Appendix 3

Result of Demonstration Test for River Litter Survey Using Stationary Cameras

1. Purpose of the demonstration test

The purpose of this demonstration test is to ensure the practicality of Section I.1 and Section II of the annex of this guideline from the perspectives outlined in Table 1.
In conducting the demonstration test, the points in Table 1 should be noted.

Table 1. Points for ensuring feasibility

Elements	Verification Method
Concreteness	Develop a method for the riverine litter survey using stationary cameras or organize the items to be included in the guidelines by having inexperienced surveyors conduct the survey under expert supervision.
Versatility	To ensure that the survey and analysis methods can be conducted in various environments both domestically and internationally without special technology, equipment, or personnel, organize not only advanced methods but also manual detection methods. Even for river flow, organize estimation methods using simple local surveys without existing data.
Representativeness	For stationary cameras at the river, since the shooting time, frequency, and range are limited, verify the representativeness by conducting multiple shooting methods (e.g., 1-minute intervals for 60 minutes, 1-minute intervals for 10 minutes, 1-meter width, 2-meter width) from a spatiotemporal perspective, demonstrating the validity of annual river flow estimates
Innovation	Compare the time required and the accuracy of litter quantification between human surveys and surveys using stationary cameras and AI, and verify whether this method can address the existing challenges of efficiency, accuracy, and reproducibility in conventional survey methods.. Accuracy will be verified by comparing with actual measurements using test litter of known weight.

2. Survey overview

The overview of the survey is shown in Table 2.

Table 2. Demonstration test outline

Items	Outline
Shooting time /frequency	- Stationary camera（Downstream camera）installation: June 13, 2024 - Video observation: From June 13, 2024 to September 25, 2024 - Shooting settings: 10:00 AM to 4:00 PM daily ・ Capture for 1 minute every hour during normal water level ・ Capture for 1 minute every 10 minutes during high water level - Visual inspection: June 26, 2024 (Normal water level), June 28, 2024 (High water level) - Mark-release-recapture experiment: July 18, 2024
Survey location	- Ishitegawa (a tributary of the Shigenobu River system, a first-class river, flowing through Matsuyama City, Ehime Prefecture) - Ishitegawa Water Pipe Bridge (located in Ichitsubonishimachi, Matsuyama City, Ehime Prefecture)
Spatial coverage of the survey area	Ishitegawa, Ishitegawa Water Pipe Bridge, and surrounding riverbanks
River overview	- Main river length: 36 km - Watershed area: 445 km² - Population in watershed: approx. 244,000 (Population density: approx. 550 people/km²) - Land use: Forest and other (wasteland, etc.) about 70%, urban area about 10%, farmland including paddy fields about 20%
Survey method (For details, refer to Appendix C)	The quantity and types of riverine litter will be surveyed and analyzed using the following four methods: I. Stationary camera at river survey & automatic detection by AI II. Stationary camera at river survey & manual detection from images III. On-site visual inspection IV. Mark-release-recapture experiment Note: (i) The timing of shooting, selection of survey locations, installation methods of shooting equipment, and expansion estimation for annual flow volume in the stationary camera at river surveys (I, II) will be conducted based on domestic survey manuals and previous studies shown in reference material 3-1 (Yoshida, Kataoka, Nihei et al. (2021)). Although there are previous cases using existing stationary cameras (disaster prevention cameras) in the stationary camera at river surveys (FY 2022 Osaka Prefecture), this demonstration test will include new stationary camera installations from the perspectives of specificity and versatility. (ii) On-site visual inspection methods (III) will be based on previous studies (Emmerik et al.). (iii) The methods for detecting and quantifying riverine litter using AI (I) will be implemented using methods currently being developed by Associate Professor Kataoka and others. (iv) To verify whether the detection and area aggregation of litter through visual image analysis (II) can be conducted without requiring specialized technology, equipment, or personnel, manual detection was performed.
Survey target	- For Method I, the amount of litter by type (in terms of area or object count) within the measurement range will be calculated based on the observation videos. - For Method I, an examination of different estimation methods, including expansion estimation methods and analysis frequency, will be conducted. - For Method II, the area and mass will be calculated through visual image analysis, and the observation accuracy will be verified (compared) with

	Method I. - For Method III, the number of objects will be calculated based on observation results, and the observation accuracy will be verified (compared) with Method I. - For Method IV, the observation accuracy will be verified (compared) by comparing the results of simulated litter (considered as the true value) with the observation results of each Method (I-III). - The working time for each Method (I-III) will be organized.
Investigator	Japan NUS Co., Ltd. (JANUS), Yachiyo Engineering Co., Ltd.
Image processing and analysis operator	Japan NUS Co., Ltd. (JANUS), Dr. Kataoka's lab
Result organization policy	- Verification of human-induced errors in stationary river camera surveys through mark-release-recapture experiment - Verification of human-induced errors in stationary river camera surveys and on-site visual inspection - Examination of analysis frequency and extrapolation methods for stationary river camera surveys - Comparison of processing times for AI/manual detection in stationary river camera surveys

Figure 1. Location map of the survey site (Matsuyama City, Ehime Prefecture)

（Source: Geospatial Information Authority of Japan (GSI) map）

Figure 2. Condition of the river surface and downstream (normal water level)

Figure 3. Condition of the river surface and downstream (rising water period: high water level)

Figure 4. Condition of the river surface and downstream (receding water period: high water level)

3. Results of the demonstration test

3.1 Organization of the survey results

3.1.1 Confirmation of human errors in stationary camera at river surveys through mark-release-recapture experiment

To verify the accuracy of the three analysis methods conducted in this demonstration test ("stationary camera survey & AI detection," "stationary camera survey & manual detection," and "on-site visual inspection"), the number flux (pieces/m/min) and weight flux (g/m/min) of simulated litter (large, medium, and small) were measured under different simulated litter flow conditions.

For weight flux, the flow litter area obtained from AI detection (or manual detection) was used to estimate the weight by applying the item-specific unit weight per unit area provided by the Kataoka Laboratory.

For the manual detection, in order to verify its applicability to regions that lack advanced manual analysis techniques and specialized personnel, standard Windows software (such as Excel and Paint) was used. The number and area of objects were manually counted and measured from the observation videos (see Appendix C for details).

Table 3 presents the obtained number flux results, while Table 4 presents the obtained weight flux results.

For both number flux and weight flux, the survey results using stationary cameras (AI detection and manual detection) and on-site visual inspection showed a consistent match corresponding to the amount of simulated litter. This suggests that the two survey methods using stationary cameras ("stationary camera survey & AI detection" and "stationary camera survey & manual detection") can serve as effective alternatives to on-site visual inspection.

Additionally, the accuracy of each survey method was compared by evaluating their detection precision based on the absolute errors of each method. Table 5 shows the results of the mean absolute error (MAE) between the true values (ground truth) of each flux, calculated using all six datasets of simulated litter.

For number flux, the "on-site visual inspection" demonstrated the smallest error, and similar results were obtained with the "stationary camera survey & manual detection." On the other hand, the "stationary camera survey & AI detection" showed the largest error.

Factors influencing the results of this investigation include the conditions imposed during river use. Specifically, (1) investigators were required to conduct the survey under safe river conditions (calm water during clear weather), and (2) all simulated litter released into the river had to be retrieved. Under these conditions, the river flow velocity was set at 0.68 m/s (about half the average walking speed of a healthy adult), and the number of simulated litter released was set at 16 pieces per minute. These conditions were deemed suitable for the two manual detection methods employed in this study. Additionally, the environmental conditions on the survey day included clear weather (cloud cover of 6), and surrounding vegetation was also intentionally released along with the simulated litter. Consequently, both sunlight reflection observed on the river surface and the drifting vegetation may have caused the AI to mistakenly detect it as simulated litter.

Regarding weight flux, AI detection demonstrated results closer to the set true value (ground truth) compared to manual detection. This outcome suggests that AI detection has an advantage due to its ability to calculate pixels at high resolution from acquired images, enabling stable and precise area recognition. On the other hand, manual detection was likely affected by human limitations in area detection, such as resolution constraints of the human eye and subjective judgment variability. Consequently, this indicates potential challenges in applying manual detection in regions without access to advanced analytical technologies and specialized personnel.

Table 3. Litter flux (item/m/min) by observation method in the mark-release-recapture experiment

Simulation Litter	Ground Truth (Set flux)	Stationary Camera & AI Detection	Stationary Camera & Manual Detection	On-Site Visual Inspection
Test litter (large)- 1st trial	1.56	3.27	1.56	1.48
Test litter (large)- 2nd trial	1.34	3.61	1.34	1.45
Test litter (medium) - 1st trial	0.83	1.76	0.83	0.85
Test litter (medium) - 2nd trial	0.72	1.60	0.72	0.85
Test litter (small) - 1st trial	0.51	1.19	0.51	0.52
Test litter (small) - 2nd trial	0.43	0.68	0.43	0.51

Notes:

1. Each flux value is rounded to the third decimal place.
2. These analysis results include uncertainties caused by false negatives and false positives.

