Proposal of a method for predicting flood risk for unexperienced rainfall using climate change prediction information

Hayase Yoneda[1,2], Tomohito Yamada[1]

1:Faculty of engineering, Hokkaido university
2:CTI Engineering Co.,Ltd.

Contents

1.Introduction

- In recent years, there have been many cases of severe flooding damage caused by the overflowing of rivers and drainage.
- In actual occurrence, flooding damage is caused by a variety of factors, **including rivers overflowing, small and medium-sized rivers overflowing, and Sewer e overflows.**

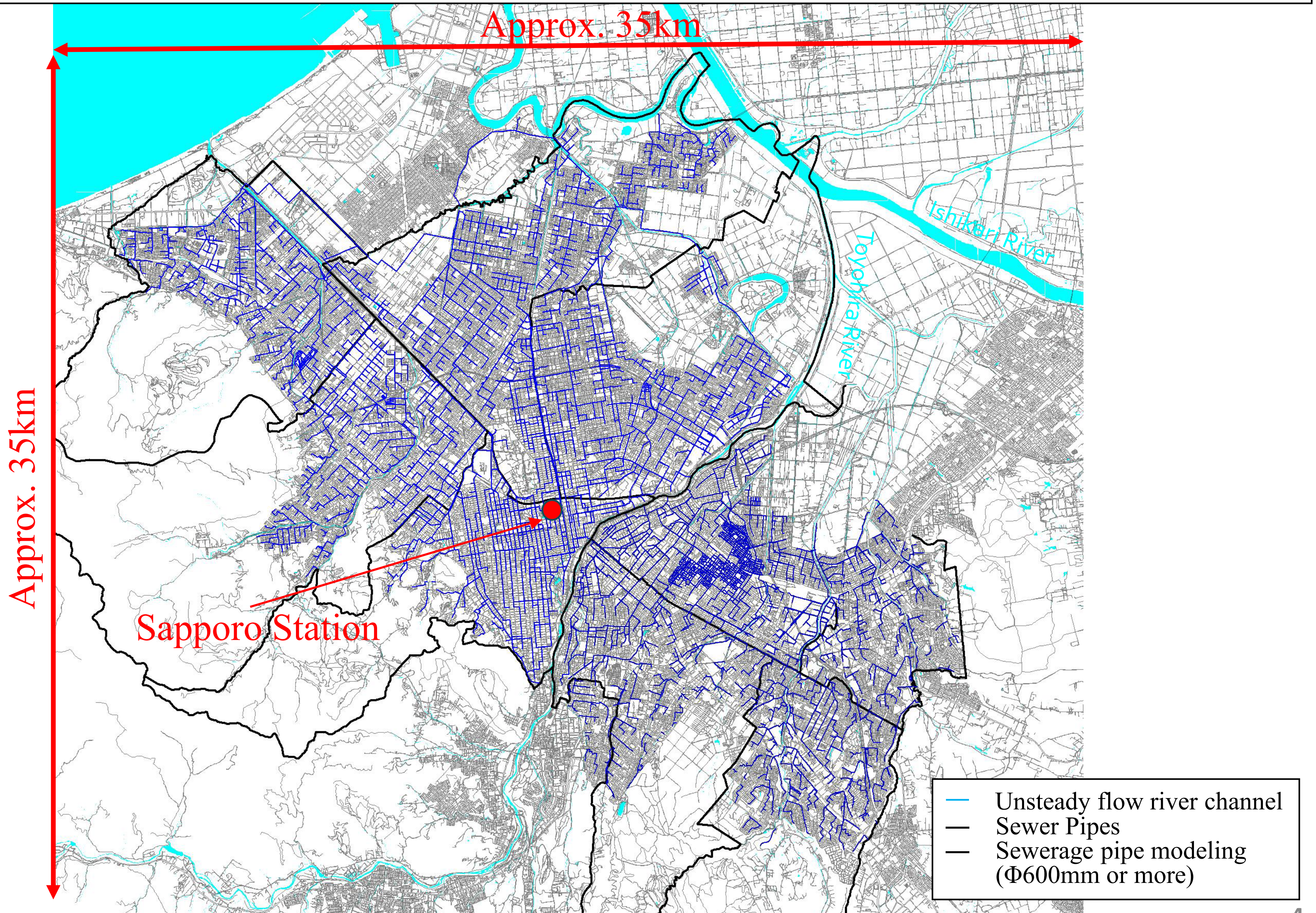
1.Introduction

- In recent years, there have been many cases of severe flooding damage caused by the overflowing of rivers and sewers.
- In actual occurrence, flooding damage is caused by a variety of factors, **including rivers overflowing, small and medium-sized rivers overflowing, and sewer overflows.**

This study proposes the risk of inundation due to flooding of rivers and sewers by unprecedented rainfall.

1.Introduction

- In this study, we conducted an investigation into the Sapporo metropolitan area, where the large Toyohira River runs through, several small and medium-sized rivers flow through the city, and the sewerage network is highly developed.



1.Introduction

- ■ The characteristics of flood damage were analyzed by inundation analysis considering rivers and sewers.
- ■ **<u>It is difficult to cover all rainfall events (patterns) that could cause flooding damage</u>** using only decades of actual rainfall data.

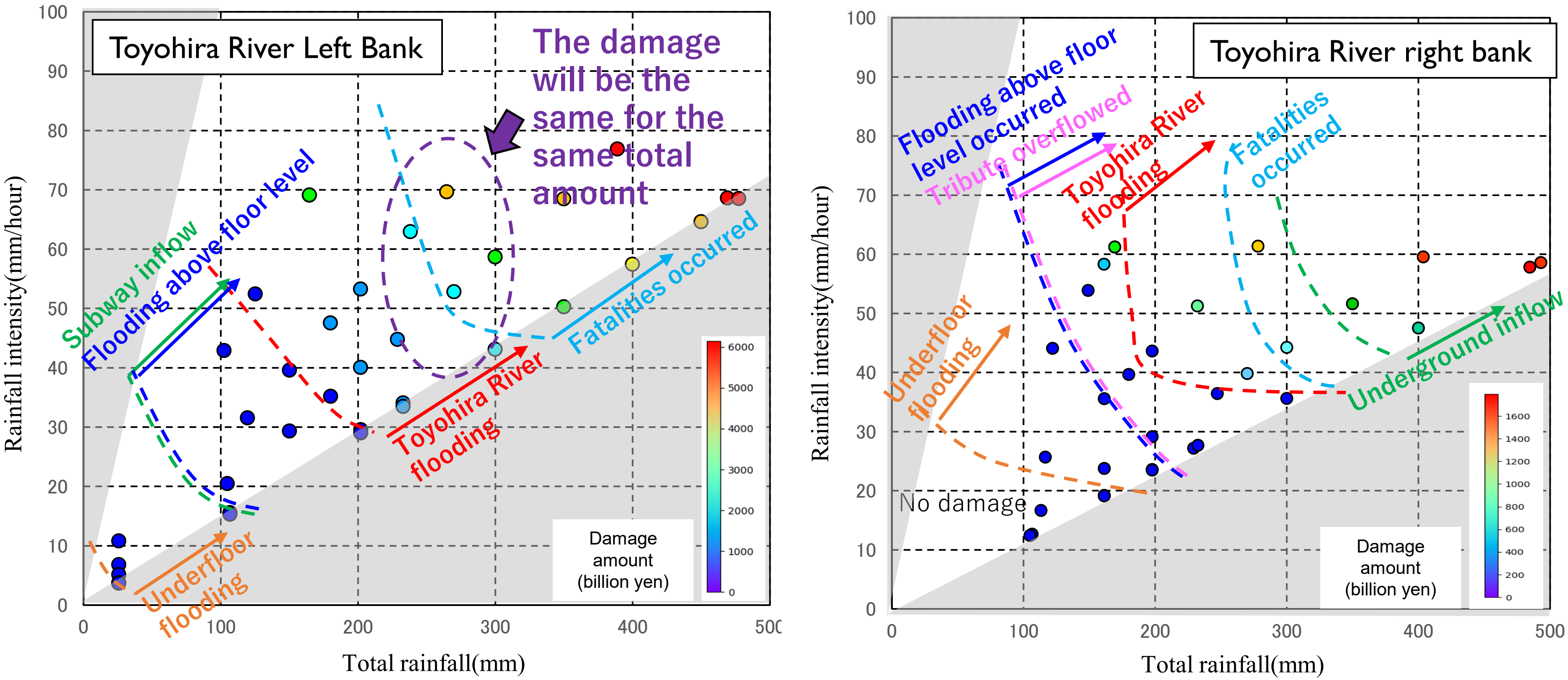


Figure - Analysis of flood damage characteristics for Toyohira River

※Hayase Yoneda, Tomohito Yamada et al.: Risk assessment of flood damage by simultaneous analysis of internal and external flooding considering uncertainties of rainfall and runoff, Journal of Japan Society of Civil Engineers, Vol. 74, No. 5, I_1387-I_1392, 2018

2. Outline of the research

■ We propose a method for calculating flood risk for possible rainfall flood analysis using rainfall data from d4PDF.

