Research on Countermeasures to Reduce Water Infiltration during Rainfall in a Separate Sewer System

Recherches et mesures pour limiter l'infiltration des eaux pluviales dans un réseau séparatif pendant l'événement pluvieux

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RÉSUMÉ

De nombreux rapports traitent de l'augmentation rapide des débits d'eau entrant dans les stations de pompage et les stations d'épuration au cours d'évènements pluvieux (appelées "infiltration d'eaux parasites par temps de pluie ") dans les installations pour les eaux usées d'un système séparatif. Ces apports d'eau de pluie peuvent surcharger la capacité des installations, conduisant à des inondations par débordement de réseaux et à des dommages causés par l'eau aux stations de pompage et aux usines de traitement, compromettant également la capacité de traitement des usines de dépollution. Dans le climat économique difficile actuel, les autorités locales responsables de la gestion des systèmes d'assainissement sont confrontées à des coûts de maintenance alourdis par l'infiltration des eaux parasites et ne sont pas à même de développer des solutions adéquates.

Cette étude propose une réponse systématique au problème d'infiltration d'eau de pluie, y compris des techniques de surveillance pour identifier les causes, et des stratégies de planification pour développer des solutions. Une procédure de surveillance des débits pour mesurer l'efficacité des mesures de réduction des eaux parasites est également présentée, accompagnée d'exemples d'utilisation. Une analyse coût-bénéfices est décrite avec les études de cas, et il est démontré qu'il s'agit d'une technique utile pour l'évaluation du projet.

MOTS CLÉS

Infiltration d'eau de pluie, système d'assainissement séparatif

ABSTRACT

There have been many reports on the rapid increase in water flows into pumping stations and wastewater treatment plants during rainfall (known as "water infiltration during rainfall") at wastewater facilities on a separate sewer system. Increased water infiltration during rainfall can overload the capacity of the facility, leading to flooding of nearby land from sewer pipelines and water damage to pumping stations and treatment plants, while also compromising the treatment capacity of treatment plants. In the current difficult economic climate, local governments in charge of the sewer system are struggling with maintenance costs associated with water infiltration during rainfall and are not able to develop adequate countermeasures.

This study proposes a systematic response to the problem of water infiltration during rainfall, including survey techniques for identifying the causes and planning strategies for developing solutions. A flowrate survey procedure for assessing the impact of countermeasures to reduce water infiltration is also presented, together with examples of use. Cost-benefit analysis of countermeasures is described, together with associated case studies, and is demonstrated to be a useful technique for project evaluation.

KEYWORDS

Water infiltration during rainfall; separate sewage system

1 INTRODUCTION

There have been many reports of a rapid increase in water flows into pump houses and wastewater treatment plants during rainfall (known as “water infiltration during rainfall”) at wastewater facilities on a separate sewer system. Increased water infiltration during rainfall can overload the capacity of the facility, leading to flooding of nearby land from sewer pipelines and water damage to pump houses and treatment plants, while also compromising the treatment capacity of treatment plants. In the current difficult economic climate, local governments with responsibility for management of the sewer system have struggled with maintenance costs associated with water infiltration during rainfall and have not been able to develop adequate countermeasures.

2 AIM

This study provides a systematic overview of countermeasures to combat water infiltration during rainfall, along with techniques for evaluating the efficacy of the countermeasures. The study also considers examples of cost-benefit analysis and examines the validity of cost-benefit analysis for evaluating countermeasures.

3 SYSTEMATIC RESPONSE TO WATER INFILTRATION DURING RAINFALL

Countermeasures for water infiltration during rainfall are divided into two categories as shown in Figure 1: emergency measures to prevent immediate damage caused by rising water levels due to rain, and medium to long-term measures consisting of effective, ongoing strategies to reduce water infiltration during rainfall. The immediate emergency measures can be further broken down into measures undertaken on infiltration routes to control the sources of water and facility countermeasures that seek to protect specific facilities from the effects of infiltration when it occurs.

