A Study on the Coastal Ground Water at Yumigahama, Tottori

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Abstract

Several years ago we published a theory and model experiments on the contact surface of fresh- and salt-water under the ground near a sandy sea-shore and fortunately some interest was taken in our study by scholars in various countries. For the actual verification, the writer intended to make observations on a real coast perform, and recently carried out his intention at Yumigahama, Tottori Prefecture. The results show that our theory of coastal ground-water based on hydrodynamical considerations holds good for the actual sea-shore as well as for model experiments.

§ 1. Introduction

One of the most interesting and practical problems of coastal ground water is the infiltration of sea-salts. Under the ground near the sandy sea-coast, a stratum of fresh water pouring into the sea from the land lies over a stratum of salt water, the state of equilibrium being maintained according to the respective specific gravities of the two layers. Herzberg[1] states, from the results of investigation in Norderney Island, that both fresh- and salt-water strata on such sandy hills are in a state of statical equilibrium, and that the depth of the contact surface of the two water layers can be determined from their specific gravities (ρ, ρ_0), and the height (y) of the water table from the sea level. He gives the following formula

$$y'\rho=(y'+y)\rho_0 \quad \text{or} \quad \frac{y'}{y}=\frac{\rho_0}{\rho-\rho_0} \qquad \text{..................(1)}$$

where y' denotes the depth of the contact surface from the sea level. But, in order to ascertain the form of the contact surface by Herzberg's equation only, me must observe the level of ground-water-table at innumerable points. Prof. Nomitsu[2] studied the problem from the hydrodynamical standpoint, and derived a formula for the shape of

1. J. f. Gasbel u. Wasservers. **44**, 815 (1901).
2. T. Nomitsu, Y. Toyohara and R. Kamimoto. These Memoirs, A, **10**, 279 (1927)

the contact surface and obtained the important result that the contact surface could be determined by measuring the level of the fresh-water table at any two points only. His formula is as follows. If we take the coordinate origin at the mean sea-level on the strand-line, and the x-axis in the horizontal direction landwards and denote by h_0, h_L and y' the heights of the water table at $x=0$ and $x=L$ and the depth of contact surface respectively, then the shape of the contact surface will be given by

$$y'^2 = H_0^2 + \frac{H_L^2 - H_0^2}{L} x \qquad \text{.............................}(2)$$

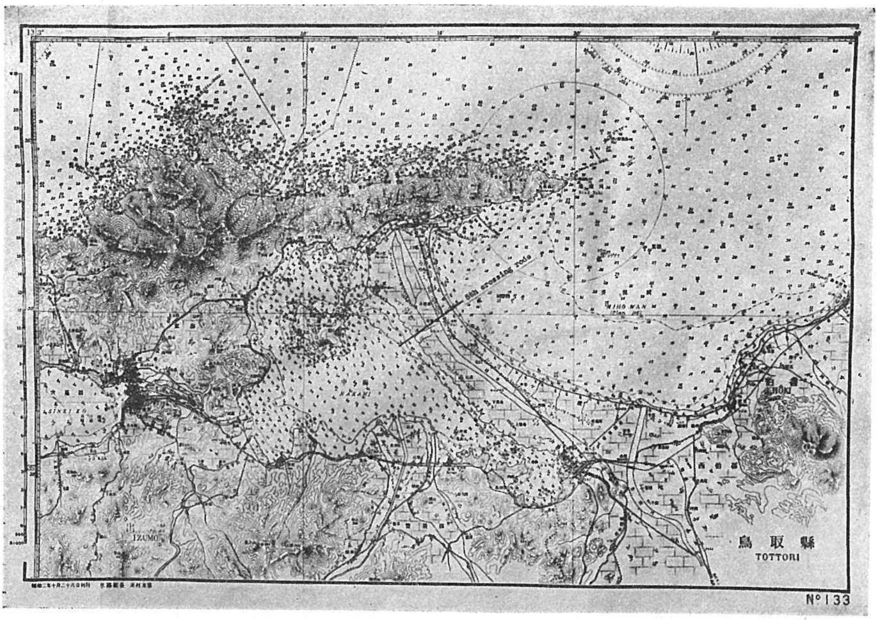
where $H_0 = \dfrac{\rho_0}{\rho - \rho_0} h_0$, $H_L = \dfrac{\rho_0}{\rho - \rho_0} h_L$. To verify this formula, the present writer with Mr. Kamimoto performed their model experiments in the laboratory, and got fairly concordant results. The theory and the model experiments were published in one paper in 1927. Then, the author was eager to complete the study by actual observations in a real coast, but the considerable expense involved prevented the execution of this plan for a long time. Fortunately, however, he got a grant from Nippon Gakujutsu Shinko-Kwai recently, and was able to perform several measurements at the coast of Yumigahama, Tottori Prefecture during about one year since July 1933.

