Exploration of Ground Water Resources in North China

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I. GENERAL

1. Value of Ground Water as a Resource

Most rivers in North China, including the Huang Ho (Yellow River) which was the "King of Tragedy" in the history of China, exhibit special features. Topographically, these rivers are known as "tenjō-gawa". (Trans. note: The word "tenjō" means ceiling. These rivers transport an enormous amount of silt from loess-covered areas and deposit it on the river beds, which are constantly being raised. This necessitates the construction of higher embankments to prevent inundation. Often a tunnel is constructed beneath the river bed to join two towns on opposite sides of the river.) On the river banks, there is an extensive distribution of redeposited loess which is similar to "mugikogashi" or parched barley flour. The amount of water that percolates through the soil is so enormous that streams become intermittent or underflow results. This type of river is unusual in Japan. Those who utilize the water must pay particular attention to the seasonal fluctuations of discharge and muddiness of the surface water.

About 60 to 70 percent of the annual rainfall is concentrated in the two months of July and August, and during these months the rivers swell suddenly, usually followed by serious floods. However, with the exception of the rainy season, the amount of river water decreases extremely or is completely absent and a dry condition results. During the dry season there is a considerable fluctuation in ground water, with, of course, a time lag such a fluctuation can be divided into a high-water period and a low-water period.

The turbidity of the river water is a result of fine-grained loess which is in a colloidal suspension, as well as from active erosion because of scanty forests in the drainage basins. According to a survey carried out by the former Water Analysis Laboratory of the Railway Technical Research Institute of the North China Traffic Company, the turbidity of the *Yung-ting Ho* averages 1,000° during the high-water season and 600° in the dry season. The turbidity of the grand canal averages 300° during the high-water season and 150° during the low-water season. However, in the *Huang Ho* (Yellow River), the maximum is said to be about

12,000°. When such turbid river water is allowed to stand for 6 to 7 hours, the majority of coarse suspended particles are deposited, and in another 24 hours two distinct parts are visible, almost clear water and a deposited layer of mud and minute sand. This shows that when the surface water is utilized it will be necessary to install a filtration pool in which the water can stand for 7 to 8 hours. By putting aluminum sulfate in the water in the pool, water with a turbidity of 700°–800° can easily be converted into water with a turbidity of only several tens of degrees. In 1944 this method was adopted for part of the railway water supply.

However, because of the geographical distribution of river water, utilization was very limited, so that when a constant large supply was required ground water had to be utilized. But the ground water in North China is found in cavities in Ordovician limestone which forms a part of the basement rock, and as the region is covered by a loess deposit and has an arid climate, not only the agent that forms the ground water varies, but also the quality of the water. Consequently, for those who attempt to utilize ground water, it is necessary to take special precautions in selecting localities where wells are to be drilled. The ground water drawn from shallow wells located in densely populated villages is markedly polluted, sometimes with a large chlorine content, and is hard. The quality of this water is quite poor, and is unsuitable not only as a municipal water supply, but even for industrial use or for train locomotives. Under such circumstances, the general tendency is to look for deep aquifers.

2. General Features of Deep Aquifers

Japanese nationals managed various installations in North China from 1937 to 1945, and the water supply for these installations was drawn from relatively deep-seated aquifers. The municipal water supply for a majority of cities, with the exception of part of Tien-chin, Ching-tao and *Chi-nan,* and most of the water for locomotives, came from deep, cased wells, with the exception of areas along the Shih-tai and Chiao-chi Railways, where the bedrock is too shallow to drill such deep wells. However, it was fortunate that river water and subsurface flows were available along these railroad lines.

During the years 1937 to 1944, 800 artesian wells were drilled by the Japanese in the provinces of Ho-pei [Hopeh], Shan-hsi [Shansi], Shan-tung [Shantung], Mongolia and a part of Ho-nan [Honan], of which 500 were drilled in the North China Plain including Ho-pei, Shan-tung and part of Ho-nan.

The former Japanese army used 450 wells. The total length of the casing (pipe) was 17,000 m in Ho-pei, 13,000 m in Shan-hsi and 11,000 m in Mongolia. The average depth per well was 70 to 80 m in Ho-pei province, 100 to 110 m in Shan-hsi province and 70 m in Mongolia. In addition to these wells, cased wells previously drilled by Chinese, English, Americans and French for public organisations, private houses, industrial plants and municipal water works existed. About 65 of these wells are found in Tai-yuan, and 15 in Pei-ping. There were about 200 artesian or semi-artesian wells (including some bamboo-cased wells drilled by Japanese), of which 7 were in Tien-chin, about 100 elsewhere and about 30 in Mongolia (if the nearly abandoned wells are included, the number reaches about 60). The aggregate number of wells is about 400. At present the total number of cased wells, which are known through geologic columnar sections or well core samples, may be as great as 1,000.

All of these wells are called deep wells as the depth of the shallowest aquifer ranges from 20 to 30 meters. Among the wells drilled in the regolith, the deepest is 302 m in Te-hsien, and a well drilled in Ordovician limestone is 550 m deep in Chang-tien. The deepest artesian well (863 meters) was drilled by the French in Lao-hsi-kuan, Tien-chin.

Table 1 shows the distribution of public wells in the principal cities. The wells listed in the table are only those for which data is available from geologic cross-sections.

Table 1. Distribution and Uses of Deep, Cased Wells in North China.

