

## Sodium Hazard of Punjab Ground Waters<sup>1</sup>

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In evaluating the suitability of waters for irrigation, an important consideration is the extent to which soils will adsorb Na from the water by cation exchange. The sodium-adsorption-ratio (SAR) together with the total salt concentration is usually an adequate index of the Na hazard involved in the use of low carbonate ( $\text{CO}_3$  and  $\text{HCO}_3$ ) waters for irrigation. With reasonable water management the steady state exchangeable-sodium-percentage (ESP) of soils irrigated with low carbonate waters is generally no more than twice the value corresponding to the SAR of the water. In the case of irrigation waters having appreciable concentrations of carbonates, however, there is a tendency for the  $\text{CO}_3$  and  $\text{HCO}_3$  to precipitate in the soil as  $\text{CaCO}_3$ , and thereby increase the proportion of Na in the soil solution and on the exchange complex. Loss of water from the soil solution by evapotranspiration, and increases in pH and temperature enhance the precipitation of  $\text{CaCO}_3$  whereas the release of  $\text{CO}_3$  from plant roots and decomposing organic matter tends to prevent precipitation. Thus, many factors influence the extent of  $\text{CaCO}_3$  precipitation and its concomitant effect on exchangeable Na accumulation in soils.

Eaton (1950) considered the precipitation of Ca and Mg by carbonates to be quantitative when irrigation waters are applied to soils, and proposed the concept of "residual  $\text{Na}_2\text{CO}_3$ " for evaluating high carbonate waters. He defined "residual  $\text{Na}_2\text{CO}_3$ " as  $(\text{CO}_3 + \text{HCO}_3) - (\text{Ca} + \text{Mg})$ , in which concentrations are expressed in me./l. Wilcox, Blair, and Bower (1954) made as many as 86 applications of synthetic irrigation waters having various concentrations of "residual  $\text{Na}_2\text{CO}_3$ " to containers of initially nonsodic soil in which grass was growing and determined the percentage of applied  $\text{HCO}_3$  which precipitated as  $\text{CaCO}_2$  in the soil as well as the increase in ESP. Sufficient drainage was allowed to take place from the containers, so that there was no

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appreciable accumulation of soluble salts in the soil. It was found that the percentage of applied  $\text{HCO}_3$  which precipitated as  $\text{CaCO}_3$  varied from 0 to 54 and the extent of exchangeable Na accumulation from the waters was related to "residual  $\text{Na}_2\text{CO}_3$ " content. It was concluded tentatively that waters containing more than 2.5 me./l. of "residual  $\text{Na}_2\text{CO}_3$ " are not suitable for irrigation, that those containing between 1.25 and 2.5 me./l. are marginal, and that those containing less than 1.25 me./l. are probably safe. Subsequent work<sup>1</sup> has shown, however, that soil irrigated with waters containing appreciable amounts of  $\text{HCO}_3$  but having no "residual  $\text{Na}_2\text{CO}_3$ " may accumulate amounts of exchangeable Na considerably in excess of that predicted by the SAR of the water. The general reliability of the "residual  $\text{Na}_2\text{CO}_3$ " concept for evaluating the Na hazard of irrigation waters has, therefore, become questionable. Moreover, Kelley (1962) has recently criticized the concept on theoretical grounds.

#### USE OF A MODIFIED LANGELIER INDEX IN COMBINATION WITH THE SAR FOR EVALUATING SODIUM HAZARD

Langelier (1936) had devised an index, termed the saturation index, for indicating the extent to which waters flowing through pipes will precipitate or dissolve  $\text{CaCO}_3$ . The saturation index is defined as the actual pH of a water (pHa) minus the pH (obtained by calculation) which the water will have when it is in equilibrium with  $\text{CaCO}_3$  (pHc), viz:

$$\text{Saturation index} = \text{pHa} - \text{pHc} \quad (1)$$

Positive values of the index indicate that  $\text{CaCO}_3$  will precipitate from the water, whereas negative values indicate that the water will dissolve  $\text{CaCO}_3$ . The equation for calculating pHc, in its simplest form and applicable over the pH range 7 to 9.5, is:

$$\text{pHc} = (\text{pK}'_2 - \text{pK}'_{\text{sat}}) + \text{pCa} + \text{pAlk} \quad (2)$$