The results of observation constitute this paper and show that our theoretical consideration is also valid for actual sea-coasts.

§ 2. Selection of Site for Experiments

To investigate the conditions in which fresh- and salt-water maintain equilibrium under the ground of the sea-coast, we must choose a place where the tidal effect is slight. Moreover, the best place is naturally a sandy coast where no rocks or other obstacles exist under-ground down to a sufficient depth. For these reasons we chose the coast of Yumigahama, Tottori Prefecture, facing the Japan Sea of small tide. This peninsula is a sandy bar about 18 kilometres in length and about 3 kilometres in width. The River Yone, an irrigation canal running along the central axis of the bar, always regulating the ground-water there. Thus this was a very suitable place for our experiments. Then, in order to find a suitable operating locality, we inspected the entire coast with the assistance of the Arable Land Section of the prefecture and neighbouring towns, and decided to operate along the fifth crossing road of the outside beach.

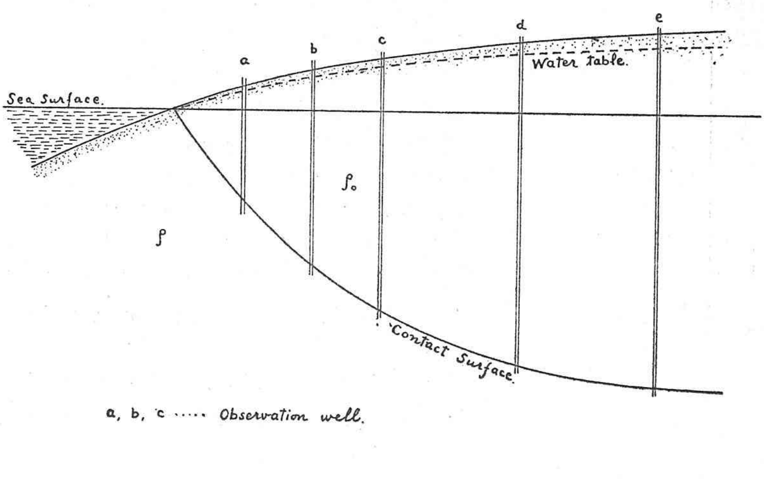
Fig, 1



§ 3. Method of Actual Experiments

We fix many observation points at various distances from the coast-line along the fifth crossing road in Yumigahama, and at each point drive an iron pipe of 2 inches diameter to make observation wells as shown in Fig. 2. By means of these wells, the level of water table, the temperature of ground-water and quantities of contained salt

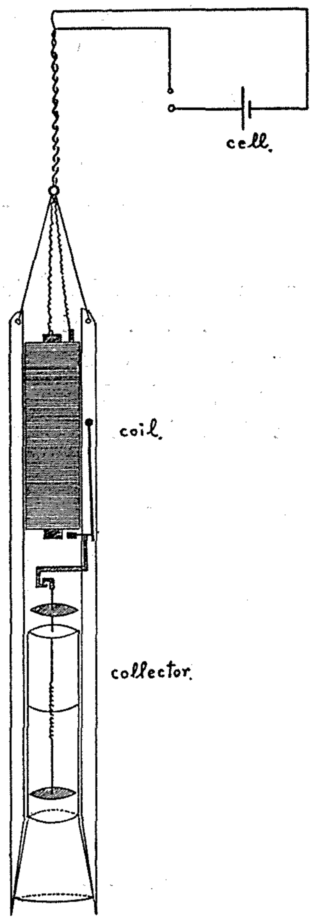
Fig. 2



are to be measured. As the soil is sandy, the iron pipes could be driven directly into ground to a depth of within 30 or 40 metres. But, for the deeper well we had to insert iron-pipes after boring with " Kazusa-bori ". Some of the iron-pipes used were ordinary ones, but others were set up with many holes specially arranged around the periphery, and their sharp ends were provided with numerous smaller holes and wrapped round with wire-gauze, etc.

