Infiltration and Inflow Amount in Wet Weather in Separate Sewerage Systems: A Case Study

Evaluation du volume d'infiltration dans les réseaux d'assainissement séparatifs par temps de pluie : une étude de cas

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RÉSUMÉ

Les réseaux d'assainissement séparatifs qui ont largement été utilisés depuis 1970 au Japon présentent actuellement des problèmes d'engorgement brusque des stations d'épuration des eaux usées et des stations de pompage par temps de pluie. Les infiltrations d'eau dans les réseaux d'assainissement qui s'étendent sur une large superficie ou dans les canalisations de drainage des habitations se multiplient par temps de pluie et non seulement leur traitement, mais également l'identification de leurs causes demande énormément de temps et d'argent. Ce rapport présente un exemple de priorisation des mesures à mettre en œuvre pour limiter les afflux d'eau dans les stations d'épuration dans des régions qui ont connu par le passé de fortes augmentations de volume par temps de pluie, et de ses effets. L'intensité de précipitations et les caractéristiques des zones d'assainissement, telles que l'étendue du réseau d'assainissement ou l'avancement des mesures de réduction des infiltrations d'eau sont indispensables pour déterminer les causes de ces afflux. Les relations entre l'intensité des précipitations, les caractéristiques des zones d'assainissement et les infiltrations d'eau ont été répertoriées spatialement en utilisant les données des 150 débits entrants sur 5 ans. Ceci a permis à la fois de chiffrer le volume d'infiltrations en fonction de l'intensité des précipitations et l'ampleur des mesures à mettre en œuvre, mais également de définir un ordre de priorité grâce auquel une planification efficace des mesures de limitation est devenue possible.

ABSTRACT

Separate sewerage systems have been widely developed in Japan since the 1970s. However, a rapid increase in the incoming flow into wastewater treatment plants and pumping stations in wet weather has become a problem. Meanwhille, infiltration and inflow in wet weather occurs at a variety of locations including sewerage facilities and residential drainage facilities that extend far and wide in sewerage district and it requires enormous cost and time to find out the causes as well as to implement countermeasures. This paper reports a case study of prioritizing measures and identifying their effects in areas where there is an urgent need for measures to reduce the increased water amount in wet weather. Such features of catchment areas as the scale of rainfalls, sewerage system development ratio, and progress of infiltration and inflow reduction measures are needed to identify the causes. The relationship among the above features of the district, rainfall intensity and the infiltration and inflow amount by area based on the incoming flow amount data at 150 points for five years were collected and analyzed. This has enabled the quantification of infiltration and inflow amount to predetermined rainfall intensity and the volume of necessary measures as well as proper prioritization to formulate a plan of effective reduction measures.

KEYWORDS

Separate sewerage system, Separate sewer overflow, Infiltration and inflow, Prioritization of sub-catchment areas for infiltration and inflow reduction

1 INTRODUCTION

Separate sewerage systems have been widely developed in Japan since the 1970s. However, a rapid increase in the incoming flow into wastewater treatment plants (hereinafter referred to as WWTPs) and pumping stations in wet weather has become a problem.

Such features of catchment areas as the scale of rainfalls, sewerage system development ratio, and progress of infiltration and inflow reduction measures are needed to identify the causes. The relationship among the above features of sewerage district, rainfall intensity and the infiltration and inflow amount, the quantification of the infiltration and inflow amount and volume of necessary measures were analyzed and their prioritization was determined.

This paper reports a case study of prioritization of measures and their effects in catchment areas that experienced incoming flow amount significantly exceeding the planned wastewater volume at WWTPs.

2 STUDY METHOD

The target area is a sewerage district with a catchment of 20,915ha. A separate sewerage system is already in place there and the flow amount is measured continuously at approx. 150 points where wastewater flows into main sewers. The purpose of this study is to find out the infiltration and inflow amount in wet weather based on the flow amount and rainfall measurement data for the past five years to suggest measures to reduce the infiltration and inflow amount at the time of planned rainfall (50mm/hr) to an amount which WWTPs can accept. The study flow is shown in Figure 1 below.