The last two terms are the negative logarithms of the molal concentration of Ca and of the equivalent concentration of the titratable base ( $\text{CO}_3 + \text{HCO}_3$ ), respectively, while  $\text{pK}'_2$  and  $\text{pK}'_{\text{sat}}$  are the negative logarithms of the second dissociation constant for carbonic acid and the activity product of  $\text{CaCO}_3$ , respectively, at the ionic strength of the water. The chemical behaviour of Mg in soils is very similar to that of Ca. Therefore in calculating pHc values for irrigation waters  $\text{p}(\text{Ca} + \text{Mg})$  is substituted for pCa in equation (2). Because the ionic strength and the total cation concentration of irrigation waters are highly correlated, values of  $(\text{pK}'_2 - \text{pK}'_{\text{sat}})$  of sufficient accuracy for practical purposes can be obtained from a graph relating this quantity and total cation

1. Wilcox, L. V., Blair, G. Y., and Bower, C. A., unpublished data, U. S. Salinity Laboratory (1956).

concentration. The graph may be constructed from the following data:

Total cation concentration, mc./l.	( $pK'_2 - pK'_{sat}$ )
1	2.04
2	2.11
4	2.20
8	2.33
12	2.43
24	2.64
36	2.80
54	3.00

Bower (1961) found for the aforementioned data of Wilcox, et al, that the fraction of applied  $HCO_3$  which precipitated as  $CaCO_3$  in the soil was highly correlated with a modified Langelier saturation index. The modification consisted of using the pH of the soil in place of the actual pH of the water for calculating the index. The justification for the modification is that because irrigation waters are poorly buffered and soils are highly buffered the pH of the water becomes nearly equal to that of the soil upon contact with the latter. Thus, it appears that for application of high carbonate waters to a soil of a given pH reading, the pHc value of the Langelier index is a measure of the tendency of  $CaCO_3$  to precipitate from the water.

The characteristics of the high carbonate waters studied by Wilcox, et al, including their SAR, "residual  $Na_2CO_3$ " and pHc values, and the ESP of the soil observed after 42 irrigations are given in table 1. As indicated previously, for waters containing "residual  $Na_2CO_3$ " there is a good relation between this value and the observed ESP but soil irrigated with waters 20bE and 10bE which contain no "residual  $Na_2CO_3$ " also accumulated more exchangeable Na than the SAR of the waters predict. Study of the data given in table 1 indicates that the observed ESP is influenced jointly by the SAR and pHc values of the waters, and can be expressed approximately by the empirical equation:

$$ESP = 2SAR + 2SAR (8.4 - pHc) \quad (3)$$

A comparison of the observed ESP values with those calculated by this equation are included in table 1. The term  $(8.4 - pHc)$  of equation (3) is analogous to Langelier's saturation index except that 8.4, the approximate pH reading of a nonsodic soil in equilibrium with  $CaCO_3$ , is substituted for the actual pH value (pHa) of the water.

#### STUDIES ON PUNJAB GROUND WATERS

Having noted that Punjab ground waters usually contain relatively high concentrations of carbonates, Hausenbuiller, Haque, and Wahhab (1960)

TABLE 1—Observed and calculated ESP value of Hanford soil following 42 irrigations with various high bicarbonate waters

(Experimental data by Wilcox, Blair, and Bower)