Table 4. Weight flux (g/m/min) by observation method in the mark-release-recapture experiment

Simulation Litter	Ground Truth (Set Flux)	Stationary Camera & AI Detection	Stationary Camera & Manual Detection	On-Site Visual Inspection
Test litter (large)- 1st trial	24.70	25.26	12.34	-
Test litter (large)- 2nd trial	25.51	30.55	6.67	-
Test litter (medium) - 1st trial	17.91	14.43	3.90	-
Test litter (medium) - 2nd trial	16.83	15.64	2.98	-
Test litter (small) - 1st trial	10.17	13.47	3.36	-
Test litter (small) - 2nd trial	10.43	6.29	1.43	-

Notes:

1. The manual detection results were obtained by manually aggregating the area from observation videos using standard Windows software.
2. Each flux value is rounded to the third decimal place.
3. These analysis results include uncertainties caused by false negatives and false positives.
4. Weight flux was not calculated for on-site visual inspection because recording the surface area of flowing litter is challenging.

Table 5. Mean Absolute Error (MAE) for Each Survey Method (Number Flux and Weight Flux)

Mean Absolute Error (MAE)	Stationary Camera Survey & AI Detection	Stationary Camera Survey & Manual Detection	On-Site Visual Inspection
Number Flux (item/m/min)	1.12	0	0.07
Weight Flux (g/m/min)	2.95	12.48	-

Note:

1. The mean absolute error (MAE) was calculated based on the following formula:

$$MAE = \frac{\sum_{i=1}^{n} |\text{Measured Value}_i - \text{Ground Truth}_i|}{\text{n}}$$

   Where:
   n = Number of data points
   Measured Value_i = Analysis result from each survey method
   Ground Truth_i = Ground Truth (set flux)
2. All numerical values are rounded to the third decimal place.

3.1.2 Comparison of AI /manual detection results from stationary camera at river survey

(1) Confirmation of human errors in stationary cameras at river surveys and visual surveys

Based on the observation results obtained from three methods—AI detection using stationary river cameras, manual detection, and on-site visual inspection—both number flux and weight flux were measured. The comparison was conducted using observation results during high water (June 28, 9:30-11:30 and 12:30-15:30) and normal water conditions (June 26, 10:00-16:00), when visual surveys were conducted. The measurement method was conducted following the same procedure as described in Section 3.1.1. The estimation results of surface river litter flow (in terms of number and weight) for each method are shown in Table 6 and Table 7.

For number flux, during normal water conditions, the results of all methods were roughly similar. However, during high water conditions, significant discrepancies were observed. These differences are believed to have been influenced by the disturbed river surface conditions and increased flow velocity associated with large-scale high water events. Specifically, during high water, the increase in natural materials such as driftwood, surface turbulence, and the formation of bubbles were confirmed through visual surveys. These factors likely caused false detections in each method. For example, in AI detection, bubbles may have been mistakenly detected as litter (false positives), whereas in manual analysis, actual litter may have been misjudged as bubbles and overlooked (false negatives). Such changes in river surface conditions and the differences in the characteristics of observation methods likely introduced uncertainty due to false detections, leading to discrepancies between the methods.

For weight flux, a difference of more than two orders of magnitude was observed between the results of AI detection and manual detection using stationary cameras. This discrepancy is believed to be influenced by detection errors, as well as the same human limitations in area detection mentioned in Section 3.1.1 (e.g., limitations in visual resolution, fatigue, decreased concentration, and variability in subjective judgment).

Table 6. Number flux (pieces/m/min) in stationary camera surveys and on-site visual inspection

Flood Scale	Stationary Camera Survey & AI Detection	Stationary Camera Survey & Manual Detection	On-Site Visual Inspection
High water	4.22	0.14	0.25
Normal water	0.04	0.02	0.01

Notes:
1. Each flux value is rounded to the third decimal place.
2. These analysis results include uncertainties caused by false negatives and false positives.

Table 7. Weight flux (g/m/min) in stationary camera surveys and on-site visual inspection

Flood Scale	Stationary Camera Survey & AI Detection	Stationary Camera Survey & Manual Detection	On-site Visual Inspection
High water	7.21	0.06	-
Normal water	0.26	0.01	-

Notes:
1. The manual detection results were obtained by manually aggregating the area from observation videos using standard Windows software.
2. Each flux value is rounded to the third decimal place.
3. These analysis results include uncertainties caused by false negatives and false positives.
4. Weight flux was not calculated for on-site visual inspections because it is challenging to record the surface area of flowing litter.

3.1.3 Examination of analysis frequency and extrapolation methods in stationary river camera surveys

(1) Examination of annual flow volume estimation method using observation results

To examine the estimation method for the annual flow volume of river surface litter, the following relationships were established:

- A relationship equation between flow rate and weight flux (L-Q curve)
- A relationship equation between the Antecedent Precipitation Index (API) and weight flux

The calculation of weight flux was based on the analysis results from the “stationary camera survey & AI detection.”

The selection criteria for video data during high water conditions were based on observation data from the Yuwatari Observation Station, located upstream of the demonstration site, during the demonstration period. Video data was selected from days when the water level rose above 3 meters during daylight hours (9:00-16:00), compared to the normal water level of approximately 2.7 meters. For normal water conditions, video data was selected from periods when the water level remained stable at the normal level at the Yuwatari Observation Station.

The recording dates of the video data used for analysis are shown in Table 8. However, in this study, due to the insufficient number of data points for both high water and normal water conditions, a strong correlation could not be obtained. Therefore, the relationship equation was created without distinguishing between high water and normal water conditions.

Table 8. Stationary-camera recorded footage used for analysis

Survey/Analysis Method	High Water Conditions	Normal Water Conditions
Stationary camera survey & AI detection	2024/6/18 2024/6/21 2024/6/28 2024/8/28	2024/6/19 2024/6/23-27 2024/7/6 2024/7/9-13 2024/8/13-18 2024/9/1-6

Flow rate was estimated based on the water level at the time of video recording using the relationship equation between flow rate and water level (H-Q curve). The H-Q curve was developed using river cross-sectional area data obtained from on-site measurements (one day during normal water conditions) and flow velocity and water level data (four days during normal water conditions). The derived H-Q curve is presented in Figure 5.

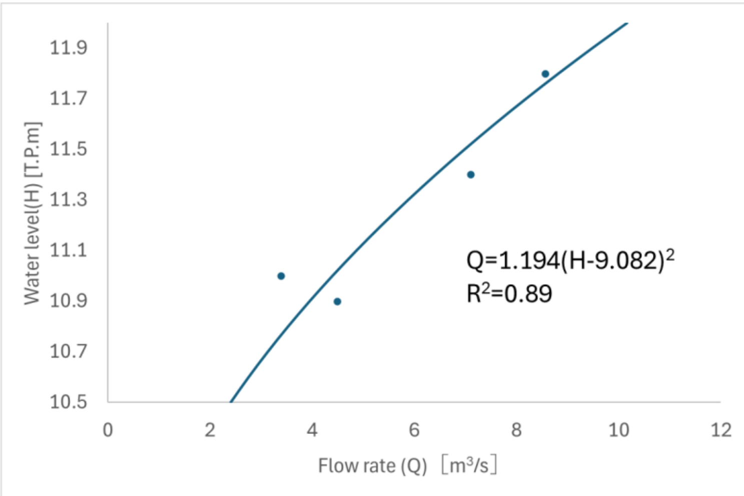

Figure 5. Relationship equation between flow rate and water level (H-Q curve).

The API was formulated based on the previous study by Yoshida et al. (2021) [1]as follows:

$$API = \sum_{i=1}^{i=N} b_i P_i$$

where Pi represents the daily precipitation up to i days prior, and bi is a coefficient (=Ki, where K is the attenuation coefficient). This equation considers the influence of precipitation over the past N days. In this study, the attenuation coefficient was set to 0.9, and daily precipitation data in Matsuyama City published by the Japan Meteorological Agency (from January 1, 2024, to December 31, 2024) were used. The target period (N) was categorized into three groups: 7 days, 15 days, and 30 days. These values are referred to as API07, API15, and API30, respectively.

Table 9 presents the flow rate, weight flux, and API values for each observation day. The relationship equation between flow rate and weight flux is shown in Figure 6, while the relationship equation between the Antecedent Precipitation Index (API) and weight flux is shown in Figure 7. The highest coefficient of determination (R^2) was 0.809, observed in the relationship equation between flow rate and weight flux.

