranspiration for crops grown in the Imperial Valley, 1973.

Crop	Area		Evapotranspiration			
			Depth		Volume	
	hectare (thousands)	(acre)	cm	(inch)	ha-m (thousands)	(acre-feet)
	Field crops					
Alfalfa (*Medicago sativa* L.)	58.7	(145)	183	(72)	107.4	(870)
Barley (*Hordeum vulgare* L.)						
Wheat (*Triticum aestivum* L.)	41.7	(103)	64	(25)	26.7	(215)
Oats (*Avena sativa* L.)						
Sugarbeets (*Beta vulgaris* L.)	28.3	(70)	112	(44)	31.7	(257)
Cotton (*Gossypium hirsutum* L.)	15.0	(37)	109	(43)	16.4	(133)
Grain sorghum (*Sorghum bicolor* L. *Moench*)	16.2	(40)	76	(30)	12.3	(100)
Sudangrass (*Sorghum sudanenses* Stapf)	5.3	(13)	76	(30)	4.0	(32)
Ryegrass, annual (*Lolium multiflorum* Lam)	7.3	(18)	76	(30)	5.5	(45)
Bermudagrass (*Cynodon dactylon* (L) Pers.)	1.6	(4)	127	(50)	2.0	(17)
Total	174.1	(430)	823	(324)	206.0	(1,669)
	Garden crops					
Lettuce (*Lactuca sativa* L.)	16.6	(41)	43	(17)	7.1	(58)
Cucurbits (*Cucurbitaceae*)	5.7	(14)	51	(20)	2.9	(23)
Carrot (*Dancus carota* L.)	2.0	(5)	41	(16)	.8	(7)
Onion (*Allium cepa* L.) and						
Garlic (*Allium sativum* L.)	2.4	(6)	58	(23)	1.4	(12)
Tomato (*Lycopersicum esculentum* Mill.)	0.8	(2)	69	(27)	.6	(5)
Brassica spp.	0.4	(1)	51	(20)	.2	(2)
Miscellaneous	0.8	(2)	51	(20)	.4	(3)
Total	28.7	(71)	364	(143)	13.4	(110)
	Permanent crops					
Citrus spp.	1.1	(2.6)	114	(45)	1.3	(9.8)
Asparagus (*Asparagus officinalis* L.)	2.0	(5.0)	140	(55)	2.8	(22.9)
Duckponds & pasture	3.3	(8.1)	152	(60)	5.0	(40.5)
Miscellaneous	0.1	(0.3)	127	(50)	.1	(1.2)
Total	6.5	(16.0)	533	(210)	9.2	(74.4)
Net total	209.3	(517)			228.6	(1,853)

of heavy machinery (for harvesting, drying, baling etc.) preclude adding enough water to satisfy crop ET needs without soil compaction (all year round) and plant scalding (during the summer).

The value of $V_{\mathrm{eff.w}}$ calculated according to Eq. [2] by subtracting the estimated volume value of ET (228 × 10^3 ha-m) from $V_{\mathrm{inf.w}}$ is 101 ha-m. This value is about 77% of the total effluent from the valley or 86% of the effluent assumed to originate from irrigated fields. The difference between the volume of effluent water and the estimated $V_{\mathrm{eff.w}}$ may be due to (i) over estimates of ET and/or (ii) possible contributions from inflow of ground water outside the valley, i.e. northern flow of ground water from Mexico as well as lateral flow from the eastern and western adjoining hills. Under these conditions, although V_{gw} may be considered constant over a period of 1 year, it should be included as both an input and output.

