Groundwater Recharge Through Rainfall Seepage Device in City Area

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1. Introduction

One of the important requirements for the location of city is to be able to obtain water. Prior to the construction of the modern water supply system, source of water in city for domestic use is considered to have depended on, in most cases, groundwater or inflow water. With the dawn of modern age when the water supply system was fully furnished, use of groundwater for general domestic purposes decreased. Nevertheless, the groundwater had been continuously used mainly for industrial purposes due to lower price compared to supplied water.

Approximately from 1920, the ground subsidence phenomena has been recognized due to pumping of groundwater. In 1950s, radical ground subsidence occurred primarily in Tokyo and Osaka, heightening danger of serious disaster such as storm surge damage. Corresponding to this situation, as ground subsidence prevention measures, the "Industrial Water law" and the "Law Regarding the Groundwater Intake for Architectural Structure" (so-called Building Water Law) were enacted in 1956 and in 1962 respectively. In cities located on the ground subsidence belt, the intake as well as the use of groundwater had become the chief concern of the regulation.

Consequently, the groundwater had been gradually unused and forgotten, so to speak, as one constituent of the water circulation in cities. On the other hand, the amount of groundwater recharge has been progressively lowered in city areas as a result of promotion in constructing road pavements and concrete buildings due to pursuit of convenience and efficiency in urban activities.

The rate of land use in the metropolitan Tokyo is as indicated in Table 1 according to the survey of existing conditions of land use carried out in 1991 (Tokyo City Planning Bureau, 1994). In consideration of the area ratio and the building coverage ratio of the residential land, which is listed in Table 1, are 47%, the impermeable area due to covering by buildings and roads is considered to reach up to 47.9% of the total area of the metropolitan Tokyo.

With the increase of the impermeable area, various forms of problems have started to appear in cities. One such problem is the increased incidence of the urban flood. In cities, rain fallen on the impermeable area directly flows into urban rivers

Table 1 Land use rate in the metropolitan Tokyo

Residential land	*56.9%*	*Park, etc.*	*5.7%*	*Unused land*	*4.1%*
Road, etc.	*21.2%*	*Agricultural land*	*2.3%*	*Water surface*	*3.7%*
Forest	*0.1%*	*Field*	*0.9%*	*Others*	*5.0%*

(As of 1991)

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through drain channels and the sewerage system. In Tokyo, the inundation damage has come to occur frequently at the Kanda River and the Meguro River. As a consequence, urban rivers have been gradually transformed into rivers hardened with concrete revetment for purposes of the flood prevention.

Another problem is the impact of diminished inflow water on the environment. With decreased volume of recharge to the groundwater due to expansion of the impermeable area, volume of inflow water, which has been long existing at the site, diminished and the volume of river water, which has its source in the inflow water, gradually decreased accordingly. As a result of decreased volume of the inflow water, such impact as the destruction of the ecosystem of animals and plants, which had been seen in the vicinity of the inflow water or the surrounding of rivers, started to occur.

Furthermore, increase of impermeable area resulted in decreased evapotranspiration from the earth surface, which reduced the amount of heat that must be lost as the latent heat through the heat balance. Consequently, the temperature indirectly rose in the inner city, which lead to the acceleration of so-called heat island phenomena (Takamura, 1994).

The solution to these problems is considered to be found as the groundwater regains its role in the urban hydrological cycle system.

With regard to the increase of urban flood, a variety of run-off control measures have become implemented based on the idea of the comprehensive flood control. In carrying out these measures, attempts have been made in various places to control the surface run-off by infiltrating the rainfall into the ground.

Nevertheless, all of these measures are mainly concerned with the run-off control at the time of flood and seem to fail in fully supporting the idea of the groundwater being positioned in the system of hydrological cycle including the time of low water. In the future, the role of the groundwater, which contributes to the urban hydrological cycle system, must be recognized with much more importance.

2. Groundwater recharge as the restoration of the natural environment

In natural condition prior to the existence of cities, it is assumed that much of precipitation infiltrated into underground, forming the hydrological cycle system primarily consisting of the groundwater.

However, demolition of existing buildings and paved roads with the aim of restoring land to its original state prior to the development of city means the denial of existence of city itself. Therefore, it is necessary to consider how environment that is closest to nature can be actualized within existing cities. In other words, method of restoring the natural environment must be considered rather than nature preservation.

The concept of the technology in the natural environment restoration is summarized by Sugiyama／Shinshi (1992). In the summary, Shinshi states the following words with the emphasis on the idea of the biological system.

"It is necessary to reconsider the engineering-oriented idea that happiness of human beings or abundance of cities can be actualized by accumulating and intensifying technologies in industry, etc. Essence of the natural environment as well as the planning principles of cities must be considered to lie rather in the "nature of life" and the "nature of biology", which had not been full appreciated until today.

