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PRINCIPLES AND THE EFFECT OF UNDERGROUND PIPING

— GROUNDWATER RECHARGE AND RUNOFF CONTROL —

地下埋管の原理と効果

—— 地下水涵養と流出抑制 ——

April, 1980

Hydrology Division, River Department,
Public Works Research Institute,
Ministry of Construction

建設省土木研究所
河川部水文研究室

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Preface

Underground piping refers to those pipes installed underground for the infiltration of water into the soil.

The Public Works Research Institute has been conducting research since fiscal 1977 on the mechanism of water infiltration, recharge capacity and the method of preventing clogging as part of a comprehensive research project with a view to the development of techniques of groundwater recharge. Since fiscal 1978, a field experiment has also been carried out at Fukaya, Saitama Prefecture, to study the actual recharge, the effect on surface crops, etc. As a result, it has been ascertained that underground pipe has a superior capacity for groundwater recharge both in quality and in quantity.

As for the techniques of groundwater recharge, the well method and the basin method are practiced in other countries. The underground piping method compares favorably with these methods and may well be a suitable method for Japan where land area is limited.

In urban areas, on the other hand, flood runoff has been on the increase due to changes in land use. If underground infiltration of surface runoff water can be made possible by the underground piping method, it will greatly contribute to the control of flood runoff and to the stabilization of base flow. Study on the method of increasing underground infiltration from this point of view has revealed that the underground piping method is also promising for runoff control.

Needless to say, the mechanism of water infiltration is and infiltration capacity may vary depending on the soil and geology; it seems therefore premature to come to any conclusion. However, in view of the urgent need for the study of comprehensive flood control measures, we decided to publish experimental results so that the present state of research would be made available to as many people concerned with the problem as possible, not to speak

of those at the Institute. We hope that this publication will be found useful by those concerned with the problem.

We wish to record our sincere thanks to Messrs. Koichi Baba, Kiyoshi Mimura, Tetsuo Nishida, Tadashi Niimi, members of the Committee on Groundwater Recharge, members of the Special Committee on Groundwater Recharge and many others for their valuable suggestions and comments. Our grateful acknowledgement for their cooperation is also due to the Municipality of Fukaya, the Saitama Agricultural Experimental Station, the Technology Center for Land Development, the Construction Technical Institute and Mr. Baba who kindly leased his land for experiments.

Katsuyoshi Ishizaki,
Head of Hydrology Division

Akira Kitagawa,
Research Engineer of
Hydrology Division

Akira Terakawa,
Research Engineer of
Hydrology Division

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Introduction

The underground piping method is a method of groundwater recharge developed in Japan. Artificial recharge may be classified into two types: injection and water spreading. In the injection method, groundwater is recharged by means of wells; clogging often occurs as recharging takes place through the walls of injection wells. Further, it is difficult to prevent and remove clogging as it occurs unnoticed.

In contrast, the water spreading method is one whereby groundwater is recharged through the ground surface. In this method, clogging may easily be dealt with, making this a dependable method of recharge. On the other hand, the normal water spreading method employing an infiltration pond requires an area of land. Therefore, it is not necessarily a suitable method of recharge in Japan where open land is very limited. Accordingly, there is a need for the development of a recharge method which is of the water spreading type but requires little land.

The underground piping method is a method of groundwater recharge developed in Japan; it is of the water spreading type which does not interfere with land use on the surface as it can operate under farmland. For upland field irrigation, an irrigation method called underground irrigation is employed. This method is to supply water underground to directly water the roots of plants through capillarity so that the irrigation effect may improve. The method widely practiced is to install clay piping of 38-75 mm in diameter at a depth of 30-60 cm underground. This may be described as underdrainage reversed.

In recent years this method has widely been applied to sewage land treatment; it is called the capillary treatment method or underground trench method and is effectively used in the treatment of sewage from sanitary sewage tanks and business establishments. Though clogging invariably poses a problem in any method of ground-

water recharge, it occurs less frequently in the above-mentioned underground trench method; application of this principle to ground-water recharge came to be considered. Underground piping is installed in the soil and the infiltrating water is purified while passing through soil zones with a concentration of microorganisms. However, when considered as recharge facilities, it must first be ascertained as to whether a sufficient amount of recharge can be obtained and whether recharge characteristics change if recharge continues over a long period of time. As for the application of underground piping, it may be used for the infiltration of rainwater for the purpose of restricting flood runoff in urban areas. This point will be touched upon later.

1. Mechanism of Groundwater Recharge by Underground Piping

1.1 Infiltration and clogging in soil water zone

Located in the surface stratum, the soil water zone plays an important role as a filter for infiltrating rainwater and surface water. The good quality of groundwater is due to this filtering mechanism. Further, the soil water zone is where plants absorb water and nutrition through their roots and where organic bodies are converted into inorganic bodies by micro-organisms in the soil.

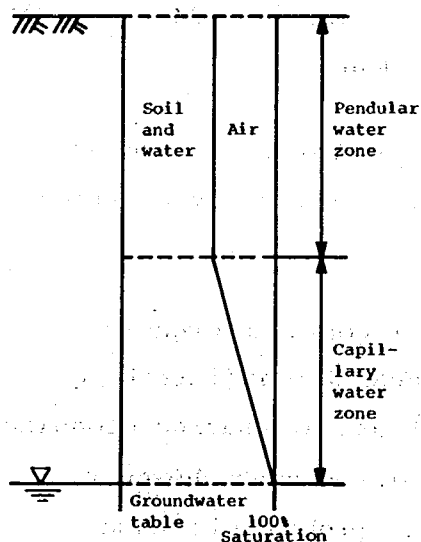


Fig. 1

As Fig. 1 shows, soil consists of three constituents: soil particles, air and water. Water is mainly supplied by rainfall. Part of the rainfall becomes groundwater, while the water stored in the soil water zone returns to the atmosphere through evapotranspiration. The soil water zone always contains air as well as water. It is, therefore, sometimes called the unsaturated zone. In this respect it greatly differs from the aquifer zone where pores are saturated with water. Further, the capillary pressure due to the surface tension of water plays an important role in the water dynamics of the soil water zone. Thus, the soil water zone differs considerably from the groundwater zone in its rheological characteristics of infiltrating water and also in the existence of diversified types of soil microorganisms.

On the other hand, soil surfaces under natural conditions are easier for rainwater to infiltrate because of their large pores. Infiltration is difficult, however, in the case of reclaimed land which has been hardened. In particular, if the soil surface

is struck directly by falling raindrops, soil aggregations are crushed; minute particles then fill the pores, restricting the infiltration of rainwater. The underground piping method is intended to recharge groundwater by directly supplying water to the soil water zone, avoiding the soil surface which shows such fragile behavior.

Fig. 2 shows the structure of the underground trench described earlier. The water supplied from the pipe is first stored in the trench below; it then infiltrates downward

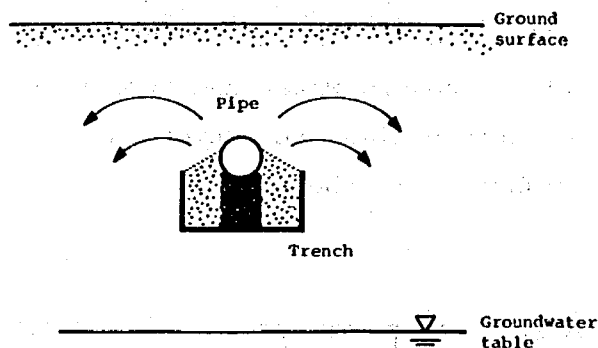


Fig. 2

by the capillary action of the sand and soil around the underground pipe. The water infiltrating soil is gradually purified by abundant soil microorganisms.

In general, if the infiltrating water contains organic material, soil microorganisms germinate near the infiltrating points of the water; this prevents infiltration, causing clogging. In the case of infiltration in the unsaturated zone, however, clogging does not occur so often. This is probably because oxygen is supplied from the air, aerobically dissolving organic material and increasing the range of propagation for microorganisms, thus creating conditions which discourage the occurrence of clogging.

It seems, therefore, that the groundwater recharge method by underground piping whereby water directly infiltrates the soil zone is a superior recharge method in that the use of surface land is permitted to some extent and clogging is less of a problem. However, basic quantitative data, e.g. recharge capacity, are not available, it is important to quantitatively ascertain

the effectiveness of underground piping for groundwater recharge facilities.

1.2 Infiltration from underground piping

1.2.1 Structure of underground piping

As regards the structure of underground piping, various types have been devised for various water qualities of infiltrating water; Fig. 3 shows representative structures of underground piping. In the case of (a), a trench is provided under the pipe so that water is first stored there before spreading and infiltrating through capillary action.

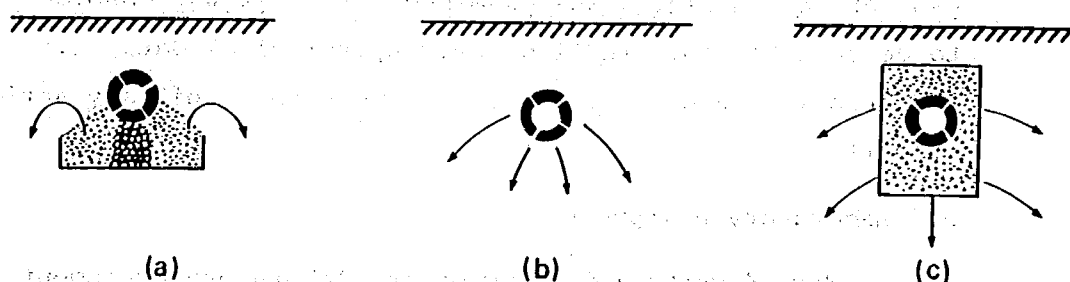


Fig. 3

In the case of possible contamination of groundwater due to organic material in the soil, purification in the soil may be expected. Further, over a long period of spreading, the irrigation effect may be large.

In the case of (b), the pipe is simply installed underground. This type is suitable where there is no danger of groundwater contamination by infiltrating water and where the soil has a high permeability. Since some degree of pressure may be applied in the pipe, a considerable amount of infiltration may be expected.