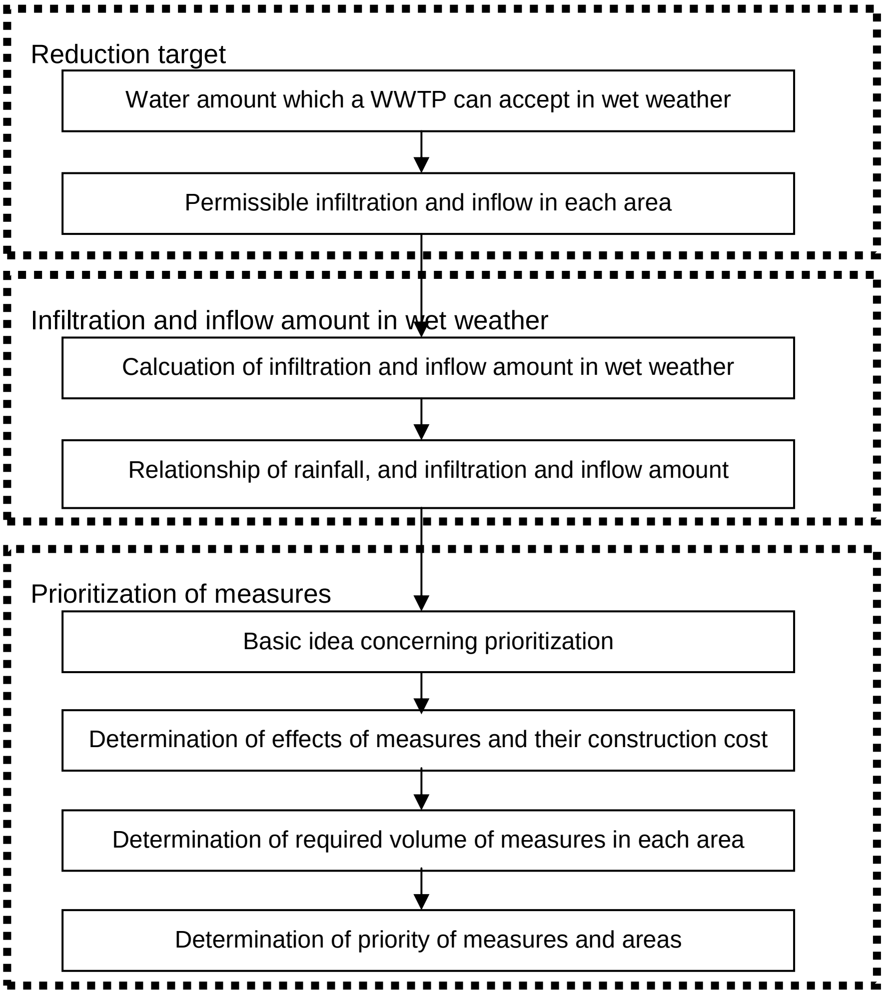

Figure 1 Study Flow

3 REDUCTION TARGET

3.1 'Water Amount which a WWTP can Accept' in Wet Weather

The maximum wastewater amount which a WWTP can accept before overflow or submersion would take place was estimated based on hydraulic analysis and it was defined as the "water amount which a WWTP can accept in wet weather". It was estimated 2,400(m^3/min) based on the analysis. The incoming flow into a treatment plant goes through secondary treatment as much as possible and the flow that exceeds the treatment capacity is discharged after simple sedimentation and disinfection.

3.2 "Permissible Infiltration and Inflow" in Each Area

Infiltration and inflow amount in wet weather needs to be controlled to satisfy the following relationship to prevent overflow or direct discahrge from WWTP:

[wastewater amount in fine weather] + [infiltration and inflow amount] ≦ [water amount which a WWTP can accept]

Figure 2 shows the calculation results of the maximum infiltration and inflow amount in wet weather. A target is set not to exceed the water amount as shown below for the planned rainfall of 50mm/hour.