Location	Municipal waterworks and railroad uses	For the Japanese Army	By foreign nationals other than Japanese
Pei-ping	30	10	6
Northern and western suburbs of Pei-ping	3	5	4
Tien-chin	7	4	About 100 (including wells extended by the use of pipes)
Shih-chia-chuang	2	2	—
Chi-nan	—	20 (including test borings)	—
Tai-yuan	4	25	About 65
Yun-cheng and Lin-fen	6	5	—
Te-hsien	2	—	—
Tang-ku	—	5	—
Kai-feng	—	8	—
Ta-tung	—	20 (including test borings)	—
Chin-huang-tao	—	20	—
Hsin-hsiang	—	6	—
Chang-hsin-tien and Liu-li-ho	6	—	—
Lang-fang	—	5	—
Chang-tien	4 (including test borings)	—	—

There are many high pressure artesian wells which were drilled into aquifers.

Hydrologically, these had very interesting features. Table 2 shows the depth of the aquifers in which the artesian cased wells were drilled.

Table 2. Location and Depth of Artesian Aquifers.

Location	Depth (m)	Location	Depth (m)
Yun-cheng	250–290 m	Tien-chin	650–690 m
An-i	200–250 m	Pao-ti	60 m (or more?)
Pao-tou	150 m	Western suburb of Pei-ping	40 m
Chang-tien	260–350 m		

The temperature of the water in the wells drilled in Lao-hsi-kuan, Tien-chin, varied from 31.5° to 34°C, the average geothermal gradient was 1°C every 30 m. The well yielded 400 tons per day.

About a half of the cased wells were drilled with portable army drilling machines. The time required for completion of a well was about 5 to 6 days in Ho-pei Province, 22 days in Shan-hsi Province and 10 days in the Mongolian Plateau. About half of the wells range from 100 to 150 mm in diameter. The amount of discharge is uncertain because various motive powers were used; however, a rough estimate is from 600 to 700 tons per day in the North China plain. Some large wells, 250 mm in diameter, in the vicinity of Pei-ping, yielded about 2,000 tons per day. In Shih-chia-chuang, a well discharged 2,800 tons per day and in Kai-feng one well discharged 4,300 tons per day through a 350 mm pipe.

3. General Features of Native Wells in China

In addition to the cased wells, which are known to draw deep-seated ground water, there are many hand-dug open wells which reach shallow aquifers (the first aquifer) and are utilized for various purposes. In most of the North China plain the ground water level is 2 to 3 m below the surface along the Chin-Pu Railway and 1 to 8 m along the Ching-han Railway.

Populated villages within the prefectural walls have utilized water from a few to several hundred wells for domestic purposes. Furthermore, such shallow wells have been widely used for farmland irrigation in the neighboring villages. Even within the North China Plain, a high density of distribution of shallow wells is found in the mountainous areas of Shan-tung and west of and along the Chin-Han Railway. It is believed that about 80 to 90 percent of a total of one million wells are distributed in these areas. The majority of hand-dug wells for farmland irrigation are shallower than 10 m or vary from 6 to 15 m in depth. Animals, mostly blindfolded horses or donkeys, are used in the pumping of these wells. The economic value of ground water in this arid loess region is high.

However, the natural ground water level is lower in both the loess tableland and loess basin of the Shan-hsi Plateau, and to draw the water from the first aquifer excavation to a depth of 30 to 60 m is usually necessary. The deepest hand-dug open well of this type is found on red clay tableland in Wan-chuan and Jung-ho Prefectures in the Chin-nan area, south of Shan-hsi Province, where artesin wells 200 m deep, one well per village, have been an important source of water.

In the Mongolian Plateau, on the other hand, the water level is generally high and ground water can be obtained at a depth of 2–3 m in flat land. However, potable water from these wells is more important for domestic animals than for the Mongolian people. Under such circumstances utilization is very limited, and as a result the degree of pollution is high and the quality of the water usually very poor.

When the purpose of the well was to draw water from localities where the infiltration of water was possible or along the perennial river banks, shallow wells were dug for railway, municipal waterworks and industrial water supplies. One of the most typical examples of this type is found in the waterworks of the Lungyen Iron Foundry in Hsuan-hua, where four large wells, about 5 m in diameter, were dug on the floor of the Yang Ho in the upper reaches of the Yung-ting Ho. The discharge from some of these wells reached 4,000 tons per day. Large shallow reservoirs to collect water at the mouth of the Nan-kou-yu, which rises in Pa-ta-ling, have been used mainly for train locomotives at the Ching-Pao railway stations. The Shih-Tai and Chiao-Chi Railways have also relied on large shallow wells for water supplies.

The discharge from many native wells ranges from 40 to 50 tons per day in the central part of North China and in the coastal region; in the gently rolling piedmont district, the amount varies from 20 to 30 tons per day. In the piedmont where the basement rocks project immediately below the plain or the nature of the surface soil is not suitable, often in wells 1 to 1.2 m in diameter, a proper discharge of water was impossible. In the industrial district north of Chi-nan, the aquifers are inadequate for the alcohol plant, despite the group of springs to the immediate south, known as the "72 springs of Chi-nan", which yield a total amount of 140,000 to 150,000 tons per day. Under such conditions, large wells were dug with many small radially-placed strainers; by doing this, a water supply has barely been assured. In the vicinity of Lo-yang, Ho-nan Province, there is a tableland consisting of a loamy mud bed resembling hard "yōkan" (a hard bean jelly), and below this bed an aquifer known as the San-men gravel. To reach this aquifer, it was necessary to dig down at least 20 m, and to assure a proper supply of water large wells were needed. Some native oval-shaped wells used for irrigation, ranging from 1.8 to 2.5 m in diameter, had already been dug. Villages which depended on ground water used bucket wells (trans. note: water is drawn from the well with a bucket) 14 or 15 m in depth, and in places the water was obtained from the aquifer, the water level of which varies from 4 to 5 meters. In the Lu-an basin of Shan-hsi Province, a thick reddish clay-like mud bed extends 200 m below the surface, intercalated with no deep-seated aquifer. Thus, in that area a large well was dug into the subsurface flow within the area of the river bed, and a supply was barely secured for the cooling device at the power station and for general water supply for the district.