Regarding correlation, a positive correlation was confirmed in the relationship between flow rate and weight flux, consistent with previous studies (e.g., Ministry of the Environment, Japan). On the other hand, while a previous study (Yoshida et al. 2021) reported a negative correlation between API and the concentration of artificial litter during high water conditions, the results of this study showed a different trend. This discrepancy is likely due to the integration of both high water and normal water conditions in the relationship equation in this study, necessitated by the limited number of observation data points.

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[1] Yoshida Takuji, Fujiyama Tomoki, Kataoka Tomoya, Ogata Riku, & Nihei Yasuo. (2021). Comparison of riverine litter transport characteristics during multiple flood events based on continuous IP camera observation and image analysis techniques.
Journal of Japan Society of Civil Engineers, Series B1 (Hydraulic Engineering), 77(2), I_1003-I_1008.

Table 9. Average flow rate, each API value, and the average weight flux

Observation Date	Average Flow Rate (m^3/s)	API07 (mm)	API15 (mm)	API30 (mm)	Average Weight Flux (kg/day)
18-Jun	8.0	82.1	95.3	113.8	208.5
19-Jun	4.4	73.8	85.8	102.4	12.7
21-Jun	7.6	109.7	119.4	132.8	49.8
23-Jun	6.4	161.0	168.1	179.8	29.0
24-Jun	7.8	140.4	144.9	161.8	13.2
25-Jun	5.9	91.2	130.4	145.6	4.0
26-Jun	5.2	82.6	117.9	129.9	9.1
27-Jun	5.4	102.3	134.6	139.9	0.8
28-Jun	12.3	121.2	173.6	178.4	269.4
6-Jul	5.1	59.3	119.6	144.2	32.1
9-Jul	4.5	0.0	73.8	103.7	40.5
10-Jul	4.5	9.0	75.4	102.3	14.5
11-Jul	11.9	142.1	201.8	226.1	177.6
12-Jul	12.9	197.9	245.7	273.5	308.3
13-Jul	7.4	181.6	213.9	249.6	44.5
13-Aug	3.6	0.0	0.0	4.1	7.8
14-Aug	3.6	0.0	0.0	2.7	3.3
15-Aug	3.6	0.0	0.0	2.3	24.7
16-Aug	3.5	0.0	0.0	2.1	4.2
17-Aug	3.4	0.0	0.0	1.9	2.5
18-Aug	3.5	0.0	0.0	1.7	10.3
28-Aug	5.6	19.8	32.6	32.6	69.6
1-Sep	4.4	115.1	123.5	123.5	12.7
2-Sep	4.2	103.1	111.1	111.1	10.6
3-Sep	4.2	92.8	93.2	100.0	10.4
4-Sep	3.9	74.4	83.9	90.0	93.2
5-Sep	3.8	42.1	75.5	81.0	6.7
6-Sep	3.7	1.1	68.0	72.9	3.1

Notes:

1. The average flow rate (m^3/s) was calculated for each observation day by applying the observed water level (m) to the pre-established HQ formula (the relationship equation between water level and flow rate).
2. The daily weight flux (kg/day) was obtained by multiplying the AI detection results from the Kataoka Laboratory (g/m/min) by the observed river width (m) to calculate the average weight flux (g/min) for each observation day. Then, a conversion factor (g/min → kg/day; x 60 x 24 ÷ 1000) was applied to derive the final value.

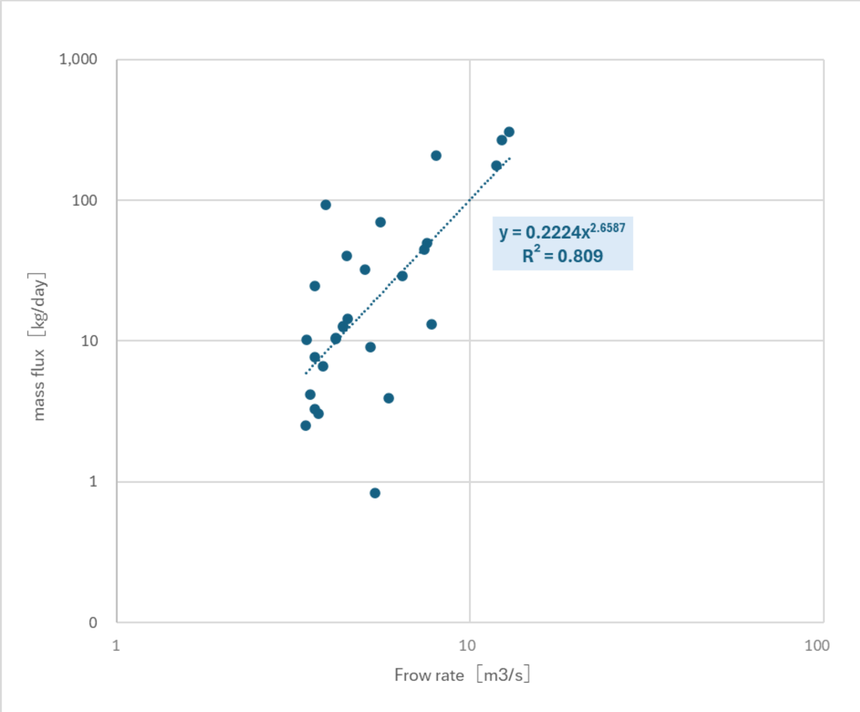


Figure 6. Relationship equation between flow rate and weight flux (L-Q curve)

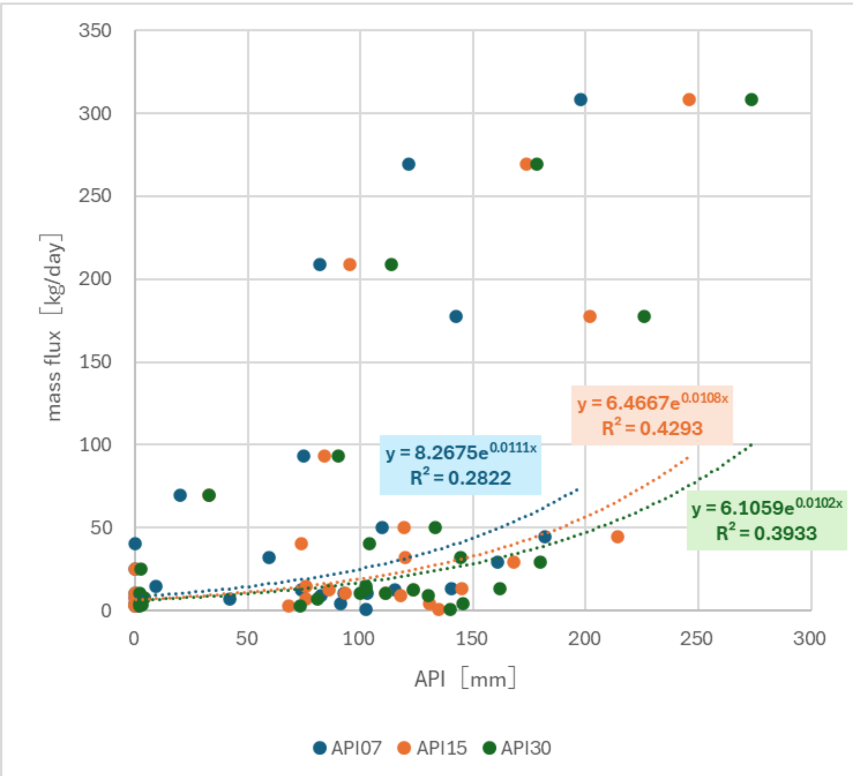


Figure 7. Relationship equation between API and weight flux

Using the four derived relationship equations, the annual flow volume of artificial litter was estimated based on stationary-camera observations. For the periods where analytical data was available, the actual analytical values were used. For non-analytical periods, the flow rate was estimated using water level data from the demonstration site, while API-based estimates were derived using daily precipitation data from Matsuyama City.

Table 10 presents the estimated annual flow volume for each estimation method. The highest coefficient of determination (R^2) was observed for the flow rate-based estimation, which yielded an annual flow volume of 4.7 tons per year. In contrast, API-based estimates showed higher values: 5.6 t/year for API07, 5.4 t/year for API15, and 5.4 t/year for API30.

These results suggest that, based on this study, the flow rate-based method provides the most reliable estimate due to its highest R^2 value. However, to improve the accuracy of these relationships, further data collection—particularly during high-water events—and refinements in analytical methods are required. These improvements will contribute to achieving more precise assessments of annual flow volume estimations.