Salt Balance

TOTAL SOLUBLE SALTS

The Imperial Irrigation District has calculated a gross salt balance (SBI) for the valley by measuring regularly: (i) the volume and salt concentration of the effluent water ($V_{\mathrm{eff.w}}$, $C_{\mathrm{eff.w}}$) discharged into the Salton Sea after correction for the water and salt brought to the valley from Mexico, and (ii) the volume and salt concentration of the influent water ($V_{\mathrm{inf.w}} \cdot C_{\mathrm{inf.w}}$) as it enters the valley from the All American Canal below Drop no. 1. The salt balance index (SBI) is calculated as the ratio of $V_{\mathrm{eff.w}} \cdot C_{\mathrm{eff.w}}/V_{\mathrm{inf.w}} \cdot C_{\mathrm{inf.w}}$. Concentration reported by IID as tons/acre-foot were converted to electrical conductivity by multipling by 0.925. Figure 3 shows the average annual (1944–1973) and monthly (1973) electrical conductivity of the influent and effluent waters and the SBI's for the corresponding periods.

The EC_{iw} increased from about 1.1 mmho/cm during the 1940's and early 1950's to 1.2–1.4 after 1960. Salinity increased because of increased salt loading from developing projects upstream along the Colorado River. The salinity of the effluent water ($EC_{\mathrm{eff.w}}$) increased gradually from 2.2 mmho/cm in 1944 to 4.7 mmho/cm in 1965, then gradually decreased to about 4.0 mmho/cm. The EC of the New River is generally 0.4 to 0.8 mmho/cm higher than the EC of the Alamo River, probably because ground water seeps into the New River and East Highline Canal water seeps into the Alamo River. The water level of the New River is lower than that of the Alamo River at the same latitudes. During Sept. 1973, the average level of water in the Alamo River was + 1.43 m (+ 4.7 feet) at the USA-Mexico border and − 43.5 m (− 143.1 feet) at about its midcourse to the north. The corresponding water levels for New River were − 12.82 m (− 43.1 feet), and − 46.56 m (− 152.9 feet). The level of the water at the mouth of both rivers was almost the same at − 71.07 m (− 233.4 feet).

The following three management practices appear to have contributed to the increasing salinity of the Valley effluent water:

1) Subsurface Drainage—In 1946, 14.5 × 10^3 ha (35.7 × 10^3 acres) of the irrigated land in the valley had subsurface tube drains. Since 1946, the areas annually provided with subsurface tube drains have averaged 7.49 × 10^3, 4.66 × 10^3, and 2.87 × 10^3 ha (18.5 × 10^3, 11.5 × 10^3, and 7.09 × 10^3 acres) for the periods 1946–1956, 1957–1966, and 1967–1973, respectively (5).

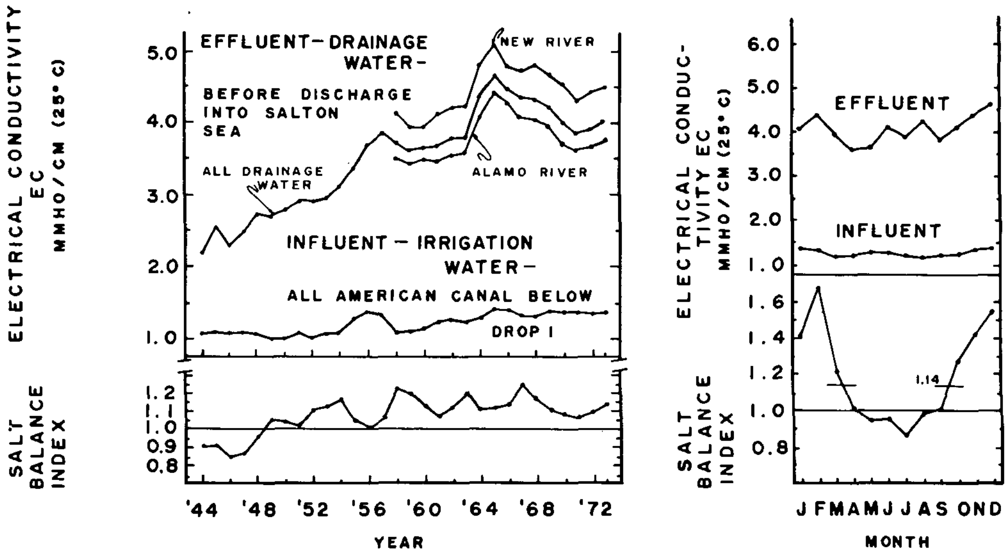

Fig. 3—Electrical conductivity of the influent water (diverted to Imperial Valley) and the effluent water discharged into Salton Sea from Imperial Valley and the respective SBI for: (i) years 1944–1973 *(left)* and for the months of 1973 *(right)*. SBI of 1.14 is the weighted average SBI for 1973.