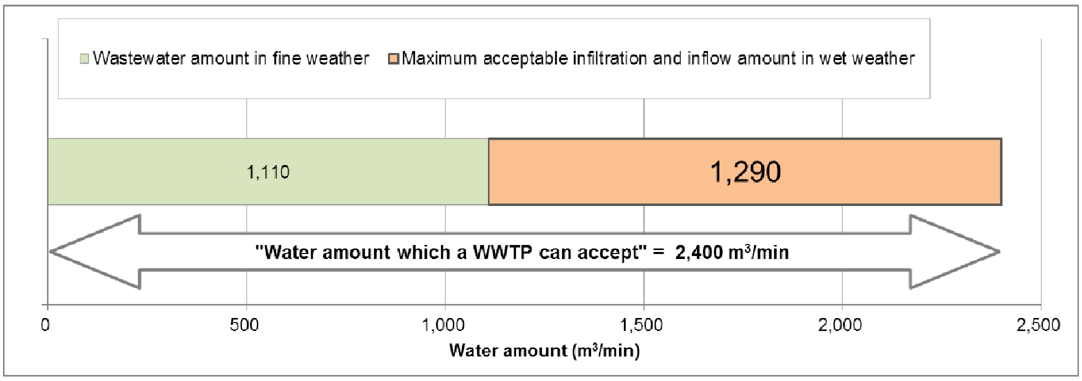

Figure 2 Estimation of Maximum Infiltration and Inflow Amount in Wet Weather

The "Permissible infiltration and inflow amount in wet weather per area" in the catchment area is determined as follows based on the calculated maximum infiltration and inflow amount:

"Permissible infiltration and inflow amount in wet weather per area" =

1,290(m^3/min)×60(min/hour)/20,915(ha)=3.7(m^3/hour/ha)

The necessary reduction amount per area in each area was calculated based on the above.

4 CURRENT CONDITION OF INFILTRATION AND INFLOW

4.1 Estimation of Infiltration and Inflow Amount

The measured incoming flow amount data for the past five years were used to estimate the infiltration and inflow amount in wet weather per area of the flow measurement at approx. 150 points. The infiltration and inflow amount is calculated in the following formula. The quantification method of the amount is also shown in Figure 3.

[Infiltration and inflow amount (m^3/hour)] = [measured flow volume (m^3/hour)] - [flow volume in fine weather (m^3/hour)]

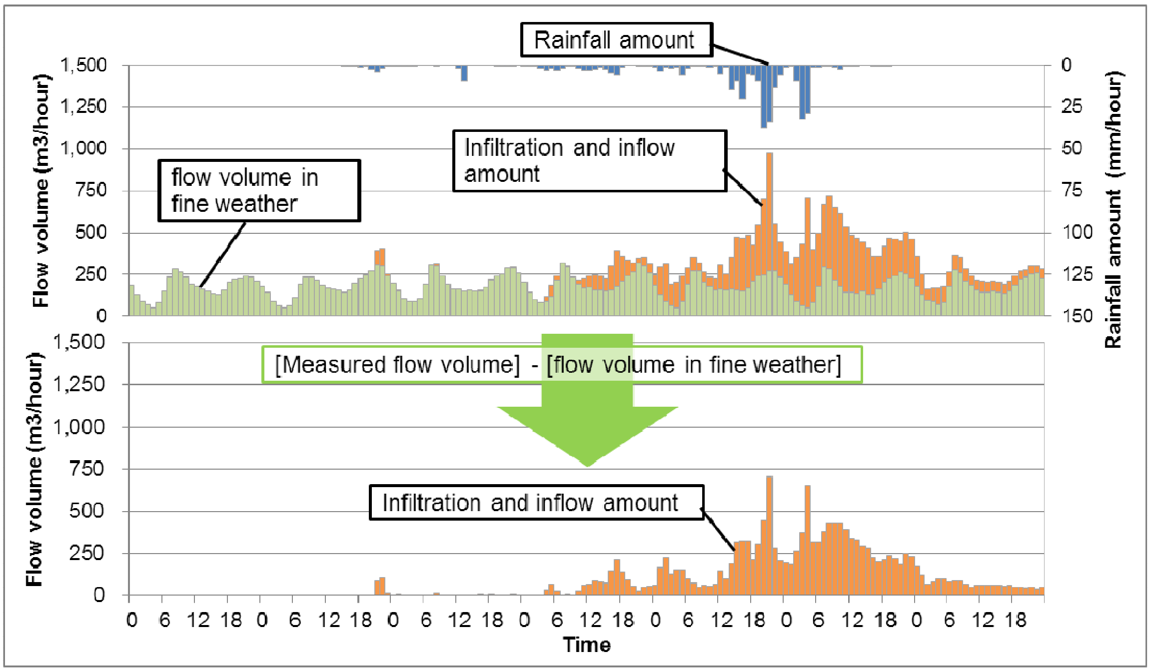

Figure 3 Quantification Method of Infiltration and Inflow

4.2 Relationship of Rainfall Amount and Infiltration and Inflow Amount

The actual measurement data include those during rainfalls of various rainfall intensities. Thus, the infiltration and inflow amount around the time of planned rainfall (50m/hour) for each area was estimated as follows : The infiltration and inflow amount with the intensity of 50mm/hour was estimated using regression line obtained by the regression analysis between the infiltration and inflow amount calculated in 4.1 and the actual rainfall intensity.