The regolith that occurs in North China can easily be dug by hand because there is no danger of cave-in, as is usually the case with gravel beds in Japan. In spite of less trouble in digging wells in North China, however, the amount of discharge per well is usually small, so that in order to alleviate this difficulty many wells that had been used for potable water supply were converted into wells to supply water for locomotives. The native wells were deepened by connecting additional pipe. As a result of this method, several railway stations east of the Shih-Te Railway were able to obtain a large amount of good-quality water.

4. General Features of Shallow-seated Ground Water

A. *Ground-water level and seasonal fluctuations*

The ground-water resources in North China and Meng-chiang* are not scarce, but water levels in both Shan-hsi and Ho-nan Provinces where the loess bed is well developed, especially in the mountain and plateau districts, are generally very low. In order to have access to even an aquifer of the free ground water table, one must bore to a considerable depth. But in the North China plain and in several basins in Meng-chiang and the Mongolian plateau, the ground water level can be reached at a comparatively shallow depth, and potable water supplying villages and cities can also be used for farmland irrigation and various other purposes. Table 3 gives general features of the ground water.

Study of the ground water levels in 43 cities in North China was begun in 1943 under the direction of Dr. F. HOMMA, but the work was forced to be suspended in 1945. However, seasonal fluctuation of ground water levels was observed at Pei-ping, a western suburb of Pei-ping, Tung-chou, Chang-hsin-tien, Shih-men (Shih-chia-chuang), Shun-te, Han-tan, Cheng-te, Tien-chin, Chi-nan and Chang-chia-kou. Along the Ching-Han Railway, the highest water level is observed during the months of February and March (high-water season) and during August and September (rainy season), and the lowest water level during July and August (dry season) and in October (low-water season). The highest water level, during February and March, is brought about by a slow but constant increase since the month of November of the preceding year. The maximum increase in ground water along the Ching-Han Railway is thought to have been brought about by precipitation during the rainy season of the preceding year on the west side of Chi-hsi and Tai-hsing Mountains. The water soaks into the plain and becomes the source of ground water six or eight months later. It is thought that such a seasonal fluctuation in water levels cannot be seen along the Chin-Pu Railway. Going eastward

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* Ed. note: Meng-chiang (or Meng-kiang) includes Mongolia and Hsin-chiang (or Hsin-kiang) Province in the northwest of China where it adjoins Mongolia and Siberia.

from the west side of the Chin-Pu Railway, fluctuation in shallow ground water, which is common along the Ching-Han Railway, seems to decrease.

Table 3. General Features of the Ground Water in North China and Meng-chiang

Location	Depth to water level from ground surface (m)	Location	Depth to water level from ground surface (m)
North China Plain		Canyon of the Fen Ho at the foot of the mountain	20–30
East of Pei-ping	4–5	Lu-an	4–8
Western part of Pei-ping	7–8	Wan-jung Tableland	
Outside the city of Pei-ping	8–10	Jung-ho	100
Western suburb of Pei-ping	5–25	Wu-wang-tu	150
Tien-chin	2.5±	Wan-chuan	220
Along the Ching-han Railway	4–6	North of Hua-chin	45±
Shun-te*	6–8	Ho-nan Province	
Along the Chin-pu Railway	2–4	Lo-yang	20
Chi-nan	2–30	Meng-chiang and Mongolia	
Hsu-chou	4–6	Chang-chia-kou	4–20
Shan-hsi Province		Ta-tung	10±
Tai-yuan	5–25	Pao-tou	Shallow in the west, deep in the east
Fen Ho Valley	6–8	Mongolian Plateau	0.5–2

* Based on the following literature:

KURATA, N., Nature of inorganic matter in shallow ground water in North China: *Japanese Jour. Limnology* (Rikusuigaku Zasshi), v. 14.

MIYOSHI, M., Nature of the irrigation water in North China: *Jour. of Sci. of Soil and Manure, Nippon* (Nippon Dojō Hirōgaku Zasshi), v. 15.

WADA, T., Agriculture of North China based mainly on water: pub. by Seibidō Shoten.

B. *Three factors governing the quality of ground water*

The quality of ground water in North China and in part of Meng-chiang is characterized by the high degree of hardness due to Ca and the large content of SO_4 and Cl.

The hardness, especially attributed to Ca content, ranges from 13° to 30° or 40°, German standard (231.3 to 534 or 712 ppm), in shallow ground water, and in some extreme cases the hardness reaches 120° to 130° (2,136 to 2,314 ppm) or even 150° (2,670 ppm). Such a high degree of hardness is due to the wide distribution of calcareous rocks. The warm and dry climate also accelerates the increase in hardness.

The SO_4 content is also high, generally ranging from 50 to 60 mg/l in good-quality water, but in poor-quality water it ranges from 300 to 400 mg/l. Such a content is attributable to the presence of coal seams, pyrite beds and gypsum. In fact, water seeping into a coal pit often had a recorded SO_4 content of as high as 500 mg/l.

The above two examples are thought due to natural causes, particularly, the quality of the water is closely related to the geology of the area, and $CaSO_4$ is detected in most cases.

On the other hand, the Cl content has two origins, natural and artificial. The content of natural Cl is high in marine formations or in saline areas. Artificial Cl seems to be responsible for pollution.

C. *Characteristic features of water in saline areas*

Shallow wells in saline areas along the gulf of Po Hai, where the water level is very shallow and the Cl content is too high for the water to be potable for both men and animals. The Cl content is very high and ranges from 2,000 to 3,000 mg/l; however, the SO_4 content is comparatively small. Artesian water in Shanhsi Province in the same saline area has a high SO_4 content and a low Cl content, showing the difference between white and black alkali. Basic land improvement is required in places where alkaline soil is present.