These drains would be expected to pick up salts from the saline ground water and from the enhanced leaching and drainage of salt-affected soils.

2) Concrete Canal Lining—In 1954, only about 1.6 km (1 mile) of canals were concrete lined. By 1972, this value had increased to about 920 km (572.2 miles) (5). The water tables in the valley are generally perched (2) as a result of overirrigation and seepage from canals. From general observations, subsurface tube drains and concrete lining of canals have lowered the water table levels and, thus, probably have diminished the contribution of relatively nonsaline seepage water and increased the relative contribution of more saline ground water to the effluent water.

3) Double Cropping—Within the last 20 years double cropping caused the cropped area in the valley to range from 1.3–1.6 times the cultivated land. Before 1954 double cropping was little practiced in the valley; in fact some fields were kept fallow for more than 1 year. Double cropping would generally enhance salt leaching. In the well-drained soils in the valley, salts leach during the crop season as well as at the preplanting irrigation(s). In many of the fine-textured soils of the valley, however, infiltration is so slow that it is difficult to apply enough water even to meet ET needs. Salt leaching in such soils as well as other saline soils usually is achieved only between cropping seasons through preplanting irrigation(s) or with continuous ponding for a few weeks or a few months. Between 1946 and 1950 the areas leached by continuous ponding ranged from about 3,600–8,100 ha (8,900–20,000 acres)[3]. With increasing interest in double cropping and with increasing provisions for subsurface drainage, the areas ponded have gradually decreased to 405–910 ha (1,000–2,000 acres) annually within the last few years.

The gradual increase in SBI from 0.90 in 1944 to 1.17 in 1954 was probably due to the increases in area of subsurface drained land coupled with increased leaching. Since 1954, the SBI has fluctuated in cycles between 1.01 and 1.23. The cause of these fluctuations is not known.

Like the WBI the monthly distribution of SBI during 1973 reflected both irrigation practice and ET which, together, determine the amount of subsurface drainage water. Generally, the SBI was highest during October to March, with the index decreasing gradually to its minimum in July for much the same reasons discussed for water balance data.

As mentioned earlier in water balance discussion many sources contribute to the effluent water, $V_{\mathrm{eff.w}}$, discharged into the Salton Sea. Salts from these sources contribute to the total concentration of the effluent water, $C_{\mathrm{eff.w}}$. To be meaningful for agricultural purposes, salt balance should be related to salt inputs and outputs in the root zone. This relation may be summarized in the following equation (10) which accounts for all the sources that contribute to the input, the output and changes of soil salinity in the profile (both soluble and exchangeable):

Salt input = Salt output ± Δ Soil salinity

$$\begin{aligned} V_{iw}C_{iw} + V_{gw}C_{gw} + S_m + S_f \\ = V_{dw}C_{dw} + S_p + S_c \pm \Delta S_{sw} \pm \Delta X_c \qquad [3] \end{aligned}$$

where

V_{iw}, V_{dw}, V_{gw} are the volumes of irrigation water (applied water-tail water), V_{iw}; drainage water, V_{dw}; and ground water, V_{gw};

C_{iw}, C_{dw}, and C_{gw} are the salt concentrations in the above mentioned three waters, respectively;

S_m, S_f are the amounts of salts brought into soil solution by mineral weathering, S_m, and from fertilizers and amendments S_f;

S_p, S_c are the amounts of salts precipitated in the soil, S_p, and removed from the soil by crops, S_c; and

ΔS_{sw}; ΔX_c represent the sum of changes in soil soluble salts, ΔS_{sw}; and exchangeable cations ΔX_c.

