Flood Risk and Climate Change Hokkaido

WP3 Risk assessment

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Flood Risk and Climate Change Hokkaido

WP3 Risk assessment

Final report

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Table of contents

1 Introduction

This report gives an overview of the activities from work package 3 (WP3). This work package is one of the three work packages that examine the flood risk for Obihiro, the case study location on Hokkaido. WP1 gives insight into the impact of climate change on extreme discharges, WP2 focusses on the probability of levee failure and WP3 determines the flood risks.

The flood risks result from the combination of flood probabilities and flood consequences. WP3 uses the results from WP2, in which the flood probabilities are determined for the flood scenarios. The method and analysis on flood probabilities are described in the WP2 report. In this WP3 report only a summary of the flood probability calculation is included.

For determining the consequences of a flood, the economic damage (direct & indirect) and loss of life including evacuation are used. Different water levels and shapes of hydrographs are used to determine consequences, creating a bandwidth that covers a range of possible flood events.

1.1 Objective

The objective of work package 3 is to determine the flood risk for the Obihiro case and give insight into the uncertainties in flood risk calculation.

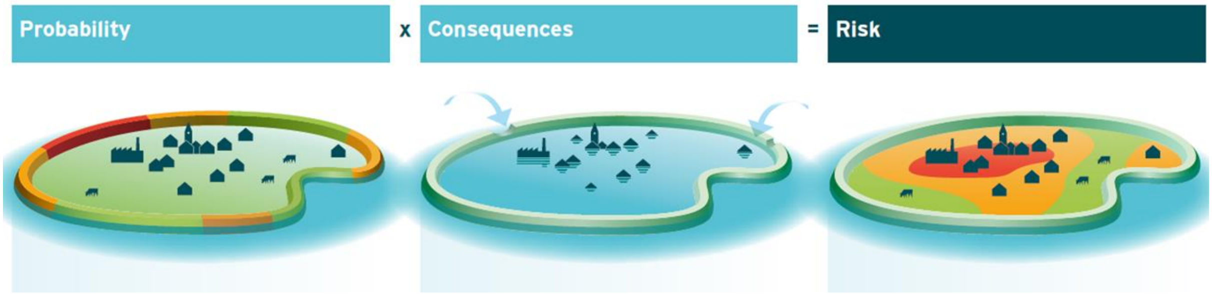
1.2 Structure report

The report starts with a brief description of the method which is used to determine the flood risk (Chapter 2). Chapter 3 gives an overview of the available flood scenarios and the selection of scenarios used in the flood risk calculation. In chapters 4, 5 and 6 the consequences (damage, evacuation, loss of life) of the flood scenarios are described. In chapter 7 a summary is given for the scenario probabilities from work package 2. The scenario probabilities (chapter 7) and the consequences (chapter 4, 5 and 6) are combined in chapter 8 to determine the flood risk. The report will end with a reflection on the results, conclusions and recommendations (chapter 9) based on the executed analyses.

2 Method

Risk is the combination of probability and consequences. To determine flood risk, it is therefore important to know the probability of a flood occurring and the impact it will have. For this purpose, the failure probabilities of the various elements of the flood defence system (various segments of levee) are determined (WP2). The consequences (economic damage and loss of life) of failures of the flood defences are also determined. The failure probability and consequences of a levee breach are not the same at each potential failure location within a levee system. Therefore, different breach locations are assessed and the flood probability per breach location is combined with the consequences of those breach locations. This approach gives the flood risks for the considered area.

Figure 1 Brief overview of risk approach



2.1 Flood probability

The calculation of the flood probabilities is done within work package 2 (WP2). The results from that work package are used in this work package to determine the flood risk. In chapter 7 a short summary is given on the flood probability. More details on determining flood probabilities can be found in the report on WP2.

2.2 Flood consequences

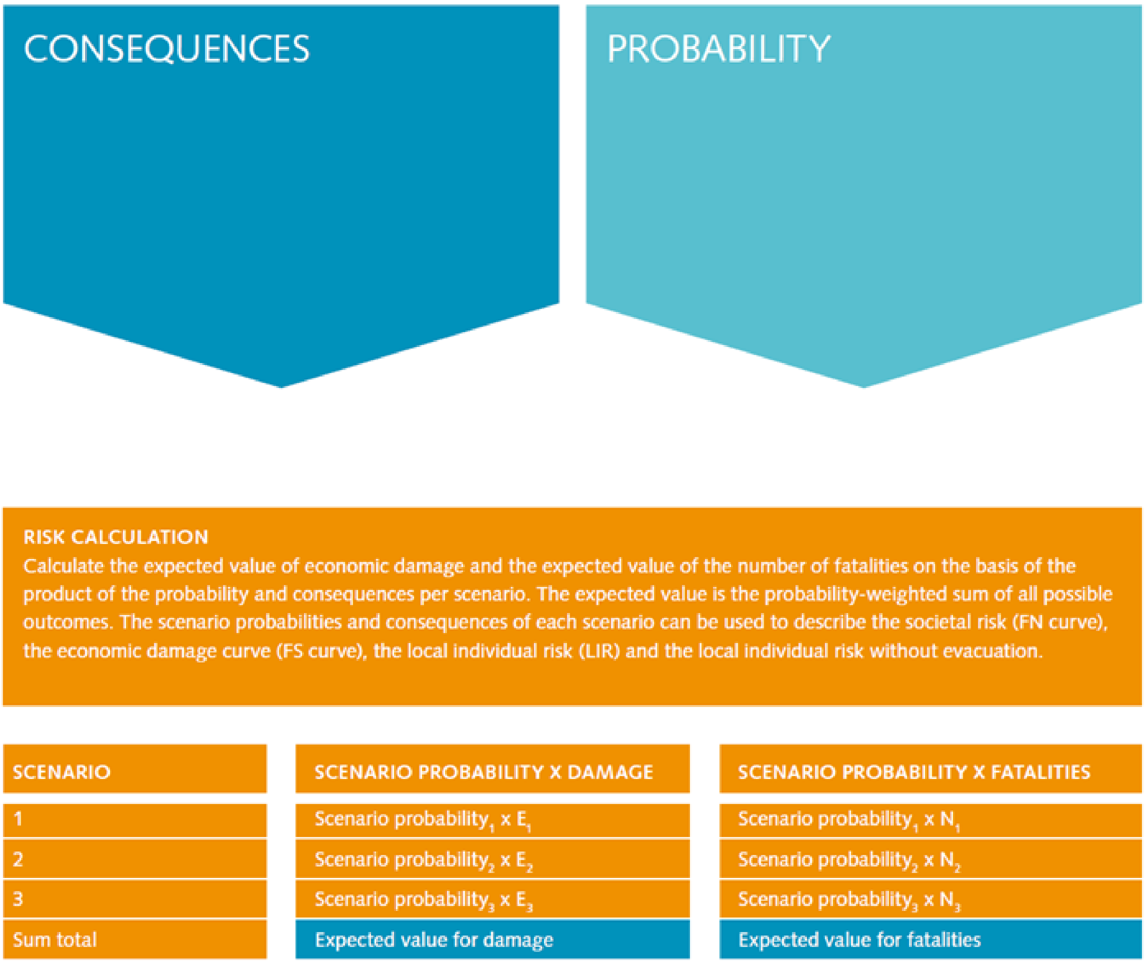
The flood consequences give insight in the amount of damage and loss of life in a certain area. It gives a spatial distribution of the loss of life and economic damage. To determine the flood consequences the brief method is as follows:

- Define consequence sections with a breach location
- Producing flood propagation models
- Defining flood scenarios
- Consequence estimates for each scenario
    - Economic damage
    - Evacuation
    - Loss of Life

2.3 Flood Risk

The flood risk is the product of the flood consequences and the flood probability. In the figure below the flood risk calculation is visualized.

Figure 2 Overview of risk calculation



RISK CALCULATION

Calculate the expected value of economic damage and the expected value of the number of fatalities on the basis of the product of the probability and consequences per scenario. The expected value is the probability-weighted sum of all possible outcomes. The scenario probabilities and consequences of each scenario can be used to describe the societal risk (FN curve), the economic damage curve (FS curve), the local individual risk (LIR) and the local individual risk without evacuation.

SCENARIO	SCENARIO PROBABILITY X DAMAGE	SCENARIO PROBABILITY X FATALITIES
1	Scenario probability$_1$ x E_1	Scenario probability$_1$ x N_1
2	Scenario probability$_2$ x E_2	Scenario probability$_2$ x N_2
3	Scenario probability$_3$ x E_3	Scenario probability$_3$ x N_3
Sum total	Expected value for damage	Expected value for fatalities

Next to the expected value of the damage and fatalities (loss of life) also the risk is expressed by the local individual risk. This provides insight in the probability that a person at a certain location will lose his live due to a flood.