Phase1. Extraction of climate-predicted rainfall data for the target basin

Setting the calculation period (extracting the planned rainfall duration of 72 hours for Toyohira River)

※Dynamic downscale rainfall by Yamada et al. 5km mesh (211 × 191) = 3000 events × 360 hours (30-minute rainfall)

・Correction was performed by applying the 10-minute rainfall waveform at the time of maximum hourly rainfall (the 10-minute rainfall waveform is a centrally concentrated waveform).

Phase2. Calculation of boundary conditions

Major river: Toyohira River

1.Calculating the average rainfall in the basin
2.Calculating the flow rate at the Karui point, etc., using the **storage function method**(taking into account flood control by dams)

Small and medium-sized rivers: Mochizukisamu River, Nopporo Rivera, etc. (18 rivers)

1.Calculation of average rainfall in the basin
2.Calculation of flow rate using a **synthetic rational formula.**

Sewerage: Manhole inflow (9975 catchment areas)

1. Calculate the amount of rainfall in each catchment area
2. Calculate the effectiveness of rainwater storage facilities
3. Calculate the flow rate using the modified **RRL method**

Converted to boundary conditions for **unsteady flow model** (10-minute flow rate)

Converted to boundary conditions for **sewerage model** (10-minute flow rate)

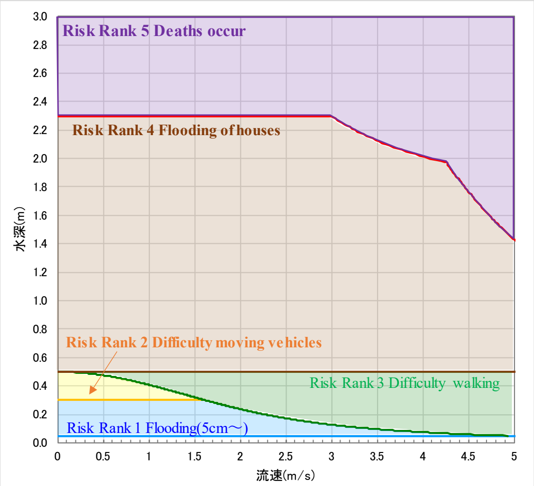
Phase3. Simultaneous analysis of domestic and foreign water

Calculations were performed using two simultaneous analysis models for both left and right bank areas.
Calculate the flood depth and flow velocity for each mesh using a two-dimensional unsteady flow calculation

- Spatial resolution: 10m mesh
- Analysis area: $270km^2$
- Modeled pipeline length: 1,250km

Phase4. Conversion of hydraulic quantities into flood damage

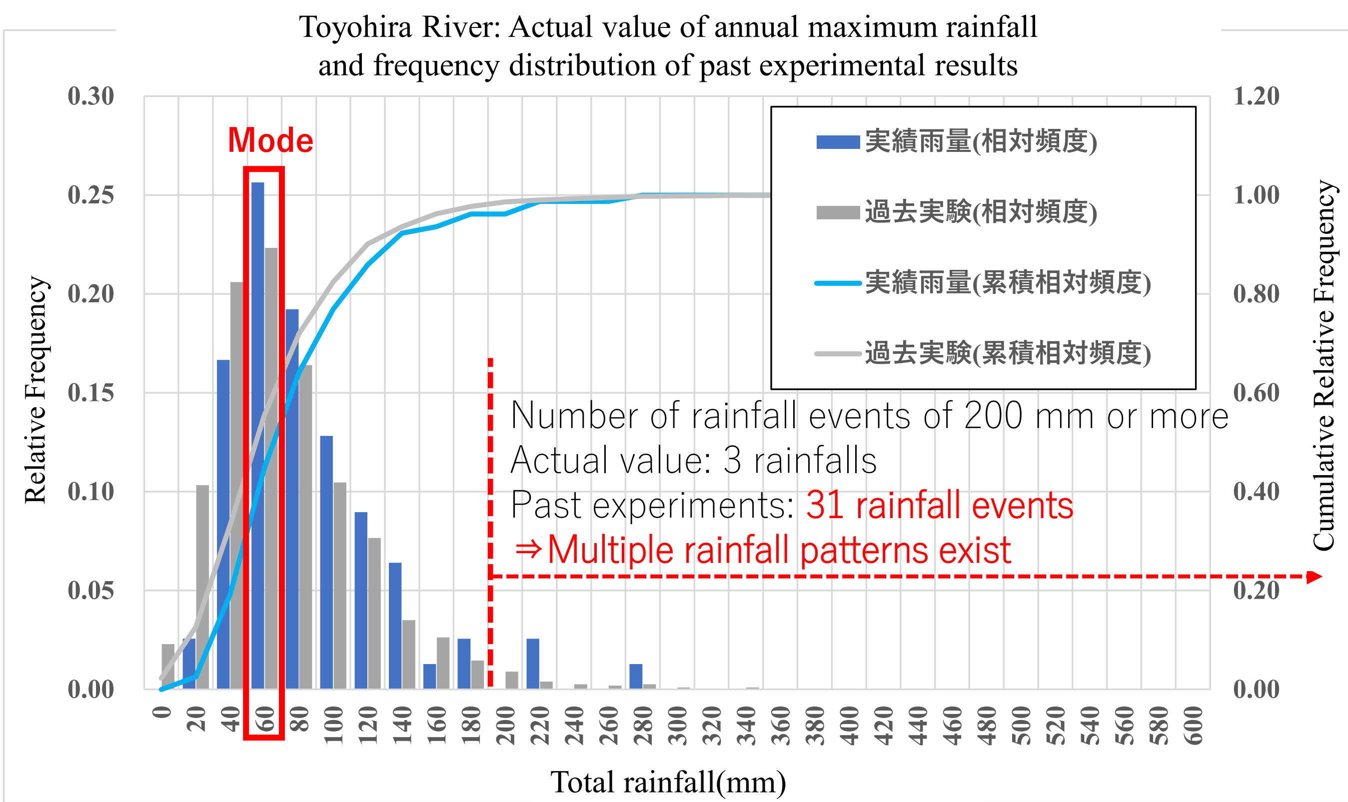
Using the inundation depth and flow velocity of each mesh, an inundation risk rank is assessed.



Flood Risk Rank

Phase1. Extraction of climate-predicted rainfall data for the target basin

- The frequency distribution of annual maximum rainfall was compared between actual rainfall and the results of a 5 km experiment at the upstream reference point of the Toyohira River.
- The most frequent total rainfall value is the same, and there are several rainfall events equivalent to the largest flood ever recorded (total rainfall of approximately 240 mm).
- By utilizing ensemble data, it is possible to predict flood damage for various rainfalls.



※The annual maximum rainfall was calculated based on the planned rainfall duration of the Toyohira River for three days (72 hours).

Figure - Comparison of frequency distribution between actual annual maximum rainfall values and past experimental results in the upstream area of the Toyohira River reference point

Table - Specifications of past experimental data for actual rainfall and ensemble data

Target data	The number of data	Target period
Actual rainfall events	93 years worth	1926-2019
5km experiment results	3,000 years worth	1951-2010 (60 years x 50 members)

Phase1. Extraction of climate-predicted rainfall data for the target basin

■ Past experimental results of large-scale ensemble data show that there are various types of rainfall with different temporal and spatial variations.