Conventionally, water administration has placed emphasis on the water utilization and the flood control. However, today as the coexistence with nature is demanded, there should be no water administration that does not incorporate the water environment into policies. It is not the structure that expects the effects of surface run-off control from the promotion of the rainfall infiltration from the point of urban flood damage, but the irreversible nature, which can be ruined by the water shortage or depletion of the groundwater, the inflow water and rivers, that must be paid serious attention. When considering the water environment along this line of idea, in addition to the point previously made, such geoscientific ideas about the land, where cities are located, as the developmental history of the topographical features or geological environment are increasingly essential. Moreover, the relationship with human living which has been built up in the course of the city development, must be also taken into consideration.

For instance, reversible effects can occur if seepage facilities and permeable pavements are thoughtlessly constructed ignoring the topographic features of the site just because the infiltration into the groundwater is important. There are many other things to be taken into account including the quality of water that is to be infiltrated and biological preservation of the area where the inflow water originates.

When considering the urban water environment restoration plan, more comprehensive plans must be established from the above-mentioned point of view.

In the following section, case studies on the groundwater infiltration in cities are introduced with the illustration of studies conducted in the ward of Setagaya, Tokyo.

3. Rainfall infiltration with the aim of maintaining inflow water (the case of Setagaya Ward)

There are several locations of the inflow water in the ward of Setagaya, Tokyo. The most typical of all can be seen along the terraced cliff, called the Kokubunji cliff line.

The Kokubunji cliff line, which continues mostly along the Tama River, is the terraced cliff formed at the Musashino Plateau with the extension of about 20 km and the elevation difference of a couple of meters to some dozens of meters. This terraced cliff begins in the surrounding area of the Sa River located at the north of Tachikawa Station, crosses the JR Chuo Line between the section of Kunitachi and West Kokubunji (measuring the relative height of about 15 m at this area), passes through the south side of the Kokubunji Station (about 15 m at this area), the former Tokyo Astronomical Observatory (15 m at this area), the south side of the Shindai Temple (15 m at this area) via the Seijoh Gakuen in the Setagaya Ward (15 m at this area), and finally ends at the Tama River in the vicinity of Kaminoge (20m at this area).

The Kokubunji cliff line, regardless of the upper or lower streams, has the distribution of the source of inflow water everywhere. Prehistoric ruins, which date back to the ancient time of the Stone Age, are found here and there and the inflow water has been used widely by the human race for purposes of drinking, agriculture, and other miscellaneous uses. There have been wide variety of biological species existing in the surrounding of the inflow water. On the south side of the Kokubunji cliff line, the Nogawa River flows from south to east, collecting the inflow water from its water source. The source of inflow water does not only follow along the cliff line but is distributed along heads and walls of small valley (the Sen River and

Koyabe River in the surrounding area of Setagaya Ward), which penetrates into internal plateau cutting the line of cliff. Numerous sources of inflow water are distributed along the Kokubunji cliff line and small valley within the ward of Setagaya.

With the development of urbanization, the Nogawa River became progressively polluted, exceeding the BOD value of 20 mg/l in the 1970s (Bureau of Environmental Protection of Tokyo, 1993). Deterioration of water quality to such degree is largely due to the undeveloped sewerage system. However, one of the reasons is considered to be attributable to the diminished amount of the inflow water flowing into the Nogawa River as a result of the expanded impermeable area due to the urbanization. Therefore one direction for the water quality improvement was presented in the "Tokyo waterfront environment conservation plan" (Bureau of Environmental Protection of Tokyo, 1993) as well as in the "Tokyo Groundwater Conservation Guideline" (Bureau of Environmental Protection of Tokyo, 1994) saying that "through the conservation of a group of inflow water and the promotion of the stormwater infiltration into the ground, the restoration of the inflow water area as well as the increase of the amount of inflow water must be achieved in order to secure the water volume of rivers for the ordinary times".

Heightened concern among general public with the environmental issues brought about the organization of a number of citizen's groups, who are interested in water, in the surrounding area of Nogawa River. These groups, are steadily participating in such activities as the restoration of the inflow water and the conservation of the waterfront environment (Tsubayama/Wakabayashi, 1991).

In addition to the seepage experiments, the present writer has been Continuously carried out observation of the groundwater level and the inflow water amount, etc., mainly targeting "Mitsuike inflow water" located at Seijoh in the ward of Setagaya, with the aim of conserving the inflow water along the Kokubunji cliff line through the infiltration of water, which is collected in the seepage inlets from roofs of private houses, into the ground (Takamura, 1988).

To conserve the inflow water along the cliff line, it is evident that the rainfall must be infiltrated as much as possible at the hinterland of the inflow water. However, in the case of rainfall infiltration with the use of seepage inlets, study must be conducted on the location and the number of seepage inlets to facilitate effective conservation.