3 Flood scenarios

3.1 Introduction

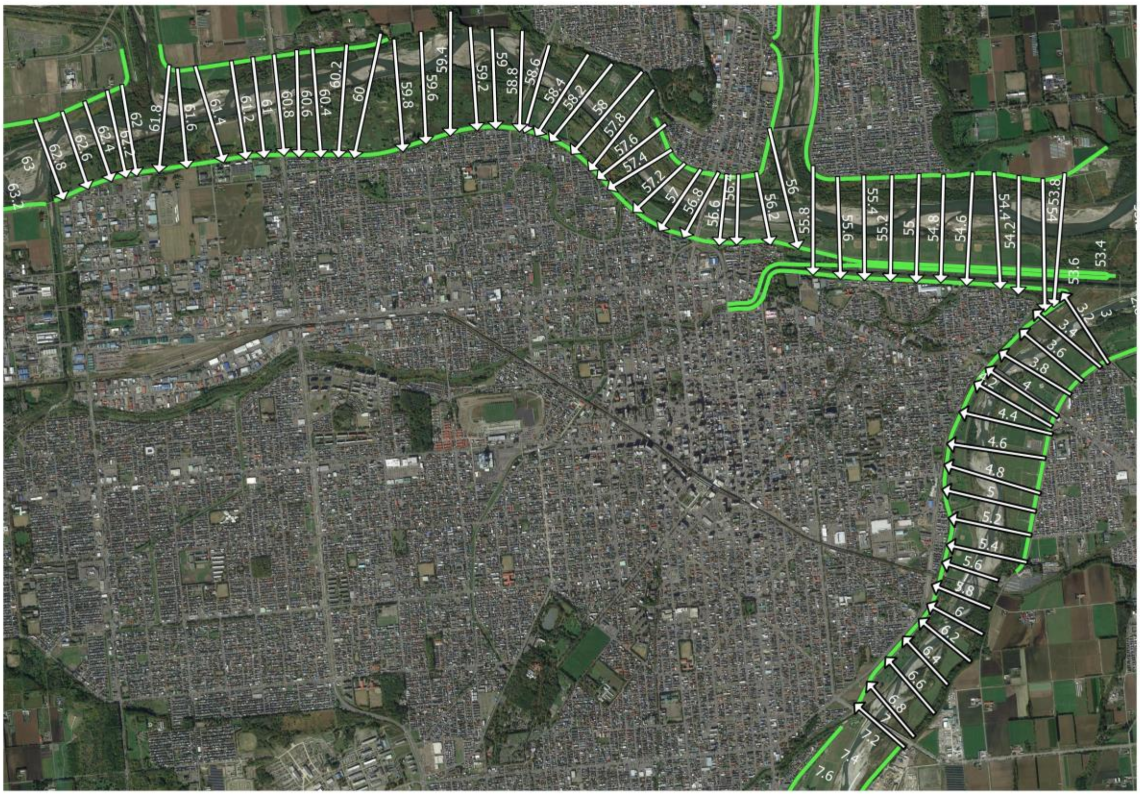
An area can be flooded from different breach locations. However, for a sufficiently accurate risk analysis it is not necessary to identify the consequences of flooding for every possible breach location. A system can be divided into sections where the flood pattern will be virtually the same, irrespective of the precise location of the breach within that section. In this chapter different breaches are grouped in sections for the Obihiro case study.

3.2 Breach locations

In order to calculate the flooded area and the flood characteristics breach locations have to be determined for which flood simulations must be derived. The choice of breach locations for a certain area depends on the hydraulic loads and the characteristics of the threatened area. For example, if there is a high element present in the area the flood pattern is influenced. Therefore, different breach locations must be determined.

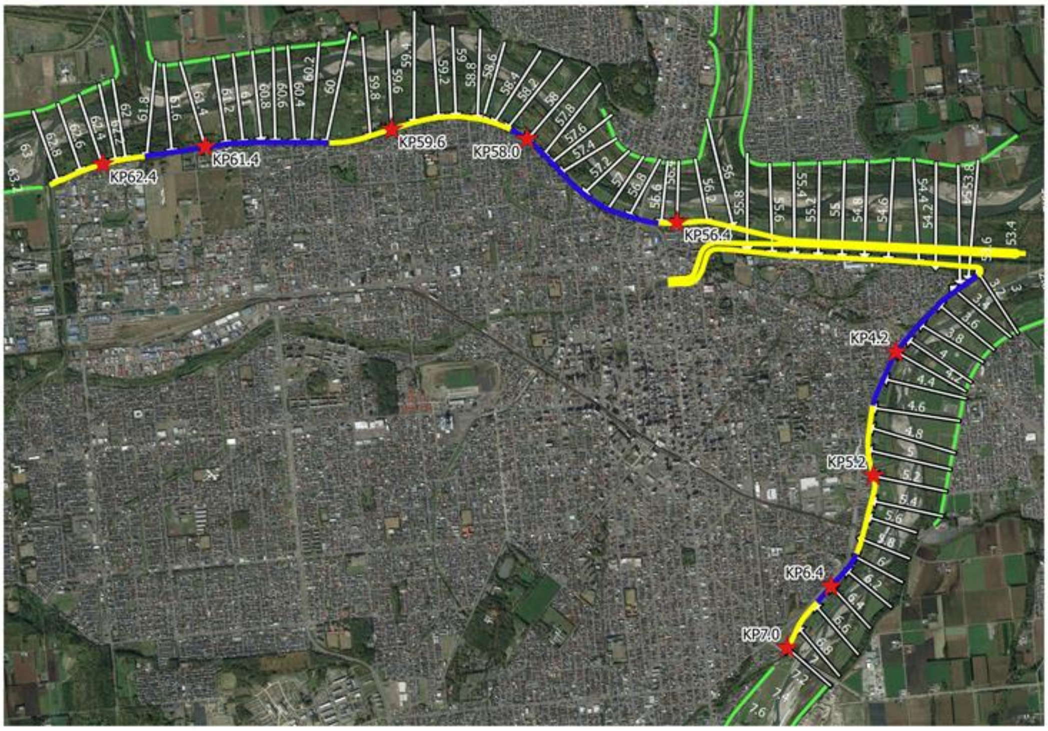
For the Obihiro case study there is a database of flood simulations available with breach locations every 200 meter, see Figure 3. As explained earlier, it is not necessary to include all breach locations for determining the flood risk due to largely overlapping flood extents of nearby breach locations.

Figure 3 Available breach location along the Obihiro case study area



All breach locations and accompanying inundation patterns were analysed and a selection has been made for breach locations used in the flood risk analysis. In the analysis, levee sections have been determined for which the breach locations are representative. To select the representative breach locations mainly flood extent and flood characteristics (water depth, flow velocity, rise rate) have been used. In the figure below the sections and breach locations are shown.

Figure 4 Levee sections and selected breach locations



The given breach locations are used for the flood risk analysis. For the Tokachi River 5 locations have been selected and for the Satsunai river 4 locations. The inundation maps and the accompanying hydrographs for these locations are available.

3.3 Hydrographs

For the selected breach locations different inundation scenarios have been identified that describe the bandwidth of the possible flood extent per breach location. This is done by linking the inundation scenarios to the associated hydrographs. The hydrograph describes the shape of the discharge and the local water height over time.

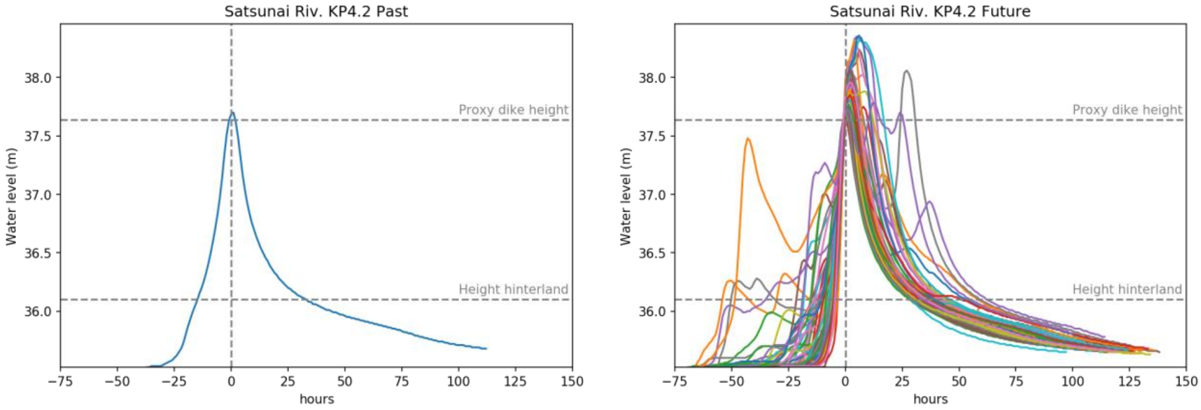
3.3.1 Climate change

For the Obihiro case study there is a database available with hydrographs. These hydrographs are divided into two sets, one set describes the current and past situation ("past") and one set describes the future situation ("future"). The difference between these two sets is that in the situation "future" climate change is incorporated. This means that discharges can be much higher, leading to larger flood extents and water depths. So for the further analysis two datasets are available, one for the current situation and one including climate change.