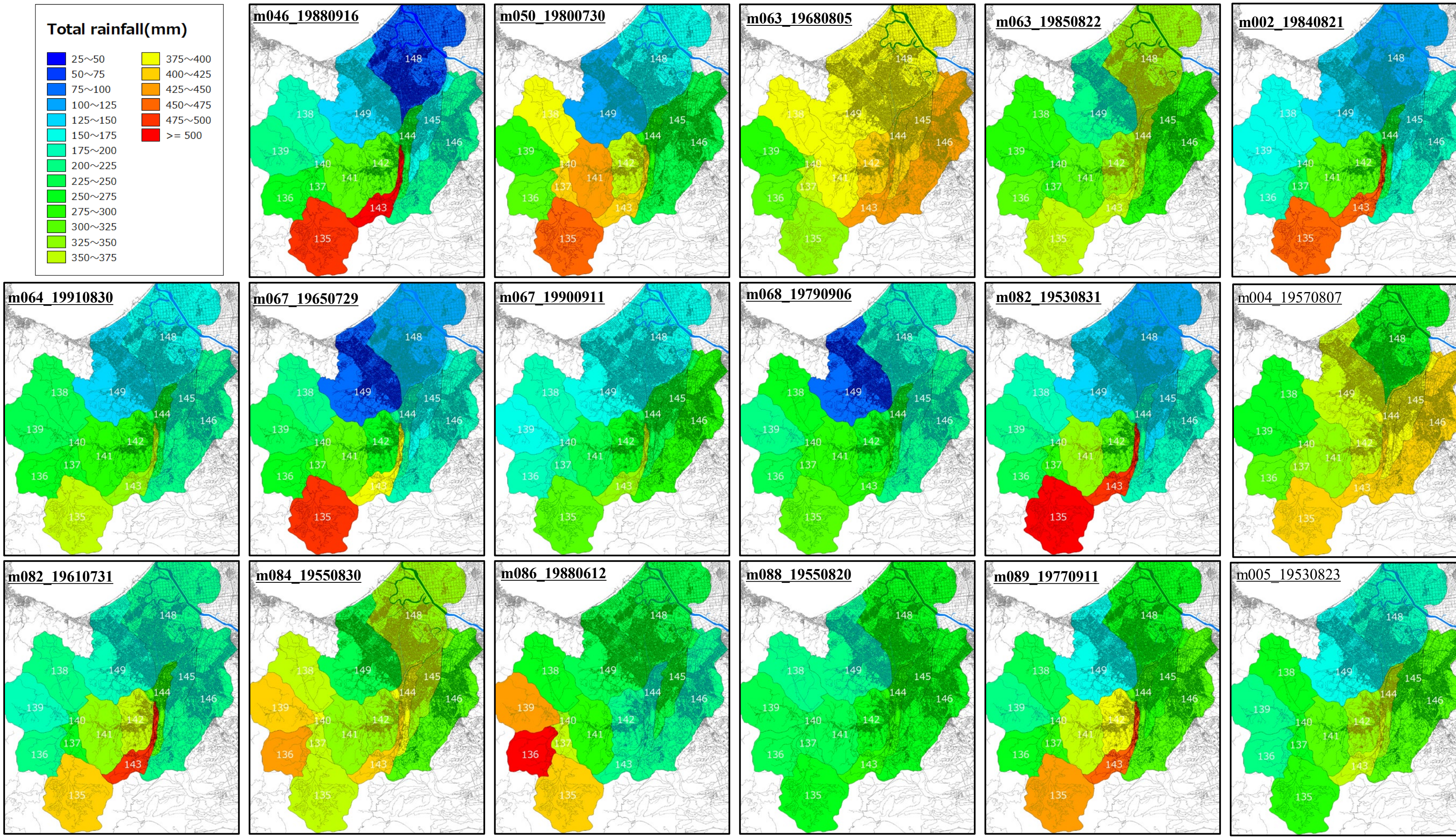
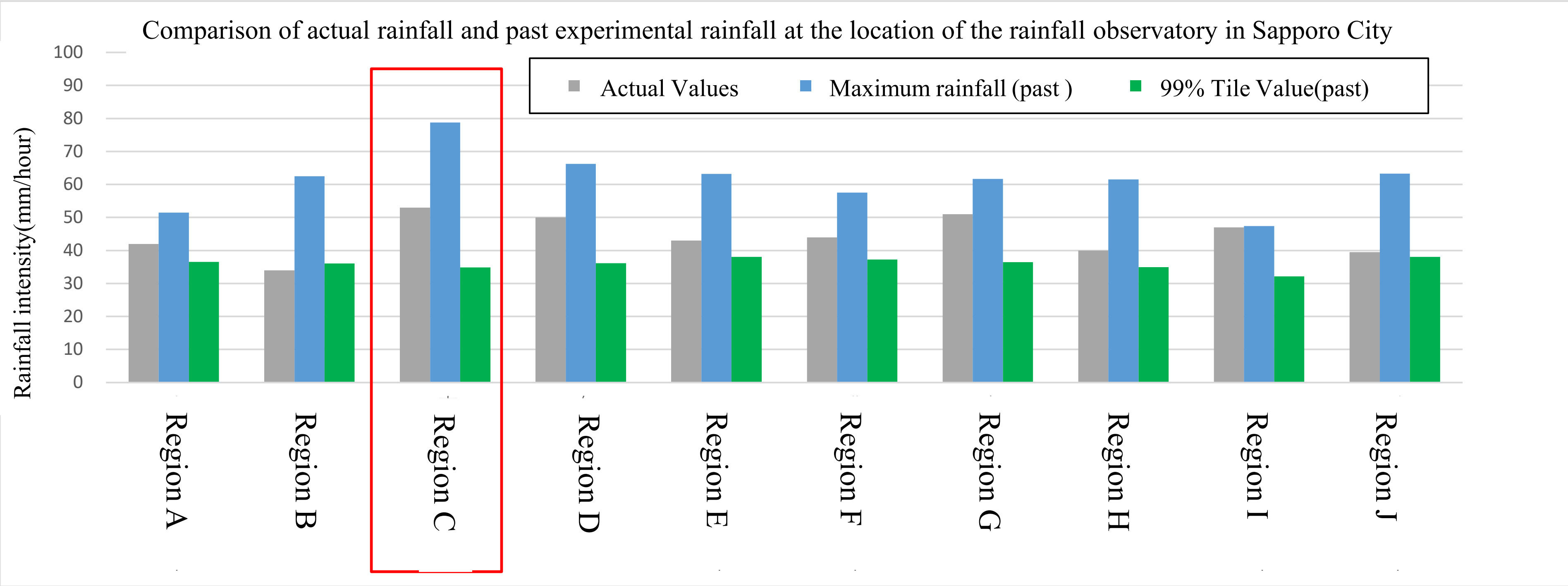


Figure - Basin average rainfall amount of rainfall events of d4PDF (past experiment) in the upstream area of Toyohira River reference point (excerpt)

Phase1. Extraction of climate-predicted rainfall data for the target basin

- In this study, used d4PDF rainfall data used.
- A comparison was made between the maximum actual rainfall observed at the civil engineering centers in each ward in Sapporo and the rainfall extracted from past and future experiments.



※d4PDF downscaled 5km mesh, rainfall in the mesh where the observation station is located is used

The maximum hourly rainfall observed in Sapporo city was about 50mm/hour
⇒Clarifying flood damage caused by unprecedented phenomena through climate change forecast rainfall and numerical analysis(Rainfall event name: HPB_m003_2010)

2. Outline of the research

■ We propose a method for calculating flood risk for possible rainfall scenarios by conducting integrated domestic and international flood analysis using rainfall data from d4PDF.

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Calculations were performed using two simultaneous analysis models for both left and right bank areas.
Calculate the flood depth and flow velocity for each mesh using a two-dimensional unsteady flow calculation

・Spatial resolution: 10m mesh ・Analysis area: 270km^2
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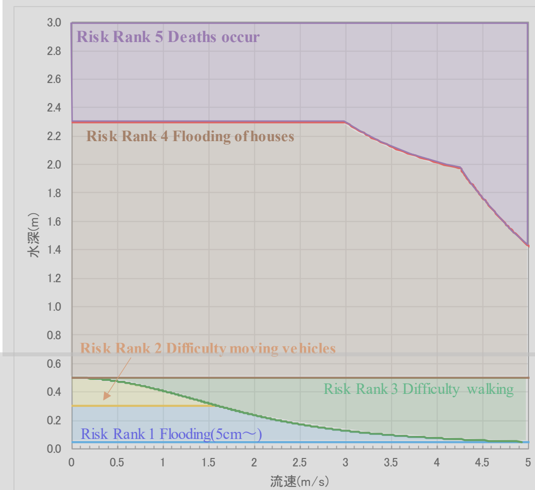
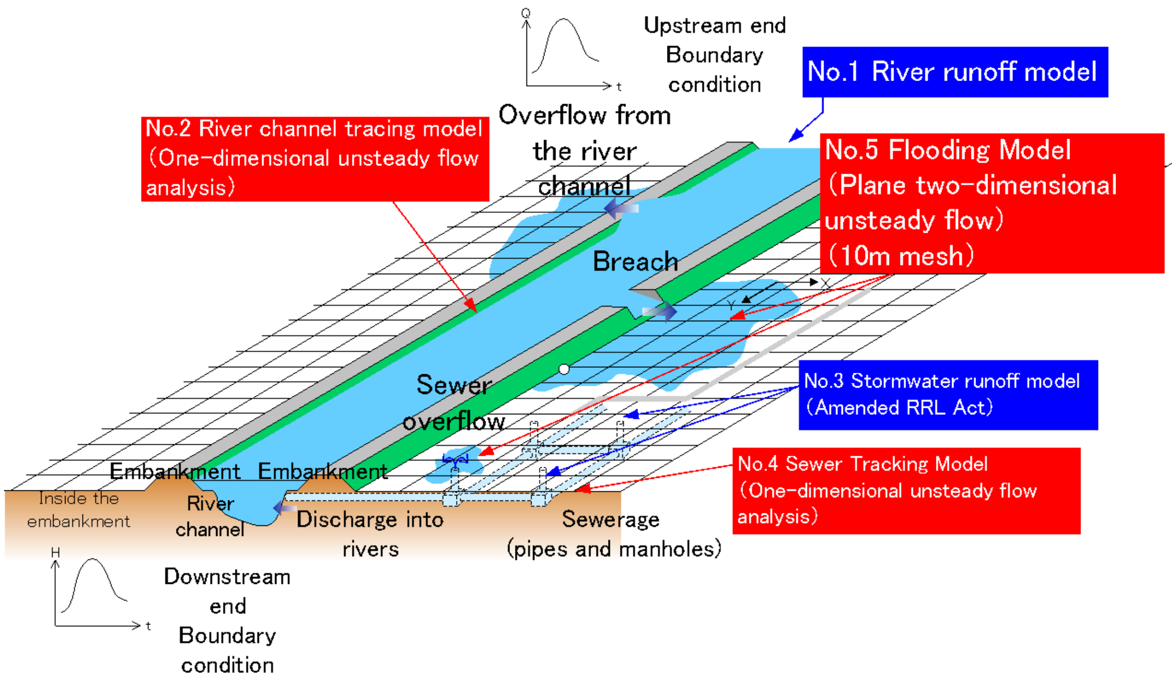


Flood Risk Rank

Phase3. Flood analysis considering flooding from rivers and sewers

- We calculated flood damage within a river basin by analyzing simultaneous internal and external flooding, modeling large rivers, medium-sized and small rivers, and sewerage systems.