A special characteristic of the water in saline areas of the coast is that the content of sodium and potassium is very high. When such water is used in a boiler, foam appears. The origin of this phenomenon can be traced to the existence of a marine formation, and the sodium contents have been retained to the present due to the prevailing swampy topography. Moreover, the dense soil tends to retain otherwise easily dissolved and lost Cl, resulting in ground water charged with a high content of Cl.

Even though the water is somewhat different from that of the coastal saline areas, part of a former continental lake (a flood-control reservoir built on the Huang Ho in the days of Yu-kung) is also noted as a district of high Cl content. This is an inland saline area similar to the Pai-yang-ting district but differs considerably in quality of water from other inland saline areas. The area along the Lung-hai Railway is a well-known poor-water area. In areas where drainage is sluggish the accumulation and concentration of polluted matter is possible, and an increase in Cl content of ground water is noticeable.

D. *Pollution in populated villages*

Ground water drawn from shallow native wells in villages and cities has usually been polluted from outside sources. The original quality of the water itself has been greatly changed. The Cl content of the original water ranged from 10 to 20 mg/l, but subsequently became several hundred or even 2,000 to 3,000 mg/l. The solid matter content is 500 to 1,000 mg/l, and due to the presence of Mg the water has become bitter. Pollution of village water becomes worse toward the center of the village or within the prefectural walls from the periphery, but the degree of pollution decreases in neighboring rivers.

An example in the neighborhood of Ku-an, Ho-pei Province, is given below. The Cl content of the water from wells in more than ten villages was investigated. For this purpose, a tentative boundary was set at 7 km from the Yung-ting Ho. The investigation revealed that the villages where two-thirds or more of the total number of wells contain more than 100 mg/l of Cl are all located more than 7 km from the river, and reversely, the villages where only one-third or less of the total number of wells contain more than 100 mg/l Cl are all situated within 7 km of the river.

In the Mongolian Plateau, the ground water level lies near the surface. Mongolians use the wells under unsanitary conditions, and the quality of the water gradually becomes worse. Increase in organic matter and Cl content is noticed. For example, within To-lun-hsien, there are more than 100 shallow wells within the city walls, of which only two or three are potable from the standpoint of bacteria content and other factors. In Meng-chiang, especially in the Mongolian Plateau, the calcium content is low and the hardness not very high.

E. *Areas with comparatively good water supplies*

Throughout North China, so-called "good water districts" for agricultural uses are situated along the Ching-Han Railway, between Pei-ping and Pao-ting, and in the vicinity of Tai-an along the Chin-pu Railway. Here the Cl content is 50 mg/l, the hardness 12° (213.6 ppm) and the SO_4 content 35 mg/l, providing the best quality water in these districts.

Pei-ping and vicinity is generally considered a "good water district", because the ground water flows from the north and the northwest. But, the southern part of Hsi-cheng, within the city walls, and outside Chien-men are very poor water areas. However, comparatively good-quality water can be found in newly-developed areas in the southern part of Tung-cheng.

The Fe content is especially high in districts outside the city walls. Water for sale from wells within the city walls (special wells where water is sold by water merchants) has a Cl content of 100 mg/l and a hardness of 15° (267 ppm). The Cl content of the water from public wells is 300 mg/l and hardness ranges from 24° to 25° (427 to 445 ppm). Chi-nan is a good-quality water area containing the so-called "seventy-two springs of Chi-nan", which is near the hill on the south side of the city. A good aquifer zone is found there, the water of which has a Cl content of 50 mg/l, but in the city the quality of water gradually becomes poor. Especially in the low swampy area in the northern and northwestern parts of the city, the flow of water becomes sluggish and the Cl content reaches 300 mg/l. The Cl content of spring water within and outside the city is 12 (mg/l) and the SO_4 content 40 (mg/l). In Hei-hu-chuan, the SO_4 content decreases further, which means better quality. Even in shallow public wells in nearby areas, the SO_4 content remains around 30 mg/l.

F. *pH and water temperature*

The pH of ground water near the surface generally ranges from 7.2 to 7.5. Only part of the Lu-an basin, Shan-hsi Province; Ching-tao city, Shan-tung Province; near Hai-chou, Chiang-su Province; and the area between Ta-tung and Kou-chuan-chen is found to have acidic ground water. None of the water is particularly alkaline. The temperature of the water varies from 12° to 13° C in winter and from 14° to 15° C in summer.

II. GROUND WATER OF PEI-PING

1. Outline of Geology

Pei-ping (Peking) and its environs are located southeast of Pei-ping-Hsi-shan (the western mountains of Pei-ping), which is a branch of the Yen-shan mountain range or the Chi-tung mountain land, and are built on sand, gravel and loess deposits, thought to derive from the Yung-ting Ho of the Pai Ho system. The fans of the Yung-ting Ho are composed mainly of varicolored gravel beds, consisting of quartzite, siliceous limestone and altered sandstone (fist-size and occasionally head-size). This grades into alternating beds of quartz sand and alluvial loess, and extending southward (beneath Peiping Castle), form one corner of subsurface deposits of the North China Plain.

The ground water of the quartz sand bed is an important artesian aquifer in both quantity and pressure, being fed from the surrounding mountains, especially from the north and the northwest, and lying east (immediately below Peiping) of the line extending from the western wall of Peiping Castle to Wan-shou-shan.