Water No.	Total conc.	Na	Ca+Mg*	HCO <sub>3</sub>	SAR	Res. Na <sub>2</sub> CO <sub>3</sub>	pH <sub>c</sub>	ESP	
								Obs.	Calc.†
	me./l.	me./l.	me./l.	me./l.		me./l.			
<b>Low-leaching regime</b>									
20b	20.0	15.00	5.00	10.00	9.5	5.00	7.2	46	42
10b	10.0	7.50	2.50	5.00	6.7	2.50	7.6	20	24
5b	5.0	3.75	1.25	2.50	4.8	1.25	8.0	10	13
1b	1.0	.75	.25	.50	2.1	.25	9.2	2.6	.84
5bL	5.0	1.25	3.75	4.25	.9	.50	7.3	3.1	3.8
1bL	1.0	.25	.75	.85	.4	.10	8.5	1.4	.72
20bMg	20.0	15.00	5.00	10.00	9.5	5.00	7.2	46	42
20bE	20.0	10.00	10.00	10.00	4.5	..	6.9	22	23
10bE	10.0	5.00	5.00	5.00	3.2	..	7.3	12	13
5bE	5.0	2.50	2.50	2.50	2.2	..	7.7	7.0	7.5
1bE	1.0	.50	.50	.50	1.0	..	8.9	2.4	1.0
<b>High-leaching regime</b>									
20b	20.0	15.00	5.00	10.00	9.5	5.00	7.2	44	42
10b	10.0	7.50	2.50	5.00	6.7	2.50	7.6	12	24
5b	5.0	3.75	1.25	2.50	4.8	1.25	8.0	10	13
1b	1.0	.75	.25	.50	2.1	.25	9.2	2.1	.84
5bL	5.0	1.25	3.75	4.25	.9	.50	7.3	2.2	3.8
1bL	1.0	.25	.75	.85	.4	.10	8.5	1.7	.72

\*Water No. 20bMg contained no calcium; all others contained no magnesium.

†Calculated by the equation:  $ESP = 2SAR + 2SAR (8.4 - pH_c)$ .

determined the extent of exchangeable Na accumulation in the 0 to 6 inch layer of field soils which had been irrigated 4 or more years with 11 of these ground waters. They found that irrigation with 4 of the 11 waters had resulted in accumulation of excessive amounts of exchangeable Na in the soil, and that the extent of Na accumulation was highly correlated with the "residual  $\text{Na}_2\text{CO}_3$ " content of the water. Hausenbuiller, et al, recognized that field studies of the type conducted are open to question and they, therefore, made a supplementary controlled study in which 60 irrigations of various synthetic waters were applied to cropped containers of soil. In agreement with the findings of Wilcox, et al, this study showed that soil irrigated with waters containing no "residual  $\text{Na}_2\text{CO}_3$ " may accumulate exchangeable Na in excess of that predicted by the SAR of the water. Hausenbuiller, et al, suggested that considerable risk may be involved in irrigating with waters containing as little as 1.25 me./l. of "residual  $\text{Na}_2\text{CO}_3$ ".

The field data of Hausenbuiller, et al, afford an opportunity to test the validity of equation (3) for predicting the Na hazard of waters under the actual