Model classification for each area		analysis method
surface	Flood analysis	Plane two-dimensional unsteady flow analysis (considering resistance from buildings)(10m mesh in Cartesian coordinate system)
river	river runoff	Storage function method: Toyohira River Rational equations, etc.: Shinkawa River, Atsubetsu River, Tsukisamu River, etc.
	River analysis	One-dimensional unsteady flow analysis
Sewerage	Sewer runoff	Modified RRL method
	Sewer analysis	One-dimensional unsteady flow analysis (basically a pipe with a diameter of 600 mm)

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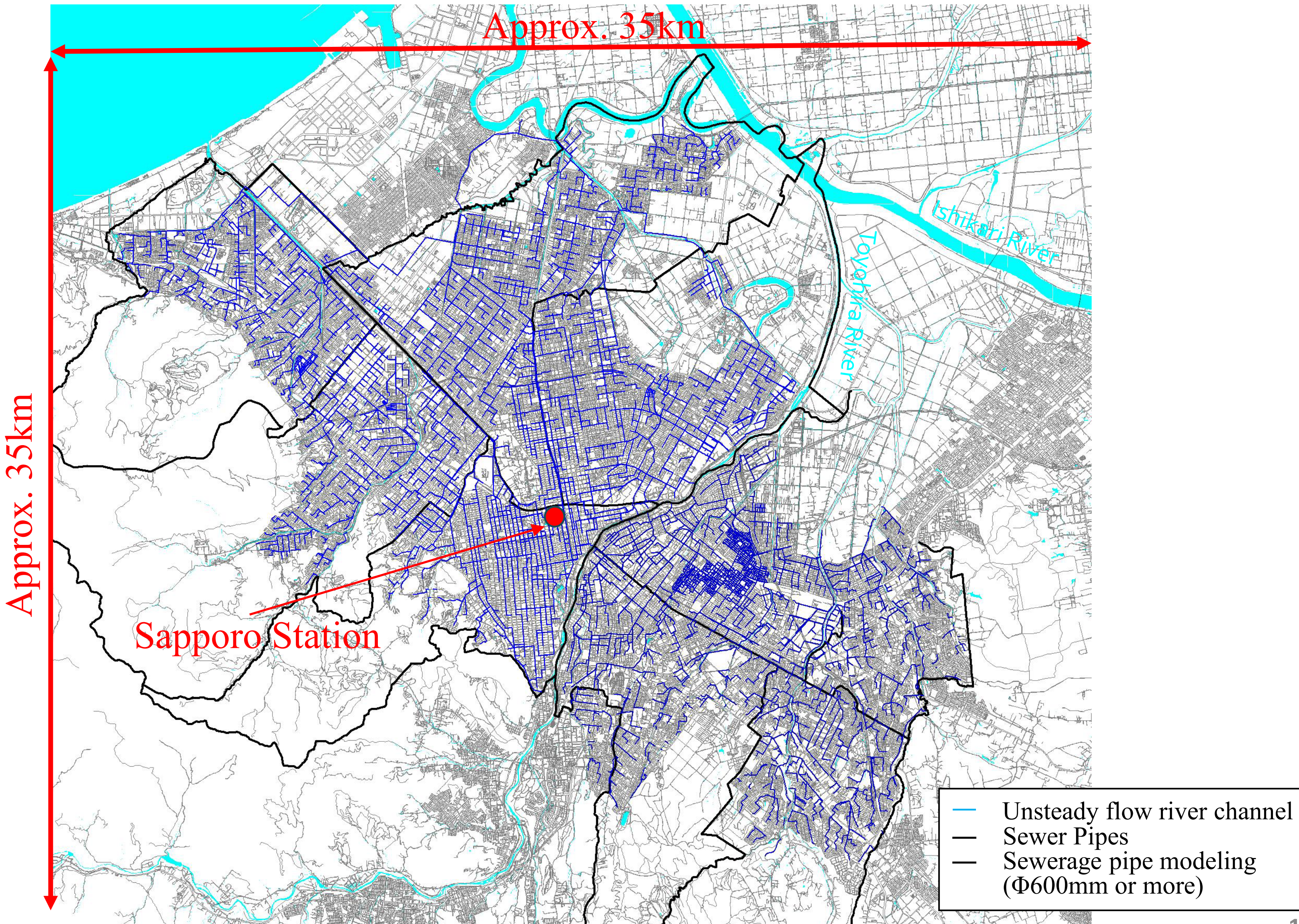

Phase3. Inundation analysis considering flooding from rivers and sewers

- The results of inundation analysis in the target rainfall are shown.
- In this way, we calculated the flooding situation in the event of predicted rainfall.
- Flooding occurred on the left and right said of the Toyohira River, and flooding of 50 cm or more occurred in Area C, where rainfall is particularly high.

2. Outline of the research

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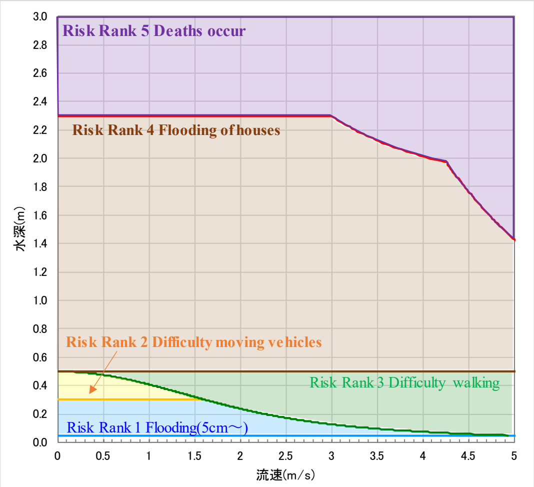


Flood Risk Rank

4. Visualization of flood risk

- In order to make the dangers of flooding easier to understand, we have organized and consolidated existing risk indicators.
- Flooding risk was categorized based on the following
  ① Difficulty in moving by vehicle, ② Difficulty walking, ③ Flooding above the floor level of houses, ④ Deaths and house collapses.

【Setting evaluation indicators】

■Vehicle movement difficulty index

Based on the "Guidelines for Flood Damage Indicator Analysis, March 2013," the flood depth was set at 30 cm, which is used as an indicator of the number of vehicles passing through that will be affected by road closures.

＜浸水による道路途絶の考え方＞
機能低下する条件は、『(4.1) 途絶する主要な道路』と同様に、浸水深 30cm を閾値として設定することを原則とする。

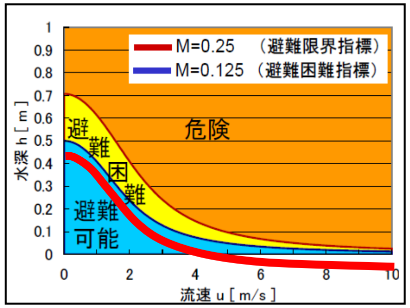
＜浸水深と自動車通行との関係＞
10 [cm]：乗用車のブレーキの効きが悪くなる
20 [cm]：道路管理者によるアンダーパス等の通行止め基準
30 [cm]：自治体のバス運行停止基準
乗用車の排気管やトランスミッション等が浸水
60 [cm]：ＪＡＦの実験でセダン、ＳＵＶともに走行不可[81]

※Source: Guide to Flood Damage Indicator Analysis H25.3

Figure–Relationship between flood depth and vehicle traffic

■Walking difficulty index

The settings were based on full-scale model experiments conducted by Kyoto University and Kansai University.



※Source: Excerpt from "Indices of Evacuation Difficulty in the Event of Underground Space Flooding and Their Applications (February 2008)", p.843

Figure–Walking difficulty index

■Flooding index for houses above floor level

According to the "Flood Control Economic Survey Manual (Draft) April 2005" for the depth of flooding above and below the floor level and the floor height standard in Article 22 of the Building Standards Act Enforcement Order, the depth of flooding above the floor level is 45cm, but to be consistent with the above-mentioned indicators of water depth that makes it difficult to walk, the depth of flooding **above the floor level is set at 50cm**. (The damage amount is calculated with 45cm as the boundary between above and below the floor level.)