3.3.2 Hydrographs and flood scenario

First the hydrographs can be used to gain insight in the hydrograph patterns by generating plots such as shown the figure below. Only the hydrographs that lead to overtopping of the levee height are shown in the figure.

Figure 5 Example of a collection of hydrographs for location KP4.2 along the Satsunai river, for both the 'Past' (HPB) and 'Future' (HFB) hydrographs

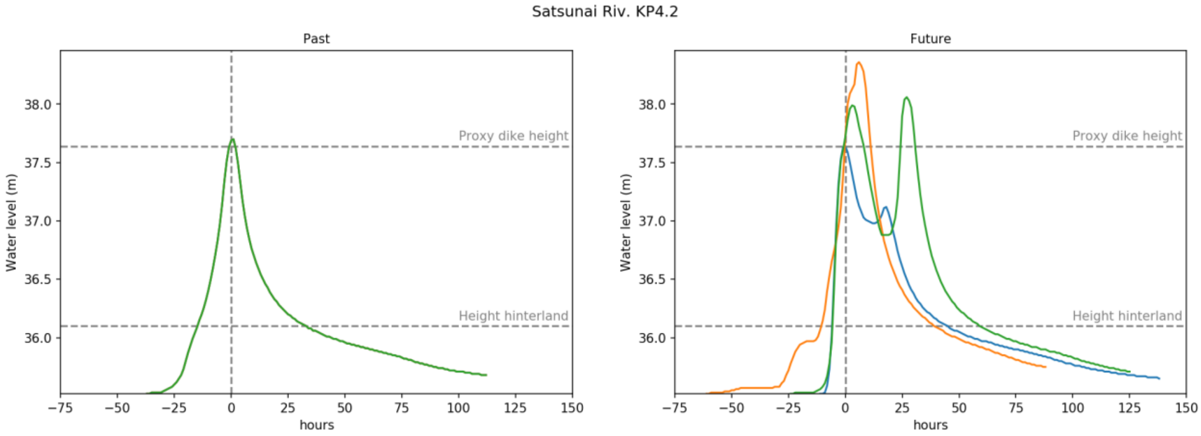


Second it can be used for selecting the hydrograph and flood extent to be used in the flood risk analysis. For a flood risk analysis, it is often unnecessary to use each individual flood scenario because differences between flood scenarios tend to be small. Therefore, it is more efficient to select a number of hydrographs that represent the whole set of flood scenarios. An example to select these scenarios is shown in Figure 6. Here, three scenarios were selected:

- The MAX scenario: the scenario with the highest peak water level
- The MIN scenario: the scenario with the lowest peak water level
- The MAXVOL scenario: the scenario with the largest surface of the hydrograph above the proxy dike height (representing the potential inflow volume).

If only one scenario leads to overtopping of the levee height, this scenario is used for all three situations.

Figure 6 Example of the selected MAX, MIN and MAXVOL hydrographs for location KP4.2 along the Satsunai river, for both the 'Past' (HPB) and 'Future' (HFB) hydrographs



For each selected breach location, the three scenarios are listed in Table 1.

Table 1 Scenarios max, min and maxvol for each location

	Past - min	Past - max	Past - maxvol	Future - min	Future - max	Future - maxvol
Satsunai Riv. KP4.2	HPB_m045_1960	HPB_m045_1960	HPB_m045_1960	HFB_GF_m111_2082	HFB_MR_m104_2078	HFB_HA_m108_2057
Satsunai Riv. KP5.2	HPB_m045_1960	HPB_m045_1960	HPB_m045_1960	HFB_GF_m114_2092	HFB_MR_m104_2078	HFB_MP_m103_2085
Satsunai Riv. KP6.4	HPB_m022_1980	HPB_m045_1960	HPB_m045_1960	HFB_GF_m107_2097	HFB_MR_m104_2078	HFB_MR_m108_2069
Satsunai Riv. KP7.0	HPB_m069_2006	HPB_m045_1960	HPB_m045_1960	HFB_CC_m104_2099	HFB_MR_m104_2078	HFB_HA_m108_2057
Tokachi Riv. KP56.4	HPB_m021_1979	HPB_m067_1978	HPB_m064_1987	HFB_CC_m108_2101	HFB_MR_m104_2078	HFB_MR_m108_2069
Tokachi Riv. KP58.0	HPB_m004_2000	HPB_m067_1978	HPB_m064_1987	HFB_CC_m108_2058	HFB_MR_m104_2078	HFB_MR_m108_2069
Tokachi Riv. KP59.6	HPB_m063_1968	HPB_m067_1978	HPB_m064_1987	HFB_CC_m112_2090	HFB_MR_m104_2078	HFB_MR_m108_2069
Tokachi Riv. KP61.4	HPB_m024_1997	HPB_m067_1978	HPB_m064_1987	HFB_MP_m105_2105	HFB_MR_m104_2078	HFB_MR_m108_2069
Tokachi Riv. KP62.4	HPB_m063_1968	HPB_m067_1978	HPB_m067_1978	HFB_GF_m112_2094	HFB_MI_m102_2109	HFB_MI_m108_2094

3.4 Flood characteristics

The flood characteristics are determined by flood simulations.

3.4.1 Flood simulation

The inundation depth of the floodplain is calculated by a two-dimensional unsteady flow calculation model. The water level in the river channel was calculated from the discharge, and the calculation was performed on the assumption that the embankment broke and the discharge flowed into the floodplain at the moment when the water level in the river channel exceeded the design water level. A conceptual diagram of the calculation model is shown in Figure 7. The calculation conditions are shown in Table 2.

Figure 7 Conceptual diagram of computational model

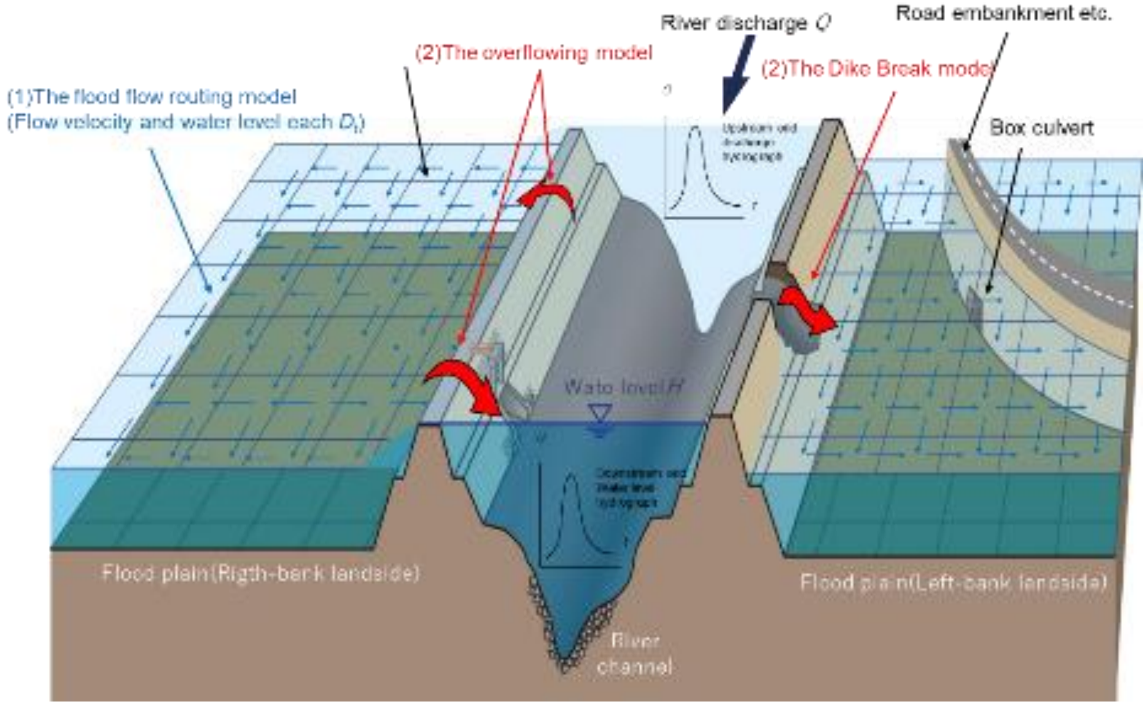


Table 2 Calculation condition list

Items	Contents
Grid Size, Ground Elevation	100m Grid size, Grid Ground Elevation is based on the latest LP data.
River Channel Status	River Channel of 2016
Flood Control Reservoir	Current Reservoir (Tokachi Dam, Satsunaigawa Dam, and Sahoro Dam)
Point of Dike Break	Flood Simulation per flood zone, based on 1 point where the maximum damage is estimated within zone.
Conditions of Dike Break	In case of the water level exceeds the set point which dike starts to break(HWL for completed dike).
Discharge Redcuction Due to Flood at the Upstream of Dike Break	Reduce the discharge when water level exceeds the height of dike or ground elevation.