(i) *Method of boring.* Generally the iron-pipes are driven in by a boring weight (about 25 kgs.) and after every one or half metre of driving a sucker is inserted, the internal water and soil are sucked out, and then the pipes are driven in again, and so on. The sucker is a cylindrical tube made of corrugated iron, 1.2 inches in diameter and about 2 metres long, having a leather valve at the lower end. When we insert it in the iron-pipe and oscillate it up and down, it absorbs the water and soil in the lowest portion of the well. The iron-pipes, with small holes at the ends or wrapped round with wire-gauze, are used generally for shallow wells within 10 metres' depth and water is taken out by a pump every half metre. Thus we can save the trouble of inserting a sucker, but is is difficult to drive pipes deeper by this method.

Fig. 3



As the " Kazusa-bori " is a method of boring, always filling up the hole liquid clay and preventing collapse by the balancing internal pressure, it is impossible to measure the salinity of the ground water while at work as in the driving method. It is a method, however, that has been used from ancient times for deep boring, so we tried it to see whether it would suit our experiments.

(ii) *Method of measurement of contained salt.* The salt contained in the ground-water can be easily measured by silver nitrate titration. The only difficulty is to collect the water from any depth within the iron-pipe of 2 inches diameter without disturbing the water. For this purpose, we constructed a special small collecting bottle, as shown in Fig. 3. This is made of metal, 35 cms. in whole length, 3 cms. in outward diameter, and its upper half portion is iron cored coil 10 cms. long, 2 cms. in diameter, and its lower half constitutes a cylindrical collector 15 cms. long and 2 cms. in inner diameter. We open the upper and lower lids by means of a spring in the centre, and suspend both poles of coil from the top with two rubbered wires. After having lowered it to the desired depth in the well, a circuit is made with a dry cell, when the two lids close simultaneously by action of the spring. When the water-bottle is opened, the water can pass freely through it, and therefore if the lowering of the bottle is done very slowly, it is possible to collect water at any depth, practically without disturbing it. The quantity of water taken in by this instrument at a time is 50 c.c., and this is sufficient for examination of the contained salt.

(iii) *Method of measuring temperature of ground-water.* In a two inch pipe, of course, an ordinary marine thermometer cannot be used. Hence we measured the temperature by the variations of electrical resistance of copper wire, and also by a platinum resistance thermometer. But in order to take a large number of measurements quickly, it was most convenient to use non-sensitive mercury thermometers, and for measuring the water-temperature only we often used ground-thermometers.

(iv) *Method of measuring level of water table.* To determine exactly the level of the water-table within the iron pipes, we used the sensitive limnimeter which we had constructed and used many years ago when we investigated the underground flow in the bed of River Hino, Tottori. Its construction was explained by Prof. Nomitsu[1] in the report of Nippon Gakujutsu Kyokai Vol. 4. Of course, the mutual heights of the upper ends of the observation wells were determined by ordinary levelling.

(v) *Additional investigation.* As it is neccessary for us to know the variation of sea-level, salinity and temperature of sea-water etc. in the outer sea, and the variation of the water table by precipitation during the executive term of observation, we set up a tidal-well near the sea-shore and put Richard's self-recording limnigraph in it, and observed the sea-level. The observations of the temperature and salinity

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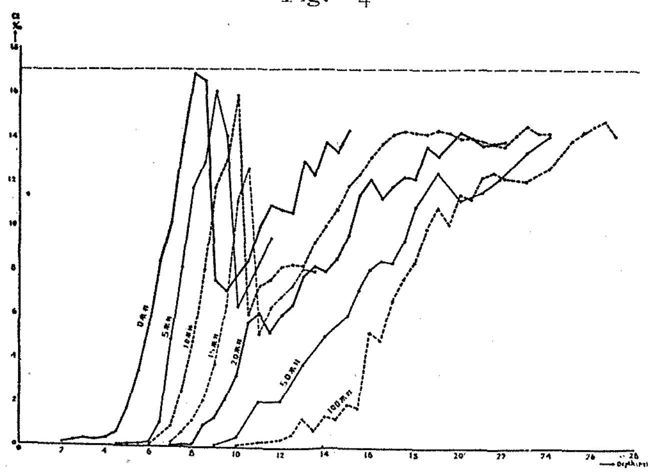
1. T. Nomitsu, On the measurement of quantities of underground-water. (Japanese) Rep. of Japanese Association for the Advancement of Science. **4**, 79 (1928).

of the coastal sea-water, and the variation of the water table in the wells were made at a fixed time every day. In order to investigate the hydrological character of sands under the ground, we collected samples of soil of about one litre at every one or half metre of boring for each observation well.

§ 4. Results of Experiments

(i) *Investigation of contained salt in the ground-water.* After we had tried various methods of boring the observed wells and compared their efficacy, we used the driving method for the most part near the shore. The results of determination of the contained salt at each depth of the observation wells, are shown in Table 1, and illustrated in Fig. 4.