・The maximum amounts of infiltration and inflow per hour at several rainfalls were used to identify the effects of measures at the peak of flow.

・The"infiltration and inflow amount per area" was taken into consideration for the estimation of the amount since the amount increases due to the expansion of served area.

・Infiltration and inflow amount was estimated by a straight-line equation which was obtained by regression analysis for relationship between the actual maximum hourly rainfall and the observed infiltration and inflow with the rainfall intensity as the explanatory variable.

5 STUDY ON PRIORITIZATION OF MEASURES

5.1 Basic idea Concerning Prioritization

The measures are prioritized with “efficiency of measures" and "necessary cost of measures" as the key factors based on the observed performance of various measures that were implemented in the target catchment areas.

a. *Efficiency of measures:* In areas where there is a larger "amount of infiltration and inflow per area", the efficiency of measures is considered higher if the density of sewerage facilities to be repaired thereof is high. Thus, efficient infiltration inflow reduction can be achieved if the implementation of measures in those areas is given high priority.

b. *Necessary cost of measures:* The cost necessary for achieving the target reduction of infiltration and inflow is calculated. Implementation of measures in areas where the investment effect is longer is prioritized.

The "necessary cost of measures" is calculated after (1) the identification of causes of problems in detailed field survey in each area and (2) the selection of types of reduction measures. However, it requires a long period of time. Therefore, the above method is not appropriate to estimate the volume of measures across the entire catchment area. Thus, the density of measures that had been implemented in the catchment area in the past was calculated and the measures to be taken in each area were decided based on the actual density obtained.

5.2 Effects of Measures and their Construction Cost

The "possible reduction amount of infiltration and inflow" and the "unit construction cost" were decided based on the "Manual for Formulating Plans of Measures against Infiltration and Inflow in Wet Weather in Separate Sewerage Systems (2009) published by the Japan Institute of Wastewater Engineering and Technology" (hereinafter referred to as “Manual”). The Manual contains descriptions of the "possible reduction amount of infiltration and inflow" and the "unit construction cost "at the time of rain of 50mm/hour for each reduction measure. The "construction cost per reduction amount of Infiltration and Inflow" of each measure can be estimated by dividing the "unit construction cost" of each measure by its "possible reduction amount of infiltration and inflow". As for the cross connection of drainage facility in housing lots, the gap between the infiltration and inflow amount before and after taking measures thereto was calculated based on actual flow data to determine the "possible reduction amount of infiltration and inflow". The mean of actual values obtained from the field survey results was used for the "unit construction cost" for the measure against cross connection of drainage facility.

Table 1 provides the "possible reduction amount of infiltration and inflow", "unit construction cost", and "construction cost per reduction of Infiltration and Inflow" for each method of reduction measure. The fixing of cross connection of the drainage system requires the least cost and the "construction costs per reduction of Infiltration and Inflow" of other measures are almost the same.

Table 1 Effects and Cost of Each Item of Reduction Measure (1€ = 130 yen)

Method of reduction measure		Possible reduction amount of infiltration and inflow	Unit construction cost	Construction cost per reduction amount of infiltration and inflow
Sewerage system	Public sewer main	0.15 m^3/50mm/m	638 €/m	4,254 €/m^3/50mm
	Lateral	0.15 m^3/50mm/location	677 €/location	4,515 €/m^3/50mm
	Gully pot	0.13 m^3/50mm/location	585 €/location	4,500 €/m^3/50mm
Drainage system on housing lot	Cross connection	3.00 m^3/50mm/location	769 €/location	254 €/m^3/50mm

5.3 Volume of Measures by Area

The volume of measures and cost necessaary for reduction of infiltration and inflow were estimated across the entire catchment area. The estimation process is shown below.