Facility countermeasures are classified into two categories: operational measures at existing facilities using available equipment such as outflow control devices (gates and orifices) and standby pump systems; and improved equipment design at new facilities, such as pipes with greater flow capacity, improved networking of pipes, and more powerful pumping systems.

Water infiltration can also be reduced through repairs and improvements such as reworking of poor pipe joins, replacement of sewers and sewer laterals, and other regenerative works.

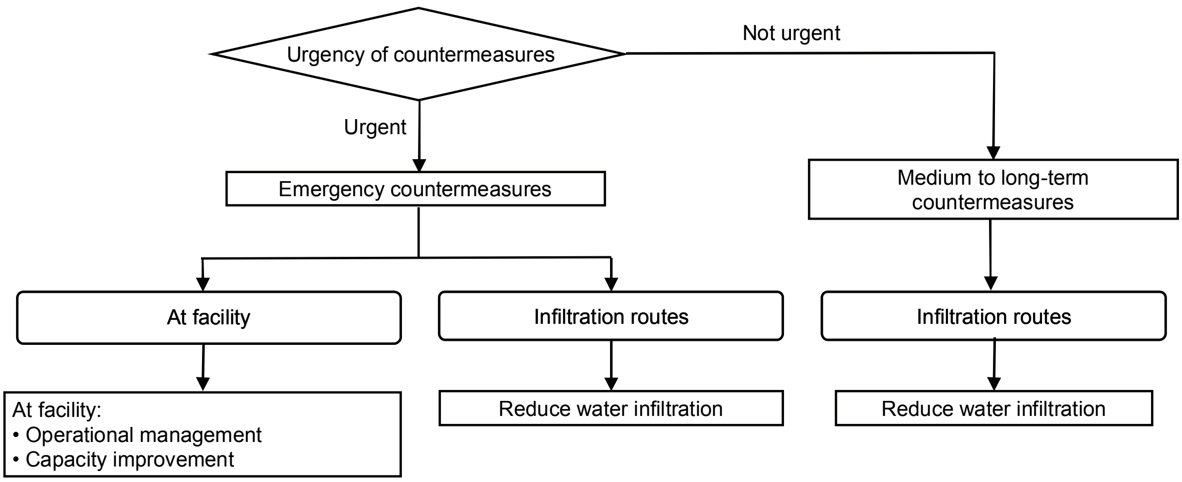

Figure 1 Water Infiltration Countermeasures

4 SURVEY TECHNIQUES TO IDENTIFY CAUSES OF WATER INFILTRATION

The surveying process to identify key sources of water infiltration involves narrowing the area from the river basin or total treatment area into successively smaller sizes (large, medium and small). The smallest blocks are then subject to detailed investigation to identify key sites and causes of infiltration. As Figure 2 shows, various techniques are available at the different stages of the classification process. Selection of techniques is governed by factors such as survey objectives, the timing of implementation, and cost constraints.