Table 10. Estimated discharge values by survey method

Period Category	Estimated Flow Volume (t)			
	Flow Rate-Based	API07-Based	API15-Based	API30-Based
Analytical period	1.5	1.5	1.5	1.5
Non-analytical period	3.2	4.2	3.9	3.9
Total	4.7	5.6	5.4	5.4

Notes:

1. For the non-analytical period, the estimation was conducted using flow rate based on water level data from the demonstration site or API based on daily precipitation data from Matsuyama City.
2. The estimated values were rounded to the second decimal place.

(2) Estimation Results by Extrapolation Method

To evaluate extrapolation methods, the results of recordings from June 26, 10:00-16:00 (normal water conditions) were analyzed using AI. The observed number of floating surface river litter (items) within the camera range was used as the basis to estimate the total litter flow across the entire river channel. The following three extrapolation methods were applied:

- Extrapolation based on river width (Width-Based Method)
- Extrapolation using river flow velocity (Velocity-Based Method)
- Extrapolation using flow rate (Flow rate-Based Method)

For the non-observed sections of the river covered by stationary cameras, corrections were made based on measurement data (flow velocity and water depth) obtained on the same day. However, for high water conditions, measuring the necessary data using portable flow meters was impractical, so no examination was conducted for such conditions. Additionally, to verify each estimation, the extrapolated values were compared with estimates based on visual river surveys conducted at the same time.

Table 11 presents the river measurement data from June 26, while Table 12 shows the extrapolation results for each method. Among the corrected flow estimates, the Width-Based Method produced the highest values, while the Velocity-Based Method yielded the lowest. This discrepancy is thought to result from differences in flow velocity and water depth between the observed and non-observed sections. Notably, during the June 26 measurements, the average flow velocity and water depth in the non-observed sections were greater than those in the observed sections, leading to higher estimated flow rate in the non-observed sections.

Furthermore, the extrapolated values obtained using the Width-Based and Flow Rate-Based Methods closely matched the estimated litter flow based on the visual river survey, suggesting the validity of these methods. On the other hand, the Velocity-Based Method produced lower values, highlighting potential issues related to the applicability of this method and the accuracy of corrections for non-observed sections.

The Width-Based Method is the simplest approach and a practical option for field applications. However, it may not fully reflect river flow velocity or flow rate, which presents a potential limitation.

Therefore, in stationary-camera surveys, it is crucial to accurately grasp the overall distribution of flow velocity and water depth at observation points and appropriately define the observation range. Particularly when there are significant differences in conditions between observed and non-observed sections, there is a risk of overestimation or underestimation in the correction values, requiring careful consideration.

Table 11. Environmental observation data for observed and non-observed sections

Observed Section	Cross-Sectional Width (m)	Average Flow Velocity (m/s)	Total Flow Rate (m^3/s)
Stationary camera observation range	9	0.26	2.05
Non-observed section	17	0.35	5.87

Notes:
1. The average flow velocity was calculated as the mean value of flow velocities measured at 1-meter intervals.
2. The total flow rate was obtained by summing the products of flow velocity and water depth measured at 1-meter intervals.
3. Both average flow velocity and total flow rate were rounded to the third decimal place.

Table 12. Surface river litter flow estimates by extrapolation method (normal water conditions)

Observed Section	Analysis Results (Items)	Corrected Litter Flow (items)			Visual Survey Litter Flow (Items)
		Width-Based Method	Velocity-Based Method	Flow Rate - Based Method	
Stationary Camera Observation Range	19.4	19.4	19.4	19.4	-
Non-Observed Section	-	56.1	25.5	55.7	-
Total	-	75.6	45.0	75.2	80

Notes:
1. The estimated litter flow in the non-observed section was calculated using the measurement results from the stationary camera observation range (river width, average flow velocity, or total flow rate) and the ratio of the observed to non-observed sections.
2. Average flow velocity, total flow rate, and surface river litter flow were rounded to the third decimal place.
3. The analysis results from the stationary-camera survey are based on the recordings taken on June 26, 10:00-16:00 (normal water conditions). The estimation was conducted using one-minute video recordings captured every 60 minutes.
4. The estimated number of litter flows from the visual survey is based on visual observations recorded for one minute every 10 minutes during June 26, 10:00-16:00 (normal water conditions).

(3) Effect of Analysis Frequency in Stationary Camera Surveys

To examine the representativeness of recording intervals, estimates of surface river litter flow during high water conditions (June 28, 9:00-16:00) were calculated at different analysis frequencies. Additionally, the average weight flux and its standard deviation were also computed.

The results for each analysis frequency are shown in Table 13. Variations in the estimated values of surface river litter flow and average weight flux were observed as the analysis frequency decreased. Furthermore, a tendency for the standard deviation of the average flux to increase as the analysis frequency decreased was noted.

These results indicate that analysis frequency affects the estimation accuracy in AI detection. While medium-frequency data (30-minute intervals) and low-frequency data (60-minute intervals) provided a certain level of accuracy for broad estimates of litter flow, they may be less suitable for capturing short-term fluctuations and peak events compared to high-frequency data (10-minute intervals).

Table 13. Analysis results by frequency (high water conditions)

Analysis Frequency	Surface River Litter Flow (kg)	Weight Flux (g/m/min)
High frequency (once every 10 minutes, 1 minute)	106.3	6.55 ± 0.65
Medium frequency (once every 30 minutes, 1 minute)	110.3	6.91 ± 1.02
Low frequency (once every 60 minutes, 1 minute)	100.3	6.34 ± 1.09

Notes:
1. Surface river litter flow (kg) was calculated by multiplying the weight flux (g/m/min) derived from AI detection by the observation time (10 minutes for high frequency, 30 minutes for medium frequency, 60 minutes for low frequency) and the river width measured on the day.
2. Surface river litter flow values are rounded to the second decimal place.
3. Weight flux values are rounded to the third decimal place.

3.1.4 Comparison of work time for AI /manual detection results from stationary camera at river surveys

To evaluate the work efficiency of different survey methods, the time required from data acquisition to analysis completion was compared. Since the survey duration per session differs between stationary camera surveys and on-site visual inspections, the time required for data acquisition was standardized based on the time taken to obtain one day's worth of data.
Additionally, to ensure a consistent basis for comparison of analysis time, the time required was evaluated based on the analysis time for the high-water period survey conducted on June 28 (9:30-11:30 and 12:30-15:30, with observations taken every 10 minutes, totaling 32 minutes of observation time).
The measurement items for each survey method and the time required per day for data acquisition and analysis are presented in Table 14. The results confirmed that the stationary camera surveys (I, II) required significantly less work time per day from data acquisition to processing compared to on-site visual inspection (III). Notably, AI-based analysis (I) allows for automated data processing and analysis, which is expected to significantly reduce human workload.On the other hand, the on-site visual inspection (III) required a total of 17.7 hours per day, with the majority of the time spent on data acquisition (on-site river observation). This indicates a very high workload. Additionally, this method is limited in that it can only obtain count-based data, presenting another challenge.
These findings highlight that the introduction of stationary camera surveys and AI-assisted automated analysis can greatly improve work efficiency while reducing human workload.
Table 15 provides details on the time required for one day of data acquisition, while Table 16 presents the time required for data processing and analysis during the high-water period (June 28).

Table 14. Time Required for Data Acquisition, Processing, and Analysis per Day

Survey Method		Measurement Item			Work Hours Required for Data Acquisition, Processing, and Analysis Per Day (Hours)		
		Items	Area	Mass	Data Acquisition	Data Processing & Analysis	Total
I	Stationary camera & AI detection				0.6	1.1	1.7
II	Stationary camera & manual detection				0.6	6.0	6.6
III	On-site visual inspection				17	0.7	17.7

Note:
1. The details of the work hours required for data acquisition, processing, and analysis per day are provided in Table 15 and Table 16.

Table 15. Details of time required for data acquisition per day

Survey Method		Survey Days	Data Acquisition (Hours)			Total Work Hours (Hours)	Work Hours Per Day (Hours)
			Preparation & Equipment Setup	Acquisition	Equipment Retrieval		
I	Stationary camera & AI detection	105	7.5 (3 person)	30 (1 person)	7.5 (2 people)	67.5	0.64
II	Stationary camera & manual detection						
III	On-site visual inspection	1	2 (1 person)	7.5 (2 people)	0	17	17

Note:

1. The stationary camera survey & AI detection (I) does not include the time required for AI model development and training data creation.
2. The stationary camera surveys (I, II) include time for regular monthly camera maintenance and data organization (7.5 hours x 4 times).
3. The work hours per day for stationary camera surveys (I, II) were calculated by dividing the total work hours by the number of observation days (105 days) in this study.
4. For stationary camera surveys (I, II) and visual survey (III), the time required for material procurement, component processing, equipment setup, and travel to survey locations is excluded from the measurement.
5. The visual survey (III) is recorded based on the number of surveyors required to observe the same area covered by the stationary camera surveys (I, II).

