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The Wells in the Central Section of the Nasuno-Basin— The Fluctuation of the Water Table

Isamu Matsui (松 井 勇)

Department of Geography, Faculty of Literature and Education, Ochanomizu University, Tôkyô

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The wells in the central section of the Nasuno-basin were observed, especially in connection with the three important characteristics, i. e. the depth, the depth of the water table and the thickness of the water, by the Ministry of Agriculture and Forestry on Oct. 1, 1950 and also by the Kantô Regional Office (Kantô Nôsei-Kyoku) of the same Ministry through May 6–8, on Jul. 23 and on Sept. 2, 1963. All these observations were analysed by the present author from the regional view point in the two preceding papers published in 1964. These papers which are concerned one with the observation in 1950 and the other with the three observations in 1963 will, hereafter, be called papers (1) and (2) respectively.

In the present paper the fluctuation of the water table, which was treated only tentatively in paper (1) forms an essential problem and is investigated chiefly by taking the seven subsections A, B, C, D, E, F and G which were delimited in paper (2) into consideration (Fig. 2).

The General Characteristics

The fluctuation of the water table in the central section has marked regional characteristics according to the seven subsections as will be discussed later, but the general tendency may be represented by a well in the Jiyû-gakuen farm in the subsection C (Fig. 2), of which the depth of the water table has been recorded daily since 1950. To demonstrate the general tendency the mean monthly depths through January to December, which are averaged through 12 years, i. e. 1950–1961, are illustrated in Fig. 1. The highest levels are attained through August to October, which may be caused by the preceding bai-u and frequent thunderstorms in summer and also by copious rainfall associated with fronts during the early autumn, which is sometimes combined with torrential rains that accompany typhoons. The lowest levels, on the contrary, occur through late winter to early spring as the result of sparse rainfall in winter

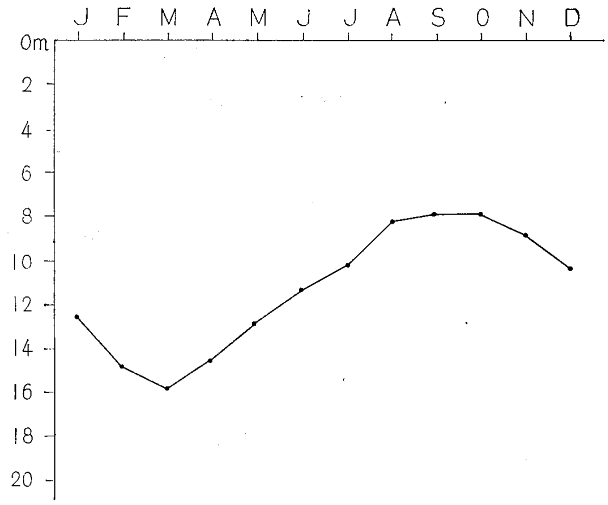

Fig. 1. Showing the fluctuation of the water table of a well in the Jiyû-gakuen farm, which is represented by the mean monthly depths of the water level through January to December, which are averaged respectively through 1950-1961.

which is characteristic of the northern Kantô region. The annual range of the fluctuation reaches some 8 m, as far as the mean monthly values are concerned.

Daily observations of the depth of the water table were also carried out by the Ministry of Agriculture and Forestry with nine wells through Oct. 1, 1950 to Sept. 30, 1951. The highest levels were recorded for those nine wells in October without exception, the lowest, on the other hand, were found generally between late February and early May according to the individual wells. Also the annual ranges were more or less different from one well to another.

Although such individual characteristics can be pointed out among the nine wells, yet the tendency remains in general quite similar to each other. This common tendency which is also represented roughly by the fluctuation curve of the above-mentioned well in the Jiyû-gakuen farm, may be taken as typical of the water table fluctuation in the central section.

