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RESIDENTIAL AREA WATER RUNOFF CONTROL WITH INFILTRATION FACILITIES

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SYNOPSIS

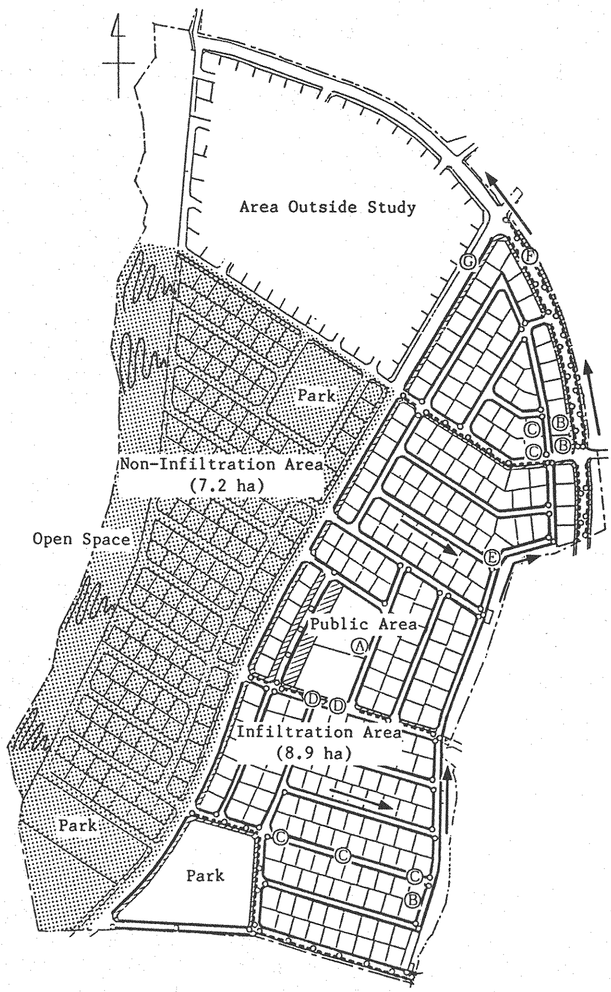
This study examines the effectiveness of facilities for infiltration of precipitation, based on observation and measurement of runoff from a residential area with infiltration facilities and adjoining residential area without infiltration facilities. Because the pattern of precipitation in time profile is an important element in analyzing the effects of infiltration, precipitation was divided into three basic patterns, and the characteristics of runoff were analyzed for each precipitation pattern. Results of our analysis from the two areas show that there is a distinct difference in runoff characteristics with respect to precipitation patterns, and that infiltration facilities are effective in all precipitation patterns. The infiltration facilities also show little deterioration over time, retaining essentially their full functions.

INTRODUCTION

The rapid advance of urbanization in recent years has led to the development of rural areas, including construction of residential areas. The resulting reduction in open space and the paving of surrounding areas has caused a reduction in the available natural surface area for infiltration of precipitation and has produced a extreme increase in runoff. At the same time, the need for efficient use of land has made it very difficult to reserve adequate regulating pondage or to improve the flow of rivers and streams. Recently, the development of infiltration facilities to provide natural infiltration into the ground has attracted considerable attention (2,3,4,5,6,7). Infiltration facilities are efficient for reducing runoff from developed areas and are also expected to assist in the recharge of ground water and control of land subsistence, as well as protection of the environment. There have been very few long-term hydrologic observations aimed at understanding the effectiveness of infiltration facilities (1). This study examines a residential area containing infiltration facilities of different types, in which hydrological observation systems were installed immediately after residential construction with the objective of studying the infiltration characteristics of precipitation. The hydrological data have been observed since 1986. This report presents the results of analysis up to the present time.

