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B-DASH Project No.34

# Guideline of introducing technology for detecting infiltration and inflow in wet weather by applying AI to acoustic data (Draft)

Wastewater System Division
Water Quality Control Department

Notice

The English version of this guideline is translated on the basis of approval by the Director of National Institute for Land and Infrastructure Management (令和４年９月２０日付け国総研評第１９号).

**the Ministry of Land, Infrastructure, Transport and Tourism, Japan**
**National Institute for Land and Infrastructure Management**

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**No. 1150 March 2021**

# B-DASH Project No.34
# Guideline of introducing technology for detecting infiltration and inflow in wet weather by applying AI to acoustic data (Draft)

Wastewater System Division
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## Overview

The purpose of this guideline is to clarify the technical performance and the procedure for introducing the technology of "Demonstration Study on Practical Application of Technology for Detecting Infiltration and Inflow in Wet Weather by Applying AI to Acoustic Data" (Demonstration Study Period: July 2019 to March 2020)" adopted in the demonstration project of innovative sewerage technology (B-DASH project) and to promote the dissemination of the technology, based on the results of the demonstration study, to reduce the cost and improve the efficiency of the investigation on rainwater inflow and infiltration countermeasures.

***keywords: separate sewer system, inflow and infiltration, acoustic data, artificial intelligence***

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## Preface

In the sewerage business with the separate sewer system which collects and drains rainwater and sewage separately, the phenomenon of increased sewage flow rate in the sewer pipes in rainy weather has been observed. This phenomenon is recognized as rainwater inflow and infiltration, and it may cause various problems such as overflow from sewer pipes, backflow to houses, flooding of treatment plants and pump stations, and lowering of treatment capacity in treatment plants.

The Ministry of Land, Infrastructure, Transport and Tourism carried out a questionnaire on rainwater inflow and infiltration for local governments which adopted a separate sewer system in FY2018. According to the result, 1,681 treatment districts (about 57%), more than half of the 2,962 treatment districts responded that "there are problems in the maintenance," and it was indicated that the rainwater inflow and infiltration has become a nationwide problem. Furthermore, among the organizations responded that there are problems, only about 40% of the local governments had conducted investigations on the places and causes of rainwater inflow and infiltration and about 37% of the local governments had conducted construction work to control the sources. The percentage of organizations that had conducted investigations or countermeasures was low even though they were aware of the events related to rainwater inflow and infiltration. Based on such background, the Ministry of Land, Infrastructure, Transport and Tourism prepared and announced "Guideline for rainwater inflow and infiltration measures (draft)" as a basic concept for drafting effective and efficient countermeasures in January 2020.

To implement effective and efficient rainwater inflow and infiltration countermeasures, it is important to properly identify the places and areas where rainwater inflow and infiltration occurs by investigation. However, the conventional investigation method usually requires a large amount of time and cost, and the situation is one of the factors that the implementation of countermeasures does not progress. Therefore, it is necessary to develop a new investigation technology for rainwater inflow and infiltration that can be carried out quickly and inexpensively. On the other hand, even if excellent new technology is developed, many sewerage business operators are cautious about the introduction of the new technology due to the lack of reference cases.

The Sewerage Department of the Ministry of Land, Infrastructure, Transport and Tourism has been implementing the “Demonstration Project of Innovative Sewerage Technology” to promote measures against rainwater inflow and infiltration by demonstrating and popularizing excellent innovative technology and to support the overseas development of water business by Japanese companies. B-DASH Project "was started in FY 2011, and the Sewerage Research Department, National Institute for Land and Infrastructure Management has been the execution organization of the demonstration study.

The technology presented in this guideline "Guideline of introducing technology for detecting infiltration and inflow in wet weather by applying AI to acoustic data (Draft)" is an innovative technology that can investigate rainwater inflow and infiltration more efficiently than the conventional method by focusing on the acoustic change in the sewer pipes when clear and rainy weather, and by AI analysis on the acoustic investigation using a commercially available voice recorder. A demonstration study has confirmed certain effects on the reduction of time and cost required for the investigation compared with the conventional investigation method. This guideline was written based on the result of the research carried out at the National Institute for Land and Infrastructure Management (Demonstration Study Project for Technology for Detecting Infiltration and Inflow in Wet Weather by Applying AI to Acoustic Data: CTI Engineering, AIST, Koriyama City, Tsukuba City, Nagoya City, Kobe City, Kumamoto City Joint Research Project Implementation. Period: FY 2020) consignment research as reference material when the sewerage business examines the introduction of innovative technology, and it is strongly hoped that the excellent technologies are spread nationwide and overseas.

Finally, I would like to express my deepest gratitude to the members of the Committee for Evaluation of Innovative Sewage Technology Demonstration Projects for their great efforts in formulating the guidelines based on the selection of technologies, the establishment of demonstration study facilities, and the demonstration of actual operations in a short period as one year, as well as to the sewerage business operators who cooperated in the hearing of opinions on the guidelines, the local governments, and research entities who cooperated in the provision of the sites.

Seiichiro Okamoto, Sewerage Research Department, National Institute for Land and Infrastructure Management,
the Ministry of Land, Infrastructure, Transport and Tourism

## Main Part

# Chapter 1 GENERAL PROVISIONS

## Section 1 Objectives

**§ 1 Objectives**

The purpose of this guideline is to reduce the cost and improve the efficiency of the rainwater inflow and infiltration investigation. For the objectives, this guideline is developed to clarify the technical performance and the procedure for introducing the technology and to promote the diffusion of the technology regarding 'Demonstration Study on Technology for Detecting Infiltration and Inflow in Wet Weather by Applying AI to Acoustic Data (Demonstration Study Period: July 2019 to March 2020)' adopted in the demonstration project of innovative sewerage technology (B-DASH project) based on the results of the demonstration study.

[Explanation]

The B-DASH Project, a demonstration project for innovative sewerage technology, has been conducted by the Ministry of Land, Infrastructure, Transport and Tourism since FY 2011. This project aims to realize significant cost reductions and the creation of renewable energy in the sewerage business by accelerating the research and development and practical application of new technologies and supporting Japanese companies to expand their water business overseas.

An overview of the entire B-DASH project is shown in Figure 1-1. In each demonstration project, As the consignment research by the National Institute for Land and Infrastructure Management ("NILIM"), each demonstration project is conducted.

So far, demonstrations in a wide range of technological fields have been completed such as water treatment technology, biogas recovery, biogas purification, biogas power generation technology, sewage sludge solid fuel technology, sewage heat utilization technology, nutrient (nitrogen) removal technology, pipe management system technology, energy generation technology to generate hydrogen from sewage sludge, energy-saving water treatment technology, technologies for water treatment management and urban flood prevention functions improvement using ICT (Information and Communication Technology), and urban flooding prediction technology and the guidelines have been developed to diffuse the technologies. In FY 2020, a demonstration study is in progress focusing on technical fields where local governments have strong needs.

This technology is an innovative technology to reduce the cost and improve the efficiency of inflow and infiltration ("I&I") investigation by using acoustic data in sewer pipes and AI analysis. The demonstration study is summarized by collecting the opinions from experts with specialized knowledge and local governments' sewerage business operators with thorough knowledge of the business practices, and by the evaluation of the "Sewerage Innovative Technology Demonstration Project Evaluation Committee" (hereinafter referred to as the "Evaluation Committee" also referred to "http://www.nilim.go.jp/lab/ebg/b-dash.html") organized by the academic experts, and the demonstration study has been evaluated as satisfactory. This guideline was developed by the NILIM to promote the introduction of this technology and apply the countermeasure for I&I which can reduce the cost and time of the rainwater I&I investigation compared with the conventional method, based on the results of the demonstration study of this technology evaluated by the Evaluation Committee. Therefore, this guideline specifies the technical performance and the introduction procedure of this technology and summarizes the matters for the diffusion and development of the technology as the reference of sewerage business operators such as local governments when considering the introduction of this technology.

Similar to the results of the demonstration study, this guideline has been approved by the Evaluation Committee after hearing the opinions of experts with specialized knowledge and local governments' sewerage operators with thorough knowledge of the business practices.

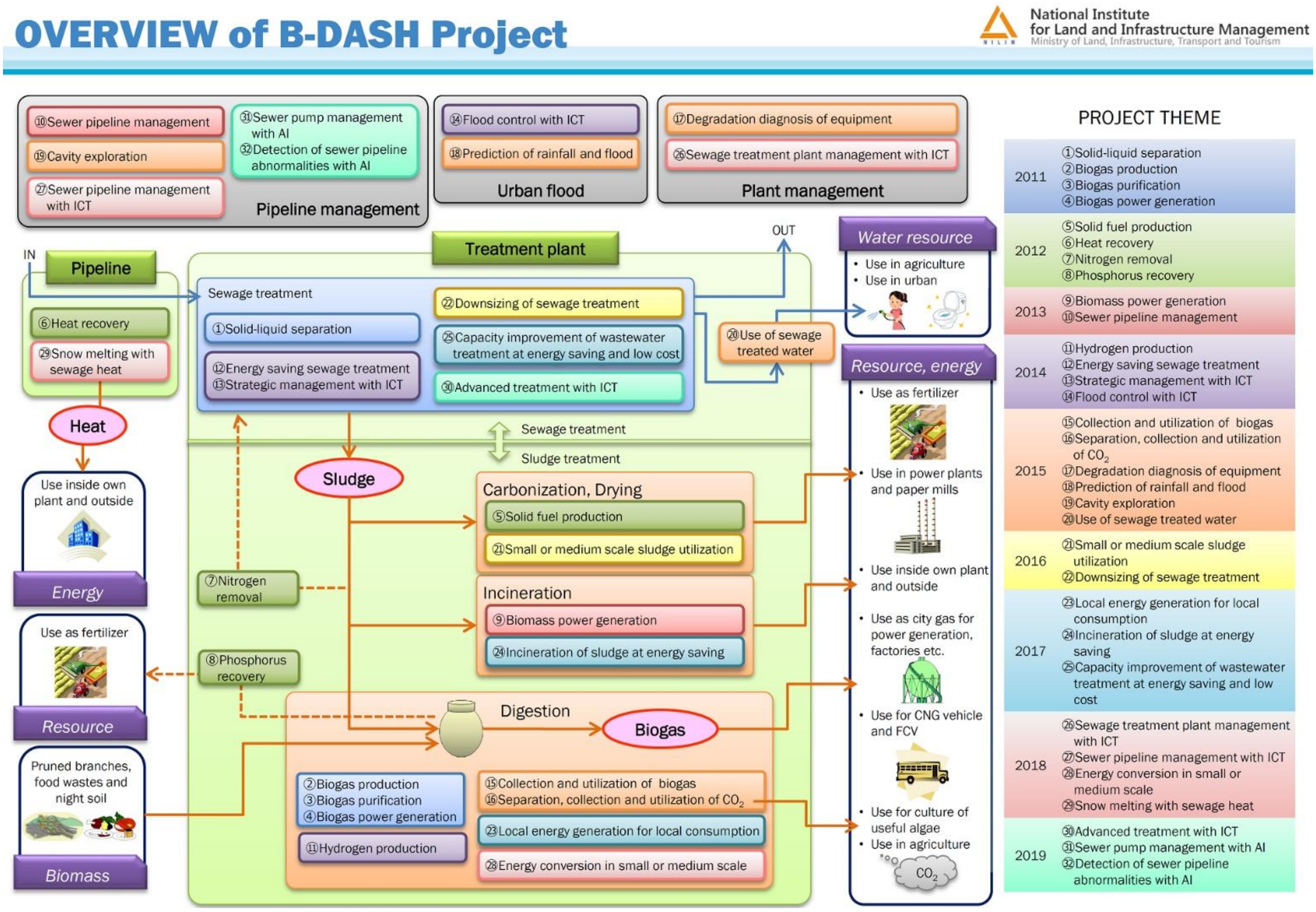


**Figure 1-1 Overview of the Innovative Sewerage Technology Demonstration Project (B-DASH Project)**

## Section 2 Scope

**§ 2 Scope**

This guideline is applied to the feasibility study and the judgment to apply this technology, and for the investigation of this technology to investigate rainwater I&I of sewer pipes in the separate sewer system.

This guideline is designed to be used by sewerage operators such as local governments and related private sectors.

[Explanation]

This guideline is the reference for the feasibility study and the judgment to apply this technology and the reference of the investigation by this technology when considering the application of this technology to the sewer pipes rainwater I&I investigation.

This guideline is designed to be used by sewerage operators such as local governments and related private sectors.

## Section 3 Structure of Guideline

**§ 3 Structure of Guideline**

This guideline consists of general provisions, technical overview and evaluation, feasibility study, investigation, and reference documents.

[Explanation]

This guideline consists of the structure shown in Figure 1-2. The relationship between the main part of this guideline and the reference part is shown in Figure 1-3.

The contents of each chapter are as follows.

(1) Chapter I General Provisions

This chapter describes the objectives, scope of the guideline, organization of the guideline, and definition of terms.

(2) Chapter 2 Technical Overview and Evaluation

This chapter describes the background of this technology introduction, the purpose and overview of the technology introduction, the overview of each element that constitutes this technology, and the evaluation result of this technology.

(3) Chapter 3 Feasibility Study

Based on the results of the demonstration study, this document presents how to evaluate the effect of this technology introduction in the rainwater I&I investigation.

(4) Chapter 4 Investigation

This chapter provides an analysis method for detecting rainwater I&I by the survey with a sound collector installed in a manhole.

In addition to the above, the following items are shown in the reference part: specifications of the sound collector, considerations to apply this technology, evaluation results in the demonstration study, case studies, feasibility study examples of acoustic investigation and analysis, outline of AI analysis in the demonstration study, and contact information.

Chapter 1 General Provisions

- Objectives
- Scope
- Structure of Guideline
- Terms and Definitions

Chapter 2 Technical Overview and Evaluation

- Objectives of Technology
- Technology Overview
- Overview of Elements Constituting This Technology
- Overview of Evaluation Based on Demonstration Study

Chapter 3 Feasibility Study

Chapter 4 Investigation

- Investigation Procedure
- Preliminary Confirmation
- Field Investigation
- Analysis
- Health and Safety Management

References

Appendix 1: Sound Collector Specifications
Appendix 2: Application of This Technology
Appendix 3: Evaluation Results of Demonstration Study
Appendix 4: Case Studies
Appendix 5: Example of Preliminary Calculation of Investigation and Analysis
Appendix 6: Overview of AI Analysis in Demonstration Study
Appendix 7: Contact Information

**Figure 1-2 Structure of guideline**

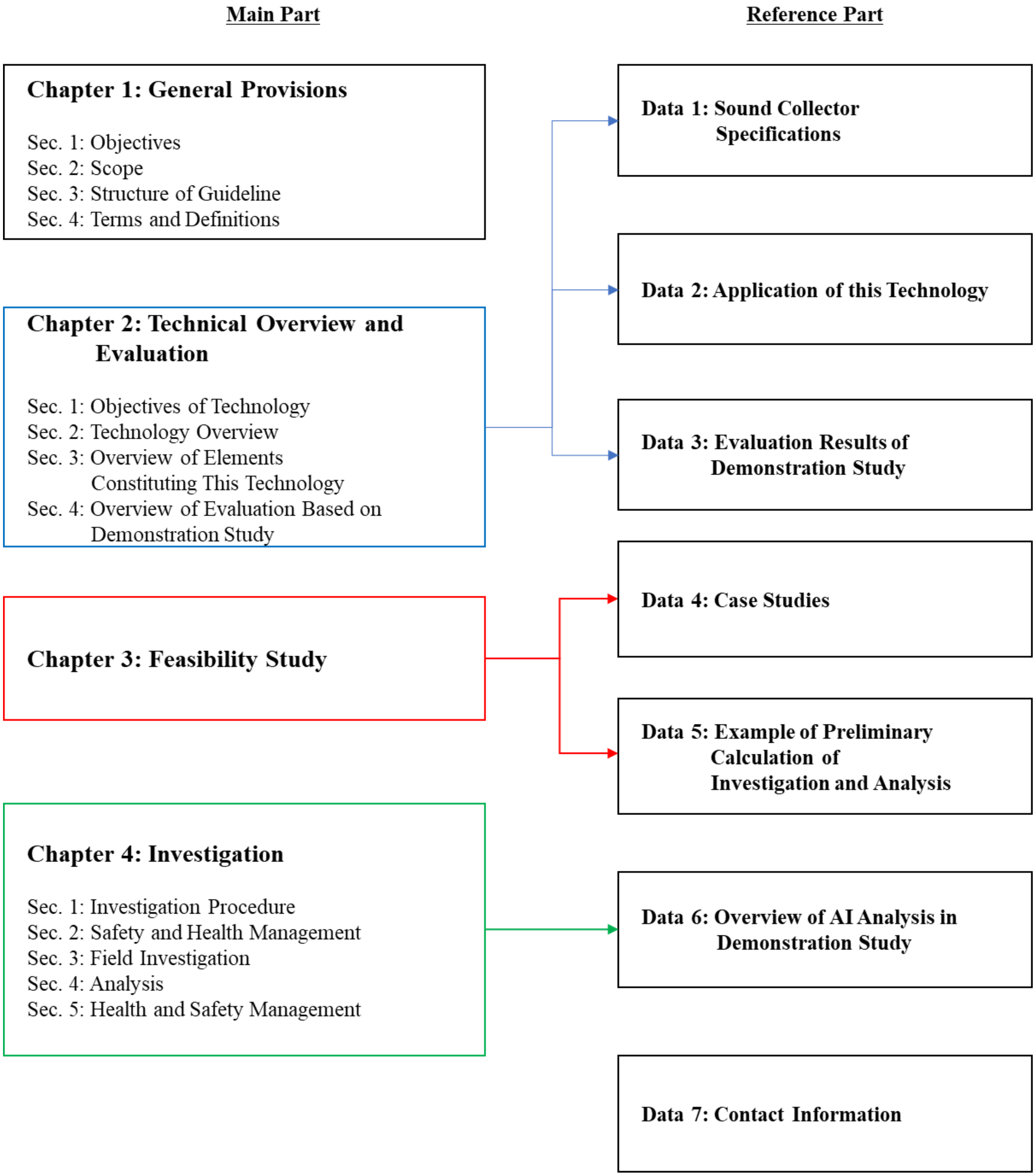


**Figure 1-3 Relationship between the main part and the reference part of the guideline**

## Section 4 Terms and Definitions

**§ 4 Terms and Definitions**

The terms used in this guideline are defined as follows. Basic terms for sewerage shall be by the "Guideline for Rainwater Infiltration Measures (Draft) [1)]", "Guideline for Inflow and Infiltration Measures [2)]", "Sewerage Facility Planning, Design Guideline, and Explanation -2019 [3)]", "Sewerage Maintenance Guideline -2014 [4)]", and "Sewerage Glossary -2000 [5)]".

(1) Element Technology

The element technology constitutes technology for detecting infiltration and inflow in wet weather by applying AI to acoustic data (hereinafter referred to as 'this technology").

The elements of this technology consist of an 'acoustic investigation' and an 'AI analysis' on the investigated acoustic data to detect rainwater I&I.

(2) Conventional Technology

Conventional technology is to analyze the existence of I&I in rainy weather by quantitative evaluation of flow meter measurement and to identify the areas and locations of rainwater I&I by engineers' analysis.

Conventional technology can determine the priority of multiple rainwater I&I areas from the analysis results.

(3) Sunny Day

A day of a week during the investigation period when no rainfall was observed.

(4) Rainy Day

A day of a week during the investigation period when the rainfall was observed to occur.

(5) Rainwater Inflow and Infiltration (I&I)

Rainwater I&I is a collective term for groundwater infiltration and direct inflow in rainy weather. The term 'groundwater infiltration' refers to groundwater that flows into the sewage system by the rise of the groundwater level on rainy days. The term 'direct inflow' refers to rainwater that flows into the sewer pipe system through manhole cover holes or misconnections to sewer pipes.

(6) Acoustic Investigation

An investigation is conducted to record the sound of water flow in the sewage system. In this investigation, a sound collector is installed in the upper part of a manhole, and the sound of water flow in the sewer pipe is recorded for more than 1 rainy day (not smaller than 0.5 mm/day rainfall intensity) and more than 14 fine days.

(7) Sound Collector

A device in which an external microphone, a voice recorder, and a power supply are stored in a waterproof and dustproof housing to observe sound in sewer pipes for acoustic investigations.

(8) AI Analysis

An analysis to detect the presence or absence of rainwater I&I using acoustic data obtained during the investigation period. In the AI analysis, the acoustic pattern on a sunny day is used as a baseline, and when the pattern on rainy days deviates from the range of the pattern on sunny days, the AI analysis detects an abnormality by assuming that the difference in the patterns is the occurrence of rainwater I&I.

(9) Feature Value

A value that quantitatively indicates the characteristics of the sound calculated from the time and frequency of the acoustic data.

# Chapter 2 TECHNICAL OVERVIEW AND EVALUATION

## Section 1 Objectives of Technology

**§ 5 Objectives of Technology**

The purpose of this technology is to reduce the cost and time required for the rainwater I&I investigation in comparison with the conventional technology by combining an acoustic investigation which records the sound of water flow in the sewer pipe and an AI analysis which discriminates the presence of rainwater I&I from the recorded acoustic data.

[Explanation]

(1) Conventional rainwater I&I investigation

Although the reduction of rainwater I&I is an urgent issue for sewerage business operators across the country, the time and cost required for the investigation are often large, which is a bottleneck to prevent sufficient progress in addressing the problem.

It is considered that rainwater enters from various parts of sewage facilities, and it ranges from a small area to a wide area. Therefore, even if a detailed investigation is carried out blindly and measures are implemented based on it, it is often difficult to see the overall effect and actual situation. Therefore, conventional investigations often apply that the survey is conducted over a wide area where rainwater I&I is considered to occur, and then narrowing down the area where countermeasures are prioritized.

In this case, it is easy to lead to an effective countermeasure because the priority of countermeasures is confirmed while narrowing down the areas where rainwater I&I occurs. On the other hand, since there are many places where rainwater I&I occurs, there are problems in terms of business feasibility and efficiency, such as the high cost and the long time required to investigate sequences according to the priority of countermeasures.

Table 2 -1 shows the rainwater I&I investigation procedure in the conventional technology, and Fig. 2 -1 shows the rainwater I&I investigation flow.

The conventional technology conducts flow rate investigation and analysis using a flowmeter for large sectors (several hundred hectares or more) that require countermeasures against rainwater I&I, and then, based on the results, narrow down the area to medium sectors (several dozen hectares) to be investigated and analyzed, and the process is repeated until the area is narrowed down to small sectors (several hectares) where the measures are implemented.

**Table 2-1 Rainwater I&I investigation procedure in the Conventional Technology**

| STEP | Contents |
|---|---|
| 1 | Divide the investigated area into sectors based on the catchment system and investigate rainwater I&I for each sector. |
| 2 | Based on the basic investigation data and results in step 1, analyze and evaluate the rainwater I&I. |
| 3 | Weight the priority of countermeasures for each block. |
| 4 | Select high prioritized sectors to provide countermeasures and further subdivide the sectors for the additional survey, analysis, and evaluation. |

(2) Objectives of this technology

This technology replaces the conventional flowmeter investigation to narrow down the investigated area with an acoustic investigation using an inexpensive sound collector and detects the presence or absence of rainwater I&I in the area by analyzing the results of the acoustic investigation to record the sound of water flow in the sewer pipe for a certain period including sunny days and rainy days by AI analysis.

This technology focuses on the characteristic of the relationship between the amount of water flow and the sound of water flow at the investigation site and determines the presence of rainwater I&I when the sound pattern on rainy days deviates from the average sound pattern on sunny days.

This enables a certain reduction in the cost and time of the investigation, which are the problems of the conventional technology described above.

As shown in Fig. 2 -1, this technology enables the detection of the rainwater I&I area in a single investigation by conducting an acoustic investigation on small sectors in a large sector at the same time, instead of narrowing down the area step by step as in the conventional technology.

Since this technology only detects the presence or absence of rainwater I&I by the unique acoustic characteristic generated at the investigation location, it is possible to conduct the investigation at low cost and in a short period, although it is not possible to identify the rainwater I&I area by using quantitative indicators such as flow rate and water level which can be relatively evaluated as in the conventional technology.

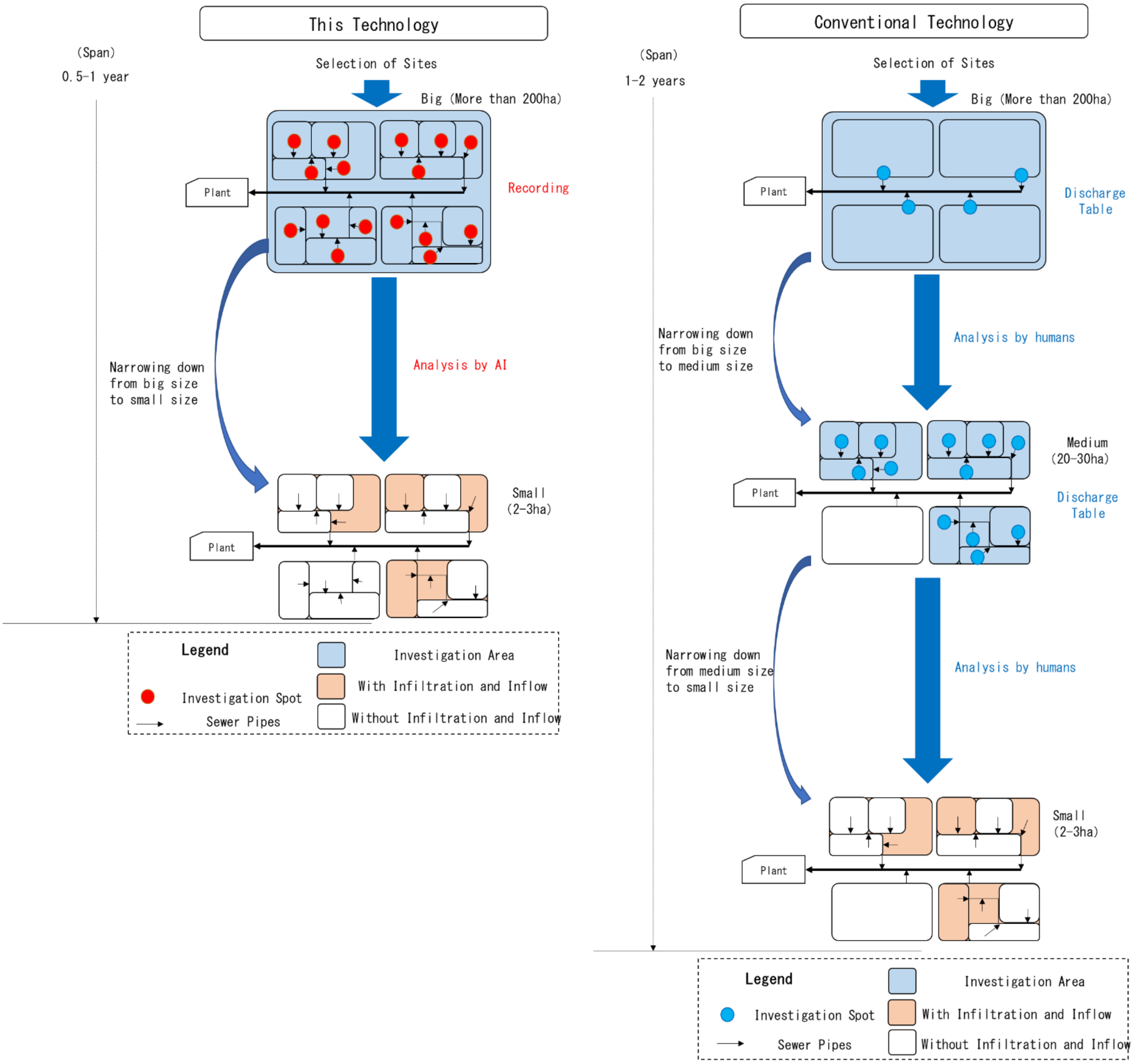


**Figure 2-2 Flow of Rainwater I&I Investigation in This Technology (left) and Conventional Technology (right)**

# Section 2 Technology Overview

**§ 6 Technology Overview**

This technology records the acoustic data of water flow in the sewer pipes by the investigation method using commercially available voice recorders, which are inexpensive and easy to install, and quickly detects the presence or absence of rainwater I&I by AI analyzing the data. This technology consists of the following element technologies.

(1) Acoustic investigation

(2) AI analysis

[Explanation]

This technology replaces the conventional flowmeter investigation to narrow down the investigated area with an acoustic investigation using a sound collector and detects the presence or absence of rainwater I&I in the area by AI analyzing the acoustic data. Focusing on the characteristics of the relationship between the amount of water flow and the sound of water flow at the investigation site, after the average sound pattern on sunny days is defined, AI determines when the acoustic data deviates from the average pattern and detects the presence or absence of rainwater I&I.

This technology consists of the following element technologies. The detailed outline of each element technology is given in Section 3.

(1) Acoustic investigation

The acoustic investigation continuously records the sound of water flow in sewer pipes in the AI analysis to detect rainwater I&I.

(2) AI analysis

The AI analysis converts the sound of water flow in sewer pipes recorded by the acoustic investigation and determines the presence or absence of rainwater I&I based on the difference in the sound characteristics between a sunny day and a rainy day.

## Section 3 Overview of Elements Constituting This Technology

**§ 7 Acoustic Investigation**

Acoustic investigations are conducted by installing commercially available voice recorders as investigation equipment in the investigated areas and continuously recording the sound of water flow in the sewer pipes on sunny and rainy days.

[Explanation]

The acoustic investigation continuously records the sound of water flow in the sewer pipes used in the AI analysis for the detection of rainwater I&I.

Regarding acoustic surveys, as shown in Fig. 2-2, a sound collector is installed inside the manhole of the selected survey site, and the sound of water flow in the sewer pipes is continuously recorded during the observation period including one or more rainy days (0.5 mm/day rainfall intensity or more) and 14 or more sunny days. It should be noted that conventional technology requires 2 to 3 rainy days with 5 ~ 10 mm/day rainfall intensity.

In the acoustic survey, if the amount of rainwater I&I increases during heavy rainfall, the external microphone and/or sound collector may be submerged due to the rising water level in the manhole. Therefore, waterproof equipment shall be used for the housing and microphone. To continuously record the sound of water flow for a certain period, a separate power supply should be installed to supply power externally to the voice recorder.

For rainfall observations, existing rain gauges installed in or near the survey area are used. However, new rain gauges will be considered if necessary.

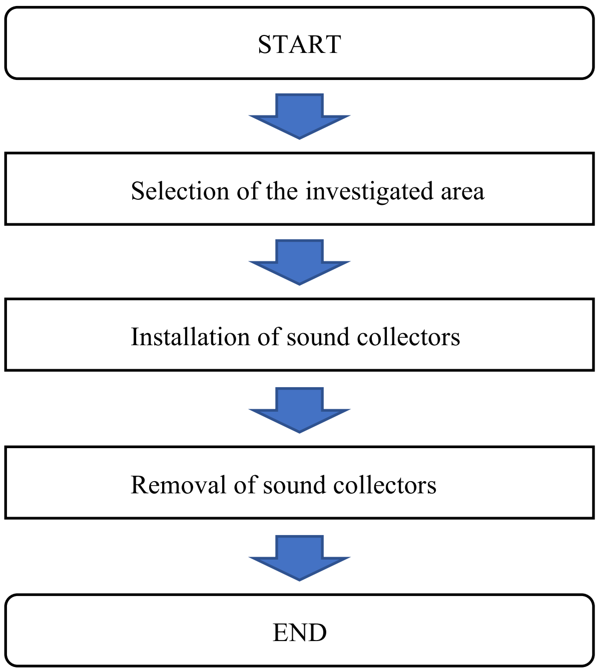


**Figure 2-3 Flow of acoustic investigation**

The configuration and specifications of the main equipment required for the acoustic investigation are shown below. For reference, the specifications of the sound collector used in the demonstration study are shown in Appendix 1.

1) External microphone
A device for collecting the sound of water flow in sewer pipes and has waterproof performance equivalent to IPX4.

2) Voice recorder
A device that can be connected to an external microphone to continuously record and store the sound during the investigation period.

3) Power supply
A power supply that enables external microphones and voice recorders to be operated continuously during the investigation period.

4) Waterproof housing
A housing that stores the voice recorder and power supply and has waterproof/dustproof performance equivalent to IP6T.

Based on the results of the demonstration study, it is recommended to exclude the investigation locations where No. 1) to 4) below are applicable since it is difficult to construct the sound patterns on sunny days in the AI analysis described later (See Appendix 2.).

1) Effect of pump start and stop
When an investigation is carried out in an area within 150 m upstream or downstream of a pumping station or manhole pump, the acoustic characteristics become irregular due to fluctuations in the flow rate and water level in the pipe upstream and downstream when starting and stopping the pump.

2) Effect of irregular drainage
When an investigation is conducted in an area affected by wastewater discharge from a factory, etc., if periodic fluctuations in wastewater cannot be grasped in the basic investigation, the flow rate and water level at the investigated area become irregular every day due to irregular wastewater discharge from the factory, etc. and the acoustic characteristics also become irregular.

3) Inspection at bend
When the investigation is conducted at the bent of the sewer pipe, the flow condition is different from the straight pipe part, and turbulence of the water flow may occur. In this case, it becomes difficult to construct a pattern on sunny days since the acoustic data tends to be disturbed.

4) Direct flow into a manhole
When an investigation is conducted at a location where there is direct inflow into the manhole from a branch sewer, etc., and where a drop pipe is not installed, the water flow sound of the main pipe may be affected by the water flow sound from the branch sewer, etc., irregularly. In this case, it is difficult to construct a pattern on sunny days because the sound of water flow is mixed.

§ 8 AI Analysis

The AI analysis determines the presence or absence of rainwater I&I in the investigated area from the difference in characteristics between sunny days and rainy days by using the acoustic data of water flow obtained from an acoustic investigation.

[Explanation]

In the AI analysis, the sound of water flow in the sewer pipes recorded by the acoustic investigation is converted into data, and the presence or absence of rainwater I&I is judged from the difference in the characteristics of the sound on sunny days and rainy days.

The basic idea of the AI analysis used in the demonstration study is to define the feature quantity as the average acoustic pattern reflecting the characteristics of sunny days, to compare the feature quantity with that similarly defined of rainy days and to determine that rainwater I&I occurs when the feature quantity of the rainy days differs from the sunny days (see Appendix 6).

The AI analysis program to determine the characteristics of the sound of water flow in this technology uses as teacher data the sound of water flow in the sewer pipes at 10 locations in the district where the occurrence of rainwater I&I has been confirmed before the demonstration study. The teacher data is the 30 days of water flow sounds recorded at the investigation site, including at least 14 sunny days and 2 rainy days with rainfall of 1.5 mm/day or more. Using this teacher data, the AI analysis program has been developed to create a feature quantity that is different from that of sunny days due to the rainwater I&I (see Appendix 6.1 ~ 6.8).

In the demonstration study, the water flow sound in the sewer pipe was recorded for 14 sunny days and 1 rainy day with rainfall of 0.5 mm/day or more in 1 location. When the feature quantity evaluated from the AI analysis on the water flow sound recorded on rainy days exceeds the upper limit of the feature quantity that can be taken at a certain time on sunny days during the recording period, it is determined that rainwater I&I has occurred (See Materials 6.11).

Figure 2-3 shows the image of how the AI determines the presence or absence of rainwater I&I based on the feature quantity obtained by the AI analysis in this technology. The feature quantity on rainy days indicated by the blue line after 13:00 exceeded the upper limit of the feature quantity obtained on sunny days during the investigation period indicated by the red single-dotted line, which indicates that rainwater I&I occurred after 13:00.

When creating an AI analysis program according to this guideline, input and output data are required to confirm the validity of the teacher data and the created program. The data can be provided by the demonstration study entities, so please inquire by referring to Appendix 7.

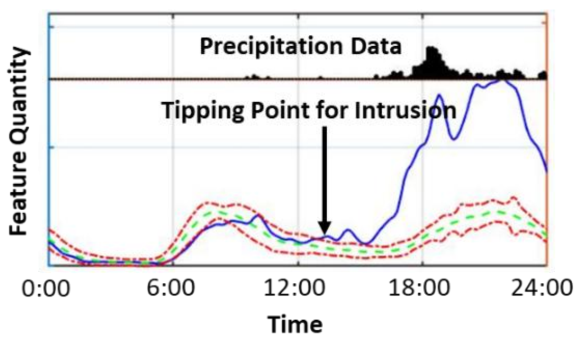


**Figure 2-4 Determining the presence or absence of rainwater I&I by an AI analysis**

## Section 4 Overview of Evaluation Based on Demonstration Study

**§ 9 Evaluation Items of This Technology**

The evaluation items of this technology based on the demonstration study are shown below.

(1) Business feasibility

(2) Efficiency

[Explanation]

To proceed with the feasibility study of this technology, it is necessary to set and present evaluation items, evaluation methods, and evaluation results to grasp the effects of the introduction of this technology quantitatively.

The evaluation items of this technology are business feasibility and efficiency. These are set because this technology enables the investigation at a lower cost and in a shorter time than the conventional technology.

(1) Business feasibility

Calculate the costs of the investigation and analysis in this technology and the conventional technology and evaluate the business feasibility by the reduction rate of this technology to the conventional technology.

1) Investigation cost

Calculate the costs required for the investigation such as installation and removal for this technology and the conventional technology. Table 2-2 shows the items subject to calculation of investigation costs .

The calculation of the investigation costs for the conventional technology is based on the latest "Sewerage Pipe Management Cost Estimation Guideline [6)]" published by the Japan Sewerage Pipeline Management Association.

In addition, the investigation costs for this technology should be set appropriately according to the situation and the number of investigation locations, equipment used, etc. In the demonstration study, the number of installations, patrol inspections, and removals was 15 places/day (see Appendix 3.3.2), the cost of machinery damage was 500 yen (3 pounds)/day (see Appendix 5.2), and the number of report preparations was 20 places/day (see Appendix 5.2). If the conditions of the investigated sites and the specifications of the equipment are not significantly different, these values can be used as a reference value.

**Table 2-2 Items subject to calculation of investigation costs**

| Items | This technology | Conventional technology | Notes |
|---|---|---|---|
| Observations | Installation<br>Removal<br>Patrol inspection<br>Machinery damage<br>Report preparation | | Measurement instrument for the estimation of machinery damage<br>This technology: Sound collector<br>Conventional technology: Flowmeter |

2) Analysis cost

Calculate the costs of a series of processes in this technology and the conventional technology, including confirmation of basic work, basic investigation, narrowing down the area of rainwater I&I, preparation of submitted documents, and planning discussions. All the processes shall be included in the cost calculation because this technology requires less basic investigation and preparation of submitted documents than the conventional technology. Since this technology uses AI analysis to narrow down the area of rainwater I&I, the analysis cost shall be calculated with reference to Appendix 5. In addition, the investigation cost in the conventional technology is calculated based on the "Manual for Planning Measures against Rainwater Inflow and Infiltration in Separate Sewer System"[7] published by the Sewerage New Technology Promotion Organization.

Table 2-3 shows the items subject to the calculation of analysis costs.

**Table 2-3 Items subject to calculation of analysis costs**

| Items | This technology | Conventional technology | Notes |
|---|---|---|---|
| Analysis | Confirmation of basic work<br>Basic investigation<br>Narrowing down the area of rainwater I&I<br>Preparation of submitted documents<br>Planning discussions | | Since the analytical method used for this technology is AI analysis to narrow down the area of rainwater I&I, the cost estimation is referred to Appendix 5. |

3) Evaluation of business feasibility

According to the purpose of the investigation, sum the costs of 1) and 2) in this technology and the conventional technology, and calculate the reduction rate to the total cost of the conventional technology based on the following equation.

$$\text{Total Cost Savings (\%)} = \frac{(B - A)}{B} \times 100$$

A: Total cost of investigation and analysis of this technology

B: Total cost of investigation and analysis of the conventional technology

(2) Efficiency

Calculate the number of working days required for the investigation and analysis for this technology and the conventional technology and evaluate the efficiency by the shortening rate of this technology to the conventional technology.

1) Number of investigation days

Calculate the number of days required for installation, removal, etc., according to the number of investigation locations in this technology and the conventional technology. It is difficult to set the investigation period from installation to removal in advance because it may be a long period depending on the availability of rainy days that can be analyzed. Therefore, in the demonstration study, the investigation period of this technology is considered the same as that of the conventional technology, and the number of investigation days is excluded from the calculation.

In calculating the number of days required for installation, patrol inspection, and removal of this technology, 15 sites/day mentioned in "(1) Business feasibility" shall be set. In addition, in calculating the number of days required in the conventional technology, the calculation is based on the latest "Sewerage Pipe Management Cost Estimation Guideline[6)]" published by the Japan Sewerage Pipe Management Association.

If it is considered inappropriate to use the above reference due to the investigated site conditions, other references can be used, but it is recommended that the reasons for the use of the other references be described separately.

**Table 2-4 Items subject to calculation of investigation days**

| Items | This technology | Conventional technology | Notes |
|---|---|---|---|
| Observation | Installation<br>Removal<br>Patrol inspection | | The number of days of the investigation period is not included in the calculation. |

2) Analysis days

Calculate the number of days required for analysis in this technology and the conventional technology. This technology reduces the time conventionally required in the process for engineers to determine the presence or absence of rainwater I&I by applying AI technology.

The number of days required for the AI analysis of this technology and the analysis of the conventional technology varies depending on the number of locations to be analyzed and is set referring to the actual results of the demonstration study (Appendix 5.).

**Table 2-5 Cost estimated items for analysis days**

| Items | This technology | Conventional technology |
|---|---|---|
| Analysis | AI analysis | Evaluation and analysis of investigation results to narrow down the area |

3) Efficiency evaluation

According to the purpose of the investigation, sum the number of days of 1) and 2) in this technology and the conventional technology, and calculate the shortening rate between the total number of days in this technology and those of the conventional technology based on the following equation.

$$\text{Total days shortening rate (\%)} = \frac{(B - A)}{B} \times 100$$

A: Total number of days required for investigation and analysis in this technology

B: Total number of days required for investigation and analysis in the conventional technology

## § 10 Evaluation Results of This Technology

Based on the demonstration study, the following items are evaluated.

