Rainwater drainage management for urban development based on public-private partnership

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Abstract The Urban Development Corporation (UDC) is one of the biggest implementation bodies for urban development in Japan. UDC has developed rainwater infiltration technology since 1975. This technology has effectively reduced runoff to a river and sewer system in the new town project areas. Recently, UDC has developed a new system which is defined as a "Rainwater Recycle Sewer System", which is supported by "Rainwater Storage and Infiltration Technology (RSIT)" applicable to new town creation and urban renewal. The new system consists of two elements: RSIT components based on Public-Private Partnership (PPP) and a stormwater drainage system. Herein, the private sector is responsible for the main part of RSIT, and the public sector is responsible for the stormwater drainage from the development area. As a result, the capacity of public facilities, such as rainwater sewers and stormwater reservoirs, can be reduced effectively. In parallel, the initial/running cost of public facilities is expected to be reduced. In conclusion, the authors would stress the importance of a co-maintenance system also based on PPP, which will be required especially in order to properly operate the whole system for the long term.

Keywords Capacity sharing for stormwater drainage; co-maintenance system; public-private partnership (PPP); rainwater storage and infiltration technology (RSIT); recovery of natural water cycle

Introduction

Urban floodings have been widely apparent in Japan due to the enlargement of the impervious area during the rapid urbanization process. Stormwater reservoirs in the development area have had an important role for urban drainage management. On the other hand, a decrease of groundwater table and deterioration of low flow discharge mechanism became recognisable too. Thus rainwater infiltration technology is recently considered as one of the best methods for natural water cycle recovery.

The Urban Development Corporation (UDC) is one of the biggest developers in Japan. It has conducted the business of new town creation and urban renewal since 1955, and has developed more than 1,400 thousand housing units and an approximately 500 km^2 housing site for about 40 years. There are 54 new towns (the total area is about 190 km^2) in the metropolitan regions, and stormwater reservoirs were constructed at 34 new towns. The technological standards for reservoirs were established by the middle of the 1970s, and the essence was adopted for development guidelines at many municipalities. UDC has also prepared a 20 km^2 housing site in total at approximately 200 locations since 1975, applying rainwater storage and infiltration technology to realize effective reduction of runoff to sewers and a river.

This paper investigated technological standards for a new system, which is defined as a "Rainwater Recycle Sewer System" based on Public-Private Partnership (PPP) and the

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capacity-reduction effect to drainage facility by applying a Rainwater Storage and Infiltration Technology (RSIT). In addition, the importance of a co-maintenance system also based on PPP was discussed.

Methods

At the first stage, both rainwater infiltration technology and storage methods utilizing voids among crushed-stones have been introduced to a housing complex project for the purpose of runoff control. Then this method has been applied to a new town project for the recovery of the natural water cycle. The function is not only environmental mitigation such as groundwater preservation, but also up-grading of aqua-landscape plus betterment of fire-protection standard, since requests for amenity enhancement are particularly high in new town areas.

Although RSIT has been essential to a water cycle recovery, the initial cost increase due to its introduction has been considered a financial burden to UDC. Accordingly, a cost-reduction scheme has been a critical issue to apply RSIT widely in urban development.

At the 8th ICUSD (International Conference on Urban Storm Drainage), the research on flood-control measures based on RSIT was reported (Yura *et al*., 1999). The runoff reduction effect of the storage and infiltration system was estimated at development areas related with the Joban New Railway Line, Ibaraki Prefecture. Herein, the capacity of infiltration facilities was 16 mm/hr as mean value, and 65% of the site was secured for the intake area. And the unit capacity of storage facilities possibly installed in the area was estimated at 150 m^3/ha (rainfall basis: 15 mm) as discussed in the paper mentioned above.

Hence, this paper focused on the effect of comprehensive rainwater drainage management, including sewer system, based on RSIT. One of the development areas called "Katsuragi-site" in the above-mentioned areas was selected for conducting a case study. Firstly, technological standards were investigated for new stormwater management under the conditions that PPP is applicable to RSIT introduction. Secondly, the decrease of runoff to rainwater sewers through RSIT components was calculated. Thirdly, the importance of a co-maintenance system also based on PPP was discussed and proposed in order to establish a new system management mode in the long term.

Results and discussion

Schematic concept for a "Rainwater Recycle Sewer System"

The schematic concept for the "Rainwater Recycle Sewer System" is quite different from a normal conventional system. Figure 1 shows the comparison of both systems.