Table 16. Time required for processing and analysis of high water condition data (one day)

Survey Method		Time Required for Data Processing and Analysis (Hours)		Total Work Time (Hours)
		Process	Detection, Classification, and Quantification	
I	Stationary camera & AI detection	1.1		1.1
II	Stationary camera & Manual detection	0.9	5.1	6.0
III	On-site visual inspection	0	0.6	0.6

Note:

1. Stationary Camera & Survey (I, II) can obtain both item flux and weight flux, while the visual survey can only obtain item flux.
2. Stationary Camera & AI detection (I) records machine (automated) processing time instead of human labor time. The computational environment used for analysis is as follows:
   - CPU: Intel(R) Xeon(R) Gold 5318Y (24 Core - 2.1GHz) x2
   - Memory: 128GB (DDR-2933)
   - GPU: NVIDIA GeForce RTX 3090 x2
   - Nvidia Driver: 510.73.05
   - OS: Ubuntu 20.04
3. The processing time for Stationary Camera & AI detection (I) is calculated based on the analysis time per video data (approximately 2 minutes per 1-minute video).
4. For Stationary Camera & Image-Based Visual Analysis (II), the total processing time includes both the time required to review recorded videos (32 one-minute videos) and the time taken to create images of floating litter (0.5 minutes per litter image). On June 28, a total of 43 pieces of litter were identified.
5. For Stationary Camera & Manual detection (II), the time required for detection, classification, and quantification was calculated based on the data aggregation time (30 minutes) and the analysis time for 43 images of floating litter (an average of 7 minutes per image, based on the assessment of two surveyors).
6. The time required for detection, classification, and quantification in Stationary Camera & Manual detection (II) depends on the number of floating litter items.
7. The processing time for Visual Survey (III) includes reviewing audio records from river observations (1 minute x 32 recordings) and data aggregation time (5 minutes).

4. Conclusion

In this demonstration test, the detection capability and time costs of the following three survey methods were evaluated: "I. Stationary river camera survey with AI detection," "II. Stationary river camera survey with manual image analysis," and "III. Visual survey."

Based on the results of the simulated litter flow test and observations in actual rivers, it was suggested that "I. Stationary river camera survey with AI detection" has a litter detection capability comparable to or greater than that of "III. Visual survey" and "II. Stationary river camera survey with manual image analysis." Stationary camera surveys were found to be suitable for long-term monitoring and for obtaining weight flux data, whereas visual surveys were effective for efficiently acquiring item flux data over short periods.

A comparison of accuracy and efficiency highlighted the advantages of stationary camera surveys, including the ability to obtain long-term data from a single survey and the potential for labor reduction through automated data analysis. Additionally, it has been reported that stationary camera surveys achieve higher accuracy than visual surveys under high water conditions (Lieshout et al. (2020)). Considering that a significant portion of terrestrial litter flows into rivers, "I. Stationary river camera survey with AI detection" is considered an effective method for long-term monitoring, including during large-scale floods, and for reducing the workload associated with long-term analysis.

However, the development and application of AI for litter analysis may not always be feasible for all survey organizations. In such cases, "II. Stationary river camera survey with manual image analysis" can serve as an effective alternative. However, in manual quantification, it is considered necessary to establish detection and estimation methods to ensure a certain level of accuracy.

The current application scope and technical limitations of "Stationary river camera survey with AI detection" and "Stationary river camera survey with manual image analysis," as clarified through this demonstration test, are summarized in Table 17. Additionally, key considerations identified during the planning, preparation, and implementation phases of the demonstration test have been included in Section I of Annex 1.3 of the International Guidelines (Table 18).

Table 17. Capabilities and technical limitations of stationary river camera surveys

Capabilities of Stationary River Cameras for River Litter Survey	Current Technical Limitations
Automatic observation of river litter	– Observation cannot be conducted at night. – Detection accuracy of surface litter may decrease depending on water transparency and flow velocity. – Depending on the camera's installation angle, sunlight or reflected light on the water surface may cause time periods where observation becomes challenging. Additionally, capturing data on litter submerged underwater and flowing downstream is difficult.
Quantification through manual detection, classification, enumeration, and weight measurement (Stationary river camera survey & manual detection)	– The size of detectable litter is greatly influenced by the camera's resolution and the survey environment (e.g., distance from the camera to the water surface). – It is challenging to uniformly determine litter using color differences as a criterion. – It is not suitable for high-resolution detection. – When estimating flow rate (g/s), it is necessary to separately determine the weight per unit area of riverine litter (see Annex C, p. 5).
Quantification through automatic detection, classification, enumeration, and weight measurement (Stationary river camera survey & manual detection)	– It can be challenging to detect items with undefined shapes, such as plastic bags and plastic fragments. – Training data is required for AI learning. – When estimating flow rate (g/s), it is necessary to separately determine the weight per unit area of riverine litter (see Annex C, p. 5).

Table 18. Items to be added to Annex 1.1 of the International Guidelines

1	Survey Target
−	Items such as caps, lids, lighters, and cigarettes may be difficult to detect due to their small size and potential to submerge underwater. (However, as PET bottle caps and cigarettes are major components of coastal litter, efforts should be made to capture them whenever possible.)
2	Setting the Shooting Range
−	When installing a stationary camera on a bridge or water pipe bridge, if it is not possible to observe the river's central flow due to space constraints, it is necessary to understand the lateral distribution of litter through additional flow velocity measurements or visual inspections.
3	Installation of Survey Equipment
−	Since there is a risk of significant impact from strong winds, such as typhoons, it is advisable to thoroughly secure and protect solar panels and stationary cameras as much as possible.
4	Conducting the Survey
−	In addition to photographing a scale, it is recommended to capture images of test litter (such as PET bottles or bottle caps with measured projected areas) to understand the minimum detectable size for each stationary camera

Detailed information on each survey method

I Stationary river camera survey & AI detection, II Stationary river camera survey & manual detection

Table 19. Stationary camera survey data

Survey planning and preparation	Camera installation period	June 12, 2024 - September 25, 2024 (Video acquisition: June 13, 2024 - September 25, 2024)
	Camera installation and preliminary Survey date	June 12, 2024
	Survey target	Artificial litter measuring 2.5 cm or larger
	Roles and responsibilities of surveyors	Camera setup preparer (e.g., metal processing): 1 person Camera installation and removal personnel: 2 people Environmental Data Collection: 3 people Simple cross-sectional survey: 3 people Riverine litter collection and measurement of weight per unit area: 3 people
Survey implementation	Environmental data collection	Low velocity within the channel was measured using a portable flowmeter as metadata related to the dynamics of surface litter.
	Installation of survey equipment	Steel pipes were secured to the aqueduct's railing using brackets, and stationary cameras along with solar panels were installed.
	Simple cross-sectional survey	The distance from the top of the aqueduct railing to the riverbed was measured using a weighted measuring tape to calculate the river's cross-sectional profile.
	Collection of riverine litter and Measurement of weight per unit area	Scattered litter around the aqueduct was collected, and the weight per unit area (g/cm^2) of artificial litter was calculated.
Image analysis	I. AI detection	Using a system developed by the Kataoka laboratory, litter detection, pixel area measurements, and flux calculations were performed.
	II. Manual detection	The recorded videos were analyzed manually to collect data on the number of items and pixel areas (surface area)

(1) Selection of the Survey Location

The Ishite River was selected as the survey site for its relatively flat riverbed and centrally located main flow, which makes it easier to observe the movement of drifting litter and understand the characteristics of the flow. During the site inspection, it was confirmed that the river width of approximately 10 meters provided an ideal environment for efficiently conducting simulated litter release and retrieval operations using waders and dip nets.

Additionally, the Kataoka laboratory had previous experience conducting stationary camera tests at this site, which allowed for the utilization of their expertise and facilitated the relatively straightforward acquisition of necessary permits. These factors contributed to the selection of the Ishite River (specifically, the Ishite River Aqueduct) as the survey location for the demonstration test. The environmental information for the demonstration test survey location is shown in Table 20

Table 20. Environmental Information of the Demonstration Test Survey Location

Item	Information
Distance from river mouth	Approximately 6 km
Tidal influence	None
Land use conditions	Land use: forest and other (wasteland, etc.) account for about 70%, urban areas 10%, farmland 20%
Population density	Population within the Ishite river basin: approximately 244,000 (Population density: ~550 people/km²)
Surrounding area usage	Within 500 m of the survey site: matsuyama central park (baseball field, pool, tennis courts, etc.) and Matsuyama velodrome
Structures in the survey area	Ishite river dam located approximately 5 km upstream
Riverbed gradient	Approximately 1/310 - 1/210

For this test, a stationary camera (a vertical camera) equipped with a control device based on a Raspberry Pi installed by the Kataoka laboratory was used to perform automatic photography according to river conditions during normal flow and flood events (Kataoka et al. 2024). Details of this camera system are shown in Table 21. Additionally, to observe the cross-sectional distribution of riverine litter and surrounding conditions, a new downstream-facing camera was installed to capture an overhead view of the downstream area. For the downstream camera, solar panels and batteries were also installed to ensure a continuous power supply.