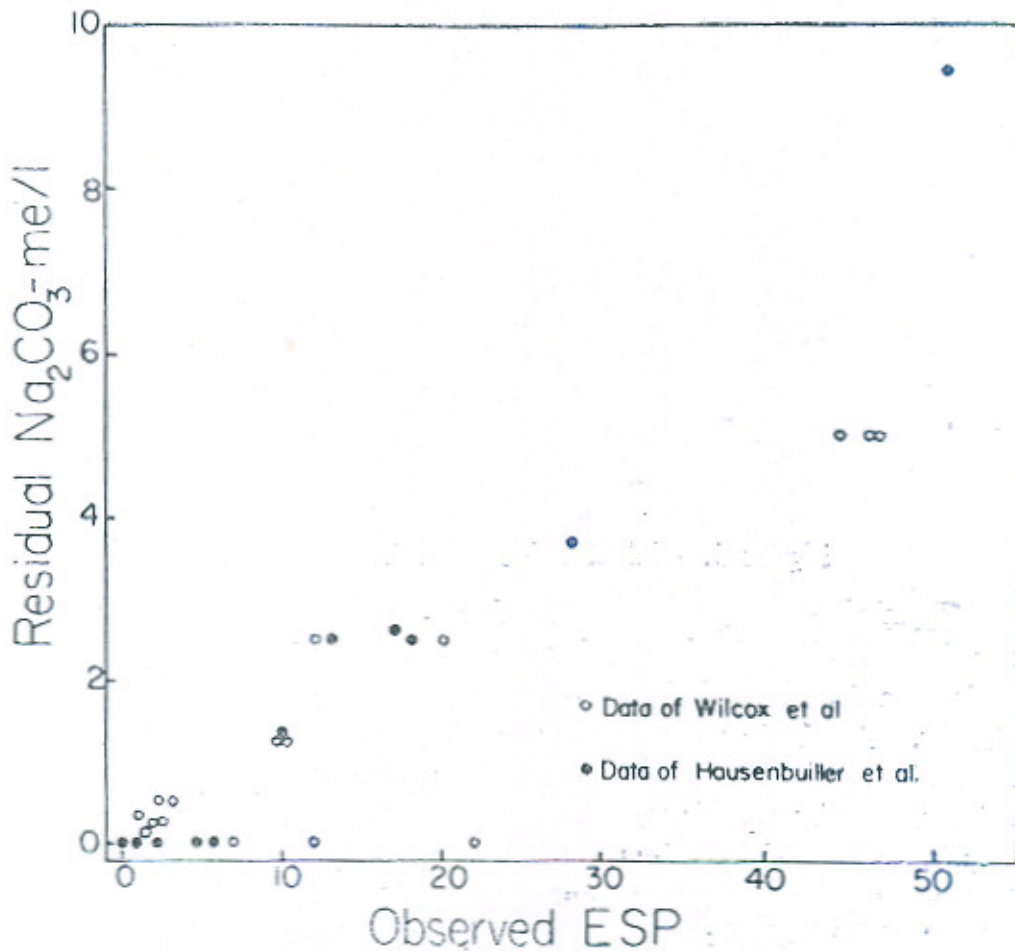


Figure 1.—Residual  $\text{Na}_2\text{CO}_3$  (in me./lt.) vs. Observed ESP

conditions of concern. The characteristics of the Punjab ground waters studied by Hausenbuiller, et al, together with observed ESP values and those calculated by equation (3) are given in table 2. The agreement found between observed and calculated ESP values is considered good in view of the difficulties involved in obtaining reliable field data of the type presented. Thus, equation (3) offers considerable promise for predicting the Na hazard of Punjab ground waters.