3.4.2 Water depth

For all selected breach locations the flood characteristics are available. One of those characteristics is the flood depth. For locations KP61.4 along the Tokachi river and KP6.4 along the Satsunai river, the flood patterns are shown in Figure 8 and Figure 9. The difference between the figures shows the effect of the combination of hydrograph and flood extent. The hydrograph with the highest local water level, Figure 4, gives the largest flood pattern. This information is available for all locations and selected hydrographs.

Figure 8 Future scenarios for location KP61.4 along the Tokachi river (MAX, MIN, MAXVOL)

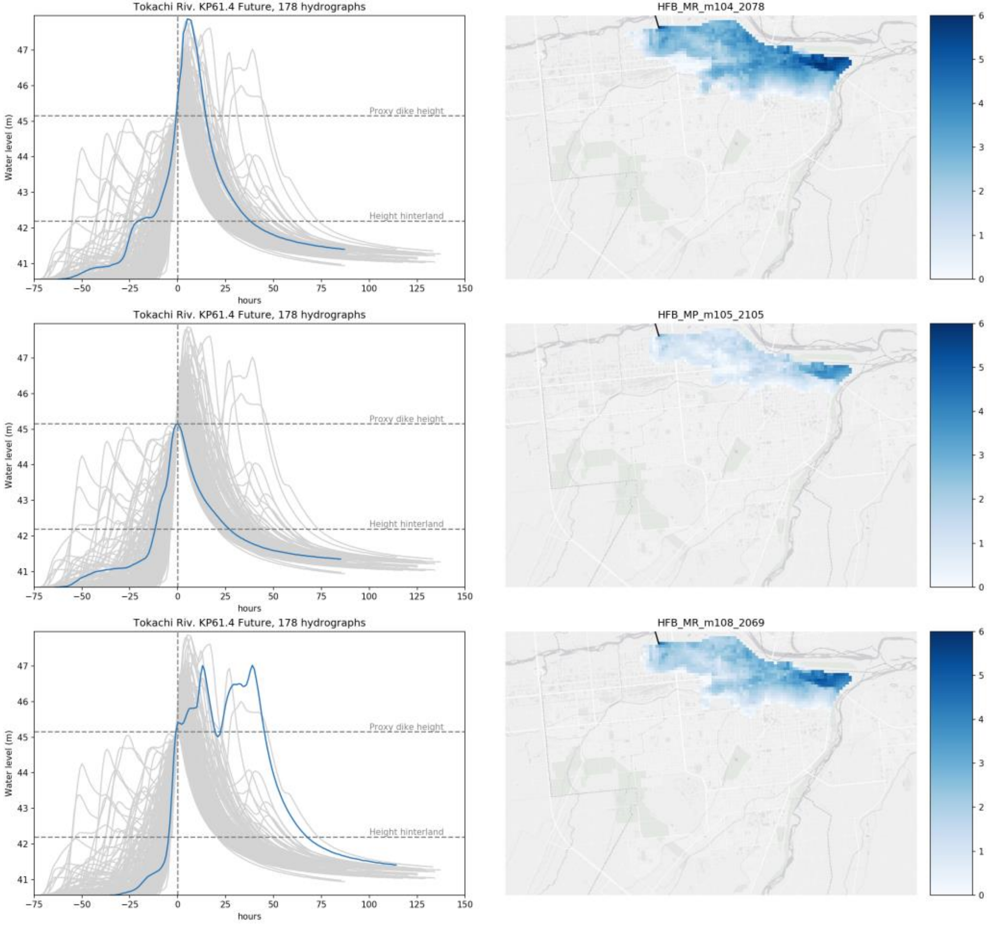
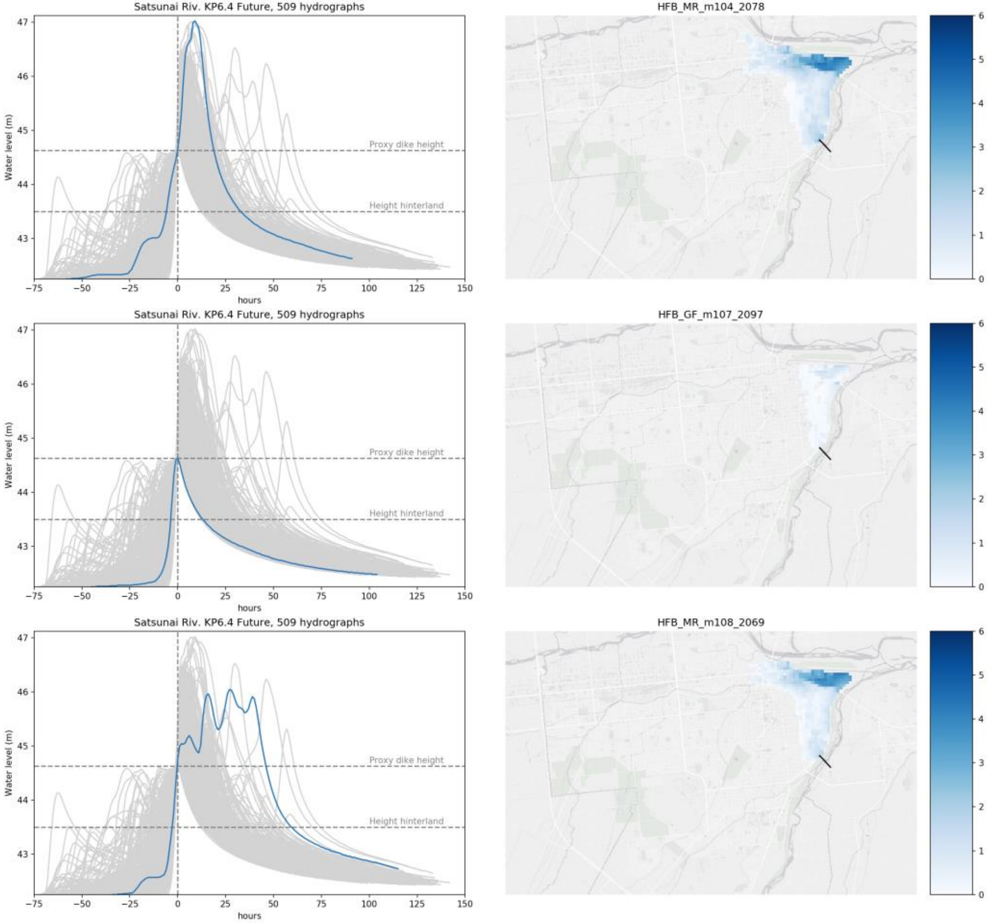


Figure 9 Future scenarios for location KP6.4 along the Satsunai river (MAX, MIN, MAXVOL)



3.4.3 Rise rate

The rise rate describes the speed at which the water rises, calculated in meters per hour. The rise rate is an important flood characteristic for determining the mortality. In case of higher rise rates in combination with larger water depths this leads to a significant increase in mortality compared to water depths with lower rise rates (for more detail see chapter 6). Therefore the rise rate is available for all flood scenarios.

3.4.4 Flow velocity

The flow velocity is another flood characteristic, important for building stability. A higher flow velocity combined with larger water depths increases the probability that a building will collapse, impacting mortality. For more detailed information see chapter 6 and specifically section 6.5. The flow velocity is also available for all flood scenarios.

3.5 Uncertainties in flood scenarios

Regarding the flood scenarios there are several aspects that have an influence on the flood extent and the flood characteristics. In general the uncertainties are:

- Breaching can occur before or after the top of the discharge peak. In the current approach the moment of breaching has been chosen as the moment the water level exceeds the design water level. Especially for the scenarios “Max” and “Maxvol” this leads to a breach before the peak, which leads to a relatively long period of inflow of water.
- When a levee is more resistant to overflow, the breach can occur at a later moment in time and the total inflow will be smaller, which reduces the flood extent and flood characteristics. But on the other hand the breach can also occur even earlier due to breaching before the levee is overflowing. This can be induced by geotechnical failure mechanisms. In that case the total inflow will be larger increasing the flood characteristics.
- The shape of the hydrograph is also an aspect that influences the flooding. So insight in the different shapes of discharge waves increases the insight in the potential flood patterns that can occur.
- Breach modelling; there are several methods to model the breach growth in flood modelling. The faster a breach grows the larger the inflow. So the speed at which the breach grows in depth and width affects the flooding.

