THE EFFECTS OF LAND DRAINAGE UPON THE EXCESS BASES OF SEA WATER[1]

PHILIP H. MITCHELL AND JULIAN L. SOLINGER

(From the Arnold Biological Laboratory of Brown University and the Woods Hole Oceanographic Institution)

The total titratable alkalinity of sea water, that is, its buffer capacity for acids, tends to reach an equilibrium such that the total buffer capacity divided by the chlorinity is a constant. This fact has been established by several investigators working on samples from the North Sea and its vicinity and by Thompson and Bonnar (1931), who studied the waters of the region of the San Juan archipelago and Puget Sound. The results of Mitchell and Rakestraw (1933) on Atlantic waters of the Cape Cod and Bermuda regions also revealed the tendency toward constancy of ratio. It is to be expected that when the only important change in the sea water composition is that due to the addition or withdrawal of water by rain or evaporation, this and similar ratios should be constant.

It appears, however, that the ratio as observed in different regions is not necessarily the same. The differences might be due, in part at least, to variations in methods of measurement but this appears not to be the entire explanation (Mitchell and Rakestraw, 1933). It would seem, then, that the oceans are not in apparent equilibrium as regards the ratio of excess base to the salts. But although some approach to a constant buffer capacity-chlorinity ratio is discernible in ocean waters, such is not the case, generally speaking, in the waters of sounds, bays and inlets where equilibrium conditions are more actively disturbed.

Thompson and Bonnar have discussed factors which alter the ratio. Among them are photosynthesis and other effects of plant life and of animal life and the effect of land drainage. Our own experience has shown the latter to be a very significant factor tending, as Thompson and Bonnar found, to raise the buffer capacity-chlorinity ratio but showing, in our observations, great variability with locality, character of the soil and rapidity of drainage, that is, whether surface or deep drainage. It has even appeared possible to us that the character of the soil in different regions of the earth might vary sufficiently in potentiality for yielding bases to the sea to account in part for the differences in the ratio as apparently found in different ocean areas.

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A satisfactory illustration of the land drainage effect was obtained by observations on Narragansett Bay. It is a relatively long and narrow body of salt water. No large, long rivers enter it so that the drainage which it receives is of comparatively local origin. Measurements of buffer capacity were made by a method described in a previous communication (Mitchell and Rakestraw, 1933). The results of typical observations, as shown in Table I, reveal what is probably demonstrable for any similar body of water, namely, that the lower the salinity the higher, in general, is the buffer capacity-chlorinity ratio. This is a tendency rather than an exact relationship because of the disturbing

TABLE I

The Relative Buffer Capacity of Narragansett Bay Water Samples Arranged in Decreasing Order of Chlorinity

Chlorinity *grams per liter*	Ratio $\frac{BC}{Cl}$	Chlorinity *grams per liter*	Ratio $\frac{BC}{Cl}$
19.50	0.1143	15.94	0.1272
19.00	0.1153	15.93	0.1242
18.10	0.1222	15.50	0.1191
17.90	0.1227	15.50	0.1216
17.38	0.1210	15.40	0.1275
17.38	0.1217	15.22	0.1266
17.02	0.1208	15.05	0.1307
17.02	0.1208	14.96	0.1229
16.85	0.1189	14.60	0.1283
16.84	0.1171	14.52	0.1383
16.73	0.1186	14.45	0.1338
16.72	0.1239	14.06	0.1345
16.55	0.1200	13.88	0.1364
16.48	0.1223	13.15	0.1258
16.36	0.1214	13.04	0.1425
16.31	0.1251	11.92	0.1535
16.20	0.1258	5.40	0.1630
16.16	0.1237	3.61	0.1690
16.05	0.1188		

effects of tidal currents, storms, freshets and local conditions such as the relative abundance of plant and animal life.

In order to demonstrate more clearly the relationship between dilution of estuary waters and their buffer capacities, observations were made upon various series of mixtures of salt water with fresh water from selected sources. In every case progressive dilution caused a rise in the buffer capacity-chlorinity ratio such that the latter plotted as ordinates against the chlorinity as abscissas gave a smooth curve. The rise in the ratio with addition of fresh water was not, however, the same in all cases. To illustrate typical variations, a number of the curves obtained are shown in Figs. 1 and 2.

Curves *A, B* and *C* were obtained by dilution of Narragansett Bay water with that of the Pawtuxet River which drains the watershed supplying the city of Providence. The fact that observations on the undiluted salt water from the bay, giving the lowest point of each curve, do not yield closely approximating results is due to the circumstance that water collections were made at different stages of the tide and in one case (*A*) shortly after an easterly storm which raised the salinity of the water above its usual value. This is in part the explanation of the different levels of the curves. But it may also be seen that the slopes of the curves are different.