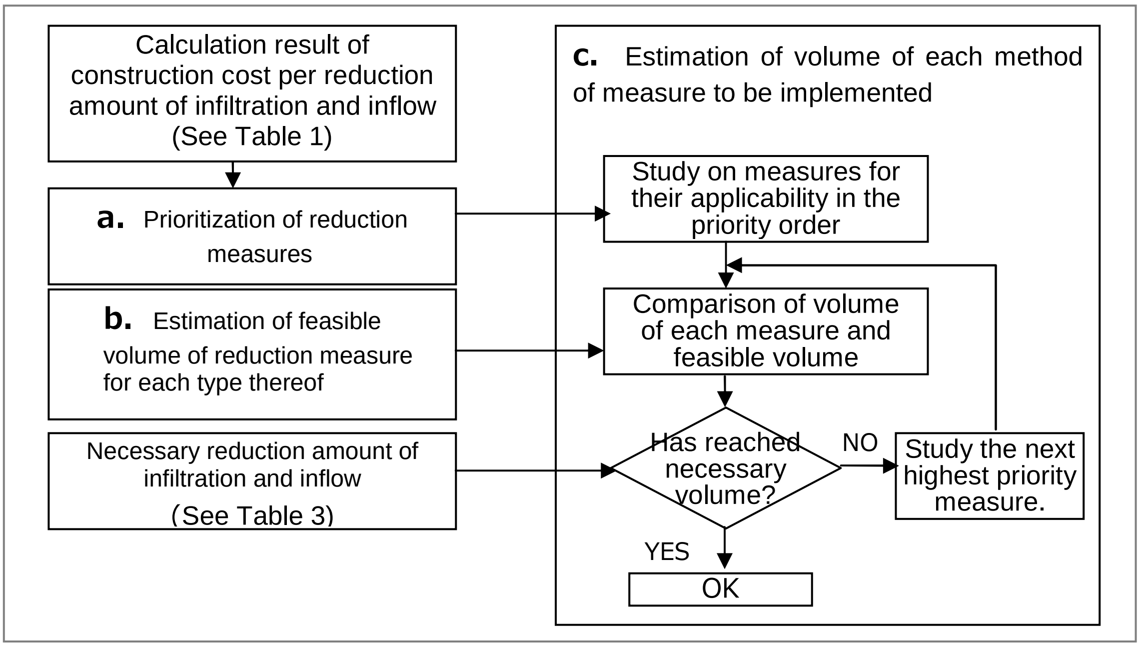

Figure 4 Estimation Process of Volume of Measure by Area

a. *Prioritization of reduction measures:* Based on the idea that measures of which "construction cost per reduction amount of Infiltration and Inflow" is less are implemented preferentially, the priority order of methods of reduction measures is decided by referring to the column of "construction cost per reduction amount of Infiltration and Inflow" in Table1.

   1. Cross connection; 2. Public sewer main; 3. Gully pot; 4. Lateral

b. *Estimation of feasible volume of method of reduction measure implementation:* Measures that have been implemented are summed up by area to obtain the "maximum implementation density" for each measure and it was assumed to be the "feasible volume of measures per unit area" in the catchment area. Figure 5 provides a conceptual diagram of how the "feasible volume of measures per area" is decided. Table 2 also shows the calculation results of it obtained from the "implementation density per area" based on the past records of implementation of measures.

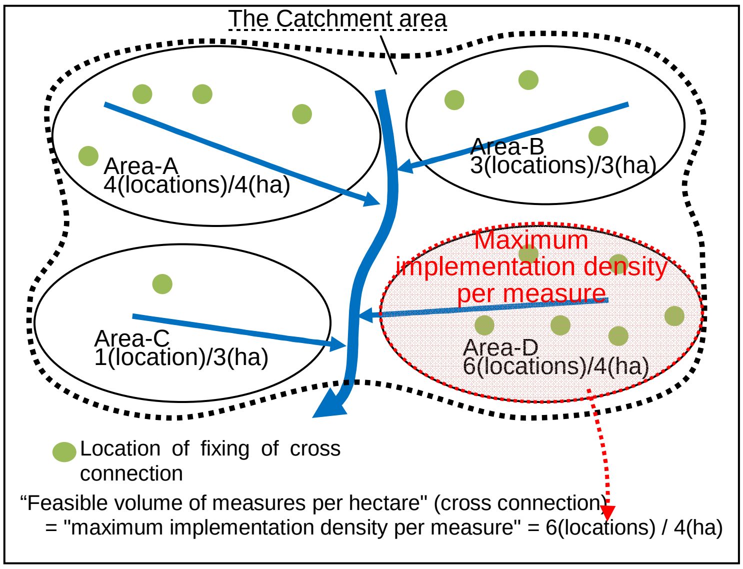

Figure 5 Estimation Process of "Feasible Volume of Implementation per Area"