The Seven Subsections—The Regional Analysis

In the following discussions the seven subsections (Fig. 2) established in paper (2) rather than the six subsections in paper (1) are taken as the basic series of subsections for the regional analysis of the fluctuation of the water table, since the subsection F which was delimited newly in paper (2) possesses a well-marked individuality when compared with both contiguous subsections C and G, not only concerning the three characteristics of the wells which were considered in

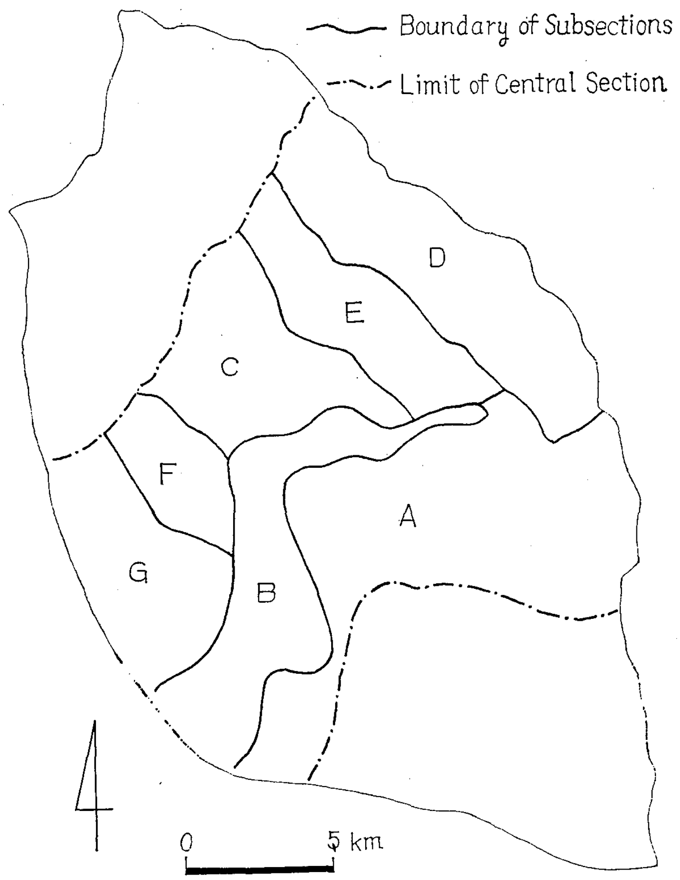

Fig. 2. A map to illustrate the series of seven subsections A, B, C, D, E, F and G, which are delimited on the basis of the observations concerning the depth of the wells, the depth of the water table and the thickness of the water, which were practised in 1963. Although these observations were carried out three times in 1963, the subsections are established in exactly the same way with regard to the respective observations. As compared with the area which was covered by those observations in 1963, the area is somewhat extended here, as far as A is concerned, because in the present paper the observations in 1961 are used jointly with the observations in 1963. The series of these seven subsections is adopted as the fundamental scheme of regional division in order to analyse the fluctuation of the water table.

paper (2), but also regarding the fluctuation of the water table as will be discussed later.

As for the seven subsections, the interregional contrasts were compared and contrasted in paper (2) in the form of those Tables 1, 2 and 3 which are reinserted here in the present paper (Tabs. 1, 2 and 3), in which the upper and the lower limits of the depth of the wells, the depth of the water table and the thickness of the water are listed for each subsection, respectively, with regard to the observations carried out through May 6–8, on Jul. 23 and on Sept. 2, 1963. Concerning the observations on Jul. 23 and also on Sept. 2, or the observations carried out during the season of high water level, when the contrasts regarding the thickness of the water were clearly pointed out among the subsections, minute explanations were practised in paper (2), in connection with those regional contrasts which are

Table 1. Upper and Lower Limits of Depth of Wells, Depth of Water Table and Thickness of Water observed through May 6-8, 1963

Symbols of Subsections	Upper and Lower Limits		
	Depth of Wells	Depth of Water Table	Thickness of Water
A	2.5— 5.5	2 — 5	0 —2.5
B	6 — 9.5	4 — 9	0.5—2.5
C	10.5—24	9 —21	0.5—3.5
D	9.5—27.5	6.5—24	1 —3.5
E	13.5—25	12.5—23	0 —3
F	8.5—12.5	6 —11.5	0.5—3
G	10 —23	7.5—17	1.5—5.5