(1) Business feasibility

(2) Efficiency

[Explanation]

The target values for both business feasibility and efficiency vary depending on the purpose and scope of the investigation and the conditions in the target area to introduce this technology. Therefore, the demonstration study compared the business feasibility and efficiency of this technology with those of the conventional technology in several demonstration fields with different target areas and narrowing processes and evaluated the effectiveness.

Since the evaluation result is based on the case where the same narrowing investigation is conducted in this technology and the conventional technology and the evaluation are conducted under the condition that the observation equipment used for both technologies is installed in the same manholes, the number of the investigation locations to be evaluated becomes the same. Table 2-6 shows survey conditions for each field in the demonstration study.

**Table 2-6 List of investigation classifications in demonstration fields**

| Target municipality | District | Area (ha) | Type of narrowing investigation | Number of sites investigated | |
|---|---|---|---|---|---|
| | | | | This technology | Conventional technology |
| Koriyama | Otsuki | 70 | Medium → Small sector | 5 | 5 |
| | Fukuyama | 130 | Medium → Small sector | 8 | 8 |
| Tsukuba | Johnan | 1,500 | Large → Medium sector | 24 | 24 |
| Nagoya | Hyogo | 10 | Medium → Small sector | 4 | 4 |
| | Kaminokura | 20 | Medium → Small sector | 10 | 10 |
| Kobe | Upper Kakogawa River Basin | 1,500 | Large → Medium sector | 14 | 14 |
| | Iwaoka Basin | 165 | Large → Medium → Small sector | 16 | 16 |
| | Seishin Basin | 900 | Large → Medium → Small sector | 18 | 18 |
| Kumamoto | Kotoh Basin | 600 | Large → Medium → Small sector | 33 | 33 |
| | Tomiai Basin | 600 | Large → Medium sector | 19 | 19 |

(1) Business feasibility

Figure 2-4 and Table 2-7 show the results of the business feasibility evaluation. In the 10 districts covered in the demonstration study, the average reduction in total costs was 57.6%. In each district, the analysis cost of this technology is comparable to that of the conventional technology, but the investigation cost is significantly reduced. This is because this technology is more efficient than the conventional technology in terms of the installation, patrol inspection, and removal work, and the sound collector is cheaper than the flow meter.

As in the case of Tsukuba City (Johnan district) and Kumamoto City (Kotoh Basin), the total cost reduction rates tended to be higher as the number of installation locations increased.

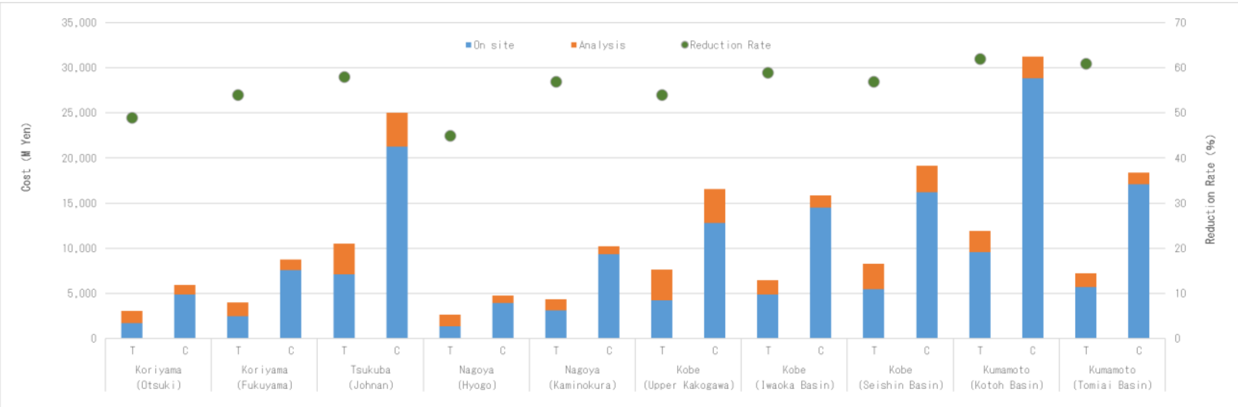


**Figure 2-4 Results of business feasibility evaluation (T: This Technology C: Conventional Technology)**

**Table 2-7 Results of business feasibility evaluation**

| Municipality | District | Area (ha) | Type of narrowing investigation | Number of Sites Investigated | This Technology | | | Conventional Technology | | | Reduction Rate (% ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Investigation Cost (1,000 Yen) | Analysis Cost (1,000 Yen) | Total Cost (1,000 Yen) | Investigation Cost (1,000 Yen) | Analysis Cost (1,000 Yen) | Total Cost (1,000 Yen) | |
| Koriyama | Otsuki | 70 | Medium → Small sector | 5 | 1,670 | 1,360 | 3,030 | 4,875 | 1,020 | 5,895 | 49 |
| | Fukuyama | 130 | Medium → Small sector | 8 | 2,480 | 1,510 | 3,990 | 7,540 | 1,220 | 8,760 | 54 |
| Tsukuba | Johnan | 1,500 | Large → Medium sector | 24 | 7,100 | 3,430 | 10,530 | 21,240 | 3,780 | 25,020 | 58 |
| Nagoya | Hyogo | 10 | Medium → Small sector | 4 | 1,370 | 1,240 | 2,610 | 3,900 | 862 | 4,762 | 45 |
| | Kaminokura | 20 | Medium → Small sector | 10 | 3,090 | 1,260 | 4,350 | 9,310 | 890 | 10,200 | 57 |
| Kobe | Upper Kako-gawa River Basin | 1,500 | Large → Medium sector | 14 | 4,210 | 3,430 | 7,640 | 12,800 | 3,784 | 16,584 | 54 |
| | Iwaoka basin | 165 | Large → Medium → Small sector | 16 | 4,850 | 1,600 | 6,450 | 14,500 | 1,350 | 15,850 | 59 |
| | Seishin Basin | 900 | Large→ Medium → Small sector | 18 | 5,450 | 2,800 | 8,250 | 16,200 | 2,940 | 19,140 | 57 |
| Kumamoto | Kotoh basin | 600 | Large → Medium → Small sector | 33 | 9,540 | 2,400 | 11,940 | 28,840 | 2,410 | 31,250 | 62 |
| | Tomiai Basin | 150 | Large → Medium sector | 19 | 5,660 | 1,550 | 7,210 | 17,090 | 1,290 | 18,380 | 61 |

(2) Efficiency

Figure 2-5 and Table 2-8 show the results of efficiency evaluation. In the 10 districts covered in the demonstration study, the average reduction in the total number of days for analysis was 61.8%. In each district, the number of days for analysis of this technology tended to be slightly shorter than that of the conventional technology, but the number of days for investigation was significantly reduced as well as the business feasibility. This is because this technology can cover a greater number of locations for installation, patrol inspection, and removal in a day compared with conventional technology.

On the other hand, in areas such as Koriyama City (Otsuki) and Nagoya City (Hyogo) where the number of investigation locations was small and the installation, patrol inspection, and removal can be done in almost the same number of days as with the conventional technology, the reduction rate of the total number of days tended to be low.

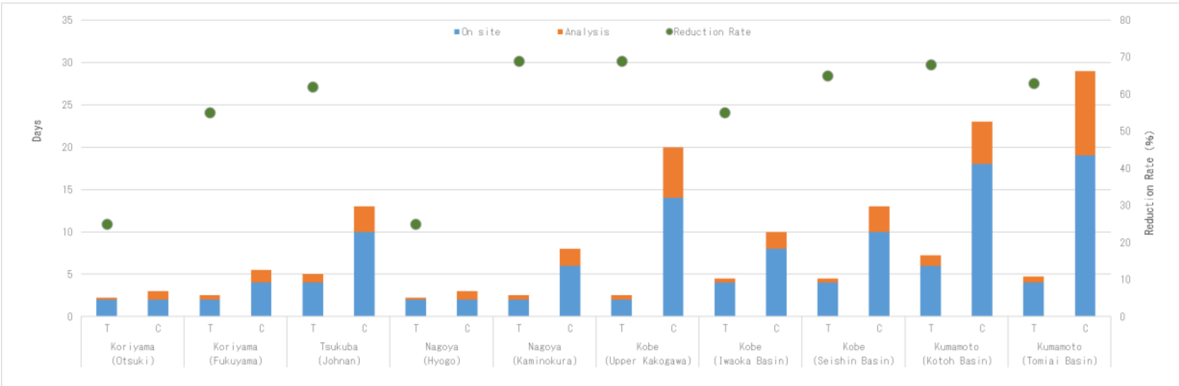


**Figure 2-5 Results of efficiency evaluation (T: This Technology C: Conventional Technology)**

**Table 2-8 Results of efficiency evaluation**

| Municipality | District | Area (ha) | Type of narrowing investigations | Number of Sites investigated | This Technology | | | Conventional Technology | | | Reduction Rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Investigation (Days) | Analysis (Days) | Total (Days) | Investigation (Days) | Analysis (Days) | Total (Days) | |
| Koriyama | Otsuki | 70 | Medium → Small | 5 | 2 | 0.25 | 2.25 | 2 | 1 | 3 | 25 |
| | Fukuyama | 130 | Medium → Small | 8 | 2 | 0.5 | 2.50 | 4 | 1.5 | 6 | 55 |
| Tsukuba | Johnan | 1,500 | Large → Medium | 24 | 4 | 1.0 | 5.00 | 10 | 3 | 13 | 62 |
| Nagoya | Hyogo | 10 | Medium → Small | 4 | 2 | 0.25 | 2.25 | 2 | 1 | 3 | 25 |
| | Kaminokura | 20 | Medium → Small | 10 | 2 | 0.5 | 2.50 | 6 | 2 | 8 | 69 |
| Kobe | Upper Kako-gawa River Basin | 1,500 | Large → Medium | 14 | 2 | 0.5 | 2.50 | 6 | 2 | 8 | 69 |
| | Iwaoka basin | 165 | Large → Medium → Small | 16 | 4 | 0.5 | 4.50 | 8 | 2 | 10 | 55 |
| | Seishin Basin | 900 | Large → Medium → Small | 18 | 4 | 0.5 | 4.50 | 10 | 3 | 13 | 65 |
| Kumamoto | Kotoh basin | 600 | Large → Medium → Small | 33 | 6 | 1.25 | 7.25 | 18 | 5 | 23 | 68 |
| | Tomiai Basin | 150 | Large → Medium | 19 | 4 | 0.75 | 4.75 | 10 | 3 | 13 | 63 |

## Chapter 3 FEASIBILITY STUDY

**§ 11 Feasibility Study Procedure**

For the feasibility study of this technology, consider the following procedure.

(1) Basic study

(2) Study of the introduction effects

(3) Introduction judgement

[Explanation]

When the study of this technology's introduction, collect the necessary information according to the procedure shown in Figure 3-1, estimate the introduction effect, and then decide on the introduction of this technology.

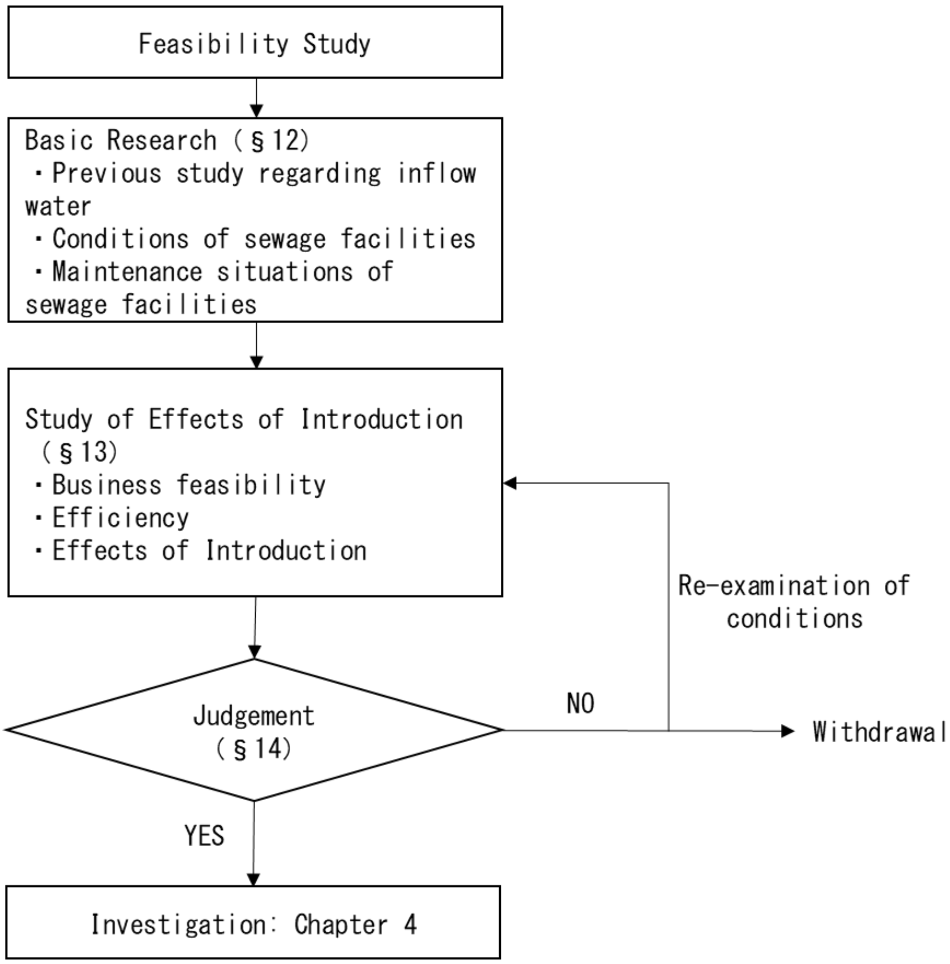


**Figure 3-1 Feasibility study procedure**

## § 12 Basic Study

Understand the following information regarding the areas where this technology is introduced.

(1) Previous rainwater I&I studies

(2) Status of sewage facilities

(3) Status of sewage facilities maintenance

[Explanation]

Confirm the relevant sewage plan, sewage ledger, maintenance information, and historical investigation of rainwater I&I as necessary information for a high-level feasibility study.

(1) Previous rainwater I&I studies

If the rainwater I&I investigation has been conducted in the investigated area using the conventional technology previously, select the investigated area where this technology is introduced based on the results. Although it is effective to prioritize the investigation for the areas with large amounts of rainwater I&I in the historical investigation, select the target areas by considering the status of rainwater I&I (trend of groundwater infiltration and direct rainwater inflow). If there is no record of a rainwater I&I investigation, select the target areas with priority based on the maintenance information in (3).

In addition, after confirming the asset management plan, it is necessary to grasp in advance the areas where the facilities have been or are scheduled to be renewed, and to take care not to conduct a rainwater I&I investigation in the areas to be renewed.

(2) Status of sewerage facilities

Using the sewage ledger, determine the direction of sewage flow in the investigated area. After understanding the locations where AI analysis is difficult as shown in § 7, extract the investigated locations that can be efficiently narrowed down in the target area as a desktop study. In addition, grasp the basic specifications of sewer pipes and manholes such as pipe type, pipe diameter, slope, earth cover, pipe bottom height, and manhole depth at the extracted investigation locations and use the basic specifications as the basic data for the business feasibility of the conventional technology.

If there are any factories in the investigated area, it is necessary to confirm the conditions of the wastewater discharge and determine whether the acoustic survey can be conducted.

(3) Status of sewage facilities maintenance

By the maintenance information of the pipe facilities, confirm the locations with a lot of rainwater I&I and the causes of flow obstruction such as clogging and blockage before the investigation. In addition, it is also effective to identify areas that need to be intensively inspected by confirming the areas where flooding occurred in the past and repair histories.

§ 13 Study of Introduction Effects

In studying the introduction effects, set a scenario for the introduction study that considers the site conditions based on the results in § 12, and estimates the evaluation items set in section § 9.

(1) Business feasibility evaluation
(2) Efficiency evaluation
(3) Understanding of the introduction effects

[Explanation]

Based on the results of the basic study, consider the introduction effects according to the following procedures. Referring to the contents of the demonstration study shown in § 10 and Appendix 3 to 5, estimate the items outlined in § 9.

(1) Business feasibility evaluation

Table 3-1 shows the comparative scope of investigation and analysis costs between this technology and the conventional technology. Study the business feasibility evaluation with reference to the conditions for calculation in § 9 and Appendix 3 to 5.

**Table 3-1 Setting of investigation and analysis costs**

| Items | This technology | Conventional technology |
|---|---|---|
| Investigation | Installation<br>Removal<br>Patrol inspection<br>Equipment damage (sound collector)<br>Report preparation | Installation<br>Removal<br>Patrol inspection<br>Equipment damage (flowmeter)<br>Report preparation |
| Analysis | Planning preparation<br>Field investigation<br>Analysis (AI analysis)<br>Report preparation<br>Planning discussion | Planning preparation<br>Field investigation<br>Analysis (organizing and analyzing survey results)<br>Report preparation<br>Planning discussion |

(2) Efficiency evaluation

Table 3-2 shows the comparative scope of the number of investigation and analysis days for this technology and the conventional technology. Same as (1), evaluate the efficiency with reference to § 9, and Appendix 3 to 5.

**Table 3-2 Setting of the number of investigation and analysis days**

| Items | | This technology | Conventional technology |
|---|---|---|---|
| Investigation | Installation | Number of possible locations per day | Number of possible locations per day |
| | Patrol inspection | Number of locations that can be inspected per day | Number of locations that can be inspected per day |
| | Removal | Number of removable locations per day | Number of removable locations per day |
| Analysis | | Number of days for AI analysis | Number of days for data analysis |

(3) Understanding of the introduction effects

Confirm the introduction effects of this technology by evaluating the business feasibility and efficiency of this technology compared with the conventional technology.

Since various investigation methods other than those discussed in this study are possible to meet the needs of local governments, it is recommended to understand the characteristics of this technology and select an effective application method of this technology.

For example, it is possible to reduce the length of a detailed investigation by narrowing it down to smaller sectors than small sectors using this technology (see Appendix 3).

**§ 14 Introduction Judgement**

Judge the introduction of this technology based on the results of the study of the introduction effect.

[Explanation]

If the introduction effect is expected to be effective based on the results of the study of § 13 in a comprehensive manner, decide to introduce this technology and move on to the study of specific investigation contents.

If the introduction effects are smaller than the target or cannot be expected, it is advisable to discontinue the feasibility study or to analyze and identify the cause and review the conditions for reconsideration of the study.

## Chapter 4 INVESTIGATION

### Section 1 Investigation Procedure of Rainwater I&I Using This Technology

**§ 15 Investigation Procedure**

Conduct the investigation in phases as described in the following items.

(1) Preliminary confirmation

(2) Field investigation

(3) Analysis

[Explanation]

In this technology, sound collectors are installed in manholes in areas or locations where the rainwater I&I is expected to occur, and a field investigation is conducted to record the sound of water flow in sewer pipes. Then, the acoustic data obtained by the investigations is analyzed to contribute to abnormality detection.

Figure 4-1 shows this investigation procedure. The details of each item are described in the following sections

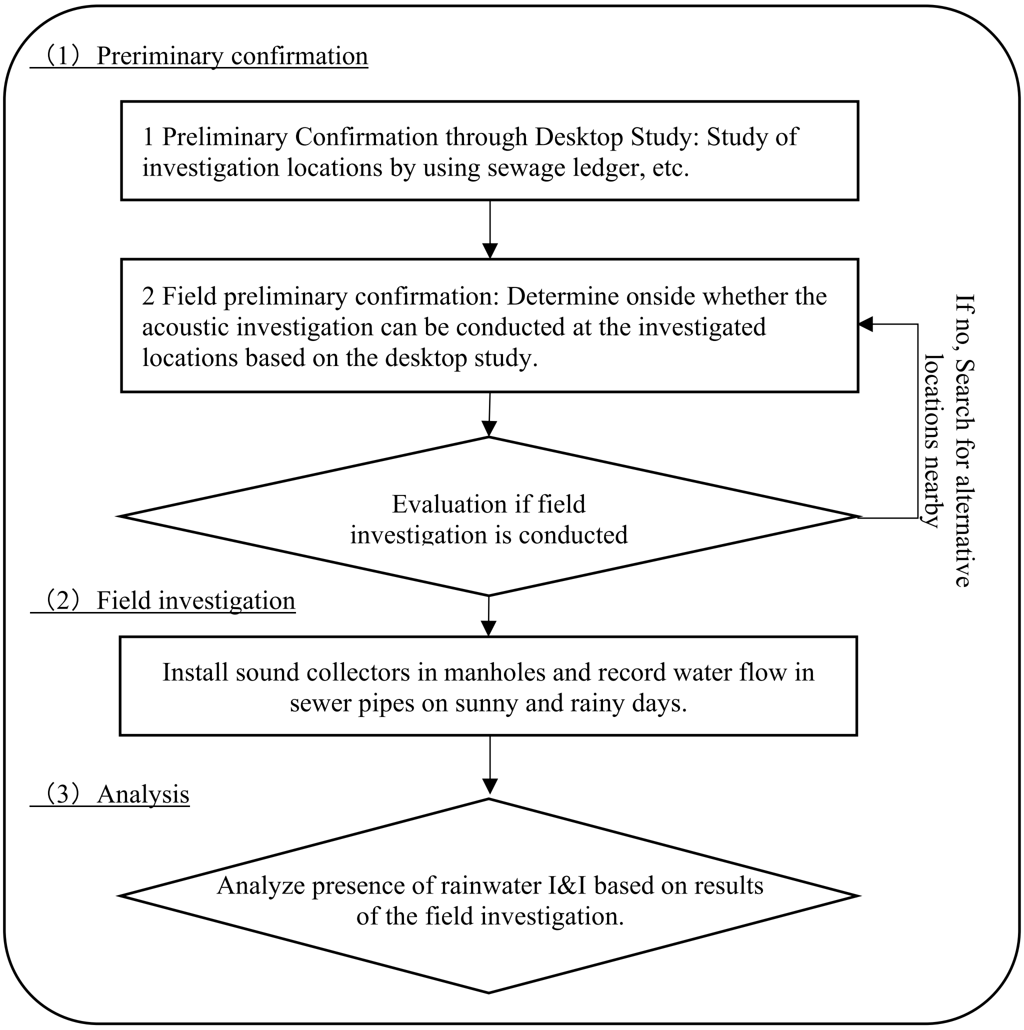


**Figure 4-1 Investigation procedure**

## § 16 Preliminary Confirmation

In the preliminary confirmation, using the sewerage ledger in the investigated area for rainwater I&I and considering the scope of exceptions to this technology as shown in § 7, conduct a desktop study of the acoustic investigation locations.

Then, at the acoustic investigation locations by the desktop study, confirm the traffic volume and the conditions in the manholes and determine on-site whether the acoustic investigation is feasible or not.

[Explanation]

In the preliminary confirmation, conduct the desktop study of the acoustic investigation locations using the sewage ledger in the investigation area, and organize the basic specifications (pipe type, pipe diameter, gradient, manhole depth, etc.) of sewer pipes and manholes upstream and downstream of the investigation locations.

Regarding the acoustic investigation locations, it is advisable to avoid selecting the following locations as much as possible considering the characteristics of this technology, and to identify backup candidate locations in case it is judged that installation is not feasible at the preliminary on-site confirmation stage.

- Junctions or bends of sewer pipes
- Around the manhole pumps

The acoustic investigation is conducted by installing sound collectors in manholes and recording the sound of water flow in sewer pipes. Therefore, at the actual site, determine whether it is feasible to conduct the acoustic investigation appropriately at the investigation locations by the desktop study, and confirm the items required for the acoustic investigation as shown in Table 4-1.

**Table 4-1 Preliminary confirmation items at the site**

| Classification | Purpose | Contents |
|---|---|---|
| Effects on the surroundings during the acoustic investigation | Implementation of safe and smooth investigations | ・When installing sound collectors in manholes on main road, check the appropriate usage of a safety harness and the locations of security guards.<br>・Confirm the need to inform residents in advance by distributing leaflets on the investigation when installing sound collectors in manholes adjacent to private houses, schools, medical institutions, etc.. |
| Situation of the site where the acoustic investigation is conducted | Implementation of reliable investigations | ・When a sound collector is installed in a manhole which has not been opened and closed for a long time, confirm the opening and closing state of the cover, and open and close in advance the cover which is difficult to be opened and closed.<br>・Check the existence and durability (corrosion state, etc.) of steps in a manhole for installing a sound collector, and if the installation of sound collector is difficult, consider installing an anchor or an alternative device.<br>・To determine the cable length of the external microphone, check the manhole depth and water trace of the acoustic investigation location.<br>・Check in advance the other construction and investigation plan such as pipe construction and CCTV camera inspection in the upstream and downstream of the acoustic investigated manhole and adjust the installation period without affecting them. |

| § 17 Field Investigation |
| --- |
| In the field investigation, record the sound of water flow in the sewer pipes on sunny and rainy days for a certain period using the acoustic investigation technology described in § 7. |

[Explanation]

The field investigation is to install a sound collector in a manhole and to record the sound of water flow generated in sewer pipes. Figure 4-2 shows the image of equipment installation during the field investigation.

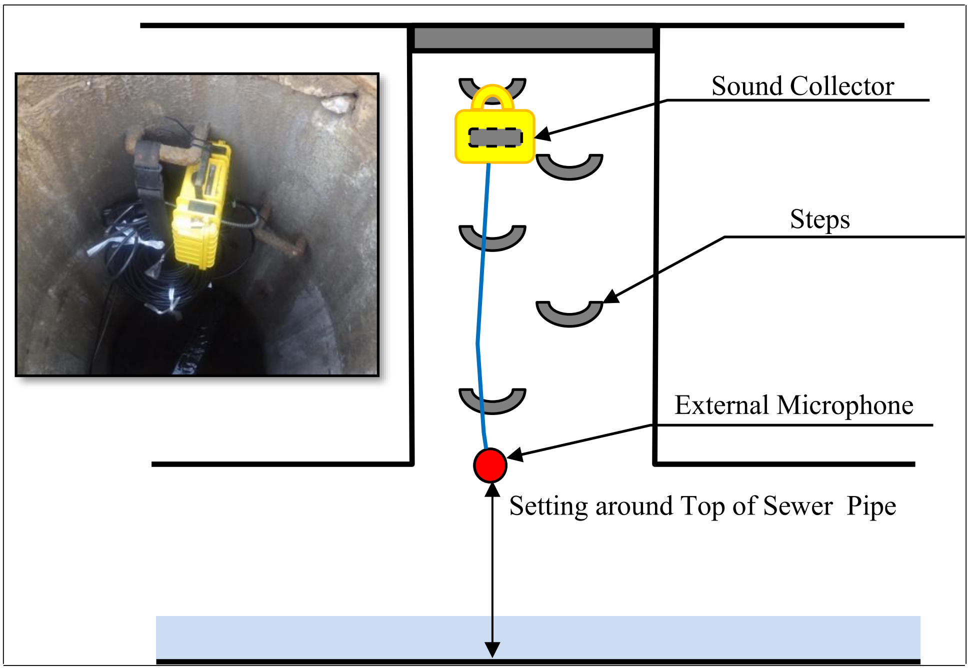


**Figure 4-2 Image of equipment installation during field investigation**

In addition, Figure 4-3 shows the sound collector installation procedure during the field investigation, and the figure also shows the task and notes in each item.

In the case of investigating in summer, it is advisable to avoid the investigation on days of extreme summer heat because the temperature in sewer pipes increases and the risk of sound collector outages increases.

1) Preparation for installation and removal

   Attach a safety harness in manholes at investigation locations and secure safety during the work. Then, open the manhole cover at the investigation location, measure the concentration of oxygen and hydrogen sulfide in the manhole, and take measures such as ventilation if necessary.

2) Sound collector installation and removal

The external microphone is installed near the top of the sewer pipe, and the installation position of the external microphone is adjusted from the ground level. The external microphone may be submerged at the investigation location where the water trace line in the manhole is above the top of the pipe. In the demonstration study, it was confirmed that when the distance between the external microphone and the water surface was 2.5 m or more, the results of acoustic AI analysis could not be properly output (See Appendix 3). Therefore, if it is necessary to investigate at such a location, the external microphone should be positioned at about 2.5 m or less from the water surface, considering the water trace line in the manhole.

It has been confirmed in the independent research stage that when the position of the external microphone significantly changes during the investigation period, the output of the recorded acoustic data significantly changes. Therefore, the external microphone should be fixed to the steps of the manhole to prevent changes in position.

Next, set the voice recorder in the sound collector to the recording mode, confirm that the sound from the external microphone is recorded, and then fix the sound collector to the steps of the manhole. It is advisable to take photographs to ensure that the sound recording is started at the installation to follow up in the event of a missing measurement due to a sound collector failure during the investigation period.

Although a patrol inspection is unnecessary, if heavy rain occurs during the investigation period that may submerge the external microphone, it is advisable to check the operation status of the sound collector on a sunny day after the rainfall.

When removing the sound collector, stop the voice recorder in the sound collector and collect the sound collector.

**Photo 4-1 Pictures of preliminary confirmation of sound collector installation**

3) Completion of installation and removal

After the installation and removal of the sound collector, close the manhole cover immediately, confirm if there are no rattling or other defects with the manhole, release the safety harness, and finish the work.

1 Preparation for Installation and Removal
- ✓ Attach Safety Harness
- ✓ Measure Oxygen and Hydrogen Sulfide in Manhole

↓

2 Sound Collector Installation and Removal
- ✓ Adjust the Position of External Microphone (only when installation)
- ✓ Start/Stop Recording of Water Flow
- ✓ Install/Remove Recorder to/from Steps of Manhole

↓

3 Completion of Installation and Removal
- ✓ Confirm any Defects with Manhole
- ✓ Release Safety Harness

**Figure 4-3 Field investigation procedure**

**§ 18 Analysis**

The analysis uses the acoustic data obtained in § 17 to determine the presence or absence of rainwater I&I at the field investigation location by the acoustic data obtained in § 17 and the AI analysis technology described in § 8.

[Explanation]

Figure 4-4 shows the flow of creating an AI analysis program. First, the acoustic data in the sewer pipe in which rainwater I&I occurs is recorded and used as the teacher data for the AI analysis. Using the teacher data, create an AI analysis program to calculate feature quantity as decision criteria for rainwater I&I detection. In this case, the feature quantity is optimized to maximize the difference between the feature quantity on rainy days when rainwater I&I occurs and that on a sunny day at the same period.

There are various AI methods applied to calculate the feature quantity. Since the teacher data used in the demonstration study is open to the public, when creating the AI analysis program for the acoustic data in sewer pipes, please contact the demonstration study body shown in Appendix 7 and coordinate how to obtain the program.

1) Extraction of acoustic data on sunny days (no rainwater I&I)

From the teacher data, extract acoustic data on sunny days when no rainwater I&I has occurred.

2) Extraction of acoustic data on rainy days (with rainwater I&I)

From the teacher data, extract the acoustic data on rainy days when rainwater I&I has occurred.

3) Creating an AI analysis program

Create an AI analysis program that optimizes feature quantity to maximize the difference between the feature quantity when rainwater I&I has occurred and the one on sunny days in the same period.

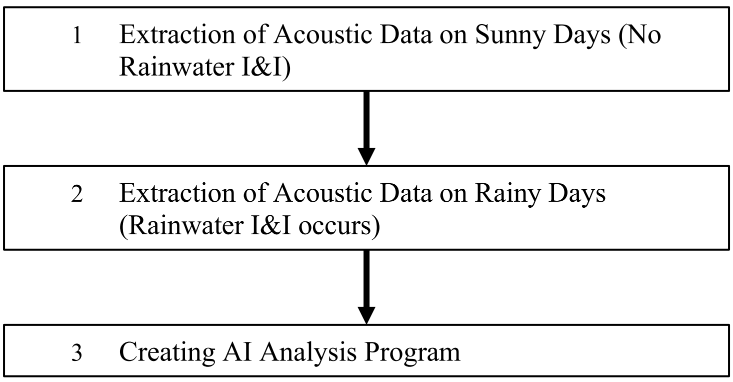


**Figure 4-4 Flow of creating AI analysis program**

Next, Figure 4-5 shows the flow of analysis on the acoustic data recorded in the field investigation. As same as the creation of the AI analysis program, classify the acoustic data recorded in the field investigation into that on sunny days and rainy days, input each data into the AI analysis program and compare the acoustic data on the sunny days and rainy days, and determine the presence or absence of rainwater I&I.

Please refer to the analysis conducted in the demonstration study based on the method as shown in Appendix 6.

1) AI analysis of acoustic data on sunny days

Analyze the acoustic data recorded on sunny days during field investigation by the AI analysis program and obtain changes in feature quantity every 24 hours on sunny days (ranges and average of feature quantities on sunny days).

2) AI analysis of acoustic data on rainy days

Analyze the acoustic data recorded on rainy days in the field investigation by the AI analysis program.

3) Judgement of the presence or absence of rainwater I&I

When the feature quantity in each hour of the rainy days exceeds the range of the same time of the sunny day, it is determined that rainwater I&I has occurred, and when it does not exceed, it is determined that rainwater I&I has not occurred.

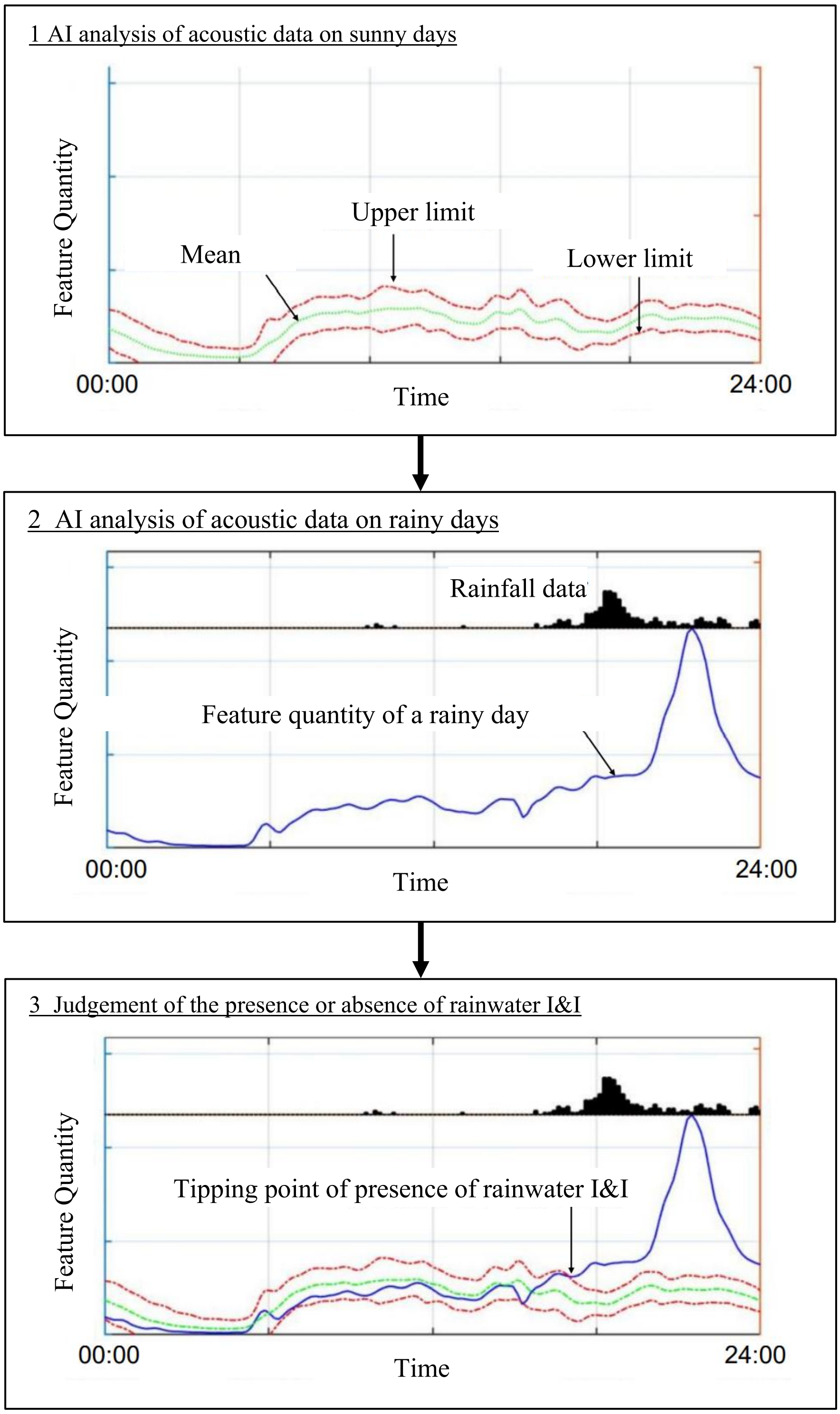


**Figure 4-5 Flow of AI analysis**

## Section 2 Health and Safety Management

**§ 19 Health and Safety Management**

Although this technology does not involve work in sewer pipes, the site conditions always involve hazards. Therefore, in addition to general safety measures, " oxygen deficiency and toxic gas control," "traffic safety management," and "response to rainfall" are emphasized as in past investigations.

[Explanation]

Although the field investigation of this technology does not involve installation or removal work in sewer pipes, it is necessary to implement countermeasures against oxygen deficiency and toxic gas when the manhole cover is opened. A series of fieldwork such as installation and removal can be conducted in a short time, but due to the work on the road, traffic safety management and countermeasures as same as those for the conventional field investigation such as the application for road use permission and the arrangement of traffic guides are necessary. In addition, since the investigation is conducted in an area where rainwater I&I is expected to occur, there is concern about the possibility of a rapid increase in the amount of sewage. Therefore, fieldwork during rainfall shall not be conducted.

For general compliance with various field operations and safety management, please refer to the "Health and Safety Management Manual for Sewerage Pipeline Management 8)" (July 2012, Japan Sewage Pipeline Management Association)," Safety Measures for Maintenance and Management of Pipes 9)" (July 2012, Japan Sewage Pipeline Management Association), and "Guideline on Safety Measures for Sewerage Pipeline Construction Work, etc., in Response to Localized Heavy Rain (draft) 10)" (October 2008, Committee to Study Safety Measures for Sewerage Pipe Construction Work, etc., in Response to Localized Heavy Rain).

[References]


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4) Japan Sewerage Association: Sewerage Maintenance Guideline -2014 (September 2014)

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6) Japan Sewage Pipeline Management Association: Sewerage Pipe Management Cost Estimation Guideline (2015)

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8) Japan Sewage Pipeline Management Association: Health and Safety Management Manual for Sewage Pipeline Management, (July 2012)

9) Japan Sewage Pipeline Management Association: Safety Measures for Maintenance and Management of Pipes (July 2012)

10) Committee to Study Safety Measures for Sewerage Pipe Construction Work, etc., in Response to Local Heavy Rain: Guidance on Safety Measures for Sewerage Pipe Construction Work, etc., in Response to Local Heavy Rain (draft), (October 2008)

## Reference Part

# 1. Sound collector specifications

The following are the specifications of each device of the sound collector used in the demonstration study. Since this equipment needs to be installed in sewer pipes for a long period, the housing shall be waterproof to prevent water from going into the housing through the sealing. The data was recorded on a 32 GB SD card.

« List of Sound Collector Specifications »

| Items | Specifications | Appearance |
|---|---|---|
| Voice recorder | SONY IC Recorder (ICD-PX 470 F) |  |
| External microphone | RoHS Omnidirectional Electret Condenser Microphone (Foil Electret Type) |  |
| External microphone cable | Fuji Electric Co., Ltd.<br>Microphone cord (MVVS)<br>Extension: 5 m |  |
| Waterproof case | B & W International OUTDOOR CASES YPE 500<br>Inner Dimensions (mm): 203 x 143 x 78.5<br>Outer Dimensions (mm): 228 x 182 x 92<br>Weight: 500 g, Volume: 2.28 L<br>Body Material: Polypropylene Waterproof and Dustproof<br>Protection Class: IP 67<br>Sponge: Lattice-shaped Cut Sponge (2 Sheets) |  |
| Power supply | 3.0 VDC, 4 AA alkaline batteries, approx. 1000 hours when using the 4 batteries | |

**Voice recorder specifications (set in the demonstration experiment)**

| Items | Specifications | Contents |
|---|---|---|
| IC recorder | Frequency range | MP3 48kbps (MONO): 50Hz～14,000Hz |
| | Supported file formats | WMA<br>・Bit rate:32kbps - 192kbps<br>・Sampling frequency: 44.1 kHz<br>・Extension: wma |
| Maximum recording time | Recording mode | MP3 48 kbps (MONO): 32 GB 1,431 hours |
| | Memory card | 32 GB (recording time up to 1,431 hours) |

**External microphone specifications**

| Specifications | Contents |
|---|---|
| Sensitivity | -38±3dB RL=2.2KQ Vs=4.5V |
| Impedance | 2.2 KQ 1 KHz maximum (RL = 2.2 KQ) |
| Frequency | 50 - 16000Hz |
| Power consumption | Up to 0.5 mA RL = 2.2 KQ Vs = 4.5 V |
| Sound pressure | 120 dB or more |
| S/N ratio | 58 dB or more |
| Waterproof | IP4 |
| Storage temperature | -40°C - 70°C |
| Operating temperature | 40°C - 110°C |

**Microphone cable specifications**

| Specifications | Contents |
|---|---|
| Size | 0.3mm$^2$ |
| Conductor resistance | 62.9 Q/km or less |
| Withstanding voltage | Air: Withstand 1000 V for 1 minute<br>Spark: Withstand 3000 V for 0.15 seconds |
| Insulation resistance | Room temperature: 5MQkm or more<br>High temperature: 0.01MQkm or more |
| Tensile strength and elongation | Insulator: Tensile strength: 10 MPa or more<br>Elongation: 100% or more<br>Sheath: Tensile strength: 10 MPa or more<br>Elongation: 120% or more |
| Heat resistance | Insulator: Tensile strength: 85% or more of the value before heating<br>Elongation: 80% or more of the value before heating<br>Sheath: Tensile strength: 85% or more of the value before heating<br>Elongation: 80% or more of the value before heating |
| Wound heat resistance | Do not crack the surface. |
| Low temperature winding resistance | Do not crack the surface. |
| Resistance to heat deformation | Insulator: Thickness reduction rate 50% or less<br>Sheath: Thickness reduction rate 50% or less |
| Flame retardancy | Disappearing spontaneously within 60 seconds |

## 2. Application of this technology

This technology records the sound of water flow in manholes with sound collectors, analyzes the results with AI, creates a pattern of sunny days, and detects abnormalities on rainy days. The basis of this technology is to create the acoustic pattern on sunny days. The recording of the sound of water flow is applicable in all manholes, but it is assumed that some conditions are not appropriate for the application.