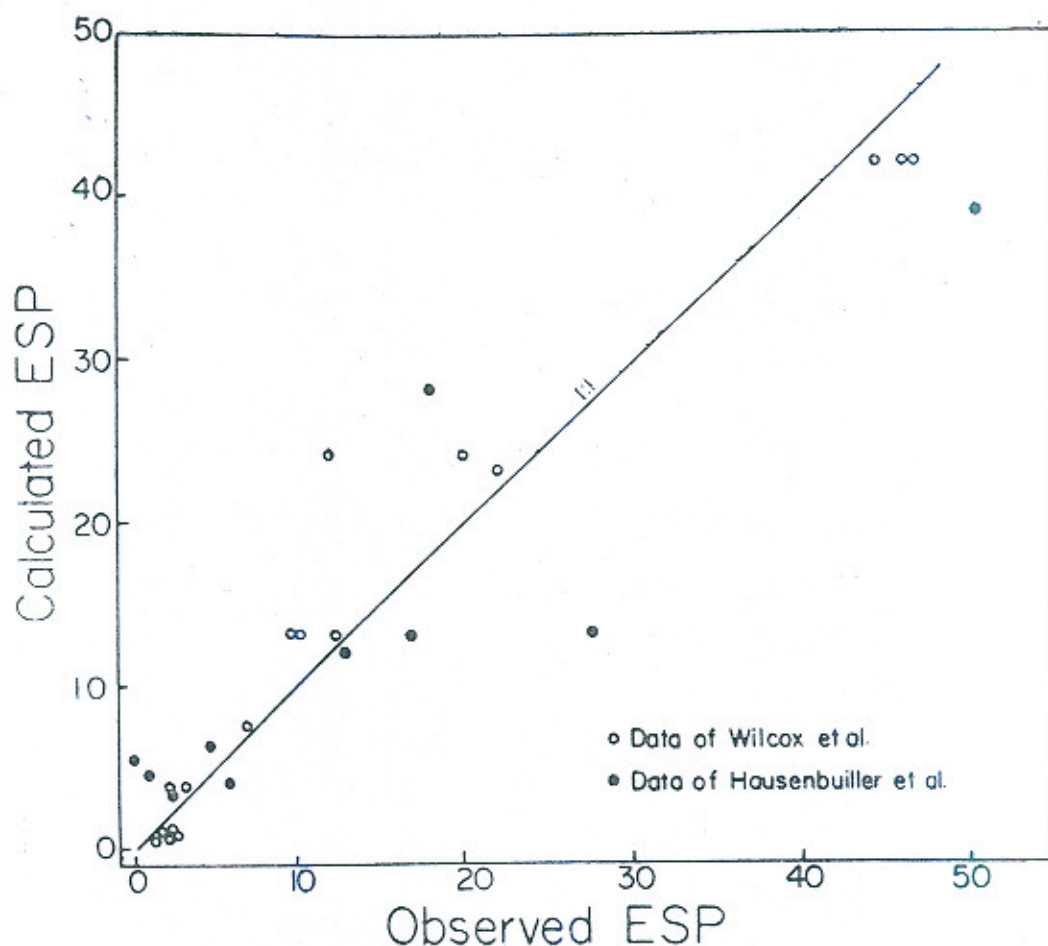


Figure 2.—Calculated ESP vs. Observed ESP

Chemical analyses of a large number of waters from recently completed tubewells in Rechna Doab have been made available by the Water and Soil Investigation Division of the West Pakistan Water and Power Development Authority. To obtain preliminary information on the Na hazard involved in the use of these waters for irrigation, the "residual  $\text{Na}_2\text{CO}_3$ " contents and the ESP values by equation (3) were calculated for the waters from approximately 10 percent of the tubewells in the Hafizabad, Khangah Dogran, Jaranwala, and Beranwala Reclamation Schemes. The results, which are given in table 3, show that over two-thirds of the waters for which calculations were made contain "residual  $\text{Na}_2\text{CO}_3$ " and half have calculated ESP values in

TABLE 2—Observed and calculated ESP values of surface soil irrigated 4 or more years with Punjab well waters.

(Experimental data by Hausenbuiller, Haque, and Wahhab)

Water No.	Total conc.	Na	Ca+Mg	CO <sub>3</sub> +HCO <sub>3</sub>	SAR	Res. Na <sub>2</sub> CO <sub>3</sub>	pH <sub>c</sub>	ESP	
								Obs.	Calc.*
	me./l.	me./l.	me./l.	me./l.		me./l.			
1	10.47	2.80	7.60	5.00	1.4	..	7.1	4.7	6.4
2	8.44	4.22	4.15	6.75	2.9	2.60	7.2	17	13
3	19.02	11.00	8.00	10.50	5.5	2.50	6.9	18	28
4	18.68	13.01	5.55	15.00	7.8	9.45	6.9	50	39
5	7.22	3.85	3.30	7.00	3.0	3.70	7.2	28	13
6	10.45	4.33	6.05	8.55	2.5	2.50	7.0	13	12
7	7.20	1.75	5.38	3.46	1.1	..	7.3	.80	4.6
8	5.72	1.59	4.10	2.18	1.1	..	7.6	5.7	4.0
9	7.18	1.90	5.20	4.60	1.2	..	7.1	..	5.6
10	9.71	4.60	5.10	6.45	2.9	1.35	7.2	10	13
11	7.54	1.20	6.30	5.75	.7	..	7.1	2.3	3.2

\*Calculated by the equation:  $ESP = 2SAR + 2SAR (8.4 - pH_c)$ .

TABLE 3—Characteristics and calculated ESP values for some Punjab tubewell waters  
(Chemical analysis by Water and Soil Investigation Division of West Pakistan Water  
and Power Development Authority)