This relation which is basically an expression of conservation of mass can be used for assessing the balance of total

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[3] G. B. Bradshaw and W. W. Donnan, 1953. Leaching studies in connection with drainage of saline soils in the Imperial Valley, Calif. SCS, USDA-Provisional Rep. (Unpublished).

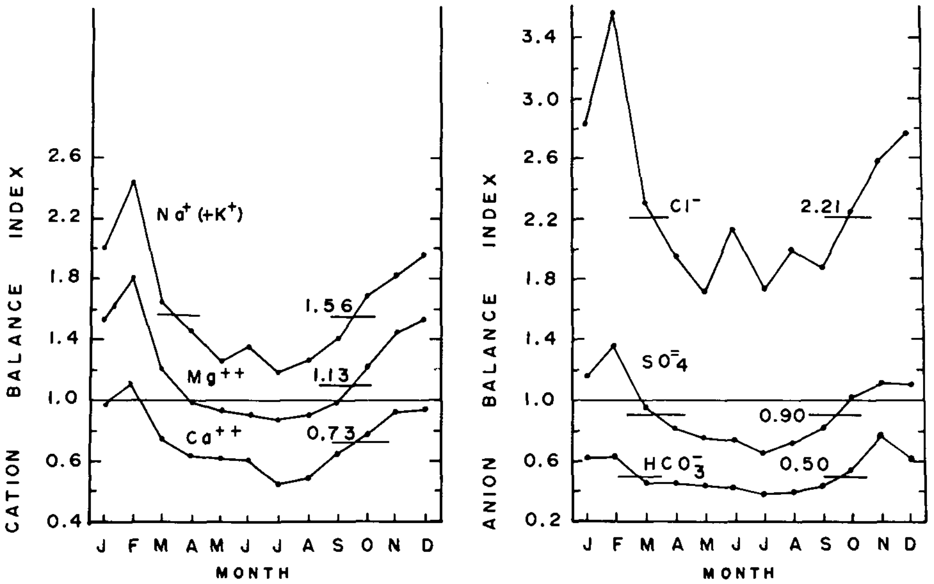

Fig. 4—Monthly cation and anion balance indexes for influent and effluent waters, 1973, Imperial Valley. SBI values above horizontal lines crossing SBI curves are the annual weighted SBI for the respective ion.

salts as well as of any ionic species. Some simplifications are made for solving Eq. [3], where some of the components of the equation are not known. For instance S_m, S_f, S_p, and S_c are usually small in relation to the other quantities, and the contributions of S_m and S_f (input) tend to cancel the contribution of S_p and S_c (output) (1). Also there is a tendency to disregard V_{gw} C_{gw}, and thus at steady state, where Δ soil salinity ≈ 0, Eq. [3] is reduced to $V_{iw}\ C_{iw} = V_{dw}\ C_{dw}$ (1, 11, 12, 13). Since V_{gw} C_{gw} is not negligible it was decided to evaluate the salt balance in equation with respect to chloride ion concentration as shown in the next section on individual solutes and ionic relations. The chloride was chosen because it is mobile and is not involved in any precipitation, dissolution, fixation or exchange reactions.

Individual Solutes and Ionic Relations

The individual ions in the influent and effluent waters may be related with respect to: (i) their total amounts in tons or ton equivalents, (ii) their concentrations in meq/liter and some ratios among these concentrations. Some of the most common ionic ratios are: the percentage of each ion with respect to the total ions of same sign, the ratios of Cl:SO_4, Ca:Mg, and Na: $[Ca + Mg/2]^{-1/2}$. The last ratio is commonly referred to as SAR (Na-adsorption ratio).

As with total salt concentration, the ratio of the amounts of any ion in effluent to the corresponding amounts in influent defines the ionic balance index.