Generally the purpose of a conventional system is to deal with stormwater drainage through sewers and a stormwater reservoir, of which management is generally undertaken by public sectors. On the other hand, the new system consists of both RSIT systems (infiltration pit and trench) and stormwater drainage systems. Herein, the private sector is responsible for the main part of RSIT, and the public sector is responsible for stormwater drainage from the development area.

As a result, the capacity of public facilities, such as sewers and a stormwater reservoir, can be reduced effectively in the new system, plus the initial/running cost of the stormwater drainage system is also expected to be reduced, when PPP is well co-ordinated by UDC. Thus such a scheme could be defined as capacity sharing for stormwater drainage.

Technological standards

Moreover, it is desired that the new system would contribute to preserve and/or enhance the aqua-environment. By securing the groundwater recharge, the previous height of ground-

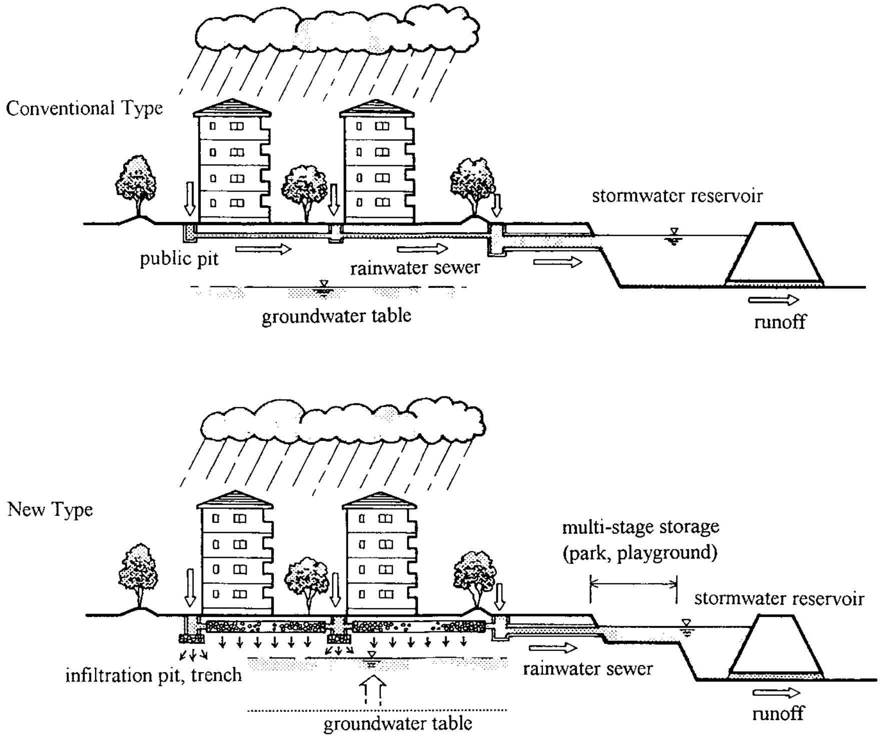

Figure 1 Comparison of two rainwater drainage systems

water table was possibly recovered. In addition, low flow of a river was also expected to be maintained at an adequate level.

In order to introduce the "Rainwater Recycle Sewer System", the most crucial thing is the way to design each RSIT component to meet total capacity to be shared by RSIT. Then the RSIT based drainage system is to be planned as described below:

- Firstly, based on the above-mentioned design, the overflow from the development area through RSIT components is estimated.
- Secondly, the sewer system is planned to properly discharge the overflow to a river.
- Thirdly, a stormwater reservoir is planned when the river's drainage capacity is not sufficient to intake the overflow.

A case study was made at development areas related with the Joban New Railway Line. Figure 2 shows a typical land use plan at "Katsuragi-Site", which belongs to the areas. Table 1 shows a guideline for RSIT component application to each land use plan respectively. For example, the effect of infiltration pit and trench plus a storage system at school and park were counted. Because the former system had a structure simple enough to be maintained easily, and the latter system was expected to be maintained with well-organised operation. On the contrary, an effect of permeable pavement at park and sidewalk was not counted in the plan because of its weak reliability for maintenance, although installation of the permeable pavement is desired from the viewpoint of environmental conservation, such as low flow recovery and groundwater recharge.