In the case of (c), part of the area surrounding the pipe is replaced by highly porous sand to increase the amount

of storage in the soil and the area of infiltration into the soil so that the amount of infiltration may increase. This structure seems to be suitable for the infiltration of rainwater to restrict runoff.

In addition, the installation depth and the interval for the underground piping are also important factors to be determined in relation to specific objectives, e.g. amount of infiltration, etc. These will be examined in the next section and elsewhere.

1.2.2 Indoor infiltration experiment of underground piping

As regards the structure of underground piping, the case of (a) in Fig. 3 was examined, since it was considered to be suitable for studying basic hydrological data, e.g. the infiltration rate, etc., as it includes the capillary action of soil.

a. Laboratory equipment

Fig. 4 shows a diagram of the laboratory equipment used. Walls marked (a) are moveable side walls and are to be considered boundaries with adjacent pipes. Thus, different distances between the (a)s correspond to different intervals between pipes. (b) is a connecting pipe and the runoff from this pipe is to be the recharge. In the experiment the water level was changed through the connecting pipe to measure the difference in recharge.

The standard sand of Toyoura was used for the experiment; grains were of roughly the same diameter, with 105-149 μ accounting for 87%. Table 1 gives the characteristics of the sand.

Table 1

- 1) Specific gravity: 2.64
- 2) Porosity: 39.4 (dry density 1.6)
- 3) Permeability: $K = 1.01 \times 10^{-2}$ cm/sec

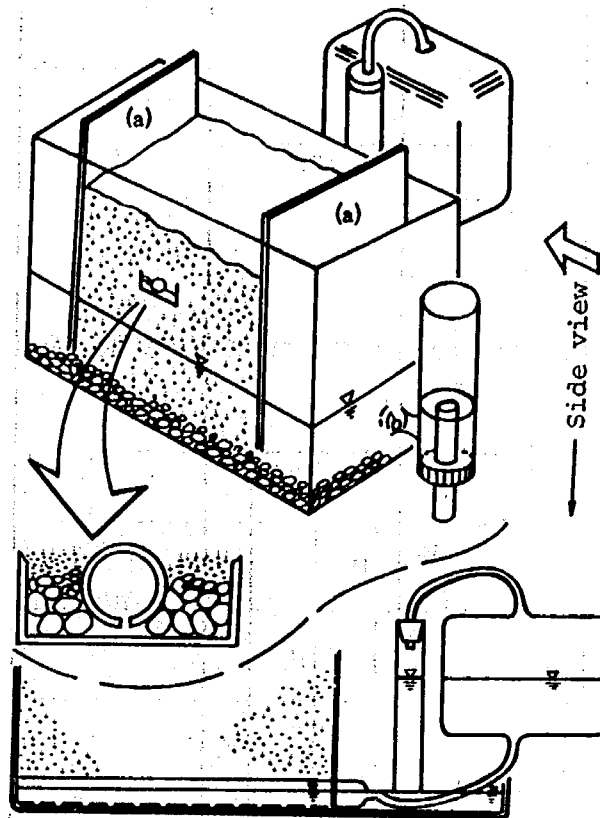


Fig. 4

b. Results of the experiment

Fig. 5 presents the conditions for the experiment and Fig. 6 the results.

For the unit of recharge, m^3/day is normally used. The recharge height is the value obtained by dividing the recharge per day by the control area of the pipe and the unit used is mm/day.

As can be seen from Fig. 6, the recharge increases as the water level difference H increases; recharge is also affected by the width B . However, the increase in recharge due to an increase in B is not linear; after a certain width, it is expected to approach a certain quantity in relation

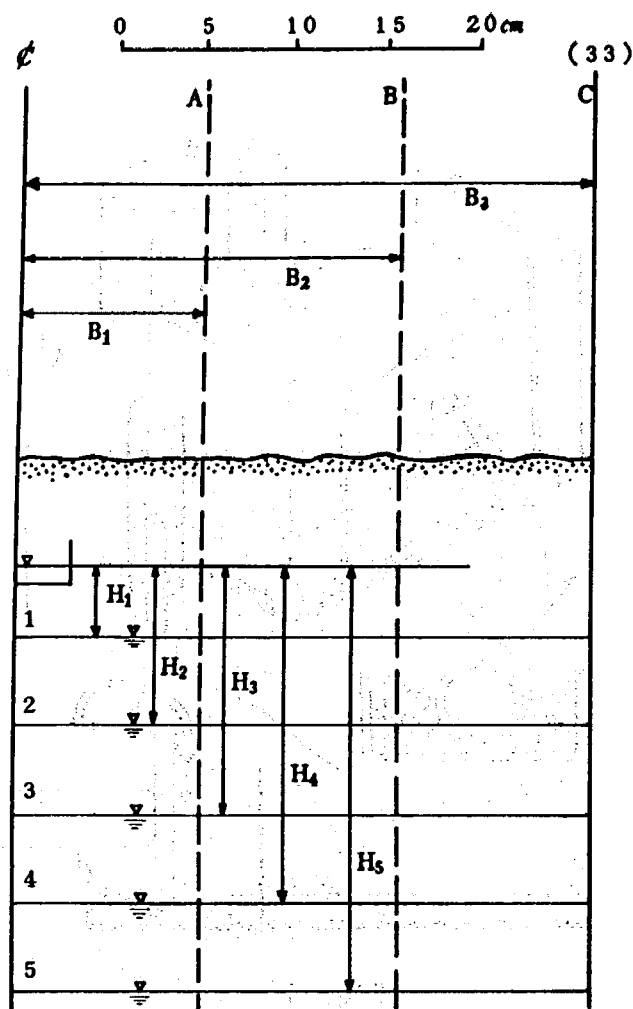


Fig. 5

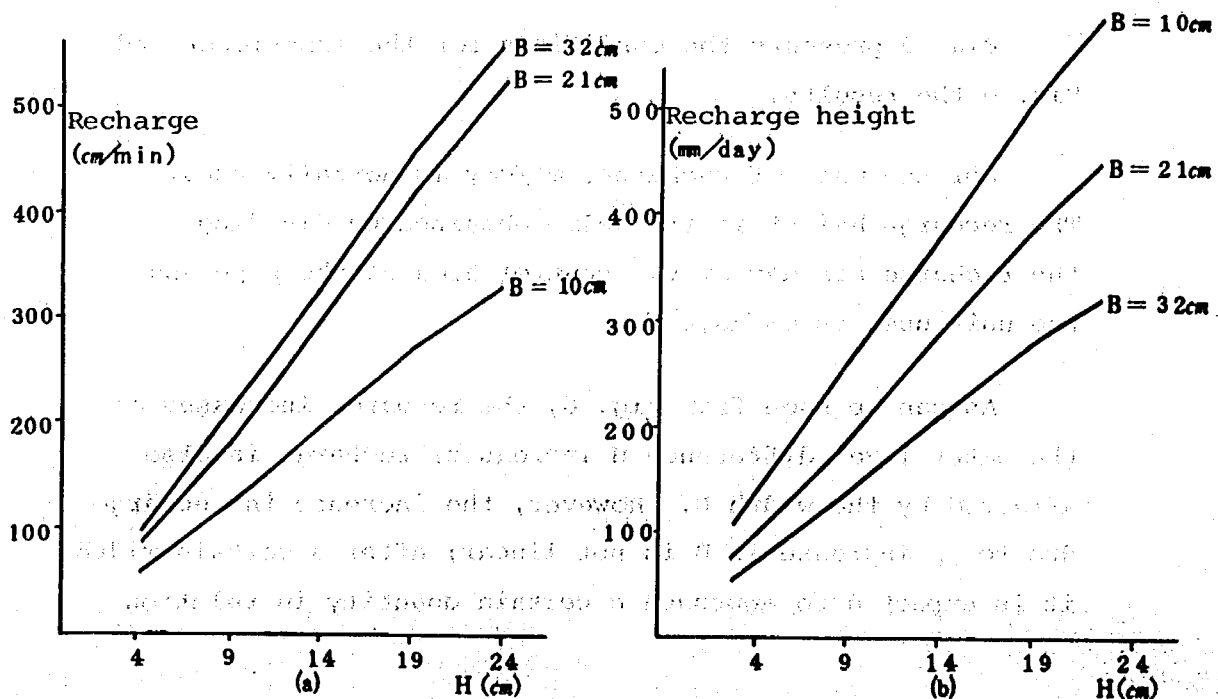


Fig. 6

to H. This is probably due to the fact that the extent of influence from seepage by the capillary action is limited. As regards the increase in H, since the water potential gradient never exceeds 1, it is expected to eventually approach a certain value.

The reason for using the Toyoura standard sand in this experiment is that its physical characteristics are stable, unlike those of ordinary soil, and it is, therefore, easy to handle. Though no soil consists of only standard sand in reality, even the 1/7 scale model showed that a recharge rate as great as 100-600 mm/day was possible. As a result, it was ascertained that underground piping possesses good recharging capacity.

1.2.3 Recharge analysis

As the above experiment is a study of recharge from underground piping under strictly controlled conditions, it is necessary to study recharge under more wide-ranging conditions. This section is devoted to recharge analysis. The propriety of the analytical results is to be ascertained by comparing them with those of the experiment; they may then be extended to actual scale.