Fig. 4



These figures (Table 1) show that the state of salinity near the shore differs greatly from that at some distance out, and that as to the former, the deeper we dig, the more the salinity increases, rapidly at first, and after momentary rapid decreases in the middle, slowly increases again. Indeed a most peculiar phenomenon! On the contrary, at some distance from the shore, the salinity increases slowly but steadily, after salt has been detected. When we investigated the rate of increase of salinity in further detail, almost similar states were found in 0 m, 5 m, 10 m and 15 m wells[1], and the rate of increase of Cl was almost 5‰

1. Name of observation well shows by the distance from original bench to landward. For example, 15m well is a well 15 metres distant from the original bench on the strand line.

Table 1

Depth \ No. of Well. Distance.	I. 0m	II. 5m	III. 10m	IV. 15m	V. 20m	VI. 50m	VII. 100m
m	%						
0.0	0.050	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.074	0.000	0.000	0.000	—	—	—
1.0	0.074	0.000	0.000	0.056	0.000	0.000	0.000
1.5	0.074	0.000	—	0.056	—	—	—
2.0	0.099	0.000	0.000	0.056	0.000	0.000	0.000
2.5	0.124	0.023	—	0.056	—	—	—
3.0	0.310	0.023	0.025	0.084	0.056	0.000	0.000
3.5	0.248	0.023	—	0.056	—	—	—
4.0	0.285	0.047	0.025	0.056	0.056	0.000	0.000
4.5	0.558	0.047	—	0.056	—	—	—
5.0	1.737	0.047	0.050	0.056	0.056	0.000	0.000
5.5	3.329	0.070	—	0.084	—	—	—
6.0	5.522	0.117	0.124	0.056	0.056	0.000	0.000
6.5	8.395	1.049	—	0.112	0.056	—	—
7.0	10.087	4.839	0.869	0.112	0.056	0.000	0.000
7.5	13.720	8.104	2.482	0.629	0.056	—	—
8.0	16.853	11.718	4.703	1.258	0.140	0.000	0.000
8.5	16.515	12.826	8.067	2.097	0.923	—	—
9.0	7.518	15.974	11.765	3.775	1.258	0.073	0.024
9.5	6.892	13.934	12.894	6.291	2.083	—	—
10.0	7.706	6.238	15.823	11.184	3.215	0.545	0.120
10.5	8.270	7.229	5.932	12.512	5.550	—	—
11.0	9.874	8.277	7.267	5.018	6.053	2.024	0.252
11.5	10.901	9.386	7.518	6.221	5.103	—	—
12.0	9.771		8.145	6.710	5.928	2.109	0.361
12.5	9.503		8.207	7.269	6.361	—	0.577
13.0	12.753		8.270	8.178	7.703	3.721	1.298
13.5	12.290		9.147	7.983	8.111	—	0.793
14.0	13.810		9.948		7.924	5.006	1.418
14.5	13.304		10.769		8.528	—	1.310
15.0	14.254		11.794		9.602	5.963	1.983
15.5			12.307		11.415	7.139	1.911
16.0			13.012		12.154	8.072	5.229
16.5			13.653		11.201	8.508	4.808
17.0			14.166		11.778	8.399	6.683
17.5			14.358		12.221	9.345	7.609
18.0			14.230		12.288	10.934	8.474
18.5			14.166		13.658	—	9.844
19.0			14.294		13.108	12.406	10.854
19.5			14.294		—	—	10.181
20.0			13.974		14.249	11.064	11.295
20.5			13.974		—	—	11.281
21.0			13.846		13.618	11.511	12.191
21.5			13.717		—	—	12.418
22.0			13.589		13.819	12.100	12.358
22.5			14.102			—	—
23.0			14.487			13.371	12.032
23.5			14.230			—	—
24.0			14.230			14.006	12.684
24.5							—
25.0							13.940
25.5							—
26.0							14.581
26.5							14.726
27.0							14.134