Table 2 "Implementation Density per Area" (actual) and "Feasible Volume of Implementation per Area"

Area \ Item of Reduction Measure	Cross connection location/ha	Public sewer main m/ha	Gully pot location/ha	Lateral location/ha
11	0.5	1.0	0.7	
12	0.7			
17		2.0	0.9	
65		0.7		
…				
48-2			0.3	0.1
17-1				0.5
19-1		14.5	1.9	
Maximum value = "feasible volume of measures per area"	**0.7**	**14.5**	**1.9**	**0.5**

Rows 11 to 19-1: Density of implemented measures

Values in shaded cell indicates that it is the actual 'maximum implementation density' for the corresponding reduction measure

c. *Estimation of volume of each method of measure to be implemented:* The volume of each measure that enables to satisfy the "permissible infiltration and inflow amount in wet weather" for each area is then estimated. In doing so, the measure in each area was supposed to be implemented within the "feasible volume of measures per area" decided in b. according to the "priority order of methods of reduction measures" decided in a. to estimate the volume of measures for each method.

Table 3 provides an example of calculation of the "volume of measures necessary for achieving the necessary reduction amount" and "cost of measures". It provides a scenario that measures for cross connection, public sewer main and gully pot are to be implemented for achieving the necessary reduction of 164(m^3/hour).

Table 3 "Scale of Measures Necessary for Achieving the Necessary Reduction Amount» and «Cost of Measures": An Example

Area No.	Area ha	Necessary reduction amount per area m³/hour/ha	Necessary reduction amount m³/hour	Amount reduced by measures m³/hour	Cost of measures 10³€
	A	B	C=A×B	D=Σ(K)	E=Σ(L)
37-1-2	37.46	4.38	**164**	**164**	388

"Necessary reduction amount" ≦ "amount reduced by measures"

"Feasible volume of measures" ≧"volume of measures necessary for achieving the necessary reduction amount"

	Unit		Cross connection	Public sewer main	Gully pot	Lateral	Total	Note
Feasible volume of measures per area unit	(No. of location or m)/ha	F	0.7	14.5	1.9	0.5	-	from Table 2
Feasible reduction amount of infiltration and inflow	m3/50mm/(No. of location or m)	G	3.00	0.15	0.13	0.15	-	from Table 1
Unit construction cost	€/(No. of location or m)	H	769	638	585	677	-	from Table 1
Feasible volume of measures	No. of location or m	I =A×F	26	543	71	19	-	
Volume of measures necessary for achieving the necessary reduction amount	No. of location or m	J	**26**	**543**	**38**	**0**	-	
Amount reduced by measures	m³/hour	K =G×J	78	81	5	0	**164**	
Cost of measures	10³€	L =H×J	20	346	22	0	388	

5.4 Priority Order for Areas

In areas where the "necessary reduction amount per area" is large, the density of sewerage facilities to be repaired thereof is considered to be high and thus the effect of measures is large. In areas where the "cost of measure per necessary reduction amount" obtained in the formula below is small, the investment effect is large. Implementing measures becomes more efficient when measures are implemented preferentially in such areas.

"Cost of measures per necessary reduction amount" = "cost of measures" / "necessary reduction amount"

The "cost of measures per necessary reduction amount" is calculated for each area and the "necessary reduction amount per area" is listed in the order from the bigger one in Table 4.

Table 4 "Volume of Measures Necessary for Achieving the Necessary Reduction Amount" and "Cost of Measures" by Areas

Area	Necessary reduction amount per area unit m^3/hour/ha	Necessary reduction amount m^3/hour	Cost of measures 10^3€	Cost of measures per necessary reduction amount €/(m^3/hour)
	A	B	C	D=C/B*1000
36-E	61.75	2,660	6,525	2,453
35-1-E	41.44	33	63	1,913
32-E	35.21	382	913	2,390
37	29.89	1,131	2,789	2,466
37-1	20.83	1,699	4,157	2,447
31	0.61	4	7	1,494
21	0.55	11	3	279
8	0.17	24	6	256
65-2	0.17	166	48	289
15-1	0.12	5	2	308

Areas are plotted on a coordinate plane with the "necessary reduction amount per area" calculated for each area on the vertical axis and the "cost of measures per reduction amount" on the horizontal axis as shown in Figure 6.

It is to be noted that measure is more efficient as the plot is higher and the investment effect is higher as the plot moves toward the left.