Table 2. Upper and Lower Limits of Depth of Wells, Depth of Water Table and Thickness of Water observed on Jul. 23, 1963

Symbols of Subsections	Upper and Lower Limits		
	Depth of Wells	Depth of Water Table	Thickness of Water
A	2.5— 5.5	1 — 3.5	0.5—3.5
B	6 — 9.5	1.5— 5	3.5—6
C	10 —24.5	3 —17	4.5—8.5
D	7.5—27.5	4.5—24	2 —4
E	13.5—25	7 —21	4 —9
F	8.5—12.5	4.5— 9.5	3 —4.5
G	10 —20	4.5—14	5.5—9

Table 3. Upper and Lower Limits of Depth of Wells, Depth of Water Table and Thickness of Water observed on Sept. 2, 1963

Symbols of Subsections	Upper and Lower Limits		
	Depth of Wells	Depth of Water Table	Thickness of Water
A	2.5— 5.5	1.5— 3.5	0.5—3.5
B	6 — 9.5	2 — 5.5	3.5—6
C	10 —24.5	3 —17	5 —8.5
D	7.5—27.5	5.5—24.5	2 —4
E	13.5—25	8 —20.5	4 —9
F	8.5—12.5	5.5—10	1.5—3.5
G	10 —20	5 —15.5	4.5—7.5

illustrated here in Tables 2 and 3.

Among the three observations in 1963 the lowest water levels were recorded through May 6–8 for almost all the wells in the central section with very few exceptions. The thickness of the water was limited between 0.5 and 3 m as far as 75 per cent of the wells were concerned, with the exception of those wells in G, in which the thickness attained was somewhat larger (Tab. 1).

If reference is made here to the formula $y=x-c$ which was introduced in paper (1) and (2) and in which c signifies a value which exists between the upper and the lower limits of the thickness of the water, both being characteristic of the respective subsections, it should be noted that during the above-mentioned low water period c remained roughly constant for all the subsections except G. Such similar and limited thickness must undoubtedly mean a certain irreducible minimum concerning the available volume of the ground water in meeting the necessity of life during the low water season. The depth of the wells is determined, as a rule, by the average depth of the water table during the low water period together with this irreducible minimum thickness.

As compared with the water table observed through May 6–8, the level rose on Jul. 23 for almost all the wells in every subsection. The amount of rising, however, was different according to the subsections (Tab. 4). Although the rise was observed most conspicuously in B, C, E and G, the amount of rising which reached more than 4 m was restricted almost exclusively to C, E and G. In comparison with these subsections, the rise remained more or less small in F and it was limited within the range of only 2.5 m in A and D.

When viewed as a series of contiguous regions, the most striking contrasts concerning the rising amount of the water level are found

Table 4. Frequency Distribution concerning Amount of Difference between Water Levels observed through May 6–8 and on Jul. 23, 1963

Amount in Meters	Symbols of Subsections						
	A	B	C	D	E	F	G
0— 1	5			4	1	3	2
1— 2	9	2	2	6	2	2	2
2— 3	4	10	2	1	2	2	1
3— 4		6	3		1	2	3
4— 5		3	8		4	1	3
5— 6					2		6
6— 7					1		1
7— 8			2				1
0— -1			1				

between A and B and also between D and E. The contrasts between F on the one hand and C and G on the other follow next. C and E are, on the contrary, quite similar to each other.

The water table of most of the wells lowered in A, D, F and G on Sept. 2 when compared with the level on Jul. 23 (Tab. 5). The amount of lowering was somewhat larger in F and G than that amount in A and D, which was restricted mainly to less than 1 m. In C, on the contrary, the water level ascended except for a few wells, forming a striking contrast to the above-mentioned subsections. The amount of rising remained, however, less than 1 m.