Based on such pre-conditions, the amount of storage and infiltration plus runoff through RSIT components were calculated in the case of an event that has constant rainfall intensity during an hour. Table 2 shows the effect of storage and infiltration. The total runoff of 5 mm rainfall has decreased to 24%, and that of 100 mm rainfall has decreased to 68%. The

Table 1 Application of storage and infiltration component to each land use

Land use	Site area (ha)	Infiltration pit and trench: Pit	Infiltration pit and trench: trench	Premeable pavement	Voids among crushed-stone storage	Surface detention	Truff and trench
Private housing	152.60	❍	❍				
Industrial facility	168.60	❍	❍	△ (parking lot)	❍	❍	
School	13.10	❍	❍	△ (parking lot)	❍	❍	
Park	18.96	❍	❍		❍*1	❍*2	❍*2
Road	77.36	❍	❍	△ (sidewalk)			
Waterway	54.08						
Total	484.70						

❍: compulsory, △: voluntary (the runoff reduction effect not considered)
*1: municipal park, *2: communal park

Table 2 Relationship of storage, infiltration and runoff

		Rainfall intensity					
		5 mm/hr	10 mm/hr	25 mm/hr	50 mm/hr	75 mm/hr	100 mm/hr
Total rainfall (m3)		22,028	44,055	110,138	220, 275	330,413	440,550
Effective rainfall		13,046	26,092	65,230	130,460	195,690	260,920
(m^3)	storage	9,394	16,097	25,311	39,194	41,412	43,629
	infiltration	564	2,777	15,307	21,733	34,350	38,721
	runoff	3,088	7,218	24,612	69,533	119,928	178,570
Effective rainfall		100%	100%	100%	100%	100%	100%
(%)	storage	72%	62%	39%	30%	21%	17%
	infiltration	4%	10%	23%	17%	18%	15%
	runoff	24%	28%	38%	53%	61%	68%

capacity of storage was high during a rainfall which was relatively small. The larger a rainfall became, the larger the contribution of infiltration to capacity became. Figures 3 and 4 show an effect of storage and infiltration at each land use. The amount of storage and infiltration for the private sector were 78–92%, 57–79% respectively. The effect of storage

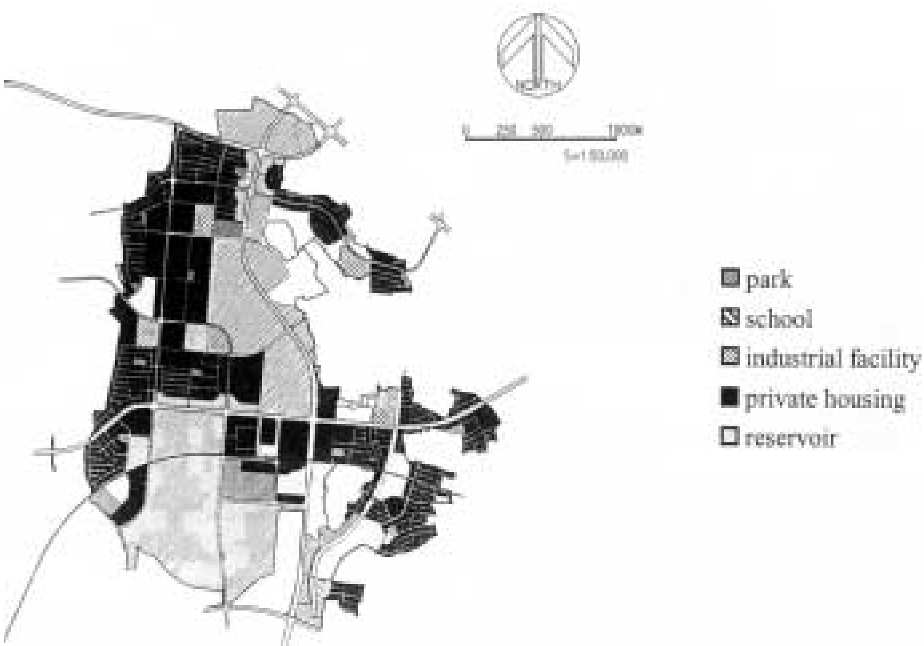

Figure 2 Land use plan at “Katsuragi-site”