per metre for the first 10 metres approximately. Namely, at about 3～4 metres depth after salinity first began to increase, almost the same salinity as in the outer sea was reached, and after further boring, the salinity decreased rapidly to 1/3 the maximum value, then increased again at a rate 1.5 ‰ of Cl per metre, down to the 20 metre stratum. Analogous rates of increase were found for 50 m and 100 m wells. As we detected salt near the 10 metre stratum for both of these wells, we knew that the condition was same in depth below 10 metre under the water table, whether near the distance from the shore. Thus the conditions of increasing salinity are divided into two quite different sorts, with a boundary at 10 metre or so, the increasing rate in the upper stratum being about three times that in the lower, and 20 m well in the middle in place has both characteristics. At depths greater than 20 metres in all observation wells, the rate of increase decreased gradually, and the salinity approached asymptotically that of the open sea. Thus, it seemed likely that the decrease of salinity near the ten metres stratum depends upon the nature of the soil. When we investigated the collected sands, the stratum in which salinity decreased rapidly was the layer in which fine sands turned to Hedro-stratum[1]. As the boring of this stratum wanted twice or thrice the time necessary for sand stratum, it would appear that the stratum is semi-impervious. The organization of the salinity distribution in such a semi-impervious stratum is a problem for future study. Moreover, the salinity in the upper part of the ground-water by the observation well nearest the coast line was very slight down to 4 metres below the level of water, and beyond 4.5 metres it increased suddenly; i. e. the contained Cl was 0.31‰ (S=0.63‰) at 4 metres' depth, i. e. the same order as common river-water, and the water can in practice be supplied as fresh-water for drinking purposes. In the immediate vicinity of the shore there exists a fresh-water layer several metres thick, a phenomenon that presents a considerable difference from prevailing ideas on a subject of which there have been few exact investigations.

I believe that this result will supply material not only for scientific hydrology but also for the more practical subject of drinking water in coastal regions.

(ii) *Observation of water-table and levelling.* It is an important

1. Hedro is the local name of a sandy slime or silt, and consists of fine sand 40% and subclay 40% besides other ingredients.

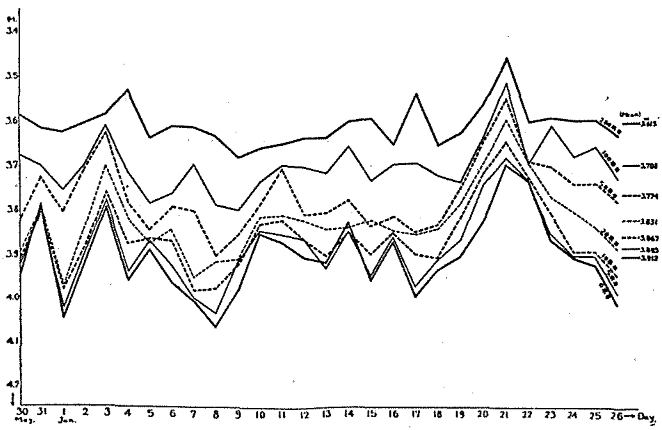
part of this investigation to determine the exact shape of the water table. As it constantly changes by virtue of rainfall and other factors, it is not so simple to decide level difference among the observation-wells. Wells near the shore are specially influenced by tidal action, and the effect differs in amplitude and phase according to the distance from the sea-shore, so that for the present purpose the relative levels cannot be obtained merely by simultaneons levelling. We must determine the shape of the water table on an average condition. At the coast under consideration, the daily amplitude of tide, though small, is 15 cms. on average, and the irregular rise and fall of the sea level, in a period of several days, happens to be 70 cms. These actions some what degree decrease within the sand stratum, but in order to determine the level difference of a few cms. order among the observation wells dear the shore, we must contrive some means to exclude the influence of fluctuation of the sea-level. For this reason, in three wells specially set up near the shore and another well 200 metres distant away from the shore, we observed the ground-water level over a period of about half a month by simple measurement with a long rule and a weight. The result showed that, during our observation, the range of variation of the ground-water itself, was 50~60 cms. near the shore, but was 18 cms. at the point 200 m. away from the shore; i. e. irregular fluctuation of the sea level, having a period of several days, gave no small influence near the coast. But, this influence of irregular fluctuation would be eliminated by taking many days' continuous observation. The influence of the regular tide near the shore can be excluded in greater part, if we fix the observation time every day during a long term. Therefore, we drove new two-inch iron-pipes for observation of water-level at eight points situated at 0, 5, 10, 15, 20, 50, 100, 200 metres distance from the original bench-mark on the strand, and took observations continuously with our accurate limnimeter at a fixed time every day for about a month.

We were afraid that the observation well might move up or down during our observation term, so we set up bench marks (5 inch wood piles plugged with concrete) beside each well. To measure the level difference between each well top and the upper surface of corresponding bench mark we used Bamberg's Level, and we made levellings twice off and on. In the middle of the observation an accident occurred to the 15 metre well and the well became useless. The observed results for the other wells are shown in Table II. and in Fig. 5.