2. Ground Water of the Western Suburbs of Pei-ping

The former river bed of the Yung-ting River lies in the western suburbs of Pei-ping, and deposits consist mainly of a varicolored gravel bed, 30 m thick, lying on a red clay bed. There are hills, (including Pa-pao-shan) composed of Triassic clay slate and quartzite. The depth of the bed rock seems to be 100 m or so, but there is no aquifer below the red clay bed. Three wells, which supply water to the western suburb (managed in 1942–43 by the Construction Office, Peiping Engineering Bureau) are all 50 m or 60 m in depth, and the gravel bed source is shallower than 30 m. There is a several meters thick alluvial loess bed near the surface, but the gravel bed reservoir is countinuous and does not intercalate any impervious stratum.

The water levels of the wells on the banks of the Yung-ting Ho rise rapidly about 2 m in the rainy season, but decrease rapidly after the rainy season. However, the ground water table is different by 15–20 m from the river water level, and the ground water seems to be independent of subsurface flow under the river. This area, inserted between Yung-ting Ho and the gate of the Pei-ping Castle, descends east-southeast with a slope of 1/800 from Shih-ching-shan; the gradient of the

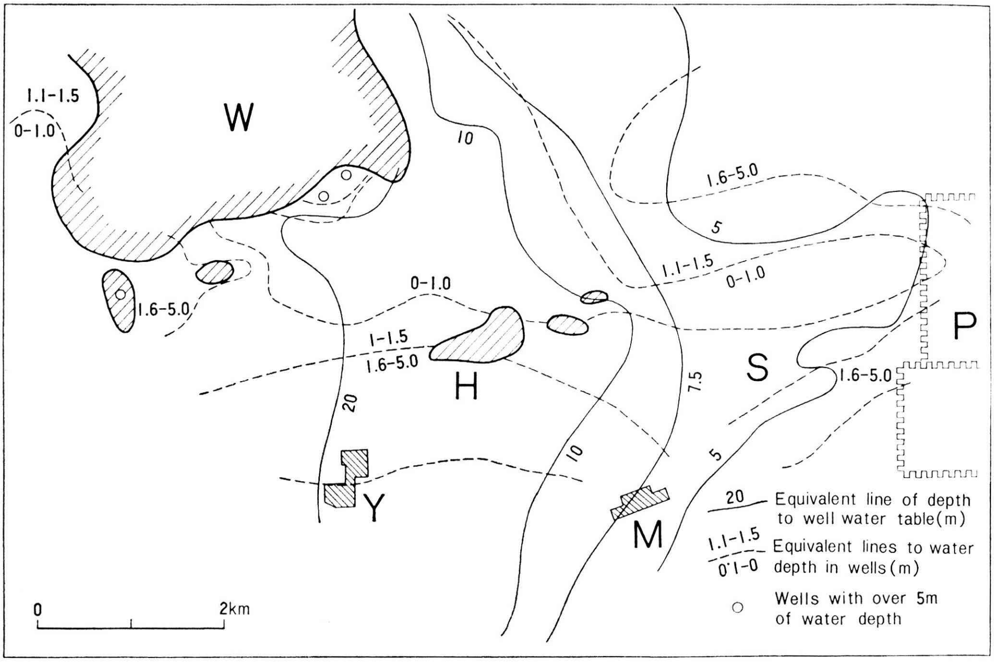

Fig. 1. Equivalent Lines of Depth to Water Surface and Water Depth in Wells of Peiping on the Western Suburbes

W: Pei-ping-hsi-shan
H : Pa-pao-shan
P : Pei-ping castle
Y : Ya-men-k'ou
M: Ta-ching-ts'un
S : Spring water near P'ao-ma-ch'ang Hsi; Pien-men-wai

ground-water table is 1/3,000, hence the water level becomes gradually lower from west to east. To be precise, it is a maximum of 24 m deep on the banks of the Yung-ting Ho, but becomes 5 m or so deep in the eastern part of the western suburbs. There are springs in a swampy zone near the Hsi-pien-men racecourse. The water level is 2 m or so and the yield is large in Ta-ching-tsun and Hsiao-ching-tsun to the south.

Existing wells in the western suburbs number 1 to 3 per settlement, and the water averages 1 m deep; the seasonal variation in water level is 0.5 m or so; the quality of the water is good and the Cl content is always less than 30 mg/1.