Tubewell No.	Date Sampled	Total conc. me./l.	Na me./l.	Ca+Mg me./l.	CO <sub>3</sub> + HCO <sub>3</sub> me./l.	SAR	Res. Na <sub>2</sub> CO <sub>3</sub> me./l.	pH <sub>c</sub>	Calc.* ESP
<b>Hafizabad Reclamation Scheme</b>									
1	1-7-61	2.60	.20	2.40	1.64	0.2	..	7.86	.6
11	1-14-61	9.40	4.40	5.00	4.10	2.7	..	7.36	11.0
21	1-18-61	8.80	3.60	5.20	4.92	2.2	..	7.25	9.5
31	12-4-60	7.16	5.03	2.13	3.34	4.8	1.21	7.76	15.7
41	12-7-60	16.07	12.19	3.88	5.15	8.7	1.27	7.49	33.2
51	12-7-60	10.77	5.19	5.58	3.84	3.1	..	7.37	12.6
61	11-25-60	8.40	4.80	3.60	4.92	3.6	1.32	7.39	12.5
71	9-19-60	10.05	6.86	3.19	6.32	5.4	3.13	7.38	21.8
81	9-19-60	10.24	7.41	2.83	7.44	6.2	4.61	7.36	25.3
93	12-3-60	7.70	3.43	4.27	6.40	2.3	2.13	7.18	10.2
102	1-19-61	8.30	2.70	5.60	4.92	1.6	..	7.25	6.9
111	6-8-60	8.47	6.36	2.11	4.29	6.1	2.18	7.69	20.9
121	9-16-60	11.58	7.94	3.64	7.75	5.9	4.11	7.27	25.1
131	9-12-60	18.50	14.04	4.46	6.78	9.3	2.32	7.37	37.8
141	7-6-60	7.00	3.30	3.70	4.40	2.4	.70	7.39	9.7
151	9-17-60	7.30	3.53	3.77	5.61	2.5	1.84	7.28	10.6
161	9-13-60	10.00	6.55	3.45	4.99	5.0	1.54	7.44	19.6
171	6-17-60	14.15	11.34	2.81	10.58	9.5	7.77	7.29	40.1
181	6-26-60	20.78	18.03	2.75	10.73	15.0	7.98	7.41	59.7
191	6-30-60	13.68	10.64	3.04	8.23	8.6	5.19	7.37	34.9
201	7-5-60	7.32	4.23	3.09	4.40	3.4	1.31	7.48	13.4
211	6-20-60	8.87	5.62	3.25	6.99	4.4	3.74	7.29	18.6
220	1-6-61	3.00	.20	2.80	.82	.2	..	8.12	.5
231	11-26-60	8.40	3.00	5.40	6.56	1.8	1.16	8.09	4.7



### Hafizabad Reclamation Scheme

241	12-12-60	8.78	2.37	6.41	7.86	1.3	1.45	6.94	6.4
251	1-19-61	9.30	4.10	5.20	4.10	2.5	..	7.34	10.6
261	6-19-60	6.90	3.62	3.28	6.04	3.0	2.76	7.31	12.5
271	5-60	3.35	.80	2.55	2.84	0.7	.29	7.62	2.5
281	5-60	7.94	4.61	3.33	6.46	3.7	3.13	7.30	15.5
291	5-60	6.45	3.99	3.19	5.87	3.1	2.68	7.32	12.9
301	6-5-60	13.62	11.97	1.65	7.90	13.0	6.25	7.64	45.8

### Khangah Dogran Reclamation Scheme

1	10-28-60	3.80	.80	3.00	1.84	.6	..	7.77	1.8
18	10-25-60	6.20	1.40	4.80	.82	.9	..	7.99	2.5
28	11-28-60	7.00	2.80	4.20	3.69	2.0	..	7.42	7.9
38	10-30-60	6.95	2.95	4.00	3.64	2.0	..	7.44	7.8
48	11-6-60	11.00	7.60	3.40	3.69	5.8	.29	7.60	20.9
57	11-17-60	5.30	1.30	4.00	2.46	1.0	..	7.57	3.7
67	11-11-60	6.00	4.40	1.60	2.46	5.0	.86	7.99	14.1
78	10-21-60	5.60	2.80	2.80	4.10	2.3	1.30	7.51	8.7
93	10-12-60	6.80	2.60	4.20	3.69	1.7	..	7.41	6.8
104	10-8-60	5.20	1.80	3.40	2.25	1.3	..	7.67	4.5
114	10-5-60	6.00	2.20	3.80	1.23	1.5	..	7.91	4.5
128	8-27-60	6.50	3.47	3.03	1.42	2.8	..	7.96	8.1
139	8-23-60	6.40	3.17	3.23	4.99	2.5	1.76	7.38	10.0
155	10-12-60	6.65	1.55	5.10	3.33	1.0	..	7.37	4.0
165	9-23-60	5.00	2.37	2.63	2.85	2.1	.22	7.68	7.2
175	9-26-60	8.20	2.72	5.48	6.42	1.6	.94	7.08	7.4
186	8-30-60	8.30	5.07	3.23	5.35	4.0	2.12	7.40	16.0
200	9-23-60	9.00	5.96	3.04	6.42	4.8	3.38	7.36	19.6
212	9-29-60	10.90	8.87	2.03	8.56	8.8	6.53	7.47	34.0
230	10-4-60	6.20	3.60	2.60	3.23	3.1	.63	7.66	10.8