Curve *A,* obtained on March 7, 1933, illustrates the effect of an easterly storm in that the undiluted bay water has a relatively high

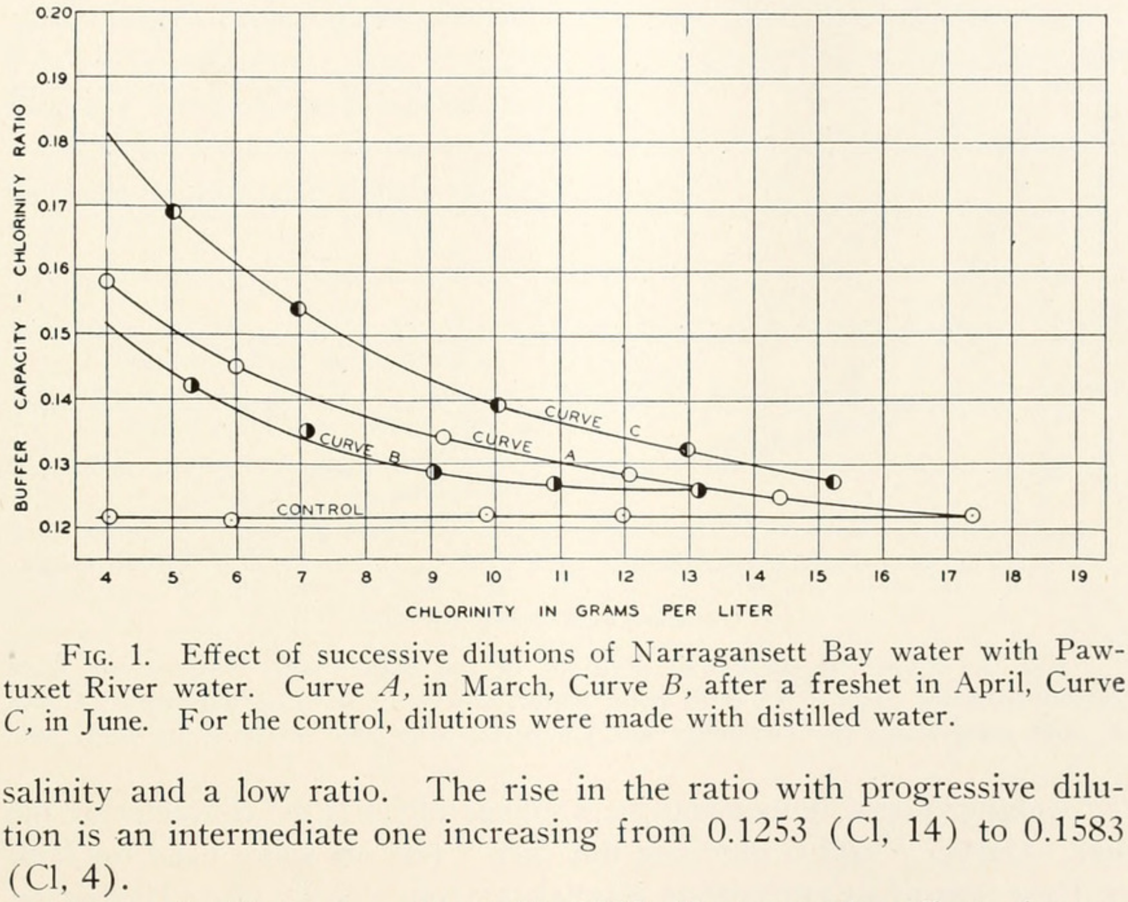

Fig. 1. Effect of successive dilutions of Narragansett Bay water with Pawtuxet River water. Curve *A,* in March, Curve *B,* after a freshet in April, Curve *C,* in June. For the control, dilutions were made with distilled water.

salinity and a low ratio. The rise in the ratio with progressive dilution is an intermediate one increasing from 0.1253 (Cl, 14) to 0.1583 (Cl, 4).

Curve *B,* obtained on April 11, 1933, illustrates the effect of mere surface drainage. There had been a light snowfall followed by especially heavy and prolonged rain. The river was at spring freshet level. The ratio increased only from 0.1252 (Cl, 14) to 0.1520 (Cl, 4).

Curve *C,* however, illustrates the more typical effect of the true soil drainage of this area. Sampled on June 13, 1933, after a period of approximately normal rainfall, the river water raised the ratio from 0.1293 (Cl, 14) to 0.1820 (Cl, 4).