The scope of application has been clarified by verifying the acoustic data observed in the actual field and is shown as follows.

**Table 2 -1 Verification items and contents of the investigation locations for this technology**

| Items | Contents of verification |
|---|---|
| Locations affected by noise on the ground | Conduct acoustic investigations at locations with high traffic volumes or noise sources nearby and verify the analysis and evaluation results. |
| Locations affected by reverberation sound in the deep manhole | Conduct acoustic investigation at deeper manhole depths and verify the analysis and evaluation results. |
| Locations where the sound of water flow is weak due to low flow rate | Conduct an acoustic investigation in the upstream area within the small sector and verify the analysis and evaluation results. |
| Effects of pump start/stop | Conduct acoustic investigation at the locations where water level fluctuations occur on the upstream and downstream of the pump stations or manhole pumps affected by the start/stop of the pump and verify the analysis and evaluation results. |
| Effect of irregular wastewater discharge (by wastewater from factories, etc.) | Conduct acoustic investigation at the locations where many factories are located and there is irregular wastewater discharge from each factory and verify the analysis and evaluation results. |
| Investigation at bend | Conduct acoustic investigation at corner sections where ripping of water flow is expected to cause the acoustic fluctuation and vibration increase and verify the analysis and evaluation results. |
| Locations where there is direct inflow into manholes | Conduct acoustic investigation at the locations where sounds other than the main pipe flow noise in case of connecting branch sewers and lateral pipes to manholes without drop pipes, etc., and verify the analysis and evaluation results. |
| Equipment (microphone) at high risk of submergence in water | Conduct an acoustic investigation at locations where the microphone is expected to be submerged due to abnormal inflows during heavy rains to confirm the deterioration of microphone performance by the fouling and verify the analysis and evaluation results. |

**« Locations affected by noise on the ground»**

The acoustic investigation of this technology is conducted in the manhole installed on a public road, which caused the following sound sources to be mainly observed in the acoustic data observations during the demonstration study. However, since these are in different frequency bands from the sound of water flow, they can be removed as noise by the band-pass filter.

Therefore, it was confirmed that ambient noise generated around the investigation location did not affect the analysis results.

- The rattling sound of manholes by vehicles pass
- Sound generated when pedestrian passes through manholes on sidewalks
- Construction noise around manholes
- Operation noise when opening manholes during installation, inspection, and removal

In addition, although the acoustic data recorded at all the investigation locations were checked, any household noises (talking, the sound of home appliances, etc.) generated from inside the houses could not be confirmed, which denied the possibility of invasion of privacy by the acoustic investigation.

**« Locations affected by reverberation sound in the deep manhole»**

Because there is a possibility that the sound of water flows in deep manholes due to the large space, it was confirmed whether AI analysis could be applied to such locations.

Since the external microphone cable length of the sound collector produced in this research was unified to 5 m, the confirmation method was decided as follows.

- Investigation by installing a sound collector near the ground surface and extending the external microphone cable to the maximum length (in cases where the water surface is far from the external microphone)
- Investigation by installing a sound collector in the middle of the manhole depth rather than near the ground surface to ensure that the sound of water flow can be detected even at great depths (in cases where the water surface is not far from an external microphone).

As a result, as shown in the following sections, it was confirmed that this technology can be applied even to deep manholes by keeping the distance between the external microphone and the water surface close.

**[Case where the water surface is far from the external microphone]**

Figure 2-1 shows an example of investigation in a case where the water surface is far from the external microphone. In this case, there was about 4 m between the external microphone and the water surface.

As can be seen clearly from this, when the external microphone is far from the water surface, the sound of water flow cannot be recorded properly, and the waveform on sunny days is distinctively different from that on conventional technology. As a result, it was impossible to detect the rainwater I&I because feature quantities on sunny days could not be created.

The investigation was also conducted in deep manholes at other locations, and the same tendency was confirmed in the case where the distance between the external microphone and the water surface was about 3 m.

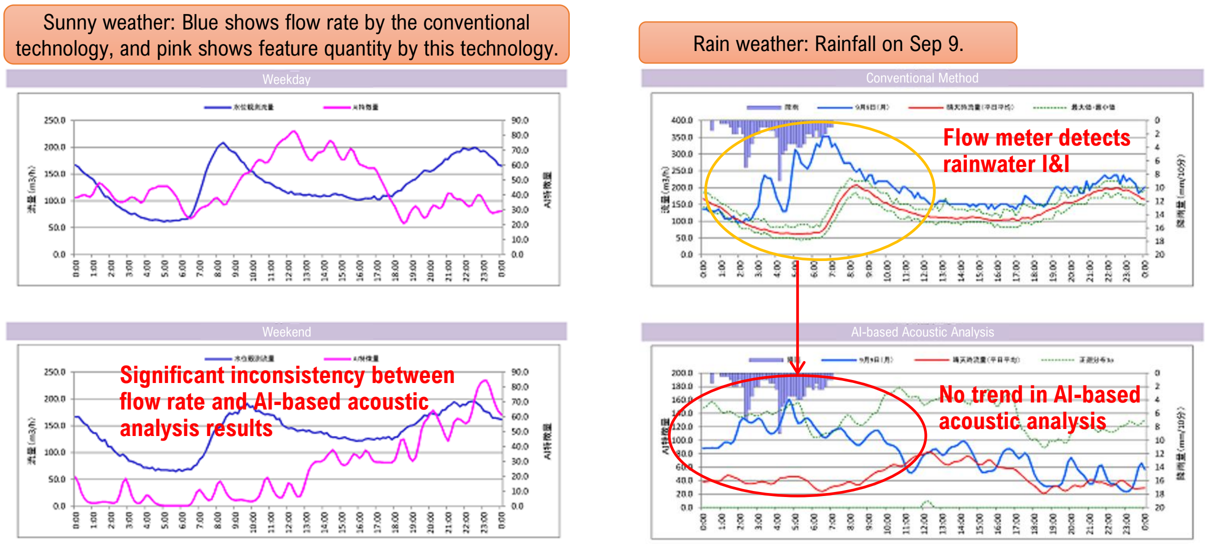



**Figure 2-1 Example of investigation in a case where the water surface is far from external microphone (Jonan Treatment Area, Tsukuba City)**

**[Case where the water surface is not far from the external microphone]**

Figure 2-2 shows the example of investigation in a deep manhole where the sound collector is lowered to the middle of the manhole to make the distance between the external microphone and the water surface close.

In this case, since both sunny days and rainy days occupy the same waveforms as those of the conventional technology, it was confirmed that the acoustic investigation could be applied even to deep manholes without any problem if the distance between the water surface and the external microphone is close enough.

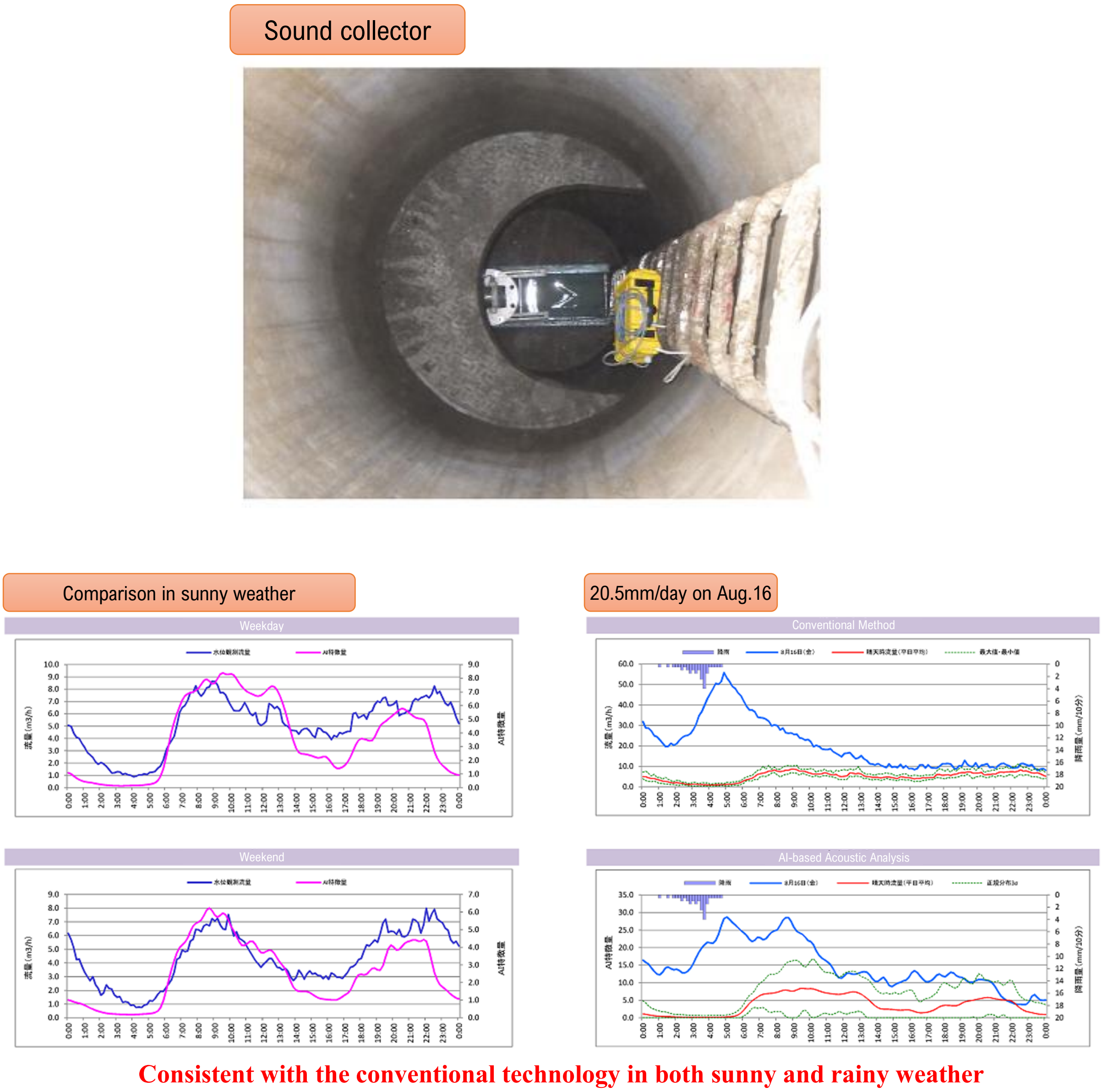



**Figure 2-2 Example of investigation when the water surface is not far from the external microphone (Iwaoka Basin, Kobe City)**

**« Locations where the sound of water flow is weak due to low flow rate »**

Since the sound collector used as the instrument of this technology is cheaper and easier to install than flow meters of the conventional technology, one of the features of this technology is to narrow down detailed investigation locations by installing many of them in a small sector.

For this reason, since it is important to be able to reliably detect rainwater I&I in a small basin, we verified this technology at a very small area in the upstream area of the basin. (Figure 2 -3).

As a result, even in the basin having about 5 spans, the presence or absence of rainwater I&I could be reliably detected, so it was confirmed that this technology can be applied to detect rainwater I&I even in a small-scale basin.

It should be noted that although it is possible to detect rainwater I&I even by the installation of the sound collector at the most upstream location close to the starting point of wastewater flow, it is advisable to limit the rainwater I&I area by securing a certain level of the watershed in consideration of the cost required for installation.

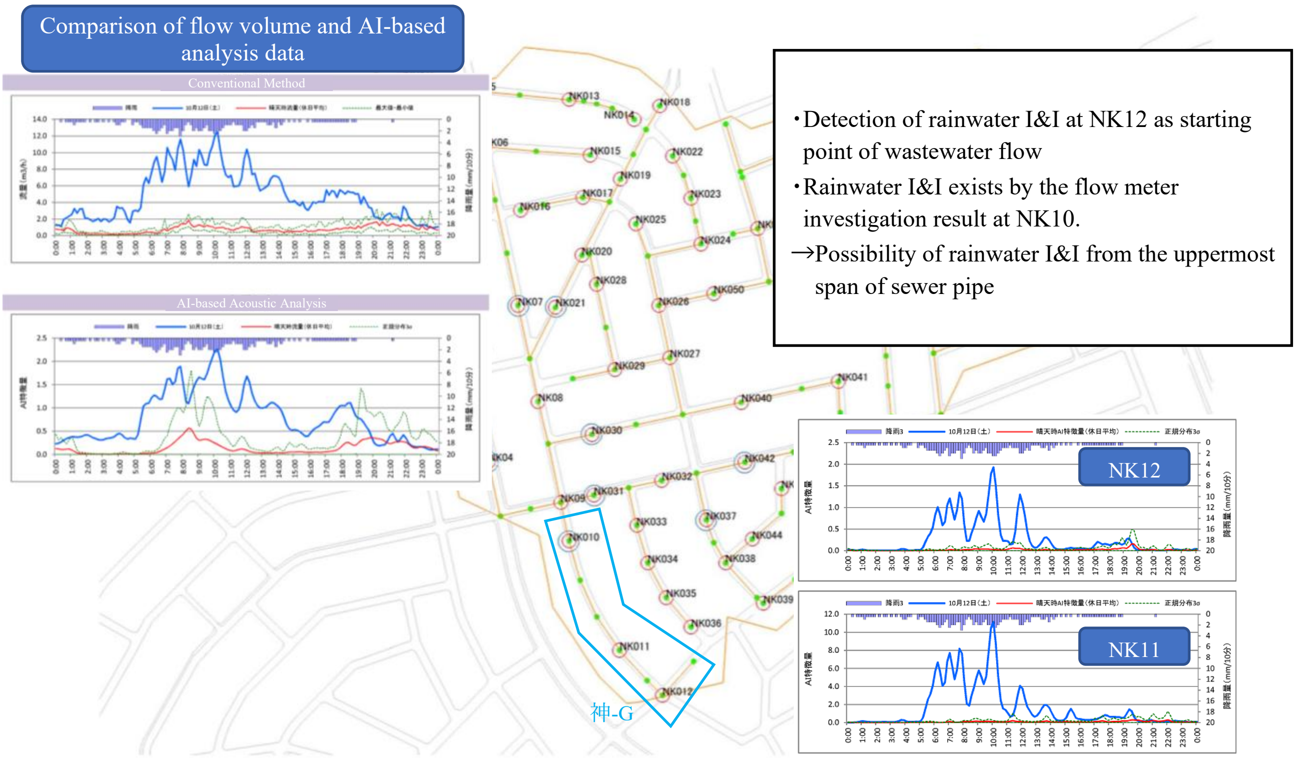



**Figure 2-3 Example of a small-scale basin investigation (Kaminokura district, Nagoya City)**

**« Effect of pump start/stop »**

An investigation by conventional technology reveals that the investigation result is affected by the water level change caused by the start and stop of the pump in the upstream part of the sewage relay pump stations and the manhole pumps. Therefore, verified whether or not it is possible to measure the proper feature quantities at these locations by the AI-based acoustic analysis and Figure 2 -4 shows the result of the verification.

As a result, it was confirmed that this technology could not be applied to the investigation locations affected by the start and stop of the pumps, because the start and stop of the pumps made it difficult to specify the feature quantity on a sunny day and generate the variation of that even on rainy days. In addition, a similar tendency is observed downstream of the pump discharge, and the locations shall not be selected for the investigation.

In this case, it was also confirmed that there were some locations easily affected by the start and stop of the pumps without any level difference in the culvert even at about 150 m. Therefore, it is advisable to confirm whether there will be any effect from the pumping station (including manhole pumps) in the sewerage ledger, etc., and then decide on the investigation site.

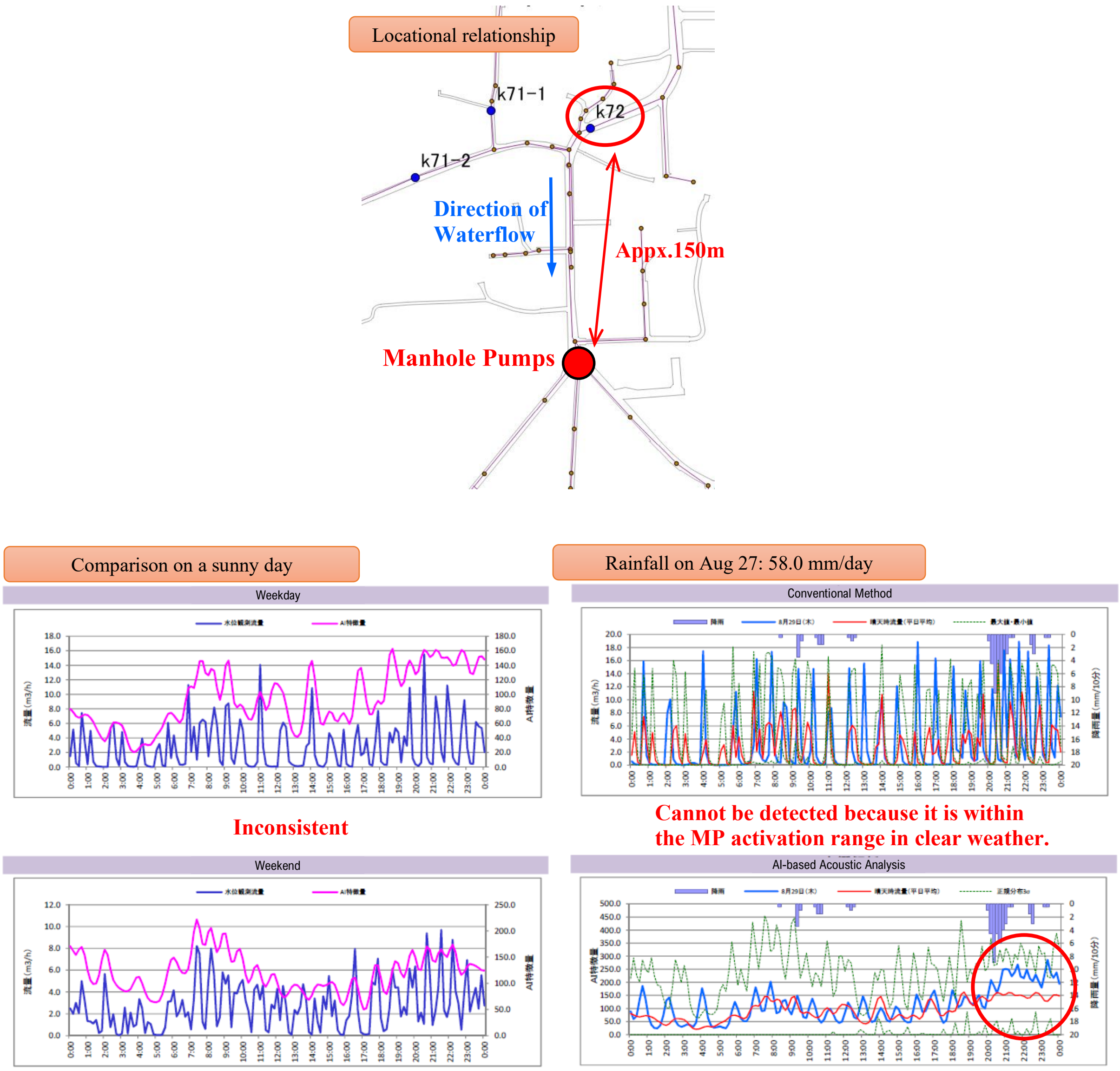



**Figure 2-4 Example of investigation at a site affected by pump start/stop (Tomiai Basin, Kumamoto City)**

**« Effect of irregular wastewater discharge (by wastewater from factories, etc.)»**

This case is similar to the case of the upstream and downstream of the pump stations described in the previous paragraph, the investigation of the conventional technology reveals that the investigation results are affected by the irregular water level change when the wastewater is discharged irregularly from a large number of factories. Therefore, verified whether or not it is possible to measure at these locations by using AI-based acoustic analysis and Figure 2 -5 shows the result of the verification.

As a result, it was confirmed that this technology could not be applied to the investigation locations because it was difficult to specify the feature quantity on a clear day due to the influence of irregular drainage, and it was difficult to detect rainwater I&I due to the expansion of normal range during the sunny days. In addition, acoustic investigation was conducted in smaller sectors, but the same results were obtained. Therefore, it is difficult to investigate in the basins where irregular wastewater discharges such as factories and building pits' wastewater discharge occur.

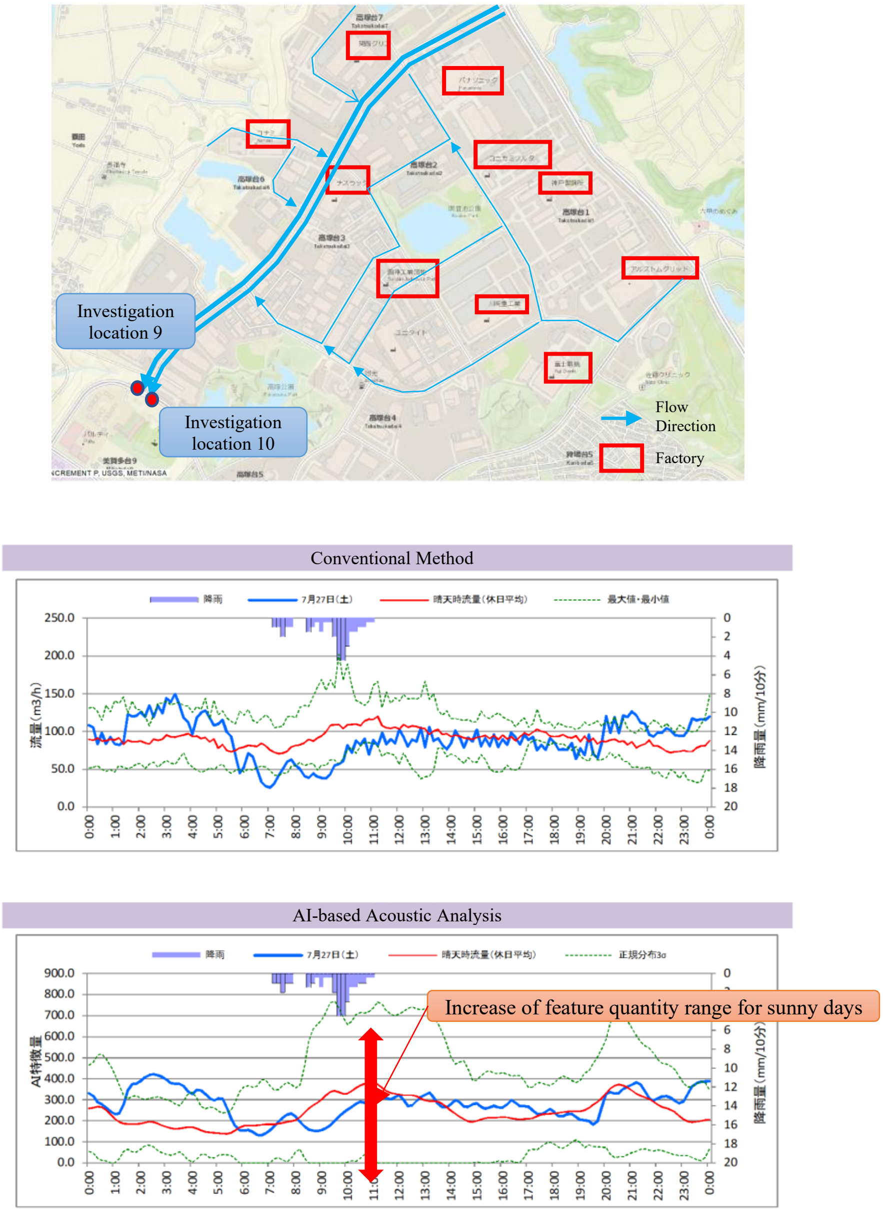



**Figure 2-5 Investigation at a site affected by irregular drainage (Nishigami basin, Kobe City)**

**« Investigation at the bend »**

In the case of investigation by conventional technology, it is advisable to avoid the investigation at the bend as much as possible because it is difficult to install equipment at the corner, and the water level changes drastically due to the wave of water flow. Therefore, we confirmed whether it is possible to apply this technology to the corners where there is a possibility of the acoustic fluctuation increase due to the wave of water flow. (Fig. 2 -6).

As a result, it is advisable to exclude the bend from the investigation locations because it is difficult to apply this technology when small rain due to the large fluctuation of the feature quantity on sunny days at the bend although it has been confirmed that it is possible to detect the rainwater I&I when heavy rain.

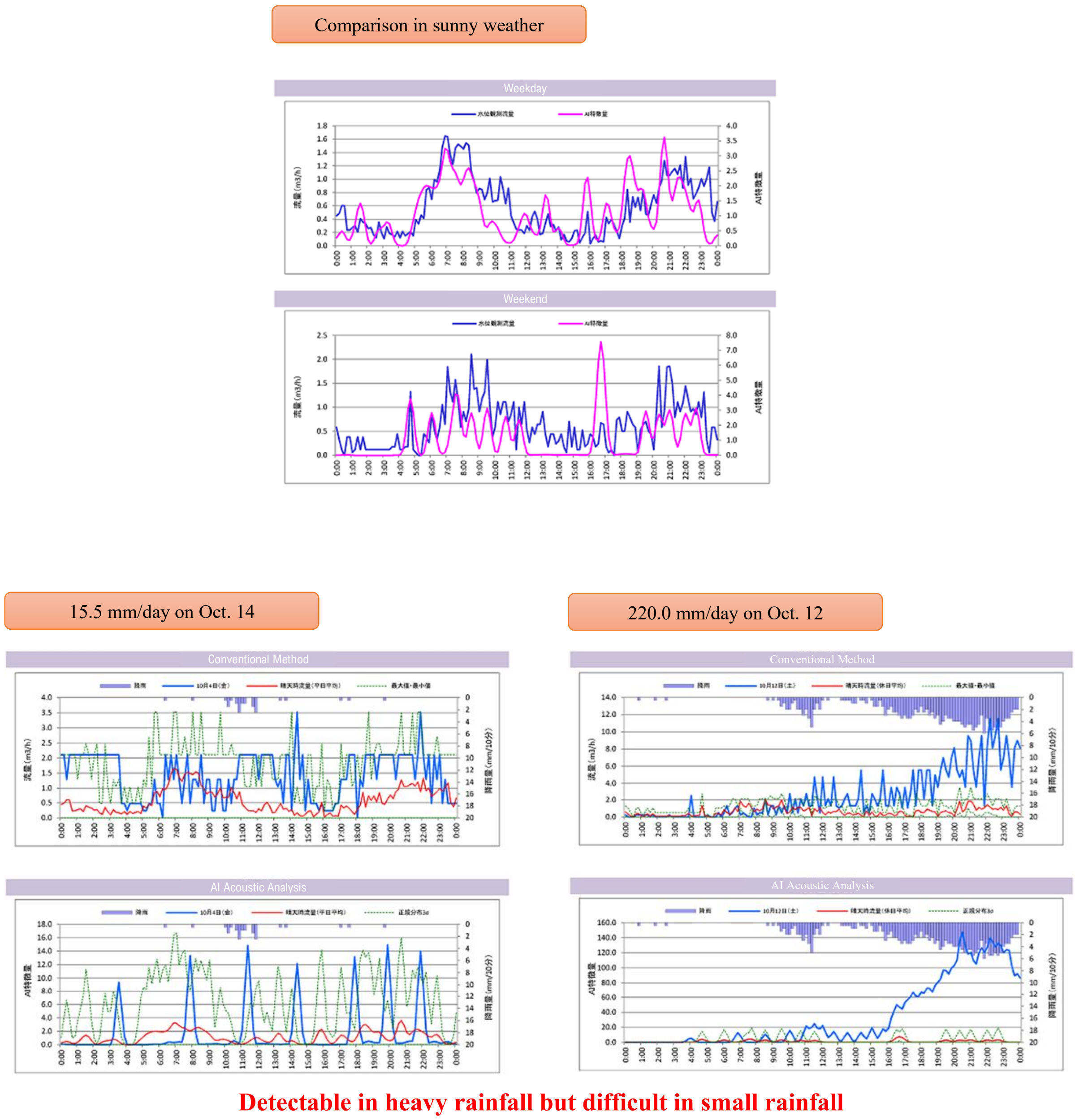



**Figure 2-6 Example of investigation at bend (Fukuyama Town, Koriyama City)**

**<u>« Locations where there is direct inflow in manholes »</u>**

The following points are estimated as locations where direct inflow into the manhole occurs. Further, even at these locations, there are several cases such as with or without a drop of inflow, and with or without a drop pipe in case with a drop of inflow. Therefore, we verified whether this technology can be applied to those cases.

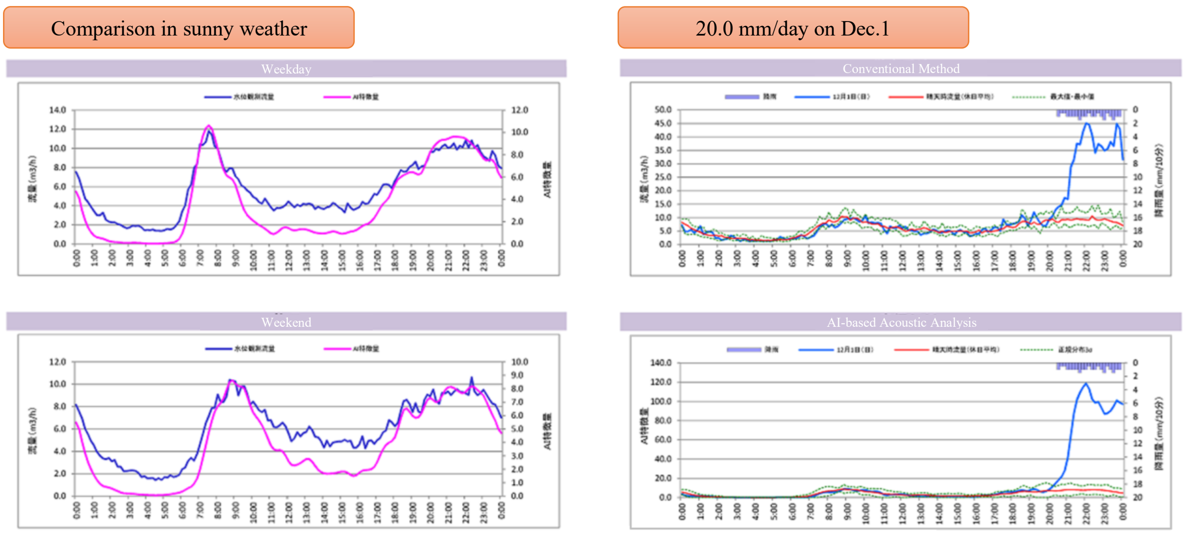
- Inflow from branch sewer
- Inflow from lateral pipe

**[Case with a connected sewer pipe (lateral pipe) has almost no drop of inflow]**

Figure 2-7 shows an example of an investigation when connected sewer pipes and lateral pipes from users have almost no drop of inflow.

The results of the AI analysis showed the same response as that of the conventional technology in the case where there is little difference in level between the pipes and the bottom of manholes.

Site Condition


Consistent with conventional method both in sunny and rainy weather

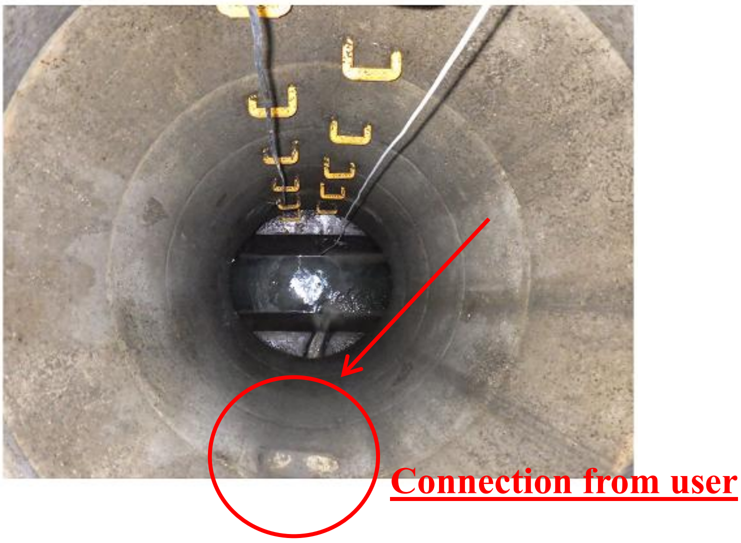
**Figure 2-7 Example of a investigation at a junction with almost no drop of inflow (Phase 2 of the Koto Basin in Kumamoto City)**

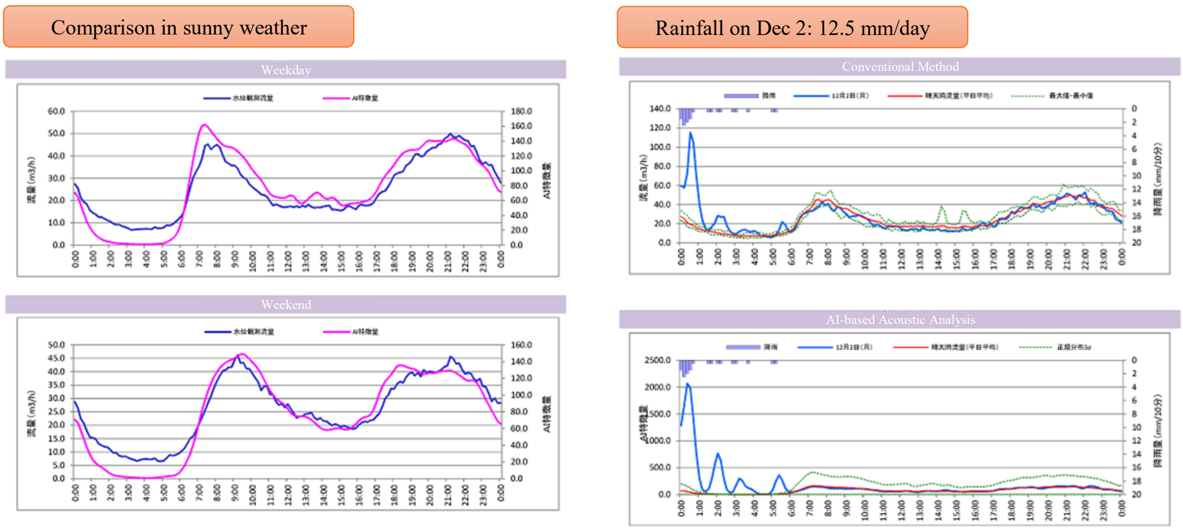
**[Case where there is a drop of inflow and drop pipe is installed]**

Figure 2-8 shows an example of investigation when there is direct inflow into a manhole and a drop pipe is installed.

As a result, it has been confirmed that the AI-based acoustic analysis can be applied without any problems in the case where the drop pipe is installed even if the direct inflow to the manhole drops to the bottom.

Site Condition




**Consistent with the conventional method in both sunny and rainy weather**

**Figure 2-8 Example of investigation in the presence of drop pipes (Phase 2 of the Koto Basin in Kumamoto City)**

**[Case where there is a drop of inflow and drop pipe is not installed]**

Fig 2-9 shows an example of the investigation when there is direct inflow into a manhole, and a drop pipe is not installed.

When the branch sewer or the lateral pipe is connected to the manhole and the drop pipe is not installed, the sound collector picks up the sound of water flow by the water drop, and it causes the bad consistency of the waveform of the values between water flow measured by the conventional technology and AI feature quantity by this technology on sunny days. It also increases the spiky waveform on sunny days. As a result, even on rainy days, the spiky waveform, and the waveform due to the effect of rainwater I&I are confused, and it has been judged that the AI-based acoustic analysis is difficult to apply to this case.

For this reason, it is advisable to avoid such investigation locations and to select suitable locations upstream or downstream of the manholes for this case.

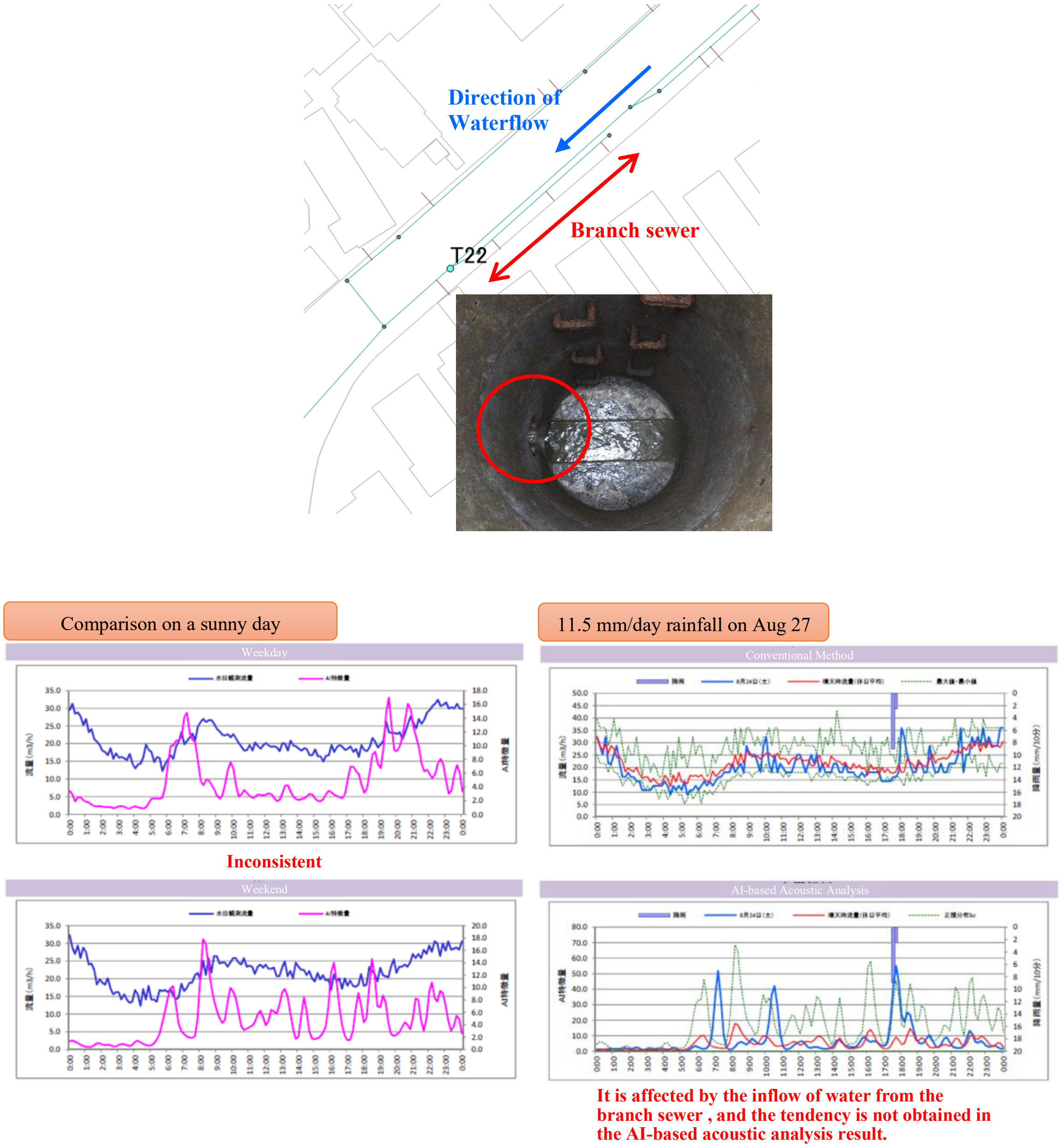



**Figure 2-9 Example of investigation when no drop pipe is installed (Jonan Treatment Area, Tsukuba City)**

**« Equipment (microphone) at high risk of submergence in water »**

Since the sound collector and the external microphone are waterproof, their functions are not lost even if they are submerged.

On the other hand, it has been confirmed that the following phenomena occurred due to the water level fluctuation in the manholes at the investigation locations (See Figure 2-10,).

- As the sound of water flow can be confirmed until the water level reaches the top of the pipe, the feature quantity increases.
- When the water level is higher than the top of the pipe, the sound of water flow decreases, and the feature quantity also decreases.
- Even if the external microphone is submerged, the tendency does not change, and the feature quantity decreases as the water level in the manhole rises.

In addition, although the function of the external microphone is not affected even if it is submerged, it has been confirmed that if dirt adheres to the surface of the microphone, there is a big difference between the recorded sound sources before and after dirt adheres. (See Fig. 2-11,).

Therefore, when there is a high possibility that the external microphone is submerged due to heavy rain, it is advisable to conduct emergency inspections and replace the sound collector as necessary.