TABLE 3—(Concluded)

Tubewell No.	Date Sampled	Total conc. me./l.	Na me./l.	Ca+Mg me./l.	CO <sub>3</sub> + HCO <sub>3</sub> me./l.	SAR	Res. Na <sub>2</sub> CO <sub>3</sub> me./l.	pH <sub>c</sub>	Calc.* ESP
<b>Jaranwala Reclamation Scheme</b>									
1/103	6-13-61	12.30	8.80	3.50	6.51	6.7	3.01	7.29	28.3
18/120	6-13-61	8.00	4.71	3.29	4.87	3.7	1.58	7.42	14.8
1	6-26-61	19.45	14.51	4.94	7.56	9.1	2.62	7.29	38.4
21	6-13-61	6.10	3.01	3.09	3.25	2.4	.16	7.57	8.8
31	6-22-61	5.36	1.86	3.50	2.70	1.3	..	7.59	4.7
41	6-24-61	5.42	2.95	2.47	3.24	.9	.77	7.66	3.2
51	6-25-61	11.86	8.16	3.70	10.26	6.0	6.56	7.15	27.0
61	6-5-61	26.00	21.68	4.32	7.05	15.0	2.73	7.48	57.6
72	6-12-61	46.00	32.20	13.80	8.68	12.0	..	7.13	54.5
81	6-7-61	13.50	10.83	2.67	7.05	9.4	4.38	7.48	57.6
136	6-14-61	18.50	12.74	5.76	8.14	7.5	2.38	7.18	33.3
156	6-12-61	9.80	6.92	2.88	2.71	5.0	..	7.79	16.1
<b>Beranwala Reclamation Scheme</b>									
1	11-26-60	16.20	11.80	4.40	7.79	8.0	3.39	7.26	34.4
11	11-25-60	10.30	6.30	4.00	4.51	4.5	.51	7.44	17.6
21	2-23-61	24.20	22.20	2.00	10.25	22.0	8.25	7.62	78.3
31	1-29-61	10.55	8.25	2.30	3.29	7.6	.99	7.80	24.3
42	2-6-61	12.40	10.40	2.00	7.38	10.0	5.38	7.56	36.8
51	2-19-61	24.11	20.27	3.84	9.43	15.0	5.59	7.38	60.6
62	3-9-61	15.35	11.98	3.37	10.86	9.2	7.49	7.22	40.1
71	3-5-61	20.86	17.19	3.67	10.77	12.0	7.10	7.29	50.6
81	2-25-61	26.72	22.68	4.04	13.30	15.0	9.26	7.24	64.8
91	2-27-61	24.00	19.56	4.44	13.12	13.0	8.68	7.16	58.2
101	3-11-61	28.57	25.16	3.41	15.33	19.0	11.92	7.28	80.6

\*Calculated by the equation:  $ESP = 2SAR + 2SAR (8.4 - pH_e)$ .

excess of 15. The "residual  $\text{Na}_2\text{CO}_3$ " and calculated ESP values for the waters are positively correlated but the coefficient of determination is not very high ( $r^2=.69$ ).

Classification of Punjab ground waters as to usability on the basis of ESP values calculated by equation (3) should be considered tentative pending further study. However, waters for which the calculated ESP is 10 or less are probably safe for direct use, those for which the calculated ESP ranges between 10 and 20 might be considered as marginal, and those for which the calculated ESP exceeds 20 are no doubt definitely hazardous unless diluted with sufficient surface water to decrease the calculated ESP to less than 20. The distribution of tubewell waters listed in table 3 among the above ESP classes is shown in table 4. For comparison, the distribution of the waters among the "residual  $\text{Na}_2\text{CO}_3$ " classes tentatively proposed by Wilcox, et al, (1954), is also given in table 4. By both standards of classification, slightly more than one-third

TABLE 4—Distribution of 74 Punjab tubewell waters among classes based on "residual  $\text{Na}_2\text{CO}_3$ " content and calculated ESP values.