Table II

No. of Well. / Distance. / Date.	I. 0^m	II. 5^m	III. 10^m	V. 20^m	VI. 50^m	VII. 100^m	VIII. 200^m
	m						
May 30	3.950	3.928	3.912	3.899	3.826	3.678	3.587
31	3.794	3.805	3.801	3.796	3.729	3.707	3.619
Jun. 1	4.052	4.027	3.988	3.976	3.810	3.760	3.630
2	3.930	3.909	3.892	3.850	3.714	3.710	3.609
3	3.792	3.776	3.764	3.706	3.627	3.613	3.591
4	3.963	3.947	3.878	3.822	3.789	3.718	3.532
5	3.894	3.875	3.870	3.876	3.852	3.792	3.648
6	3.969	3.931	3.874	3.849	3.801	3.768	3.620
7	4.013	4.006	3.991	3.961	3.809	3.702	3.623
8	4.073	4.039	3.983	3.923	3.911	3.795	3.641
9	3.988	3.930	3.930	3.920	3.868	3.806	3.688
10	3.858	3.852	3.841	3.822	3.800	3.744	3.670
11	3.880	3.861	3.829	3.820	3.717	3.705	3.659
12	3.911	3.877	3.874	3.832	3.820	3.713	3.647
13	3.922	3.938	3.913	3.848	3.811	3.727	3.645
14	3.839	3.854	3.855	3.847	3.786	3.664	3.606
15	3.968	3.954	3.905	3.830	3.838	3.738	3.601
16	3.872	3.865	3.856	3.851	3.814	3.702	3.660
17	4.002	3.983	3.901	3.860	3.854	3.700	3.647
18	3.941	3.922	3.917	3.850	3.839	3.732	3.661
19	3.910	3.876	3.826	3.792	3.762	3.746	3.634
20	3.833	3.748	3.725	3.701	3.651	3.643	3.570
21	3.702	3.690	3.654	3.604	3.553	3.525	3.466
22	3.742	3.741	3.736	3.703	3.701	3.709	3.611
23	3.873	3.862	3.818	3.780	3.708	3.618	3.602
24	3.912	3.907	3.897	3.812	3.749	3.688	3.608
25	3.929	3.912	3.900	3.846	3.750	3.667	3.609
26	4.018	3.996	3.952	3.893	3.789	3.740	3.642
Mean.	3.912	3.893	3.867	3.831	3.774	3.708	3.615

Fig. 5



(iii) *Observation of temperature of the ground-water.* In order to determine the specific gravity of ground-water we must measure its temperature as well as its salinity. Therefore, we previously arranged to measure the temperature at the same time as the salinity. But the measurement of the temperature compelled us to stop boring for the time being, which was not necessary in determining the salinity. This, however, interfered with the progress of operations, and moreover, in regions deeper than 5 or 6 metres, the variation of temperature is very small. We therefore put a ground-thermometer after sunset into the lowest portion reached at the end of the day's boring, and read it before commencing operations next morning. Table III shows the temperatures observed by this method.

Table III

Well.	Depth.	Temperature.	Date.
	m	°	
0 m	2.0	15.6	May 7
	7.0	13.0	„ 8
	10.0	13.2	„ 9
	12.5	13.3	„ 10
	16.0	13.1	„ 11
		13.65 (mean)	
5 m	6.0	13.6	May 26
	12.0	13.1	„ 27
		13.35 (mean)	
10 m	7.0	12.9	May 6
	11.0	13.5	„ 7
	12.0	13.4	„ 8
	15.0	13.4	„ 9
	21.0	13.9	„ 19
	26.0	13.6	„ 20
		13.45 (mean)	
15 m	5.0	13.4	May 27
	11.0	13.6	„ 28
	16.0	14.0	„ 29
		13.67 (mean)	
20 m	11.0	13.4	May 28
	15.0	13.2	„ 29
	24.0	13.4	„ 30
		13.33 (mean)	
50 m	8.0	13.6	Nov. 22
	11.0	13.7	„ 23
	15.0	13.4	„ 30
	19.5	13.5	Dec. 3
	21.5	13.7	„ 4
	26.0	13.3	„ 6
		13.57 (mean)	
100 m	4.0	14.3	Oct. 17
	7.0	14.1	„ 19
	22.0	13.5	„ 26
	27.0	13.2	Dec. 4
		13.78 (mean)	
200 m	20.0	13.7	Nov. 14
	30.0	13.9	„ 18
	50.0	14.2	Dec. 3
		13.93 (mean)	

From the vertical distribution of temperature in each well, we see that the variation of temperature of the part deeper than 5 or 6 meters is of the same order as the observation-error; only in the 200 m well, bored deepest, the temperature indicated a slight rise in the deep stratum. The vertical average temperature of each well is about 13°, and the total average is $13^{\circ}.60$.