Table–Damage rate by flood depth

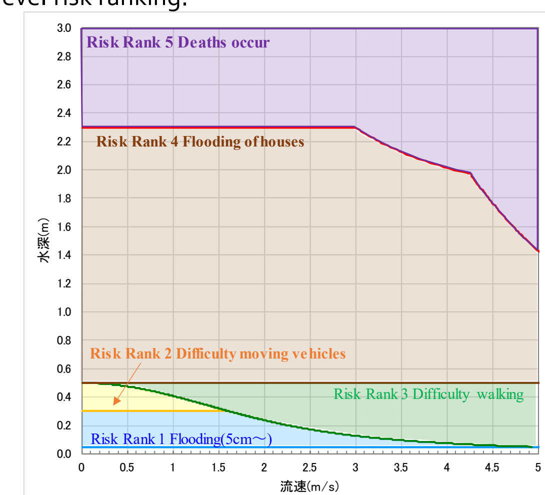
浸水深 / 地盤勾配	床下	床上					土砂堆積（床上）	
		50cm未満	50～99	100～199	200～299	300cm以上	50cm未満	50cm以上
Ａグループ	0.032	0.092	0.119	0.266	0.580	0.834	0.43	0.785
Ｂグループ	0.044	0.126	0.176	0.343	0.647	0.870		
Ｃグループ	0.050	0.144	0.205	0.382	0.681	0.888		

Ａ：1/1000 未満、Ｂ：1/1000～1/500、Ｃ：1/500 以上
注：1．平成５年～平成８年の「水害被害実態調査」により求められた被害率。（ただし、土砂堆積は従来の被害率）

※Source: Flood Control Economic Survey Manual, April 2005

Setting evaluation indices that integrate various indices

Using various indicators, the relationship between flow speed and water depth was graphed and integrated to set a five-level risk ranking.



Figure–Relationship between flow rate and water level for various indicators

■Fatality Index

In the "Guidelines for Flood Damage Indicator Analysis, March 2013," the floor height on the first floor is set at 50cm, and the distance from the floor height on the first floor to the floor height on the second floor is set at 2.7m. The danger water level for people aged 65 or older who require assistance in the event of a disaster is set at a water depth of 1.8m or more. Considering damage to people who require assistance in the event of a disaster in a one-story house, **a flood depth of 2.3m**, calculated as 0.5m (floor height) + 1.8m, is used as the indicator for **the risk of fatalities**.

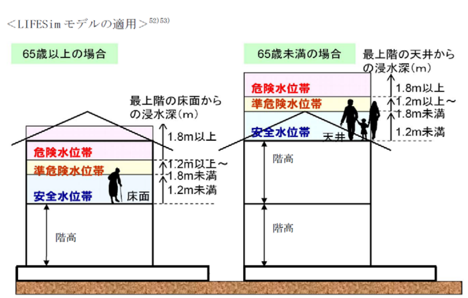
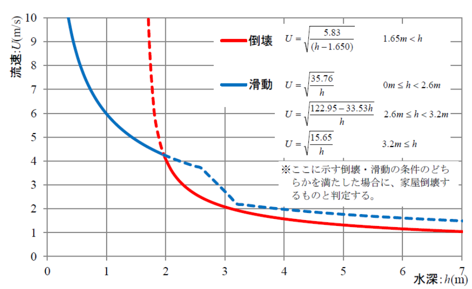


Figure:–Dangerous water levels for fatalities based on LIFESim model

■House collapse occurrence index

This was based on the estimated limits for the collapse of wooden houses in the "Manual for Creating Flood Inundation Area Maps (4th Edition) July 2015."

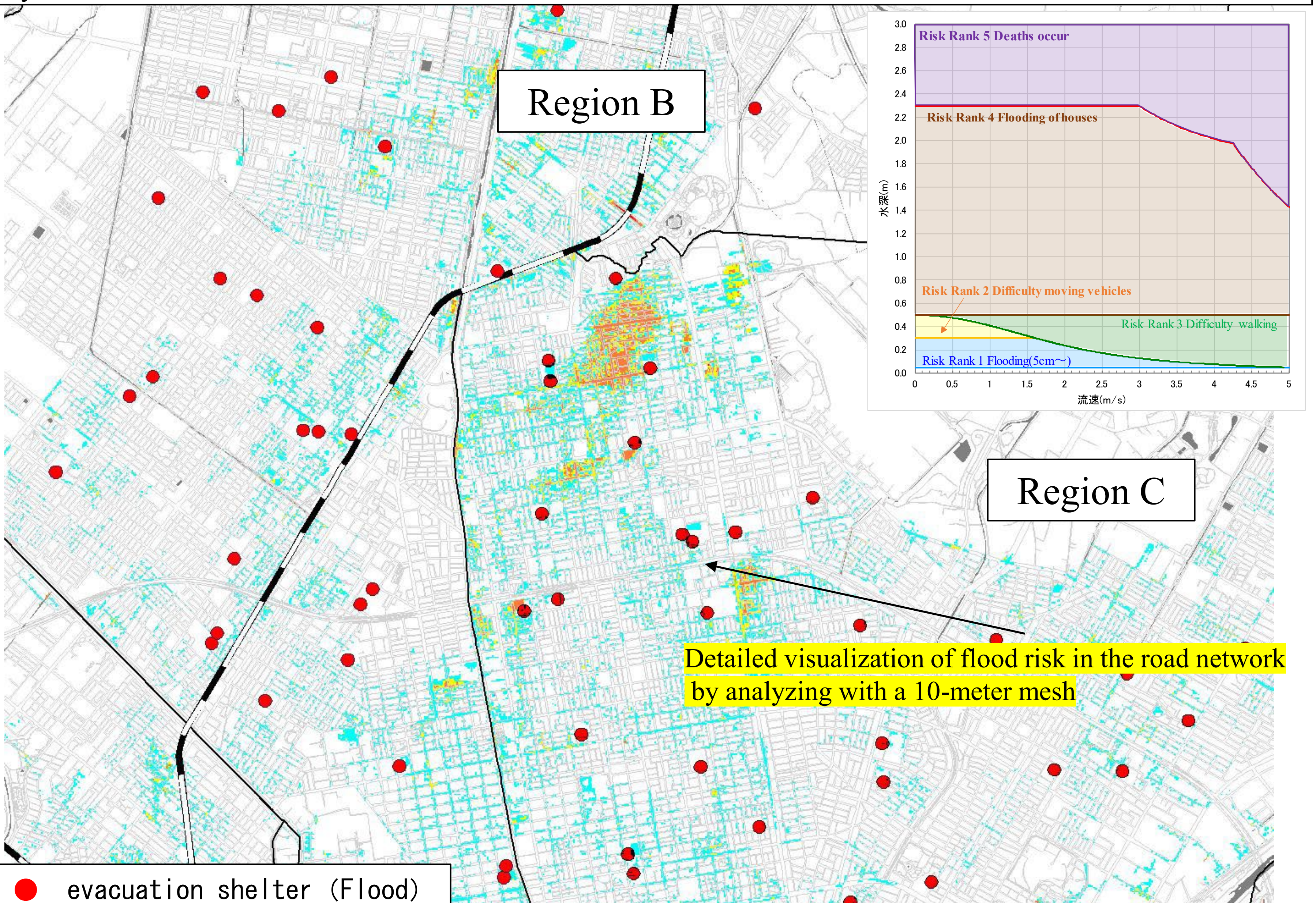


Figure–Example of estimated collapse limit for wooden houses

※Source: Flood Inundation Area Mapping Manual (4th Edition) July 2015

4. Visualization of flood risk

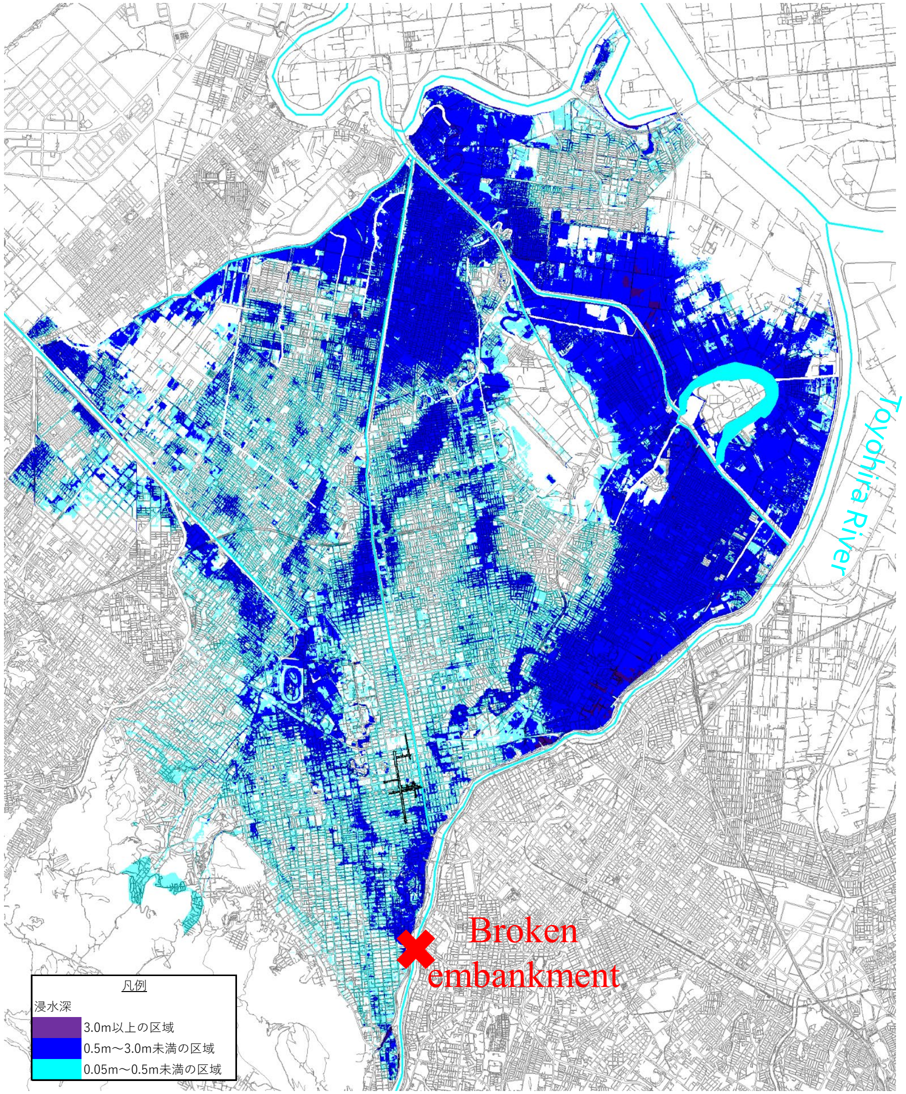
■ Flood risk was visualized using water depth and flow velocity for each 10m mesh obtained from simultaneous analysis of internal and external water.