Residual $\text{Na}_2\text{CO}_3$ , me./l.	No.	%	Calculated ESP	No.	%
<1.25 (safe)	33	44.6	<10 (safe)	24	32.4
1.25 — 2.50 (marginal)	14	18.9	10 — 20 (marginal)	21	28.4
>2.50 (hazardous)	27	36.5	>20 (hazardous)	29	39.2
Total	74	100	Total	74	100

of the waters may be considered hazardous. Of the remaining waters the calculated ESP places a considerably higher percentage in the marginal class than does the "residual  $\text{Na}_2\text{CO}_3$ " content.

#### SUMMARY AND CONCLUSIONS

It has been firmly established that carbonates in irrigation waters may precipitate in soils as  $\text{CaCO}_3$ , and that the precipitation enhances the tendency of the soil to accumulate exchangeable Na from the water. The fraction of carbonate applied in irrigation water which precipitates in soil is variable and is influenced by several factors including the relative and absolute concentrations of  $\text{Ca} + \text{Mg}$  and  $\text{CO}_3 + \text{HCO}_3$  in the water, the  $\text{Ca} + \text{Mg}$ ,  $\text{CO}_2$  and pH status of the soil, and the degree to which the ionic concentrations of the soil solution increase owing to loss of water by evapotranspiration. The extent to which exchangeable Na accumulates in soils irrigated with high carbonate waters depends upon the SAR of the water as well as upon the fraction of applied carbonate

that precipitates as  $\text{CaCO}_3$ . Moreover, a steady state condition with respect to accumulation of exchangeable Na may not be attained short of nearly complete saturation of the exchange complex for the following reason: As exchangeable Na accumulates, the pH of the soil usually increases and this enhances the precipitation of  $\text{CaCO}_3$ . With additional precipitation of  $\text{CaCO}_3$  the proportion of Na in the soil solution and on the exchange complex increases further, leading to an additional increase in pH and a repetition of the above-described process. The data of Wilcox, et al (1954), showing the pH and ESP of soil following 42 and 86 irrigations with water No. 20b, illustrate this point.

For evaluating the usability of waters containing  $\text{CO}_3 + \text{HCO}_3$  in excess of Ca+Mg, the "residual  $\text{Na}_2\text{CO}_3$ " concept of Eaton seems to have some merit. However, for waters containing high amounts of carbonates but no "residual  $\text{Na}_2\text{CO}_3$ " the concept is unsatisfactory. The empirical equation— $\text{ESP} = 2\text{SAR} + 2\text{SAR} (8.4 - \text{pH}_e)$  involving the SAR and a modified Langelier index appears to be reasonably satisfactory for predicting the Na hazard of high carbonate waters regardless of whether they contain "residual  $\text{Na}_2\text{CO}_3$ ". The equation should be used on a tentative basis, however, pending further study of its reliability.

If the 74 tubewell waters considered in this study are representative of a substantial fraction of Punjab ground waters, then by either the "residual  $\text{Na}_2\text{CO}_3$ " concept or the empirical equation a potential sodium hazard is involved in the use of many of these waters for irrigation. It seems evident that if some of the ground waters are used as the sole source of water for irrigation, the soil will accumulate injurious amounts of exchangeable Na with time. On the other hand, if hazardous ground water is used to supplement surface water for irrigation by dilution or by alternate use, no excessive accumulation of exchangeable Na may occur. Rainfall, where appreciable and effective, may also be expected to have a retarding effect on the accumulation of exchangeable Na from hazardous waters. It is evident that the Na hazard of Punjab ground waters needs further study with particular attention being given as to how surface waters, ground waters, and soils can be managed so as to prevent harmful accumulations of exchangeable Na. In any case, changes in the ESP and permeability of soils over time resulting from the use of ground waters of various qualities should be measured as a means of acquiring information on the Na hazard of the ground waters.

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