Table 21. Overview of the Stationary Camera (Vertical Camera) Used for Image Analysis

Item	Information
Overview of the camera	Powered via an integrated solar system, enabling automatic data acquisition based on river conditions. The system is managed by a control device based on a Raspberry Pi, connected to a solar system, IP camera, and ultrasonic water level gauge (WLG).
Camera installation angle	90° (vertical orientation)
Camera shooting settings	Normal water level: 1-hour intervals; high water level: 10-minute intervals. The shooting interval automatically switches based on river water level data obtained by the ultrasonic water level gauge mounted on the stationary camera.
Camera resolution/frame rate	3840 x 2160 pix, 15 fps
Distance from camera to water surface	7.56 m (normal water level)
GSD (Ground sampling distance)	3.22 mm/pix (normal water level)
Data storage	Recorded video data and water level data are transmitted to Google Drive, allowing remote access and storage.

Source: Kataoka, T., Yoshida, T., & Yamamoto, N. (2024). Instance segmentation models for detecting floating macroplastic litter from river surface images. Frontiers in Earth Science, 12, 1427132. doi:10.3389/feart.2024.1427132.
Supplementary Materials available at doi:10.3389/feart.2024.1427132.

(2) Acquisition of Environmental Information

From the Ishite River Water Pipe Bridge, the flow velocity in the river channel was measured as metadata related to the dynamics of surface litter using a portable flowmeter. The measurements were taken from the upper part of the railing on the water pipe bridge (Figure 8). The measurement interval in the transverse direction was set at 1-meter intervals within the normal water channel.

Figure 8. Flow velocity measurement

(3) Installation and measurement using a stationary camera (downstream camera)

A steel pipe was secured to the railing of the Ishite River Aqueduct using brackets, and a downstream-facing camera and solar panels were installed (Figure 9).

Figure 9. Installation of a stationary camera (downstream camera)

(4) Implementation of simple cross-sectional survey

Using a weighted measuring tape, the distance from the top of the Ishite River Aqueduct railing to the riverbed was measured (Figure 10). Measurements were taken at 1-meter intervals across the low-flow channel and at 2-meter intervals across the high-water area. For locations with steep gradients, measurements were taken as close to those points as possible. On the levee area, measurements were conducted at points where the gradient changed. Based on the collected data, the river width and cross-sectional profile were calculated (Table 22 and Figure 11).

Figure 10. River cross-sectional measurement

Table 22. Simple cross-sectional survey results at the Ishite River Aqueduct

Raw Data		Corrected Value
Distance from the Right Bank of the Water Pipe Bridge [m] (Transverse Distance)	Height [m]	Height [m]
0.00	3.28	-6.02
3.60	5.28	-4.02
15.30	5.58	-3.72
17.30	5.78	-3.52
19.30	6.42	-2.88
21.30	7.18	-2.12
23.30	7.83	-1.47
25.30	7.52	-1.78
27.30	7.47	-1.83
29.30	7.37	-1.93
31.30	7.85	-1.45
33.30	8.61	-0.69
35.30	8.96	-0.34
38.80	8.06	-1.24
40.30	9.36	0.06
41.30	9.30	0.00
42.30	9.29	-0.01
43.30	10.35	1.05
44.30	10.38	1.08
45.30	10.41	1.11
46.30	10.25	0.95
47.30	10.13	0.83
48.30	10.11	0.81
49.30	10.08	0.78
50.30	10.01	0.71
51.30	10.02	0.72
52.30	9.96	0.66
53.30	9.92	0.62
54.30	9.87	0.57
55.30	9.81	0.51
56.30	9.61	0.31
57.30	9.48	0.18
58.30	9.38	0.08
59.30	9.30	0.00
59.70	9.12	-0.18
61.70	8.75	-0.55
63.20	8.20	-1.10
65.80	8.53	-0.77
67.44	9.09	-0.21
69.20	8.96	-0.34
70.40	8.59	-0.71
78.09	5.75	-3.55
82.72	5.56	-3.74
87.15	3.34	-5.96

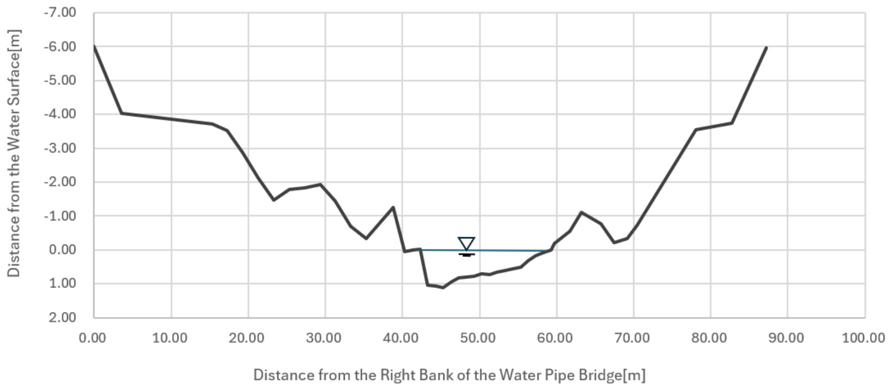


Figure 11. Simple cross-sectional survey results

(5) Collection of riverine scattered litter and measurement of weight per unit area
To assess the feasibility of implementation, the unit weight per unit area for each litter category was measured. The collection of riverine litter was conducted within a 50-meter width upstream and a 50-meter width downstream of the Ishitegawa Water Pipe Bridge. After collection, the scattered litter was analyzed using a 1 cm mesh board and processed with the image analysis software ImageJ to calculate the surface area (cm^2) (Figure 12).
Additionally, the measured dry weight (g) was used to calculate the weight per unit area (g/cm^2) for each type of litter. The weight per unit area (g/cm^2) for each litter category and its standard error are shown in Table 23.

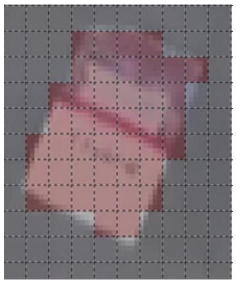
Figure 12. Examples of riverine scattered litter used for area measurement

Table 23. Measurement results of weight per unit area for riverine scattered litter around the Ishite River（n=64）

Item	Count	Weight Per Unit Area by Litter Type（g/cm^2）
Drink bottles	11	0.22±0.01
Food containers	27	0.03±0.00
Shopping bags	2	0.03±0.02
Other plastics	18	0.14±0.06
Cans	6	0.32±0.07

(6) Image Analysis
Based on the video footage obtained from the stationary camera and the measured weight per unit area of riverine litter, calculations for item flux and weight flux were performed. For AI detection, the AI system developed by the Kataoka Laboratory at Ehime University was used to detect surface-flowing litter and estimate fluxes. For manual image analysis, in order to verify its applicability to regions lacking advanced analytical technologies and specialized personnel, standard Windows applications (such as Excel and Paint) were used. The number and area of items were manually counted from the recorded footage, and calculations for item flux and weight flux were performed accordingly. The image-based visual analysis procedure in this demonstration test is shown in Table 24.

Table 24. Image-based visual analysis procedure in this demonstration test

No.	Procedure	Image
1	Adjust the recorded video so that the floating litter is positioned at the center of the image, then save a still image as a screenshot. Additionally, to track the number of floating items, record the identification number, floating time, and item type in a field notebook (such as Excel).	
2	Display a grid on the screenshot and save the image again after applying the grid. In this demonstration test, Paint was used to overlay grid lines on the screenshots. The magnification of Paint (i.e., grid size) was set to stationary values depending on the size of the litter.	
3	Measure the sections corresponding to floating litter in the grid-applied image on a per-grid basis. In this demonstration test, grids where more than 50% of the area was covered by floating litter were considered relevant sections.	
4	Based on the known floating litter and the scale length, the side length of one grid is calculated, and from this value, the area of one grid is estimated. Using the area of the grid thus obtained, the area covered by floating litter is estimated. The estimated litter area is then multiplied by the previously determined average weight per unit area (g/cm^2) for each category of artificial litter item, in order to estimate the total weight.	