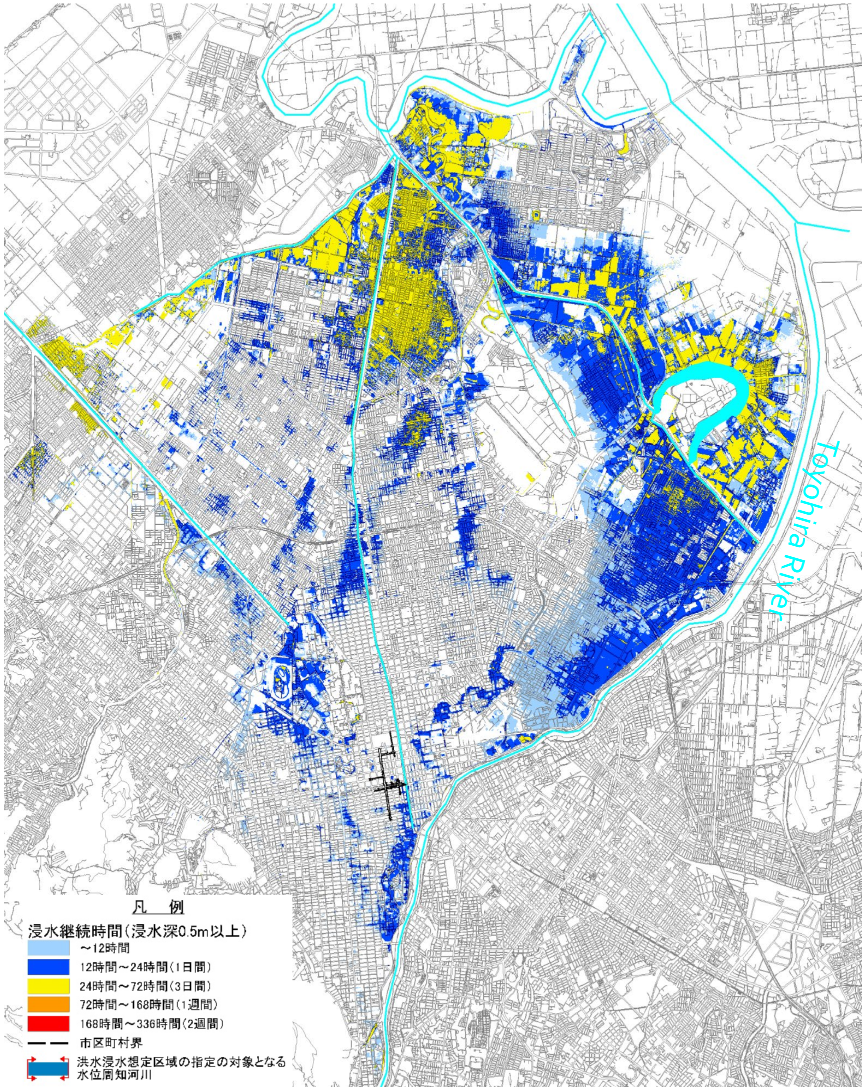
4. Visualization of flood risk

■ Finally, an example of flood analysis results is shown due to rainfall external forces that cause broken embankment.

Maximum flood depth map

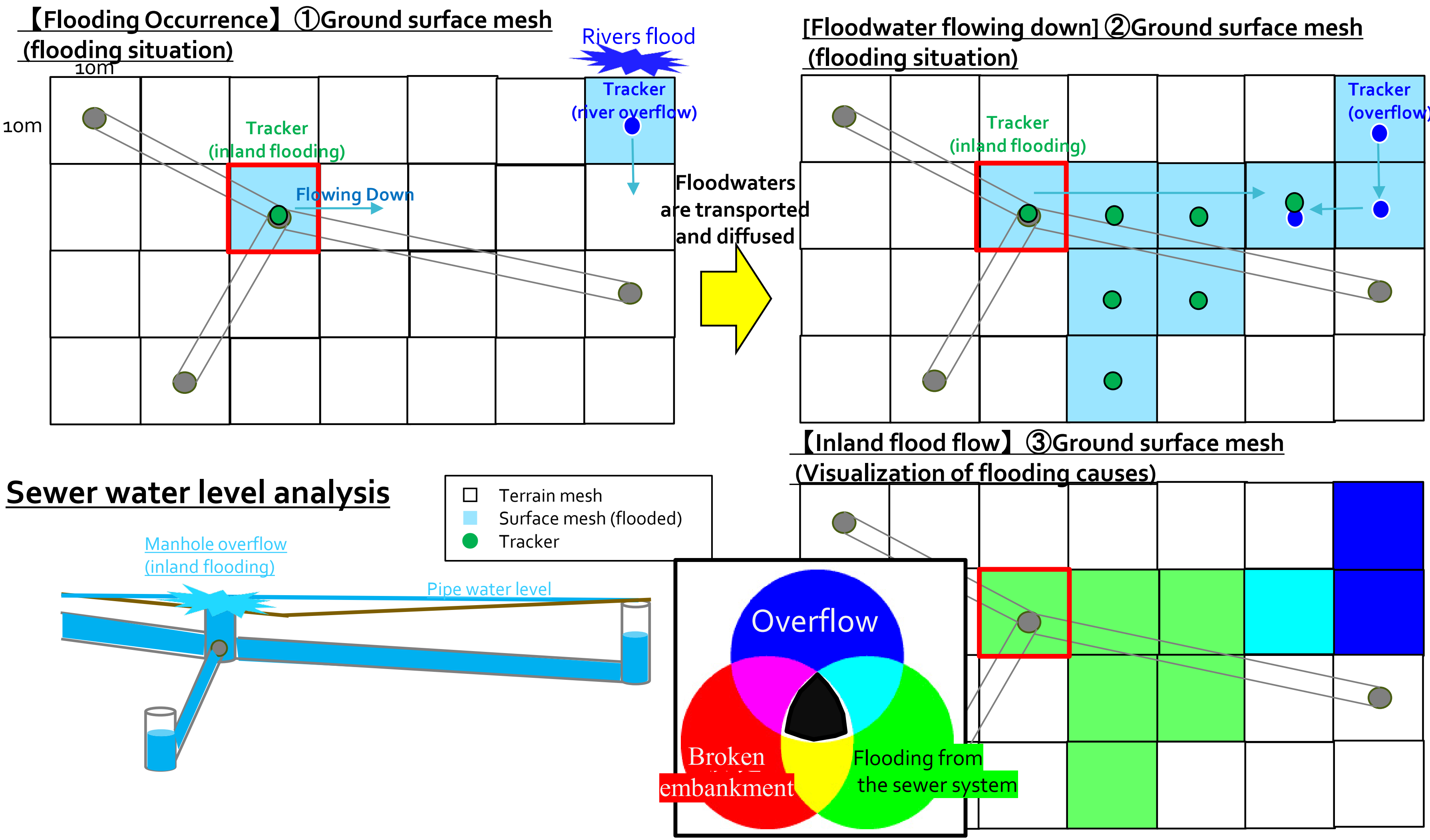


Flood duration Time



4. Visualization of flood risk

- In the future, it will be important to elucidate the factors that cause flood damage in each area.
- In this study, tracers are placed in flood flows according to the cause of flooding, and the behavior of flood flows is tracked temporally and spatially.



4. Visualization of flood risk

- It is important to consider what factors will cause flood flow to cause inundation in each area within a floodplain in future flood control development and flood prevention measures.
- This method can clearly show the causes of flood damage in each area.

Figure - Visualization results of flooding characteristics
using simultaneous analysis of internal and external water

4. Summary

・In this study, we proposed a method to predict the risk of inundation for unprecedented rainfall.