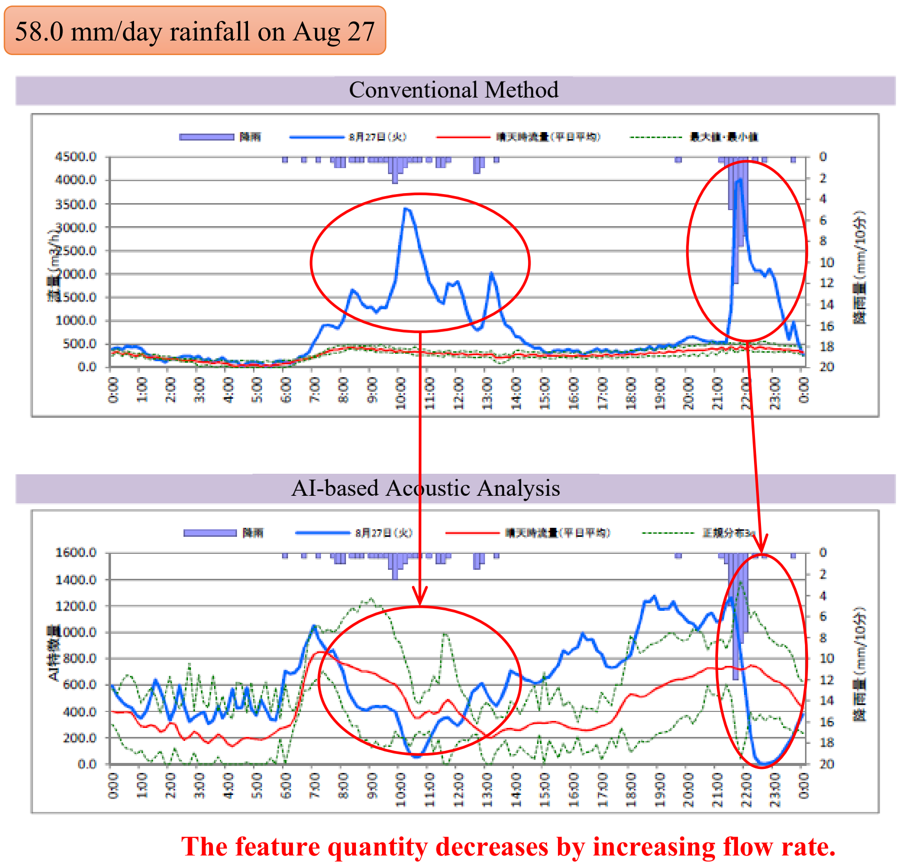



**Figure 2-10 Example of investigation where an external microphone was submerged (Jonan Treatment Area, Tsukuba City)**

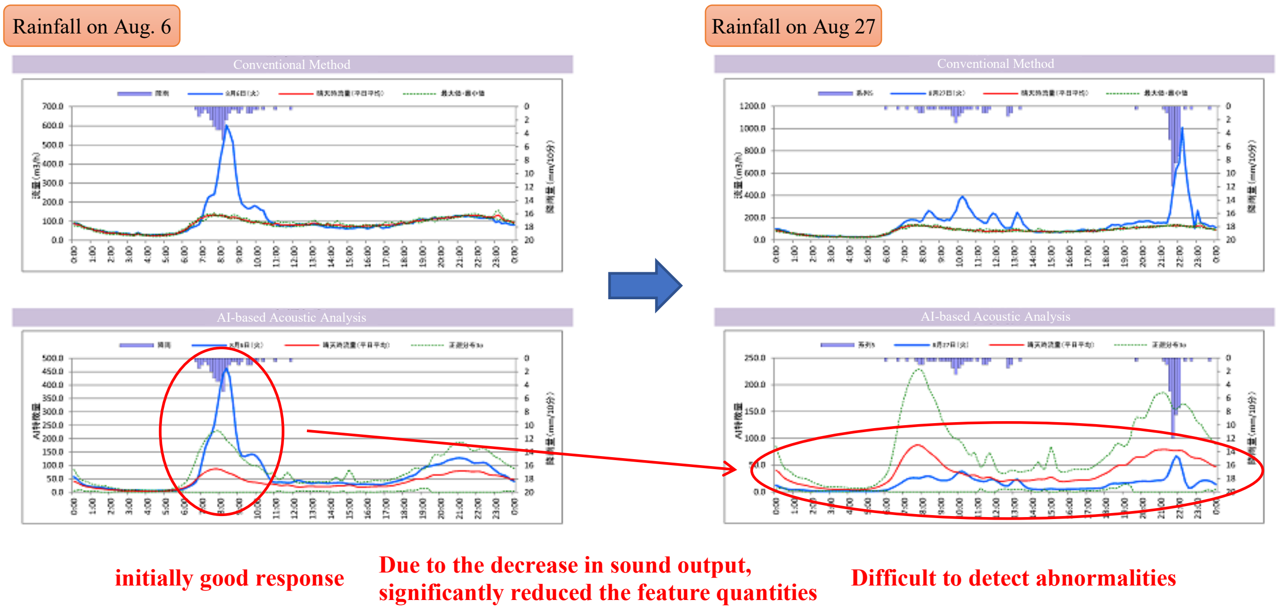



**Figure 2-11 Example of investigation where the feature quantity decreased after submergence of an external microphone (Koto basin, Kumamoto City)**

**Figure 2-12 Situation of submerged external microphone (Jonan Treatment District, Tsukuba City)**

Summarizing the above results, Table 2-2 shows the evaluation results of the scope of the application.

- Since this technology observes the sound of water flow in the manhole, it has been confirmed that "noise," "great depth," and "small flow rate," which were verified for the characteristics, could be applied without any problem at the place where this was carried out.

- Regarding the cases of "Effect of pump start/stop" and "Effect of irregular wastewater discharge," it was very difficult to construct a pattern of feature quantity on sunny days because the water level in the sewer pipes fluctuated due to the effect of pump start/stop and irregular wastewater discharge. Therefore, those cases are excluded from the scope of application because they affect the detection of abnormality in rainy weather.

- In the case of "investigation at a bend," the range of feature quantities at the time of pattern construction in sunny weather tended to be large because the acoustic vibration tends to become large due to water flow disturbance. Therefore, although the investigation itself is possible, it is advisable to reconsider the investigation location, for example, by investigating the upstream or downstream of the manholes, because the judgment of abnormality detection in rainy weather becomes difficult.

- As for the case where “there is direct inflow into the manhole”, it has been confirmed that it is difficult to construct the pattern of feature quantities on sunny days because the pattern is strongly affected by the sound at the inflow pipe. Therefore, the case is excluded from the scope of application because it affects the detection of abnormality in rainy weather.

- Regarding the case where “the risk of equipment (microphone) submergence is high," it has been confirmed that the submergence of the external microphone affects the observation data. On the other hand, when the distance between the microphone and the water surface is large (more than 3 m), it is difficult to analyze the sound of water flow. Therefore, the following points should be taken into consideration when conducting investigations.

  - When observation, confirm a trace of water adhering to the manhole, and a microphone is installed at the point higher than the trace of water.
  - If the water trace is far from the water surface in the manhole of the investigation location, adjust the microphone installation position up to 2.5 m from the water surface. Avoid the investigations at the manholes where the water trace is located more than 2.5 m above the water surface as much as possible or conduct inspections at the emergency inspection location in case of heavy rain.
  - For the investigation locations with high a risk of submergence of the microphone, confirm the submergence of the microphone at the site after heavy rain. If the microphone is submerged, confirm if the sensitivity of the microphone is decreased at the site, and if the sensitivity is decreased, replace the sound collector, and continue the investigation.

Table 2-2 Summary of evaluation results of the scope of application

| Items | Applicability | Applicable district | Validation results |
|---|---|---|---|
| Locations affected by noise on the ground | ✓ | | Applicable for both acoustic investigation and AI analysis without any influences. |
| Locations affected by reverberation sound in the deep manhole | ✓ | | Applicable for both acoustic investigation and AI analysis without any influences. |
| Locations where the sound of water flow is weak due to low flow rates | ✓ | | Applicable for both acoustic investigation and AI analysis without any influences. |
| Effects of pump start/stop | | Tsukuba City<br>Kumamoto City | When the water level and the acoustics of the upstream and downstream fluctuate depending on the operation condition of the pump, regardless of sunny or rainy weather, due to the effect of the start/stop of the pump station and the manhole pump, it is difficult to construct the pattern of feature quantities in sunny weather becomes very difficult, and as a result, the abnormal determination and the detection in rainy weather becomes difficult. |
| Effect of irregular wastewater discharge<br>(by wastewater from factories, etc.) | | Kobe City<br>(Nishijin Basin) | If many factories are in the investigation area and wastewater is discharged irregularly according to operating conditions on weekdays and holidays, it is very difficult to construct the pattern of future quantities in sunny weather, and as a result, abnormality determination and detection in rainy weather becomes difficult. |
| Investigation at bend | Conditional | | At the corner of water flow, the acoustic fluctuation tends to be increased due to the wave of water flow, and the normal range of feature quantities is widened in the pattern construction in sunny weather, which makes abnormality determination and detection difficult when small rain. |
| Locations where there is direct inflow into the manholes | | Tsukuba City<br>Kumamoto City | When a branch sewer or a lateral pipe is connected to a manhole without a drop pipe, it becomes difficult to construct a pattern of feature quantities in sunny weather due to these noises. |
| Equipment (microphone) at high risk of submergence | Conditional | | Where the microphone is submerged due to abnormal inflow during heavy rain, it may be difficult to judge the inferior performance or abnormality detection due to dirt on the microphone. |

# 3. Evaluation results of demonstration study

3.1 Detection accuracy

3.1.1 Evaluated rainfall for detection accuracy

The following items were evaluated through continuous monitoring for about 1 month in the demonstration fields (10 areas in 5 cities) where the generation of rainwater I&I is expected, by installing sound collectors and flowmeters for comparison and verification purposes.

Table 3-1 shows the number of sites in each area. Acoustic investigations were also conducted at the sites where the flow rate investigation was conducted, and the detection accuracy was evaluated for the top 5 rainfall events during the investigation periods at 203 sites in 5 cities.

The definition of rainfall and the conditions for selecting the evaluated rainfall are as follows.

- 1 rainfall was defined as observed from 0:00 to 24:00 on the same day.
- For the selection of the evaluated rainfall, rank each of total rainfall volume per 1 rainfall, 10-minute maximum rainfall volume, and hourly maximum rainfall volume, and 5 rainfalls were selected from the lowest total ranking.

**Table 3-1. List of investigation sites and periods**

| Surveyed municipality | Watershed name | Narrowing type | Investigation period | | | Notes |
|---|---|---|---|---|---|---|
| | | | Start | End | Days | |
| Koriyama City | Otsuki Town | Medium to small sectors | Sep./21/2019 | Oct./24/2019 | 33 | |
| | Fukuyama Town | Medium to small sectors | Sep./21/2019 | Oct./24/2019 | 33 | |
| Tsukuba City | Jōnan | Large to medium sectors | Aug./24/2019 | Sep./27/2019 | 34 | |
| Nagoya City | Hyogo District | Medium to small sectors | Sep./14/2019 | Oct./25/2019 | 41 | |
| | Kaminokura District | Medium to small sectors | Sep./14/2019 | Oct./25/2019 | 41 | |
| Kobe City | Upper Kakogawa River | Large to medium sectors | Jul./24/2019 | Sep./9/2019 | 47 | |
| | Iwaoka Pump Basin | Large to medium sectors | Jul./27/2019 | Sep./9/2019 | 44 | First phase |
| | Iwaoka Pump Basin | Medium to small sectors | Nov./9/2019 | Dec./12/2019 | 33 | Second phase |
| | Nishijin Basin | Large to medium sectors | Jul./27/2019 | Aug./28/2019 | 32 | First phase |
| | Nishijin Basin | Medium to small sectors | Nov./8/2019 | Dec./10/2019 | 32 | Second phase |
| Kumamoto City | Koto Basin | Large to medium sectors | Aug./1/2019 | Sep/20/2019 | 50 | First phase |
| | Koto Basin | Medium to small sectors | Nov./16/2019 | Dec./20/2019 | 34 | Second phase |
| | Tomiai Basin | Large to medium sectors | Aug./3/2019 | Sep./20/2019 | 48 | |

## Table 3-2. Evaluated rainfall (Koriyama City)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 9/23 | 9/29 | 10/4 | 10/6 | 10/7 | 10/8 | 10/11 | 10/12 | 10/13 | 10/14 | 10/18 | 10/19 | 10/22 |
| Rainfall (mm) | Daily volume | 4 | 1 | 15.5 | 1.5 | 2 | 6.5 | 6 | 220 | 15 | 16.5 | 1.5 | 25 | 34.5 |
| | 10 min max | 0.5 | 0.5 | 2.5 | 0.5 | 0.5 | 0.5 | 1 | 6 | 5 | 1 | 0.5 | 1.5 | 1.5 |
| | Hourly max | 1 | 0.5 | 6 | 1 | 1 | 1.5 | 3 | 30 | 14.5 | 3.5 | 0.5 | 5 | 5 |
| Total rainfall time | | 1.33 | 0.33 | 2.67 | 0.50 | 0.67 | 2.17 | 1.67 | 14.33 | 1.17 | 4.67 | 0.50 | 6.67 | 8.50 |
| Ranking | Daily volume | 9 | 13 | 5 | 11 | 10 | 7 | 8 | 1 | 6 | 4 | 11 | 3 | 2 |
| | 10 min max | 8 | 8 | 3 | 8 | 8 | 8 | 6 | 1 | 2 | 6 | 8 | 4 | 4 |
| | Hourly max | 9 | 12 | 3 | 9 | 9 | 8 | 7 | 1 | 2 | 6 | 12 | 4 | 4 |
| | Rainfall time | 8 | 13 | 5 | 11 | 10 | 6 | 7 | 1 | 9 | 4 | 11 | 3 | 2 |
| | Points | 34 | 46 | 16 | 39 | 37 | 29 | 28 | 4 | 19 | 20 | 42 | 14 | 12 |
| | Overall ranking | 9 | 13 | 4 | 11 | 10 | 8 | 7 | 1 | 5 | 6 | 12 | 3 | 2 |
| Evaluated rainfall | | | | ✓ | | | | | ✓ | ✓ | | | ✓ | ✓ |
| Evaluated rainfall | No. | | | 1 | | | | | 2 | 3 | | | 4 | 5 |
| | Rainy day | | | 10/4 | | | | | 10/12 | 10/13 | | | 10/19 | 10/22 |

## Table 3-3. Evaluated rainfall (Tsukuba City)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 8/21 | 8/22 | 8/23 | 8/24 | 8/25 | 8/26 | 8/28 | 8/30 | 9/9 | 9/10 | 9/11 | 9/16 | 9/18 | 9/22 | 9/23 | 9/25 |
| Rainfall (mm) | Daily volume | 4 | 6 | 2 | 11.5 | 3.5 | 3.5 | 4 | 7 | 97 | 4.5 | 15 | 24 | 6.5 | 4 | 4 | 1 |
| | 10 min max | 2.5 | 4 | 0.5 | 9 | 0.5 | 1 | 0.5 | 1.5 | 9 | 1.5 | 7.5 | 1.5 | 1 | 1 | 1 | 0.5 |
| | Hourly max | 2.5 | 5.5 | 0.5 | 11.5 | 1.5 | 2.5 | 1 | 5 | 28 | 4 | 13.5 | 5.5 | 1.5 | 3 | 2.5 | 0.5 |
| Total rainfall time | | 0.67 | 0.50 | 0.67 | 0.33 | 1.17 | 1.00 | 1.33 | 1.50 | 6.33 | 0.83 | 1.33 | 6.00 | 2.00 | 1.00 | 1.17 | 0.33 |
| Ranking | Daily volume | 9 | 7 | 15 | 4 | 13 | 13 | 9 | 5 | 1 | 8 | 3 | 2 | 6 | 9 | 9 | 16 |
| | 10 min max | 5 | 4 | 13 | 1 | 13 | 9 | 13 | 6 | 1 | 6 | 3 | 6 | 9 | 9 | 9 | 13 |
| | Hourly max | 9 | 4 | 15 | 3 | 12 | 9 | 14 | 6 | 1 | 7 | 2 | 4 | 12 | 8 | 9 | 15 |
| | Rainfall time | 12 | 14 | 12 | 15 | 7 | 9 | 5 | 4 | 1 | 11 | 5 | 2 | 3 | 9 | 7 | 15 |
| | Points | 35 | 29 | 55 | 23 | 45 | 40 | 41 | 21 | 4 | 32 | 13 | 14 | 30 | 35 | 34 | 59 |
| | Overall ranking | 10 | 6 | 15 | 5 | 14 | 12 | 13 | 4 | 1 | 8 | 2 | 3 | 7 | 10 | 9 | 16 |
| Evaluated rainfall | | | | | ✓ | | | | ✓ | ✓ | | ✓ | ✓ | | | | |
| Evaluated rainfall | No. | | | | 1 | | | | 2 | 3 | | 4 | 5 | | | | |
| | Rainy day | | | | 8/24 | | | | 8/30 | 9/9 | | 9/11 | 9/16 | | | | |

## Table 3-4 Evaluated rainfall (Nagoya City)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 9/17 | 9/18 | 9/20 | 9/21 | 9/22 | 9/23 | 10/3 | 10/4 | 10/7 | 10/11 | 10/12 | 10/14 | 10/18 | 10/19 |
| Rainfall (mm) | Daily volume | 0.5 | 0.5 | 1 | 0.5 | 1 | 2 | 7 | 18.5 | 1 | 4.5 | 101.5 | 2 | 48.5 | 16 |
| | 10 min max | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 4 | 3 | 0.5 | 0.5 | 3 | 0.5 | 3 | 3 |
| | Hourly max | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 7 | 9.5 | 0.5 | 2 | 12.5 | 0.5 | 13 | 11.5 |
| Total rainfall time | | 0.17 | 0.17 | 0.33 | 0.17 | 0.33 | 0.50 | 0.50 | 2.33 | 0.33 | 1.50 | 16.33 | 0.67 | 8.67 | 2.17 |
| Ranking | Daily volume | 12 | 12 | 9 | 12 | 9 | 7 | 5 | 3 | 9 | 6 | 1 | 7 | 2 | 4 |
| | 10 min max | 7 | 7 | 7 | 7 | 7 | 6 | 1 | 2 | 7 | 7 | 2 | 7 | 2 | 2 |
| | Hourly max | 8 | 8 | 8 | 8 | 8 | 7 | 5 | 4 | 8 | 6 | 2 | 8 | 1 | 3 |
| | Rainfall time | 12 | 12 | 9 | 12 | 9 | 7 | 7 | 3 | 9 | 5 | 1 | 6 | 2 | 4 |
| | Points | 39 | 39 | 33 | 39 | 33 | 27 | 18 | 12 | 33 | 24 | 6 | 28 | 7 | 13 |
| | Overall ranking | 12 | 12 | 9 | 12 | 9 | 7 | 5 | 3 | 9 | 6 | 1 | 8 | 2 | 4 |
| Evaluated rainfall | | | | | | | | ✓ | ✓ | | | ✓ | | ✓ | ✓ |
| Evaluated rainfall | No. | | | | | | | 1 | 2 | | | 3 | | 4 | 5 |
| | Rainy day | | | | | | | 10/3 | 10/4 | | | 10/12 | | 10/18 | 10/19 |

**Table 3-5 Evaluated rainfall (Upper Kakogawa River Basin, Kobe City)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall No. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Rainy day | | 7/27 | 8/14 | 8/15 | 8/16 | 8/19 | 8/21 | 8/22 | 8/23 | 8/24 | 8/25 | 8/27 | 8/28 | 8/29 | 8/30 | 8/31 |
| Rainfall (mm) | Daily volume | 20.5 | 3 | 110 | 42 | 4 | 0.5 | 2 | 21.5 | 0.5 | 11 | 11.5 | 23 | 7 | 8 | 0 |
| | 10 min max | 4 | 1.5 | 9 | 4.5 | 1.5 | 0.5 | 1 | 13 | 0.5 | 3.5 | 1.5 | 3 | 4.5 | 2 | 0 |
| | Hourly max | 10.5 | 2 | 43.5 | 18.5 | 2 | 0.5 | 2 | 16 | 0.5 | 7 | 4.5 | 6.5 | 7 | 4 | 0 |
| Total rainfall time | | 2.83 | 0.67 | 8.33 | 4.33 | 1.00 | 0.17 | 0.50 | 2.50 | 0.17 | 0.83 | 2.83 | 4.33 | 0.33 | 1.33 | 0.00 |
| Ranking | Daily volume | 5 | 11 | 1 | 2 | 10 | 13 | 12 | 4 | 13 | 7 | 6 | 3 | 9 | 8 | 15 |
| | 10 min max | 5 | 9 | 2 | 3 | 9 | 13 | 12 | 1 | 13 | 6 | 9 | 7 | 3 | 8 | 15 |
| | Hourly max | 4 | 10 | 1 | 2 | 10 | 13 | 10 | 3 | 13 | 5 | 8 | 7 | 5 | 9 | 15 |
| | Rainfall time | 4 | 10 | 1 | 2 | 8 | 13 | 11 | 6 | 13 | 9 | 4 | 2 | 12 | 7 | 15 |
| | Points | 18 | 40 | 5 | 9 | 37 | 52 | 45 | 14 | 52 | 27 | 27 | 19 | 29 | 32 | 60 |
| | Overall ranking | 4 | 11 | 1 | 2 | 10 | 13 | 12 | 3 | 13 | 6 | 6 | 5 | 8 | 9 | 15 |
| Evaluated rainfall | | ✓t | | ✓ | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | | | |
| Evaluated rainfall | No. | **1** | | **2** | **3** | | | | **4** | | **5** | **6** | **7** | | | |
| | Rainy day | 7/27 | | 8/15 | 8/16 | | | | 8/23 | | 8/25 | 8/27 | 8/28 | | | |

**8/27 and 8/28 rainfall are excluded from the evaluation because the number of evaluation sites will be small.**

**Table 3-6. Evaluated rainfall (Iwaoka pumping station and Nishijin Basin, Kobe - phase 1)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall No. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Rainy day | | 7/27 | 8/14 | 8/15 | 8/16 | 8/19 | 8/20 | 8/23 | 8/24 | 8/27 | 8/28 | 8/29 | 8/30 | 8/31 |
| Rainfall (mm) | Daily volume | 31.5 | 0.5 | 52 | 20.5 | 1 | 0.5 | 12.5 | 0.5 | 7 | 6.5 | 14.5 | 7.5 | 0.5 |
| | 10 min max | 4.5 | 0.5 | 4 | 4 | 0.5 | 0.5 | 4.5 | 0.5 | 1.5 | 0.5 | 9.5 | 3.5 | 0.5 |
| | Hourly max | 13.5 | 0.5 | 8.5 | 11.5 | 0.5 | 0.5 | 8 | 0.5 | 3.5 | 1.5 | 14 | 6.5 | 0.5 |
| Total Rainfall Time | | 3.50 | 0.17 | 8.17 | 3.33 | 0.33 | 0.17 | 1.67 | 0.17 | 1.67 | 2.17 | 0.50 | 0.83 | 0.17 |
| Ranking | Daily volume | 2 | 10 | 1 | 3 | 9 | 10 | 5 | 10 | 7 | 8 | 4 | 6 | 10 |
| | 10 min max | 2 | 8 | 4 | 4 | 8 | 8 | 2 | 8 | 7 | 8 | 1 | 6 | 8 |
| | Hourly max | 2 | 9 | 4 | 3 | 9 | 9 | 5 | 9 | 7 | 8 | 1 | 6 | 9 |
| | Rainfall time | 2 | 10 | 1 | 3 | 9 | 10 | 5 | 10 | 5 | 4 | 8 | 7 | 10 |
| | Points | 8 | 37 | 10 | 13 | 35 | 37 | 17 | 37 | 26 | 28 | 14 | 25 | 37 |
| | Overall ranking | 1 | 10 | 2 | 3 | 9 | 10 | 5 | 10 | 7 | 8 | 4 | 6 | 10 |
| Evaluated rainfall | | ✓t | | ✓ | ✓ | | | ✓ | | | | ✓ | | |
| Evaluated rainfall | No. | 1 | | 2 | 3 | | | 4 | | | | 5 | | |
| | Rainy day | 7/27 | | 8/15 | 8/16 | | | 8/23 | | | | 8/29 | | |

**Table 3-7. Evaluated rainfall (Iwaoka pumping station and Nishijin Basin in Kobe city - phase 2)**

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Rainfall No. | | 1 | 2 | 3 | 4 | 5 |
| Rainy day | | 11/14 | 11/18 | 11/19 | 11/28 | 12/2 |
| Rainfall (mm) | Daily volume | 0.5 | 4 | 0.5 | 0.5 | 16 |
| | 10 min max | 0.5 | 1.5 | 0.5 | 0.5 | 2 |
| | Hourly max | 0.5 | 2.5 | 0.5 | 0.5 | 6.5 |
| Total rainfall time | | 0.17 | 0.83 | 0.17 | 0.17 | 3.50 |
| Ranking | Daily volume | 3 | 2 | 3 | 3 | 1 |
| | 10 min max | 3 | 2 | 3 | 3 | 1 |
| | Hourly max | 3 | 2 | 3 | 3 | 1 |
| | Rainfall time | 3 | 2 | 3 | 3 | 1 |
| | Points | 12 | 8 | 12 | 12 | 4 |
| | Overall ranking | 3 | 2 | 3 | 3 | 1 |
| Evaluated rainfall | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Evaluated rainfall | No. | 1 | 2 | 3 | 4 | 5 |
| | Rainy day | 11/14 | 11/18 | 11/19 | 11/28 | 12/2 |

## Table 3-8. Evaluated rainfall (Koto Basin, Kumamoto - phase 1)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 8/6 | 8/7 | 8/14 | 8/15 | 8/19 | 8/20 | 8/23 | 8/24 | 8/25 | 8/26 | 8/27 | 8/28 | 8/29 | 8/30 | 8/31 | 9/1 | 9/3 | 9/4 | 9/5 | 9/6 | 9/8 | 9/12 | 9/13 |
| Rainfall (mm) | Daily volume | 31.5 | 4.5 | 3.5 | 56 | 12.5 | 12.5 | 48.5 | 24.5 | 10 | 18.5 | 58 | 4.5 | 93.5 | 13 | 8.5 | 11 | 22 | 16 | 17.5 | 0.5 | 17 | 7 | 2 |
| | 10 min max | 5 | 2.5 | 0.5 | 3.5 | 2.5 | 1 | 3 | 5 | 1 | 3.5 | 12 | 0.5 | 8.5 | 5 | 1.5 | 1.5 | 8 | 5.5 | 5.5 | 0.5 | 10 | 2 | 0.5 |
| | Hourly max | 12.5 | 4 | 1 | 9 | 6 | 4.5 | 8.5 | 14.5 | 2 | 5.5 | 27 | 1.5 | 34.5 | 10.5 | 2.5 | 6.5 | 8 | 8.5 | 15.5 | 0.5 | 15.5 | 2.5 | 1.5 |
| Total rainfall time | | 3.83 | 0.50 | 1.17 | 10.17 | 2.67 | 3.33 | 9.33 | 3.83 | 2.83 | 3.17 | 6.17 | 1.50 | 5.67 | 1.50 | 2.00 | 2.17 | 2.17 | 1.50 | 1.33 | 0.17 | 0.83 | 1.33 | 0.67 |
| Ranking | Daily volume | 5 | 19 | 21 | 3 | 13 | 13 | 4 | 6 | 16 | 8 | 2 | 19 | 1 | 12 | 17 | 15 | 7 | 11 | 9 | 23 | 10 | 18 | 22 |
| | 10 min max | 7 | 13 | 20 | 10 | 13 | 18 | 12 | 7 | 18 | 10 | 1 | 20 | 3 | 7 | 16 | 16 | 4 | 5 | 5 | 20 | 2 | 15 | 20 |
| | Hourly max | 6 | 16 | 22 | 8 | 13 | 15 | 9 | 5 | 19 | 14 | 2 | 20 | 1 | 7 | 17 | 12 | 11 | 9 | 3 | 23 | 3 | 17 | 20 |
| | Rainfall time | 5 | 22 | 19 | 1 | 10 | 7 | 2 | 5 | 9 | 8 | 3 | 14 | 4 | 14 | 13 | 11 | 11 | 14 | 17 | 23 | 20 | 17 | 21 |
| | Points | 23 | 70 | 82 | 22 | 49 | 53 | 27 | 23 | 62 | 40 | 8 | 73 | 9 | 40 | 63 | 54 | 33 | 39 | 34 | 89 | 35 | 67 | 83 |
| | Overall ranking | 4 | 19 | 21 | 3 | 13 | 14 | 6 | 4 | 16 | 11 | 1 | 20 | 2 | 11 | 17 | 15 | 7 | 10 | 8 | 23 | 9 | 18 | 22 |
| Evaluated rainfall | | ✓ | | | ✓ | | | | ✓ | | | ✓ | | ✓ | | | | | | | | | | |
| | No. | 1 | | | 2 | | | | 3 | | | 4 | | 5 | | | | | | | | | | |

## Table 3-9. Evaluated rainfall (Koto Basin, Kumamoto - phase 2)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 11/18 | 11/24 | 11/28 | 12/1 | 12/2 | 12/16 | 12/17 | 12/18 |
| Rainfall (mm) | Daily volume | 8 | 14.5 | 5.5 | 20 | 12.5 | 0.5 | 14 | 2.5 |
| | 10 min max | 2.5 | 1.5 | 0.5 | 1.5 | 2.5 | 0.5 | 6 | 0.5 |
| | Hourly max | 4.5 | 5 | 1.5 | 6.5 | 8 | 0.5 | 8 | 2 |
| Total rainfall time | | 1.83 | 3.33 | 1.83 | 3.50 | 2.33 | 0.17 | 2.17 | 0.83 |
| Ranking | Daily volume | 5 | 2 | 6 | 1 | 4 | 8 | 3 | 7 |
| | 10 min max | 2 | 4 | 6 | 4 | 2 | 6 | 1 | 6 |
| | Hourly max | 5 | 4 | 7 | 3 | 1 | 8 | 1 | 6 |
| | Rainfall time | 5 | 2 | 5 | 1 | 3 | 8 | 4 | 7 |
| | Points | 17 | 12 | 24 | 9 | 10 | 30 | 9 | 26 |
| | Overall ranking | 5 | 4 | 6 | 1 | 3 | 8 | 1 | 7 |
| Evaluated rainfall | | ✓ | ✓ | | ✓ | ✓ | | ✓ | |
| Evaluated rainfall | No. | **1** | **2** | | **3** | **4** | | **5** | |
| | Rainy day | 11/18 | 11/24 | | 12/1 | 12/2 | | 12/17 | |

## Table 3-10. Evaluated rainfall (Tomiai Basin, Kumamoto City)

| | Rainfall No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainy day | 8/6 | 8/7 | 8/14 | 8/15 | 8/19 | 8/20 | 8/23 | 8/24 | 8/25 | 8/26 | 8/27 | 8/28 | 8/29 | 8/30 | 8/31 | 9/1 | 9/3 | 9/4 | 9/6 | 9/8 |
| Rainfall (mm) | Daily volume | 18.5 | 11.5 | 7 | 58 | 17 | 10.5 | 38.5 | 29 | 8 | 12 | 44.5 | 2.5 | 49 | 6 | 6.5 | 18 | 24.5 | 9 | 0.5 | 5 |
| | 10 min max | 2.5 | 5.5 | 2 | 3 | 3.5 | 1.5 | 6 | 4 | 1.5 | 3 | 14 | 0.5 | 9 | 2 | 1 | 5 | 6.5 | 2 | 0.5 | 4.5 |
| | Hourly max | 7 | 11.5 | 2.5 | 9.5 | 10 | 4 | 10 | 12 | 2.5 | 7 | 20 | 0.5 | 29 | 3 | 2.5 | 10.5 | 13.5 | 6.5 | 0.5 | 5 |
| Total rainfall time | | 3.67 | 0.50 | 1.67 | 9.33 | 2.83 | 2.67 | 6.17 | 3.83 | 2.00 | 2.00 | 5.50 | 0.83 | 3.67 | 1.33 | 1.83 | 2.50 | 1.83 | 1.50 | 0.17 | 0.33 |
| Ranking | Daily volume | 7 | 11 | 15 | 1 | 9 | 12 | 4 | 5 | 14 | 10 | 3 | 19 | 2 | 17 | 16 | 8 | 6 | 13 | 20 | 18 |
| | 10 min max | 12 | 5 | 13 | 10 | 9 | 16 | 4 | 8 | 16 | 10 | 1 | 19 | 2 | 13 | 18 | 6 | 3 | 13 | 19 | 7 |
| | Hourly max | 10 | 5 | 16 | 9 | 7 | 14 | 7 | 4 | 16 | 10 | 2 | 19 | 1 | 15 | 16 | 6 | 3 | 12 | 19 | 13 |
| | Rainfall time | 5 | 18 | 14 | 1 | 7 | 8 | 2 | 4 | 10 | 10 | 3 | 17 | 5 | 16 | 12 | 9 | 12 | 15 | 20 | 19 |
| | Points | 34 | 39 | 58 | 21 | 32 | 50 | 17 | 21 | 56 | 40 | 9 | 74 | 10 | 61 | 62 | 29 | 24 | 53 | 78 | 57 |
| | Overall ranking | 9 | 10 | 16 | 4 | 8 | 12 | 3 | 4 | 14 | 11 | 1 | 19 | 2 | 17 | 18 | 7 | 6 | 13 | 20 | 15 |
| Evaluated rainfall | | | | | ✓ | | | ✓ | ✓ | | | ✓ | | ✓ | | | | | | | |
| Evaluated rainfall | No. | | | | **1** | | | **2** | **3** | | | **4** | | **5** | | | | | | | |
| | Rainy day | | | | 8/15 | | | 8/23 | 8/24 | | | 8/27 | | 8/29 | | | | | | | |

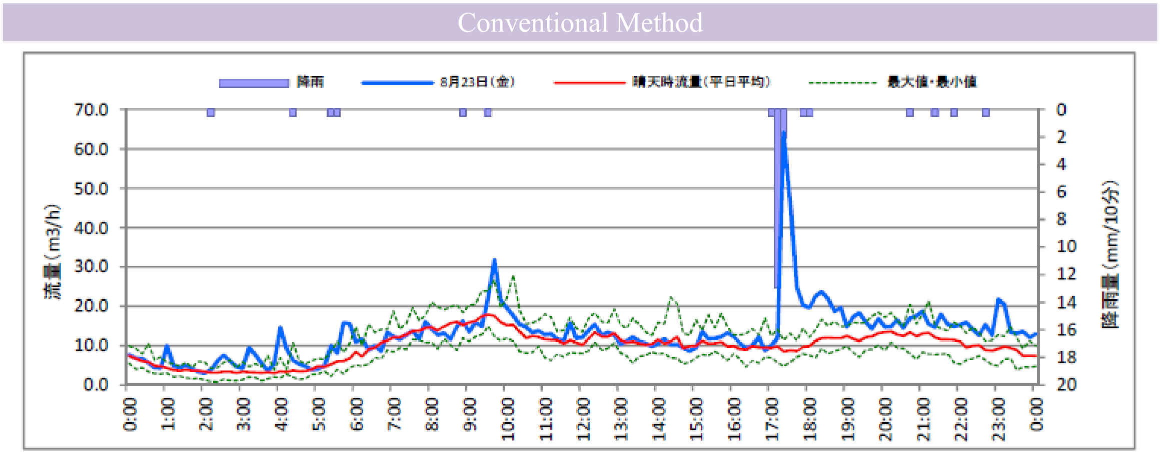
3.1.2 Detection accuracy evaluation results

As for the performance evaluation, the outline of the detection accuracy evaluation results is shown below.

[Large to Medium Sectors investigation]

Example of detection accuracy evaluation results in Kakogawa (1) Area, Kobe City

8/23/2019: (Total rainfall 21.5 mm/day, hourly maximum rainfall 16.0 mm/hr)



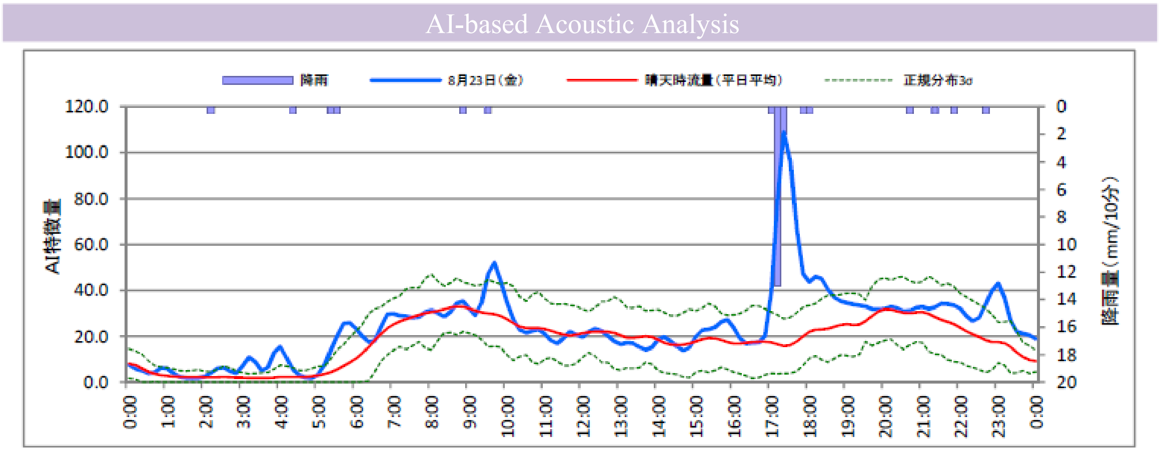



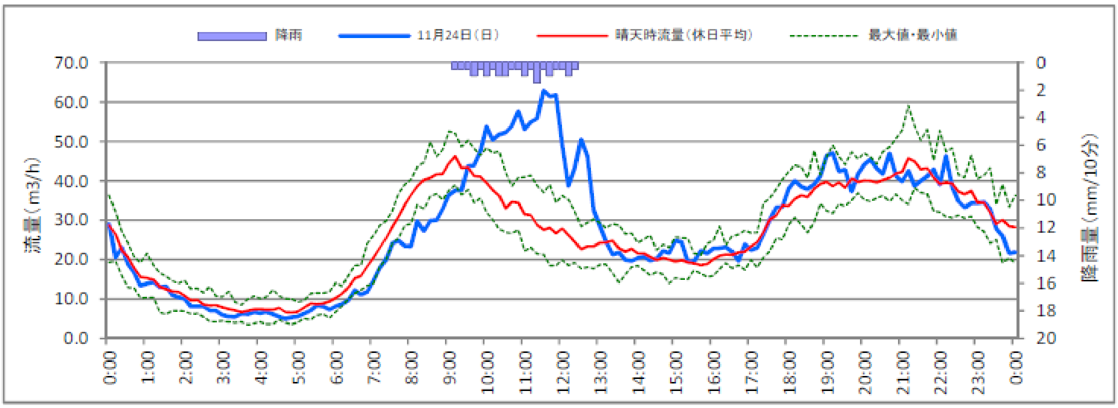

**Figure 3-1 Example of detection accuracy evaluation results (Large to Medium Sector)**

[Medium to Small Sectors]

Example of detection accuracy evaluation results in K9 -1 district, Kumamoto City

11/24/2019 (Total rainfall 14.5 mm/day, hourly maximum rainfall 5.0 mm/hr)

Conventional Method




AI-based Acoustic Analysis

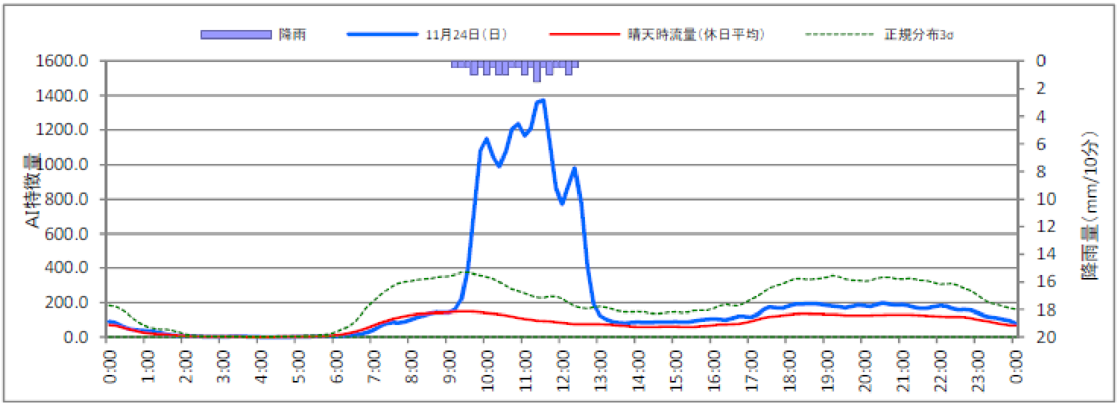


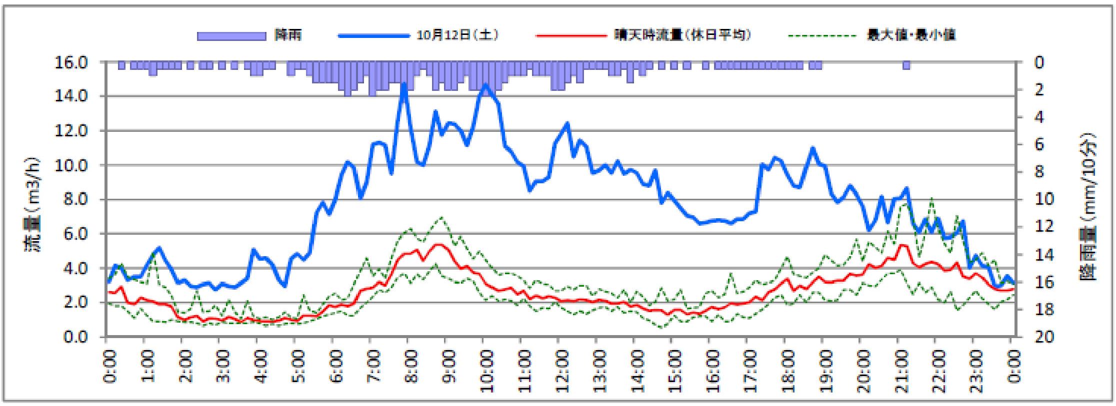

**Figure 3-2 Example of Detection Accuracy evaluation results (Medium to Small Sector)**

[Medium to Small Sectors]

Example of detection accuracy evaluation results in NK7 district, Nagoya City

10/12/2019 (Total rainfall 101.5 mm/day, hourly maximum rainfall 12.5 mm/hr)