So in general there are several uncertainties in determining the flood extents and flood characteristics. But with the chosen approach which incorporates different flood scenarios these uncertainties are properly included in the analysis.

An important research question that remains is the probability that different type of discharge waves occur. What is the distribution between the different types of discharge waves, narrow and peaked versus long and wide.

4 Damage

Based on the results of the inundation simulation described in the previous section, the expected damage is calculated.

4.1 Calculation method

The calculation of damage was based on the "Manual for Flood Control and Economic Survey (Draft)", which is a common method for expressing the effects of flood control projects in Japan in terms of cost-effectiveness. The" Manual for Flood Control and Economic Survey (Draft)" provides a specific method for determining the economically assessable effects of flood control projects from the basic quantities and damage rates published nationwide. Currently, the latest version is the one published in April 2020, but in this study, each damages are calculated according to the April 2005 version.

There are two types of damage caused by flood inundation: direct damage caused by the inundation of houses, offices, and crops, and indirect damage caused by the cessation of production at flooded offices and the cutting off of lifelines, etc. In this report, 12 items are listed as damage that can be economically evaluated at this stage.

Table 3 Items for which damage is recorded

Classification				**Description of damage**
Directly damage	Asset damage	General asset damage	House	Damage to residential and business buildings
			Household articles	Flooding damage to furniture, automobiles, etc.
			Office amortization assets	Flood damage to amortization assets, excluding land and buildings, among fixed assets of business establishments.
			Office inventory assets	Flooding damage to office inventory
			Agricultural and fishery amortization assets	Flooding damage to amortization assets of households involved in agricultural and fishery production, excluding land and buildings.
			Agricultural and fishery inventory assets	Flooding damage to agricultural and fishery inventory
		Agricultural product damage		Flooding damage to crops
		Public civil facilities damage		Flooding damage to public civil facilities, utility facilities, farmland, and agricultural facilities
Indirectly damage	Operational damage	Damage caused by business suspension	Business office	Suspension or stagnation of production at flooded business office (decrease in production)
			Public and utility services	Suspension or stagnation of public and utility services
	After the fact Damage	Cost of emergency measures	Household economy	Post-event activities such as cleanup of flooded households, new investments in purchasing alternative supplies such as drinking water, and other damages
			Business office	

4.2 Asset

4.2.1 Examining directly affected assets and asset data

The basic quantities of assets, households, and employees in the inundation area, which are necessary for calculating the amount of damage, are calculated for each computational mesh of the inundation simulation. Assets to be surveyed are as follows, and the basic quantity will be surveyed using regional mesh statistics published by the Statistics Bureau of the Ministry of Internal Affairs and Communications.

Assets under investigation

- House(floor area)
- Household articles (number of households)
- Office Amortization/Inventory Assets (number of employees)
- Agricultural and fishery Amortization/Inventory Assets (number of agricultural and fishery households)
- Agricultural product (area of rice paddies and fields)

Basic quantity survey

Table 4 Basic asset quantity survey

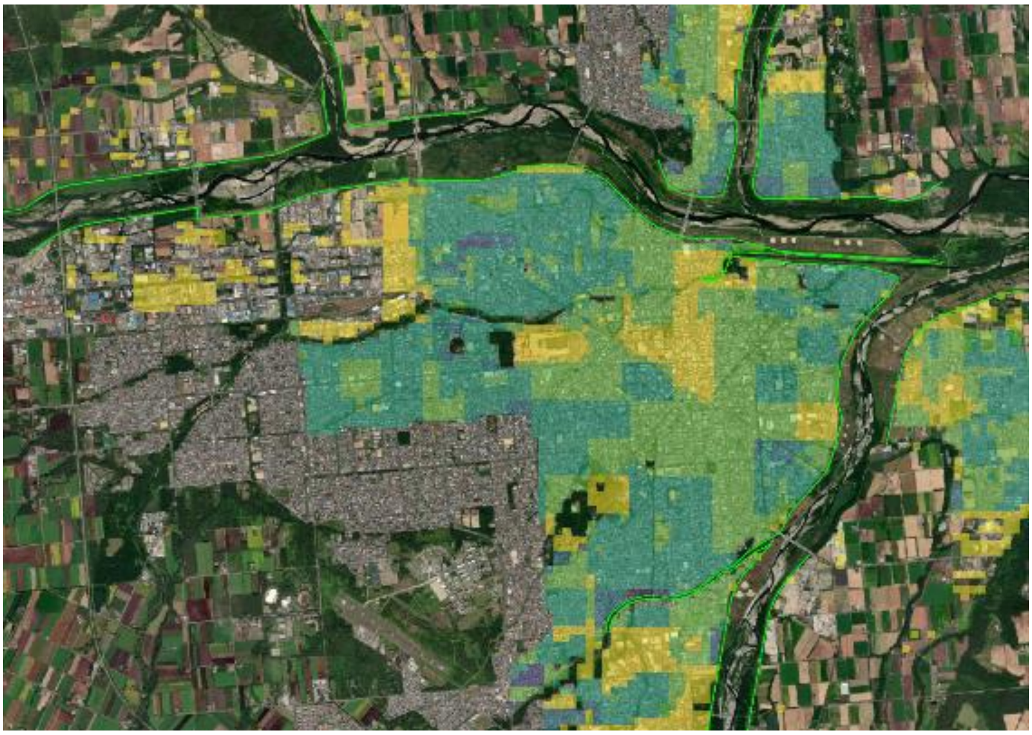
Items	Units	Regional mesh statistics	Sources
Population	people	2010 Census	Statistics Bureau of the Ministry of Internal Affairs and Communications
Houses	floor area	2010 Total Floor Area Data	Japan Construction Information Center
Household articles	number of households	2010 Census	Statistics Bureau of the Ministry of Internal Affairs and Communications
Offices	number of employees	2009 Economic Census	Statistics Bureau of the Ministry of Internal Affairs and Communications
Agricultural and fisheries	number of households	2010 Census	Statistics Bureau of the Ministry of Internal Affairs and Communications
Agricultural products	area of fields	2009 National Land Information	Geographical Survey Institute, Ministry of Land, Infrastructure, Transport and Tourism

4.2.2 Calculation of asset amount

The asset value is calculated by multiplying the asset quantity of the calculation mesh unit by the asset valuation unit costs. For the asset valuation unit costs, the items except for agricultural and fishery, and fields were based on the "Flood Control Economic Survey Manual (Draft): Various Asset Valuation Unit Costs and Deflators (River Planning Division, River Bureau, Ministry of Land, Infrastructure, Transport and Tourism, revised March 2016)" published annually. The valuation unit costs of agricultural and fishery, and fields were set according to the regional characteristics, based on the fact that the scale of agricultural management in the area is 16.5 times larger than the national average.

Table 5 Unit costs of asset value (1000 yen)

Asset items		**2015 Unit costs (1000 yen)**		**Remarks**
Houses		186.2		per 1m^2 of house
Household articles		13,230		per household
Offices		Amortization assets	Inventory assets	
Industrial Classification	mining, quarrying, sand mining	14,418	2,255	per employee
	construction	1,452	2,669	
	manufacturing	4,803	4,691	
	electricity/gas/heat/water supply	113,483	5,267	
	information and communication	5,150	991	
	transportation, postal services	5,719	1,015	
	wholesale/retail trade	2,158	1,741	
	finance, insurance	1,115	210	
	real estate、goods leasing	21,437	7,405	
	academic research, professional and technical services	1,767	445	
	accommodations, restaurants	1,525	92	
	life related services, entertainment	3,652	233	
	education and learning support	1,052	267	
	medical care, welfare	1,386	58	
	complex service industry	1,115	210	
	service industry	1,115	210	
	public affairs	1,115	210	
Agricultural and fisheries		9,267	1,070	per household
Agricultural products	rice paddies	997		per ha
	fields	853		per ha



4.3 Damage

4.3.1 Amount of direct damage

In order to calculate the amount of damage to general assets and agricultural products, apply the amount of assets and the damage rate based on the inundation depth. Public engineering facilities, etc. are calculated by applying the rate of damage to general assets.

General asset damage rate

Table 6 General asset damage rate (Damage to house)

Inundation depth / Ground gradient	under floor level	above floor level				
		less than 50 cm	50～99	100～199	200～299	more than 300 cm
Group A	0.032	0.092	0.119	0.266	0.580	0.834
Group B	0.044	0.126	0.176	0.343	0.647	0.870
Group C	0.050	0.144	0.205	0.382	0.681	0.888

Ground slope A: Less than 1/1000 , B: 1/1000~1/500, C: more than 1/500

Notes:

1. Damage rates based on the available "Survey of Actual Flood Damage" for the period 1993 to 1996.
2. The figures also take into account the total destruction of houses.