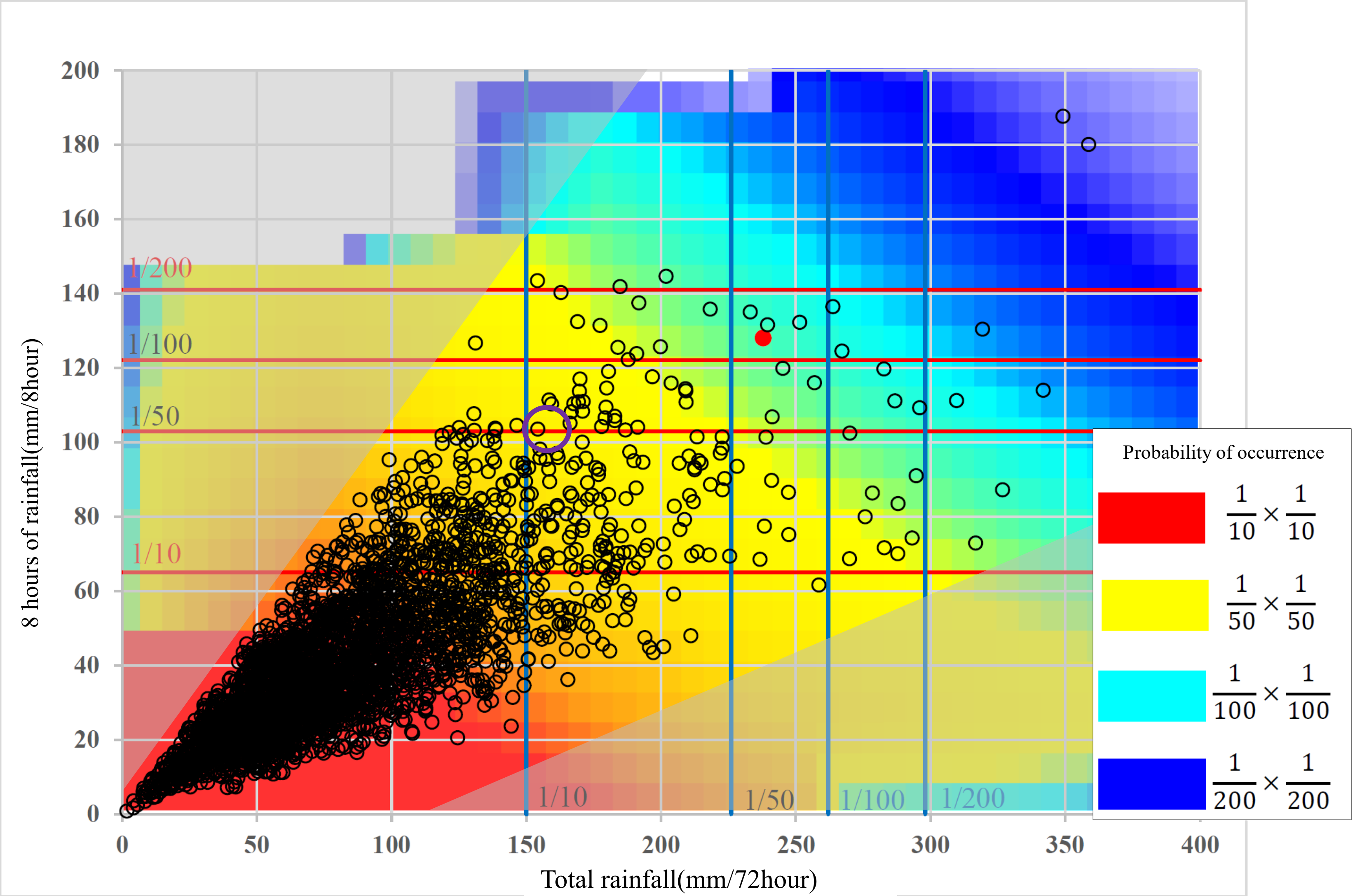
・In this study, we classified the characteristics of rainfall of daily scale and other time scales, and extracted rainfall that had never been experienced in the target area and could cause flood damage. In addition, we analyzed changes in the characteristics of rainfall in the future by comparing rainfall that actually occurred in the past with rainfall in climate prediction information.

・Inundation analysis using rainfall from climate change projection information showed the possibility of inundation damage in areas that had not been flooded in the past, and clarified the specific form of damage caused by the inundation.

・Finally, we predicted the flood risk using an index that converts the predicted flood range from the depth and velocity of the water into the risk of flood damage such as evacuation of residents and flooding of houses , etc. By applying this method to the latest climate prediction information, we extracted rainfall with flood risk and predicted the risk of flood damage in the future.

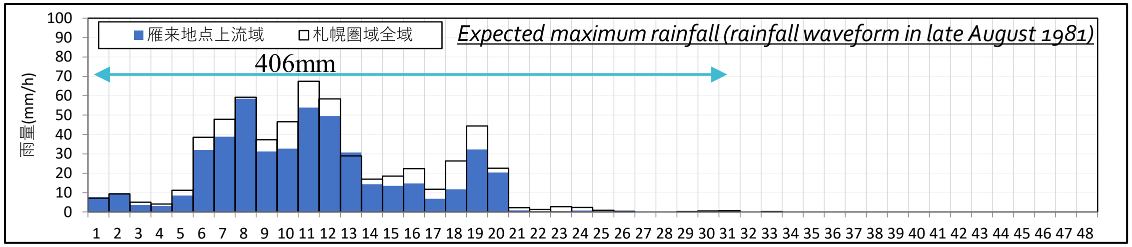
Phase1. Extraction of climate-predicted rainfall data for the target basin

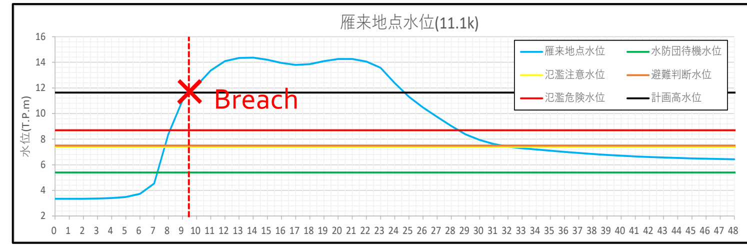
■ How much damage would the "HPB_m003_2010" rainfall event cause in the Sapporo area.
(Based on the 72-hour rainfall amount at the Toyohira River reference point, this amount has a 1/10 chance of occurring.)



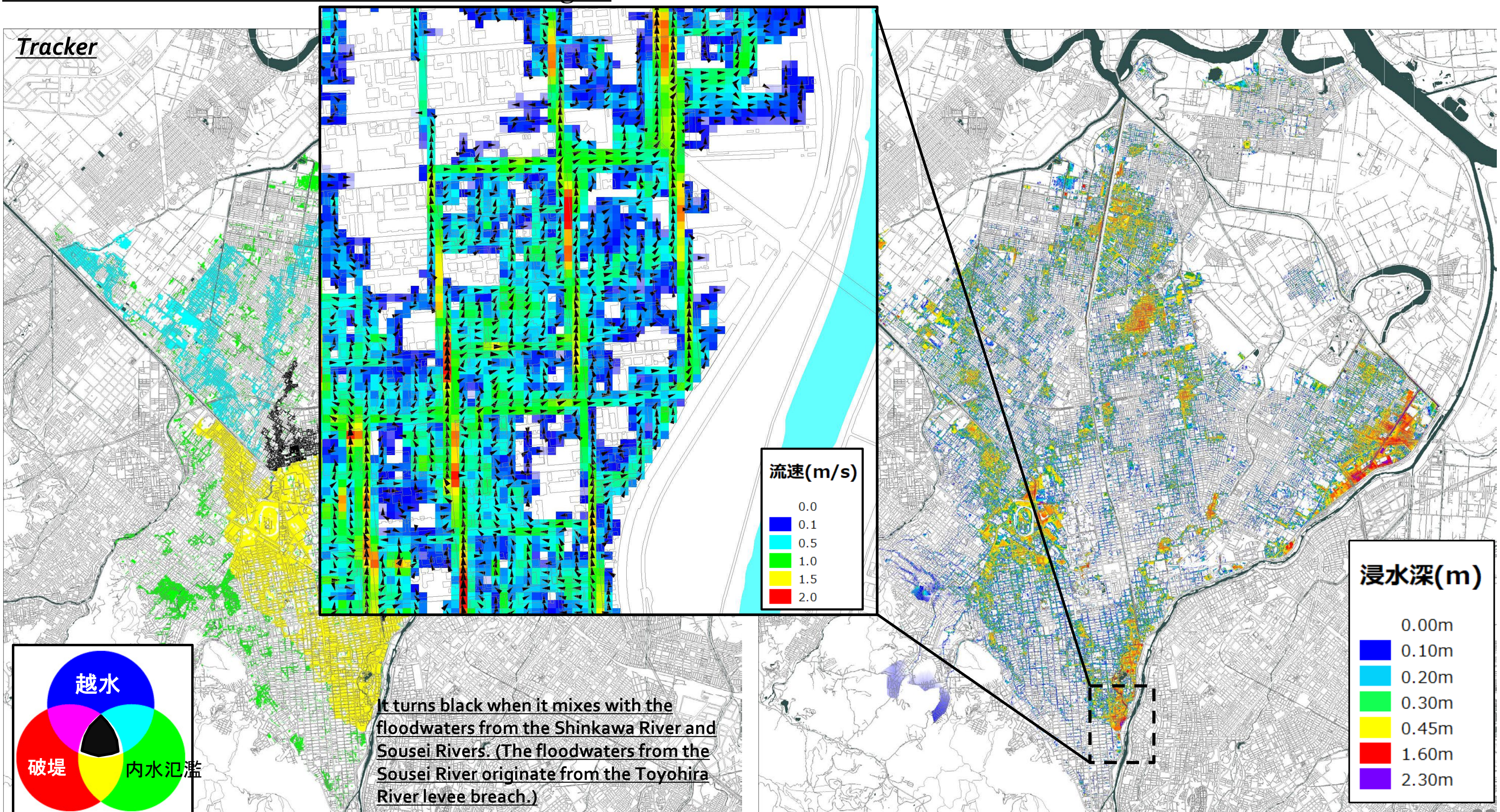
※Proposal of a method for evaluating rainfall external forcing using composite probability with large-scale ensemble climate data