In 1973, the total amounts of the various ions in the influent and effluent waters were:

Ion	Influent water	Effluent water
	(100 metric ton equivalent)	
HCO_3^-	112.1	55.4
SO_4^{2-}	254.4	227.2
Cl^-	133.2	294.0
Ca^{2+}	192.2	139.3
Mg^{2+}	100.1	112.3
Na^+	207.5	322.2

Thus, in 1973, SB was negative for HCO_3^-, SO_4^{2-}, and Ca^{2+}, and positive for Cl^-, Mg^{2+}, and Na^+. As will be discussed later, the negative SB was partly due to precipitation of $CaCO_3$ and $CaSO_4$ and the positive SB was partly due to contribution from ground water. Figure 4 shows the monthly cation and anion balance indexes. The trend in changes in the various ionic balance indexes were similar to trends in SBI discussed earlier.

The ionic composition, equivalent ionic percentages, and some cation and anion ratios for 1973 are presented in Table 2. The total concentration of anions in influent water ranged from 13.1 to 15.0 meq/liter with the lowest values occurring during July and the highest values occurring during the winter months Nov.-Feb. The concentration of anions in effluent water were from 1.4 to 7.0 times the concentration in influent water. The equivalent percentages of Ca^{2+}, HCO_3^- and SO_4^{2-} were lower and those of $Na^+ + K^+$ and Cl^- were higher in effluent water than in influent water. Magnesium equivalent percentages were almost the same in both waters. Precipitation of $CaCO_3$ and CaSO would account for the reduced equivalent percentages of Ca^{2+}, HCO_3^- and SO_4^{2-}, in effluent water. Because of the differences in equivalent percentages of cations and anions, the Na-adsorption ratio (SAR) and the Cl^-/SO_4^{2-} ratio were higher, and the Ca/Mg ratio was lower, in effluent water than in influent water. Monthly differences in any of these ratios for either the influent or the effluent waters were generally small. The small changes in monthly ratios (SAR, Ca/Mg, Cl/SO_4) of the effluent and the almost parallel curves for the monthly cation and anion balance indexes (Fig. 4) were unexpected. It seems that the effluent salinity reflects ground water salinity more than root zone salinity. The individual solute proportions of the latter would be expected to vary with seasonal differences in the leaching fraction (9). These data appear to represent dilution and/or displacement of ground water of a constant composition. The amount of ground water displaced or diluted would

Table 2—Comparison of compositions of influent (inf) and effluent (eff) waters in the Imperial Valley, Calif., 1973.