Accordingly, a typical study was carried out, as indicated below, to find the appropriate condition of the rainfall infiltration (Takamura, 1996a, 1996b).

4. Functions required for the inflow water conservation

(1) Water flow of the cliff line inflow water

When considering the inflow water conservation, preliminary study must be carried out as to how precipitation transforms itself into the inflow water (Takamura, 1994).

The geological structure of the plateau, which is the hinterland of the inflow water found along the Kokubunji cliff line in the ward of Setagaya, consists of the loam layer at the top, the clay loam layer, and the Musashino gravel layer at the bottom. The precipitation fallen onto the earth surface infiltrates into the loam layer and further reaches down to the gravel layer over time, forming the groundwater surface in the Musashino gravel layer. Because the spring of the inflow water is found at the outcrop of the Musashino gravel layer on the cliff, the groundwater of the Musashino gravel layer is considered to spring out as the inflow water.

Much of the precipitation fallen on the ground surface infiltrates as long as the location is either the bare land or the vegetation covered land. However in the case of built-up areas or paved roads, rainfall runs off into the sewage without infiltration.

The infiltrated water first travels within the uppermost layer, or the loam layer. The loam layer (including the loam clay layer) is considered to remain constantly unsaturated, not being saturated with water.

The water reaching the saturated stratum in the Musashino gravel layer runs off at the spring of inflow water where the gravel layer crops out. As a result of the run-off, height of the groundwater surface becomes lower as nearing the inflow water spring and the total flow of the groundwater is formed in a horizontal direction toward the inflow water spring. As a matter of fact, not only the flow toward the inflow water spring but also the total flow of the continuous Musashino gravel layer is considered to exist.

If the process of yearly flux, from the state of precipitation through the inflow water, is expressed in the discharge duration curve which is arranged in the order of precipitation, a gentle curve must be formed at the later part of the discharge duration curve. It is desirable to have gentle discharge duration curve because the most important item in maintaining the inflow water depends on the maintenance of flux during dry period.

The mechanism of smooth discharge duration curve must lie in the traveling process of water as mentioned above. This can be roughly divided into the 2 types of delays: one accompanied with the vertical travel of water in the unsaturated stratum and the other accompanied with the horizontal travel of water in the saturated stratum. More detailed classification of this is indicated in the following.

① Thickness of the unsaturated layer

The thicker the unsaturated layer, the smoother the curve of discharge duration must become.

② Permeability of the unsaturated layer

It is considered that the higher the permeability of the unsaturated layer, the smoother the curve of the discharge duration. However, the total amount of permeability can be reduced if the permeability is too low, preventing a large volume of precipitation from infiltration. Low permeability is also considered a cause of losing water to the evapotranspiration because of stagnation of water in the upper part of the unsaturated layer for the long period of time.

③ Horizontal expansion of the saturated layer

A gentle curve of the discharge duration is considered to be attributable to the widely expanded aquifer at the hinterland of the inflow water because the wider the range of aquifer, the slower the water to reach the inflow water.

④ Thickness of the saturated layer

It is considered that the thick saturated layer increases the amount of flux to the horizontal direction, causing to form a sharp gradient of the discharge duration curve.

⑤ Permeability of the saturated layer

Similar to the case of thickness, it is considered that the high permeability of the saturated layer increases the flux to the horizontal direction, contributing to the acute gradient of the discharge duration curve.

Measures for the inflow water maintenance can be inferred if the effectiveness of each above-mentioned element is revealed.

Among items discussed in the above, the thickness of the unsaturated layer, the horizontal expansion of the saturated layer and the form of seepage facilities have been herein studied independently through the typical model with respect to the influence on the discharge duration curve.

(2) Influence of the thickness of the unsaturated layer

To study the influence on the thickness of the unsaturated layer, an analysis was carried out using a 1-dimensional unsaturated seepage model. The basic equation for the calculation is as follows.

$$\rho_w C \frac{\partial \Psi_m}{\partial Z} = \frac{\partial}{\partial t} \left[K \frac{\partial \Psi_m}{\partial Z} + Kg \right] \quad \cdots\cdots\cdots\cdots\cdots (1)$$

Here,

Pw : Water density

Ψm : Matrix potential

C : Specific water volume

$\left[= \frac{\partial \theta}{\partial \Psi_m}, \theta : \textit{Water content by volume} \right]$

K : Unsaturated permeable coefficient (i. e. function of Ψm)

g : Gravitational acceleration

The numerical analysis was carried out with the adoption of the finite difference method on 5 types of thickness : 2 m, 4 m, 6 m, 8 m and 10m.

As boundary condition, the precipitation in addition to the evapotranspiration were given daily as flux at the upper edge. At the lower edge, the air invasion potential was given as the constant value, considering that the lower edge actually is the upper edge of the capillary water belt. The value given is −2 J/kg = −20.4cm H_2O.