2. Evaluating flood characteristics through visualization of flood occurrence factors





11 hours and 30 minutes after calculation begins

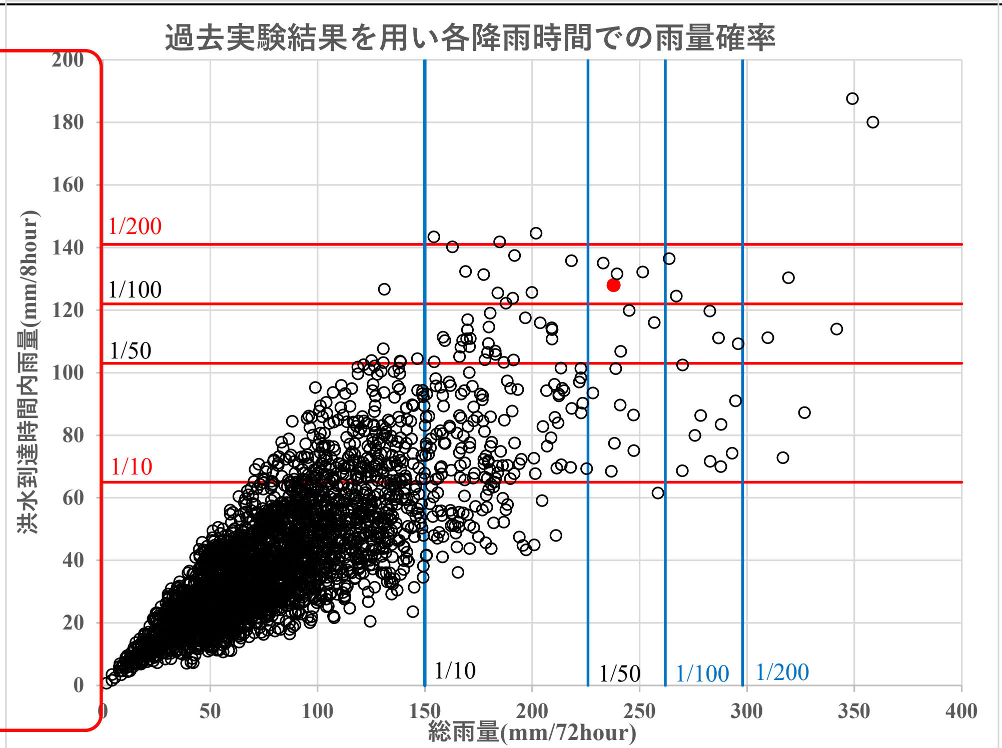


3. Proposal for rainfall external force evaluation and extraction method using composite probability

- To calculate the probability of rainfall for each axis, the total rainfall and the rainfall within the flood arrival time were evaluated probabilities using the results of past experiments.
- In order to make the study easier to understand and to cover rainfall equivalent to the design scale, it was assumed that the total rainfall and the rainfall within the flood arrival time were independent events. In addition, the probability assessment of each rainfall event was calculated by assuming a normal distribution of the rainfall probability.

Probability evaluation results for 8-hour rainfall

確率年	8時間雨量
5	50.4
10	65.4
20	81.1
30	90.8
40	97.8
50	103.4
60	108.1
70	112.1
80	115.6
90	118.7
100	121.6
125	127.7
150	132.8
175	137.1
200	141.0



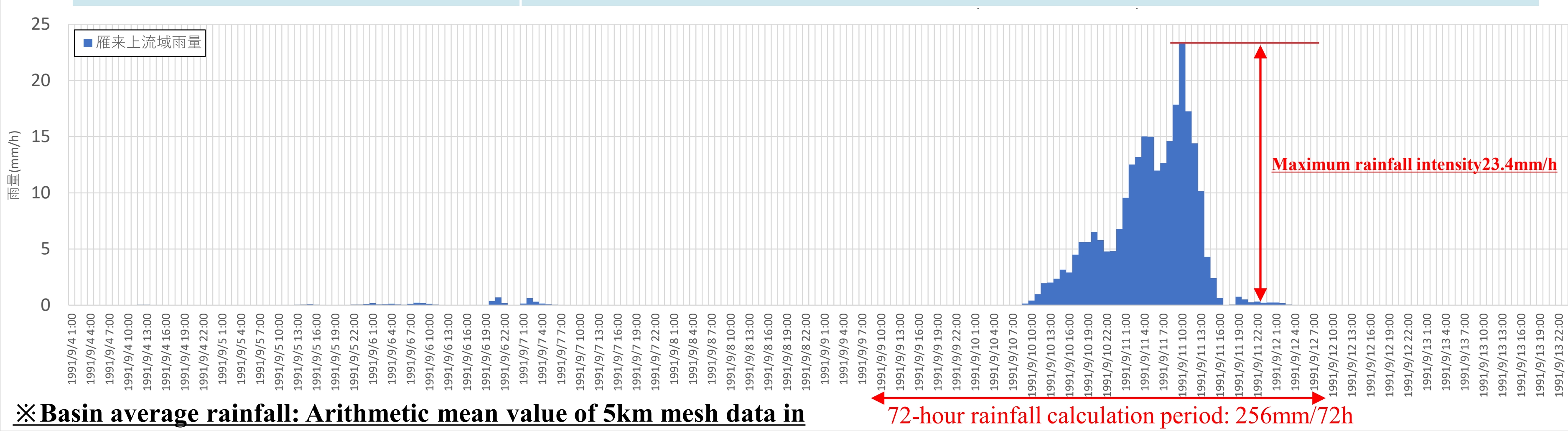
Probability evaluation results for 72-hour rainfall

確率年	5	10	20	30	40	50	60	70	80	90
72時間雨量 (mm)	119.1	150.4	182.3	201.5	215.4	226.4	235.5	243.2	250.0	256.1
確率年	100	125	150	175	200	250	300	400	500	1,000
72時間雨量 (mm)	261.5	273.2	282.9	291.2	298.5	310.8	321.0	337.4	350.3	392.0

4. Proposal of a method to calculate flood risk for possible future rainfall scenarios

- In this study, d4PDF rainfall data (3,000 years of past experiment + 5,400 years of future experiment) are used.
- ・The rainfall in the upstream area of the Kariki site was calculated by extracting the maximum annual rainfall over a three-day period (72 hours) from the 5 km mesh downscale rainfall obtained in previous experiments.

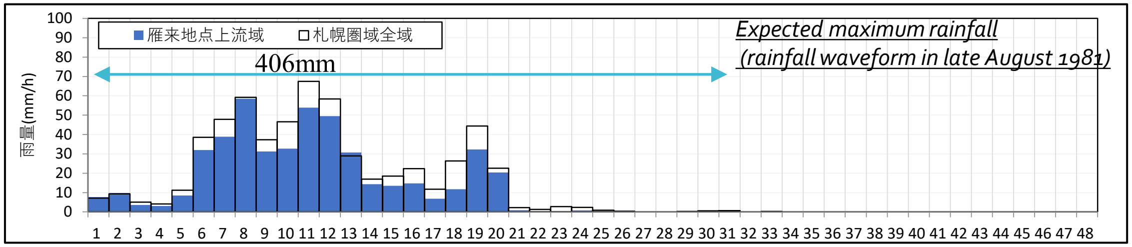
item	Contents
Number of experiment members	Past experiment: 50 members Future experiment: 90 members
Experiment period	Past experiments: 1951-2010 (60 years) Future experiments: 2051-2110 (60 years) ※Statistical processing of future experiments and analysis of each waveform have been carried out for 1,000 years.
Downscaling Period	15 days including the period with the maximum rainfall of the year on the 3rd day at Ishikari Ohashi Bridge

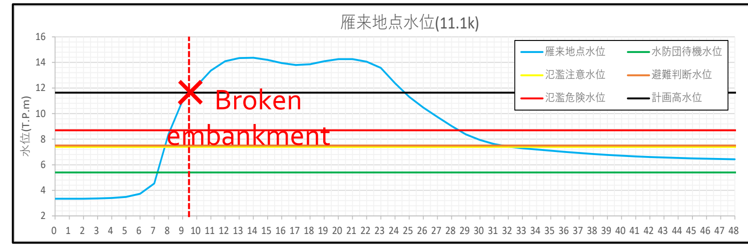


※Basin average rainfall: Arithmetic mean value of 5km mesh data in the upstream area of the Karui station

※A bias correction value of 0.97 was used.

4. Visualization of flood risk





13 hours and 30 minutes after calculation begins