There is then a seasonal variation in land drainage effects upon the titratable base of estuary waters. The larger the proportion of deep soil drainage to surface run-off, the greater is the effect in this particular type of drainage area.

Curves *D* and *E* illustrate the relatively large effect of deep soil drainage in another way. The salt water in these cases came from Sakonnet Point at the more easterly of the two mouths of Narragansett Bay. The fresh water in the case of curve *D* was taken from a pond about one mile inland from the Sakonnet shore and in the case of curve *E* from a clear deep spring near the edge of the same pond. The ratio in curve *D* increased from 0.1240 (Cl, 16) to 0.1381 (Cl, 6) while in curve *E* the increase was much greater, from 0.1182 (Cl, 16) to 0.1490 (Cl, 6).

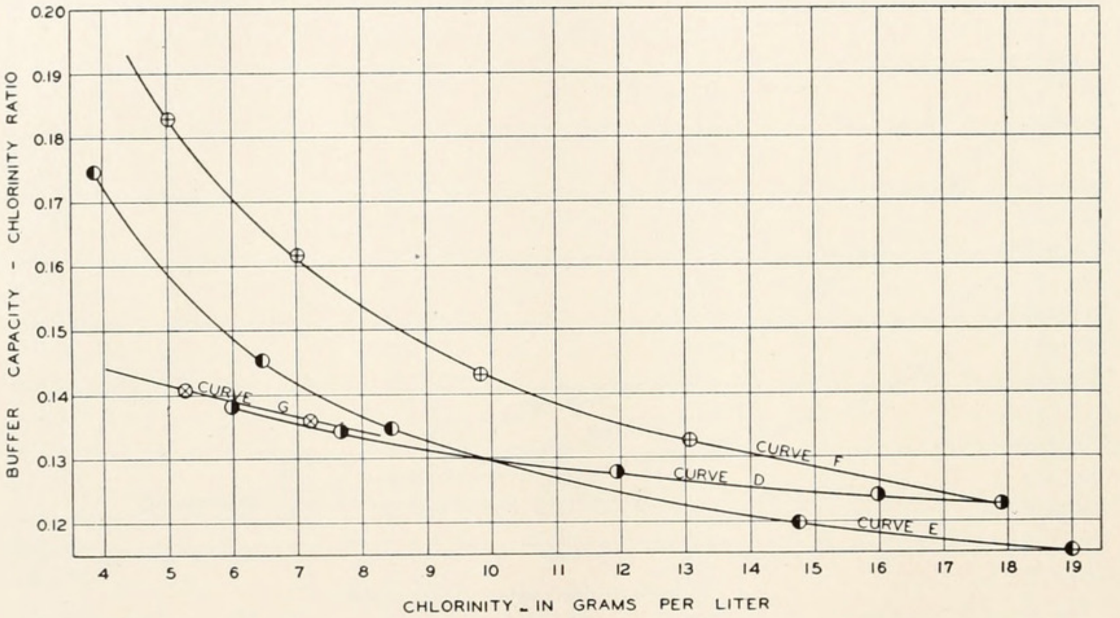

FIG. 2. Effect of successive dilutions of sea water with fresh water from various sources. Curve *D,* with pond water, Curve *E,* with spring water, Curve *F,* with pond water from swampy soil, Curve *G,* with pond water from sandy soil.

Another factor influencing the drainage effect is the character of the soil. Curves *F* and *G* illustrate this fact. The sea water used for both of these sets of measurements was taken from Woods Hole Harbor on June 14, 1933, after a period of only moderate rainfall. The fresh water used for the dilutions of curve *F* was collected on the same day from a nearby pond in a swampy area, while that used for curve *G* came from another pond about four miles away entirely surrounded by very sandy soil. Curve *F* shows a rise of the ratio to 0.1832 (Cl, 5) but curve *G* rises only to a ratio of 0.1416 at the same dilution. Apparently a barren, sandy soil yields comparatively little excess base to its drainage water.

The curve at the bottom of Fig. 1 indicates data for a control upon the accuracy of the measurements and the reproducibility of the results. It was obtained by adding distilled water to a sample of Narragansett Bay water. It shows no change, in excess of the limits of observational error, in the ratio even when the chlorinity is diluted to 4 grams per liter. The probable error of a single determination of the ratio is found to be approximately ± 0.0007, a value in accord with numerous other estimations of the probable error of this method.

Summary

1. Land drainage tends, in general, to raise the buffer capacity-chlorinity ratio of sea water.

2. Heavy rains measurably decrease the proportional effect.

3. The effects of deep soil drainage are greater in raising the ratio than are those of mere surface drainage.

4. The character of the soil alters the effect. Sandy soil may yield measurably less base than a richer soil.

REFERENCES

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