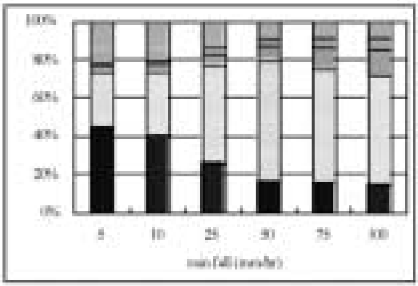

Figure 3 Contribution of storage function

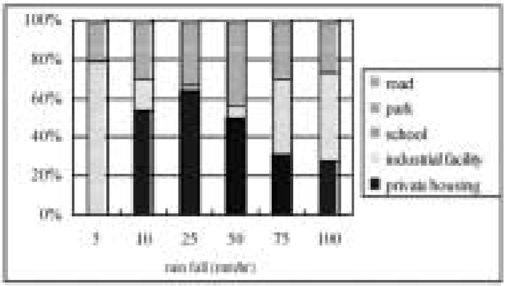

Figure 4 Contribution of infiltration function

in private housing was large during a rainfall which was relatively small. And the effect of infiltration at private housings was also large when the RSIT components began to work. In those cases, the effect of storage and infiltration in the school and park were classified as a private sector category, since these facilities were defined as "supra-structure ", meanwhile roads were classified as "infra-structure".

Rainwater drainage plan

The sewer network herein reflects the effect of RSIT, in the case of the network located downstream of RSIT components. It is a basic idea that watershed management standard is satisfied by the whole system consisting of RSIT components plus a sewer network and a river. Furthermore, the diameter of sewers could be shortened if peak flow attenuation is to be considered. Firstly, runoff was calculated at the drainage area (252.1 ha) in the "Katsuragi-Site". Figure 5 shows a hyetograph and a hydrograph under the condition of rainfall intensity of 50 mm/hr. The peak flow at the outlet from its drainage area has decreased to 73%, and the total amount of runoff has decreased to 55%. The total amount of runoff yielded a similar result, shown in Table 2. It was recognized that the load to the

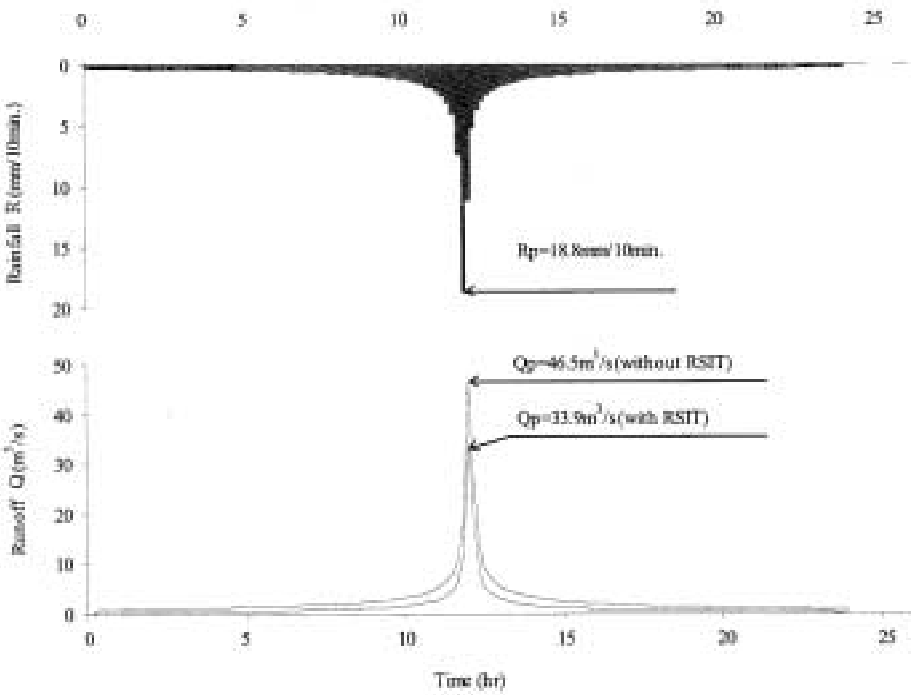

Figure 5 Hyetograph and hydrograph at case study (252.1 ha, 50 mm/hr)

downstream area was effectively decreased by the built-in-the-basin storage and infiltration system, for which the private sector was responsible.