The evapotranspiration was given only on days without precipitation.

With respect to the precipitation, the year 1984, which recorded the least precipitation in 11 years (measuring the annual precipitation of 928.5 mm) between 1981 and 1991, was targeted among the precipitation observed at Seijoh Mitsuike. However, the previous year of 1983 was utilized as the warm-up period for the calculation.

For the evapotranspiration, the calculated value of the monthly evapotranspiration, which is resulted from the application of the Thornthwaite's formula, divided by the number of days per month was used. For the temperature, the mean monthly temperature according to the Meteorological Agency (located at Ohtemachi) was used. The upward flux at the upper edge on days without precipitation was given to evapotranspiration as the boundary condition. However, to avoid infinite evapotranspiration, the evapotranspiration was to be zero when the pressure head at the earth surface became below -50 J/kg = -510cm H_2O. On days with precipitation, the evapotranspiration is smaller than the value of the calculated mean monthly evapotranspiration divided by the number of days in a month.

The following formula was applied to the water retention curve (Campbell, 1987).

$$\Psi_m = \Psi_e \left(\frac{\theta}{\theta_s} \right)^b \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

In this formula, Ψ_e represents the air invasion potential and θ_s the water content by volume in saturation. Values of "b" and θ_s shall be : b = 5 and θ_s = 0.3.

The coefficient of the unsaturated permeability was obtained through the following formula.

$$K = K_s \left(\frac{\Psi_e}{\Psi_m} \right)^n \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

In this formula, K_s stands for the coefficient of the saturated permeability, n = 2 + 3 / b. The value of the saturated permeable coefficient was to be 1.0×10^{-3} cm/sec.

The amount of run-off at the lower edge of the unsaturated layer, which is obtained from each case of calculation, arranged in the value of hydraulical regime is indicated in Fig. 1. In this calculation, because the boundary condition is to be in saturation at the lower edge, the amount of run-off at the lower edge of the unsaturated layer (i. e. flux) can be regarded as the amount of recharge to the saturated layer. As indicated in Fig. 1, the hydraulical regime is greatly influenced by the thickness of the unsaturated layer. The low water flux as well as the dry flux, in particular, are affected more than the time of abundant water such as the wet flux. Because of this reason, when installing seepage facilities for the purpose of the inflow water maintenance, it is considered preferable to install the facilities at the location with the thickest possible loam layer, which plays a role of the unsaturated layer. Estimating solely from the results of this calculation, in the case of the unsaturated layer with the thickness of less than 5 m, it is considered that the maintenance of the dry flux may not be achieved even with the installation of the seepage facility.

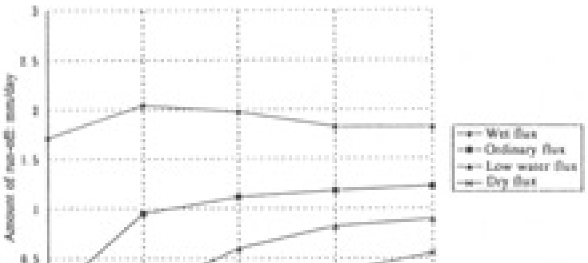

Fig. 1 Difference of the hydraulical regime according to the thickness of the unsaturated layer

(3) Influence of the horizontal expansion of the saturated layer

The influence of the horizontal expansion of the saturated layer on the hydraulical regime was studied through the horizontal 1-dimensional flow model of the saturated groundwater. The basic equation of the model is as follows.

$$\frac{\partial}{\partial_x} K(h-g) \frac{\partial h}{\partial_x} = n \frac{\partial h}{\partial t} + R \quad \cdots\cdots\cdots\cdots (4)$$

Here,

K : Coefficient of permeability

h : Groundwater level

g : Aquifer bedrock altitude

n : Effective percentage of void

R : Amount of recharge per unit area

For "R" in the above formula, the amount of run-off from the unsaturated layer shall be given.

The finite difference method was adopted for the numerical solution method.

Five cases of horizontal length were established : 100m, 200m, 300m, 400m and 500m.

The height and the boundary condition of bedrock were fixed as leveled 0 m and the water level of 1 m only on one side respectively. The amount of the run-off can be obtained at the point where the water level is fixed.

The amount of recharge shall be the amount of run-off obtained at the thickness of 8 m in the unsaturated layer, which is used for the previously discussed calculation. Calculation was conducted also for the period of two years including one year of the warm-up period.