	Cations						Anions								
Month (water)	Ca	Mg	Na(k)	Ca	Mg	Na(k)	HCO_3	SO_4	Cl	HCO_3	SO_4	Cl	Ionic relations		
	meq/liter			% of total cations			meq/liter			% of total anions			Ca/Mg	SAR	Cl/SO_4
Jan – inf	5.28	2.96	6.38	36.1	20.2	43.6	3.14	7.47	4.21	21.2	50.4	28.4	1.81	3.14	0.56
– eff	11.45	9.51	27.13	23.8	19.8	56.4	4.17	18.60	25.30	8.7	38.7	52.6	1.20	8.38	1.36
Feb – inf	5.42	2.71	6.15	38.0	19.0	43.1	3.15	7.25	3.90	23.6	50.7	27.3	2.00	3.05	0.54
– eff	11.68	9.57	29.37	23.1	18.9	58.0	3.96	19.33	27.32	7.8	38.2	54.0	1.22	9.01	1.41
Mar – inf	5.22	2.63	5.50	39.1	19.7	41.2	3.09	6.64	3.63	23.1	49.7	27.2	1.98	2.78	0.55
– eff	10.56	8.54	24.33	24.3	19.7	56.0	3.85	17.01	22.57	8.9	39.2	52.0	1.24	7.87	1.33
Apr – inf	5.18	2.66	5.11	40.0	20.5	39.5	2.98	6.50	3.47	23.0	50.2	26.8	1.95	2.58	0.53
– eff	9.89	7.74	22.00	24.9	19.5	55.4	4.01	15.59	19.91	10.1	39.5	50.4	1.28	7.41	1.28
May – inf	5.48	2.74	5.92	38.5	19.4	42.0	3.18	7.05	3.86	22.6	50.0	27.4	1.98	2.93	0.55
– eff	10.08	7.70	22.18	25.2	19.3	55.5	4.19	15.81	19.96	10.5	39.6	49.9	1.31	7.47	1.26
June – inf	4.80	2.92	5.59	36.1	21.9	42.0	3.00	7.18	3.13	22.5	53.9	23.5	1.64	2.81	0.44
– eff	9.52	8.78	25.19	21.9	20.2	57.9	4.26	17.44	21.80	9.8	40.1	50.1	1.08	8.33	1.25
July – inf	4.98	2.65	5.53	37.8	20.1	42.0	2.95	6.88	3.30	22.2	52.4	25.1	1.88	2.83	0.48
– eff	9.75	8.25	23.67	23.4	19.8	56.8	4.14	16.72	20.81	9.9	40.1	49.9	1.18	7.89	1.24
Aug – inf	5.14	2.78	5.35	38.7	20.9	40.3	3.03	6.89	3.35	22.9	51.9	25.2	1.85	2.69	0.49
– eff	10.73	8.90	23.96	24.6	20.4	55.0	4.17	17.88	23.63	9.1	39.1	51.7	1.21	7.65	1.32
Sept – inf	5.29	2.68	5.34	39.7	20.1	40.1	3.03	6.74	3.54	22.8	50.6	26.6	1.97	2.68	0.53
– eff	10.33	8.11	22.96	25.0	19.6	55.5	4.08	17.04	20.29	9.9	41.1	49.0	1.27	7.56	1.19
Oct – inf	5.39	2.77	5.81	38.6	19.8	41.6	3.07	7.07	3.83	22.0	50.6	27.4	1.95	2.88	0.54
– eff	10.75	8.48	24.56	24.5	19.4	56.1	4.19	18.07	21.53	9.6	41.3	49.2	1.27	7.92	1.19
Nov – inf	5.55	2.85	6.45	37.3	19.2	43.4	3.29	7.37	4.20	22.1	49.6	28.0	1.95	3.15	0.57
– eff	11.56	9.23	26.23	24.6	19.6	55.8	5.68	18.61	24.01	11.8	38.5	49.7	1.25	8.14	1.29
Dec – inf	5.89	2.81	6.28	39.3	18.8	41.9	3.26	7.41	4.32	21.7	49.4	28.8	2.10	3.01	0.58
– eff	11.67	9.12	26.17	24.9	19.4	55.7	4.25	17.39	25.31	9.1	37.0	53.9	1.28	8.12	1.46
Year: – inf	5.28	2.75	5.70	38.5	20.0	41.5	3.08	6.99	3.66	22.4	50.9	26.7	1.92	2.84	0.52
– eff	10.61	8.59	24.60	24.2	19.6	56.2	4.23	17.35	22.46	9.6	39.4	51.0	1.24	7.94	1.29
eff/inf	2.01	3.12	4.32				1.37	2.48	6.14						

vary with the amount of percolated water, yet the ionic ratios of the effluent water would change little.

We tried to allocate the effluent Cl among the three possible components of the effluent, i.e., subsurface ground water (gw), root zone drainage water (dw), and surface drainage water of tail water (tw) and to ascertain the contribution of ground water displacement to the Valley's effluent salt load. Chloride was chosen, as mentioned earlier, because it is mobile and is not involved in any precipitation, dissolution, fixation or exchange reactions.