OUTLINE OF INFILTRATION FACILITIES AND METHODS OF MEASUREMENT

The subject areas were farm lands converted into residential areas, located in the northwest portion of Chiba. As Figure 1 shows, this area consists of two parts, an infiltration area (8.9 ha) in which infiltration facilities have been constructed and a non-infiltration area (7.2 ha) with no infiltration facilities. The area slopes gently downward from south to north. The soil is a layer of Kanto loam about 50 cm below the surface, and



○ : Infiltration Street Inlet
—— : Infiltration Side-gutter
---- : Infiltration Trench

\\\\\\ : Porous Pavement
→ : Direction of Runoff

Ⓐ : Rainfall Measurement Point
Ⓑ : Flow Measurement Points for Residential Lot
Ⓒ : Flow Measurement Points for Infiltration Side-gutter
Ⓓ : Flow Measurement Points for Infiltration Trench
Ⓔ : Flow Measurement Point for Storm Water Sewer
Ⓕ : Flow Measurement Point at End of Infiltration Area Drainage
Ⓖ : Flow Measurement Point at End of Non-Infiltration Area Drainage

Fig. 1 Area of the research study

upper part of that is ando soils. Most of it is a cutting except for an area of about 50 cm banking near the center. The rain water in the infiltration area flows from the infiltration facilities constructed at the road (shown by the thick lines and the dotted lines), into the storm-water sewer on the eastern edge, and along the route indicated by arrows past the flow measurement point Ⓕ at the end of the area.

In the infiltration area there are 262 residential lots in all, and as Figure 2 shows,

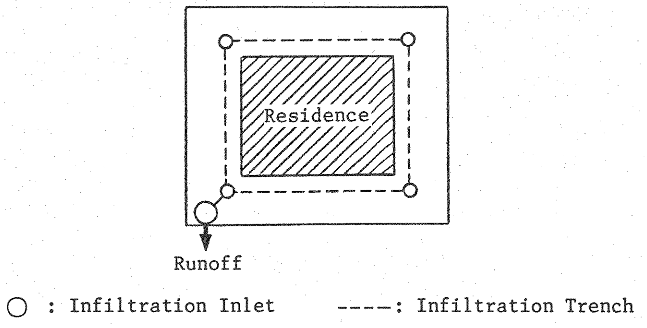


Fig. 2 Location of infiltration facilities on a residential lot

in each lot there is an infiltration trench with an overall length of 16 m as well as one large (730 x 730 mm) and four small (554 x 554 mm) infiltration inlets. Any water that does not infiltrate in the lot flows into the side-gutter of the street. In the edge of road there are infiltration side-gutters or an infiltration trench in Figure 3, with an

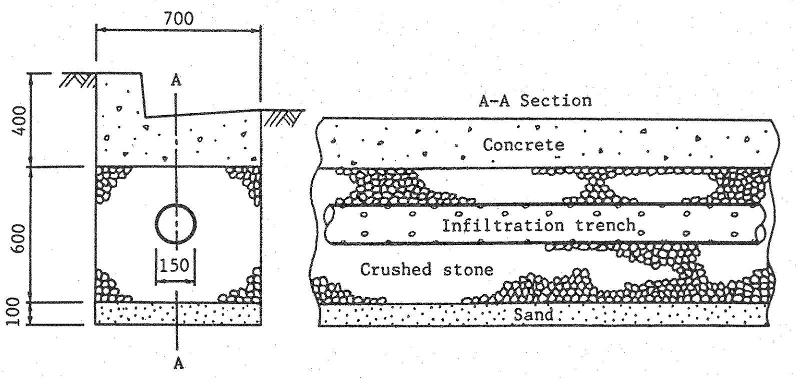


Fig. 3 Infiltration trench facility in the edge of road

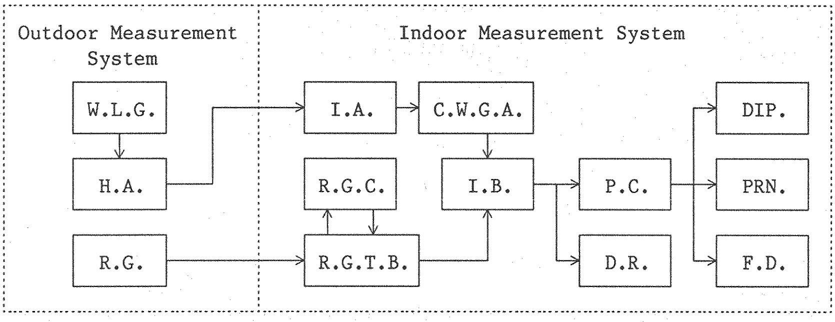
infiltrational street inlet at each end. The sidewalks and parking lots in public areas are paved with porous pavement. The number and size of these facilities are shown in Table 1.