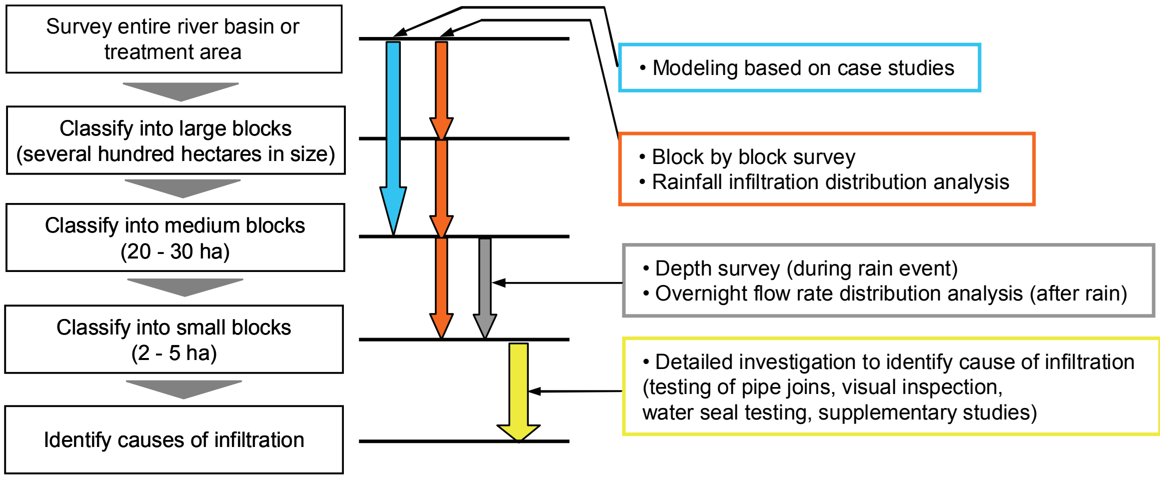

Figure 2 Infiltration survey techniques to identify causes

5 DEVELOPING RAINFALL INFILTRATION COUNTERMEASURES

On the basis of problems and issues identified in the rainfall infiltration survey, the optimum technique is selected for each cause and used to develop and evaluate an overall package of countermeasures.

Figure 3 shows the procedure for developing rainfall infiltration countermeasures.

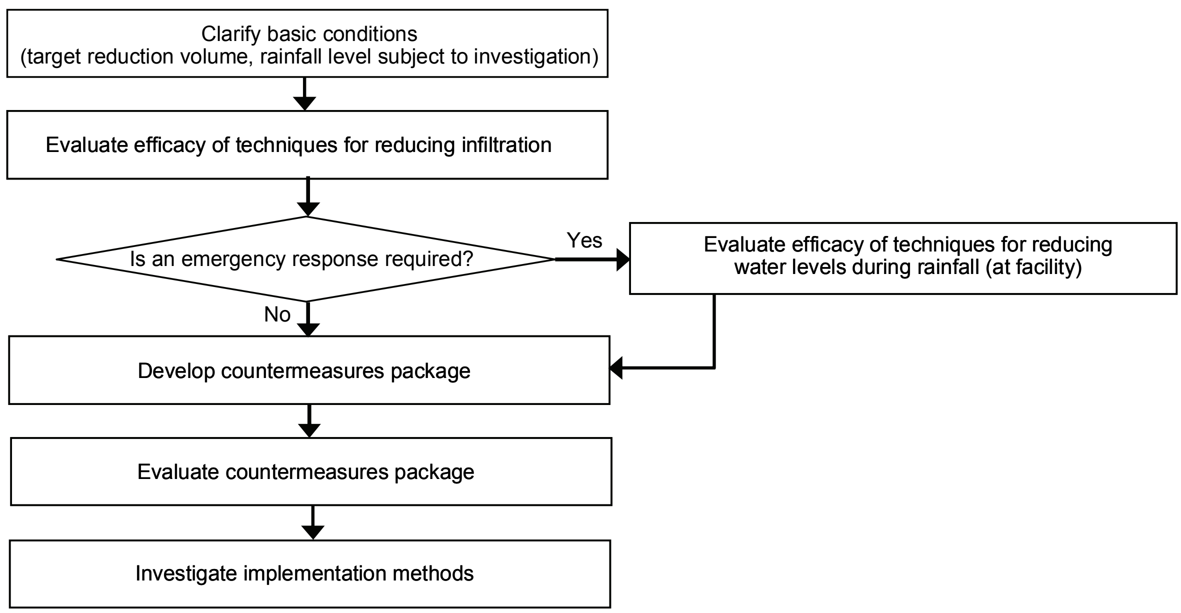

Figure 3 Procedure for developing rainfall infiltration countermeasures

6 EVALUATING THE EFFICACY OF WATER INFILTRATION COUNTERMEASURES

Figure 4 outlines the procedure for evaluating the efficacy of water infiltration countermeasures. The first step is to define the model area. Next, measures are introduced incrementally in the model area, and the corresponding benefit (water reduction) is monitored at each facility. Monitoring results are used to calculate the unit reduction in water infiltration volume at each facility. The unit water reduction volumes are then multiplied by the total number of countermeasures to produce the overall reduction volume (per block).