(a) Basic analytical equation

Groundwater flow may be determined by the basic equation given below, which combines both saturated and unsaturated conditions.

$$\left\{ \rho g s (\alpha + n\beta) + \rho n \frac{2S}{2\psi} \right\} \frac{2\psi}{2t} = \text{div} \{ \rho K(\psi) \cdot \text{grad} (\psi + Z) \} \dots\dots (1)$$

Given:

ρ = water density	β = water compression ratio
g = gravity acceleration	ψ = water head
S = saturation degree	Z = vertical coordinates

n = porosity

t = time

α = compression ratio
of sand grain

Further, permeability $K(\psi)$ is a function of ψ and may be approximated by the equation below as shown in Fig. 7.

$$K(\psi) = \begin{cases} K_0 & \psi > \psi_b \\ K_0 (\psi_b / \psi)^\eta & \psi \leq \psi_b \end{cases} \quad (2)$$

Given:

K_0 : saturated permeability

η : constants relating
to the sand grain
diameter and the
granular variation

ψ_b : value when air appears in the soil
under dehydration from saturation

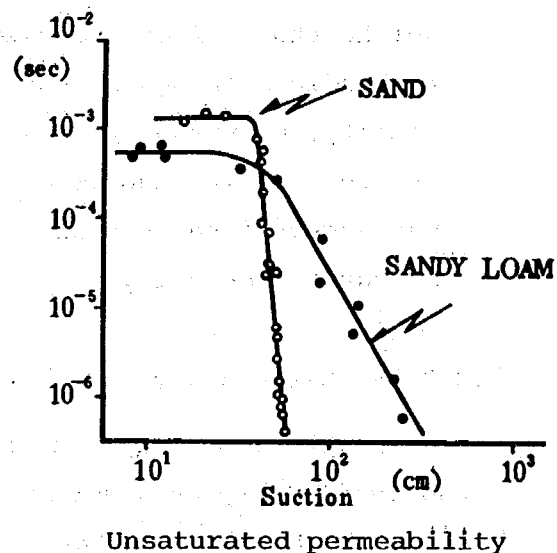


Fig. 7

In the case of normal unsaturated infiltration,
equation (1) may be simplified as below.

$$\text{div} \{ \rho K(\psi) \cdot \text{grad} (\psi + Z) \} = 0 \quad (3)$$

(b) Results of analysis

Numerical calculation was made by converting equation (3) to a differential equation. For $K(\psi)$, 1.01×10^{-2} cm/sec was obtained for K_0 ; $\psi_b = -36$ m and $\eta = 18.2$ were obtained from Fig. 7. Fig. 8 shows the results from both the experiment and analysis. It shows that the results roughly correspond to one another -- an indication of the propriety of the analysis.

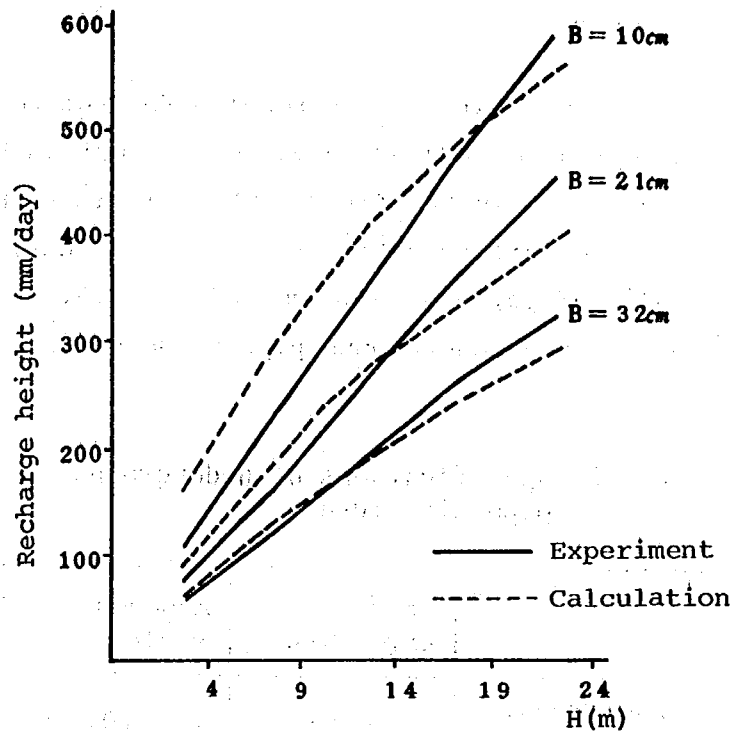


Fig. 8

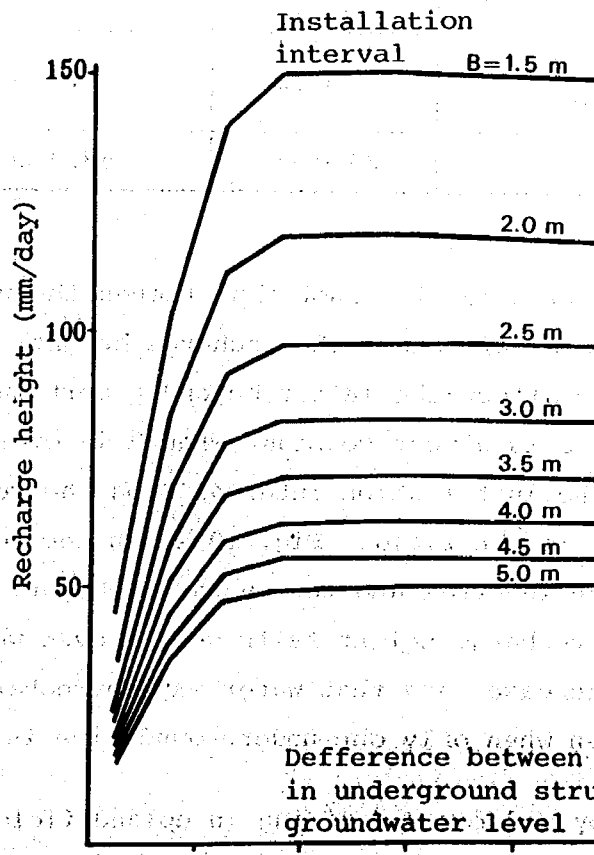


Fig. 9

Fig. 9 shows the calculation results for the recharge height extending the scale on the assumption that recharge is conducted in the field. The soil is to be sandy loam with its permeability taken from Fig. 7. Thus, $K_0 = 5.6 \times 10^{-4}$ cm/sec, $\psi_b = -39.8$ cm and $\eta = 3.5$. Specifications of the underground pipe structure are given below.

Table 2 Specifications of underground pipe structure

	Indoor experiment	Assumed field scale
Width of underground structure	3.0 cm	20.0 cm
Height of underground structure	2.5 cm	7.0 cm
Water depth in underground structure	1.0 cm	3.5 cm
Earth top	26.0 cm	58.0 cm

The calculation results show that though the water level difference H influences the recharge height, the former ceases to affect the latter beyond a certain point. The recharge rate is almost constant when H is over 1m. The effect of the installation interval B on the recharge rate is greater in the field. Fig. 10 shows the relationship between the interval and the recharge height. It shows that the recharge height falls gently even when the interval increases and that water may be recharged over a wide area even when only one underground pipe is used.

Recharge by underground piping in upland fields poses the problem of impact on crops; a problem arises from a possible increase in soil moisture due to the recharge from underground piping. Accordingly, numerical calculation was made for soil

moisture distribution by using an equation relating the capillary pressure under unsaturation to soil moisture. The relationship between capillary pressure and soil moisture is shown in Fig. 11.

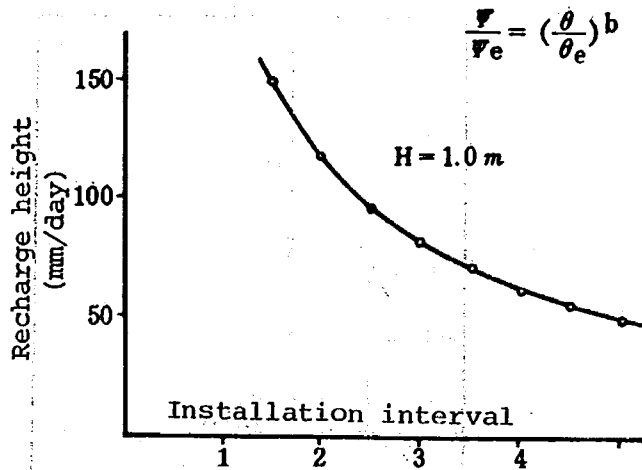


Fig. 10 Installation interval and recharge height

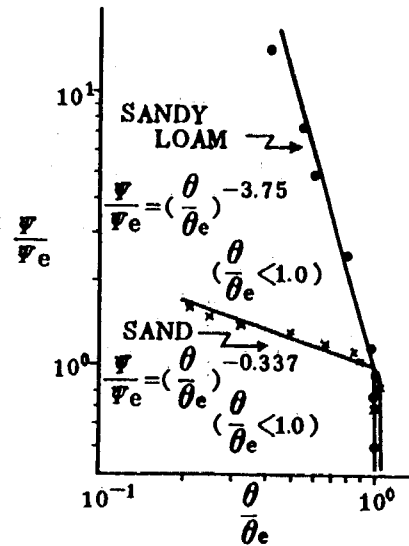


Fig. 11

Given:

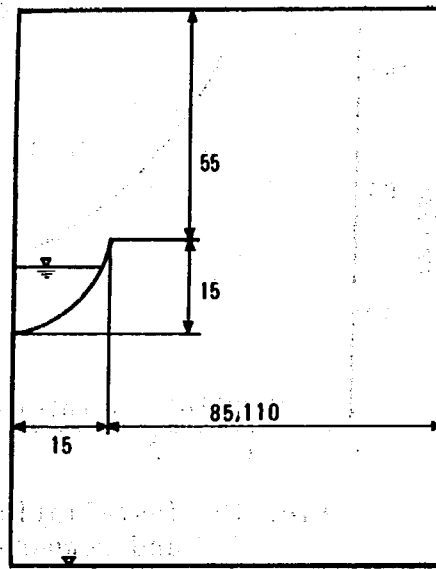
- θ : soil moisture
- ψ_e : constant almost equal to ψ_b , determined by physical characteristics of soil
- θ_e : value of ψ which produces $\psi = \psi_e$
- b : constant for fixed physical characteristics of soil

Fig. 13 shows the calculation results for moisture distribution when the structure of underground piping was as shown in Fig. 12. Table 3 gives the values given to the constant in the equation (4). The water level difference H was 0.75m. According to the calculation results, the water content near the surface seems to be high at over 40%. However, since the loam contains large amounts of fixed moisture with the water content at 40-50% under normal conditions, the results are not exceptionally high. Further, since groundwater recharge is carried out intermittently, the moisture distribution shown by Fig. 13 gives maximum values.