Table 1 Infiltration facilities

Infiltration Facilities	Amount
Large Infiltration Inlet in Residential Lot	1 /lot
Small Infiltration Inlet in Residential Lot	4 /lot
Infiltration Trench in Residential Lot	16 m/lot
Infiltration Side-gutter	5236 m
Infiltration Trench	905 m
Infiltrational Street Inlet	119
Porous Pavement	3553 m^2

In this paper, we attempted to understand the function and effectiveness of the infiltration facilities with respect to actual precipitation by comparing with rainfall and runoff from the infiltration facilities. Rainfall was measured at point Ⓐ near the center of the subject area, using a tipping-bucket type rain gauge with a unit measurement of 0.5 mm. Runoff was measured at 13 points, using capacitance water level gauges and converting observed water levels to discharge by means of a stage-discharge curve obtained beforehand from laboratory experiments.

Figure 4 shows an on-site hydrological observation system. In order to prevent data



W.L.G. : Water Level Gauge Detection Unit , H.A. : Head Amp
R.G. : Rain Gauge Sensing Unit , I.A. : Isolation Amp
C.W.G.A. : Capacitance Water Gauge Amp , R.G.C. : Rain Gauge Converter
R.G.T.B. : Rain Gauge Terminal Board , I.B. : Input Box
P.C. : Parsonal Computer , D.R. : Dot-impact Recorder
DIP. : Display , PRN. : Printer
F.D. : Floppy Disk

Fig. 4 Hydrological observation system

loss from system malfunctions, two way systems were used; one is a data recording system with a personal computer, another is a sequential dot-impact recording system. The observation system is fully automatic and operates continuously full day. When the rain gauge detects precipitation, the rain gauge data as well as water level data from each flow measurement point are recorded at five minute intervals on a floppy disk, displayed on a screen and printed on a printer. In order to accommodate fluctuations in the water surface level, water level data is recorded as twelve data points one second apart. The maximum and minimum are excluded, and the average of the remaining ten points is recorded as the representative water level. Rainfall and runoff were measured continuously until runoff from the infiltration area decreased to zero. In cases of exceptionally heavy rainfall and intensity, the end of observation came sixteen hours after precipitation was no longer detected.

RESULTS OF OBSERVATION

Because there are a variety of infiltration facilities in the subject area, it is important to study the function of each of the facility types. However, we will begin with an overall comparison of runoff from the infiltration area (point Ⓕ) and the non-infiltration area (point Ⓖ). Figure 5 shows a comparison of rainfall and runoff with respect to time, in both the infiltration area and non-infiltration area, for precipitation of March 4, 1989. The data shows that runoff from the two areas was observed immediately following the detection of precipitation and that after several minutes, changes in runoff were observed corresponding to changes in the rainfall intensity. In contrast to the remarkable increase in runoff with respect to time in the non-infiltration area, the increase in the infiltration area is comparatively gradual. We believe this runoff pattern reflects the effectiveness of the infiltration facilities. In the precipitation occurring seven hours from the beginning of measurement, the peaks in rainfall bear a resemblance to the peaks in runoff, indicating a correlation between rainfall and runoff. The peaks occur slightly later in the infiltration area than in the non-infiltration area, and the peak