(iv) *Observations of salinity and temperature in the open sea.* If the ground is completely pervious, the salinity in the deep stratum should agree with that of the open sea. Moreover, in order to determine the specific gravity of sea-water its temperature must be known. Hence we observed temperature and salinity of the coastal sea-water once a day during the operational period. Mean salinity and mean temperature of sea-water and mean specific gravity calculated from these data are as follows :—

Observation period.	Quantities of (Cl).	Temperature. (θ)	Specific gravity. (σ_t)
Oct. 12～Oct. 28	17.495‰	$20^{\circ}.84$	21.99
Nov. 12～Dec. 5	17.414	16.09	23.02
May 5～Jun. 26	17.017	19.07	21.78

Especially, mean values during investigation of boring near the coast (May 5th～28th) are Cl=17.03 ‰ $\theta=18^{\circ}.02$ $\sigma_t=22.06$. The quantities of contained chlorine in the table above are those of coastal sea-water; and a sectional observation in the front offing shows us that the quantities increase 1 ‰ or so.

§ 5. Comparison with Our Theory

Let us now compare the results of experiments with our theory.

(i) *The upper boundary of fresh-water layer.* The theoretical formula for the upper boundary of fresh-water is

$$y^2=h_0^2+\frac{h_L^2-h_0^2}{L}x \qquad \cdots\cdots(3)$$

The mean water-level in each well reduced from Table II, taking a standard surface near the sea-level and measuring y vertically upwards, is as follows :

Distance from the coast (x)	m 0	5	10	20	50	100	200
Water level from standard surface (y)	m 0.030	0.049	0.075	0.111	0.168	0.234	0.327

There is a level difference of 29.7 cms. between 0 m. well and 200 m. well. Now using the values of only these two wells, let us determine the shape of the upper boundary from the above formula.

$h_0=0.030$, $h_L=0.327$ and $L=2000$ $\therefore$ $y^2=0.009+0.000530\,x$ ...(4)

If we calculate the water-levels of other wells from this theoretical equation (4) and compare the results with the observed values, a very fair coincidence will be seen, as shown herewith:

Distance x	0 m	5	10	20	50	100	200
Calculated y	0.030 m	0.060	0.079	0.107	0.166	0.232	0.327
Observed y	0.030	0.049	0.075	0.111	0.168	0.234	0.327

Further, the empirical formula obtained by Least Square, using the observed values of the above-mentioned seven wells, agrees with the theoretical equation (4) very well, as shown below:

Empirical formula $y^2=0.000854+0.000533\,x$

Theoretical formula $y^2=0.000900+0.000530\,x$

(ii) *The lower boundary of fresh-water layer.* (Contact surface of fresh- and salt-water) The theoretical formula for the lower boundary may be transformed into the following formula from equations (2) and (3)