Detailed study requires a non-stationary analysis which takes account of the water content as it changes over time.

Table 3

	Sand	Sandy loam
θ_e	0.34	0.54
h_e	38 cm	40 cm
b	0.337	3.75



(Unit: cm)

Fig. 12

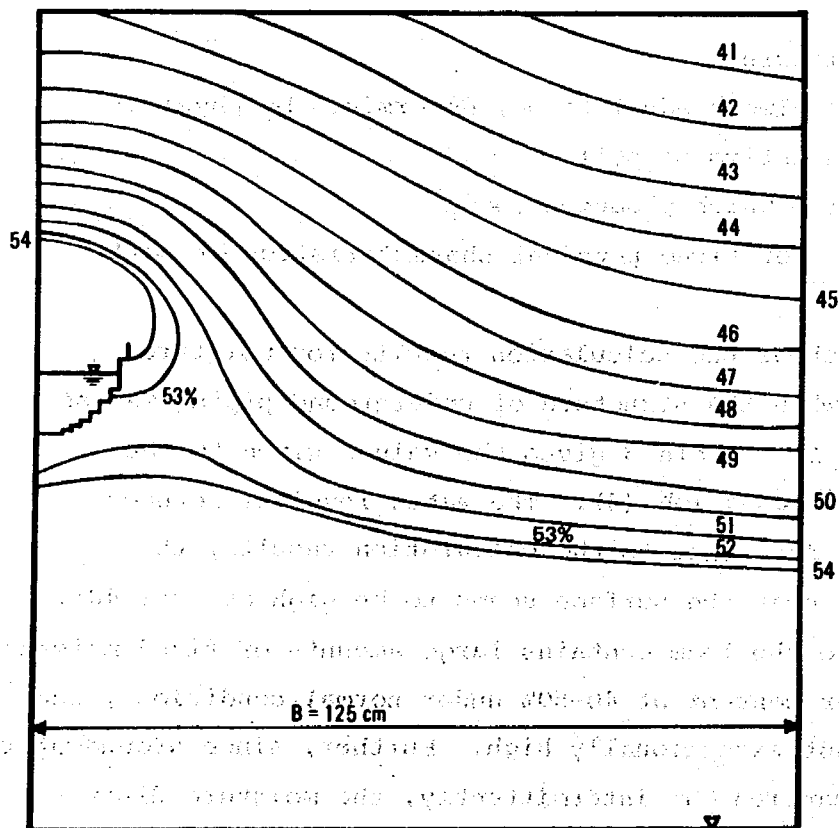


Fig. 13

Figs. 14 and 15 show the distribution of capillary pressure, direction and velocity of soil moisture flow for a single case.

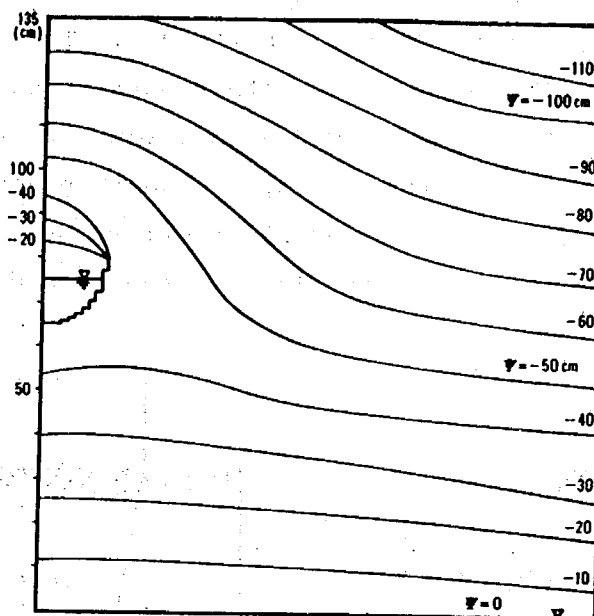


Fig. 14

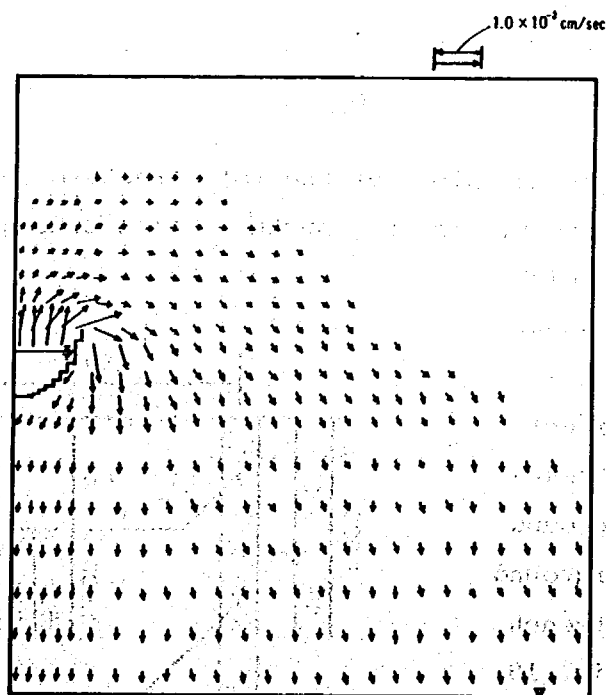


Fig. 15

2. Field Experiment of Underground Piping

2.1 Outline of field experiment

Field experimentation was conducted in the Arakawa Sagan alluvial fan, one of the alluvial fans of the River Arakawa, on the outskirts of Fukaya, Saitama Prefecture. The alluvial fan is located on a diluvium plateau with a surface covered by loam stratum. The test area was divided into four square sections with 10m sides. Underground pipes, 10m each in length, were installed at an interval of 2.5m in the first section, having the structure (a) shown in Fig. 16. In the second and third

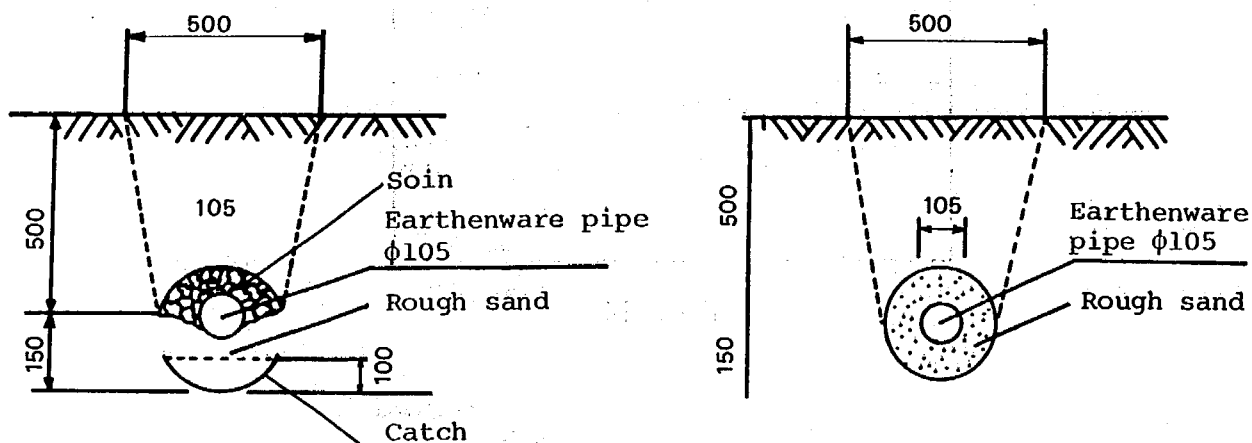


Fig. 16

sections underground pipes of the (b) structure were installed in the same pattern. In the fourth section underground pipes were installed with the structure shown in Fig. 17 to ascertain the effect of rainwater treatment by underground piping. Underground pipes with a trench as shown in Fig. 18 were also installed in the fourth section.

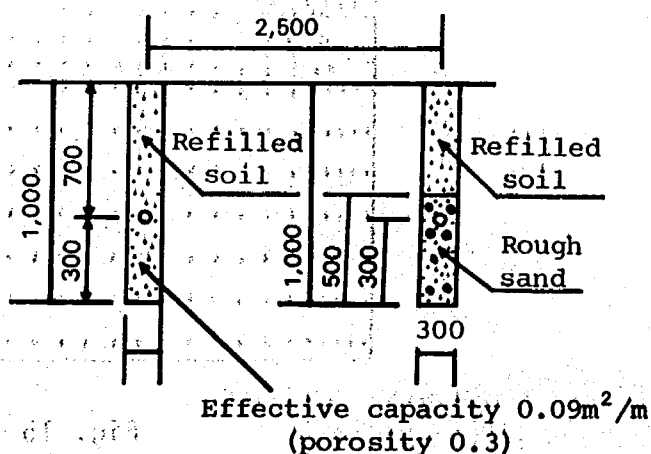


Fig. 17

The main objectives of this field experiment were to ascertain the maximum recharge by underground piping and long-term recharge characteristics. The experiment to ascertain maximum recharge ability was conducted in the first section. In the second and third sections, a study of long-term recharge characteristics, i.e. interference with recharge due to clogging, was conducted.

Since the start of the experiment, the same amount of water was regularly supplied to the second section up to the present. In the third section, the daily supply was gradually increased to ascertain the extent daily recharge could be expected over a long period of time. The underground pipe with a trench in the fourth section was of the structure used for infiltrating water containing a considerable amount of organic material. A study of underground recharge was made in this case. Further, an experiment was performed to ascertain the effect of rainwater treatment by different installation structures. The saturation permeability of the soil in this field experiment was 5×10^{-4} cm/sec, similar to that of the sandy loam shown in Fig. 7.