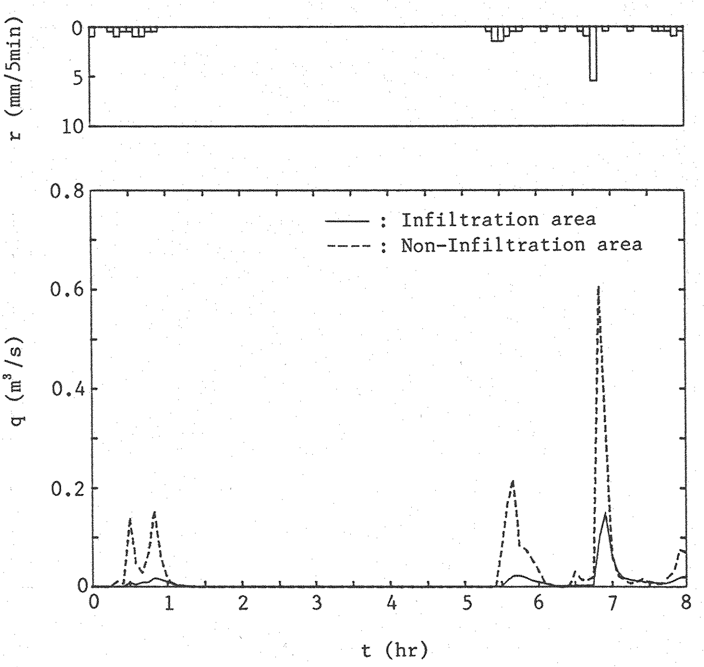


Fig. 5 Measurement of rainfall and runoff in infiltration area and non-infiltration area, March 4, 1989

discharge was 0.151 m^3/s in the infiltration area, compared to 0.608 m^3/s in the non-infiltration area. Also, total runoff was 355 m^3 from the infiltration area, compared to 1,351 m^3 from the non-infiltration area. To better compare the runoff characteristics of the two areas, runoff may be evaluated in relation to unit of area. It is apparent that both in total runoff and in peak discharge, the infiltration area was about 20% of the non-infiltration area, indicating that the infiltration facilities were functioning effectively. The rainfalls occurring at one hour, and at five to six hours after the start of observation were nearly identical with hourly rainfall of 6.5 mm and 5.5 mm respectively, but differed in maximum intensity, the former at 1.0 mm/5 minutes and the latter more intense at 1.5 mm/ 5 minutes. Corresponding runoff from the infiltration area were 23.5 m^3 and 31.3 m^3, with peak discharge of 0.019 m^3/s and 0.024 m^3/s respectively. Comparing runoff to rainfall, the rainfall at five to six hours was higher than the rainfall at one hour by 25% in total runoff, and 33% in peak discharge. Comparable figures for the non-infiltration area are 32% for total runoff and 40% for peak discharge, strongly resembling the pattern of the infiltration area. We believe this indicates that even with nearly identical hourly rainfall, maximum rainfall intensity may differ, and the resulting changes in intensity over time lead to differences in runoff patterns. To verify this, Figure 6 shows the results of measurement of runoff from a rainfall with hourly rainfall of 6.0 mm. Immediately after the onset of rainfall, a rainfall of 3.5 mm was recorded, and total runoff from the infiltration area was 68.3 m^3, with a peak discharge of 0.101 m^3/s. From the non-infiltration area, total runoff was 216.5 m^3, and peak discharge was 0.526 m^3/s. From Figure 5 and Figure 6 we see that even though the total rainfall in one hour following the beginning of observation is nearly identical in both cases, runoff from the infiltration area is much higher in Figure 6 than in Figure 5. This indicates that both total runoff of rainwater and peak discharge are affected by the characteristics of rainfall intensity. Thus it can be said that in runoff analysis it is important at least to consider similarity among rainfall patterns. We divided rainfall patterns into the following three types, and examined the characteristics of runoff from the infiltration area.

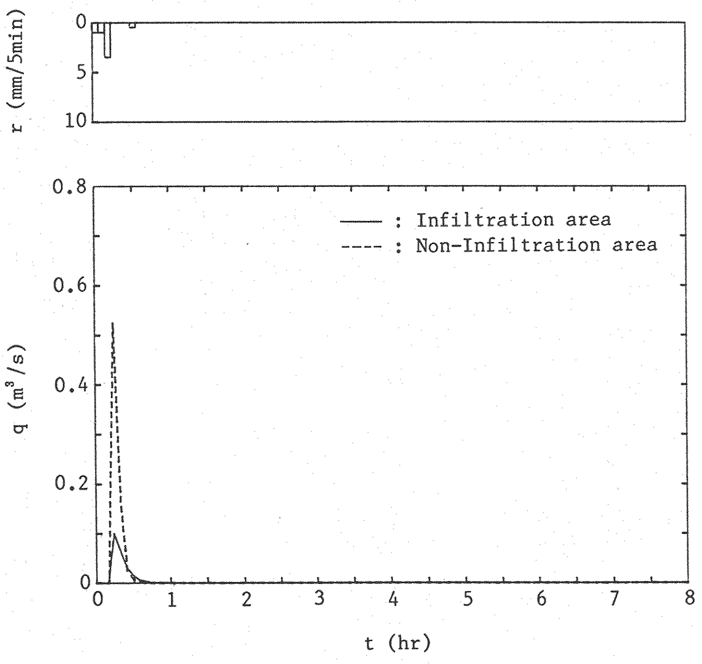


Fig. 6 Measurement of rainfall and runoff in infiltration area and non-infiltration area, September 3, 1989