Table 5. Frequency Distribution concerning Amount of Difference between Water Levels observed on Jul. 23 and on Sept. 2, 1963

Amount in Meters	Symbols of Subsections						
	A	B	C	D	E	F	G
0— 1	4	9	15	3	8	1	2
1— 2			1				
0— -1	13	12	1	8	5	3	4
-1— -2		1	1	2		6	8
-2— -3							3
-3— -4	1						1
-4— -5							1
+	4	9	16	3	8	1	2
—	14	13	2	10	5	9	17

In connection with B, it is scarcely possible to point out such a general tendency, since the water level of some wells lowered and of others ascended in this subsection, although the range of movement was limited mainly within ± 0.5 m.

Finally among five wells in E, the water level of which lowered on Sept. 2, four wells are distributed exclusively along the eastern margin bordering on D, distinguishing this narrow belt from the main part of E where the water table rose on the same date with the exception of only one well.

When considered as a series of contiguous regions, the contrast is most remarkable between C and F, regarding the comparison between the water level on Jul. 23 and the level on Sept. 2, since the movement of the water table occurred in perfectly opposite directions according to the subsections. The same contrast is also pointed out between D and the main part of E, because in the latter the water level rose as mentioned above. The main part of E, on the other hand, presents an almost complete similarity to C where the water level ascended in general. A similarity is also found between F and G because of the same tendency of the water level movement which was commonly descending in these subsections.

Putting together those three observations which were carried out through May 6–8, on Jul. 23 and on Sept. 2, 1963, the seven subsections are compared and contrasted as follows, regarding the fluctuation of the water table.

The subsection C and the main part of E present an almost complete similarity concerning the fluctuation, i. e. conspicuous rising being followed by slight rising, exhibiting a striking contrast to the neighboring D and F, both of which are characterised by ascending which changes into descending. Although G shows a similar trend of movement to the neighboring F, the amounts of both ascending and descending are somewhat larger as compared with those amounts in F. In brief, C, D, E, F and G are well differentiated and well recognized as forming a series of contiguous regions in connection with the fluctuation of the water table, except those neighboring C and main part of E, in which the movements are completely similar to each other.

The couple of contiguous subsections C and E which are similar not only regarding the fluctuation of the water table but also concerning those above-mentioned three characteristics of the wells (Tabs. 1, 2 and 3), is still considered as being separated in the present paper, following the boundary line established in paper (1) on the basis of the observation carried out on Oct. 1, 1950, when differences were recognized between C and E especially regarding both the thickness of the water and the depth of the water table. These differences are considered as being a result of a rise in the level of the water, which occurred, in all probability, differently between C and E. As was asserted emphatically in paper (1), it was the most conspicuous character of C that the depth of the water table was so small as to be comparable with that of A and B, which was due to the markedly large thickness of the water caused by conspicuous rising of the water table during the high water season in 1950. In connection with the fluctuation of the water table, taking this characteristic of C into consideration, the separation between C and E is carried out as it was done in paper (1) and accepted as a basic regional division in the present paper.

In addition to the above-discussed regional analysis on the basis of the observations in 1963, some supplementary regional comparisons are made especially between A and B, concerning the fluctuation of the water table. One of those surveys have already been referred to in paper (1), in which the average values of the height of the water table for every successive five days through January to October 1962, the observation of which was also carried out by the Ministry of Agriculture and Forestry, were analysed in connection with the former A and B which were established in that paper. Here in the present paper the same observation is rearranged taking A and B which were newly delimited in paper (2) into consideration. With regard to those average values in 1962, the highest water level occurred in August and September and the lowest in March, April and May similarly in A and B, although for some wells in A the highest occurred also in July. As for the amount of fluctuation, the annual range was restricted to less than 2.5 m in A, making a striking contrast to B, in which the range attained was between 2.5 and 6 m. In other words, the amount of the rise of the water table during the high water season in 1962 was characteristically larger in B as compared with A, in the same manner as it was in 1963.