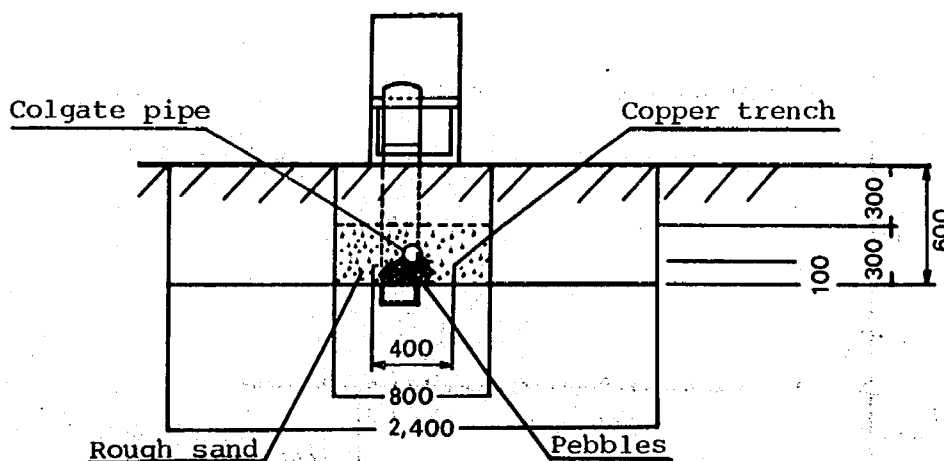


Fig. 18



Photo. 1 Experiment in recharge with the use of underground piping installed in an upland field

Survey of the amount of infiltration, the effect on vegetables, etc. of underground recharge combined with upland field irrigation by means of underground piping.

2.2 Results of the experiment

2.2.1 Maximum recharge

Fig. 19 shows the results of a 24-hour experiment.

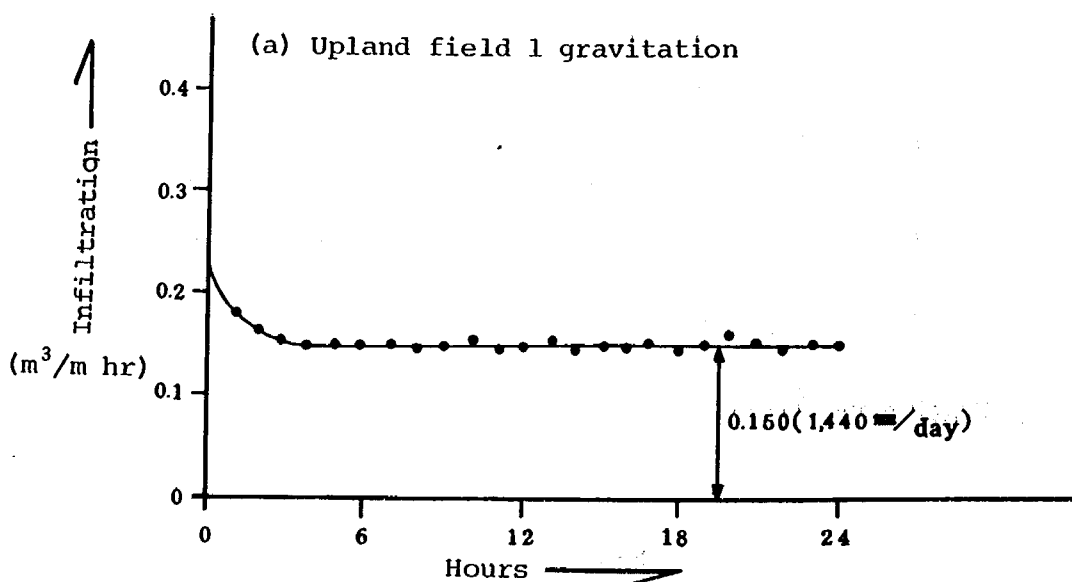


Fig. 19

The experiment aimed to observe fluctuations in the infiltration capacity of the pipe by trying to supply an amount of water equal to capacity. As shown in the figure, it reached a constant three hours after the commencement of the experiment and hardly changed thereafter. The constant infiltration was $0.150\text{m}^3/\text{hr}$ per 1 m of 1 underground pipe, or 1,440 mm/day per unit area. Though it is questionable if such a large volume of recharge could continue over a long period of time, underground piping has a good possibility of sufficiently responding to the situation where the flow regime requires an increase in the groundwater storage in a short period of time.

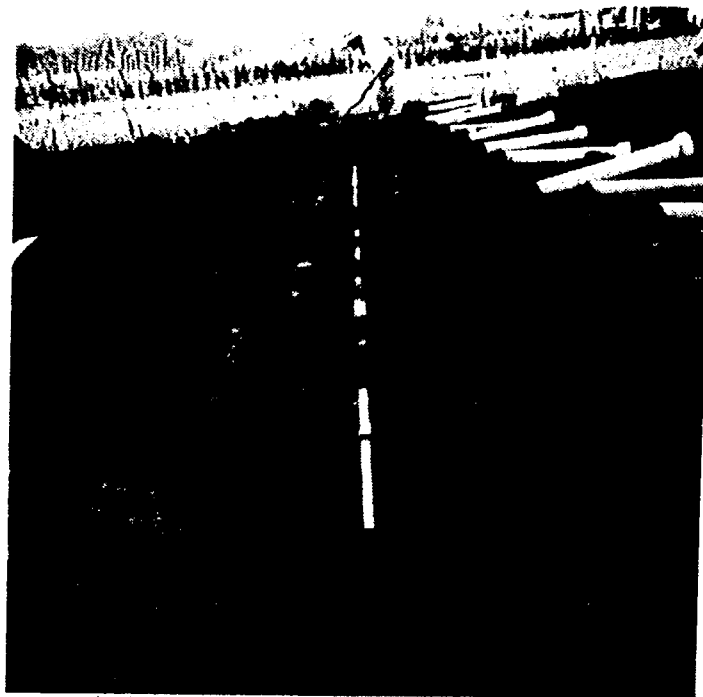


Photo. 2 Underground pipes

Earthenware pipes of 100 mm in diameter and 1m in length are installed horizontally with water supplied to each pipe.

2.2.2 Long-term recharge characteristics

Recharging of 50 mm/day was carried out in the second section since November, 1978, up to the present. Fig. 20 shows the relationship between the infiltration and the SS weekly load by the infiltrating water in the second section. Water is supplied to this section six times a day so that the recharge per unit area reaches 50 mm/day. The vertical axis gives the average infiltration during supplying time periods for each week; the broken line shows the SS load per week in the infiltrating water.

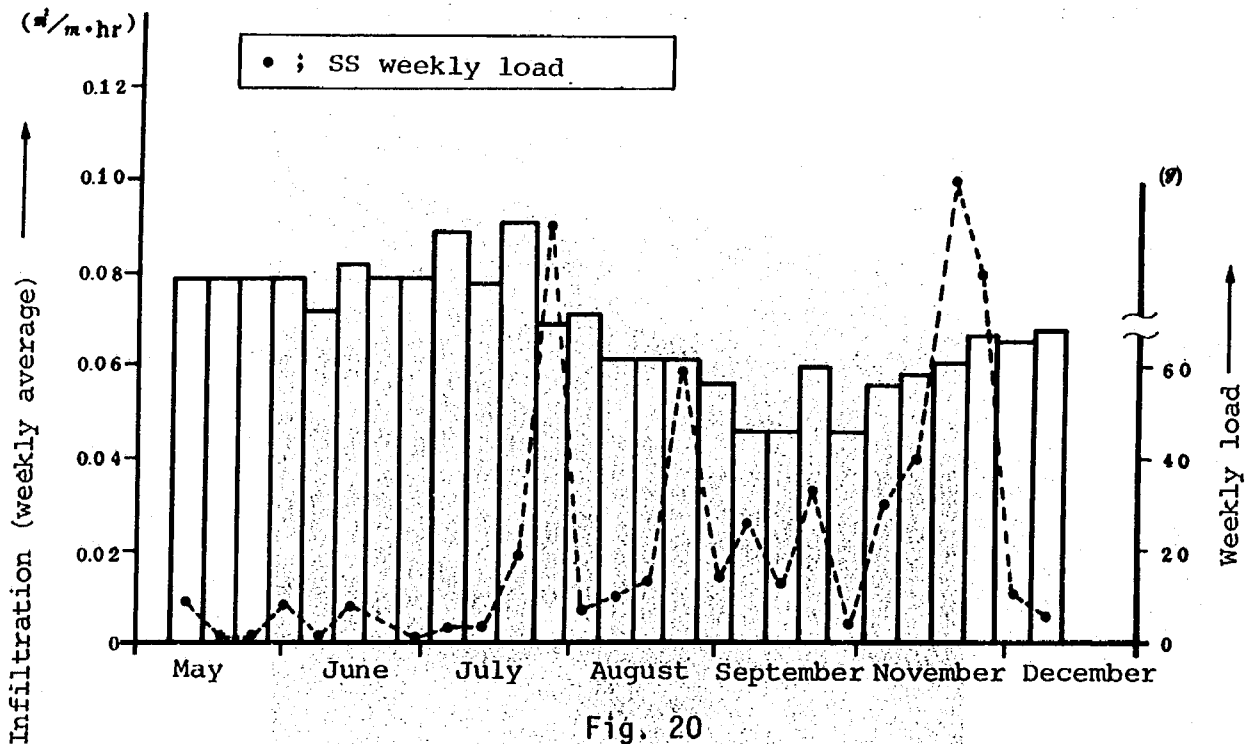


Fig. 20

The figure shows that no change in infiltration is observed when the SS load is small; but infiltration tends to slacken somewhat as the load increases. Though the data are not sufficient, the infiltration volume shows a tendency to recover from October onward. With water supplied intermittently, it might be due to the dissolution of organic SS in the soil after the load has been reduced; but further data will be necessary. However, a recharge of 50 mm/day is sufficient.

The results of this experiment have to be utilized to ascertain the service life of underground pipes (the number of years after which they need to be replaced by excavation).

Fig. 21 shows the long-term pattern of water supply in the third section. Recharge of over 200 mm/day has been carried out since August 21 up to the present. The recharge of 200 mm/day serves as a limit for recharge by underground piping.