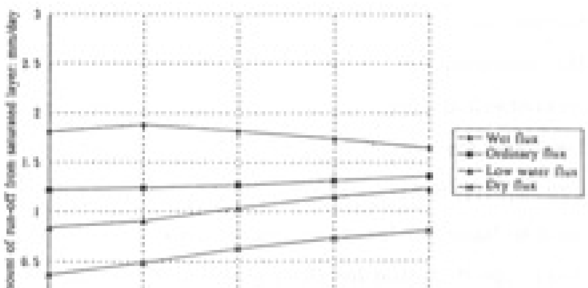

Fig. 2 Difference of the hydraulical regime according to the thickness of the saturated layer

The results of the calculation on the amount of the run-off are summarized in Fig. 2 . Each of these results of the calculation on the run-off amount is indicated as the height of run-off (mm/day), in which the calculated amount of run-off is divided by the size of the domain.

As shown in this figure, the expansion of the saturated layer is influencing both the wet flux and the dry flux. From the point of the dry flux, difference of more than twofold exists between the amount for 100 m and the 500 m.

For the size of approximately 100 m, there is no significant difference observable from the hydraulical regime of the amount of run-off from the unsaturated layer. Based on this fact, it is assumed that the inflow water with the narrow range of influence depends the delay of the run-off largely on the delay in the unsaturated layer.

(4) Influence of the form of seepage facilities

When the seepage facilities such as seepage inlets are installed, the amount of seepage at the seepage facilities is equivalent to the precipitation collected at the intake facilities. Therefore if simply viewing the location of the seepage facilities, several times the amount of the actual precipitation is suppose to infiltrate into the ground. The infiltration in the unsaturated layer is characterized by the increase in the water content in percentage of total weight with the larger amount of the infiltration, resulting in the larger coefficient of the unsaturated permeability. Therefore between hypothetical cases of the infiltration on the bare land and the concentrated infiltration at the seepage facility, the centrally infiltrating case is considered to have the larger gradient of the curve of the discharge duration for the run-off from the unsaturated layer.

Not only the vertical flow but also the horizontal direction of the flow is supposed to occur at directly below the seepage facility. Therefore the analysis was carried out with the use of the 3-dimensional unsaturated seepage model.

The following formula, which collectively expresses the water flow in the 3-dimensional unsaturated layer in addition to the saturated layer, was adopted for the basic equation of the model.

$$\frac{\partial}{\partial_x}K\frac{\partial\Psi}{\partial_x}+\frac{\partial}{\partial_y}K\frac{\partial\Psi}{\partial_y}+\frac{\partial}{\partial_z}K\frac{\partial\Psi}{\partial_z}=(S_s+C)\frac{\partial\Psi}{\partial_t} \quad \cdots (5)$$

Here,

Ψ : Total head $=\Psi_m+\Psi_p$ (Ψ_m : Matrix potential, Pressure head, Ψ_p : Location potential, potential head)

K : Coefficient of permeability (In saturated area, $K=K_s$: Coefficient of saturated permeability, In unsaturated area, $K=K(\Psi_m)$: Function of pressure head)

S_s : Specific storage in saturated area, Zero in unsaturated area

C : In unsaturated area, Specific water volume

$C=\frac{\partial\theta}{\partial\Psi_m}$ (θ : *Water content by Volume*)

In saturated area, C = 0

The finite difference method was adopted for the numerical solution method.

Unlike the 1-dimensional model, it is difficult for the 3-dimensional model to calculate values equivalent to one year because the 3-dimensional model requires much more time for the calculation than the 1-dimensional model. Therefore, it was decided that the analysis be carried out on the reaction of the amount of the run-off to the uniform precipitation.

The form of the calculation target model shapes the domain of the rectangular parallelepiped with the square form of the upper surface plane. The saturated permeability coefficient of 0.1 cm/s, which is equivalent to the gravel layer, was given to the lower 2 layers. For the upper layers, the saturated permeability coefficient of 0.001 cm／s was given, assuming all the layers are of loam origin. The relationships among the water retention curve, the pressure head, and the coefficient of the unsaturated permeability were to be the same as the one indicated in (2), which discussed the influence of the thickness of the unsaturated layer. Two cases of layer thickness were considered : 5.5 m and 3.1 m.

Calculation was conducted on two cases of infiltration. In the first case, the uniform infiltration was given to all the mesh on the upper surface, assuming the bare land. In the other case, twenty five times the amount of the uniform infiltration was given only to the central mesh, which is equivalent to 1／25 of the area of the upper surface, assuming the concentrated infiltration through the seepage facilities.

The amount of the infiltration was given as a form of triangle so that the infiltration increases rectilinearly from the beginning of calculation, reaches its peak in one hour, and reduces rectilinearly until the second hour. The amount of the run-off from the bottom surface was obtained through the 50-hour of calculation.

Hourly change of the amount of the run-off obtained from the model is indicated in Fig.3 and Fig.4.