III On-site visual inspection

Table 25. On-site visual inspection data

Survey plan	Visual survey dates	June 26, 2024 (normal water conditions) June 26, 2024 (high water conditions)
	Survey target:	Artificial litter measuring 2.5 cm or large
	Roles and responsibilities of surveyors	Environmental data collection: 3 people Visual survey: 4 people
Survey implementation	Environmental data collection	Metadata such as weather conditions, atmospheric conditions, and river flow velocity was collected from the Ishite River Aqueduct.
	On-site visual inspection (high and normal water level)	From the Ishite River Aqueduct, the river surface was observed vertically, and the number of litter items flowing downstream was counted.
Compilation of results	III. On-site visual inspection	The number of items was tallied based on the field observation notebook, and the item flux was calculated.

(1) Environmental data collection
Metadata such as weather conditions, atmospheric conditions, and river flow velocity was collected from the Ishite River Aqueduct. Observation metadata during the visual survey is shown in Table 26.

Table 26. Metadata for On-site visual inspection

Category	Metadata	Normal Water Level	High Water Level
Basic information	Observation date	June 26, 2024	June 28, 2024
Weather and atmospheric conditions	Weather	Cloudy	Rain
	Cloud cover	9	10
	Wind speed	1.1-3.5 m/s	1.3-4.5 m/s
Surface litter dynamics	River flow velocity	0.00-0.68 m/s	Not measurable
	Presence of litter retention or accumulation	Retention: none Accumulation: none	Retention: none Accumulation: none
Surrounding environment	River transparency	50 cm or more	Approximately 8 cm

(2) Visual survey (normal water level)
Observations were conducted as planned during low-flow conditions (10:00-16:00, once every 10 minutes for 1 minute per interval) (Figure 13). The observation positions of the observers are shown in Figure 14, and the river width for each section along with the total number of macroplastic litter observed is summarized in Table 27.
The observation range covered approximately 84% of the total river width (22 meters out of a 26-meter river width). However, Sections 1-4 were excluded from the observation range because it was determined that no litter flowed through these areas due to the dense growth of reeds.

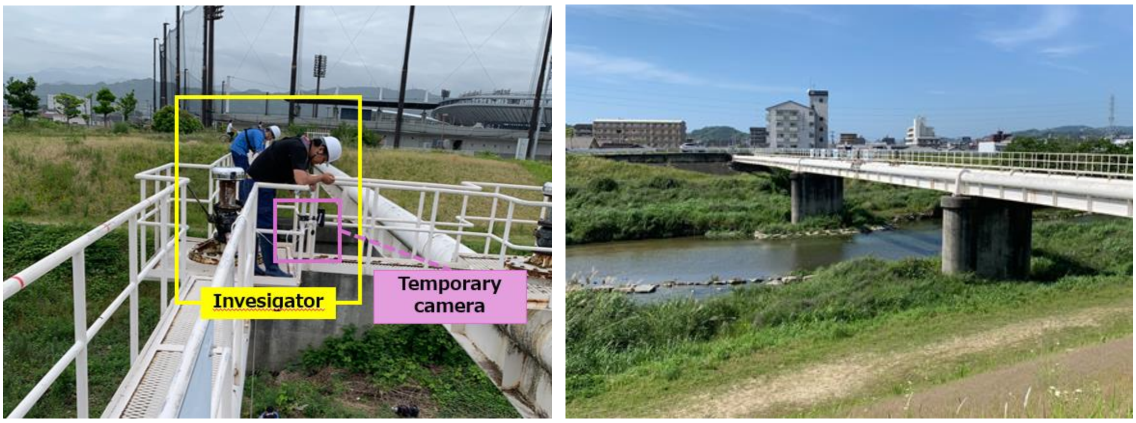


Figure 13. Visual inspection during normal water conditions

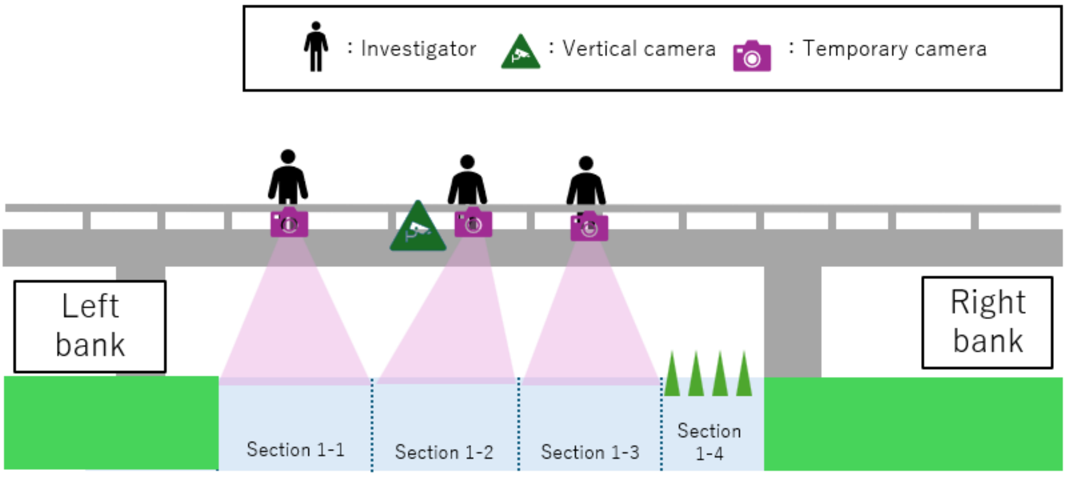


Figure 14. Observation position map during normal water conditions

Table 27. Observation width and total number of observed macroplastic litter during low-flow conditions

Section	Section 1-1	Section 1-2	Section 1-3	Section 1-4
River width (m)	7	7	8	4
Total number (pieces)	0	7	1	Not measured
Number observed per meter (pieces)	0	1	0.1	—

(3) Visual survey (high water)

The observation period was conducted from 9:30 to 11:30 and from 12:30 to 15:30, with 1-minute observations every 10 minutes. Observations began 30 minutes earlier than planned due to rainfall timing. No observations were made between 11:30 and 12:30 due to a lunch break.

The observation positions are shown in Figure 16, and the river width for each section along with the total number of observed macroplastic litter is summarized in Table 28. While the temporary camera positions for Sections 2-2 to 2-4 remained unchanged from the low-flow survey, high-flow conditions caused the river width to expand. As a result, observations could not be conducted for some sections (2-1 and 2-5). The observation range covered approximately 71% of the total river width (27 meters out of a 38-meter river width).

Figure 15. Visual inspection during high water conditions

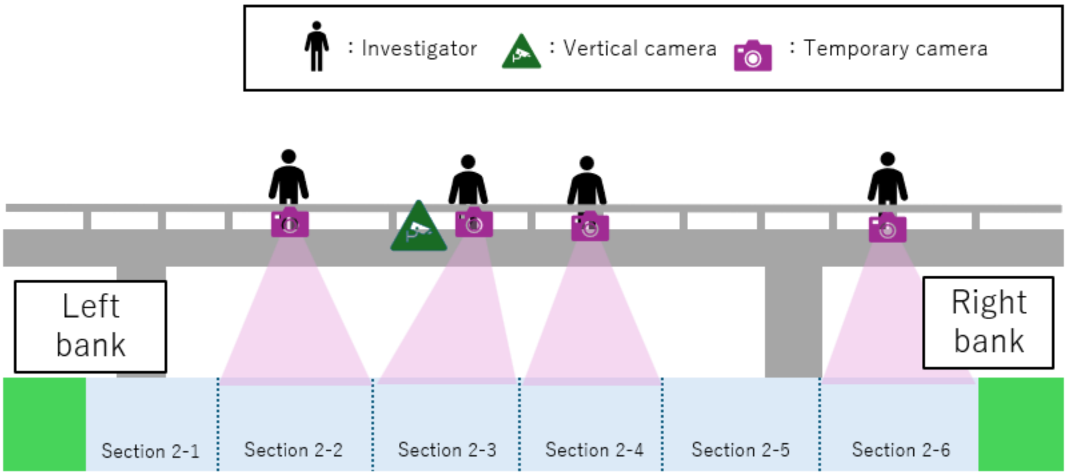


Figure 16. Observation position map during high-flow conditions

Table 28. Observation width and total number of macroplastic litter observed during high water level

Section	Section 2-1	Section 2-2	Section 2-3	Section 2-4	Section 2-5	Section 2-6
River width (m)	7	7	6	7	4	7
Total number (pieces)	Not measured	34	62	55	Not measured	67
Number observed per meter (pieces)	—	4.8	10.3	7.8	—	9.5

IV Mark-release-recapture experiment

Table 29. Survey data from the mark-release-recapture experiment

Survey plan	Survey date and time	July 18, 2024, at 10:00 AM Weather: Sunny
	Survey target	Artificial litter measuring 2.5 cm or larger, with known area and weight
	Roles and responsibilities of surveyors	Preparation of simulated litter: 2 people Deployment of simulated litter: 1 person Visual observation: 1 person Retrieval of simulated litter: 2 people
Survey implementation	Preparation of simulated litter and measurement of weight per unit area	Representative riverine litter was prepared, and the weight per unit area (g/cm^2) of the simulated litter was calculated.
	Environmental data collection	Metadata such as weather conditions, atmospheric conditions, and river flow velocity was collected from the Ishite River Aqueduct.
	Measurement of simulated litter by vertical camera and visual observer	The river surface was observed vertically from the Ishite River Aqueduct, and the number of simulated litter pieces flowing downstream was counted.
Image analysis and compilation of results	I. AI detection:	Using the system developed by the Kataoka Laboratory, the number of pieces, pixel counts, and flux were calculated.
	II. Manual image detection:	Based on observation videos, the number of pieces and pixel counts were manually aggregated.
	III. On-site visual inspection:	The number of pieces was aggregated based on the observation notebook.