Secondly, a rainwater drainage design method was investigated. The simplified method based on the Rational Method was proposed to calculate runoff or overflow through RSIT components. Herein, the new formula is proposed in the following manner, through modifying the Rational Method, which is indicated as a Modified Rational Method (MRM).

$$Q = 1/360 * C_1 * I * A_1 + 1/360 * C_2 * (I - Ic) * A_2 + \Sigma q$$

Q: maximum rainfall runoff at the calculating point (m^3/s)
C_1: runoff coefficient in direct runoff area without RSIT adoption
C_2: runoff coefficient in the area covered by infiltration system
I: average rainfall intensity in the concentration time to the point (mm/hr)
Ic: average infiltration intensity of RSIT components (mm/hr)
A_1: drainage area of direct runoff area (ha)
A_2: drainage area covered by infiltration system (ha)
q : maximum rainfall runoff from each storage tank (m^3/s)

Rational Method has been usually applied to design stormwater sewers in Japan. And the return period was basically settled from 5 to 10 years. In this case, the return period was 7 years and rainfall intensity was calculated by Talbot Type (I (mm/hr)=4,500/(t (min.)+30)). A runoff coefficient was 0.15–0.85 according to the land use plan. In MRM, the terms were additionally attached for calculating infiltration and storage effect. At every block runoff was calculated, and the runoff from storage tanks (q) was simply summed up at any point downstream. The result (Q) was confirmed by comparing that of the usual method, in which a hydrograph was synthesized considering its lag time. It was clarified that this method was adequate to calculate runoff, if the overflow through RSIT components was not so large compared to the total runoff.

Applying MRM, a case study was conducted at the other drainage area (82.3 ha) in the "Katsuragi-site". Figures 6 and 7 compare the runoff and sewer diameter of the new system (with RSIT) to those of a conventional system (without RSIT), where storage and/or infiltration components were not applied at all. Runoff has decreased to 74% (an average for the sewer system), and this result yielded similar peak flow attenuation, shown in Figure 5. As the capacity of the sewer was decreased, so the construction cost of the sewer network was decreased by approximately 13%.

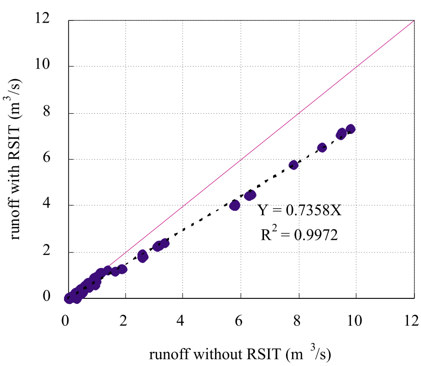

Figure 6 Decrease of runoff

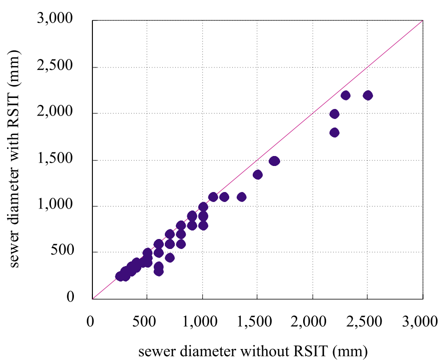

Figure 7 Decrease of sewer diameter

In terms of the economic aspect, introduction of RSIT decreased the construction cost for the sewer by 10% based on the analysis at the Katsuragi-site (484.7 ha) as shown in Figure 8. When the cost of RSIT by private sectors was included, the total drainage cost increased by 14%.

However, taking into consideration stormwater reservoirs for flood control in the lower basin, the whole cost could be decreased by 8%. Thus the benefit of RSIT introduction was recognized economically and the significance of Public-Private Partnership was furthermore clarified.

In addition, it is strongly recommended that subsidy measures should be adopted by public sectors in order to promote RSIT introduction more smoothly and positively.

Co-maintenance system

It is very important to manage the project during every stage from planning, designing and construction to maintenance. In relatively large-scale facilities, such as stormwater reservoirs for runoff control, there should be an agreement between developers and local governments for their management standard. On the contrary, RSIT components were small-scale and installed at private housing in the development process. Thus new settlers are expected to well maintain such components over the long term.

The following describe desirable stages for participation of the private sector in RSIT management:

- Mowing and cleaning for the common area are regularly conducted in accordance with the requirement of the public sector. Such activities are commonly conducted at a housing complex in Japan.
- Positive participation is required for betterment of RSIT management. Core members should be chosen from inhabitants and closely instructed.
- Enhancement of communal bondage among new settlers and local residents is desired for further extension of the systems.

Generally, inhabitants are inclined to contribute their own energy to water cycle rehabilitation activities, if they know of the worthiness of their voluntary communal workings. To accelerate such inclination, the planner should propose a symbiosis-like relation between people's environment-friendly life style and aqua-landscape supported by such life styles. Figure 9 shows the typical scheme introduced for this purpose in the Nagaike-Pond-Site Reviving Project in Tama New Town, which is located in the western suburbs in Tokyo. Herein, rainfall storage tanks were built in a housing complex in order to recharge a revived waterway, along which housing was drawn up. In addition, an underground dam, even if only a small-scale one, was constructed for the same purpose in a park alongside the waterway.