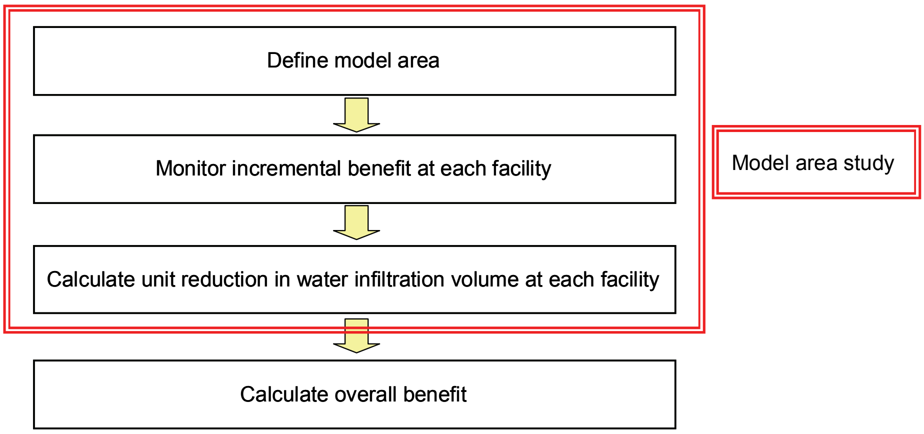

Figure 4 Procedure for calculating reduction in water infiltration

6.1 FLOW RATE SURVEY TO DETERMINE REDUCTION BENEFIT

By introducing countermeasures progressively within the model area and measuring flow rates before and after each stage, we can obtain a plot of total rainfall versus water infiltration during rainfall as shown in Figure 5. The reduction in water infiltration volume after introduction of a countermeasure represents the benefit attributable to the countermeasure.

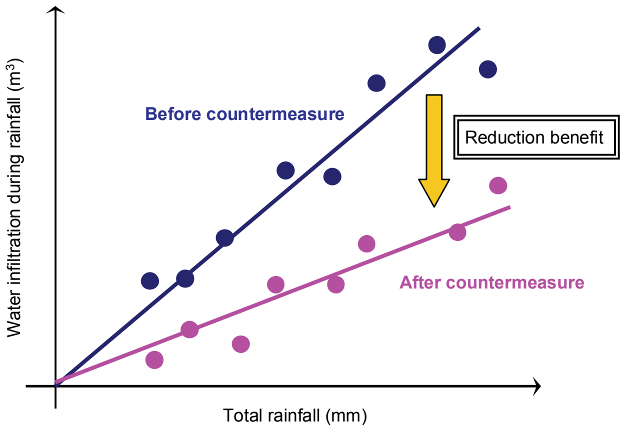

Figure 5 Flow rates before and after the countermeasure

The type of water infiltration countermeasure and the associated reduction benefit will differ according to the type of facility (public inlet, lateral, drainage system).

Figure 6 illustrates the incremental approach to evaluating the benefit of countermeasures. First, the scale and quantity of the countermeasures is determined on the basis of a detailed study of the model area. The countermeasures are then introduced incrementally at each facility and flow rates are monitored at each stage (before and after). The monitoring results are used to calculate the benefit at each facility in terms of flow rate reduction.

The reduction in volume per countermeasure at each facility is multiplied by the number of countermeasures at the facility to arrive at the benefit relative to the total countermeasures volume.