(1) Preparation of simulated litter and measurement of weight per unit area

Artificial litter was prepared, and its area and weight were measured. For "other plastics," representative items commonly observed in coastal and river litter were selected. Additionally, vegetation from around the demonstration test site (leaves, branches, and reeds) was also prepared alongside the simulated litter. The amount of simulated litter was categorized into three size groups—large, medium, and small—based on the number of items, and tests were conducted twice for each category (a total of six times). Table 30 presents the number of prepared simulated litter. Additionally, as reference values, Table 31 shows the measured average unit weight per unit area (g/cm^2) for each category of artificial litter, along with its standard error.

Table 30. Number of items by category for the simulated litter and surrounding vegetation used in the test

Trial No.	1	2	3	4	5	6
Category	Large_1st	Large_2nd	Medium_1st	Medium_2nd	Small_1st	Small_2nd
Drink bottles	10	10	5	5	3	3
Food containers	10	10	5	5	3	3
Shopping bags	10	10	5	5	2	2
Other plastics	40	40	20	20	10	10
Can	10	10	5	5	2	2
Surrounding Vegetation	80	80	40	40	20	20

Table 31. Measurement results of weight per unit area for simulated litter

Item	Count	Weight Per Unit Area by Litter Type（g/cm^2）
Drink bottles	10	0.40±0.04
Food containers	10	0.06±0.01
Shopping bags	5	0.01±0.01
Other plastics	39	0.45±0.09
Cans	5	0.27±0.02

(2) Environmental data collection

Metadata such as weather conditions, atmospheric conditions, and river flow velocity was collected from the Ishite River Aqueduct. Observation metadata during the visual survey is shown in Table 32.

Table 32. Metadata for Mark-release-recapture experiment

Category	Metadata	Mark-Release-Recapture Experiment
Basic information	Observation date	July 18, 2024 (River flow velocity measured on July 17)
Weather and atmospheric conditions	Weather	Sunny
	Cloud cover	6
	Wind speed	2.0-2.4 m/s
Surface litter dynamics	River flow velocity	0.00-0.68 m/s
	Presence of litter retention or accumulation	Retention: none Accumulation: none
Surrounding environment	River transparency	50 cm or more

(3) Measurement of simulated litter using vertical camera and visual observers

Simulated litter was released upstream of the Ishite River Aqueduct and measured using a vertical camera and visual observation (Figure 17 and Figure 18). The visual observers were not provided with prior information about the number or composition of the simulated litter.

During the release of simulated litter, a collection net was installed upstream to prevent contamination, and any non-simulated litter flowing downstream was retrieved by workers to ensure clean data collection.

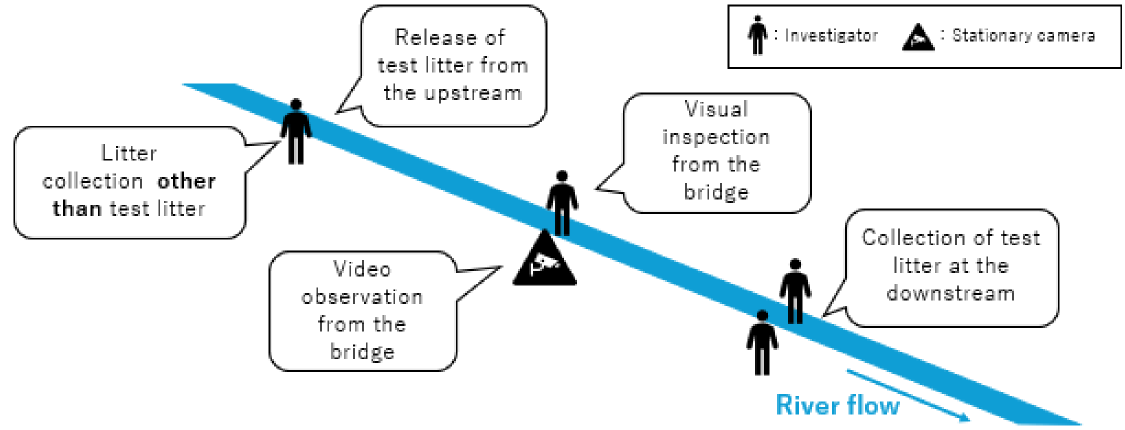


Figure 17. Diagram of the mark-release-recapture experiment overview

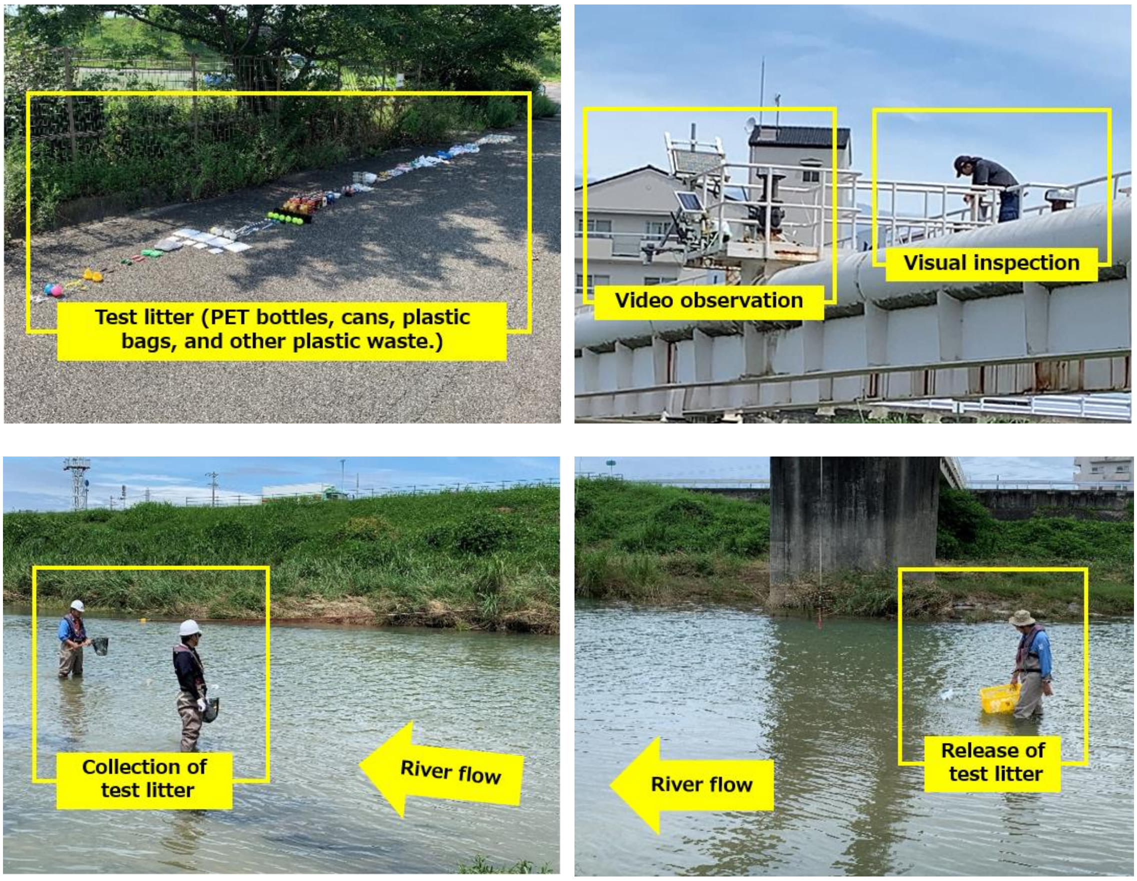


Figure 18. Implementation of the mark-release-recapture experiment