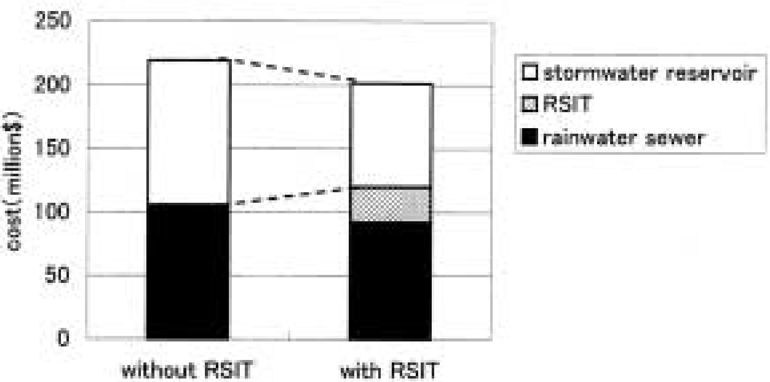

Figure 8 Cost comparison at Katsuragi-site

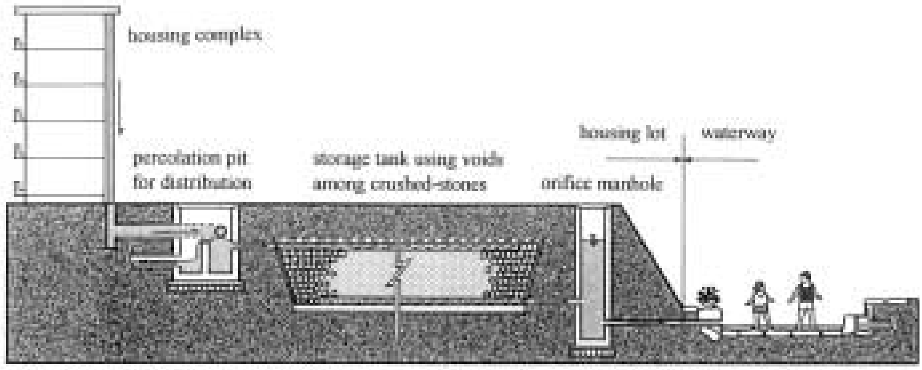

Figure 9 Rainwater storage tank built in a housing complex

Urban renewal

The “Rainwater Recycle Sewer System” can be applied to urban renewal without any obstacles. Recently areally-concentrated rainfall has caused inundation frequently in urban areas. It is expected that stormwater reservoirs and infiltration components will make up for the capacity of existing sewer networks. Figure 10 shows a stormwater reservoir under the apartment house built by UDC. The reservoir has been needed from the viewpoint of flood control by Tokyo Metropolitan Government, which subsidized the project.

UDC will change its business gradually from new town creation to urban renewal, as rapid urbanization has cooled off. In the case of urban renewal, a key point will be utilization of existing public facilities such as roads, bridges and etc., as far as construction of sewer network and a river is ended there. Consequently, as mentioned above, betterment and/or rehabilitation of such facilities will be required in line with the urban renewal operation. In comparison with the high coverage rate of the sewer system in urban areas, the capacity of rainwater drainage however is not sufficient. When UDC is a co-ordinator of urban renewal, the “Rainwater Recycle Sewer System” will play a leading role.

Conclusions

In this paper, the “Rainwater Recycle Sewer System” was newly proposed and discussed. In particular, the capacity reduction of public facilities or infra-structure and the due cost performance were discussed. This system consists of two elements: (1) RSIT based on PPP

Figure 10 Multi-utilization of storage tank under an apartment house

and (2) stormwater sewers. Herein, the private sector is responsible for the main part of RSIT, and the public sector is responsible for the stormwater drainage. In parallel, it is recognized that the initial/running cost of drainage facilities is effectively reduced. Thus it is concluded that such a scheme is defined as the capacity for sharing for rainwater drainage management. Furthermore, an establishment of a co-maintenance system based on PPP will be important and crucial for properly operating the whole system. Presumably, this concept will be workable in other fields, such as solid waste, where PPP is likely to be indispensable for up-grading previous management standards in the future.

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