Table 7 General asset damage rate (Damage to household articles)

Inundation depth	under floor level	above floor level				
		less than 50 cm	50～99	100～199	200～299	more than 300 cm
Damage rate	0.021	0.145	0.326	0.508	0.928	0.991

Notes: Damage rates based on the available "Survey of Actual Flood Damage" for the period 1993 to 1996.

Table 8 General asset damage rate (Damage to office amortization/inventory assets)

Inundation depth / Assets	under floor level	above floor level				
		less than 50 cm	50～99	100～199	200～299	more than 300 cm
Amortization	0.099	0.232	0.453	0.789	0.966	0.995
Inventory	0.056	0.128	0.267	0.586	0.897	0.982

Notes: Damage rates based on the available "Survey of Actual Flood Damage" for the period 1993 to 1996.

Table 9 General asset damage rate (Damage to agricultural and fishery amortization/inventory assets)

Inundation depth	under floor level	above floor level				
		less than 50 cm	50～99	100～199	200～299	more than 300 cm
Amortization	0.0	0.156	0.237	0.297	0.651	0.698
Inventory	0.0	0.199	0.370	0.491	0.767	0.831

Notes: Damage rates based on the available "Survey of Actual Flood Damage" for the period 1993 to 1996.

Table 10 General asset damage rate (Damage to agricultural product)

	subject	Crown inundation											
	crown inundation water depth	less than 0.5m				0.5～0.99m				1.0m			
crop type	inundation days	1～2	3～4	5～6	more than	1～2	3～4	5～6	more than 7	1～2	3～4	5～6	more than 7
rice paddies	wet-land rice	21	30	36	50	24	44	50	71	37	54	64	74
fields	upland rice	20	34	47	60	31	40	50	60	44	60	72	82
	sweet potato	11	30	50	50	27	40	75	88	38	63	95	100
	Chinese cabbage	42	50	70	83	58	70	83	97	47	75	100	100
	greens	19	33	46	59	20	44	48	75	44	38	71	84
	root vegetable	32	46	59	62	43	57	100	100	73	87	100	100
	cucurbits	22	30	42	56	31	38	51	100	40	50	63	100
	beans	23	41	54	67	30	44	60	73	40	50	68	81
	field average	27	42	54	67	35	48	67	74	51	67	81	91

Note) "greens" includes green onions, spinach, and others; "root vegetable" includes Japanese radish, taro, burdock, and carrot; "melon" includes cucumber, melon, and watermelon; and "beans" includes red beans, soybeans, peanuts, and onions.

Damage rate of public civil engineering facilities, etc.

The damage rate of public engineering facilities is defined as the rate of damage to the amount of damage to general assets (the total amount of damage to houses, household articles, offices, and agricultural and fisheries), and was determined based on the "Flood Statistics" (River Bureau, Ministry of Land, Infrastructure, Transport and Tourism (Ministry of Construction)) and "Disaster Records" (Hokkaido) for the past 40 years (1975-2014) of flood damage in Hokkaido. For the calculation, each year was converted to the 2014 value based on the Comprehensive Price Index (flood damage deflator).

Table 11 Damage rate of public engineering facilities in Hokkaido calculated from flood statistics and disaster records.

Facility	road	bridge	sewerage system	urban facilities	public welfare	farm land	industrial facilities	subtotal
Damage rate	84.9	11.3	0.1	1.3	15.5	15.5	117.2	245.8

Value calculated based on flood statistics and disaster records for floods in Hokkaido from 1975 to 2014.
Source 1: "Flood Statistics" (1975-2014), Ministry of Land, Infrastructure, Transport and Tourism (Ministry of Construction), Water Management and Land Conservation Bureau (River Bureau)
Source 2: "Disaster Records" (1975-2011), Hokkaido

4.3.2 Amount of indirect damage

Of the inundation damage except for direct damage, three items that can be economically evaluated at this stage were calculated as indirect damage based on the "Flood Control and Economic Survey Manual (Draft)" (River Bureau, Ministry of Land, Infrastructure and Transport, April 2005). They are 1) business interruption losses, 2) household emergency measures costs, and 3) office emergency measures costs.

Business interruption losses
Business interruption loss was calculated by multiplying the number of employees in the flooded area by the total number of days lost due to business suspension or stagnation, and then multiplying by the value added per person for each day.

The amount of damage, D, was calculated for each major industrial category using the following equation, and the business interruption loss was calculated as the total of them.

$$Di = Mi \times (n_0 + n_1/2) \times Pi$$

i: broad industry category, M: number of employees, P: value-added （yen/（person・day））,
n0:business suspended days, n1:business stagnant days

The suspended days are shown in the table below, and the stagnant days are twice the suspended days.

Table 12 Days of suspension or stagnation (days)

inundation depth	Under floor level	above floor level				
	less than 45cm	less than 50cm	50～99cm	100～199cm	200～299cm	more than 300cm
days of suspension	3.0	4.4	6.3	10.3	16.8	22.6
days of stagnation	6.0	8.8	12.6	20.6	33.6	45.2

Table 13 Added value per employee for each day (2015 assessed value, yen/(person ・day))

Industrial Classification	Added value
mining, quarrying, sand mining	115,235
construction	23,254
manufacturing	31,460
electricity/gas/heat/water supply	93,098
information and communication	38,749
transportation, postal services	24,543
wholesale/retail trade	26,464
finance, insurance	20,439
real estate、goods leasing	46,152
academic research, professional and technical services	35,924
accommodations, restaurants	21,594
life related services, entertainment	22,317
education and learning support	24,046
medical care, welfare	16,969
complex service industry	20,216
service industry	20,924
public affairs	20,924

Source: "Various Asset Valuation Unit Costs and Deflators: Flood Control Economic Survey Manual (Draft) (Revised in March 2016, Ministry of Land, Infrastructure, Transport and Tourism, Water Management and Land Conservation Bureau)

Household emergency measures costs

- Cleaning labor compensation

The amount of damage caused by household cleaning labor costs was calculated by multiplying the number of households by the unit labor cost per household and the total days of cleaning required in the table below.

Table 14 Unit labor costs: 10,731 yen per day (assessed in 2015) Days of cleaning (days)

inundation depth	Under floor level	above floor level				
	less than 45cm	less than 50cm	50～99cm	100～199cm	200～299cm	more than 300cm
days	4.0	7.5	13.3	26.1	42.4	50.1

Note: The total number of days required for cleaning and clearing up was obtained from the "Questionnaire Survey on Flood Disasters" conducted in 1995 and 1996.

Source: "Flood Control Economy Research Manual (Draft)" (April 2005, River Bureau, Ministry of Land, Infrastructure and Transport)

- Expenditures for alternative activities, etc.

The amount of damage caused by alternative activities, such as the purchasing of drinking water and alternative transportation for commuting, was calculated by multiplying the number of households by the damage unit costs shown in the table below.

Table 15 Alternative activity expenses (at household) (Unit cost: 1000 yen per household)

inundation depth	Under floor level	above floor level				
	less than 45cm	less than50cm	50～99cm	100～199cm	200～299cm	more than 300cm
unit cost	82.5	147.6	206.5	275.9	326.1	343.3

Note: The unit costs were obtained from the "Questionnaire Survey on Flood Disasters" conducted in 1995 and 1996.

Source: "Flood Control Economy Research Manual (Draft)" (April 2005, River Bureau, Ministry of Land, Infrastructure and Transport)

Office emergency measures costs

The amount of damage caused by alternative activities, etc. was calculated by multiplying the number of inundated business offices by the damage unit costs shown in the table below.

Table 16 Alternative activity expenses (at office) (Unit cost: 1000 yen per household)

inundation depth	Under floor level	above floor level				
	less than 45cm	less than50cm	50～99cm	100～199cm	200～299cm	more than 300cm
unit cost	470	925	1,714	3,726	6,556	6,619

Note: The unit costs were obtained from the "Questionnaire Survey on Flood Disasters" conducted in 1995 and 1996.

Source: "Flood Control Economy Research Manual (Draft)" (April 2005, River Bureau, Ministry of Land, Infrastructure and Transport)

4.3.3 Result of economic damage

For the Obihiro case study the damage is calculated for both the "past" set and the "future" set. In the figure below the spatial distribution of the economic damage for a breach at Satsunai River location KP4.2 is shown. The top figures describe the damage for the "past" situation and the lower figures for the "future". The difference is that in the "future" situation larger discharges occur leading to floodings with a larger flood extent and greater water depths.