Conventional Method




AI-based Acoustic Analysis

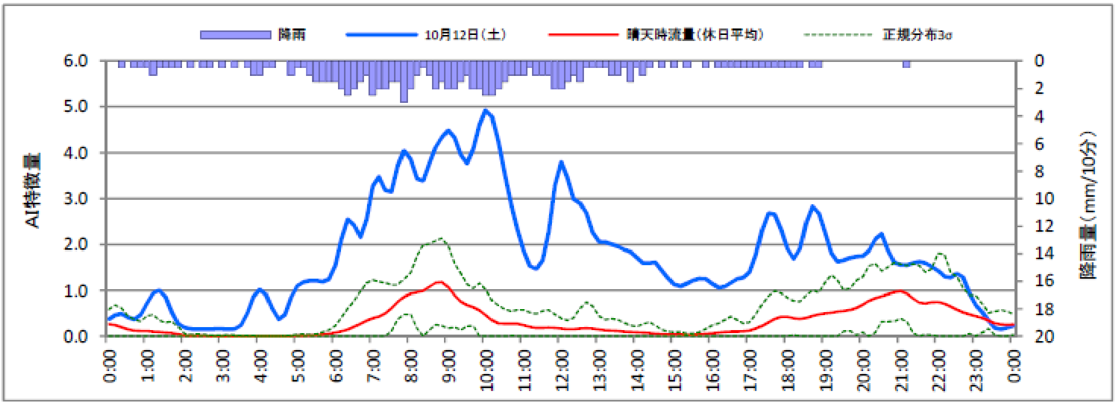



**Figure 3-3 Example of detection accuracy evaluation results (Medium to Small Sectors)**

## Table 3-11 Detection accuracy evaluation results (Otsuki-cho, Koriyama City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| 01 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| 02 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | - | - | Missing Flow Data measurement |
| 03 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| 04 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| 05 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| 06 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| 07 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| 08 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 40 | 5 | 2 | 0 | 33 | 33 | 33 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with missing data deducted.
Evaluation B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-12 Detection accuracy evaluation results (Fukuyama-cho, Koriyama City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| F1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F3 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F4 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| F6 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F7 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F8 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| F9 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| F10 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F11 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F12 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| F13 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| F14 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| F15 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| F16 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| Total | 75 | 0 | 19 | 0 | 56 | 56 | 56 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted.
Evaluation B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-13 Detection accuracy evaluation results (Jonan Treatment Area, Tsukuba City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| T02 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | Inflow pipe effect |
| T03 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | microphone position |
| T06 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | inflow pipe effect |
| T08 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| T09 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | microphone position |
| T10 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular wastewater discharge |
| T12 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | - | - | Missing acoustic data |
| T13 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| T17 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| T18 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular wastewater discharge |
| T22 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | inlet pipe effect |
| T23 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | Pump effect |
| T27 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| T30 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| T31 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| T35 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| T37 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| T38 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| T39 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| T44 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | Pump effect |
| T45 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| T46 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| T47 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | Pump effect |
| T48 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | Pump effect |
| Total | 120 | 0 | 19 | 55 | 101 | 46 | 46 | 46% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted.
Evaluation B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-14 Detection accuracy evaluation results (Kaminokura area, Nagoya City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| NK04 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK07 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| NK10 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK21 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK30 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK31 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK37 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK42 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NK48 | 5 | 4 | 0 | 0 | 1 | 1 | 1 | 100% | 100% | |
| NK49 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 50 | 4 | 2 | 0 | 44 | 44 | 44 | 100% | 100% | |

*Concept of Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted.
Evaluation B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-15 Detection accuracy evaluation results (Hyogo area, Nagoya City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls: Missing data deduction ⑤ = ① - ② - ③ | Evaluated number of rainfalls: Out of scope deduction | | Evaluation A ⑦/⑤ | Evaluation B ⑦/⑥ | |
| NH02 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH06 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH10 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH14 | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| NH26 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH30 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH35 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH43 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| NH44 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 45 | 1 | 0 | 0 | 44 | 44 | 44 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted.
Evaluation B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-16 Detection accuracy evaluation results (Upper Kakogawa River Basin, Kobe City)

| Investigation locations No | Evaluated rainfall | | | | | | Successful detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls: Missing data deduction ⑤ = ① - ② - ③ | Evaluated number of rainfalls: Out of scope deduction ⑥ =⑤ - ④ | | Evaluation A ⑦/⑤ | Evaluation B ⑦/⑥ | |
| Ka (1) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (2) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (3) | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| Ka (4) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (5) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (6) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (7) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (8) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (9) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (10) | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| Ka (11) | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| Ka (13) -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (13) -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Ka (14) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 70 | 0 | 10 | 0 | 60 | 60 | 60 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted.
Assessment B: Accuracy of detection for the evaluated rainfall with the out-of-scope deducted from Evaluation A

## Table 3-17 Detection accuracy evaluation results (Iwaoka Basin, Kobe - phase 1)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow rate data ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| Iwa (1) | 5 | 2 | 0 | 0 | 3 | 3 | 3 | 100% | 100% | |
| Iwa (2) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa (3) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa (4) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa (5) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa (6) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa (7) | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| Iwa (8) | 5 | 2 | 2 | 0 | 1 | 1 | 1 | 100% | 100% | |
| Iwa (9) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa (10) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Total | 50 | 10 | 6 | 0 | 34 | 34 | 34 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-18 Detection accuracy evaluation results (Iwaoka Basin in Kobe - phase 2)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| Iwa 6 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 6 -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 6 -3 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 6 -4 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 6 -5 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 9 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Iwa 9 -2 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Iwa 9 -3 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| Iwa 9 -4 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| Total | 45 | 0 | 6 | 0 | 39 | 39 | 39 | 100% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-19 Detection accuracy evaluation results (Kobe City Nishijin Basin - phase 1)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ = ① - ② - ③ | Out of scope deduction ⑥ =⑤ - ④ | | | | |
| West (1) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West (2) | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| West (3) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| West (4) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West (5) | 5 | 1 | 0 | 0 | 4 | 4 | 4 | 100% | 100% | |
| West (6) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West (7) | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West (8) | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| West (9) | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| West (10) | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| Total | 50 | 2 | 4 | 15 | 44 | 29 | 29 | 66% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-20 Detection accuracy evaluation results (Kobe City NishiJin Basin - phase 2)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls: Missing data deduction ⑤ = ① - ② - ③ | Evaluated number of rainfalls: Out of scope deduction ⑥ =⑤ - ④ | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| West 1 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -3 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -4 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -5 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -6 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -7 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 1 -8 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -3 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -3 -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -4 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| West 3 -5 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 3 -5 -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 6 -1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 6 -2 -1 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| West 6 -2 -2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 6 -3 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 6 -4 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| West 9 -1 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| West 9 -2 S | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| West 9 -3 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| West 9 -4 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| West 9 -5 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| Total | 120 | 0 | 6 | 20 | 114 | 94 | 94 | 82% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-21 Detection accuracy evaluation results (Kumamoto City Koto Basin - phase 1)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls: Missing data deduction ⑤ = ① - ② - ③ | Evaluated number of rainfalls: Out of scope deduction ⑥ =⑤ - ④ | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| K01 | 5 | 2 | 2 | 0 | 1 | 1 | 1 | 100% | 100% | |
| K02 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | - | - | acoustic absence measurement |
| K05 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K07 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| K08 | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| K12 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| K13 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| K14 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K15 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K16 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | - | - | acoustic absence measurement |
| K17 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | inlet pipe effect |
| K18 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K19 | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| K20 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K26 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K27 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K28 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| k31 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K32 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K33 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K35 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 105 | 2 | 33 | 10 | 70 | 60 | 60 | 86% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-22 Detection accuracy evaluation results (Kumamoto City Koto Basin - phase 2)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ ＝ ① - ② - ③ | Out of scope deduction ⑥ ＝⑤ - ④ | | | | |
| K09-1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K09-2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K09-3 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K09-4 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K09-5 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | - | - | acoustic absence measurement |
| K09-6 | 5 | 0 | 1 | 1 | 4 | 3 | 3 | 75% | 100% | |
| K09-7 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K09-8 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K09-9 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K09-10 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K17-1 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-2 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-3 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-4 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-5 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-6 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-7 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-8 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K17-9 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-10 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-11 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-12 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K17-13 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| Total | 115 | 0 | 12 | 1 | 103 | 102 | 102 | 99% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

## Table 3-23 Detection accuracy evaluation results (Tomiai Basin, Kumamoto City)

| Investigation locations No | Evaluated rainfall | | | | | | Normal detection ⑦ | Detection accuracy | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of rainfall events ① | Missing flow ② | Missing acoustic data ③ | Out of scope ④ | Evaluated number of rainfalls | | | Evaluation A ⑦／⑤ | Evaluation B ⑦／⑥ | |
| | | | | | Missing data deduction ⑤ ＝ ① - ② - ③ | Out of scope deduction ⑥ ＝⑤ - ④ | | | | |
| K37 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| K42 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K43 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K44 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K46 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K48 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K49 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K50 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K53 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K54 | 5 | 2 | 0 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K56 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | irregular drainage |
| K61 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| K71-2 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K63 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| K64 | 5 | 0 | 3 | 0 | 2 | 2 | 2 | 100% | 100% | |
| K65 | 5 | 0 | 5 | 0 | 0 | 0 | 0 | - | - | acoustic absence measurement |
| K66 | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| K68 | 5 | 0 | 2 | 0 | 3 | 3 | 3 | 100% | 100% | |
| K69 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K70 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K71-1 | 5 | 0 | 4 | 0 | 1 | 1 | 1 | 100% | 100% | |
| K72 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 0% | - | P effect |
| K73 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K76 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K79 | 5 | 0 | 0 | 0 | 5 | 5 | 5 | 100% | 100% | |
| K80 | 5 | 0 | 1 | 0 | 4 | 4 | 4 | 100% | 100% | |
| Total | 130 | 2 | 26 | 40 | 102 | 62 | 62 | 61% | 100% | |

*Concept of Evaluation
Evaluation A: Accuracy of detection for the evaluated rainfall with the missing data deducted
Evaluation B: Accuracy of detection for the assessed rainfall after deducting the out-of-scope from assessment A

3.2 Business feasibility

The business feasibility of this technology was evaluated based on the total cost, including investigation, analysis, and detailed investigation. The target value of the business feasibility was set as a "50% reduction" compared with the total cost of the conventional technology. In the verification method of the business feasibility, it was decided to compare the costs required for organizing and analyzing the data, and the total costs of the subsequent detailed investigation, when sound collectors of this technology were installed at a site where flow meters were installed for the narrowing investigation of the conventional technology in the demonstration fields. In addition, in the rainwater I&I investigation covered by this technology, after identifying the abnormal areas or locations, detailed investigations such as TV camera investigation of sewer pipes and smoke investigation to detect misconnections are conducted. Since this technology does not allow the determination of priority for the detailed investigation based on the relative comparison of the amount of rainwater I&I, there is a possibility that the number of the investigated sites and the length may increase when the narrowing investigation and the detailed investigation. Therefore, the business feasibility including the difference in the number of investigated sites and the scope of the detailed investigation is evaluated.

**Table 3-24 Evaluation of business feasibility (example)**

| Items | This Technology (Acoustic investigation) 60 Locations installed (1,000 yen) | Conventional technology (Flow rate observation) 40 Locations installed (1,000 yen) | Reduction (%) |
|---|---|---|---|
| Investigation | 15,000 | 35,000 | 57 |
| Analysis | 7,000 | 6,000 | -17 |
| Detailed investigation | 25,000 | 19,000 | -32 |
| Total | 47,000 | 60,000 | 22 |

### 3.2.1 Evaluation method

This evaluation uses the results of rainwater I&I investigations conducted in 10 districts in 5 cities nationwide. As a comparison between this technology and conventional technology, the investigation in each city is divided into two parts: the part where the investigation equipment used by both technologies is installed and observed in the same manhole, and the part where the investigation equipment is installed and observed by this technology alone to confirm the performance.

In the evaluation of business feasibility, compare the number of installations of both technologies at the same site. Comparisons shall be calculated separately for investigations and analyses and shall be evaluated based on the total cost of the investigations and analyses. Here, as described above, the number of investigation sites for comparison and the scope of the detailed investigation shall be set according to the characteristics of the demonstration field, and the evaluation shall not necessarily be conducted at the same number of sites or by length.

(1) Investigation

By the number of investigation locations in each area, calculate the operating cost required for the installation and removal of equipment in this technology and the conventional technology. This evaluation is applied to the locations where both technologies are applied in the same manhole to narrow down the rainwater I&I.

(2) Analysis

With this technology, the time required for conventional engineers to judge the presence or absence of infiltration water in rainy weather of rainwater I&I is reduced by applying AI technology. Here, the operating cost in the processes from data arrangement to analysis (detection) in both technologies is calculated.

(3) Detailed investigation

By the length of the detailed investigation in each city, the operating cost is calculated when the detailed investigation (TV camera investigation) is carried out in the area where the occurrence of rainwater I&I is detected by this technology and the conventional technology.

Based on the evaluation method described above, this technology and the conventional technology are evaluated based on the following evaluation formula.

[Evaluation formula: reduction rate in operating cost]

$$\text{reduction in operating cost (\%)} = \frac{(B - A)}{B} \times 100$$

A: Total cost for investigation, analysis, and detailed investigation of this technology (million yen)
B: Total cost for investigation, analysis, and detailed investigation of the conventional technology (million yen)

### 3.2.2 Setting conditions

(1) Characterization of investigation and analysis

Conventional technology can prioritize the investigation area by narrowing down the area since relative comparison among sectors based on a quantitative index (m3) obtained from observation results is possible. On the other hand, this technology cannot compare the sectors relatively since the feature quantity obtained from the AI analysis is an index specific to the site. Therefore, to obtain a result similar to that of the conventional technology, a survey using this technology requires more installation locations than those of the conventional technology.

**Table 3-25 Investigation technologies comparison**

| Type of technology | Content of the technology | |
|---|---|---|
| | Investigation | Analysis |
| This technology | Acoustic investigation | Multi-Point Detection over a wide area using AI Analysis |
| Conventional technology | Screening investigations using flowmeters | Data arrangement and analysis by engineers to narrow down the investigation area by the prioritization |

**Table 3-26 Characteristics to be considered in comparative evaluation between the conventional technology and this technology**

| | |
|---|---|
| Conventional technology | Conducting the quantitative investigation at multiple sites and the quantitative indicators (m3) are taken by the result of the evaluation and the analysis. This method prioritizes and narrows down areas with high effectiveness in implementing countermeasures by comparing the relative volume of the rainwater I&I |
| This technology | Since the AI analysis results at the investigation location are a value (feature quantity) calculated only for the detection of abnormality at that location, it is difficult to compare it with other investigation locations. Therefore, since it is difficult to determine the priority as in the conventional technology, this method is to conduct the investigation at multiple locations over a wide area. |

(2) Scope of cost estimation

The scope of cost estimation in the overall flow applying this technology is the entire process shown in Figure 3-4, and the operating cost to be calculated is the operating price (see Figure 3-5).

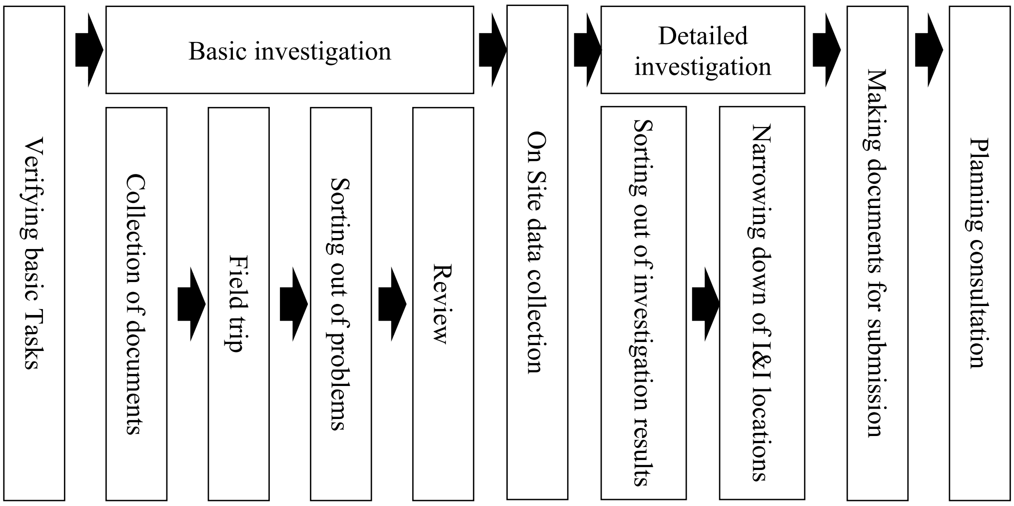



**Figure 3-4 Scope of cost estimation of this technology**

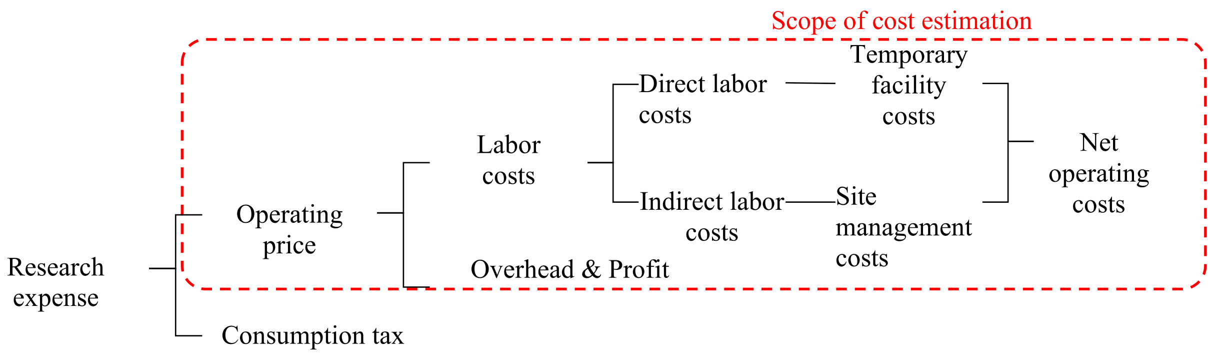



**Figure 3-5 Scope of operating costs for investigation and analysis**

(3) Cost estimation conditions

Table 3-27 shows the cost estimation conditions for comparing the feasibility of this technology and the conventional technology. In comparison, there is a difference in the number of investigation sites and the analysis by AI analysis and engineers between the two technologies. The cost per sewer pipe length is the same for detailed investigations but based on the results of investigations and analyses, the length of the detailed investigations becomes different.

The reason why the evaluation includes the detailed investigation as mentioned above is to confirm that the total cost is more advantageous than that of the conventional technology by shortening the length of the detailed investigation even when the number of investigation locations is larger than that of the conventional technology.

**Table 3-27 Cost estimation conditions**

| Items | This technology | Conventional technology |
|---|---|---|
| Investigation method | Acoustic investigation | Flow rate observation investigation |
| Investigation | 1) Installed at the same place as conventional technology<br>2) Places where further narrowing down areas can be expected | Installed at locations required for narrowing down investigations |
| Analysis | AI analysis | Engineer Analysis |
| Detailed investigation | CCTV camera investigations: 2,000 yen/m | CCTV camera investigations: 2,000 yen/m |
| Cost Estimation | Cost estimation by the research body | Sewerage Pipeline Management Cost Estimation Guidelines |
| Estimate items | Investigation, Analysis, Detailed investigation | Investigation, Analysis, Detailed investigation |

3.2.3 Evaluation results

As the business feasibility evaluation, the following two evaluations are conducted when the equipment is installed in the places required for narrowing down investigation by this technology and the conventional technology.

Evaluation (1)：Business feasibility evaluation based on the investigation narrowing down from large to middle sectors
(Detailed investigation is not included as detailed investigation is not conducted.)

Evaluation (2)：Business feasibility evaluation based on the investigation narrowing down from medium to small sectors
(Since the scope of the detailed investigation is calculated based on the results of narrowing down the area, detailed investigation is included in the evaluation.)

**Table 3-28 List of conditions for business feasibility evaluation**

| City Name | District | Evaluation | | Evaluation points (number of points) | | Narrowing down result (CCTV camera investigation length (m)) | |
|---|---|---|---|---|---|---|---|
| | | | | This technology | Conventional technology | This technology | Conventional technology |
| Koriyama | Otsuki Town | 2 | Research + Analysis + Detailed Research | 7 | 5 | 505.02 | 658.36 |
| | Fukusan Town | 2 | Research + Analysis + Detailed Research | 18 | 8 | 3,655.52 | 4,337.54 |
| Tsukuba | Jonan Treatment District | 1 | Investigation + Analysis | 24 | 24 | — | — |
| Nagoya | Hyogo District | 2 | Research + Analysis + Detailed Research | 9 | 4 | 2,396.92 | 2,396.92 |
| | Kaminokura District | 2 | Research + Analysis + Detailed Research | 20 | 10 | 2,099.74 | 3,511.58 |
| Kobe | Kakogawa River basin | 1 | Investigation + Analysis | 14 | 14 | — | — |
| | Iwaoka basin | 2 | Research + Analysis + Detailed Research | 27 | 16 | 4,384.68 | 6,079.45 |
| | Nishijin Basin | 2 | Research + Analysis + Detailed Research | 29 | 18 | 10,976.26 | 12,879.85 |
| Kumamoto | Koto basin | 2 | Research + Analysis + Detailed Research | 52 | 33 | 14,768.98 | 16,489.91 |
| | Tomiai Basin | 1 | Investigation + Analysis | 19 | 19 | — | — |
| Total | | | | 219 | 151 | 38,787.12 | 46,353.61 |

« Evaluation (1) Results »

In the case of Tsukuba City (Jonan Treatment Area), Kobe City (upstream Kakogawa River basin), and Kumamoto City (Tomiai Basin), where detailed investigations were not necessary, the average project cost reduction rate was 57.7%.

**Table 3-29 Business feasibility evaluation (1) results**

| Items \ local government | 3) Tsukuba City | | 6) Kobe City (Upstream of the Kakogawa River) | | 9) Kumamoto City (Tomiai Basin) | |
|---|---|---|---|---|---|---|
| | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology |
| Type of investigation | Large to medium sector | | Large to medium sector | | Large to medium sector | |
| Target area (ha) | 1,500 | 1,500 | 1,500 | 1,500 | 150 | 150 |
| Observation method | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate |
| 1) Locations | 24 | 24 | 14 | 14 | 19 | 19 |
| 2) Research expenses (1000 yen) | 7,100 | 21,240 | 4,210 | 12,800 | 5,660 | 17,090 |
| 3) Analysis expenses (1000 yen) | 3,430 | 3,780 | 3,430 | 3,784 | 1,550 | 1,290 |
| 4) Detailed investigation cost (1000 yen) | — | — | | | — | — |
| 5) Total Cost (2) + 3) + 4)) | 10,530 | 25,020 | 7,640 | 16,584 | 7,210 | 18,380 |
| 6) Rating (%) | 42% | 100% | 46% | 100% | 39% | 100% |
| 7) Reduction (%) | **58%** | | **54%** | | **61%** | |

« Evaluation (2) Results »

Koriyama City, Kobe City (Iwaoka and Nishigami basin), Nagoya City (Kaminokura, Hyogo), and Kumamoto City (Koto), which were evaluated for detailed investigations, achieved an average reduction of about 27.3% in project costs in the seven districts.

**Table 3-30 Business feasibility evaluation (2) results**

| local government / Items | 1) Koriyama City (Otsuki Town) | | 2) Koriyama City (Fukuyama Town) | | 7) Kobe City (along the Iwaoka River) | | 8) Kobe City (Nishijin Basin) | | 4) Nagoya City | | 5) Nagoya City (Kaminokura district) | | 10) Kumamoto City | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology |
| Type of investigation | Medium to small sector | | Medium to small sector | | Large, medium to small sector (Phase 1 and 2) | | Large, medium to small sector (Phase 1 and 2) | | Medium to small sector | | Medium to small sector | | Large, medium to small sector (Phase 1 and 2) | |
| Target area (ha) | 70 | 70 | 130 | 130 | 165 | 165 | 900 | 900 | 10 | 10 | 20 | 20 | 600 | 600 |
| Observation method | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate | Acoustic | Flow rate |
| 1) Locations | 7 | 5 | 18 | 8 | 27 | 16 | 29 | 18 | 9 | 4 | 20 | 10 | 52 | 33 |
| 2) Research expenses (1000 yen) | 2,180 | 4,875 | 5,450 | 7,540 | 7,880 | 14,500 | 8,450 | 16,200 | 2,780 | 3,900 | 5,950 | 9,310 | 14,620 | 28,840 |
| 3) Analysis expenses (1000 yen) | 1,350 | 1,020 | 1,500 | 1,220 | 1,600 | 1,350 | 2,800 | 2,940 | 1,230 | 862 | 1,250 | 890 | 2,390 | 2,410 |
| 4) Detailed investigation cost (1000 yen) | 1,010 | 1,317 | 7,311 | 8,675 | 8,769 | 12,159 | 21,953 | 25,760 | 4,794 | 4,794 | 4,199 | 7,023 | 29,538 | 32,980 |
| 5) Total Cost (2) + 3) + 4)) | 4,540 | 7,212 | 14,261 | 17,435 | 18,249 | 28,009 | 33,203 | 44,900 | 8,804 | 9,556 | 11,399 | 17,223 | 46,548 | 64,230 |
| ⑥ Rating (%) | 63% | 100% | 82% | 100% | 65% | 100% | 74% | 100% | 92% | 100% | 66% | 100% | 72% | 100% |
| ⑦ Reduction (%) | **37%** | | **18%** | | **35%** | | **26%** | | **8%** | | **34%** | | **28%** | |

Evaluation (2) is a comparison including the detailed investigation, and although the average reduction effect of operating costs was 27.3%, which obtained a certain result, the target value of "50% reduction" was not achieved in comparison with the conventional technology. The reason for not achieving the target is considered to be related to the detailed investigation volume. Although this technology can perform the same degree of narrowing down areas as the conventional technology in the detection of rainwater I&I, since it is difficult to determine the priority based on the quantitative evaluation as in the conventional technology, the narrowing down from the medium to the small sectors requires more installation of the equipment than that of the conventional technology.

As a result of the investigation and analysis using this technology, when the infiltration water is widely generated in the area where the rainwater I&I is generated, the detailed investigation volume is the same as that of the conventional technology, and therefore, the effect of reducing the operating cost is hardly generated. As a result, since the number of locations to install the equipment is larger than that of the conventional technology in the initial narrowing down areas, the effect of reducing the project cost is shown in the evaluation (1), in which the number of investigation locations in the two technologies mentioned above is the same, cannot be obtained in the evaluation (2).

3.3 Efficiency evaluation

The efficiency of this technology was evaluated by comparing the number of days required for each investigation and analysis with the conventional technology. The target value in the evaluation was set as a "50% reduction" compared with that in the conventional technology.

As a demonstration method of the efficiency, the number of days required for installation and removal of the investigation equipment in this technology and the conventional technology was calculated for the investigation, and the number of days required for organizing and analyzing the field investigation data was compared for the analysis.

Since the analysis in this technology is performed by AI analysis, it is not under the same conditions as the data analysis for engineers in conventional technology. Also, AI analysis depends on the computer's specification, etc. in this technology and the skill of the engineer, etc. in the conventional technology. As for the present comparison, it is difficult to assimilate the conditions to a certain extent even considering the above, and comparison and evaluation will be conducted based on the actual values (number of days) in this study.

**Table 3 -31 Efficiency assessment (Image)**

**Comparison condition: Same as evaluation of business feasibility (Figures in the table are examples)**

| | Items | Sites (This technology) | Sites (Conventional technology) | Reduction rate (%) |
|---|---|---|---|---|
| Installation | Number of possible locations (locations/day) | 15 | 4 or 6 | — |
| | Total number of days for installation (days) | 4 | 7 - 10 days | 43 - 60 |
| Removal | Number of removable locations(locations/Day) | 15 | 10 | — |
| | Total number of days for removal (days) | 4 | 4 | 0 |
| Total | Total number of days required for installation, inspection and removal (days) | 10 | 15 - 18 | 33 - 67 |

| Item | This technology | Conventional technology | Reduction rate (%) |
|---|---|---|---|
| **Required data to analyze 1 location x 60 days (days)** | ● | ▲ | ■ |
| **Required total days to analyze target locations x 60 days (days)** | ○ | △ | □ |

### 3.3.1 Evaluation method

Efficiency evaluation is divided into investigation and analysis. The evaluation method in the investigation is evaluated by the reduction rate by comparing the total number of days required from the installation to the removal of the equipment between this technology and the conventional technology. In addition, the evaluation method in the fractionation is also evaluated by the reduction rate in comparison with the number of days in the data analysis obtained from the investigation results between this technology and the conventional technology. In the evaluation, a comparison is made under the same scenario in consideration of the difference in the investigation method between this technology and the conventional technology in the same manner as in the above-described evaluation of the feasibility.

(1) Number of investigation days

The number of installation/removal locations per day is calculated from the time (minutes) required for installation/removal of equipment in the site in this technology and the conventional technology, and the reduction rate of the number of days required for the investigation is evaluated by the number of locations. In this evaluation, the observation period is the same number of days (30 days) for both technologies, and since the investigation period does not differ depending on the characteristics of both technologies, it is excluded from the number of days for calculating the reduction rate.

(2) Analysis period

The time required for engineers in conventional technology to judge the presence or absence of rainwater I&I is shortened by applying AI technology. The demonstration method compares the process from data arrangement to analysis (detection) in the AI analysis and the time required for the same process in the conventional technology and evaluates it by the reduction rate.

(3) Detailed study period

By the extension of the detailed investigation in each city, calculate the number of investigation days when the detailed investigation (CCTV camera investigation) is carried out for the area where the occurrence of rainwater I&I is detected by this technology and the conventional technology.
(Set CCTV camera investigation daily inspected length as 300 m/day)

Based on the evaluation method described above, this technology and the conventional technology are evaluated based on the following evaluation formula.

[Evaluation efficiency reduction rate]

$$\text{reduction in working days (\%)} = \frac{(B - A)}{B} \times 100$$

A: Total number of days required for investigation, analysis, and detailed investigation in this technology
B: Total number of days required for investigation and analysis and detailed investigation in the conventional technology

### 3.3.2 Setting conditions

(1) Characterization of investigation and analysis

In conventional technology, since relative comparison between sectors based on a quantitative index (m3) obtained from investigation results is possible, priority determination can be made in narrowing down areas. On the other hand, with respect to this technology, since the feature quantity obtained from the AI analysis is an index specific to the relevant location, relative comparison as in the conventional technology is impossible. Therefore, to obtain a result similar to that of the conventional technology, the investigation using this technology requires more installation locations than those of the conventional technology.

**Table 3-32 Comparative investigation technologies**

| Type of technology | Content of the technology | |
|---|---|---|
| | Investigation | Analysis |
| This technology | Acoustic investigation | Multi-Point detection over a wide area using AI analysis |
| Conventional technology | Screening investigations using flowmeters | Narrowing down investigation by data arrangement and analysis by engineers for priority determination |

**Table 3-33 Characteristics to be taken into consideration in comparative evaluation between the conventional technology and this technology**

| | |
|---|---|
| Conventional technology | In this method, flow rate investigations are conducted at several investigation sites, and quantitative indicators (m3) are used based on the analysis and evaluation of the results to compare the amount of rainwater I&I entering the site in each location relatively and to investigate preferentially the areas that are highly effective in implementing countermeasures. |
| This technology | Since the AI analysis results at the investigation location are the value (feature quantity) calculated only for the detection of abnormality at that location, it is difficult to compare it with other investigation locations. Therefore, since it is difficult to determine the priority evaluation as in the conventional technology, this technology applies the method for conducting the investigation at multiple locations over a wide area. |

(2) Setting investigation conditions

In the investigation of this technology, following the flow shown in Fig. 3-6, the sound collectors are installed in the sewer pipes. In this technology, there is no need to enter the manhole, but when the manhole cover is opened, the concentration of oxygen and hydrogen sulfide must be measured to confirm the generation of toxic gas. In addition, the height of the external microphone attached to the sound collector must be adjusted to be installed at the top level of the pipe in consideration of avoiding submergence to surely acquire acoustic data of the flowing water sound.

Considering the above, following the flow shown in Fig. 3-6, it was found that the installation was able to be completed in about 10 minutes by measuring the installation at the site. Although the number of installations per day depends on the distance between the installation locations, it was also found that 15 ~ 20 installations per day (and the same number of removals) are possible.

**Table 3-34 Days of equipment installation and removal**

| | Items | 60 locations by this technology | 40 locations by the conventional technology | Reduction Rate (%) |
|---|---|---|---|---|
| Installation | Number of possible installation locations (locations/day) | 15 | 4 or 6 | — |
| | Total number of days for installation (days) | 4 | 7-10 days | 43 ～60 |
| Removal | Number of possible removable locations (locations/day) | 15 | 10 | — |
| | Total number of days for removal (days) | 4 | 4 | 0 |
| Total | Total number of days required for installation, inspection and removal (days) | 10 | 15 ～18 | 33 ～67 |

*The number of locations (this technology: 60 places, conventional technology: 40 places) is set as an example to calculate the total number of days.

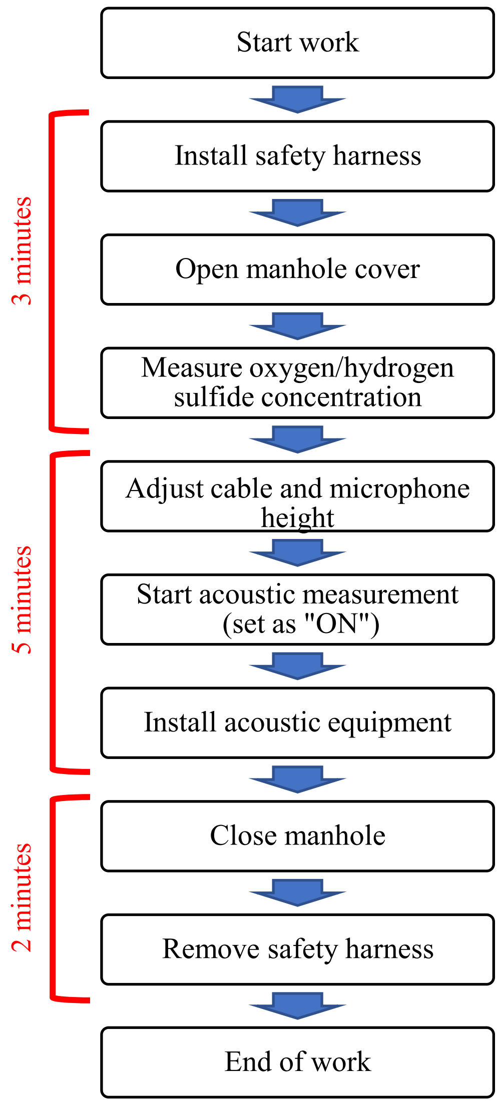



**Figure 3-6 Installation flow of sound collector**

***Each time (red font) in the figure is the average time (actual value) required for each municipality investigated this time.**

| Tasks | Pictures |
| --- | --- |
| Install a safety harness<br>Open a manhole cover |  |
| Measure oxygen/hydrogen sulfide concentration |  |
| Adjust cable and microphone height |  |
| Start acoustic measurement |  |
| Install an acoustic equipment |  |

(3) Setting analysis conditions

This technology uses AI to define "normal (sunny days)" and defines data that deviates from the definition of rainy days as "abnormal" to detect areas and locations where rainwater I&I occurs. In the AI of this technology, the feature quantity to be sunny days pattern is extracted from acoustic data (after noise removal) in a manhole using descriptive statistics exceeding about 200 in the time domain and the frequency domain. Then, by adjusting the AI parameters, the sunny day pattern is constructed so that the variation range of each sunny day in the acoustic investigation period is minimized. For abnormality detection, the sunny day pattern becomes the teacher data, and the data separated from it on rainy days is judged as abnormal (= rainwater I&I detection).

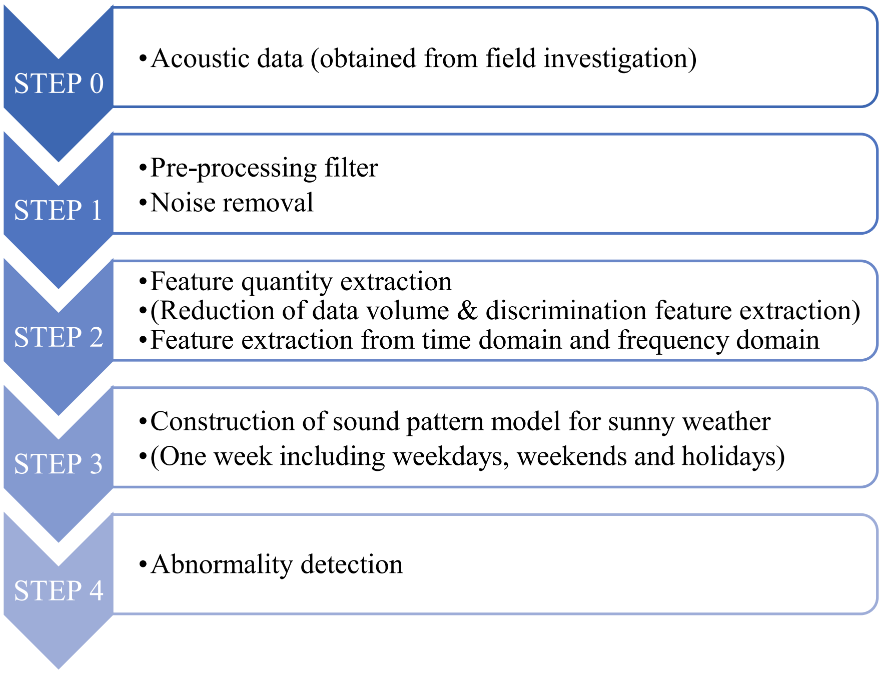



**Figure 3-7 Overview of AI analysis flow of this technology**

Table 3-36 shows the computer specifications used in the AI analysis and the required analysis time. Under this condition, when 50 points were analyzed by AI using acoustic data for about 1 month, the result of abnormality detection was able to be obtained in about 42 hours (about 2 days).

**Table 3-36 Analysis specifications used in the analysis of the demonstration study**

| Items | Time Required | Notes |
|---|---|---|
| SD card: 1 month's worth of audio data (approx. 15.0 GB) read by card reader<br>PC: CPU Xeon2125 4.0Ghz<br>Memory 128GB ECC<br>HD M.2 PCle SSD512GB | | |
| Data capture | 7 min | SD — card reader —Computer |
| Noise removal and analysis | 270 min | Establishment of sunny days pattern<br>Rainy days feature extraction |
| Evaluation | 60 min | Abnormality detection<br>(Create graph) |
| Total | 337 min≒6.0 hr | |
| Analysis time in demonstration study | | |
| 5 locations | 6hr | PC: 8<br>(with 4 card readers) |
| 10 locations | 12hr | |
| 15 locations | 12hr | |
| 20 locations | 18hr | |
| 50 locations | 42hr | |
| 100 locations | 78hr | |

In the demonstration study of this technology, Xeon 2125 was used as a CPU. Table 3-37 shows the result of comparing the total time when the same process shown in Table 3-36 is processed with one month's worth of acoustic data (about 15.0GB) using other CPUs. The price of a PC in the table is the general price as of April 2020.

If the specifications of the computer used in this demonstration study are considered medium, the computation time is increased or decreased depending on the CPU. In the case of the high specification (high specification 2 in table 3-37), it is possible to complete the analysis in half the time required in this case. Naturally, the purchase price of the high-specification computer becomes expensive, so the actual computer specifications should be selected based on the number of analysis locations and the constraint period (construction period).

**Table 3-37 Effect of CPU differences on computation time**

| | Low specification 1 | Low specification 2 | PC specifications used for this technology | High specification 1 | High specification 2 |
|---|---|---|---|---|---|
| CPU name and clock count | Core i5 9400 | Ryzen 5 3600 | Xeon 2125 | Core i9 9900K | Ryzen 9 3950K |
| Clock Count | 2.9 GHz | 3.6 GHz | 4.0 GHz | 3.6 GHz | 3.5 GHz |
| Number of Cores | 6 | 6 | 4 | 8 | 16 |
| Number of threads | 6 | 12 | 8 | 16 | 32 |
| Installed RAM | 16GB | 16GB | 128 GB | 32 GB | 64GB |
| Price of a PC (As of April 2020) | 80,000 yen | 100,000 yen | 150,000 yen | 200,000 yen | 300,000 yen |
| Data acquisition time | 10 min | 10 min | 10 min | 10 min | 10 min |
| Noise processing and analysis time | 390 min | 340 min | 2T0 min | 210 min | 110 min |
| Evaluation time | 85 min | T5 min | 60 min | 45 min | 25 min |
| Total time | 485 min | 425 min | 340 min | 265 min | 145 min |
| Total time savings compared to the PC used in this technology | + 43 % | + 25 % | — | - 22% | - 57% |

(4) Setting evaluation methods

The evaluation method is not a simple comparison of investigation locations, given the difference between the investigation methods of this technology and the conventional technology, and the evaluation is conducted by the method shown in Table 3-38. This time, in this technology and the conventional technology, the comparison with the same number of locations is not conducted, and the comparison is conducted with the number of investigation locations necessary to perform narrowing down areas based on the characteristics of both technologies. Therefore, the scope of the detailed investigation covers the different lengths of both technologies.

Areas outside the scope of application of both technologies shall be excluded from the investigation locations for the evaluation. Therefore, in the field investigations, there are locations where only sound collectors are installed on a trial basis (Hereinafter referred to as "test site".) to clarify the detection accuracy and application range of this technology regardless of the narrow-down investigation. This location shall also be excluded from the investigation locations for the evaluation.

**Table 3-38 Evaluation methods of this technology and the conventional technology**

| | This technology | Conventional technology |
|---|---|---|
| Investigation | Multi-site investigation of each small sector in large sectors<br>*Excluded the experimental installations that contribute to performance evaluation and the locations outside the scope of technology application from the number to be compared. | 1) Narrowing down from large to medium sectors<br>2) Narrowing down from medium to small sectors<br>*Excluding the outside of the scope of this technology from the number to be compared. |
| Analysis | Analyze and evaluate all investigation locations. (AI analysis) | Analyze and evaluate the total number of investigation locations in 1) and 2). (Work by engineers) |
| Detailed investigation | Conducted CCTV camera investigations in areas where abnormalities were detected | |

a) Investigation summary (Tsukuba City)

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In Tsukuba City, the total number of investigation locations of this technology is 24, and the total number of investigation locations of the conventional technology is 24. Since the detailed investigation is determined after further narrowing down the investigation, it is excluded from the evaluation. In this basin, all the investigation locations in this technology and the conventional technology are installed in the same manhole.