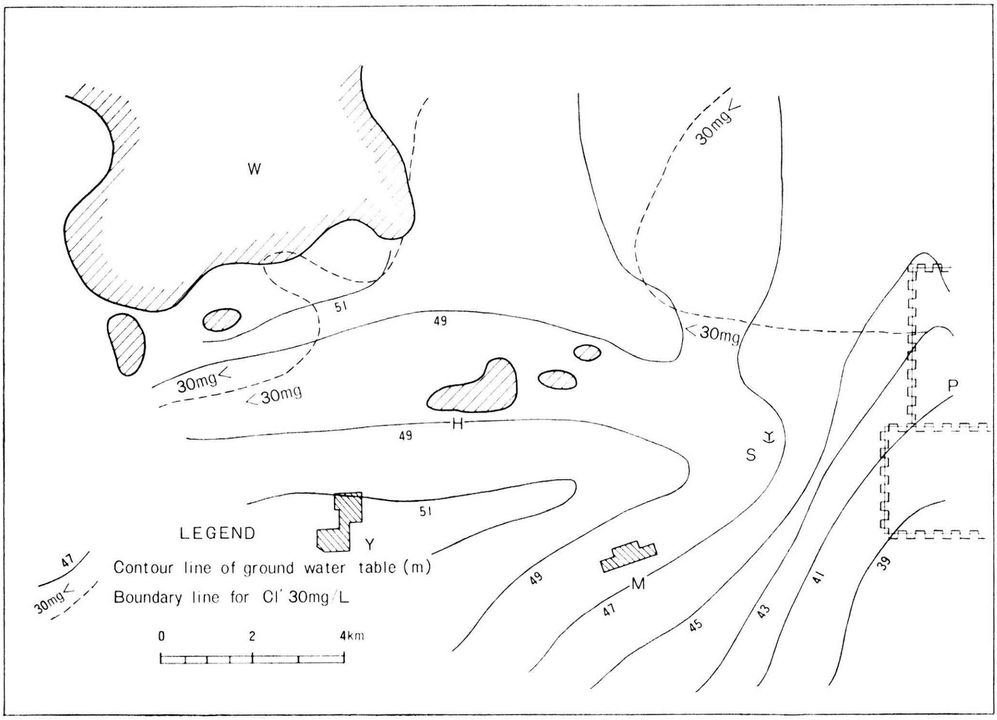

Fig. 2. Countour Lines of Ground Water Surface and Cl Content of Ground Water on the Western Suburbs of Peiping.

W, H, P, Y, M and S, are same as Fig. 1.

3. Confined (artesian) Ground Water in Pei-ping Castle and its Environs

In the subsurface of Pei-ping Castle, the varicolored gravel bed extending to the western suburbs alternates with yellowish-brown loessic mud beds and yellowish-white quartz sand beds. These three beds as a whole are mixed and a red clay-like mud bed lies underneath. The bed rocks are unknown, but the aquifer is a gravel bed in a horizon above the clay-like mud bed. All well drillings that encounters the red clay-like mud bed is stopped by the stickiness.

The depth to this clay-like impervious bedrock is 72–75 m in the western part of Hsi-cheng, 85 m in the vicinity of An-ting-men, 80 m in the vicinity of Hsuan-wu-men, 100–120 m in the vicinity of Chao-yang-men and Tung-pien-men and 90 m in the vicinity of Tung-chi-men; then the surface drops generally eastward.

The amount of superposition of the varicolored gravel bed, the quartz sand bed and loessic mud bed differs in places, but if the depositional layers are connected in accordance with data obtained from deep well drilling, small scale lenses seem to be irregularly superposed. The quartz sand bed is intercalated frequently, especially in the vicinity of An-ting-men. A large number of *Planorbis* are contained.

The water of these aquifers seems to be supplied from the NNW or N. Deep wells depending on this aquifer are nearly flowing wells and show no annual variation. The breadth of this prominent zone of artesian flow is limited to between the west wall of Pei-ping Castle and the outside of Tung-men for a length of about 10 km; the zone does not reach the Tung-chou castle, where the water seems to be from another source. This artesian flow zone fosters springs where it is shallow at Tang-shan, Ma-fang-chen and Yu-chuan-shan, but the ground water flows southward due to pressure from above and behind.

Since the source of water of Pei-ping City was changed from the surface water of the Pai Ho to ground water, the water is being supplied by drilled wells, which in 1945 numbered 6 within the castle, 15 or 16 outside Tung-chi-men, and 6 or 7 outside An-ting-men and Te-sheng-men. A plan was being advanced to increase the total number by 24. The average yield was 2,000 tons per day (12 inches) per well, and pumpage totalling 50,000 tons per day. The plan was being initiated outside An-ting-men, Te-sheng-men and Tung-chi-men.

4. Variation in Ground Water Level in Pei-ping Castle

Concerning free ground water within Pei-ping Castle, including the inner and outer castle, W. T. Kuo of the North China Tungjen Society examined the quality from the viewpoint of sanitation in 1938, but since then no overall investigation or study has been made. The author began an investigation of the water level and other factors in 1943 for the purpose of establishing a model for prolonged observation of ground water levels in 43 cities in both North China and Mongolia by the All North China Research Institute. As a result, the author obtained data on the tendency, variation in level and quality of free ground water.

In April 1944, the water level and depth were observed for 800 Chinese wells (150 connected wells) in the castle, and the absolute water level obtained by levelling. From this a ground water contour map was made with a contour interval of 0.5 m and a map showing water depth (separated into regions of water depth from 0–1 m, 1–2 m, 2–3 m and over 3 m). As a result, it was found that the shallow ground water within the castle is related to the water of Shih-cha-hai, Pei-hai and Chung-nan-hai. Also, the water level is high in this area and descends eastward, westward and southward, and the depth to water in wells is generally low in the west part of the Castle—from 0 to 1 m, while it is over 3 m in one part east of Tung-tze of the East Castle and Wang-pu-ching Street. When some of these wells were re-examined in October of the same year, an average drop in the water level of 0.5 m was observed. Then, wells of various kinds were selected, namely wells for private use, public use and sale, connected wells, and wells along streets and ponds, and the variation in water level was observed every day. The variation in water level of these wells up to October 1945 is shown in Figure 3.

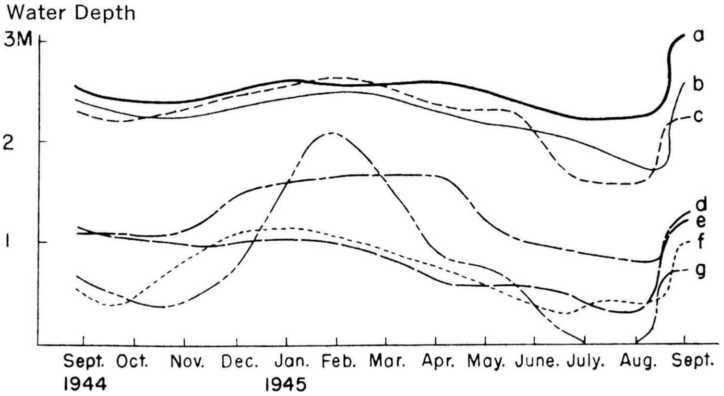

Fig. 3. Variation of Ground Water Level (showing as Water Depth) in the Various Wells in Pei-ping during a Period from Sept. 1944 to Sept. 1945.