In the case of thickness of 5.5 m, difference between the dispersed infiltration and the concentrated infiltration was fairly small. In contrast, in the case of layer thickness of 3.1 m, the peak run-off amount assumed to be occurring at the seepage facilities is about 1.5 times that of the bare land.

In the case assuming to utilize the seepage facilities, the seepage water, which is concentrated in the beginning of the infiltration, begins to disperse also in the horizontal direction with time. The model shall assume that once centrally infiltrated water can be infiltrated in a dispersing manner with certain degree of thickness in the unsaturated layer.

Therefore, although water is centrally infiltrated

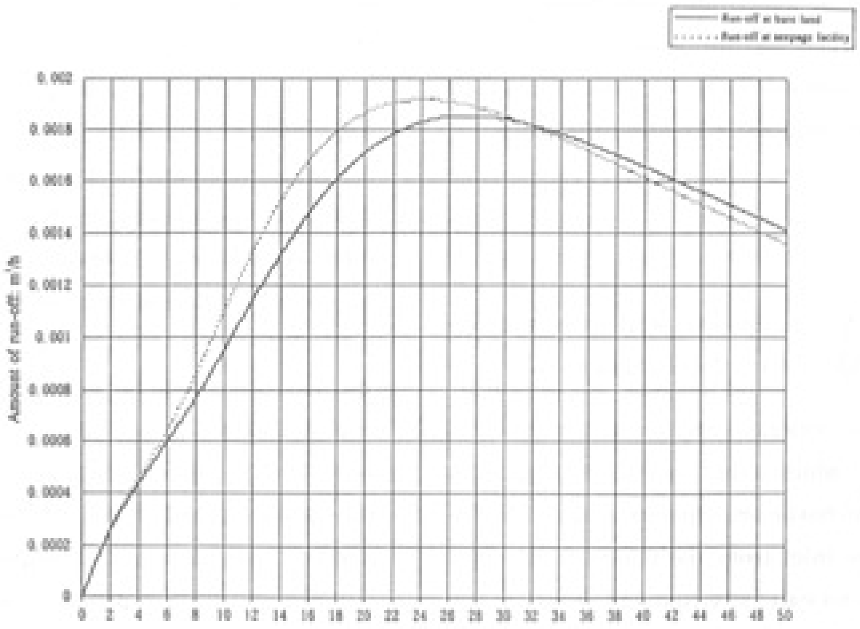

Fig. 3 Amount of run-off from 3-dimensional model (1)

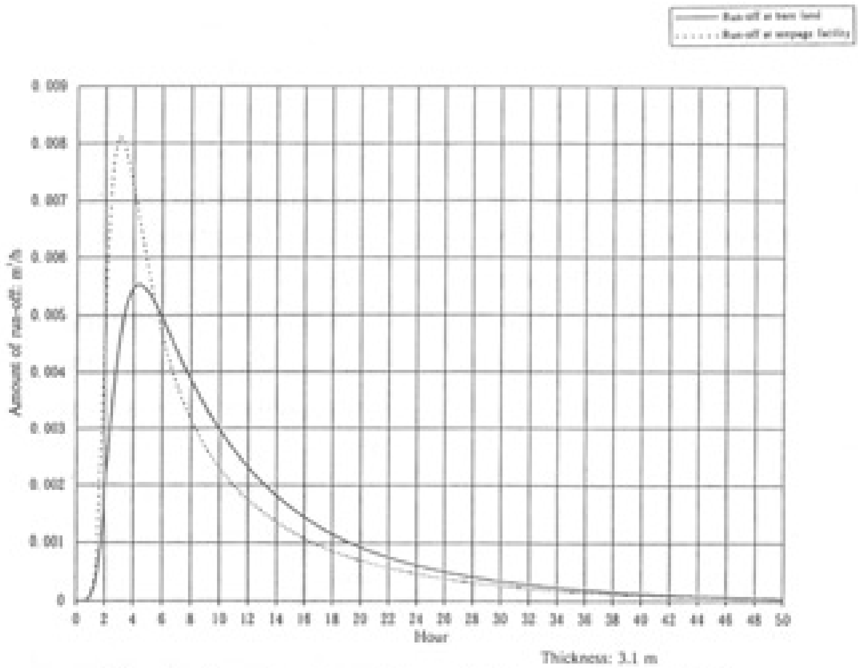

Fig. 4 Amount of run-off from 3-dimensional model (2)

at the seepage facilities, the condition of water seepage is considered not to be drastically different from the case where the infiltration occurs at the bare land as long as the unsaturated layer lying below the bare land has the certain degree of thickness. On the contrary, in the case of the thick unsaturated layer, water infiltrates faster than at the bare land when the infiltration is assumed to occur at the seepage facilities. Therefore it is evident that installation of the seepage facility is desirable at locations with the thickest possible unsaturated layer.