**Table 3-39 Number of investigation locations in Tsukuba City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 50 | 24 | 26 | — |
| Conventional technology | 24 | 24 | — | — |

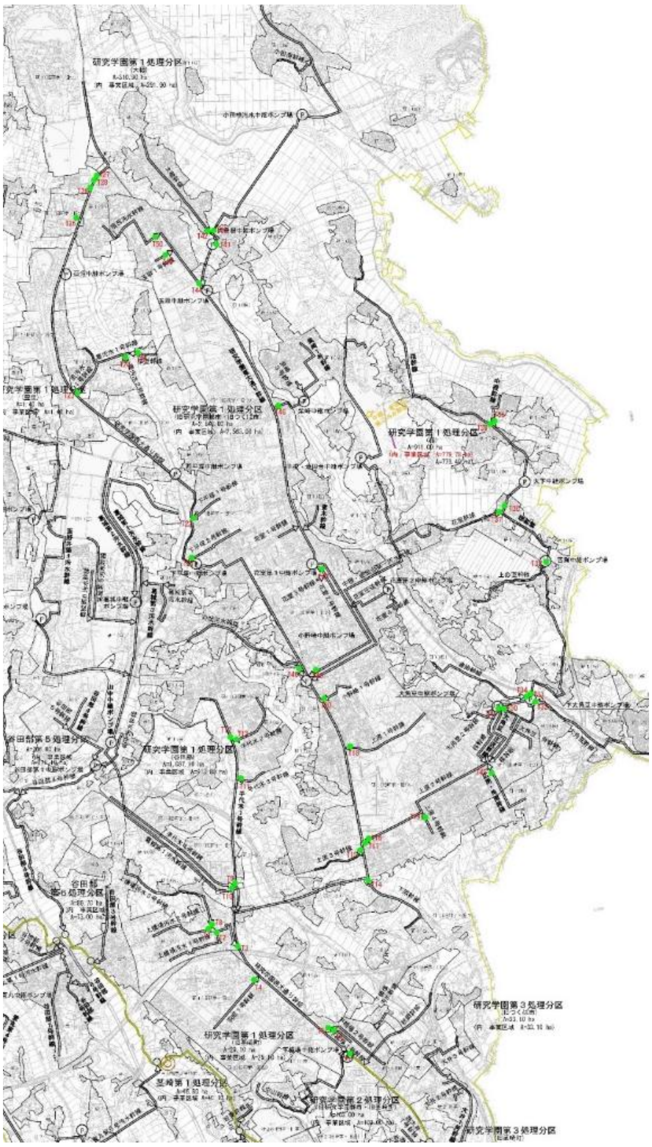


**Figure 3-8 Site location map (Tsukuba City)**

b) Investigation summary (Kobe City (Upstream Kakogawa River Basin))

The number of investigation points required for narrowing down in this technology and the conventional technology is shown below. In the upstream basin of the Kakogawa River, the total number of investigation locations by this technology is 14, and the total number of investigation locations by conventional technology is 14.

Since the detailed investigation is determined after further narrowed down the investigation, it is excluded from the evaluation. In this basin, all the investigation locations in this technology and the conventional technology are installed in the same manhole.

**Table 3-40 Number of investigation locations in the Upstream Kakogawa River basin, Kobe City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
| --- | --- | --- | --- | --- |
| This technology | 14 | 14 | — | — |
| Conventional technology | 14 | 14 | — | — |

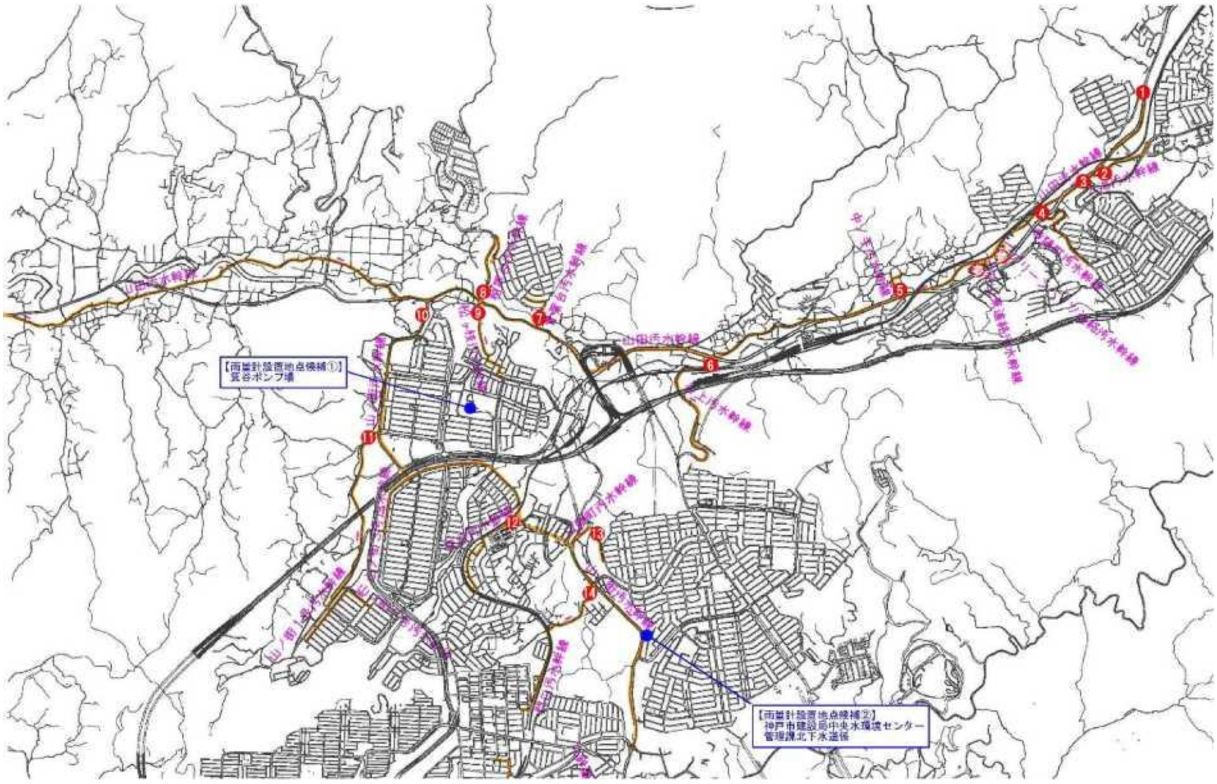



**Figure 3-9 Site location map (Upstream Kakogawa River Basin, Kobe City)**

c) Investigation summary (Kobe City (Iwaoka Basin))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Iwaoka Basin of Kobe City, the total number of locations investigated by this technology is 39 (sum of 1st and 2nd phases), and the total number of locations investigated by the conventional technology is 19 (sum of 1st and 2nd phases). The number of investigation locations in this evaluation is 27 in this technology and 16 in the conventional technology based on the locations required for the narrowing down investigation in the conventional technology. According to the analysis of the investigation results, the length of the detailed investigation was about 4,384.68 m with this technology and about 6,079.45 m with the conventional technology.

In this basin, this technology is also installed in the investigation locations of conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-41 Number of investigation locations in the Iwaoka basin, Kobe City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 39 | 27 | 12 | 4,384.68 |
| Conventional technology | 19 | 16 | — | 6,079.45 |

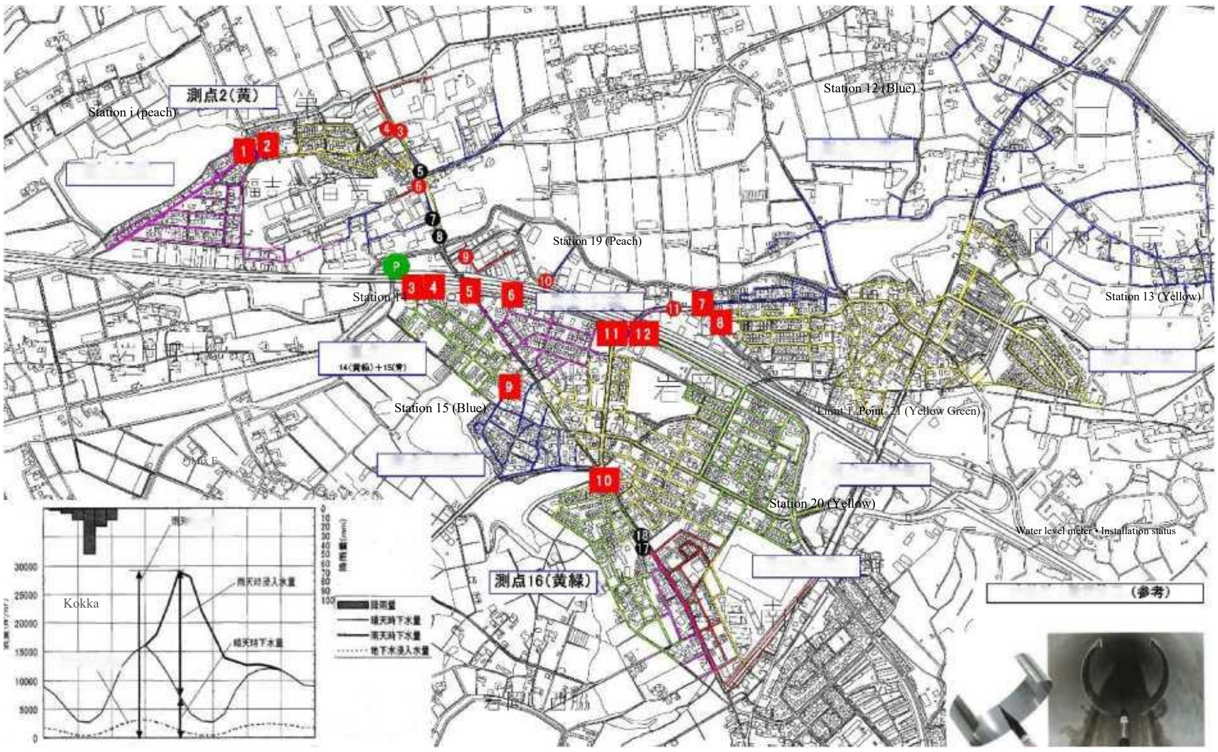



**Figure 3-10 Site location map (Iwaoka Basin, Kobe City)**

d) Investigation summary (Kobe City (Nishijin Basin))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Nishishin Stream of Kobe City, the total number of investigation locations by this technology is 53 (sum of 1st and 2nd phases), and the total number of investigation locations by the conventional technology is 34 (sum of 1st and 2nd phases). The number of investigation locations in this evaluation is 29 in this technology and 18 in the conventional technology based on the locations necessary for narrowing down the investigation in the conventional technology. According to the analysis of the investigation results, the length of the detailed investigation was about 10,976.26 m with this technology and about 12,879.85 m with the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-42 Number of investigation locations in the Nishijin Basin, Kobe City**

| Category | Investigation site | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 53 | 29 | 24 | 10,976.26 |
| Conventional technology | 34 | 18 | — | 12,879.85 |

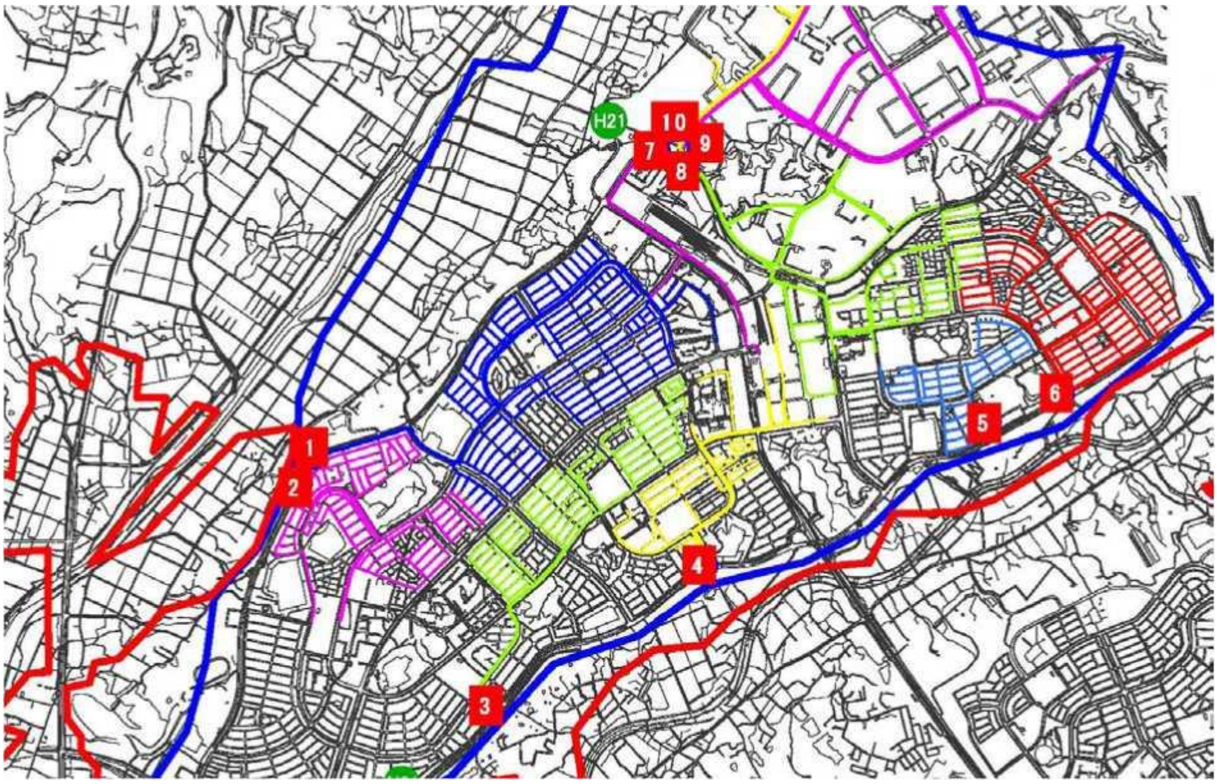



**Figure 3-11 Site location map (Nishijin Basin, Kobe City)**

e) Investigation summary (Kumamoto City (Koto basin))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Koto basin area of Kumamoto City, the total number of investigation locations by this technology is 55 (sum of 1st and 2nd phases), and the total number of investigation locations by conventional technology is 44 (sum of 1st and 2nd phases). The number of investigation locations in this evaluation is 52 in this technology and 33 in conventional technology based on the locations necessary for narrowing down the investigation in the conventional technology. The detailed investigation length by the analysis of the investigation results was about 14,770 m by this technology and about 16,490 m by the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-43 Number of investigation locations in the Koto Basin, Kumamoto City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 55 | 52 | 3 | 14,768.98 |
| Conventional technology | 44 | 33 | — | 16,489.91 |

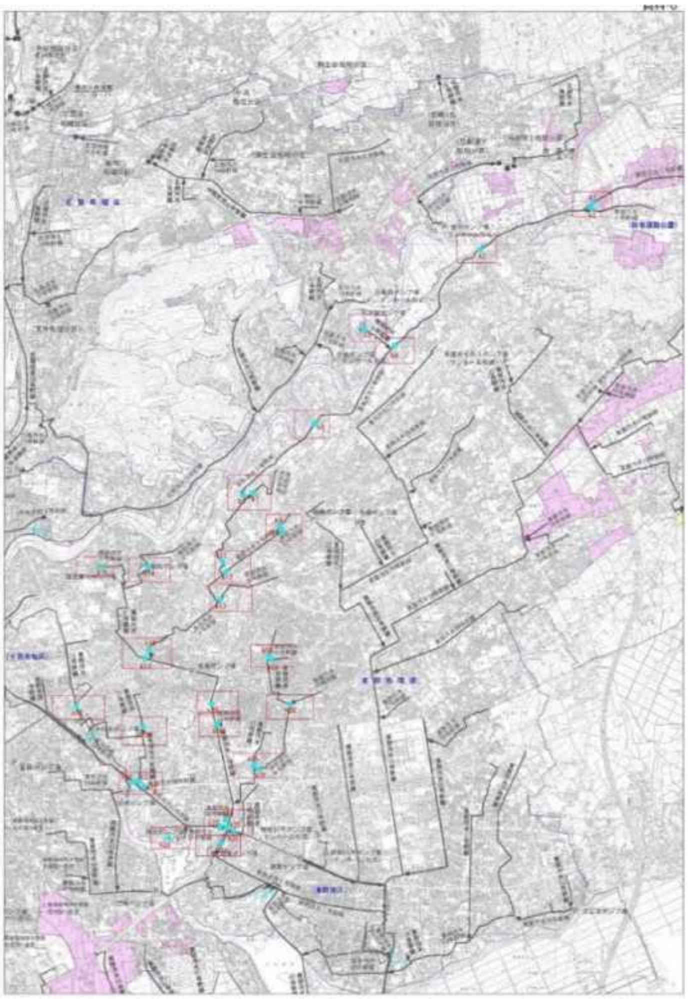


**Figure 3-12 Site location map (Koto basin, Kumamoto City)**

f) Investigation summary (Kumamoto City (Tomiai Basin))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Tomiai basin area in Kumamoto City, the total number of investigation locations of this technology is 45, and the total number of investigation locations of the conventional technology is 19. The number of investigation locations in this evaluation is 38 in this technology and 19 in the conventional technology based on the locations required for the narrowing down investigation in the conventional technology. Since the detailed investigation is determined after further narrow-down investigation, it is not subject to evaluation here.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-44 Number of investigation locations in the Tomiai Basin, Kumamoto City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 45 | 19 | 26 | — |
| Conventional technology | 26 | 19 | — | — |

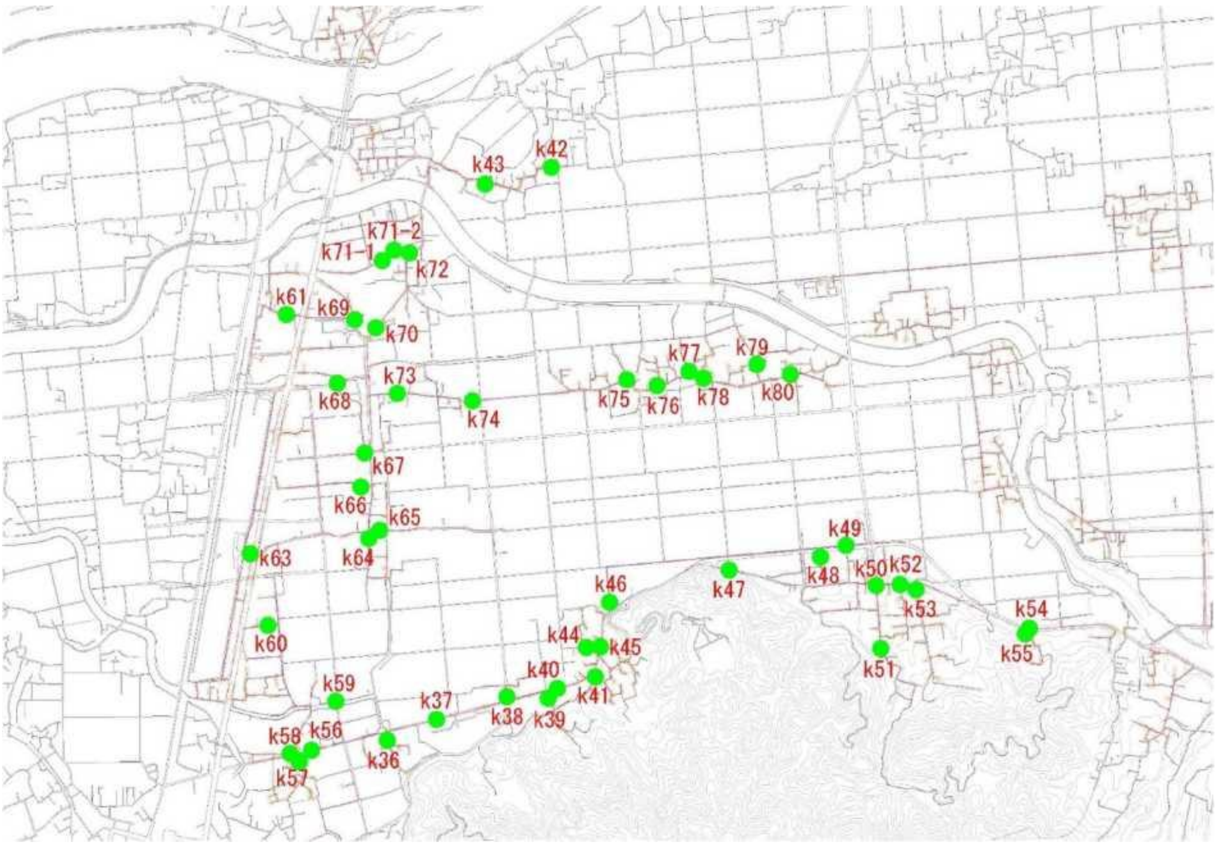



**Figure 3-13 Site location map (Tomiai Basin, Kumamoto City)**

g) Investigation summary (Nagoya City (Hyogo district))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Hyogo district of Nagoya City, the total number of investigation locations for this technology is 50, and the total number of investigation locations for the conventional technology is 8. The number of investigation locations in this evaluation is 12 in this technology and 4 in the conventional technology, based on the locations required for narrowing down the investigation in the conventional technology. According to the analysis of the investigation results, the detailed investigation length was 2,396.92 m for both this technology and the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of sites of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-45 Number of investigation location in Hyogo district, Nagoya City**

| Category | Investigation locations | Number of locat ions to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 50 | 8 | 42 | 2,396.92 |
| Conventional technology | 9 | 4 | — | 2,396.92 |

**Figure 3-14 Site location map (Hyogodistrict, Nagoya City)**

h) Investigation summary (Nagoya City (Kaminokura district))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In the Kaminokura district of Nagoya City, the total number of investigation locations for this technology is 50, and the total number of investigation locations for conventional technology is 10. The number of investigation locations in this evaluation is 20 in this technology and 10 in the conventional technology based on the locations required for the narrowing down investigation in the conventional technology. According to the analysis of the investigation results, the detailed investigation length was 2,099.74 m for this technology and 3,511.58 m for the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-46 Number of investigation locations in the Kaminokura district, Nagoya City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 50 | 20 | 30 | 2,099.74 |
| Conventional technology | 10 | 10 | — | 3,511.58 |


**Figure 3-15 Site location map (Kaminokura area, Nagoya City)**

i) Investigation summary (Koriyama City (Otsuki-town))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In Otsuki-cho, Koriyama City, the total number of investigation locations by this technology is 15, and the total number of investigation locations by the conventional technology is 8. The number of investigation locations in this evaluation is based on the locations required for the narrowing down investigation in conventional technology and is 7 in this technology and 5 in the conventional technology. According to the analysis of the investigation results, the detailed investigation length was about 505 m for this technology and 658.36 m for the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-47 Number of investigation locations in Otsuki Town, Koriyama City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This technology | 15 | 7 | 8 | 505.02 |
| Conventional technology | 8 | 5 | — | 658.36 |

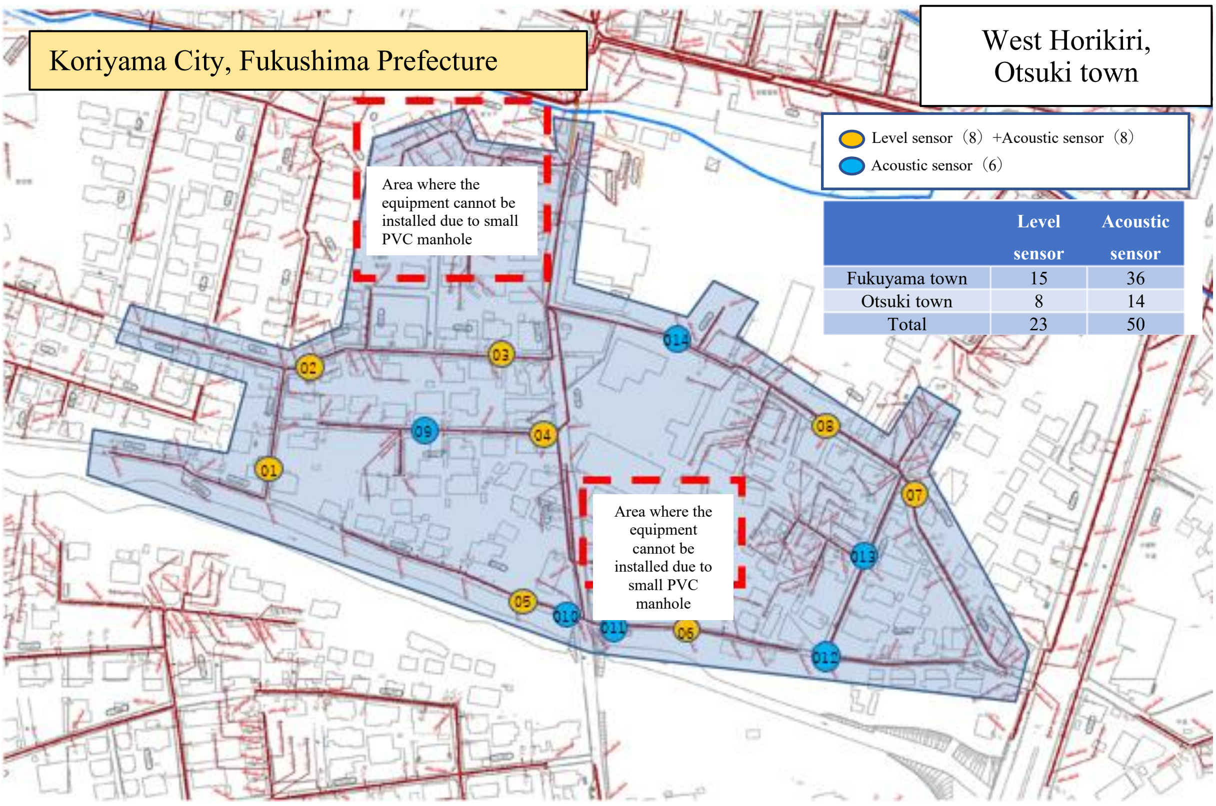



**Figure 3-16 Site location map (Otsuki Town, Koriyama City)**

j) Investigation summary (Koriyama City (Fukuyama town))

The number of investigation locations required for narrowing down in this technology and the conventional technology is shown below. In Fukuyama town, Koriyama City, the total number of investigation locations by this technology is 36, and the total number of investigation locations by conventional technology is 14. The number of investigation locations in this evaluation is 18 in this technology and 8 in the conventional technology, based on the locations required for the narrowing down investigation in the conventional technology. According to the analysis of the investigation results, the detailed investigation length was 3,655.52 m for this technology and 4,337.54 m for the conventional technology.

In this basin, this technology is also installed in the investigation locations of the conventional technology, but the number of locations of this technology is increased due to the difference in the range which can be narrowed down.

**Table 3-48 Number of investigation locations in Fukuyama town, Koriyama City**

| Category | Investigation locations | Number of locations to be evaluated | Test site | Detailed investigation (m) |
|---|---|---|---|---|
| This Technology | 36 | 18 | 18 | 3,655.52 |
| Conventional Technology | 14 | 8 | — | 4,337.54 |

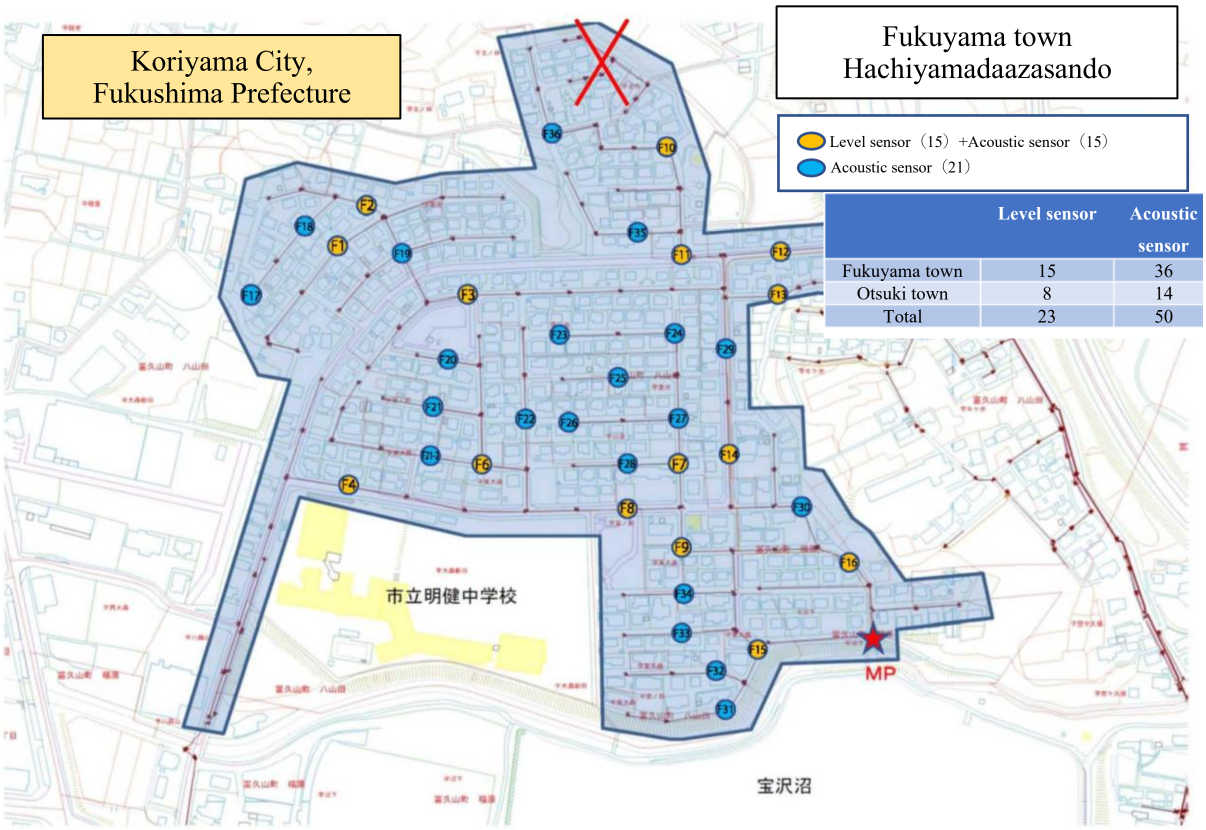



**Figure 3-17 Site location map (Tomiyama town, Koriyama City)**

3.3.3 Evaluation results

Table 3-49 shows the results of the efficiency evaluation. It was confirmed that more than 15 locations/day were able to be installed in all the fields. It has also been confirmed that removal can be done in the same period as installation. For both installation and removal, the work time per 1 location was about 10 minutes from the installation of the safety harness to the installation and removal of the equipment. For analysis time, refer to the next page and after the page. As a result of the evaluation, it was confirmed that the time required for the investigation and analysis was able to be reduced by 50% or more compared with the conventional technology. However, it should be noted that this does not apply to the locations where it takes time to travel between investigation locations, go in and out of deep manholes, and safety zone release due to heavy traffic.

Efficiency was evaluated in 2 ways under the same conditions as the feasibility evaluation. In addition, the number of days required for installation and removal in the investigation of this technology is set at 15 locations/day for both installation and removal based on the results of the demonstration study. Also, the number of days required for analysis (AI analysis) in this technology is set based on the results of the demonstration study (refer to Table 3-34). For the detailed investigation, the investigation volume is assumed to be 300 m/day for the CCTV camera inspection, and the number of investigation days is calculated from the length of the coverage. On the other hand, the conventional technology is set from "Sewerage pipe management cost estimation guideline - 2015 -."

The results of the efficiency evaluation are shown in Tables 3-50 and 3-51.

Evaluation (1): Business feasibility evaluation based on the investigation narrowing down from large to middle sectors.
(Detailed investigation is not subject to the evaluation as the detailed investigation is not conducted.)

Evaluation (2): Business feasibility evaluation based on the investigation narrowing down from middle to small sectors.
(Since the scope of the detailed investigation is calculated based on the results of narrowing down areas, the detailed investigation is subject to evaluation.)

**Table 3-49 Efficiency (investigation) evaluation results**

| City Name | District | Evaluation | | Evaluation locations (number of locations) | | Narrowing down result (CCTV camera inspection length (m)) | |
|---|---|---|---|---|---|---|---|
| | | | | This technology | Conventional technology | This technology | Conventional technology |
| Koriyama City | Otsuki Town | ② | Investigation + Analysis + Detailed Investigation | 7 | 5 | 505.02 | 658.36 |
| | Fukuyama Town | ② | Investigation + Analysis + Detailed Investigation | 18 | 8 | 3,655.52 | 4,337.54 |
| Tsukuba City | Jonan Treatment District | ① | Investigation + Analysis | 24 | 24 | — | — |
| Nagoya City | Hyogo District | ② | Investigation + Analysis + Detailed Investigation | 9 | 4 | 2,396.92 | 2,396.92 |
| | Kaminokura District | ② | Investigation + Analysis + Detailed Investigation | 20 | 10 | 2,099.74 | 3,511.58 |
| Kobe City | Kakogawa River Basin | ① | Investigation + Analysis | 14 | 14 | — | — |
| | Iwaoka Basin | ② | Investigation + Analysis + Detailed Investigation | 27 | 16 | 4,384.68 | 6,079.45 |
| | Nishijin Basin | ② | Investigation + Analysis + Detailed Investigation | 29 | 18 | 10,976.26 | 12,879.85 |
| Kumamoto City | Koto Basin | ② | Investigation + Analysis + Detailed Investigation | 52 | 33 | 14,768.98 | 16,489.91 |
| | Tomiai Basin | ① | Investigation + Analysis | 19 | 19 | — | — |
| Total | | | | 219 | 151 | 38,787.12 | 46,353.61 |

« Evaluation (1) Results »

In the case of "Tsukuba City (Jonan Treatment Area)," "Kobe City (upstream Kakogawa River basin)," and "Kumamoto City (Tomiai Basin)" where detailed investigations were not necessary, the reduction of the investigation and analysis time was 64.0% on average.

**Table 3-50 Efficiency evaluation (1) results**

| Items \ local government | 3) Tsukuba City | | 6) Kobe City (Upstream of Kakogawa River) | | 9) Kumamoto City (Tomiai Basin) | |
|---|---|---|---|---|---|---|
| | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology |
| Type of investigation | Large to medium sector | | Large to medium sector | | Large to medium sector | |
| Target area (ha) | 1,500 | 1,500 | 1,500 | 1,500 | 150 | 150 |
| Observation method | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter |
| 1) Locations | 24 | 24 | 14 | 14 | 19 | 19 |
| 2) Investigation Period (days) | 4 | 10 | 2 | 6 | 4 | 10 |
| 3) Analysis Period (days) | 1.00 | 3 | 0.50 | 2 | 0.75 | 3 |
| 4) Detailed Investigation Period (Days) | — | — | — | — | — | — |
| 5) Total Days ((2) + (3) + (4)) | 5.00 | 13 | 2.50 | 8 | 4.75 | 13 |
| 6) Rating (%) | 38% | 100% | 31% | 100% | 37% | 100% |
| 7) Reduction (%) | **62%** | | **69%** | | **63%** | |

« Evaluation (2) Results »

In case of Koriyama City, Kobe City (Iwaoka and Nishijin Basin), Nagoya City (Kaminokura and Hyogo), and Kumamoto City (Koto), all of which were evaluated for detailed investigations, the duration reduction rate was 25.0% on average in 7 districts.

**Table 3-51 Efficiency evaluation (2) results**

| Items \ local government | 1) Koriyama City (Otsuki Town) | | 2) Koriyama City (Fukuyama Town) | | 7) Kobe City (along the Iwaoka River) | | 8) Kobe City (Nishijin Basin) | | 4) Nagoya City | | 5) Nagoya City (Kaminokura district) | | 10) Kumamoto City | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology | This technology | Conventional technology |
| Type of investigation | Medium to small sector | | Medium to small sector | | Large, medium to small sector (Phase 1 and 2) | | Large, medium to small sector (Phase 1 and 2) | | Medium to small sector | | Medium to small sector | | Large, medium to small sector (Phase 1 and 2) | |
| Target area (ha) | 70 | 70 | 130 | 130 | 165 | 165 | 900 | 900 | 10 | 10 | 20 | 20 | 600 | 600 |
| Observation method | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter | Acoustical device | Flowmeter |
| 1) Locations | 7 | 5 | 18 | 8 | 27 | 16 | 29 | 18 | 9 | 4 | 20 | 10 | 52 | 33 |
| 2) Investigation Period (days) | 2 | 2 | 4 | 4 | 4 | 8 | 4 | 10 | 2 | 2 | 4 | 6 | 8 | 18 |
| 3) Analysis Period (days) | 0.50 | 1 | 0.75 | 1.5 | 1.00 | 2 | 1.00 | 3 | 0.50 | 1 | 0.75 | 2 | 1.75 | 5 |
| 4) Detailed Investigation Period (Days) | 2 | 3 | 13 | 15 | 15 | 20 | 37 | 43 | 8 | 8 | 7 | 12 | 50 | 55 |
| 5) Total Days ((2) + (3) + (4)) | 4.50 | 6 | 17.75 | 21 | 20.00 | 30 | 42.00 | 56 | 10.50 | 11 | 11.75 | 20 | 59.75 | 78 |
| 6) Rating (%) | 75% | 100% | 87% | 100% | 66% | 100% | 75% | 100% | 95% | 100% | 59% | 100% | 77% | 100% |
| 7) Reduction (%) | **25%** | | **13%** | | **34%** | | **25%** | | **5%** | | **41%** | | **23%** | |

Evaluation (2) is a comparison including the detailed investigation, and the reduction effect in the investigation and analysis was 25.0% on average, which was a constant result, but the "50% reduction" as the target value was not able to be achieved in comparison with conventional technology. As for the cause of not achieving the target, it is considered that the detailed investigation volume is related, which is almost the same as the evaluation of business feasibility described in the previous session. In terms of efficiency, in the case of multi-location investigations, which is a characteristic of this technology, many investigations can be conducted in a short period, and the analysis time is also shortened so that the effectiveness is considered to be increased compared with the conventional technology. On the other hand, in the case of the investigation of about 10 locations in a small area, a large reduction effect is not produced because the conventional technology can be conducted in a short period.

# 4.Case study

4.1 Setting conditions

The cost reduction rate is evaluated by comparing the total cost (direct personnel cost + direct expense) required for the investigation, analysis, and subsequent detailed investigation between this technology and the conventional technology. In the evaluation, given the difference in the investigation method between this technology and the conventional technology, rather than simply comparing the investigation locations, the following scenarios leading to the detection of rainwater I&I are prepared and compared. (See Table 4-2).

**Table 4-1 Characteristics to be considered in comparative evaluation between the conventional technology and this technology**

| | |
|---|---|
| Conventional technology | The method in which a flow rate investigation is conducted at several investigation locations, by a quantitative indicator (m3) based on the analysis and evaluation of the results to compare the rainwater I&I volume at each location, preferentially conduct investigations and narrows down areas where countermeasures are effective. |
| This technology | Since the AI analysis results at the investigation locations are the value (feature quantity) calculated only for the detection of abnormality at those locations, it is difficult to compare it relatively with other investigation locations. Therefore, since it is difficult to determine the priority as in conventional technology, this technology is the method of conducting investigations at multiple locations over a wide area. |

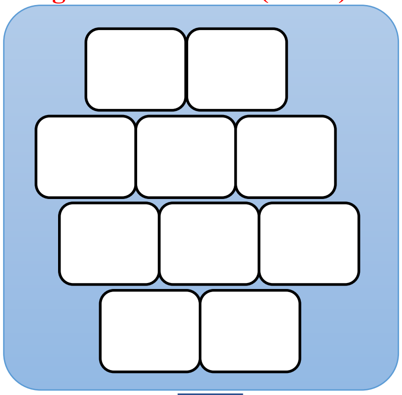
According to Table 3-26, conventional technology allows relative comparison based on a quantitative index, so it is possible to determine the priority of the detailed investigation. However, with this technology, since the feature quantity is an index specific to investigation locations and the relative comparison is not possible, to obtain the same result as the conventional technology, it is necessary to conduct the investigations at multiple locations over wide areas. In other words, when conducting the investigation using this technology, more investigation locations are required than those in the conventional technology.

**Table 4-2 Business feasibility comparison scenarios**

| | This technology | Conventional technology |
|---|---|---|
| Investigation | Multi-point investigation of small sectors in large sectors<br>*All small sectors are subject to the investigation regardless of the presence or absence of rainwater I&I. | (1) Narrowing down investigation from large to middle sectors<br>(2) Narrowing down investigation from middle to small sectors<br>*Areas, where the rainwater I&I volume is small or different are excluded from the target of the investigation during the narrowing down process. |
| Analysis | Analyze and evaluate all sites. (AI analysis) | Analyze and evaluate the total number of investigation locations in (1) and (2) above. (Work by engineers) |
| Detailed investigation | Conduct CCTV camera inspections in areas where abnormalities were detected | CCTV camera inspections were conducted in the areas narrowed down by (2) above. |

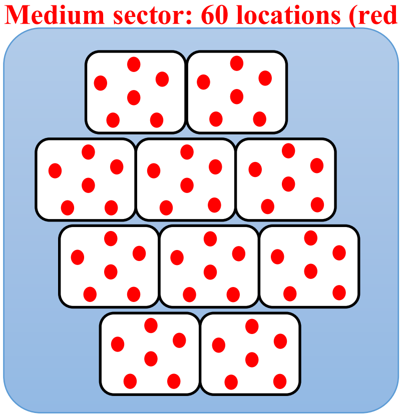
**Proposed technology I**
**Acoustic survey from large sectors (300 ha) to small sectors (5 ha)**

**Large sector: 300 ha (100%)**



| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | – | – |
| Analysis | – | – |
| Total | – | – |

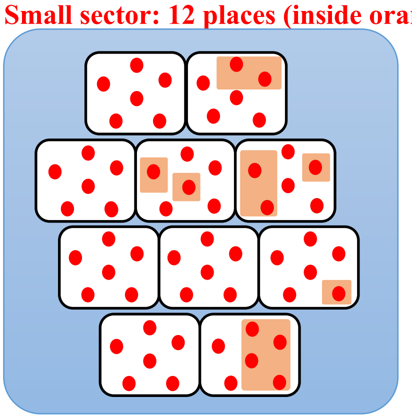
**Medium sector: 60 locations (red dot) x 5 ha = 300 ha (100%)**



- An acoustic device is installed in small sectors in the whole area to detect Rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | 60 | 16,730 |
| Analysis | 60 | 2,550 |
| Total | 60 | 19,280 |

**Small sector: 12 places (inside orange squares) x 5 ha = 60 ha (20%)**



At the small sectors where rainwater I&I was detected, conduct detailed investigation (CCTV camera) contributing to the countermeasure.