a - Side of Tung-tan-kuang-chang
b - SW corner of Lung-fu-ssu
c - Within An-ting Men [Mai-shui-ching]
d - Side of San-tso-men-to-chieh
e - West well in front of Chien-ch'ang
f - East well in front of Chien-ch'ang
g - Road side of Fu-yu-kai

The water level decreased from September to October in 1944, but increased from November to December and through January in 1945, and became a maximum in February and March. It thereafter decreased from April to June and reached a minimum in the middle of August. At that time, dry wells amounted to about 30 percent in the northern part of the West and North Castle areas. After August 15th, the water level in all wells increased equally suddently due to several days of continued rain (twice: from the 15th to the 23d of August and from the 1st to the 10th of September), and reached a maximum level 2 weeks and several days after the beginning of the second period of rainfall. The level subsequently decreased rather rapidly.

During the period of observation, the average increase in water level from February to March was 1 m or so, and that of September 1–1.5 m. Some wells reached the highest level during the year in the former period, but others in the latter. In summary, the annual variation has two seasons of decrease (the lowest in June, July and August; and in October) and two seasons of increase (in February and March, and in August and September). The heavy rains of the rainy season in 1945 fell in the last half of August, later than usual, so the increase in water level seems to have been late. However, this may be a change in water level due in part to percolation and inflow accompanying the rain. On the other hand, the gradual increase in water in February and March was very remarkable. If this was due to the geology, the water must have percolated in the preceding year from the western and northern mountains into the deposits composed of 60 percent gravel and 40 percent mud, and then flowed into the plain 6 to 8 months later, thus presenting a high water level during February and March in the vicinity of Pei-ping Castle.

Observations of the water levels of selected wells at Shih-chia-chuan, Shun-te Han-tan and Chang-te will be introduced in the following. All wells are similar to those of Pei-ping, and seem to be affected 6 to 8 months after rains in the western mountains (during the preceding year). Of course, pressure not only from a horizontal direction but also from a vertical direction through impervious strata is considered for the flow of ground water.

In this connection, R. KANEKO of Peiping University (now with the Agriculture Research Institute in Japan) closely observed the ground water level in the Agriculture Institute and on the University farm northeast of Tien-tsin. According to him, the increase phenomenon in February and March does not appear as clearly in the low dump of Tien-tsin as in Pei-ping, and only the increase in the rainy season is clear. Hence, the aspect of seasonal variation in water level seems to be different between the Ching-Han Railway and Tsin-Pu Railway regions.

In areas where the depth of water is greater than 3 or 4 m, an increase in water level does not appear without continued rain of more than 100 mm. Thus, rain water in seasons other than the rainy season is wholly exhausted at the spot.

III. GROUND WATER OF TSI-NAN

1. Topography and Geology

Tsi-nan (Chi-nan) is situated 350 km from Tien-tsin and 320 km from Hsu-chou along the Tsin-Pu Railway, on the northern slope of the Shan-tung mountainland in the center of Shan-tung Province. It is given the name of Tsi-nan (south of Tsi), because it is on the southern bank of the Huang Ho (Yellow River), which formerly was called "Tsi".

Ssu-li Shan, Ma-an Shan, Li Shan and Chien-fo Shan, all consisting of Ordovician limestone, can be seen in the background on the southern side of the city, and the North China Plain spreads widely to the front on the northern side. Part of a diorite body, which metamorphosed the Ordovician limestone along the zone of contact, stands on the sediments of the plain to the peaks of Chin-niu Shan, Feng-huang Shan, and others are scattered northwest [literal translation] of Tsi-nan. The portion having the aspect of an ancient archipelago extends southward along the Tsin-Pu Railway to the northern bank of Ta-sha Ho west of Tsi Shan.

Geological surveys show that south of Tsi-nan, the Ordovician limestone dips 15 degrees northward and is folded with an east-west axis. The rock facies is a beded limestone composed of thin layers, less than several meters thick. Contact with the diorite on the north is found in the vicinity of former Hing-a street, running east to south west of Tsi-nan Castle, and in the western business section. A calcareous breccia bed and loess overlie these limestones and diorite, and most of Tsi-nan City is situated on them.

This limestone gravel bed is called the Tsi-nan gravel bed by the author; its maximum thickness is 40 m and is interbedded with a muddy loess bed, although the geologic age is unknown. The mud bed is well developed in the upper reaches of the valley, while the gravel bed is well developed in the lower reaches of the valley, and occurs even in places as high as 100 m above sea level. In the north, including the northern half of Tsi-nan City, the flood plain deposits of the Yellow River cover the Tsi-nan gravel bed. They are very thin in the part of the corporate city, but become gradually thicker toward the river.

2. The "Seventy-two Springs" of Tsi-nan and Their Mechanism

Tsi-nan is commonly called the "city of seventy-two springs", and seems to deserve the name. Actually, there are two great springs, Hei-hu-chuan southeast of the outer castle and Pao-tu-chuan to the southwest. The number of springs both in and out of the city total about 50, and the total yield amounts to 140,000 or 150,000 tons/day, forming the largest spring group in yield throughout North China and Mongolia. The spring water of Hei-ho-chuan, Pao-to-chuan, etc., become the stream surrounding the castle wall, and water from the spring group within the castle flow into the historically famous lake of Ta-ming-hu, 8 km in circumference; the outflow joins with flows outside the city to form the Hsiao-ching Ho.

The quality of the water from the springs is generally 12 mg/l for Cl and 40 mg/l for SO_4; the water of Hei-hu-chuan is low in SO_4 and is the best quality ground water in North China.