5. Installation guidelines and the subsidy system for the rainfall seepage inlet

In the ward of Setagaya, approximately 20 years have passed since the beginning of the groundwater recharge activities, which utilize the rainfall seepage inlet from the point of conservation of the groundwater environment as well as the inflow water environment. In the meantime, installation and propagation of rainfall seepage inlets in cities, including, not to mention the Setagaya Ward, the cities of Musashino, Koganei, and Mitaka (all of which are located at the Nogawa River basin in Tokyo), the Nerima Ward (the Shirako River basin), and the city of Matsudo, have been expanded nationwide. The expansion was made possible by the following background : the project planning established by the local government, development of the subsidy system, improvement／simplification of the materials used for the seepage facilities and the reduced cost of the facility installation. In the case of the seepage inlet installation as the project of the local government, the public land and the corporate facilities are mostly targeted. On the other hand, in the case the facility installation with the assistance of the subsidy system, in general, private homes and the collective housings are mainly targeted. Types of the seepage facilities and the method of subsidy, and the contents of installation guidelines ／ outlines, etc. differ depending on the local government. However, these are summarized in general as follows.

(1) Type of seepage facility

Types of seepage facilities for roads, ground, parks, and lots, etc., include permeable pavement, infiltrative gutters, infiltration inlets, infiltration trenches (including the joint use of perforated drain pipe). These facilities are used singly or in combination considering the effectiveness of infiltration, or topographical ／ geological features, and land condition of the surrounding areas from the point of disaster prevention.

In general, the civil specification developed with the aim of the run-off (flood) control (which specifies that the total subsidy be granted to buildings ／ structures constructed prior to 1988 with the cost of the construction shared by the Tokyo metropolitan government and the city government, except for the newly constructed housings in which the facilities must be constructed at the self expense of owners) by the Tokyo City Planning Bureau, which is carrying out related projects jointly with the local government of the city of Mitaka, etc., tends to be large in scale. Whereas, the specification aiming to conserve environment in cooperation with the city of Kokubunji, etc., tends to be smaller in scale. The cost of installation is illustrated by the case of infiltration inlets. In the formerly mentioned case, the cost of installation is illustrated by the case of infiltration inlets. In the formerly mentioned case, the cost of installation ranges approximately from 200,000 to 600,000 yen per unit due to frequent additional use of large-diameter perforated drain pipes, trenches, and permeable sheets. On the other hand, in the latter case, a single use of small size infiltration inlet costs about 30,000 to 60,000 yen while there is a case (in which the related expense was shared between the Tokyo metropolitan government and the government of the Setagaya Ward, and the total cost of installation was covered with the subsidy) where the cost of about 30,000 yen per meter was added to the original cost when the infiltration trench, with small diameter perforated drain pipes being buried, was connected to the infiltration inlet.

Records of projects (as of the end of 1995), which were carried out by the city of Mitaka and the ward of Setagaya under the above-mentioned circumstances, show that the former installed 743 units of infiltration inlets, which amount to the total of 24,004 units, with the length of 327 m for infiltration trenches, while the latter installed 2, 963 units of infiltration inlets and 1,808 m-long of infiltration trenches. In the case of the ward of Setagaya, on top of the above-mentioned installation, infiltration inlets, etc. are installed at 281 locations (consisting of 860 units of infiltration inlets and 70 m in the length of infiltration trenches) based on the rainfall seepage facility installation project outline, which conforms to the master plan for the groundwater／inflow water conservation. Areas other than the city of Mitaka and the ward of Setagaya have the similar installation records, and the groundwater recharge effects of about 60㎥／year per unit is expected with the use of rainfall by installing 3 units of rainfall infiltration inlets for a house with the roof area of 160㎡, assuming there is 1,500㎜ of yearly precipitation.

(2) Structure of rainfall infiltration inlet

Types of rainfall infiltration inlets used in Japan vary depending on the location of installation (including the circular type, square type, porous side wall type, and the permeable as well as impermeable types). Structure of a typical infiltration inlet model (circular permeable porous pipe), which is promoted by the Department of Water and Green, Division of Environment in the ward of Setagaya, is shown in Fig. 5 . In general, to construct the structure, permeable sheets are laid in the pit, which has a side or a diameter of 50 cm to 70 cm and a depth of 150 cm to 70 cm, and the pit is filled with gravel with a diameter of 3 to 4 cm (or sometimes sand, charcoal, and synthetic fibers are jointly used) prior to the installation of the infiltration inlet at the center of the pit. When installing multiple number of infiltration inlets, each inlet is often connected to each other with the infiltrative trenches (egg-shaped perforated drain pipes are buried) filled with gravel. Although maintenance of these facilities after the installation is not too demanding, a little effort indicated below can facilitate the long lasting performance of infiltration inlets.