Case 1: Rainfall occurs only within the first five minutes after the beginning of measurement, and no rainfall is observed for the following hour.

Case 2: Comparatively light rainfall observed continuously for two hours from the beginning of measurement, with no clearly observable peaks.

Case 3: Rainfall with a peak observed within one hour of the beginning of measurement.

Using these three rainfall patterns, we studied rainfall over the period from August 10, 1986 to September 19, 1990.

(1) Result of Case 1

In this rainfall pattern there is virtually no runoff, and nearly all of the rainfall infiltrates and is absorbed into the ground.

(2) Result of Case 2

In this pattern rain falls continuously at a constant intensity, as in the example in Figure 7. The data indicates rainfall observed on November 9, 1986, and runoff from both the infiltration and non-infiltration areas. The rainfall in this case continued intermittently but never exceeded 0.5 mm in five minutes. Runoff per unit of area from the infiltration area was about 15% of that from the non-infiltration area, indicating that the infiltration facilities had a major effect in controlling runoff.

Figure 8 presents data from the first two hours of the same case, showing the relation between total rainfall and total runoff from the infiltration and non-infiltration areas over that time. Runoff from the infiltration and non-infiltration areas show a tendency to increase as total rainfall increases, but this tendency is much more pronounced in the non-infiltration area than in the infiltration area.

Figure 9 shows total rainfall for the first two hours following the beginning of observation, and its relation to the ratios of runoff from the infiltration area and the non-infiltration area. The ratio of runoff in the infiltration area is less than 0.1 of the total rainfall, indicating that the infiltration facilities have a significant runoff control effect. In contrast, the ratio of runoff from the non-infiltration area shows a degree of variability but is as high as 0.5. Figure 8 and Figure 9 incorporate all data falling within this case type from the first year of observation through the present year, and there is no noticeable change in runoff throughout this time.

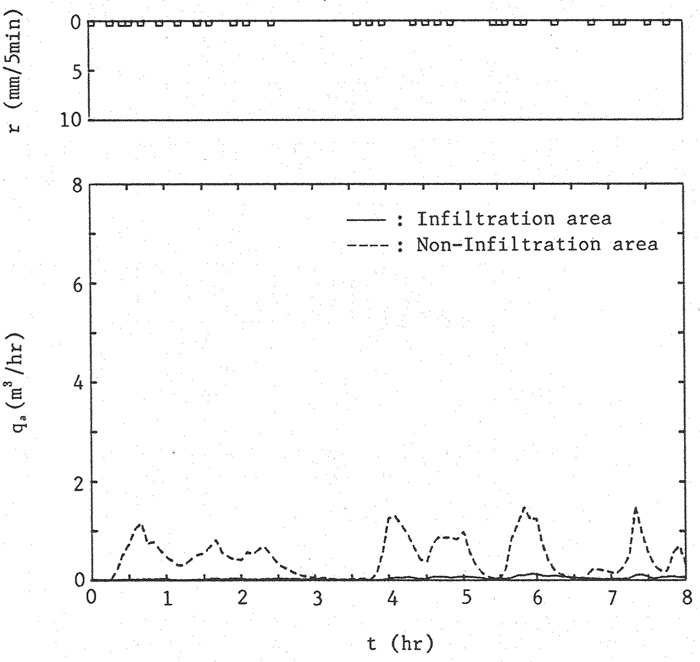


Fig. 7 Measurement of rainfall and runoff in infiltration area and non-infiltration area, Case 2 (November 9, 1986)