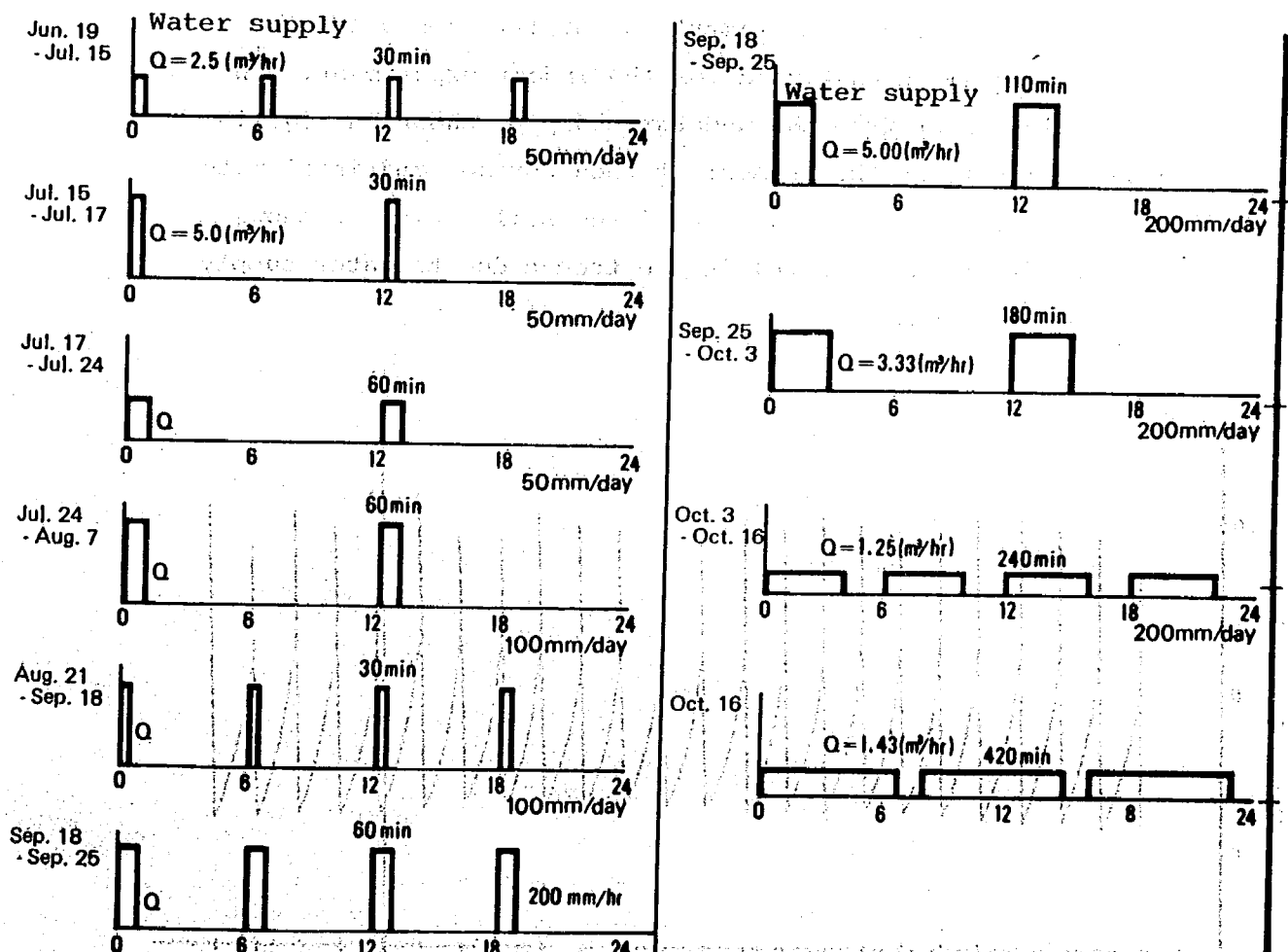


Fig. 21 Water supply conditions for long-term infiltration in the third section

November, 1978 - June 18, 1979: 25 mm/day

In view of the fact that the depletion depth in paddy fields in this area is about 100 mm/day, it is clear that underground piping provides effective recharge facilities. As regards the service life of underground piping mentioned above, when it is actually employed for an underground reservoir, ground-water recharge does not always continue. Accordingly, it seems necessary to study the marginal cumulative recharge. At any rate, it seems safe to say that underground piping has a practical capacity.

2.2.3 Capillary infiltration experiment

This is a field experiment on infiltration using the same mechanism as that used for the indoor experiment. Infiltrating water from the underground pipe shown in Fig. 18 first collects in the trench; it then spreads and infiltrates upward by the capillary action of the soil. Fig. 22 shows changes in the water level in the trench due to water supply and infiltration.

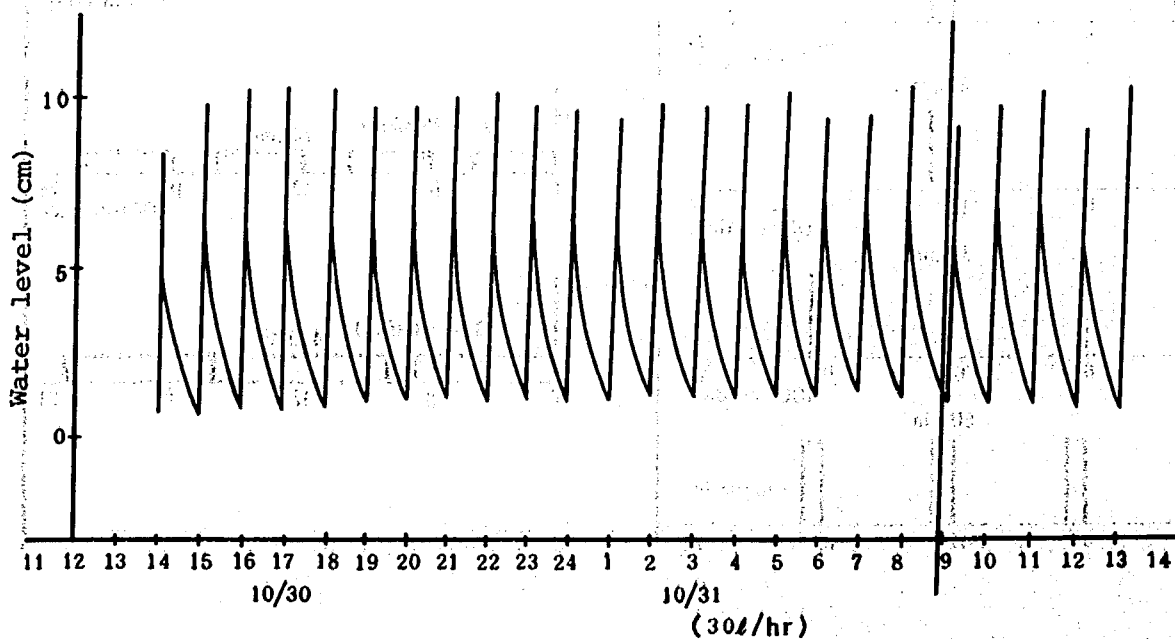


Fig. 22

Water is supplied at a rate of 30 l/hr. If the water level is high in the trench, the capillary action is strong, resulting in a high rate of fall in the water level, i.e. a high rate of infiltration into the soil. Though the rate of change decreases as the water level in the trench falls, the figure shows a rate of infiltration of about 30% per hour. It does not show a tendency for the water level to gradually rise immediately after water has been supplied.

Since the length of the equipment is 2.4m, infiltration per unit length is $0.0125 \text{ m}^3/\text{hr}$. If pipes are installed at an interval of 5m, the recharge rate per unit area will be 60 mm/day. Though there is a difference in structure, e.g. refilled sand, since there is a similarity in soil, the results were similar to those of the analysis in Fig. 10.

2.2.4 Experiment on infiltration of rainwater

In areas of marked urbanization, rainwater storage works are used as flood control measures. It is conceivable

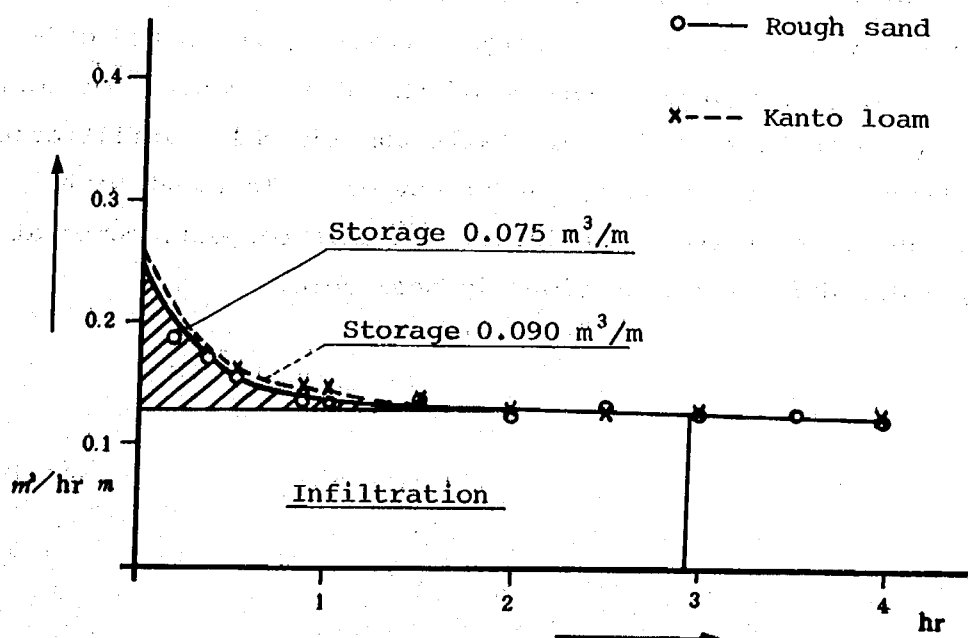


Fig. 23

that flood flow may be controlled through infiltration of rainwater by underground piping. As rainwater concentrates in a short period of time during flooding, it was thought that a temporary storage function should be provided in addition to stationary infiltration by underground piping; an experiment on infiltration was thus conducted with the structure illustrated in Fig. 17. The results are shown in Fig. 23.