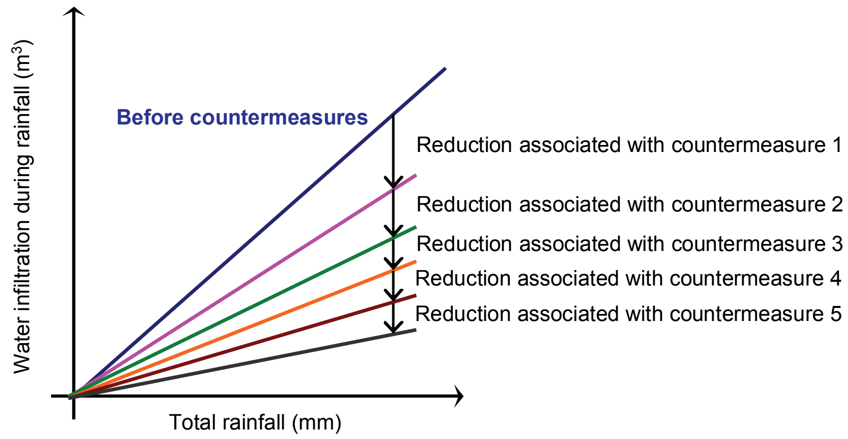

Figure 6 Incremental countermeasure benefit calculation

6.2 EXAMPLES OF USE

This section provides sample calculations of the reduction in water infiltration volumes for various different techniques. Table 1 presents the main statistics of the model area.

Area	2.5ha
Households	99
Date of construction of public sewerage system	1973

Table 1 Main statistics of model area

Countermeasures were introduced incrementally at specific public inlets, laterals and drainage systems in the model region. Water infiltration during rainfall was measured at each stage to determine the reduction in infiltration volumes associated with each countermeasure.

Table 2 shows the calculated reduction volumes per countermeasure at each facility, while Figure 7 plots the reduction volume per facility in graph form. It can be seen that drainage systems exhibited the greatest reduction per countermeasure in this example.

Facility type	Public inlet	Lateral			Drainage system	
Countermeasure stage	Lining public inlet	Lining lateral	New public inlet + lateral	Closure of unused pipes	Fix poor joins	Fix poor seals
All	96	118			99	
Countermeasures = n	65	51	31	14	10	25
Water infiltration during rainfall (m^3/mm) before countermeasure = A	1.145	0.971			0.687	
Water infiltration during rainfall (m^3/mm) after countermeasure = B	0.971	0.687			0.415	
Water volume reduction (m^3/mm) C = A - B	0.174	0.284			0.272	
Water volume reduction per location (m^3/mm/location) C/n	0.0027	0.0030			0.0078	

Table 2 Sample volume reduction per countermeasure

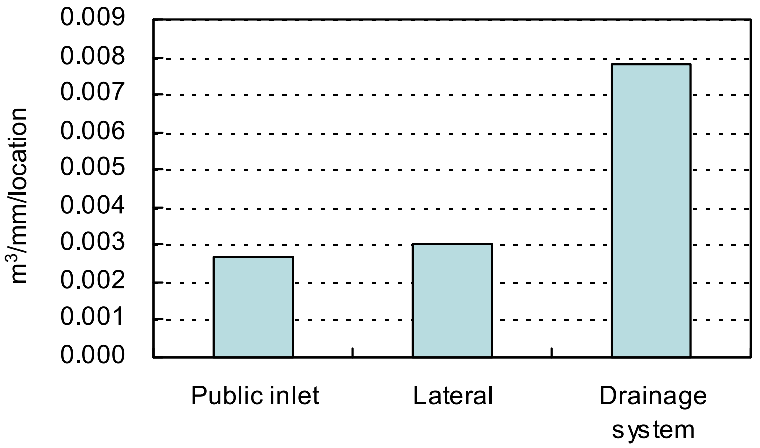

Figure 7 Sample volume reductions by location of countermeasure

7 EVALUATION OF PROPOSED COUNTERMEASURES

In order to evaluate the impact of countermeasures to reduce water infiltration during rainfall, it is necessary to select the optimum package of countermeasures via a comparison of proposals, and to perform an overall cost-benefit analysis of implement of the countermeasures.

An overall evaluation takes into consideration factors such as regional circumstances and the anticipated benefits of the countermeasure as well as economic feasibility, viability of works, maintenance and upkeep, expected reliability, and the period over which the benefits will be provided.

7.1 Cost-effects Analysis

If the various outcomes from a countermeasure are represented in economic terms as the benefit (B), and expenses associated with implementation of the countermeasure and associated facility maintenance and management expenses are represented as the cost (C), then the cost-benefit ratio for the countermeasure can be expressed as B/C.

The benefit includes economic savings through reduced water damage to buildings, offices, roads and other facilities due to flooding and submergence, as well as savings in treatment costs. The implementation cost, meanwhile, is normally determined on the basis of past municipal projects and case studies in model areas.