As easily found, although the areas where the measure efficiency and investment effect are both higher are not found in the study, the measure efficiency is relatively high for the group on the upper right side of the graph, and thus measures should be implemented for this group preferentially. The bottom left area of the graph is an area where the investment effect is relatively higher and they should be also given priority.

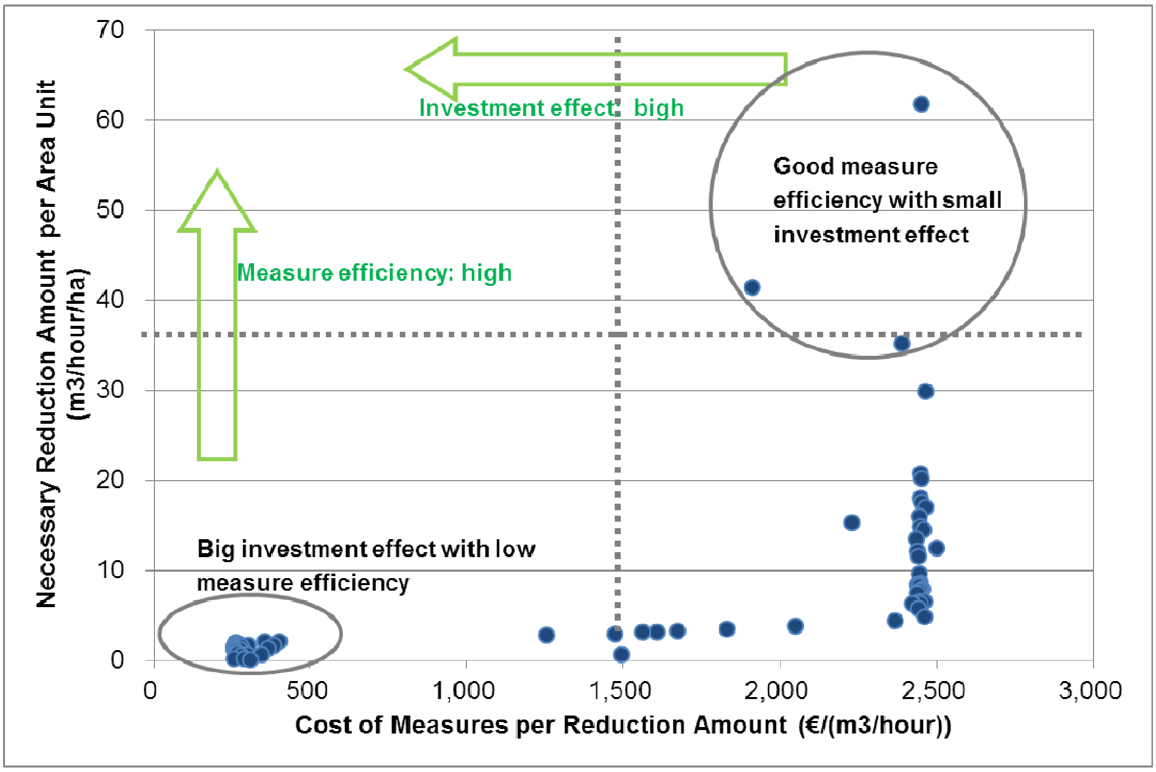

Figure 6 Efficiency of Measure and Investment Effect of Each Area

6 CONCLUSION

Measures to be implemented are to be clarified after the identification of where the problems are and what are causing them based on flow volume survey of smaller area blocks possibly with serious problem of infiltration and inflow to identify the locations of the problems and detailed survey to find out the causes. However, the series of survey requires a long period of time and it is not practical. Thus, the volume of measures and their cost were estimated in a simplified manner based on the past measures in the catchment area to calculate measures necessary for reduction of infiltration and inflow For this purpose, rainfall and flow volume data for the last five years at 150 locations in the catchment area were used. This approach enabled the estimation of the "necessary reduction amount per area" and "cost of measures per reduction amount" and the illustration of them in a graph with the measure efficiency and investment effect as indicators to quantify the priority order of measure implementation and areas where the measures are to be taken. Rough cost for implementing measures estimated in this study is also considered to contribute to the formulation of annual improvement plans in accordance of the budget.

LIST OF REFERENCES

Japan Institute of Wastewater Engineering and Technology. (2009). *Manual for Formulating Plans of Measures against Infiltration and Inflow in Wet Weather in Separate Sewerage Systems*.