In filtration characteristics of two structures, one having the vicinity of the underground pipe refilled with rough sand and the other with the original soil, were compared; but hardly any difference was found. The results of the experiment show that if the water is supplied from the underground pipe to the surrounding area where the soil has been either replaced or refilled, it mostly moves sideways or downward at a rate of $0.125 \text{ m}^3/\text{hr}$ per 1 m of pipe. Since the storage capacity in the replaced or refilled area is 0.09 m^3 per meter, it is clear that most of the water supplied infiltrated underground immediately. In view of the fact that replacement with rough sand has a larger storage effect because of a higher porosity and that it is also effective for infiltration, prior to the experiment, the effect was expected to be large. However, no marked difference emerged, probably because of the above reason. Of course, if the permeability of the soil falls considerably, infiltration will decrease. As a result, the effect of replacement with rough sand is expected to be large. In this respect, comparative study under different conditions is desirable.

3. Effect of Sewage Treatment by Underground Piping

As has been mentioned, soil has a strong dissolving power against organic material. An indoor experiment was conducted to confirm the purifying effect of soil. The results of the experiment are outlined below.

3.1 Indoor experiment

Fig. 24 shows the equipment used for the experiment which was conducted over a period of 100 days from November. Table 4 presents the results

of the analysis of water inflow. Both BOD and COD were around 20 ppm. The daily flow into the equipment was just under 10 mm/day per unit area of the equipment.

Parallel to this experiment, another experiment was conducted using the same equipment to study clogging. Tap water provided the inflow.

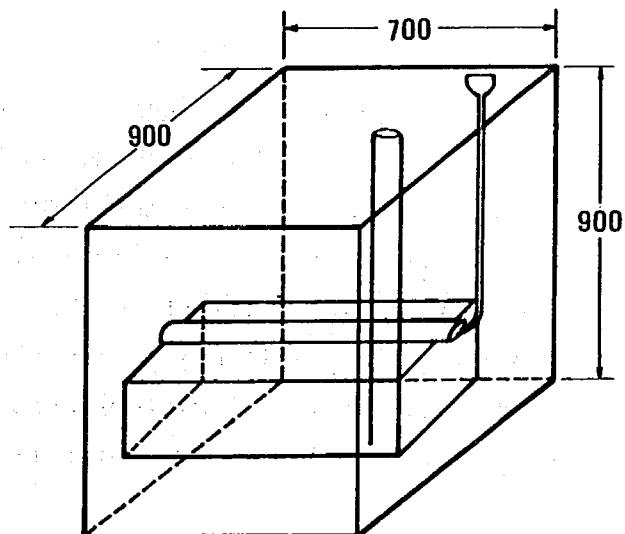


Fig. 24

The state of clogging was ascertained by studying the change in the amount of remaining water in the trench shown in the figure at a specific time following the commencement of intake.

Table 4 Analysis of water inflow

Date	12/4	19	26	1/9	17	24
pH	6.85	6.50	6.75	6.55	6.70	6.60
BOD	20.53	24.80	19.05	20.60	23.00	25.00
COD	22.05	21.17	18.05	25.32	22.00	22.00
NH ₄ - N	9.86	11.64	8.90	9.59	8.90	8.90
NO _x - N	11.27	12.33	10.27	11.64	11.64	12.33
T - N	21.13	23.97	19.17	21.23	20.54	21.23
T - S	320	320	500	516	514	510

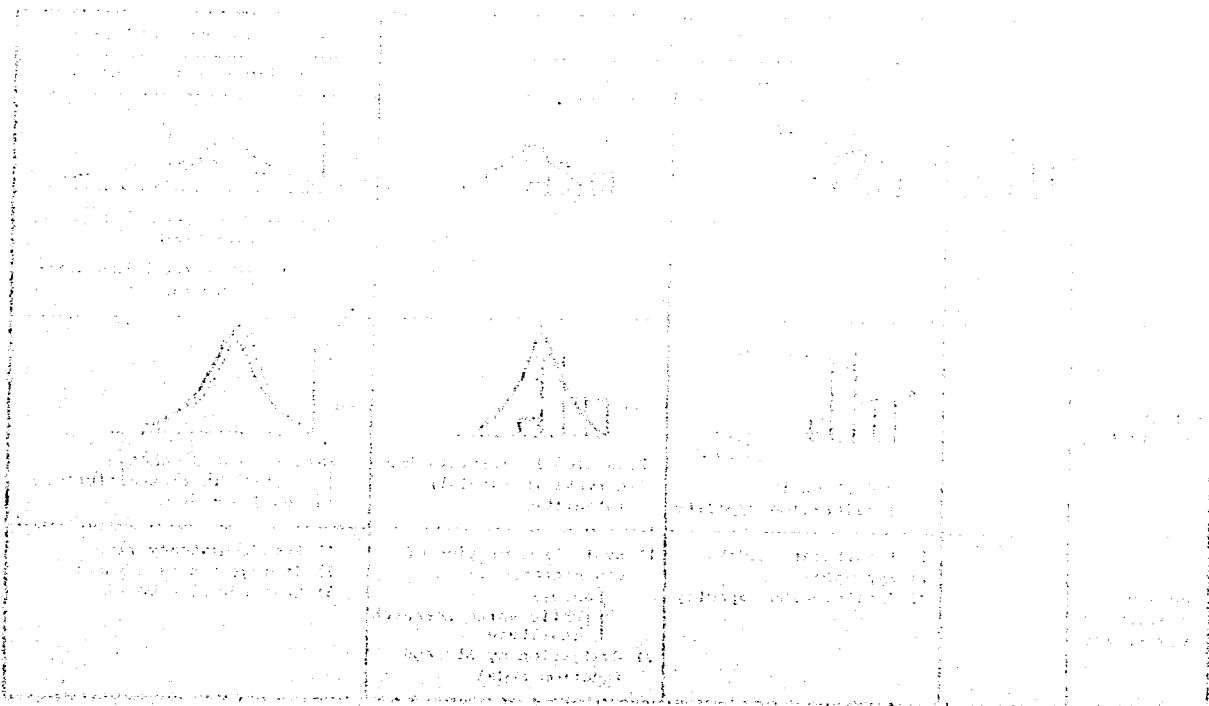
3.2 Results of the experiment

Table 5 gives the results of the analysis of the water outflow. They show that both COD and BOD were almost completely purified by the soil. As infiltration from the underground pipe of the structure shown in Fig. 24 is always in a state of unsaturation, efficient aerobic decomposition seems to have occurred. Since soil has a structure suitable for the habitation of large quantities of microorganisms, they were probably involved in the purification of the water from the underground pipe.

Table 5 Analysis of water outflow

Date	11/15	22	28	12/4	12	19	26	1/9	17	24
pH	6.75	6.80	6.75	6.85	6.80	6.75	6.70	6.80	6.70	6.70
BOD	0.83	0.58	0.81	0.05	0.06	0.33	1.06	1.29	1.88	2.46
COD	0.63	0.21	0	0	0	0	0.42	0.52	0	0
NH ₄ -N	0	0	0	0	0	0	0	0	0	0
NO _x -N	26.06	23.24	23.95	21.13	18.90	15.75	18.49	18.49	21.23	21.23
T - N	26.06	23.24	23.95	21.13	18.90	15.75	18.49	18.49	21.23	21.23
T - S	320	316	40	290	320	510	430	232	282	254
DO	-	-	10.53	9.78	9.51	11.30	11.11	12.52	12.03	14.52

As regards clogging, no significant occurrence was observed compared with the experiment with tap water. As has been mentioned, in the case of infiltration from the underground pipe, a proliferation of microorganisms is not concentrated around the pipe because of the presence of air; efficient decomposition thus takes place over a wide area. It may be assumed, therefore, that the condition makes it difficult for clogging due to microorganisms to occur.



4. Control of Flood Runoff by Underground Piping

4.1 Necessity of the infiltration method

As regards the method of controlling flood runoff due to urbanization, so far flood control ponds and interbuilding storage facilities have been adopted. They are intended to delay by storage the peak runoff concentration during the second runoff process mentioned above. This concentration has been aggravated by rapid urbanization.

In future, however, it may be necessary to reduce the runoff itself during the first runoff process in parallel to the above-mentioned steps by maintaining the original infiltration capacity of rainwater in an area. Under natural conditions, the amount of rainwater infiltration is unexpectedly large; in recent surveys infiltration of 40-80% was found to be normal. In particular, for Kanto loam which covers the Kanto Plain, the infiltration ratio is large, resulting in a flood runoff ratio of 0.2-0.4. Because urbanization of the basin markedly increases surface runoff, conservation of the infiltration capacity of rainwater has considerable significance.