Figure 10 Damage (Satsunai Riv. KP4.2)

4.4 Damage case Obihiro

The method of determining economic damage is described in section 4.1 to 4.3. When applying this to the selected breach locations the economic damage is calculated. In section 0 the breach locations are given and for each hydrograph the economic damage is shown. The table gives insight in the extent of the flood damage and the difference between the different locations and the impact of the different hydrographs. In Figure 10 section 4.3.3 the distribution of the damage over the Obihiro area is shown for breach location KP4.2. The table below shows that for the "past" scenarios there is no difference in the calculated damage, for the "future" scenario the flood extents are different and that leads to a variation in calculated damage. The damage varies between approximately 80,000 million Yen and 269,000 million Yen for the minimum and maximum scenario. The difference is approximately a factor 3.

When looked at all scenarios, the bandwidth between the different flood scenarios is in general a factor 1.5 to 2.5. Exception is breach location Tokachi KP56.4, the difference for that location is larger, approximately a factor 6. So for that breach location the calculated damage is more sensitive to the type of discharge wave that runs through the river.

Table 17 Economic damage for "past" and "future" scenarios (unit: million Yen)[1]

	Location	Max	Min	MaxVol
Past	Satsunai_KP4_2	83200	83200	83200
	Satsunai_KP5_2	170400	170400	170400
	Satsunai_KP6_4	362700	201800	362700
	Satsunai_KP7_0	308000	224800	308000
	Tokachi_KP56_4	311300	143500	290200
	Tokachi_KP58_0	465600	309300	450200
	Tokachi_KP59_6	568200	488200	541200
	Tokachi_KP61_4	641300	597600	637400
	Tokachi_KP62_4	606800	547800	606800
Future	Satsunai_KP4_2	269000	77800	177500
	Satsunai_KP5_2	330400	141000	324300
	Satsunai_KP6_4	483200	193000	380100
	Satsunai_KP7_0	480600	226400	430700
	Tokachi_KP56_4	834000	129000	479400
	Tokachi_KP58_0	855900	294200	598300
	Tokachi_KP59_6	865000	483000	697000
	Tokachi_KP61_4	917000	583800	778000
	Tokachi_KP62_4	798400	532300	837400

4.5 Uncertainties in calculating damage

Given the flood scenarios the economic damage is calculated. Determining the damage is also subject to uncertainty. The following aspects are a first overview of uncertainties:

- Important factor is the flood extent and the vulnerability of vital and high value infrastructure. When flood extent varies and these type of assets are on the edge of the flood extent it can influence the amount of damage significantly.
- The relation between direct and indirect economic damage. The direct damage is the damage to existing assets. But the indirect damage due to failure of the economic activities can have a significant impact especially when vital infrastructure is flooded.

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[1] When the damage is the same for the different scenarios it means that there is only one or two scenarios for that breach location that lead to a flood.

5 Evacuation

5.1 Evacuation Rate of Target Area

When an evacuation Advisory/Order was issued to roughly 54,000 people [1] in the target area of the entire Obihiro city in the event of Hokkaido Heavy Rain Disaster 2016, only 1,954 residents [2] (3.6%) actually evacuated. It is necessary to set up a population parameter with population within the flooded area, in order to apply an actual evacuation rate to estimate fatality of the flooded area. It is, however, not appropriate to use an actual evacuation rate, since Obihiro city did not suffer from flood damage due to overflowing in Hokkaido Heavy Rain Disaster 2016. This project, therefore, suggests a new method of setting up an evacuation rate, based on the existing Japanese and Dutch method to apply for estimating fatality of large-scale flood in Japan.

5.2 Method to Set up Evacuation Rate

5.2.1 Japanese Method

In order to estimate fatality of the flooded area in Japan, an evacuation rate is determined based on the past 6 floods in Japan and the United States [3]. In reference to the evacuation rates of the past 6 floods indicated in Table 18, the basic setup is 0%, 40% and 80%, to estimate the remaining population (exposure) in flooded area. The evacuation rates of large-scale floods in recent years [4][5], however, are not included. It can be considered that there might be a gap from an actual evacuation rate under the impact of ongoing climate change. Few cases have applied such actual evacuation rates in risk analysis of large-scale floods, though there are some cases in an observational study by means of Evacuation Simulator by Kawashima et al. [6] and diverse experimental studies of evacuations by Baba et al.[7].

Table 18 Evacuation rate in the past floods

Disaster Name	Year of Disaster	Evacuation Rate（%）
Heavy Rain in Nagano	1982	13
Heavy Rain in Tokai Region	2000	44
Typhoon No.9, Kitakami River	2002	32
Heavy Rain in Niigata and Fukui	2004	19（Mitsuke City, Niigata Prefecture） 23（Sanjo City, Niigata Prefecture） 36（Nakanoshima Town, Niigata Prefecture）
Typhoon No.23, Toyooka Flood	2004	33
Hurricane Katrina	2005	About 80（New Orleans City）

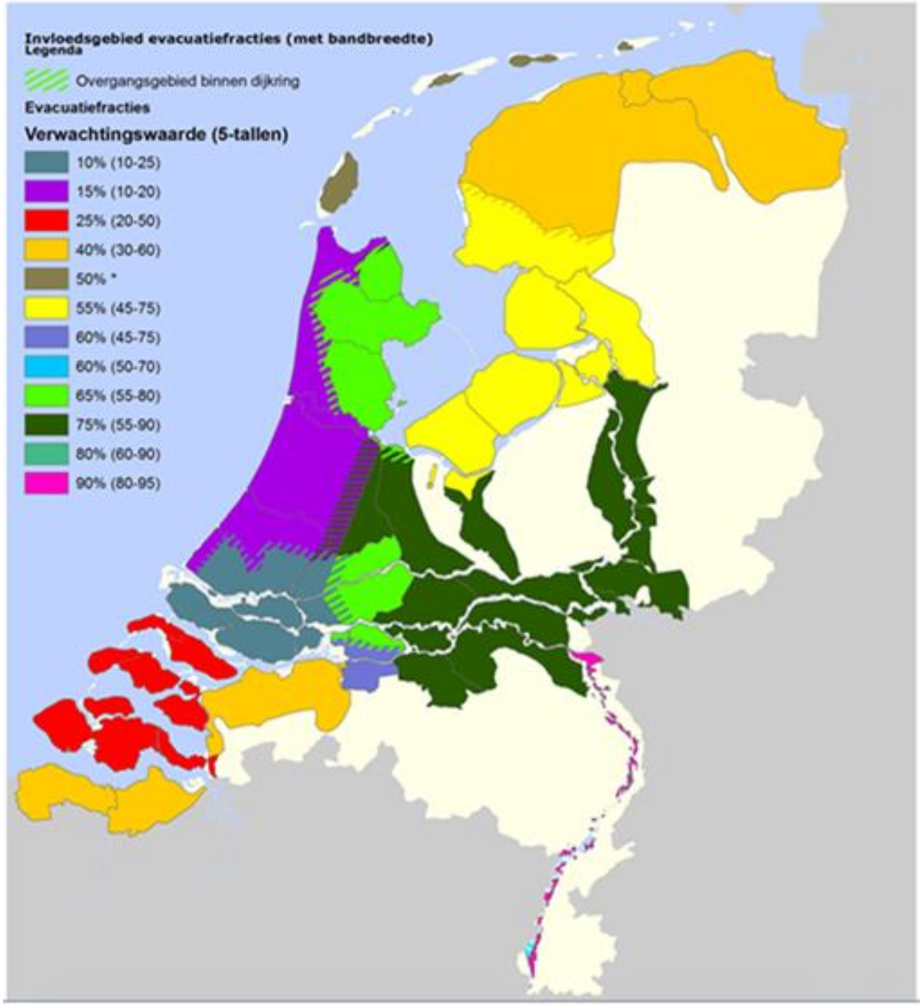
5.2.2 Dutch Method

In the Netherlands, evacuation rate is determined, based on interviews with experts to estimate fatality of the flooded area.8）Expected value of evacuation rate per dike ring is calculated by estimating evacuation rate of diverse scenarios. These scenarios are classified by the below evacuation process. Especially “Detection and recognition of the threat” is defined by so-called “Lead Time,” available time to evacuate, which means evacuation rate varies due to whether they have enough lead time, or whether they need to rush because of a short lead time.

1. Detection and recognition of the threat.
2. Organization and strategy choice: decision making and strategy choice by government and society.
3. Execution: manner and route of evacuation.

In order to estimate evacuation rate per scenario, an evacuation model is used, taking into account various possibilities, such as road congestion and traffic regulations. Uncertainty and bandwidth is, therefore, included in evacuation rate as indicated in Figure 11. Finally an event tree is created, including all the relevant events associated as parameters to estimate an evacuation rate. Challenge here is that the model is not verified in terms of applicability and calibration because, fortunately, flood disasters have not occurred in recent years.