In other words, cleaning of the inner side of infiltration inlets one in several years can remove unnecessary clog and prevent the diminishing effect of permeability. In the case infiltration inlets with impermeable side walls, infiltration from the bottom of inlets can be promoted by washing

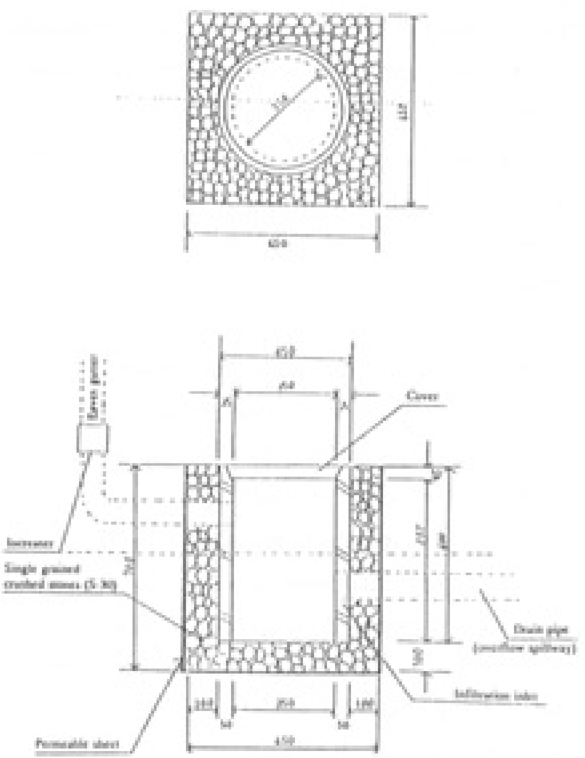

Fig. 5 Structural model of rainfall seepage inlet

gravel or sand used for filling inside the inlets.

6. In closing

In recent years, it is often pointed out that the groundwater level in large cities like Tokyo has been restored as a result of the groundwater intake control. This is due to restored water level of deep wells in some areas, difficulty in executing underground foundation works for building construction because of tendency of increasing groundwater pressure, and increasing incidence of leakage within underground cavities of the building structures. Nevertheless, groundwater levels in shallow layers under megalopolis have not yet risen. Depletion of the inflow water is rather on the rise, in stead of showing a sign of rebirth.

As illustrated so far, the rise of water levels in urban deep wells does not mean the restoration of entire groundwater environment and should be considered the seeming restoration. This is because the current rise of water level in city areas is not the product of the increased absolute volume of the groundwater, but simply is the groundwater rising phenomena occurring as a result of diminished volume of the aquifer and the water retention layers due to drastically increased number of buildings and underground structures (Takamura, 1994). Thus, it is still essential to recharge the groundwater through the rainfall seepage facilities and the indication of promotion in utilizing urban groundwater must be given a warning.

The rainfall seepage promotion measures using the seepage facilities are expected to bring about the common effects applicable to all the aims of measures, including the flood control, the environmental conservation and the renewal of the environment, in wide areas. Therefore with the efforts of perpetuating the projects and widening the target project areas, it is possible to resuscitate the urban groundwater/inflow water environment and these efforts must continue toward the future. Successful installation and propagation of infiltration inlets, etc., depend on the understanding and cooperation of residents. To achieve this, unified efforts among government, educational institutions, and industries must be made to relieve anxiety and meet expectations of residents by reducing the cost of construction, appropriately arranging facilities to fit the land features, and infiltrating satisfying quality of rainfall as much volume as possible into the underground, all of which are indispensable for restoring the urban waterfront environment including the groundwater and the inflow water rivers as well as the urban environment.

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要　旨

都市の地下水涵養の効果

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1920年ごろから京浜地区、阪神地区はじめとする在来工業地帯において地下水の過剰揚水に起因する地下水の水位低下・塩水化、地盤沈下などの現象が現れるようになって以来、地下水・地盤沈下防止対策は、1956年に「工業用水法」、さらに1962年には「建築物用地下水の取水に関する法律(いわゆるビル用水法)」などの制定など法的対応による地下水の取水と利用を規制することが主眼となっていた。その後、用水源の転換や揚水量の減少などにより地下水位の低下や地盤沈下がある程度停止し、地下水障害が消滅したかに見える。特に、最近地下水位が上昇しているという報告をよく耳にする。しかし、これらは、都市域における水を通さない建造物や舗装道路などの地表構造物による被覆率の上昇に起因する雨水地下浸透の減少からすると、地下水の揚水量の減少を考慮に入れても疑問を感じざるを得ない。

そこで、雨水による不飽和帯の涵養システムについて、多摩川支流野川の水文環境のモニタリング・データから世田谷区の実験水域のモデリング・シミュレーションを実施し、実際に雨水浸透促進に用いている家屋用の雨水浸透マス施設の適正配置と涵養効果について検討する。