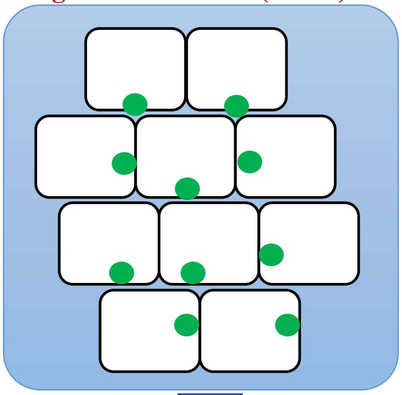
| | Number of locations and length | Expenses (1000 yen) |
|---|---|---|
| Investigation | 60 | 16,730 |
| Analysis | 60 | 2,550 |
| Details investigation | 12,600m (210m/ha) | 25,200 (2,000 yen/m) |
| Total | 300ha→60ha | 44,480 |

Legend
- Large sector (300 ha)
- Medium sector (30 ha)
- Rainwater I&I detection area
- Location of water level sensor installed location (conventional technology)
- Location of acoustic device installed (proposed technology)

**Figure 4-1 Flow of narrowing investigation using this technology**

## Conventional technology
## Narrowing down investigation from large sectors (300 ha) to medium sectors (30 ha) and small sectors (5 ha)

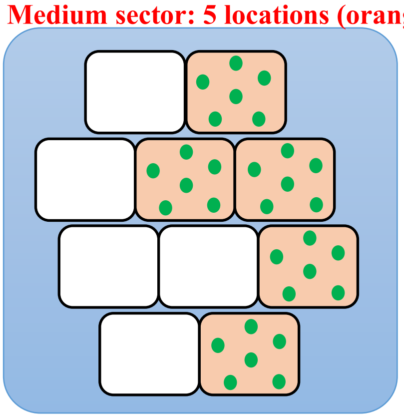
**Large sector: 300 ha (100%)**



- Install water level sensor in middle sectors within a large sector and detect rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | 10 | 9,310 |
| Analysis | 10 | 1,750 |
| Total | 10 | 11,060 |

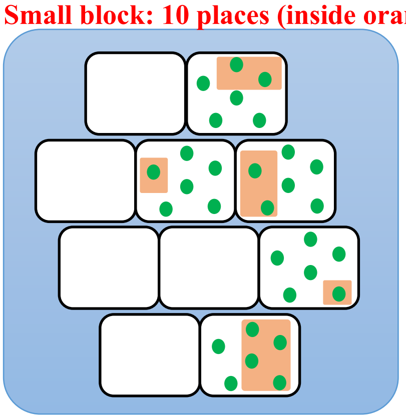
**Medium sector: 5 locations (orange) x 30 ha = 150 ha (50%)**



- Install water level sensor in small sectors within the medium sector and detect rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | 30 | 26,240 |
| Analysis | 30 | 920 |
| Total | 30 | 29,160 |

**Small block: 10 places (inside orange squares) x 5 ha = 50 ha (17%)**



At small sectors where rainwater I&I were detected, conduct detailed investigation (CCTV camera) contributing to the countermeasure.

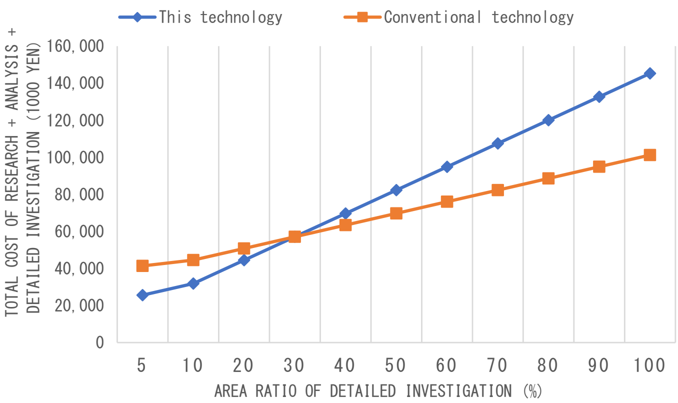
| | Number of Points "Extend | Expenses (1000 yen) |
|---|---|---|
| Investigation | 10＋30＝40 | 35,550 |
| Analysis | 10＋30＝40 | 2,670 |
| Details investigation | 10,550m (210m/ha) | 21,000 (2,000 yen/m) |
| Total | 300ha→50ha | 59,170 |

Legend
- Large sector (300 ha)
- Medium sector (30 ha)
- Rainwater I&I detection area
- Location of water level sensor installed (conventional technology)

**Figure 4-2 Flow of narrowing down investigation using the conventional technology**

| | |
|---|---|
| This technology | Investigations (60 sites) are conducted at 5ha of small sectors in 300 ha of large sector. |
| Conventional technology | (1) Narrowing down from 300 ha (100%) to 150 ha (50%) from large sector to medium sectors<br>↓<br>(2) Investigations are conducted at small sectors (5 ha) in a 30 ha x 5 area = 150 ha (30 locations).<br>↓<br>(3) As a result, the cost of investigation + analysis + detailed investigation was calculated for the areas requiring detailed investigation from 5 – 100%.<br><br>Ex: In the case of 5%, 150 ha x 5% = 7.5 ha is the area for the detailed investigation.<br>In the case of 100%, 150 ha x 100% = 150 ha is the area for the detailed investigation. |

The total cost of this technology is higher than that of the conventional technology when an abnormality of 90 ha or more, which is 30% of the 300 ha large sector, is detected (in the case of conventional technology: 30% (45 ha)). Conversely, in case an abnormality detection area is less than 30%, this technology tends to be cheaper than the conventional technology.



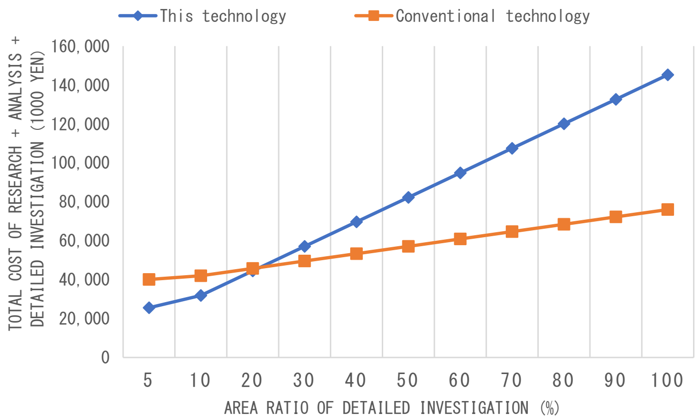

Unit: 1000 yen

| Area ratio of detailed investigation (%) | Total cost of research + analysis + detailed investigation | |
|---|---|---|
| | This technology | Conventional technology |
| 5 | 25,580 | 41,370 |
| 10 | 31,880 | 44,520 |
| 20 | 44,480 | 50,820 |
| 30 | 57,080 | 57,120 |
| 40 | 69,680 | 63,420 |
| 50 | 82,280 | 69,720 |
| 60 | 94,880 | 76,020 |
| 70 | 107,480 | 82,320 |
| 80 | 120,080 | 88,620 |
| 90 | 132,680 | 94,920 |
| 100 | 145,280 | 101,220 |

**Figure 4-3 Cost comparison between this technology and the conventional technology by percentage of area for detailed investigation (1)**

« Reference 1: When the size of the sector is reduced from 300 ha (100%) to 150 ha (50%) »

The total cost of this technology is higher than that of the conventional technology when the abnormality is detected at 60 ha or more, which is 20% of the 300-ha large sector. Conversely, if an abnormality detection area is less than 20%, the cost of this technology tends to be less than that of the conventional technology.



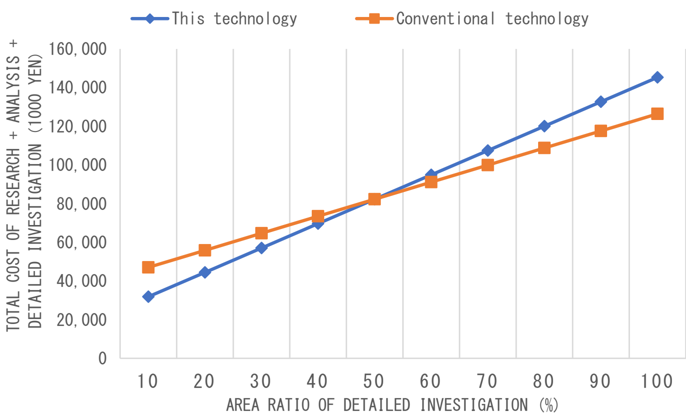

Unit: 1000 yen

| Area ratio of detailed investigation (%) | Total cost of research + analysis + detailed investigation: This technology | Conventional technology |
|---|---|---|
| 5 | 25,580 | 40,110 |
| 10 | 31,880 | 42,000 |
| 20 | 44,480 | 45,780 |
| 30 | 57,080 | 49,560 |
| 40 | 69,680 | 53,340 |
| 50 | 82,280 | 57,120 |
| 60 | 94,880 | 60,900 |
| 70 | 107,480 | 64,680 |
| 80 | 120,080 | 68,460 |
| 90 | 132,680 | 72,240 |
| 100 | 145,280 | 76,020 |

**Figure 4-4 Cost comparison between this technology and the conventional technology by percentage of area for detailed investigation (2)**

« Reference 2 When the size of the sector is reduced from 300 ha (100%) to 210 ha (70%) »

The total cost of this technology is higher than that of the conventional technology when the abnormality is detected at 150 ha or more, which is 50% of that of 300 ha. Conversely, if the abnormality detection area is less than 50%, the cost of this technology tends to be less than that of the conventional technology.




Unit: 1000 yen

| Area ratio of detailed investigation (%) | Total cost of research + analysis + detailed investigation: This technology | Conventional technology |
|---|---|---|
| 5 | 25,580 | 42,630 |
| 10 | 31,880 | 47,040 |
| 20 | 44,480 | 55,860 |
| 30 | 57,080 | 64,680 |
| 40 | 69,680 | 73,500 |
| 50 | 82,280 | 82,320 |
| 60 | 94,880 | 91,140 |
| 70 | 107,480 | 99,960 |
| 80 | 120,080 | 108,780 |
| 90 | 132,680 | 117,600 |
| 100 | 145,280 | 126,420 |

**Figure 4-5 Cost comparison between this technology and the conventional technology by percentage of area for detailed investigation (3)**

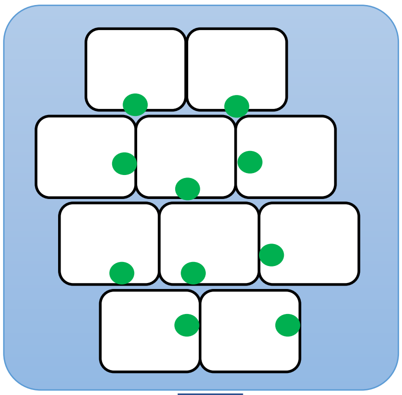
4.2 Efficient application of this technology

It is considered that many local governments have obtained the results of the previous rainwater I&I investigations. In such a case, since it is assumed that this technology will be utilized after utilizing existing information, case studies of the implementation effects in the patterns of the investigation are shown below.

It should be noted that although the scope of the detailed investigation is assumed in each case, the amount of detailed investigation varies depending on the actual investigation and analysis results. Therefore, it is necessary to estimate the effect of implementation in each local government by referring to this case based on the existing maintenance information, etc.

**Conventional technology + Proposed technology**
**Narrowing down investigation from large sector (300 ha) to medium sectors (30 ha) and small sectors (5 ha)**

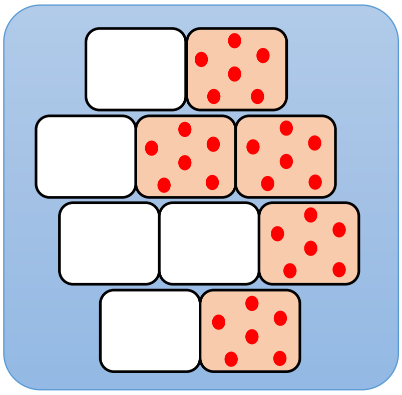
**Large sector: 300 ha (100%)**



◆ Install water level sensors at the edge of the middle sectors within a large sector to detect rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | 10 | 9,310 |
| Analysis | 10 | 1,750 |
| Total | 10 | 11,060 |

**Medium sector: 5 locations (orange areas) x 30 ha = 150 ha (50%)**

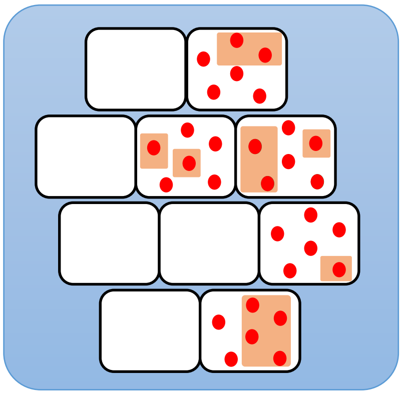


◆ Install acoustic devices at small sectors within the medium sectors to detect rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | 30 | 8,730 |
| Analysis | 30 | 2,210 |
| Total | 30 | 10,940 |

Rainwater I&I detected in 11 small sectors (orange squares in below)

**Small block: 12 places (orange squares) x 5 ha = 60 ha (20%)**



At small sectors where rainwater I&I was detected, conduct the detailed investigation (CCTV camera) contributing to the countermeasure.

| | Number of locations and length | Expenses (1000 yen) |
|---|---|---|
| Investigation | Water level 10 + Acoustic 30 = 40 | 18,040 |
| Analysis | Water level 10 + Acoustic 30 = 40 | 3,950 |
| Details investigation | 12,600m (210m/ha) | 25,200 (2,000 yen/m) |
| Total | 300 ha to 60 ha | 47,190 |

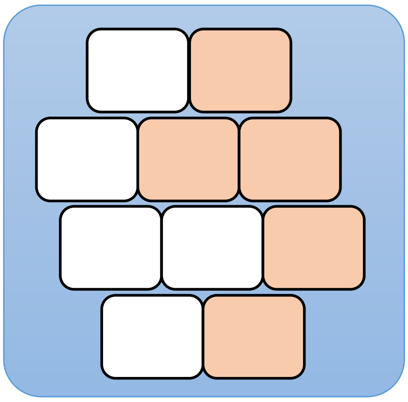
Legend

- Large sector (300 ha)
- Medium sector (30 ha)
- Rainwater I&I detection area
- Location of water level sensor installed (conventional technology)
- Location of acoustic device installed (proposed technology)

**Figure 4-6 Flow of narrowing down investigation combining this technology and the conventional technology**

**Proposed technology (utilizing existing information)**
**Acoustic investigation to narrow down from medium sectors (30 ha) to small sectors (5 ha) based on the existing information**

**Large sector: 300 ha (100%)**

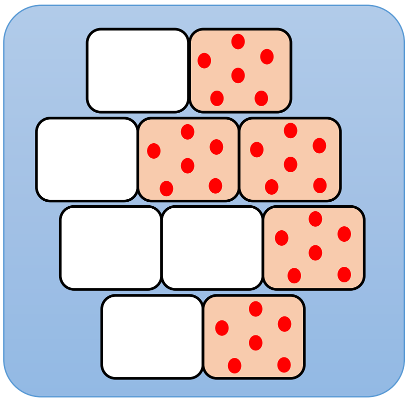


- There is the information by previous investigations that rainwater I&I is expected to occur in some middle sectors within a large sector.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| Investigation | | |
| Analysis | | |
| Total | | |

Existing information available
(Existing documents, case-based modeling technology, and conventional technology investigations)

**Medium sector: 60 locations (orange areas) x 5 ha = 300 ha (100%)**

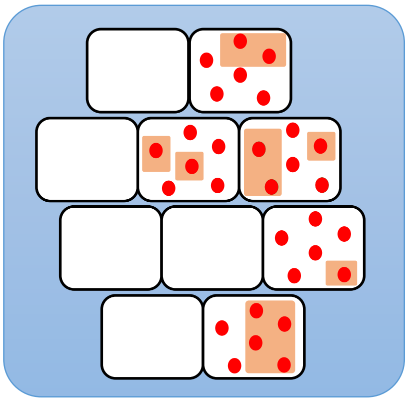


- Install acoustic devices at small sectors within the medium sectors to detect rainwater I&I.

| | Number of locations | Expenses (1000 yen) |
|---|---|---|
| investigation | 30 | 8,730 |
| Analysis | 30 | 2,210 |
| Total | 30 | 10,940 |

Rainwater I&I detected in 11 small sectors (orange squares in below)

**Small sector: 12 places (orange squares) x 5 ha = 60 ha (20%)**



Conduct the detailed investigation (CCTV camera) contributing to countermeasure at small sectors within the middle sectors to detect rainwater I&I.

| | Number of locations and length | Expenses (1000 yen) |
|---|---|---|
| Investigation | 30 | 8,730 |
| Analysis | 30 | 2,210 |
| Details investigation | 12,600m (210m/ha) | 25,200 (2,000 yen/m) |
| Total | 300 ha to 60 ha | 36,140 |

Legend

- Large sector (300 ha)
- Medium sector (30 ha)
- Rainwater I&I detection area
- Location of water level sensor installed (conventional technology)
- Location of acoustic device installed (proposed technology)

**Figure 4-7 Flow of narrowing down investigation of this technology using existing information**

4.3 Understanding the application effectiveness

Table 4-3 shows the evaluation result of the application effectiveness of this technology. In the case where there is a difference in the number of investigation locations and the investigation range between this technology and the conventional technology in consideration of the investigations' characteristics, this technology is expected to reduce the cost by about 25% compared with the conventional technology ((2)/(1) in table 4-3). As a reference, when (3) the case of combining with the conventional technology, (4) the case of utilizing existing information, as the effective method of utilizing this technology, are compared with (1) the case of the conventional technology, the cost reduction effect of the case (3) is slightly smaller than that of the case (2). On the other hand, in the case of (4), since the investigation volume itself is small, the most effective business feasibility can be obtained (cost reduction of approximately 40%).

Although this technology is superior in that it can be quickly installed at multiple locations over wide areas and the speed of AI analysis in abnormality detection is also fast, since it can only determine the presence or absence of abnormality detection, it is not possible to classify the areas with small amount of rainwater I&I as the areas not subject to detailed investigation or the areas with low priority of the detailed investigation. Because of this technical characteristic, the scope (length) of the detailed investigation may become enormous if multiple locations are installed in the whole area of large and medium sectors.

Considering the above, in the practical stage, it is considered to be an efficient method to install multiple locations in areas of high priority where the occurrence of rainwater I&I is expected, based on the results of previous investigations and studies by local governments. In addition to the cases discussed in this study, various methods of investigation can be assumed to meet the needs of local governments. It is advisable to select effective methods of application based on the understanding of the characteristics of this technology.

**Table 4-3 Evaluation result of application effectiveness**

| Category | Investigation | Total project cost (1000 yen) *direct cost basis | Evaluation (%) | Notes |
|---|---|---|---|---|
| (1) Conventional technology | • Water level 40 locations<br>• CCTV Camera 10, 550 m | 59,170<br>(Including CCTV camera inspection cost: 21,000) | 100<br>(0) | base case |
| (2) This technology | • Acoustic 60 locations<br>• CCTV Camera 12, 600 m | 44,480<br>(Including CCTV camera inspection cost: 25,200) | 75.2<br>(-24.8) | (2)/ (1) |
| (3) Reference:<br>Conventional + This Technology | • Water level 10 locations<br>• Acoustic 30 locations<br>• CCTV Camera 12, 600 m | 47,190<br>(Including CCTV camera inspection cost: 25,200) | 79.8<br>(-20.2) | (3)/ (1) |
| (4) Reference:<br>This technology<br>(Using Existing Information) | • Acoustic 30 locations<br>• TV Camera 12, 600 m | 36,140<br>(Including CCTV camera inspection cost: 25,200) | 61.1<br>(-38.9) | (4)/ (1) |

# 5. Example of preliminary calculation of investigation and analysis

5.1 Standard work of this technology

Analysis part: Rainwater I&I Countermeasure Establishment Plan Manual for Separate Sewer System - March 2009 -

Compiled based on page 232 of the Japan Sewerage New Technology Promotion Organization, 6. Cost Estimation References (draft)

1. Confirmation of basic work, 2. Basic investigation, 4. Preparation of submitted documents, 5. We use the above-accumulated data and the same manual method for planning consultation
3. For the identification of the cause of rainwater I&I, we estimate the cost by the research

**Table 5-1 Standard work of this technology**

| Work Items | Work contents | Details |
|---|---|---|
| 1.Confirmation of Basic Work | ・Confirmation of basic items and meeting to confirm requirements | ・Target areas, work policies and work schedules |
| 2. Basic Investigation | | |
| 2-1. Collection and arrangement of materials | ・Arrangement of the status of rainwater I&I<br>・Arrangement of the current plan<br>・Arrangement of existing facilities and facilities' outlines<br>・Arrangement of maintenance and management status | ・Arrangement of pipes, pumping stations, rainwater I&I going into treatment plants, damage conditions, and other ripple effects<br>・Arrangement of superordinate plans, overall sewage plans, authorization plans, various related plans, etc.<br>・Arrangement of the scale and capacity of existing facilities and equipment, the year of installation, and the degree of deterioration<br>・Arrangement of records of inspection and repair of facilities and equipment, status of deterioration of pipelines, and changes in maintenance and management costs |
| 2-2. Understanding regional characteristics for field investigation | ・Understanding regional characteristics<br>・Understanding the status of facilities and equipment | ・Understanding topography, river and waterway conditions, and housing conditions<br>・Understanding the status of existing sewerage-related facilities |
| 2-3. Arrangement of issues | ・Arrangement of the current issues | ・Arrangement of the current issues and the problems at each facility |
| 2-4. Summary and review | ・Preparation, review, and finalizing of policies in work items | ・Review and finalizing of policies and review of work contents in the "Basic Investigation" |

| Work items | Work contents | Details |
|---|---|---|
| 3.Identification of the cause of rainwater I&I | | |
| 3-1. Narrowing down investigation of rainwater I&I generation area | ・Narrowing down investigation | ・Acoustic investigation (cost estimated separately) |
| 3-2. Arrangement of investigation results | | ・Arrangement of the acoustic investigation results |
| 3-3. Narrowing down the rainwater I&I locations | | ・Analysis and evaluation by AI analysis |
| 4. Preparation of submitted documents | | ・Preparation of reports, drawings and other related documents |
| 5. Planning consultation | ・Planning consultation with the client | ・Consultation on rainwater I&I investigation |

Remarks on the cost estimation

(1) Target area: 300 ha

(2) Design standard construction period: about 3 months

(3) Correction: correction factor = (x/300) 0.55 $(x \geqq 100)$

correction factor = 0.00182 x + 0.364 $(x < 100)$, x = target area (ha)

(4) Other consideration items for the cost estimation:

- The work related to the investigation of the narrowing down area of the rainwater I&I generation is calculated separately.
- The cost estimation of the acoustic investigation is conducted separately by the research body with reference to the "Sewerage Pipeline Facilities Maintenance and Management Cost Estimation Material 2015 (Japan Sewage Pipeline Management Association).

5.2 Project cost calculation results

(Condition) Target area : 20ha
Acoustic investigation locations : 20 locations

**Analysis part: 1,250,000 yen**

| Work items | Approximate price (yen) | Notes |
|---|---|---|
| 1. Confirmation of basic work | 37,580 | |
| 2. Basic investigation | 261,840 | |
| 3. Narrowing down the rainwater I&I generation area | 612,450 | |
| 4. Preparation of submitted documents | 130,920 | |
| 5. Planning consultation | 210,600 | Assumed 3 times |
| Total | 1,250,000 | Round down at 1,000 yen |

**[Acoustic investigation part]: 5,950,000 yen**

| Name | Shape and dimensions | Units | Quantity | Unit price | Price | Notes |
|---|---|---|---|---|---|---|
| 1. Direct operating expenses | | | | | | |
| (1) Acoustic investigation | | Set | 1 | | 3,197,140 | |
| Total direct operating expenses | | | | | 3,197,140 | |
| | | | | | | |
| 2. Overhead cost | | | | | | |
| Common temporary cost | | Set | 1 | | 261,206 | |
| Safety cost | | Set | 1 | | 144,846 | |
| Net operating cost | | | | | 3,603,192 | |
| Site management cost | | Set | 1 | | 1,469,381 | |
| Net working cost | | | | | 5,072,573 | |
| General and administrative expenses | | Set | 1 | | 1,027,703 | |
| Total indirect operating expenses | | | | | 2,758,290 | |
| | | | | | | |
| Actual situation investigation (A) | | | | | 5,950,000 | Round down at 1,000 yen |

**[Acoustic investigation]: 3,197,140 yen**

| Name | Shape and dimensions | Units | Quantity | unit price | Amount | Notes |
|---|---|---|---|---|---|---|
| Acoustic investigation | Installation | Locations | 20 | 6,328 | 126,560 | |
| | Removal | Locations | 20 | 6,328 | 126,560 | |
| | Patrol inspection | Locations | 20 | 6,103 | 122,060 | |
| | Machine loss | Days x Locations | 600 | 500 | 300,000 | |
| | Preparation of report | Locations | 20 | 126,098 | 2,521,960 | |
| Total | | | | | 3,197,140 | |

5.3 Computation time for AI analysis

Table 5-2 shows the computer specifications for the AI analysis in the demonstration experiment. By using a computer with a CPU equivalent to Xeon W-2125 4.0GHz, it takes only about 6 hours from the acquisition of acoustic data for 1 month at 1 location to display the results. By increasing the number of PCs, it is possible to analyze multiple locations simultaneously.

On the other hand, with respect to conventional technology, although it is possible to process the data efficiently until the data arrangement, it takes much longer time for the confirmation time by the engineer (human) at the stage of analysis and evaluation when the number of locations increases. In this technology, the processing time varies greatly depending on the performance of the computers and the number of the computers. By installing multiple high-performance computers, the processing time is reduced, but it is necessary to analyze the number of the analysis locations and the cost required for the required number of computers in advance.

**Table 5-2 Analysis specifications used in the analysis in the demonstration**

| Items | Time required | Notes |
|---|---|---|
| SD card: 1 month's worth of audio data (approx. 15.0 GB) read by card reader<br>PC: CPU Xeon2125 4.0Ghz<br>Memory 128GB ECC<br>HD M.2 PCle SSD512GB | | |
| Data capture | 7min | Reading through a card reader |
| Noise processing and analysis | 270min | Establishment of sunny days patterns |
| Evaluation | 60min | Abnormality detection<br>(Creating graph) |
| Total | 337min = ~6.0hr | |
| Analysis time in the demonstration experiment | | |
| 5 locations | 6hr | 8 PCs<br>(with 4 card readers) |
| 10 locations | 12hr | |
| 15 locations | 12hr | |
| 20 locations | 18hr | |
| 50 locations | 42hr | |
| 100 locations | 78hr | |

In the demonstration experiment, Xeon 2125 was used as the CPU, and Table 5-3 shows the comparison of the total time for the same processing with 1 month's acoustic data (about 15.0 GB) using other CPUs. The price of a PC in Table 5-3 is the general price as of April 2020.

If the PC specification used in the demonstration experiment is considered to be medium performance, the calculation time will be increased or decreased by CPU specification. In the case of the high specification (high specification 2) shown in Table 5-3, it is possible to complete the analysis in half of the time required in this demonstration experiment. The purchase price of a high-spec PC is high, so in practice, it is necessary to select the PC specifications to be used based on the number of analysis locations and the constrained period (delivery schedule).

**Table 5-3 Effect of CPU differences on computation time**

| | Low specification 1 | Low specification 2 | Demonstration experiment PC Specifications | High specification 1 | High specification 2 |
|---|---|---|---|---|---|
| CPU name and clock count | Core i5 9400 | Ryzen 5 3600 | Xeon 2125 | Core i9 9900K | Ryzen 9 3950K |
| Clock count | 2.9 GHz | 3.6 GHz | 4.0 GHz | 3.6 GHz | 3.5 GHz |
| Number of cores | 6 | 6 | 4 | 8 | 16 |
| Number of threads | 6 | 12 | 8 | 16 | 32 |
| Installed RAM | 16GB | 16GB | 128 GB | 32 GB | 64GB |
| Price of a PC (As of April 2020) | 80,000 yen | 100,000 yen | 150,000 yen | 200,000 yen | 300,000 yen |
| Data acquisition time | 10 min | 10 min | 10 min | 10 min | 10 min |
| Noise processing and analysis time | 390 min | 340 min | 270 min | 210 min | 110 min |
| Evaluation time | 85 min | 75 min | 60 min | 45 min | 25 min |
| Total time | 485 min | 425 min | 340 min | 265 min | 145 min |
| Total time savings compared to the PC used in this technology | 43% | 25% | — | -22% | -57% |

# 6. Overview of AI analysis in a demonstration study

In recent years, AI (Artificial Intelligence) has proven its effectiveness by applying machine learning using neural networks such as deep learning to various social issues. By comparing human and machine evaluations, the report shows that modern AI can replace humans in image and speech recognition. What's more, AI has advantages over humans, such as being free of human error and working 24 hours a day.

Deep learning is a form of machine learning in which the hidden layers of a neural network are arranged in multiple stages, and the computer optimally selects an input parameter called a feature quantity, thereby dramatically improving learning accuracy in image recognition. However, the realization of deep learning requires a large amount of training data and a computer with powerful computing power. Therefore, when this project is applied to the case of detecting rainwater I&I from the acoustic data of a sewerage system, it is necessary to prepare a very powerful computer for collecting and analyzing a large amount of the acoustic data. In the case of the acoustic data, it is obvious that the time domain and the frequency domain parameters are the feature values, and the merit of using deep learning is small.

From the viewpoint of low cost, high efficiency, and high automation, the application of AI to the detection of rainwater I&I, which is the object of this study, is considered to be the application of discriminant analysis, subspace method, and support vector machine to the feature quantity evaluation of the acoustic data. Regarding this technology, considering the accuracy of rainwater I&I detection, calculation cost, model stability, and database requirements, the application of the subspace method in machine learning shown in Figure 6-1 is considered to be the most suitable calculation method.

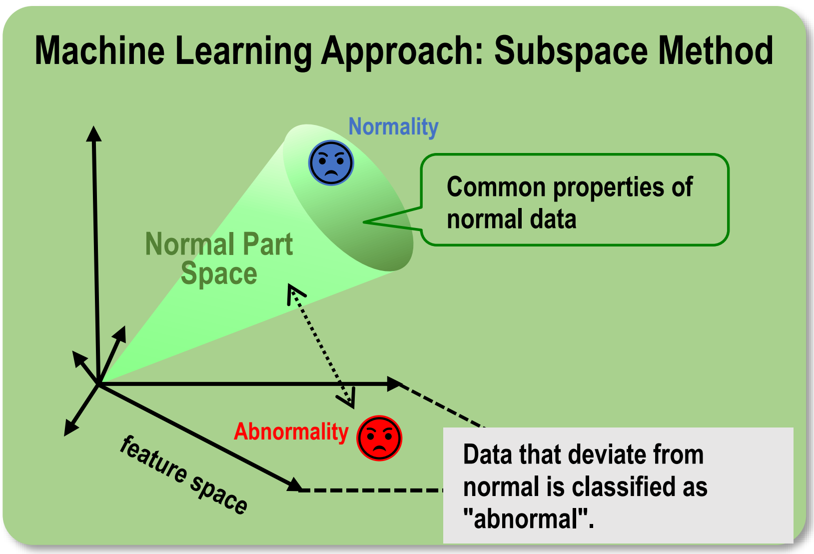



**Figure 6-1 Overview of the subspace method**

6.1 Flow of AI analysis

The overview of the analysis is as follows. First, the acoustic data in the sewerage service area were analyzed separately in the time domain and the frequency domain and the characteristic quantities such as amplitude and spectrum distribution were evaluated. Then, a weighting coefficient to each feature quantity is determined using AI, and the feature quantity FAI, which is a value obtained by summing the product of each feature quantity vector F and the weighting coefficient vector w, is calculated. That is, the feature quantity FAI is expressed by the following equation using the feature quantity vector F and the weight coefficient vector w.

$$F_{AI} = W^T F$$

Here, the superscript T of the weight coefficient vector w represents the transposition of the vector. This feature quantity is an index that contains various feature quantities such as the temporal change of acoustic power and sound quality in the sewer pipe.

When the feature quantity obtained in the field investigation of this study was analyzed, the change behavior with the periodicity of 24 hours was observed. This is natural because the pattern of life is repeated every day.

The acoustic data in the sewer pipe collected in the field investigation of this study was processed by the signal processing based on the flow shown in Figure 6-2 and determined the presence or absence of rainwater I&I. Details of the signal processing in each step are shown in Figure 6-2.

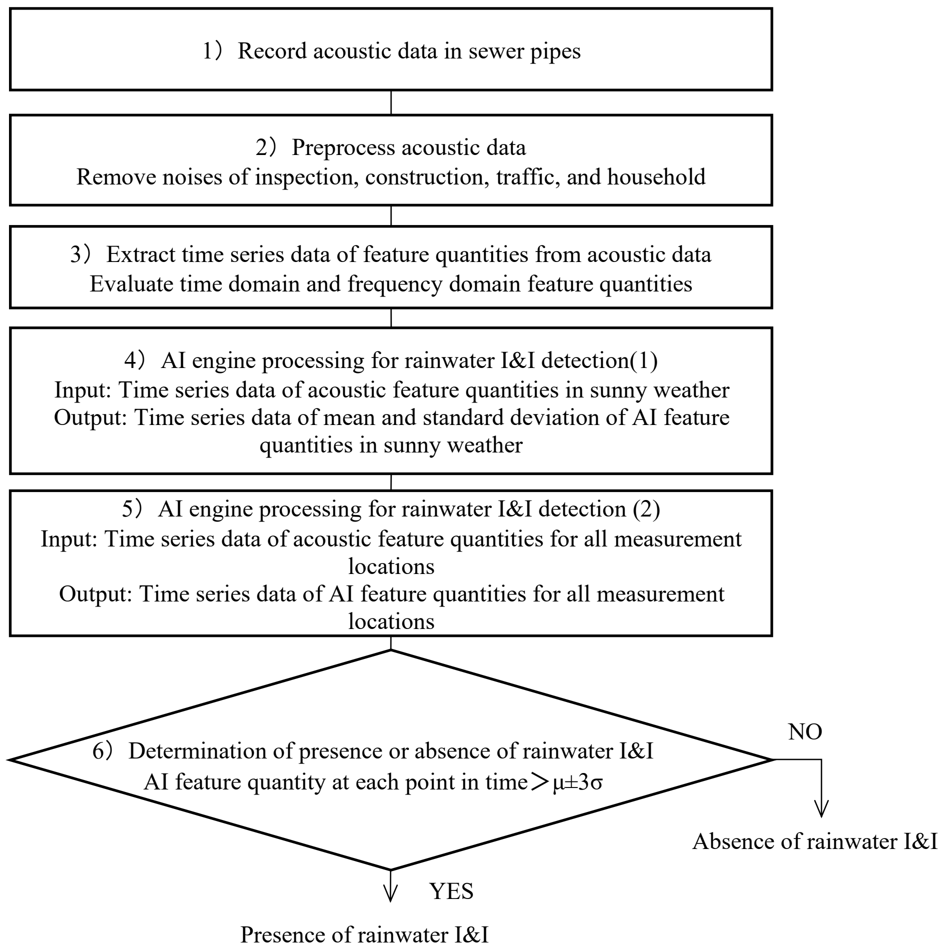



**Figure 6-2 Flow of data analysis in AI abnormality detection**

6.2 Recording of acoustic data in sewer pipes

The sound collector containing a voice recorder was installed in the upper part of the manhole to record the sound generated in sewer pipes. As the recording period of the acoustic data becomes longer, the standard deviation representing the variance of the evaluated feature quantity becomes smaller, so that the detection accuracy is considered to be improved.

In this project, about 1 month of acoustic data was recorded at each investigation location, and the analysis confirmed that it was possible to detect rainwater I&I if there was acoustic data for at least 3 weeks including rainy days.

6.3 Preprocessing of acoustic data

The recorded acoustic data includes noise unrelated to the sound of water flow in the sewer pipes, such as sound from inspection work such as installation of the sound collectors, replacement of a battery or a memory, passing sound of vehicles passing near the manhole, and construction sound being carried out nearby. In this study, a bandpass filter is applied to remove these noises, which are not related to the sound of water flow and are the obstacles for the analysis.

The left side of Figure 6-3 shows the acoustic waveform and its spectrogram before noise removal. Sudden noise is generated around the center of the horizontal axis of the figure due to vehicle passage, and in the spectrogram, high intensity appears in the low-frequency region. By bandpass filtering the acoustic waveform, the noise and the low-frequency components in the spectrogram were removed as shown in the right side of the figure.

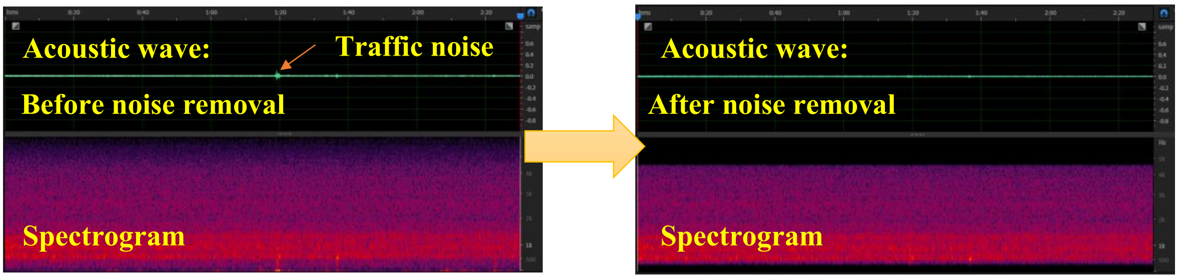



**Figure 6-3 Noise processing example of acoustic data**

6.4 Time series data extraction of feature quantities from acoustic data

When a human hears the acoustic data of the sewerage systems, it is recognized that some abnormality occurs when a loud sound or a sound of a different band appears. To identify the occurrence of the abnormality in a computer, a technique is employed in which acoustic power, frequency characteristics, and the like contained in acoustic data called a feature quantity are extracted at fixed time intervals to examine the temporal change of the feature quantity.

Acoustic data is the time-varying amplitude of sound and is expressed as a sine wave with a uniform period when expressed as a graph with time on the horizontal axis and amplitude on the vertical axis. A waveform composed of sine waves of different frequencies is called a distorted wave and is expressed by an addition formula of the sine waves of the constituted frequencies. For example, if the frequencies fl and f2 of amplitudes A1 and A2 are mixed, the following equation can be expressed:

$$A_1 \sin 2\pi f_1 + A_2 \sin 2\pi f_2$$

Acoustic data recorded in the sewer pipes are composed of sounds of many frequencies with different amplitudes and are expressed by a mathematical formula consisting of several sine wave terms in the above formula. To capture such characteristics of the acoustic data, 2 types of methods are considered: a method for observing the waveform of the acoustic data, and a method for observing the acoustic data for each frequency constituted. The former is called analysis based on time domain representation, and the latter is called analysis based on frequency domain representation. The analysis based on the frequency domain representation is generally called FFT (Fast Fourier Transformation), and by utilizing the orthogonality of the sine function, it is possible to extract the amplitude for each frequency component from complex acoustic data having several frequency components.

Therefore, in this technology, the time domain feature quantities obtained from the waveform information of the acoustic data and the frequency domain feature quantities obtained from the frequency analysis of the acoustic data were extracted. Concretely, a total of 282 feature quantities of 72-time domain feature quantities and 210 frequency domain feature quantities were evaluated for every 10-minute acoustic data with respect to the water flow acoustic data in the sewer pipes.

Table 6-1 shows the lists of the time and frequency domain features used in the AI analysis of this technology. These feature quantities can be easily obtained by using MATLAB ® which is commercial software for scientific and technological calculation. MATLAB is a numerical analysis software developed by MathWorks, and a function package called toolbox is sold for each analysis application, and statistics machine learning toolbox and signal processing toolbox are used for the feature calculation of this technology. For reference, the function of MATLAB which evaluates each feature quantity is described together with the feature quantity.

**Table 6-1 List of feature quantities for time and frequency domain used in AI analysis**

| Time Domain (72) | Frequency domain (210) |
|---|---|
| Maximum, max *(s (t))* | Frequency Power Spectrum (35) sum ($fft_{freq}$ (s (t)).^2) |
| Minimum, min *(s (t))* | Average Frequency Amplitude (35) mean (abs ($fft_{freq}$ (s (t))) |
| Standard deviation, std *(s (t))* | Mean Absolute Deviation (35) mad (abs ($fft_{freq}$ (s (t))) |
| Mean, mean *(s (t))* | Entropy (35) entropy (abs($fft_{freq}$(s(t))) |
| Median, median *(s (t))* | Skewness (35) skewness (abs ($fft_{freq}$ (s(t))) |
| Mode, mode *(s (t))* | Kurtosis (35) kurtosis (abs ($fft_{freq}$ (s(t))) |
| Variance, median *(s (t))* | |
| Deviation, var *(s (t))* | |
| Mean absolute deviation, mad *(s (t))* | |
| Autocorrelation coefficient, corr *(s (t), s (t -1))* | |
| Skewness of waveform intensity distribution, skewness *(s (t))* | |
| Kurtosis of the waveform intensity distribution, kurtosis *(s (t))* | |
| Waveform intensity quantiles with a probability of occurrence of 5% (20), quantile *(s (t))* | |
| Median value of the histogram divided by 20 intensity ranges of the waveform intensity distribution (20) [$bin_{center}$] = histogram (s (t), nbins = 20) | |
| Frequency of appearance of histogram obtained by dividing the intensity range of waveform intensity distribution into 20 parts (20) [$count_{frequency}$] = histogram (s (1), nbins = 20) | |

***The numbers in brackets represent the number of features, and each feature contains the MATLAB function used for evaluation.**

The meanings of the listed time domain features in Table 6-1 are listed below. These time domain features are generally used in acoustic analysis.[1)]

Maximum: Maximum value of the waveform amplitude
Minimum: Minimum value of the waveform amplitude
Standard deviation: An index of the variation in waveform amplitude.
Mean: Mean value of the waveform amplitude
Median: The value placed in the center when the waveform amplitude values are sorted in descending order.
Mode: The amplitude value that appears most frequently in the waveform amplitude
Variance: An index of the variation in waveform amplitude, expressed as the square of the standard deviation.
z score: An index that represents the variation in waveform amplitude with the mean value normalized to 0 and the standard deviation normalized to 1.
Mean Absolute Deviation: An index of the variation in the difference from the mean value of the amplitude of the acoustic data waveform.
Autocorrelation Coefficient: An index of similarity to adjacent acoustic data waveforms
Skewness: An index of how distorted the frequency distribution of waveform amplitude is from the normal distribution.
Kurtosis: An index of how sharp the frequency distribution of waveform amplitude is from the normal distribution.
Waveform Amplitude Quantile: The median value of the amplitude segment at every 5% probability of occurrence in the probability density distribution of the waveform amplitude
Interval Median Value: Median interval in each division when the waveform amplitude range is divided into 20 divisions
Appearance Frequency: Number of events in each division when the waveform amplitude range is divided into 20 divisions

In this technology, the waveform amplitude quantile, interval median value, and appearance frequency listed at the end of the time domain feature quantity are used as the feature quantity in each division when the whole distribution is divided into 20 divisions. The method of expressing the distribution shape by dividing the area is a frequent operation in statistics, and 2 is used for the smallest division number, and 1,000 is used for the largest division number2). In past research that extracted the feature quantity from the probability density distribution, it was reported that the whole distribution was analyzed by dividing it into 10 divisions3). In this technology, 20 divisions were adopted to express the distribution state accurately with a relatively small number in extracting the feature quantity.