Countermeasures to reduce water infiltration during rainfall are generally implemented incrementally starting from the highest priority blocks. The priority ranking of blocks is determined on the basis of various factors including past damages and cost-benefit results. Damage from water infiltration must be addressed quickly, given the potential impact on areas such as public health and treated water quality. For this reason, in the event of damage from water infiltration, countermeasures are required as a matter of urgency. With the exception of urgent cases, however, when the costs outweigh the benefits it is preferable to develop countermeasures from a medium to long-term perspective in conjunction with renovation or redevelopment plans.

<table>
<tr><th>History of damage from water infiltration during rainfall (Y/N)</th><th>Cost-benefit ratio</th><th>Priority level</th></tr>
<tr><td>Yes – previous damage</td><td>-</td><td>Urgently required</td></tr>
<tr><td rowspan="2">No – no previous damage</td><td>1.0 or more</td><td>Implement in order starting from highest cost-benefit ratio</td></tr>
<tr><td>Less than 1.0</td><td>Implement from medium to long-term outlook overall in conjunction with renovation, redevelopment and/or seismic reinforcement work</td></tr>
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Table 3 Priority ranking evaluation standards

7.2 Case Study

We conducted a case study involving an examination of the priority ranking of countermeasures to reduce water infiltration and the associated scope of implementation, as well as a cost-benefit analysis on the combined impact of countermeasures to reduce water infiltration and countermeasures to reduce water levels (at facility).

Table 4 provides key statistics about the city chosen for the case study.

Item	Overall plan	Currently	Remarks
Area	1,000 ha	700 ha	-
Population	80,000	56,000	-
Service commencement	FY1965	-	-
Annual sewage treatment volume	13,720,000 m^3	8,000,000 m^3	-
Annual chargeable water volume	-	7,000,000 m^3	-
Annual unknown water volume	-	1,000,000 m^3	-
Annual rainfall	-	1,600 mm	-
Ratio of water infiltration during rainfall	-	2.5%	Relative to rainfall
Water infiltration during rainfall	-	280,000 m^3 per year	1,600 x 2.5/100 x 700 x 10
Normal water infiltration	-	720,000 m^3 per year	Unknown water volume — water infiltration during rainfall
Treatment unit price	-	¥55/m^3	-

Table 4 Key statistics of case study city

In terms of countermeasures to reduce water levels during rainfall, a 1,000 m^3 storage tank was constructed based on the findings of the outflow analysis model simulation, with the objectives of minimizing water damage and extending the usable life of the facility.

In terms of countermeasures to reduce water infiltration, the model area was divided into ten blocks labeled A through J. Each block was assigned a threshold value for the allowable proportion of faulty or unsound equipment (sewage mains, laterals and public inlets). The implementation cost of the repairs and replacements (i.e., countermeasures) required in order to attain the threshold value was then calculated. Next, the anticipated decrease in the water infiltration volume as a result of the countermeasures was calculated. This figure was multiplied by the unit cost of treatment to obtain the expected savings on treatment expenses. Finally, the expected savings on treatment expenses relative to implementation cost was calculated for each block. This figure was used to establish a priority ranking of the blocks.

Table 5 shows the cost-benefit ratio (B/C) at each stage assuming initial implementation of countermeasures to reduce water levels during rainfall, followed by successive implementation of countermeasures to reduce water infiltration in accordance with the priority ranking of the blocks.