The water relation of V_{gw}, V_{dw}, V_{tw}, $V_{eff.w}$, V_{iw} may be summarized in the following simplified equations:

$$V_{eff.w} = V_{tw} + V_{dw} + V_{gw}{}^{4} \quad [4]$$

$$V_{iw} = V_{inf.w} - V_{tw}{}^{5} \quad [5]$$

Multiplying the volumes in Eq. [4] by the respective salt (or ionic) concentration and substituting for V_{tw} from Eq. [5] yields Eq. [6] when the following assumptions and appropriate substitutions are made: (i) the system (valley) as a whole has reached a steady state or quasi-steady state within the soil root zone (i.e., $C_{iw}\,V_{iw} = C_{dw}\,V_{dw}$.), and (ii) the concentration of tail water and water infiltrated in the field are the same as $C_{inf.w}$, since tail water hardly picks up any salt from the soil.

$$C_{eff.w} \cdot V_{eff.w} = C_{inf.w} V_{inf.w} + C_{gw} V_{gw} \quad [6]$$

Substituting the appropriate values for 1973,
$V_{inf.w} = 364 \times 10^3$ ha-m; $V_{eff.w} = 131 \times 10^3$ ha-m
$Cl_{inf.w} = 3.66$ meq/liter; $Cl_{eff.w} = 22.46$ meq/liter
The value of $Cl_{gw}\,V_{gw} = 161 \times 10^8$ equiv.

Comparison with the mass of Cl in the effluent (294.2 × 10^8 equiv.) yields the estimate that 54.7% of the discharged Cl is derived from gw.

If we further assume $V_{tw} = 0.75\ V_{eff.w}$ (the estimate supplied by the IID) and that C_{tw} is equivalent to $C_{inf.w}$ then substitution into Eq. [4] and multiplying by the respective concentrations yields

$$C_{dw} \cdot V_{dw} = 103.0 \times 10^2 \text{ ton eq.}$$

which is equal to 35.0% of $C_{eff.w}\,V_{eff.w}$. Thus, assuming the above assumptions are valid, we estimate the chloride load in the effluent water from Imperial Valley in 1973 contributed as follows: 54.7% from ground water, 35.0% from root zone drainage water, and 10.3% from tail water.

Increased accuracy in the evaluation of V_{cw} and V_{tw} would enable us to better estimate V_{gw}, and V_{dw} and hence C_{gw} and C_{dw}. Values of V_{gw} and V_{dw} (Eq. [7] and [8]) are derived from Eq. [4] and [5] and the relation $V_{iw} = V_{cw} + V_{dw}$.

$$V_{gw} = V_{cw} + V_{eff.w} - V_{inf.w} \quad [7]$$

$$V_{dw} = V_{inf.w} - V_{tw} - V_{cw} \quad [8]$$

The data and findings presented here show that conventional Schofield-type salt balance evaluations do not distinguish origin of salt in the effluent and do not provide information about changes in root zone salinity within the project. Also, conclusions as to the adequacy of proper leaching management based on SB evaluations can be very misleading, since much of the salt contributing to the positive SB may be derived from extraneous sources such as the ground water. Thus, we conclude that salt balance as now evaluated is not a generally meaningful criterion on which to base the adequacy of leaching and salinity control of large irrigation projects. The data needed to ascertain the root zone salt balance, a more meaningful evaluation, include measures of water actually diverted to the farms and amount infiltrated and percolated. If such data are difficult

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[4] As mentioned earlier, V_{gw} includes canal seepage and may be subsurface inflow to Valley from Mexico and from adjoining hills. Contribution of canal spillage is considered as tail water.

[5] Water diverted for domestic use was omitted for simplification from the right-hand side of Eq. [5]; its value is about 5% of $V_{inf.w}$.

to obtain, then one could establish a network of soil salinity monitoring stations, where soil samples would be taken periodically. This would be similar to the work initiated on 10 farms by Kelley et al. (6) from 1935 to 1945. The use of soil resistivity measured by the four-electrode probe, a reliable and economical technique for assessing soil salinity (8) would greatly reduce the efforts of soil sampling and laboratory analysis. It could also be used for monitoring changes in water table levels.

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