The yield: the Hei-hu-chuan gushes from a small cliff of limestone conglomerate, but Pao-tu-chuan gushes up about 10 cm from a pipe, and tends to gush up everywhere in the bottom of the pond. Accordingly, the mechanism of the springs immediately before gushing out is considered as follows: The water intruded into limestone conglomerate has made irregular channels and is forced through the channels from the back to blow or gush out everywhere.

The source of the municipal water supply in 1942 was Pao-tu-chuan, but the water became muddy in the rainy season of that year, causing a three-day interruption of supply. In addition, the source is located in an area of the city that is crowded with houses, the topography is low and there is risk of pollution. On the other hand, a source was desired where water could be supplied by natural flow and under favorable circumstances, because coal for pumping power was in short supply. For this purpose, the water works station of Tsi-nan City (Y. YAMAMOTO, Japanese advisor) investigated the subsurface flows in the Chung-kung district south of Tsi-nan to investigate the old tale that the water of the seventy-two springs came from Tai Shan.*

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* Primary report and photographs. 2 volumes.

In 1944, the author and others explored the geology of the southern part of the city and the southern suburbs, and 7 holes (three at depths of 96 m, 70 m and 42 m, and four at 30 m each) were bored in the vicinity of Tsi-lu University, Chi-li-wa and the foot of Chien-fo Shan.

Of these borings, those at Chi-li-wa twice encountered limestone caves, several m thick. A bed of rounded gravel and a red compact hard clay bed, 2 m thick, were found in the bottom of the caves, and indications of flowing water were, although the quantity was probably small. Then the chlor-calc test was performed in cooperation with the North China Dojin-kai, in order to examine whether or not the water was connected with the springs, but no reaction was found in the springs in the lower reaches. Therefore, it was decided that there was no connection between them. Furthermore, in two borings, one made in former Hing-a street and the other at Chien-fo Shan, the former encountered caves 2 or 3 m thick, but there was no clear indication of water. Therefore, a boring was made in the northeastern extremity of Tsi-lu University to examine the well lying in the university at the same time. It passed through the limestone conglomerate bed into the limestone bed rock 40 m below the surface, and was successful in obtaining a large amount of water 2 or 3 m below that depth.

An examination of the results of boring and measurements of 2 or 3 existing wells led to the following supposition: the ground water in the limestone comes from the south and encounters the diorite, which caused contact metamorphism in the limestone in the vicinity of former Hsing-a street. As the limestone is very compact and impervious, the water tends to ascend along the contact plane to some degree and intrudes the limestone conglomerate.*

In August of 1944, the subsurface geology of the environs of former Hing-a Street was surveyed by the resistivity method in cooperation with Y. KUROKAWA of Kyoto University for the purpose of a precise geographical survey of the course of water behind these springs. As a result of this survey, on the basis that a low resistivity suggests the occurrence of ground water, a water-bearing cave was detected at a depth of 40 m below the surface of the semi-dome structure on the northwestern ridge of Chien-fo Shan, a place which looked promising from the first. Thus, the possiblility of following the underground position of the water increased. This underground flow extends at least to the unique well in the district—the well in the Blind and Dumb School, which never dries up, is 27 m deep and has a natural water level of 27 m. The flow also extends to one or two wells of superior quality, and to Hei-hu-chuan.**

The results of this survey at least exploded the past conjecture that the source of the seventy-two springs of Tsi-nan might be percolating water of the Yellow River, and pointed out that the resistance of the diorite body is the mechanism that causes the ground water in limestone in Chien-fo Shan to gush up.

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* Second survey on boring report by the well-drilling team of the Army.

** Third survey.

3. Ground Water in Part of the Corporate Town of Tsi-nan

In October 1944, an additional ground water survey was performed on the existing 200 wells. Test holes were bored into the limestone conglomerate in the business area, and in and west of the castle in order to make sure of the results. A water table map was made at a contour interval of 2 m, showing also lines of equal depth of water in wells and lines of equal values in chlorine content. Efforts were made to determine the flow of ground water in the limestone conglomerate by the flow gradient and water quality.

Results showed that the water levels range from 30 m to 60 m and the Cl content is less than 50 mg/1. The quality is good in the area of brick factories spotted along the mountain foot south of the city, but the water becomes suddently worse northward in the corporate part of the city. The flow of ground water seems to be fast, with a rather steep slope in the business section. There, the quality is maintained and even among the shallow wells in the spring area the Cl content stays at 30 or so mg/1. However, where the amount of flow is small, pollution increases due to stagnation, and the Cl content reaches 300 mg/1. The water tends to be worse in the low swampy area in the northern and western suburbs.

In addition, the results of boring and electrical prospecting, shown on the map, more clearly indicated the flow mechanism behind the prominent spring Hei-hu-chuan. The Cl content indicates flow from south of the business area to the southeast corner of the outer castle, finally connecting with Pao-tu-chuan. Thus, a zone remarkable in flow and velocity was found.

In March 1945, S. Hanada of the North China Development Co. had an opportunity of re-examining the area south of Tsi-nan City with a Meggar-tester in search of a water source for the Army. As a result, he hypothesized that a flat lenticular water vein was the mechanism of ground water distribution in the limestone. This seems to be reasonable, considering the fact that the limestone as a whole is thin and very compact in the district.*

Several investigations involving surface exploration, boring, electrical prospecting and sanitation tests did not result in the discovery of a site to obtain a new source of water supply,** but gave a rather clear answer as to the tendency and mechanism of occurrence of ground water in the vicinity of and behind the seventy-two springs of Tsi-nan.

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* Fifth survey.

** The war had terminated when boring materials were transported to make sure of the result, and the plan was abandoned.

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