Since the frequency domain feature quantities have different characteristics for each frequency, the following 6 feature quantities are evaluated for each fixed frequency in this technology. Since the sampling frequency is 44.1 kHz in this technology, the upper limit frequency that can be analyzed is 22.05 kHz according to the sampling theorem. In this study, this upper limit frequency was modeled after the previous study4), and 6 feature quantities of every 630 Hz divided into 35 parts, a total of 210 feature quantities were evaluated. The analysis points in the frequency analysis are 1,024 points (analysis time width 23.2 ms).

Frequency Power Spectrum: An index indicating the component intensity at each frequency of 630 Hz and is the sum of the squares of the component intensities.
Mean Value of Frequency Amplitude: An index indicating the component intensity at each frequency of 630 Hz, and the mean value of the component intensity
Mean Absolute Deviation: An index indicating the variation in the difference between the intensity of the frequency component and the mean value of the intensity of the component in each analysis window.
Entropy: An index indicating the variation in the frequency component intensity distribution. In physics, entropy is used as an index of variability, with a broad distribution having a high entropy and a narrow distribution having a low entropy.
Skewness: An index indicating how distorted the frequency component intensity distribution is from the normal distribution.
Kurtosis: An index indicating how sharp the frequency component intensity distribution is from the normal distribution.

Figure 6-4 shows the example of the maximum value and the minimum value which are exemplified as time series data of feature quantities extracted every 10 minutes from acoustic data recorded for 34 days.

In this technology, for 282 feature quantities, the time series data shown in Figure 6-4 is evaluated, and input to the rainwater I&I detection AI engine described later to obtain the feature quantity time series data and to determine the presence or absence of rainwater I&I.

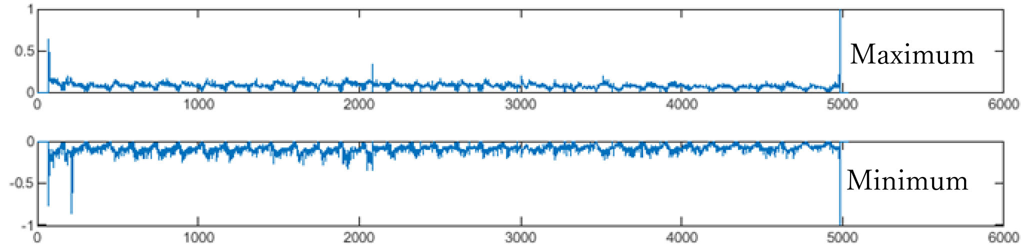



**Figure 6-4 Example of time series data of feature quantities extracted from acoustic data**

6.5 AI engine processing for rainwater I&I detection (1)

The time series data of the feature quantities only on sunny days obtained by removing the data on rainy days from the recorded acoustic data is input to the rainwater I&I detection AI engine to obtain the time series data (duration 24 hours) of the mean value and standard deviation of the feature quantity on sunny days.

Considering the effect of indirect infiltration after rainfall, the day excluding the day of rainfall and the next day of the rainfall was defined as sunny days.

Figure 6-5 shows an image of obtaining time series data of the mean value and the standard deviation of the feature quantities on sunny days from the time series data of the acoustic feature quantities on sunny days.

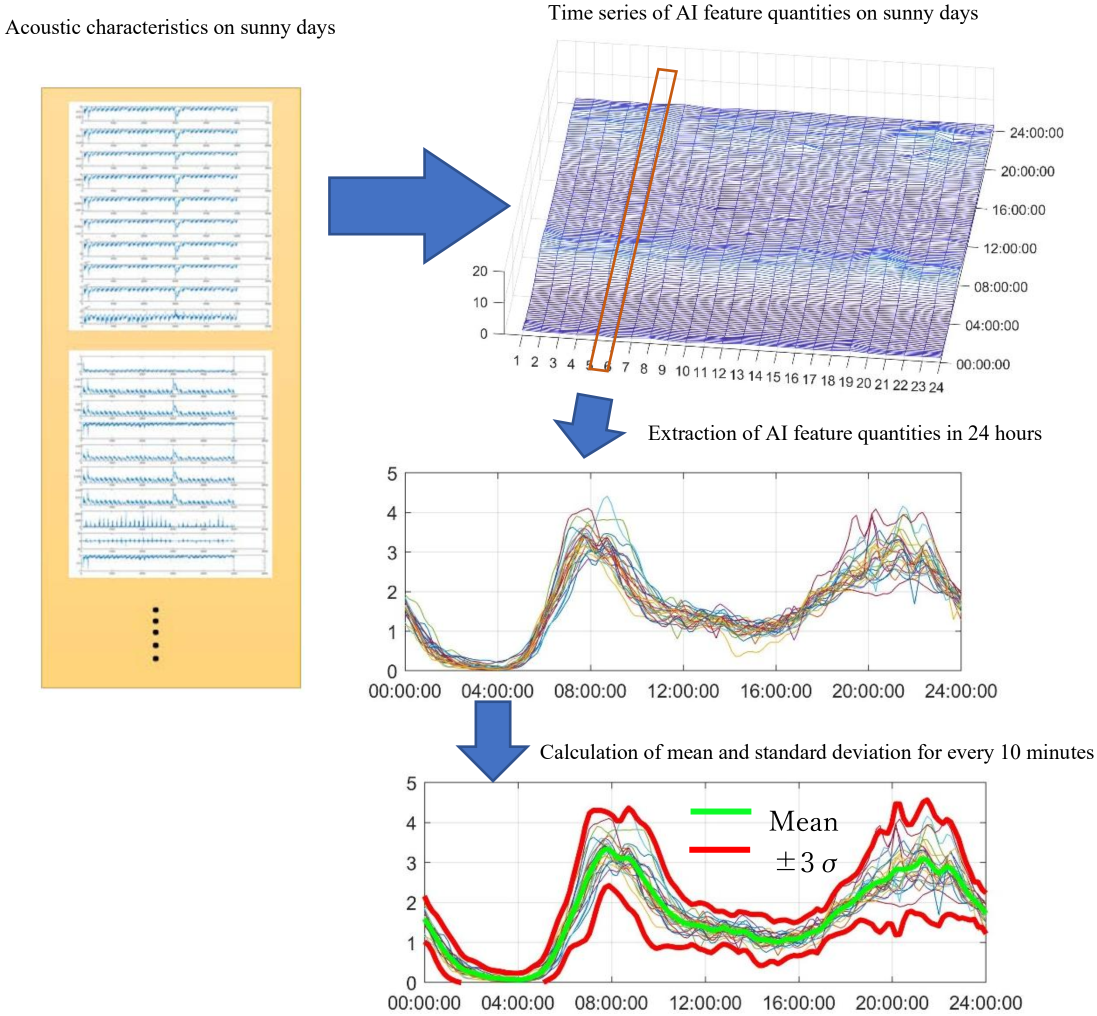
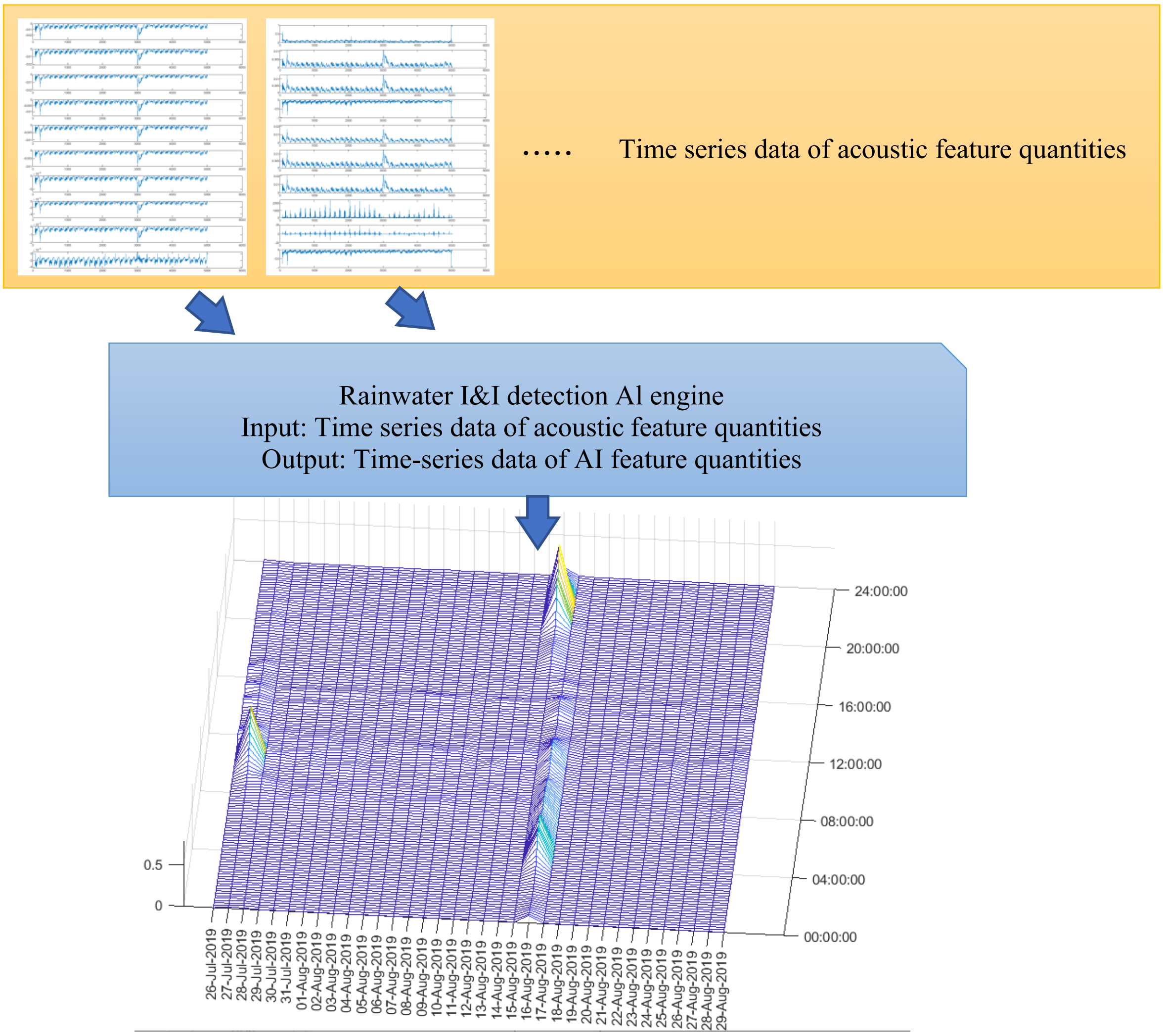



**Figure 6-5 Image of Conversion of Acoustic Feature Quantities Time Series Data to Feature Quantities**

6.6 AI engine processing for rainwater I&I detection (2)

Time series data of feature quantities of all measurement locations of the recorded acoustic data is input to the rainwater I&I detection AI engine to obtain time series data of feature quantities of all measurement locations.

Analysis image of this process 5) is shown in Figure 6-6. When 282 pieces of time series data of the acoustic feature quantities are inputted to the rainwater I&I detection AI engine, the engine outputs time series data of the feature quantities. In the process 5), 2- dimensional map of the date and time is obtained by obtaining the time series data of feature quantities of all the measurement dates.




Time series of Al Characteristics

**Figure 6-6 Image of input and output of the rainwater I&I detection AI engine**

6.7 Judgment on the presence or absence of rainwater I&I

The time series data of feature quantities obtained in “6.6 AI engine processing for rainwater I&I detection (2)” are separated every 24 hours. The relationship between the feature quantity (duration 24 hours) of the days to be determined and the mean feature quantity time series data (duration 24 hours) of the sunny days obtained by the “6.5 AI engine processing for rainwater I&I (1) ” is evaluated, and the case in which the threshold value is exceeded is regarded as an abnormal condition, that is, the condition in which rainwater I&I is detected (Figure 6-7).

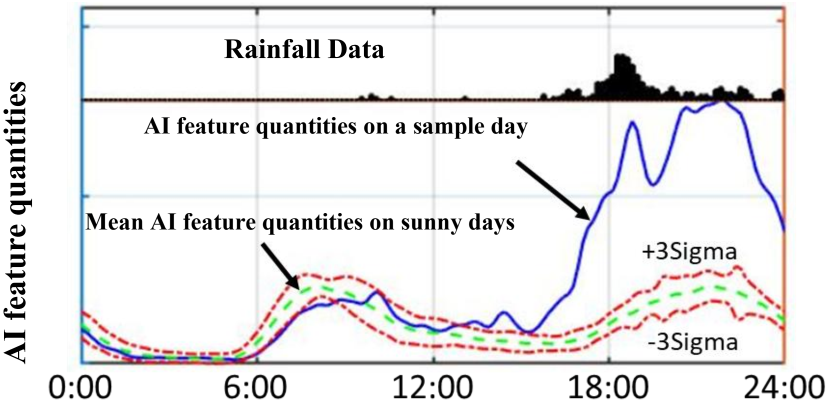



**Figure 6-7 Image of judgment of presence or absence of rainwater I&I**

The process shown in Figure 6-2 has been explained separately, and the process flow is summarized in Figure 6-8.

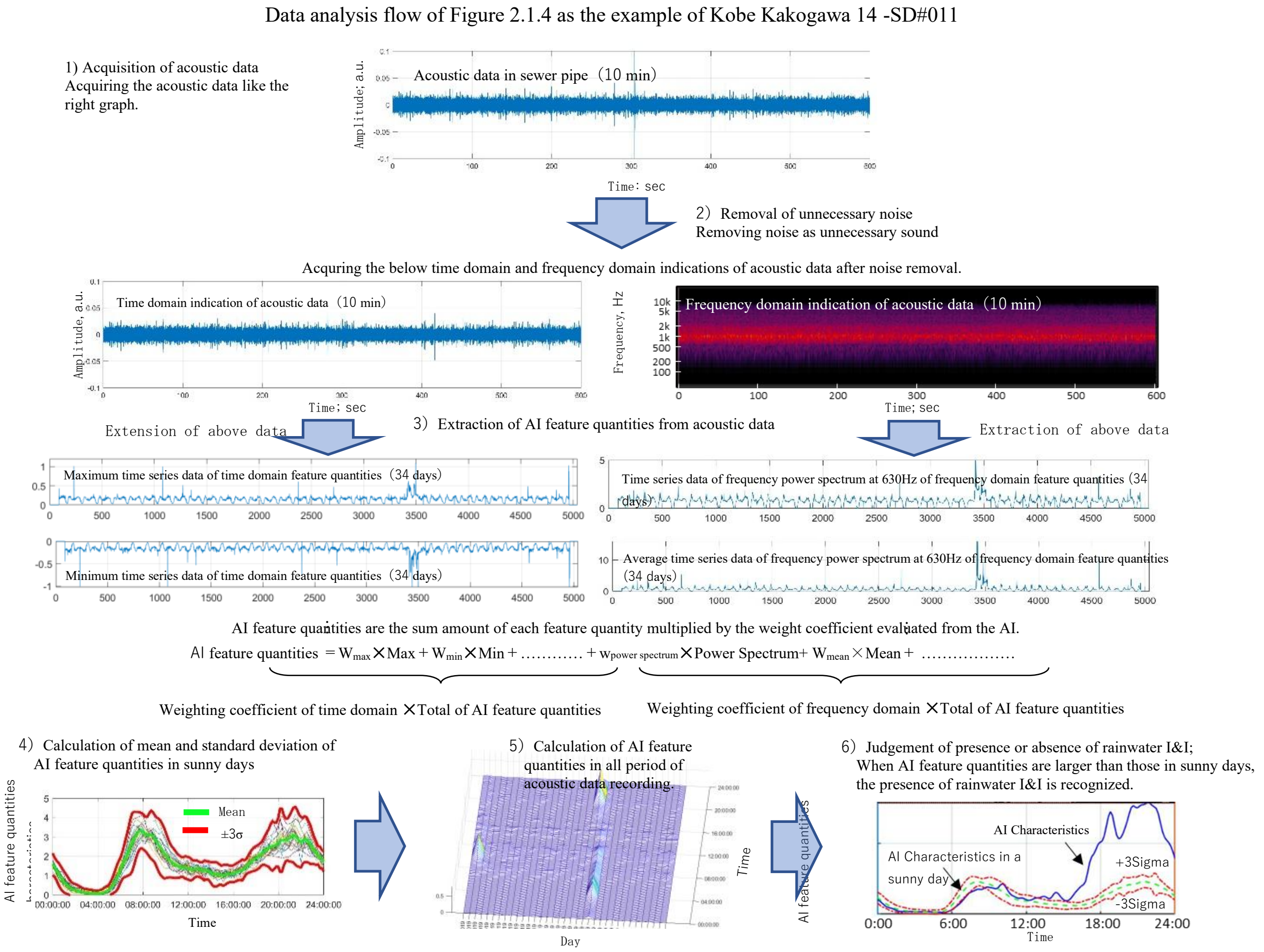



**Figure 6-8 Sequence of flow images for acoustic analysis**

6.8 Overview of rainwater I&I detection AI engine

The rainwater I&I detection AI engine used in this technology is the program created by the flow shown in Figure 6-9.

(1) The sound in sewer pipes recorded at various locations is used as input data.

(2) Signal processing equivalent to “6.3 Preprocessing of Acoustic Data” is applied to remove noise unrelated to the sound of water flow from acoustic data.

(3) Signal processing equivalent to “6.4 Time Series Data Extraction of Feature Quantities from Acoustic Data” is applied to evaluate the time series data of feature quantities of water flow sound in the sewer pipes.

(4) Machine learning of the acoustic feature quantities pattern on sunny days to determine weighting coefficients of each feature quantity necessary for feature quantity calculation.

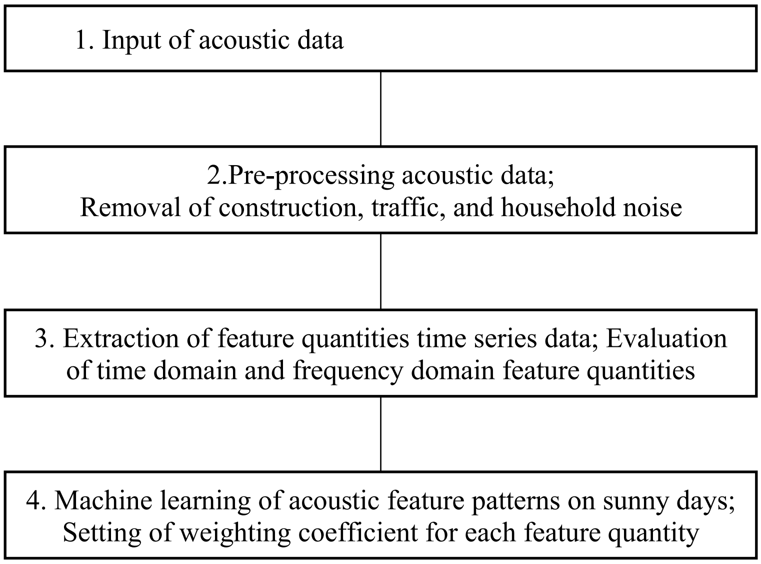



**Figure 6-9 Overview of rainwater I&I detection AI engine**

In the construction of the feature quantities evaluation formula in the above No. 4, an index having the following special features obtained by aggregating the feature quantities of the acoustic data was considered.

1. There is little change in the index evaluated on sunny days.
2. The index evaluated in the case of the presence of rainwater I&I is very different from the value on sunny days.

If such an index can be created, the presence or absence of rainwater I&I can be discriminated from the value of the index. In this technology, the sum of the values of each feature quantity and the weight coefficient is defined as the feature quantity as an index, and the optimum weight coefficient for the rainwater I&I detection is evaluated from the discriminant analysis method which is one of the methods of machine learning.

The optimum weighting coefficient "w" by the discriminant analysis method is determined by minimizing the difference between the feature quantity on sunny days and the mean feature quantity on sunny days and maximizing the difference between the feature quantity on rainy days and the mean feature quantity on sunny days The theory is expressed by the following equation.

$$\min_{w} \|w^T(F_s - \bar{F_s})\|^2 \quad and \quad \max_{w} \|w^T(F_r - \bar{F_s})\|^2$$

Here, $F_{s\ (sunny)}$, $\bar{F}_{s\ (sunny)}$, $F_{r\ (rainy)}$, and w represents the acoustic feature quantity vector on sunny days, the mean acoustic feature quantity vector on sunny days, the acoustic feature quantity vector on rainy days, and the weight coefficient vector, respectively. The superscript T of the weighting factor vector represents the transpose matrix. The weight coefficients described here are calculated based on the discriminant analysis.[5])

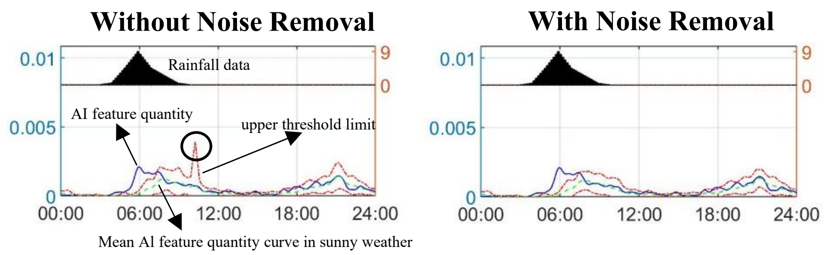
When the time series data of the acoustic feature quantities is input to the rainwater I&I detection AI engine, the time series data of the feature quantities is output.

6.9 Importance of preprocessing acoustic data

Finally, the importance of the pre-processing of the acoustic data is shown in the flow in Figure 6-2.

It is very important to remove noise from acoustic data to provide a correct threshold in the detection of rainwater I&I. An example of the influence of acoustic noise removal on the upper threshold limit is shown in Figure 6-10.

In this example, the upper limit of the threshold value at 11 AM is increased due to the influence of the noise generated by the inspection work at the same time (the time point circled on the left side of figure 6-10). Such an increase in the threshold value results in a false detection of rainwater I&I. Therefore, by removing the noise different from the water flow sound, the upper limit of the stable threshold can be set as shown on the right side of figure 6-10.




(Left) If noises due to the sound collector inspection conducted at around 11:00 AM are not removed, the upper threshold limit suddenly increases at the same time (Circled area in the figure).

(Right) By removing the work noise, the sudden increase in the upper threshold limit can be eliminated.

**Figure 6-10 Effect of acoustic noise removal on upper threshold limit**

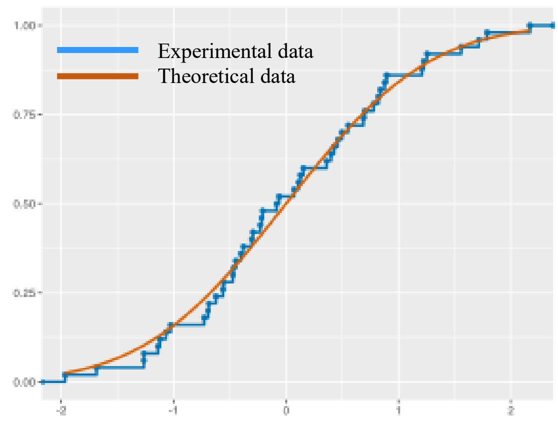
6.10 Judgment criteria for abnormality detection in this technology

In the independent research before the start of this study, the feature quantity of fine weather day showed the normal distribution. Therefore, it was considered to adopt the abnormal time discrimination standard generally adopted in taking the normal distribution. First, we examined whether to take a normal distribution on the acoustic data observation results obtained in this study.

6.10.1 Confirmation method for normal distribution

The value of a feature quantity at a certain time shows a probability distribution. It is known that such a stochastic variable statistic follows a probability density distribution represented by a normal distribution, the Poisson distribution, and the Rayleigh distribution.6)

Therefore, we performed the Kolmogorov Smirnov test7) on the feature quantity data on sunny days of the five cities collected in this study, and confirmed whether the normal distribution was obtained at the significance level 5%8), which is most used as the standard for the test. (Figure 6-11)




The distribution of theoretical probability can be obtained by using the experimental average, μ, and the standard deviation, σ.

When dis_max is defined as the maximum discrepancy between theoretical data and experimental data and n is defined as the number of samples, if dis_max<1.36/sqrt(n), the normal distribution, $N(m,\sigma^2)$, can be certified at 5% of the significance level.

In this case, the 5% of the significance level means that there is 5% probability that the AI feature quantities is not normally distributed.

Generally, 5% is used as the significance level in hypothesis testing.

**Figure 6-11 Summary of the Kolmogorov-Smirnov test**

6.10.2 Normalization confirmation result

In this study, the Kolmogorov-Smirnov test was performed on the feature quantities of sunny days based on the results of acoustic data obtained at the same locations as the flow rate investigation, and the confirmation results whether or not it follows the normal distribution are shown in Table 6-2 to 6-7.

As a result, the following points were clarified.

- All the locations outside the scope of the application did not follow the normal distribution.
- All the other locations followed a normal distribution.

In this study, the investigation results were obtained at approximately 200 locations, and all the applicable locations followed the normal distribution. From the above, it is judged that there is no problem in assuming that the feature quantities of the acoustic data recorded at the applicable locations take the normal distribution.

**Table 6-2 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Koriyama City)**

| Koriyama City | | | | | |
|---|---|---|---|---|---|
| Otsuki Town | | | Fukuyama Town | | |
| Location number | Normality | Notes | Location number | Normality | Notes |
| O1 | ○ | | F1 | ○ | |
| O2 | ○ | | F2 | ○ | |
| O3 | ○ | | F3 | ○ | |
| O4 | ○ | | F4 | ○ | |
| O5 | ○ | | F6 | ○ | |
| O6 | ○ | | F7 | ○ | |
| O7 | ○ | | F8 | ○ | |
| O8 | ○ | | F9 | ○ | |
| | | | F10 | ○ | |
| | | | F11 | ○ | |
| | | | F12 | ○ | |
| | | | F13 | ○ | |
| | | | F14 | ○ | |
| | | | F15 | ○ | |
| | | | F16 | ○ | |
| **8** | **8** | **0** | **15** | **15** | **0** |

**Table 6-3 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Tsukuba City)**

| Tsukuba City | | |
|---|---|---|
| Jōnan | | |
| Location number | Normality | Notes |
| T2 | X | Not applicable |
| T3 | X | Not applicable |
| T6 | X | Not applicable |
| T8 | 〇 | |
| T9 | X | Not applicable |
| T10 | X | Not applicable |
| T12 | X | Not applicable |
| T13 | 〇 | |
| T17 | 〇 | |
| T18 | X | Not applicable |
| T22 | X | Not applicable |
| T23 | X | Not applicable |
| T27 | 〇 | |
| T30 | 〇 | |
| T31 | 〇 | |
| T35 | 〇 | |
| T37 | 〇 | |
| T38 | 〇 | |
| T39 | 〇 | |
| T44 | X | Not applicable |
| T45 | 〇 | |
| T46 | 〇 | |
| T47 | X | Not applicable |
| T48 | X | Not applicable |
| **24** | **12** | **12** |

**Table 6-4 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Nagoya City)**

| Nagoya City | | | | | |
|---|---|---|---|---|---|
| Kaminokura | | | Hyogo | | |
| Location number | Normality | Notes | Location number | Normality | Notes |
| NK4 | 〇 | | NH2 | 〇 | |
| NK7 | 〇 | | NH6 | 〇 | |
| NK10 | 〇 | | NH10 | 〇 | |
| NK21 | 〇 | | NH14 | 〇 | |
| NK30 | 〇 | | NH26 | 〇 | |
| NK31 | 〇 | | NH30 | 〇 | |
| NK37 | 〇 | | NH35 | 〇 | |
| NK42 | 〇 | | NH43 | 〇 | |
| NK48 | 〇 | | NH44 | 〇 | |
| NK49 | 〇 | | | | |
| **10** | **10** | **0** | **9** | **9** | **0** |

**Table 6-5 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Kobe City) (1)**

| Kobe City | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kakogawa | | | Iwaoka Phase 1 | | | Iwaoka Phase 2 | | |
| Location number | Normality | Notes | Location number | Normality | Notes | Location number | Normality | Notes |
| Ka (1) | ○ | | Iwa (1) | ○ | | Iwa 6 -1 | ○ | |
| Ka (2) | ○ | | Iwa (2) | ○ | | Iwa 6 -2 | ○ | |
| Ka (3) | ○ | | Iwa (3) | ○ | | Iwa 6 -3 | ○ | |
| Ka (4) | ○ | | Iwa (4) | ○ | | Iwa 6 -4 | ○ | |
| Ka (5) | ○ | | Iwa (5) | ○ | | Iwa 6 -5 | ○ | |
| Ka (6) | ○ | | Iwa (6) | ○ | | Iwa 9 -1 | ○ | |
| Ka (7) | ○ | | Iwa (7) | ○ | | Iwa 9 -2 | ○ | |
| Ka (8) | ○ | | Iwa (8) | ○ | | Iwa 9 -3 | ○ | |
| Ka (9) | ○ | | Iwa (9) | ○ | | Iwa 9 -4 | ○ | |
| Ka (10) | ○ | | Iwa (10) | ○ | | | | |
| Ka (11) | ○ | | | | | | | |
| Ka (13) -1 | ○ | | | | | | | |
| Ka (13) -2 | ○ | | | | | | | |
| Ka (14) | ○ | | | | | | | |
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| **14** | **14** | **0** | **10** | **10** | **0** | **9** | **9** | **0** |

**Table 6-6 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Kobe City) (2)**

| Kobe City | | | | | |
|---|---|---|---|---|---|
| Seishin Phase 1 | | | Seishin Phase 2 | | |
| Location number | Normality | Notes | Location number | Normality | Notes |
| West (1) | 〇 | | West 1 -1 | 〇 | |
| West (2) | 〇 | | West 1 -3 | 〇 | |
| West (3) | 〇 | | West 1 -4 | 〇 | |
| West (4) | 〇 | | West 1 -5 | 〇 | |
| West (5) | 〇 | | West 1 -6 | 〇 | |
| West (6) | 〇 | | West 1 -7 | 〇 | |
| West (7) | 〇 | | West 1 -8 | 〇 | |
| West (8) | *X* | Not applicable | West 3 -1 | 〇 | |
| West (9) | *X* | Not applicable | West 3 -2 | 〇 | |
| West (10) | X | Not applicable | West 3 -3 -1 | 〇 | |
| | | | West 3 -3 -2 | 〇 | |
| | | | West 3 -4 | 〇 | |
| | | | West 3 -5 -1 | 〇 | |
| | | | West 3 -5 -2 | 〇 | |
| | | | West 6 -1 | 〇 | |
| | | | West 6 -2 -1 | 〇 | |
| | | | West 6 -2 -2 | 〇 | |
| | | | West 6 -3 | 〇 | |
| | | | West 6 -4 | 〇 | |
| | | | West 9 -1 | X | Not applicable |
| | | | West 9 -2 S | 〇 | |
| | | | West 9 -3 | X | Not applicable |
| | | | West 9 -4 | X | Not applicable |
| | | | West 9 -5 | X | Not applicable |
| **10** | *7* | **3** | **24** | **20** | **4** |

**Table 6-7 Confirmation results of normal distribution by Kolmogorov-Smirnov test (Kumamoto City)**

| Kumamoto City | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Koto Phase 1 | | | Koto Phase 2 | | | Tomiai | | |
| Location number | Normality | Notes | Location number | Normality | Notes | Location number | Normality | Notes |
| K01 | 〇 | | K17-1 | 〇 | | K37 | X | Not applicable |
| K02 | X | Not applicable | K17-2 | 〇 | | K42 | X | Not applicable |
| K05 | 〇 | | K17-3 | 〇 | | K43 | X | Not applicable |
| K07 | 〇 | | K17-4 | 〇 | | K44 | 〇 | |
| K08 | 〇 | | K17-5 | 〇 | | K46 | 〇 | |
| K12 | 〇 | | K17-6 | 〇 | | K48 | 〇 | |
| K13 | 〇 | | K17-7 | 〇 | | K49 | 〇 | |
| K14 | 〇 | | K17-8 | 〇 | | K50 | 〇 | |
| K15 | 〇 | | K17-9 | 〇 | | K53 | 〇 | |
| K16 | X | Not applicable | K17-10 | 〇 | | K54 | 〇 | |
| K17 | 〇 | | K17-11 | 〇 | | K56 | 〇 | |
| K18 | 〇 | | K17-12 | 〇 | | K61 | 〇 | |
| K19 | 〇 | | K17-13 | 〇 | | K63 | 〇 | |
| K20 | X | Not applicable | K09-1 | 〇 | | K64 | X | Not applicable |
| K26 | 〇 | | K09-2 | 〇 | | K65 | X | Not applicable |
| K27 | 〇 | | K09-3 | 〇 | | K66 | 〇 | |
| K28 | 〇 | | K09-4 | 〇 | | K68 | 〇 | |
| K31 | 〇 | | K09-5 | X | Not applicable | K69 | X | Not applicable |
| K32 | 〇 | | K09-6 | 〇 | | K70 | X | Not applicable |
| K33 | 〇 | | K09-7 | 〇 | | K711 | 〇 | |
| K35 | 〇 | | K09-8 | 〇 | | K712 | 〇 | |
| | | | K09-9 | 〇 | | K72 | X | Not applicable |
| | | | K09-10 | 〇 | | K73 | 〇 | |
| | | | | | | K76 | 〇 | |
| | | | | | | K79 | 〇 | |
| | | | | | | K80 | 〇 | |
| **21** | **18** | **3** | **46** | **22** | **1** | **26** | **18** | **8** |

6.11 Judgment on the presence or absence of rainwater I&I in this study

In this study, the relationship between the time series data of the feature quantity obtained by the acoustic data investigation on rainy days and the time series data of the average feature quantity (length of 24 hours) on sunny days is evaluated, and the case in which the threshold value is exceeded is regarded as the abnormal state, that is when the rainwater I&I is detected.

If the statistic takes a normal distribution, the 3σ method is often used as the threshold for abnormal conditions using artificial intelligence 9), 10). σ is the standard deviation representing the variance of the data. For a normal distribution, σ is "3 times the standard deviation of the mean value" (mean value ± 3σ.), which is 99.73% of the data exists in the range of $\mu \pm 3\sigma$, and only less than 0.3% of the data outside that range, resulting in rare events which occurs fewer than 3/1,000. Therefore, it was determined that the feature quantity on sunny days falls within the range of "3 times the standard deviation of the mean value " ($\mu \pm 3\sigma$), and outside the range of ($\mu \pm 3\sigma$) corresponds to the abnormal state due to the increase in the feature quantity due to rainwater I&I or the decrease in the feature quantity due to microphone submergence.

That is when the feature quantity at a certain point in time is equal to or less than the mean value of the sunny days' feature quantity at the corresponding point in time and the range of $\mu \pm 3\sigma$ calculated by the standard deviation σ, it is judged that there is the presence of rainwater I&I. At other times, it is judged that there is the absence of rainwater I&I.

Figure 6-12 shows the image of the analysis. The ±3σ curve (red dotted line in the figure) centered on the mean feature on sunny days (green dotted line in the figure) is compared with the larger/smaller feature quantity curve on the day of rainfall. In this example, after 15:30 when the rainfall data started to increase, the feature quantity for the day exceeded +3σ, therefore, it is judged that there is the presence of rainwater I&I.

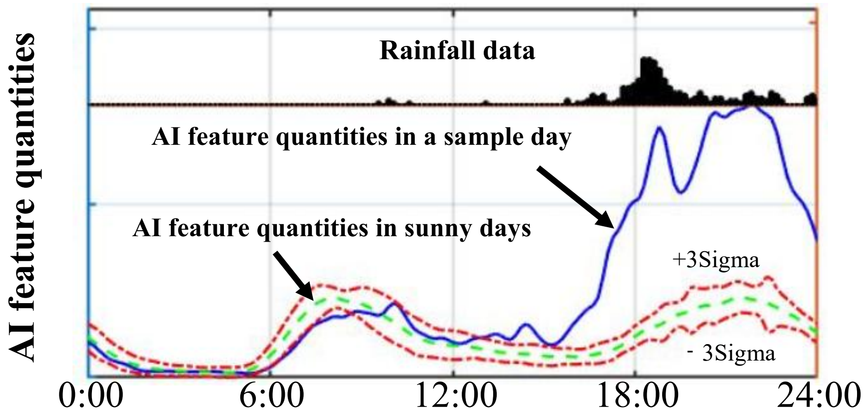


**Figure 6-12 Image of judgment on the presence or absence of rainwater I&I**

Figure 6-13 shows an example of a change in the feature quantity when only a specific period is cut out of Figure 6-12 with the examples of data observed in this study. The right figure of the graph shows feature quantity arranged in time series, and the left figure shows feature quantity in probability density.

As can be seen from the figure on the right, the feature quantity increases on rainy days and exceeds the threshold value, so that the rainwater I&I is detected on rainy days. Since the normal distribution is not confirmed here, there is no problem in arbitrarily setting the class width.

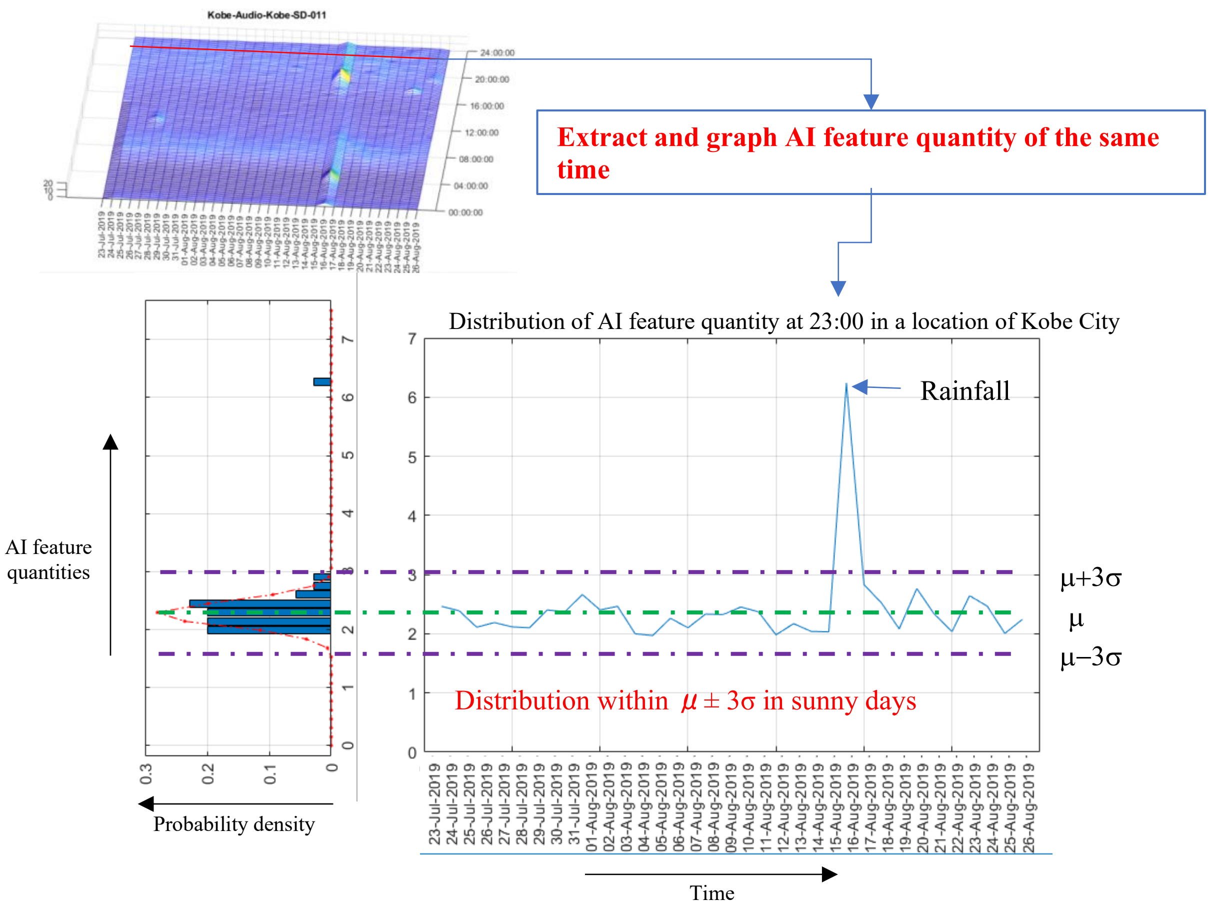


**Figure 6-13 Arrangement of feature quantities at the same period**

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# 7.Contact information

For inquiries regarding these technical guidelines, please contact with the following:



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| | |
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