Countermeasures		Area (ha)		Cost (x ¥1,000/year)		Benefit (x ¥1,000/year)		Benefit / cost	
		By block	Cumulative	By countermeasure (1)	Cumulative (2)	By countermeasure (3)	Cumulative (4)	By countermeasure (3)/(1)	Cumulative (4)/(2)
Countermeasures to reduce water levels during rainfall	Countermeasures at facility			25,600	25,600	48,000	48,000	1.8750	1.8750
Countermeasures to reduce water infiltration	I	85	85	9,736	35,336	3,180	51,180	0.3266	1.4484
	C	62	147	8,488	43,824	2,671	53,851	0.3147	1.2288
	F	92	239	10,647	54,471	3,318	57,169	0.3116	1.0495
	D	90	329	6,382	60,853	1,984	59,153	0.3109	0.9721
	A	51	380	3,964	64,817	1,210	60,363	0.3052	0.9313
	J	32	412	2,293	67,110	699	61,062	0.3048	0.9099
	G	90	502	7,163	74,273	2,180	63,242	0.3043	0.8515
	B	61	563	8,625	82,898	2,487	65,729	0.2883	0.7929
	H	90	653	12,584	95,482	3,626	69,355	0.2881	0.7264
	E	47	700	6,396	101,878	1,829	71,184	0.2860	0.6987

Table 5 Cost-benefit ratio (B/C)

Figure 8 shows the cost-benefit ratio for incremental implementation of countermeasures. The graph suggests that facility countermeasures should be implemented at the initial stage along with water infiltration countermeasures in three blocks—I, C and F—where cost-benefit ratio is greater than 1.0. Water infiltration countermeasures can then be implemented in the remaining blocks at a later date in conjunction with renovation, redevelopment or seismic reinforcement works.

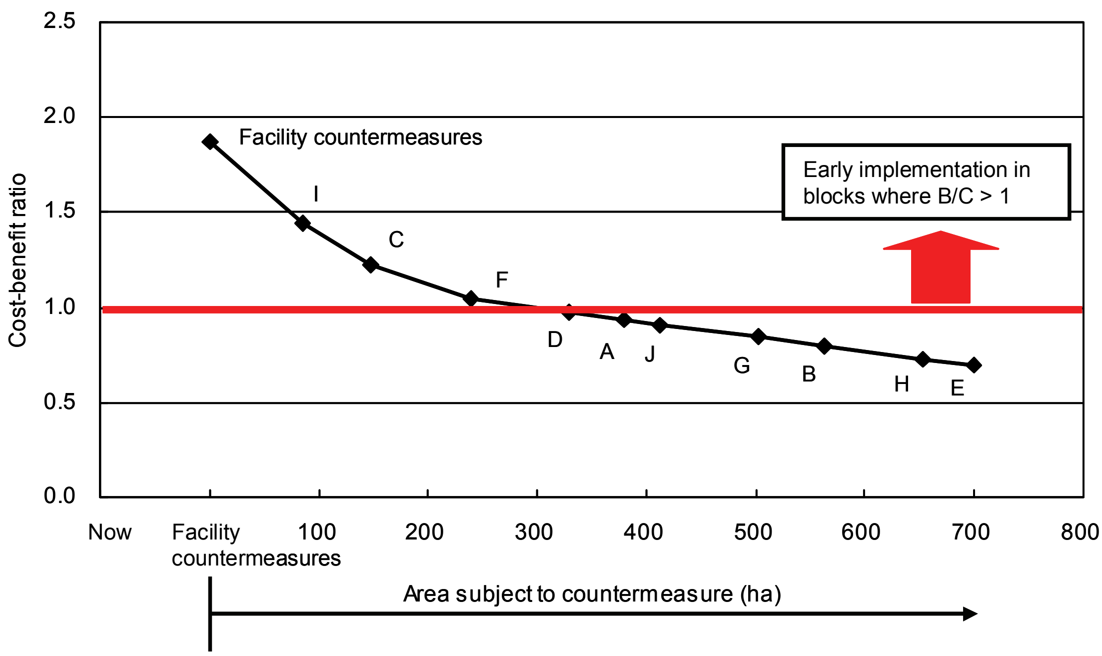

Figure 8 Cost-benefit ratios for incremental implementation of water infiltration countermeasures

8 CONCLUSIONS

We employed an incremental approach to the implementation of countermeasures designed to reduce water infiltration during rainfall within a defined model area. We demonstrated that this approach can be used to evaluate the impact of the countermeasures at individual facilities.

We also demonstrated the validity of cost-benefit analysis for assigning a priority order to countermeasures to reduce water infiltration when implemented on an incremental basis.

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