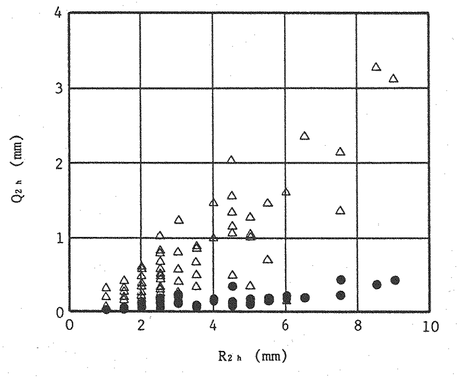


Fig. 8 Relation between rainfall and runoff in infiltration area and non-infiltration area, Case 2

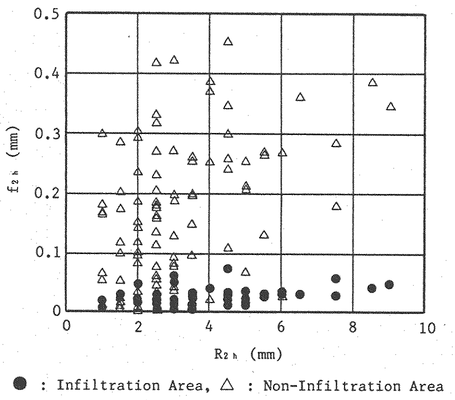


Fig. 9 Relation between rainfall and the ratio of runoff in infiltration area and non-infiltration area, Case 2

(3) Result of Case 3

These cases are those in which there is a noticeable peak in rainfall soon after the beginning of observation, such as the case in Figure 10. This data is from August 13, 1988, and it shows that the peak discharge from the infiltration area, when converted to a per-unit-area basis, is about 43% of that from the non-infiltration area. The runoff control effect in this case is somewhat less than in Case 2. Here, it can be seen that the time of peak discharge from both the infiltration area and the non-infiltration area is virtually the same as the time of maximum rainfall intensity.

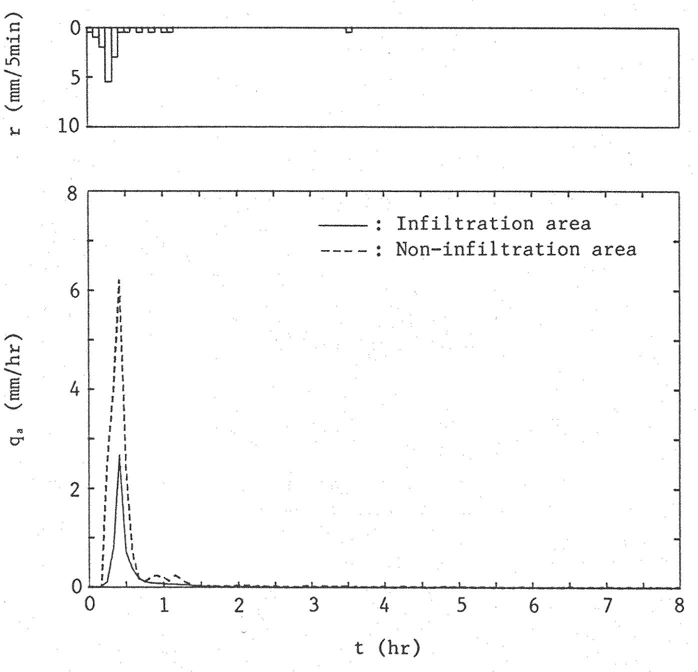


Fig. 10 Measurement of rainfall and runoff in infiltration area and non-infiltration area, Case 3 (August 13, 1988)

Figure 11 shows the relation between total rainfall and runoff from both areas over the first two hours after beginning observation in Case 3. Runoff from the infiltration area tends to increase as the rainfall increases, but it can be seen that this trend is somewhat more pronounced at rainfall of 10 mm and more. Runoff from the non-infiltration area also increases as rainfall increases, but the trend is uniform throughout, and is significantly greater than for the infiltration area.