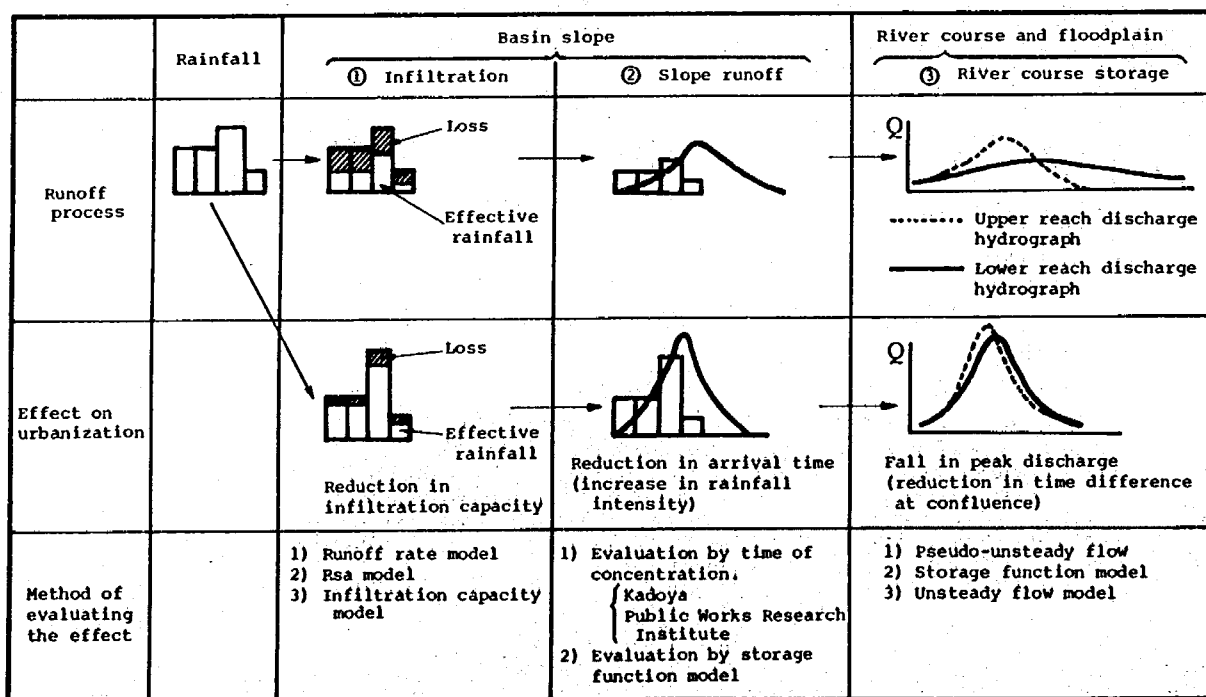


Fig. 25

An example is found in the underground injection by means of wells operated by the Housing Corporation at the Saiwaicho Housing Complex, etc. on the Musashino Plateau, where rainwater has been treated entirely by wells for the last ten years. At the Kumamoto Airport, located on the lava plateau of Mt. Aso, drainage is led to a pond installed in the neighborhood of the airport for treatment by infiltration.

As described above, infiltration of rainwater has been practiced in the past; but it seems that this is made possible by the existence of a stratum with a high infiltration capacity near the surface. The underground piping method is intended to extend the application of rainwater infiltration over a wider area.

4.2 Infiltration of rainwater by underground piping

Since natural land surfaces are covered with many gaps, due to the existence of vegetation and small animals, the infiltration of rainwater is made easy. In contrast, infiltration is difficult on reclaimed land where the surface has been hardened and has few gaps. The condition of the soil, however, is not changed even by reclamation; the vertical movement velocity of water infiltrated from the surface appears unchanged after reclamation. Therefore, rainwater may directly be led underground by means of underground piping bypassing surfaces where infiltration capacity has been reduced.

Though infiltration of rainwater through wells is based on the same principle as above, since groundwater supply is made at points, the spreading capacity of rainwater in the soil may be limited unless the stratum has a good permeability. In contrast, since water is supplied along lines in case of underground piping, underground spreading of rainwater is possible even if the stratum has low permeability.

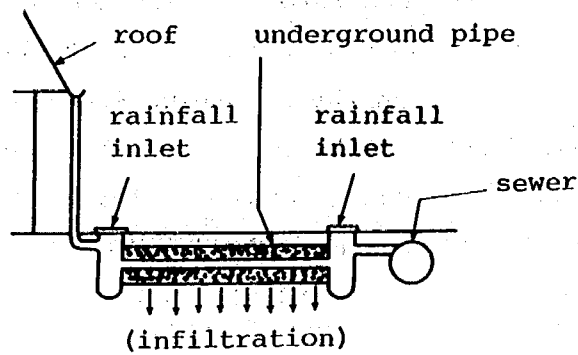


Fig. 26. Case of a private house

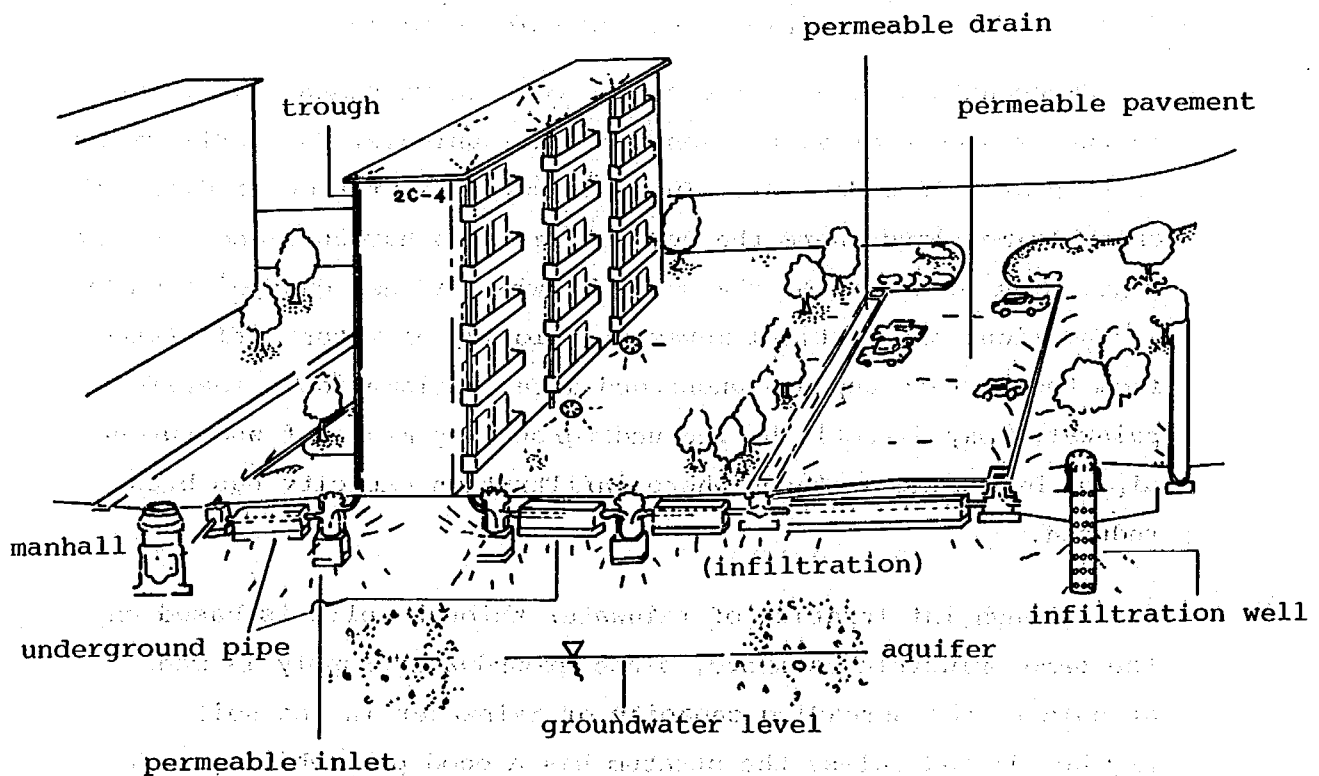


Fig. 27. Rainfall infiltration for runoff control

Let us now calculate the length of the underground pipe necessary for rainwater to infiltrate.

Though the infiltration rate from an underground pipe seems to vary according to the soil condition around the pipe installation, let us assume a fixed rate of $0.1 \text{ m}^3/\text{hr}$ per meter of underground piping. If pipes are installed at an interval of 5 m, the infiltration will be $0.1 \text{ m}^3/\text{hr} \div 5 \text{ m} = 20 \text{ mm/hr}$. This is equivalent to 100 mm in five hours -- a considerable loss. In addition, the gaps in the area surrounding the pipe may be expected to add rainwater storage of about 0.1 m^3 per 1 m of pipe, equivalent to 20 mm; this may function to balance changes in the hourly rate of rainfall.

Installation of underground pipes at an interval of 5 m implies that a site of 200 m^2 for a private house will require a 40 m length of pipe in total. A length of this extent may be obtained simply by installing piping around the site.

Underground piping may also be considered in combination with rainwater storage facilities such as inter-building storage. This may lead to a reduction in the area for interbuilding storage and in flooding frequency. The total length of underground pipes increases where infiltration is low due to geological conditions; but this problem can be solved by reducing the installation interval of underground piping.

4.3 Problems in practice

As has been outlined above, underground piping offers a good possibility for controlling flood runoff by facilitating the infiltration of rainwater. This method has the merit that installation is possible on a small scale, e.g. a house basis. Further, costs are extremely low compared with the prices for land or houses. Thus, even if a developer is obliged to install pipes under the principle of originator's burden, this should seldom

interfere with the progress of development or dishearten the developer. The only concern is for maintenance and control.

In urban areas, even rainwater is not necessarily of good quality. In particular, since the rainwater contains suspended matter once it has fallen to the ground, clogging may also occur. This point may require a finely-designed filter device. There may also be some concern as to groundwater pollution by infiltration of rainwater.

As regards pollution, since the soil is expected to perform its purification function, water of poor quality is not expected to infiltrate underground as it is; in some cases the quality of groundwater may even improve. It will be necessary, however, to ascertain the service life of underground piping, including the question of pollution, so that a method of removing the clogging may be devised. Therefore, it is necessary to apply this method on a trial and error basis to housing, both private and public, in parallel with indoor experiments.

Though it is encouraging to see that this method is under study by the Kanto Construction Bureau and the Housing Corporation, it is to be hoped that it will be tried out at as many places as possible under different conditions.

Conclusion

The underground piping method has been studied with regard to its mechanism and capacity of infiltration. Though the initial aim was to develop a method of groundwater recharge, one of the byproducts of the investigation was the discovery of applications to the control of flood runoff.

The results of the study were more favorable than had been anticipated and they permit us to have great expectations for the future. Concentrated research directed toward technical development seems to be worthwhile.

The hydrology of the unsaturated zone which handles soil water near the surface is a new, expanding field of study. It thus offers various exciting research opportunities and attention should be paid to its development and exploitation.

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