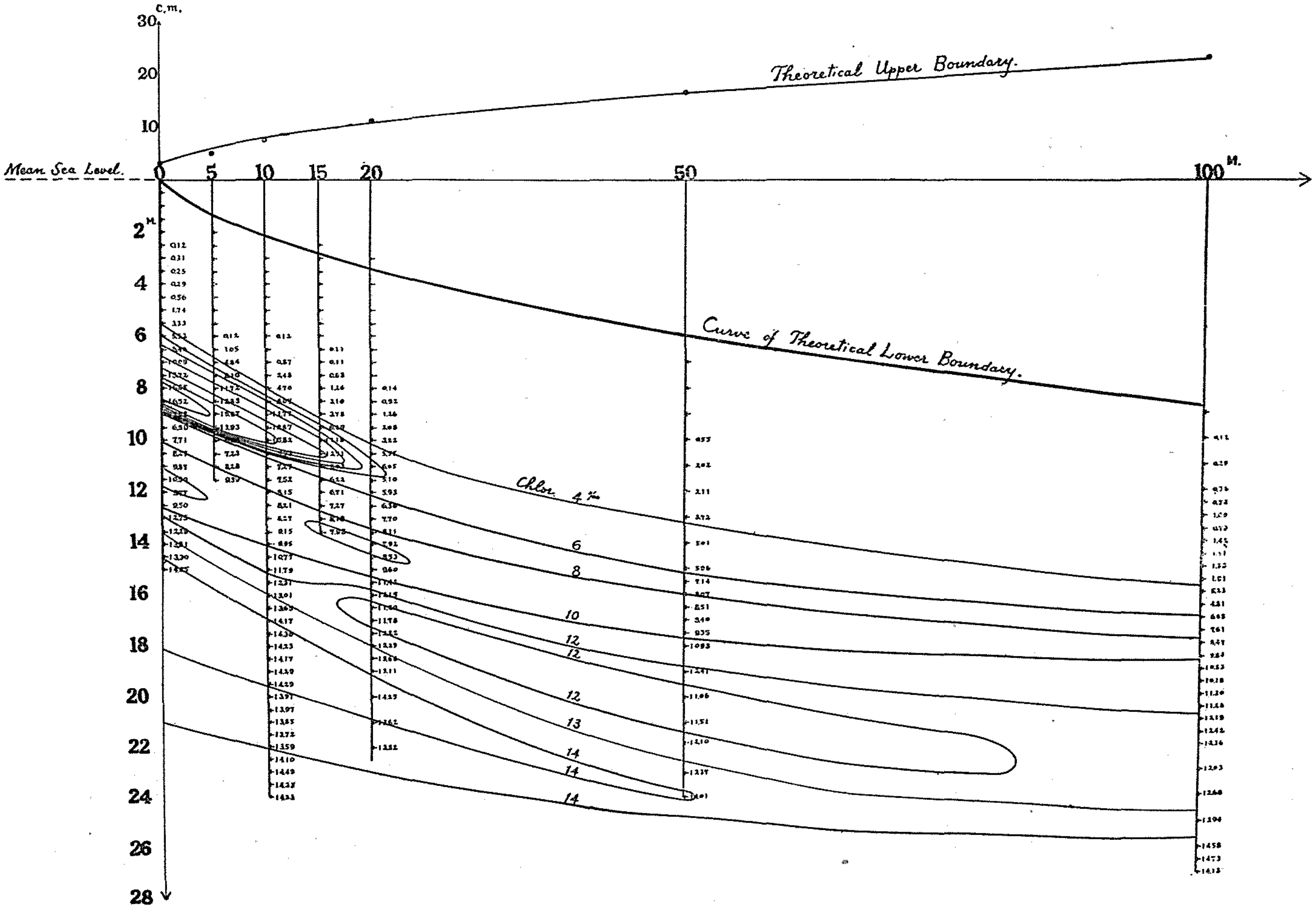
$$y'=\frac{\rho_0}{\rho-\rho_0}y \qquad \text{...(5)}$$

Using the mean salinity in the open sea Cl$=17.03$ ‰ and the average temperature of the ground-water $\theta=13.^{\circ}60$, we get the specific gravity in situ $\rho=1.02303$ as $\rho_0=1$, and formula (5) becomes $y'=43.42y$

$\therefore$ $y'^2=1.6968+0.0999207\,x$ ....(6)

This is the theoretical curve obtained by means of the water-levels of wells at both ends and by the specific gravity of fresh- and salt-water under the ground. On the other hand, the sectional-diagram of the actual distribution of salinity is as in Fig. 6.

Owing to the Hedro stratum (Semi-impervious) which exists at about 10 metres' depth, the distribution of salinity is quite different at its upper and lower extremities; and though we cannot determine the lower boundary of the fresh water as distinctly as the upper, the shape of the isohaline is very similar to the curve which is given by theoretical formula (6), that is the thick line in the figure. If there is no Hedro stratum and the whole is sand, the isohaline may crowd, and probably the lower boundary will resemble the line shown as Cl$=6$ ‰ in the figure. If we put the theoretical curve over it, it nearly coincides. In addition, we notice that every isohaline shows a tendency to rise for the 100 m. well, as compared with the theoretical curve.


c.m.
30
20
10
Theoretical Upper Boundary.
Mean Sea Level.
0
5
10
15
20
50
100 M.
2 M
4
6
8
10
12
14
16
18
20
22
24
26
28
Curve of Theoretical Lower Boundary.
Chlor. 4 ‰
6
8
10
12
12
12
13
14
14
14

§ 6. Conclusion

According to the above results, our theoretical view of the coastal ground-water based on hydrodynamical considerations was ascertained to hold good for the actual sea-shore as well as in model experiments. Moreover, we found that the fresh-water layer may sometimes be 4 metres thick, even at the actual coast line. Besides, we met several other noticeable facts relating to the condition of diffusion of salt near the contact surface of both layers, the peculiar distribution of salt due to a semi-impervious stratum, and the effect of ununiformity of hydrological character of sand stratum, etc. Studies of these problems will be reserved for some later days after careful examination of the 300 soil samples collected during the experiments.

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