In the second place, the fluctuation of the water table is examined further, also in connection with A and B, being based upon the observations carried out through Jun. 14–16, 1961, on Oct. 17, 1961 and through Feb. 19–21, 1962, all of which were made by the Ministry of Agriculture and Forestry. Although the water table on Oct. 17, ascended in B in comparison with the level through Jun. 14–16, in A, on the other hand, the movement represented conspicuous areal differentiation, i. e. in the western and the northern part, the movement was ascending in general while in the southeastern part, it was descending, on the contrary. Regarding the amount of movement, B represented as a whole distinctly larger values than A, since those wells which have the amount exceeding 1 m occupy in A and B, respectively, some 35 and 70 percent of all the wells. As compared with the water level on Oct. 17, 1961, the water table descended through Feb. 19–21, 1962 in both A and B with very few exceptions. In so far as a greater part of the wells is concerned, the amount, however, remained within 1 m in A, making a striking contrast to B, where the amount exceeded 1 m.

Summarizing the above-mentioned observations concerning the water level in A and B in those years 1961, 1962 and 1963, the characteristics of A and B are compared and contrasted in Table 6, in connection with the fluctuation of the water table. Although the movement of the water table occurred not always in one direction, i. e. either exclusively ascending or descending within the range of those respective subsections, the amount of movement was recorded usually definitely larger in B than that amount in A, a fact upon the basis of which it is possible to distinguish clearly between A and B as different but contiguous subsections.

Table 6. Comparison between A and B, concerning Movement of Water Level, Figures represent Amount of Movement in Meters

Dates	A	B
Jun.—Oct. 1961	Ascending and descending Amount, smaller	Ascending Amount, larger
Oct. 1961—Feb. 1962	Descending <1	Descending 1—4
Jan.—Oct. 1962	Annual range <2.5	Annual range 2.5—6
May—Jun. 1963	Ascending <2.5	Ascending 2—4.5
Jun.—Sept. 1963	Descending <0.5	Ascending and descending <0.5

Discussion

Although the observations analysed in this paper are restricted within narrow limits both concerning the number of field surveys and the extent of the area they cover within the Nasuno-basin, the contrasts among the seven subsections which constitute the central section are so striking in connection with the fluctuation of the water table that they permit of the following discussion which, however, remains hypothetic because of the deficiency of indispensable data.

According to Sagehashi, four main sources are pointed out as for the origin of the ground water of the Nasuno-basin with the exception of the precipitation received on the region concerned; (a) the water flowing from the Naka-river into the Nabekake-gravel bed exposed near Yui, especially when the river rises, (b) the percolating water from the Sabi- and the Kuma-river into the fan-gravel bed, (c) the water flowing from the Hôki-river into the Torinome-gravel bed exposed at a portion of the valley wall near Kanesawa, and (d) the percolating water from the Nasu-canal into the fan-gravel.

Excepting the Nasu-canal which traverses the basin from NE to SW following the upper limit of the central section and which exerts its influence upon the ground water of perhaps all parts of that section, the above-mentioned three river systems have their own sphere of influence which probably corresponds in a certain degree to those subsections D, C and G, respectively, in the order of the rivers Naka, the couple of Kuma and Sabi and lastly Hôki. As a result it is quite natural that within the range of C, D and G, the water level fluctuates in a manner which is characteristic for each of these subsections.

The remaining E and F are considered as forming those subsections in which the water levels are controlled more or less indirectly by the above-mentioned river systems. The characteristic of F which is markedly different from the neighboring C and at the same time comparatively similar to G, regarding the water level fluctuation, may be due to those Fujinidayama- and Karasugamori-hills which stretch from northwest to southeast. The former forms the eastern boundary of F, while the latter runs near the western bundary of the same subsection. These hills, the bedrock of which is formed by the impervious Ôtawara-pumice flow, may serve as dividing barriers of the subdrainage areas which correspond respectively to C, F and G in such a manner as the separation of F and C by the Fujinidayama-hill is far more complete than the separation of F and G by the Karasugamori- and other minor hills. Consequently, as far as the fluctuation of the water table is concerned, the subsection F which is completely beyond the control of the river Sabi, lies, on the other hand, under the indirect control of the river Hôki, in a form somewhat differing from G which is directly controlled by the same river.