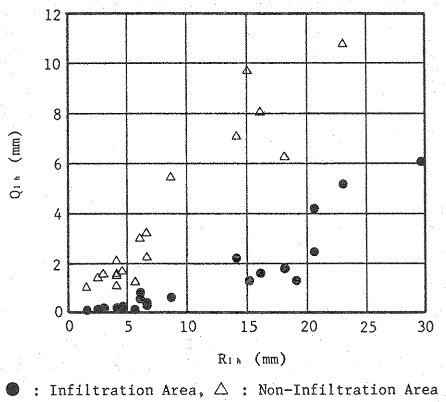


Fig. 11 Relation between rainfall and runoff in infiltration area and non-infiltration area, Case 3

Figure 12 shows the relation between total rainfall within one hour after the beginning of observation and the ratios of runoff of both areas. The ratio of runoff of the infiltration area increases as the rainfall increases and is slightly higher than the ratio of runoff with respect to rainfall in Case 2, but remains less than 0.2. In contrast, the ratio of runoff from the non-infiltration area is greater, showing a maximum ratio of runoff of 0.65, and is not affected by rainfall.

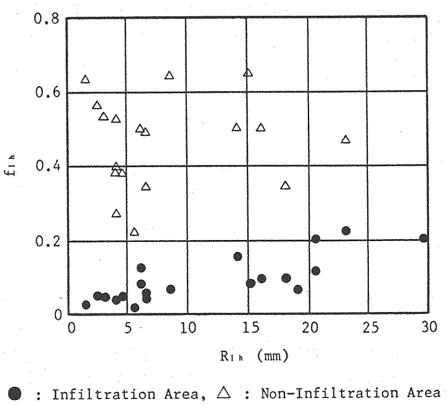


Fig. 12 Relation between rainfall and the ratio of runoff in infiltration area and non-infiltration area, Case 3

In observations up to this date, no significant deterioration over time is apparent in the ratios of runoff from either the infiltration area or the non-infiltration area. We believe this is because runoff facility maintenance procedures in the residential area have been fully effective, and there has been little progress in physical occlusion of the facilities.

CONCLUSIONS

In order to understand the effectiveness of infiltration facilities in controlling runoff, a hydrological observation system was installed in a residential area. This system has been recording valid data for an extended period of time with few omissions. This report compares the data from the infiltration area with data from the non-infiltration area, the results of which may be summarized as follows.

(1) To study the effects of different rainfall patterns, our study divided rainfall into three patterns, and demonstrated that there is a relation between the precipitation pattern and runoff pattern, regardless of the presence or absence of infiltration facilities.

(2) When the rainfall intensity is less than 0.5 mm in the first hour after the beginning of observation, regardless of the frequency of precipitation, the study confirms that most of the rainfall is captured by the infiltration facilities, and infiltrates into the ground.

(3) Runoff in the infiltration area tends to increase as rainfall increases. The ratio of runoff in continuous, comparatively light rainfall is a maximum of 0.1. The ratios of runoff in more intense rainfall, in which a peak rainfall is observed within the first hour of observation, tend to increase as the rainfall increases, however in hourly rainfall of 20 mm, the ratio of runoff is around 0.2.

(4) Runoff in the non-infiltration area also increases as rainfall increases, however the ratio of runoff in continuous, comparatively light rainfall does not seem to increase according to rainfall, and is around 0.5. And in rainfall patterns with peak observed, the ratio of runoff may go as high as 0.65.

Based on the above comparison of runoff from the infiltration area and non-infiltration area, it is possible to measure the effectiveness of the infiltration facilities in controlling runoff. However the data from the beginning of observation to the present is not sufficient to ascertain changes in the infiltration capacity over time. This is believed to be caused by the absorption of almost all of the rainfall on lots by infiltration facilities placed within the lots themselves, so that very little runs off from the lots and therefore little accumulation of foreign matter in the infiltration facilities and no observable development of occlusion phenomena.

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APPENDIX - NOTATION

The following symbols are used in this paper:

t = observation time;

r = rainfall intensity;

q = runoff discharge;

q_a = runoff discharge per unit of surface area;

R_{1h} = rainfall within 1 hours after beginning of observation;

Q_{1h} = runoff per unit of surface area within 1 hours after beginning of observation;

f_{1h} = ratio of runoff within 1 hours after beginning of observation;

R_{2h} = rainfall within 2 hours after beginning of observation;

Q_{2h} = runoff per unit of surface area within 2 hours after beginning of observation; and

f_{2h} = ratio of runoff within 2 hours after beginning of observation.

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