According to Watanabe, Sagehashi and Shindô two underground valleys filled respectively with the Torinome- and the Nabekake-gravels are reported as ancient river beds of the Naka-river, which run west of the present Naka-river in parallel with it. The subdrainage area which corresponds to D may be controlled mainly by these underground channels containing the ground water flowing down from the present Naka-river in the neighborhood of Yui especially on those occasions when the abnormal rise of the river occurs. The noticeable difference between D and the main part of E regarding the fluctuation of the water table suggests that the latter subsection lies definitely beyond the sphere of influence of the Naka-river, which is restricted within narrow limits by the underground valleys in question. On the other hand, the main part of E is reasonably supposed to belong to the sphere of influence of the river Kuma because of the water level fluctuation which moves in a manner quite similar to that fluctuation in C. When viewed, however, from the fact that the thickness of the water in E was definitely smaller as compared with that thickness in C, a fact which was observed on Oct. 1, 1950 and which is taken as the basis for separating C and E, it is quite natural that E, differing from C which lies always under the direct control of the Sabi and the Kuma, is considered as being affected more or less indirectly by the influence of the Kuma, which was evidently found especially in that case when the rise of the river was abnormaly sudden and great.

Since those above-mentioned ground water systems converge into B and A, these subsections, as a natural consequence, must locally exhibit heterogeneous movement of the water level, i. e. the water table ascends in certain wells and descends, on the contrary, in the others. As far as the aforecited regional analyses are concerned, however, it is not sufficiently distinct to distinguish any subdrainage systems within these subsections. Nothing can also be certainly elucidated concerning the difference between the amounts of the water-table movement of A and B.

Summary and Conclusion

From the foregoing regional analyses it is clearly known that the seven subsections A, B, C, D, E, F and G which were established in paper (2) on the basis of the three important characteristics of the wells, i. e. the depth of the wells, the depth of the water table and the thickness of the water in the wells, are also contrasted and compared, respectively as a whole, regarding a fourth basic characteristic of the wells, namely, the fluctuation of the water table. When considered as a series of contiguous regions, the most striking contrasts are found between the respective couples A and B, D and E, and C and F. Similarities, on the other hand, are pointed out between C and E, and F and G.

These regional contrasts are hypothetically considered to be due to the three different and independent subdrainage systems, i. e. the systems which are controlled respectively by those rivers Naka, the couple of Kuma and Sabi and lastly Hôki. While the sphere of influence of these subdrainage systems perhaps corresponds directly with D, C and G, respectively in order of mention, on the other hand, both E and F are under the respective indirect influence of the Kuma and the Hôki. As for A and B such subdrainage systems are yet unknown.

Such and other important items still remain uncertain in connection with the origin of the areal differentiations regarding the fluctuation of the water table. It is, however, undoubtedly clear that the regional division of the central section into those seven subsections is also reasonable and useful when viewed from the fourth angle, i. e. the fluctuation of the water table, at least as far as the observations in 1950, 1961, 1962 and 1963 are concerned.

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References

1) Matsui, I.: The Wells in the Central Section of the Nasuno-Basin—A Problem of the Regional Division. Natural Science Report, Ochanomizu University, **15** (1964), 41-52.
2) Matsui, I.: The Wells in the Central Section of the Nasuno-Basin—A Problem of the Regional Division (2). ibid. **15** (1964), 93-104.
3) Suzuki, A.: The Explanatory Text of the Hydrogeological Map of Tochigi Prefecture. 1963. (in Japanese)
4) Watanabe, K., Sagehashi, N. and Shindô, S.: Geologic Structure of the Nasu Plain, Tochigi Prefecture, with Special Reference to the Ancestral River Course of the Naka River. Chishitsugaku-Zasshi, **66** (1960), 113-122. (in Japanese)
5) Watanabe, K. and Sagehashi, N.: A Preliminary Survey for Ground-Water Development in the Nasuno-Plain. Basic Studies for Multipurpose Development of the Northern Nasu-Region. 1961. (in Japanese)