Figure 11 Evacuation rate per dike ring



5.2.3 Collaboration between Japanese and Dutch Method

In reference to the above, this project collects large amount of published flood questionnaire survey results, and creates a simple event tree based on many flood cases in Japan to estimate evacuation rate (expected value) including uncertainty. Event tree is created by estimating evacuation rate, on the ground of lead time to evacuate given to residents right before floods, according to three scenarios with No lead time, Short lead time (less than 3 hours) and Long lead time (3 hours and more).

5.3 Available data and information

Majority of questionnaire surveys in Japan are conducted by the central government, municipalities and research institutes to the residents hit by floods. The information given by these surveys suggests behavioral psychology of residents during floods, and contributes to consider effective flood control measures, crisis management, and local disaster prevention plan. This project creates an event tree, collecting data of 86 cases of flood questionnaire surveys in Japan (Table 19). It is, however, necessary to note that each survey employs its own population parameter.

Table 19 Collected flood cases in Japan

Year	Target disaster	Target area
1982	Yamato River Flood	Oji town, Nara prefecture
1982	Yamato River Flood	Matsubara city, Osaka prefecture
1982	Flood in September, 1982	Kishima area, Iiyama city, Nagano prefecture
1982	Flood in September, 1982	Tokiwa area, Iiyama city, Nagano prefecture
1983	Heavy Rain Disaster in Sanin region	Suzu, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Furuminato, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Monden, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Ekimae, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Minatoshimomachi, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Morimizo, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Misumi, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Mukainota, Misumi town, Shimane prefecture
1983	Heavy Rain Disaster in Sanin region	Kurosawa, Misumi town, Shimane prefecture
1983	Flood in September, 1983	Tokiwa area, Iiyama city, Nagano prefecture
1986	Typhoon No.10	Motegi town, Tochigi prefecture
1986	Typhoon No.10	Akemono town, Ibaraki prefecture
1986	Typhoon No.10	Ishige town, Ibaraki prefecture
1986	Typhoon No.10	Mito city, Ibaraki prefecture
1998	Flood in Ketsu region ,Niigata prefecture	Sasakami village,Niigata prefecture
1998	Heavy Rain Disaster in East Japan	Kooriyama city, Fukushima prefecture
2000	Heavy Rain Disaster in Tokai region	Tenpaku ward, Nagoya city, Aichi prefecture
2000	Heavy Rain Disaster in Tokai region	Nishi ward, Nagoya city, Aichi prefecture
2000	Heavy Rain Disaster in Tokai region	Shinkawa town, Aichi prefecture
2000	Heavy Rain Disaster in Tokai region	Nishi-biwajima town, Aichi prefecture
2000	Heavy Rain Disaster in Tokai region	Kita ward, Nagoya city, Aichi prefecture
2001	Heavy Rain Disaster in Southwestern Kochi prefecture	Shimokawaguchi village, Kochi prefecture
2002	Typhoon No.6 Flood	Higashiyama town and Kawasaki village, Iwate prefecture
2002	Typhoon No.6 Flood	Kooriyama city, Fukushima prefecture
2004	Heavy Rain in Niigata and Fukushima prefecture	Sanjo city, Niigata prefecture
2004	Heavy Rain in Fukui prefecture	Toyooka city, Hyogo prefecture
2004	Typhoon No.23 Flood	Fukui city, Fukui prefecture
2005	Heavy Rain in Northern Kyushu region	Kawayama area, Mikawa town, Yamaguchi prefecture
2005	Heavy Rain in Northern Kyushu region	Naguwa area, Mikawa town, Yamaguchi prefecture
2005	Heavy Rain in Northern Kyushu region	Nekasa area, Mikawa town, Yamaguchi prefecture
2005	Heavy Rain in Northern Kyushu region	Iwakuni city, Yamaguchi prefecture
2006	Heavy Rain in July, 2006	Stsuma-kawauchi city, Kagoshima prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Satsuma town, Kagoshima prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Ookuchi city, Kagoshima prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Hishikari town, Kagoshima prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Yusui town, Kagoshima prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Ebino city, Miyazaki prefecture
2006	Heavy Rain in Northern Kagoshima prefecture	Minowa town, Nagano prefecture
2007	Typhoon No.9 Flood	Kamiochiai area, Fujioka city, Gunma prefecture

Year	Target disaster	Target area
2009	Heavy Rain in Chugoku and Northern Kushu region	Sayo town, Hyogo prefecture
2009	Typhoon No.9 Flood	Ootoshi area and Hirakawa area, Yamaguchi city, Yamaguchi prefecture
2010	Heavy Rain Disaster on 15th, July	Kani city, Gifu prefecture
2010	Heavy Rain Disaster on 15th, July	Yaotsu town, Gifu prefecture
2010	Heavy Rain Disaster on 15th, July	Mitake town, Gifu prefecture
2010	Heavy Rain Disaster	Oyama town, Shizuoka prefecture
2011	Typhoon No.15 Flood	Kooriyama city, Fukushima prefecture
2011	Typhoon No.15 Flood	Sukagawa city, Fukushima prefecture
2012	Heavy Rain in Northern Kyushu region	Tatsuda area, Kumamoto city, Kumamoto prefecture
2012	Heavy Rain in Northern Kyushu region	Hita city, Ooita prefecture
2012	Heavy Rain in Northern Kyushu region	Nagano area, Yame city, Fukuoka prefecture
2012	Heavy Rain in Northern Kyushu region	Joyomachi, Yame city, Fukuoka prefecture
2012	Heavy Rain in Northern Kyushu region	Hoshinomura,Yame city, Fukuoka prefecture
2014	Flood in August, 2014	Wajiki area, naka town, Tokushima prefecture
2015	Heavy Rain in Kanto and Tohoku region	Joso city, Ibaraki prefecture
2016	Typhoon No.10 Flood	Otomo, Iwaizumi town, Iwate prefecture
2016	Typhoon No.10 Flood	Mukaicho, Iwaizumi town, Iwate prefecture
2016	Typhoon No.10 Flood	Horono, Iwaizumi town, Iwate prefecture
2016	Typhoon No.10 Flood	Hinata, Iwaizumi town, Iwate prefecture
2016	Typhoon No.10 Flood	Hikage, Iwaizumi town, Iwate prefecture
2016	Typhoon No.10 Flood	Otofuke town, Hokkaido prefecture
2016	Typhoon No.10 Flood	Minamifurano town, Hokkaido prefecture
2017	Heavy Rain in Northern Kyushu region	Tofo vallage, Fukuoka prefecture
2017	Heavy Rain in Northern Kyushu region	Asakura city, Fukuoka prefecture
2017	Heavy Rain in Northern Kyushu region	Hita city, Ooita prefecture
2018	Heavy Rain in Western Japan	Aki city, Kochi prefecture
2018	Heavy Rain in Western Japan	Seiyo city, Ehime prefecture
2018	Heavy Rain in Western Japan	Kawabe, mabicho, Kurashiki city, Okayama prefecture
2018	Heavy Rain in Western Japan	Arii, mabicho, Kurashiki city, Okayama prefecture
2019	Typhoon No.19 Flood	Nagano city, Nagano prefecture
2019	Typhoon No.19 Flood	Kashimadai, Oosaki city, Miyazaki prefecture
2019	Typhoon No.19 Flood	Higashimatsuyama city, Saitama prefecture
2019	Typhoon No.19 Flood	Chofu city, Tokyo metropolitan area
2019	Typhoon No.19 Flood	Oosato town, Miyagi prefecture
2019	Typhoon No.19 Flood	Marumori town, Miyagi prefecture
2020	Heavy Rain in July, 2020	Takayama city, Gifu prefecture
2020	Heavy Rain in July, 2020	Seki town, Gifu prefecture
2020	Heavy Rain in July, 2020	Nakatsugawa city, Gifu prefecture
2020	Heavy Rain in July, 2020	Hitoyoshi city, Kumamoto prefecture
2020	Heavy Rain in July, 2020	Gero city, Gifu prefecture
2020	Heavy Rain in July, 2020	Yashiro city, Kumamoto prefecture
2020	Heavy Rain in July, 2020	Shirakawa city, Gifu prefecture
2020	Heavy Rain in July, 2020	Kuma village, Kuma district, Kumamoto prefecture

5.4 Analysis and Results

Definition

- Evacuation rate

  Evacuation rate is defined to be a ratio of "move out" (horizontal evacuation) in this project. The destinations are not only shelters, but also other safe places, such as higher ground and relatives / friends' home.
- Lead time to evacuate

  Lead time in this project is determined by a standard throughout all cases, taking into account distance from home to shelters and walking speed, though it should have been better if it were determined per area/river, dependent on water rising rate of each river/flood. Definition of lead time to evacuate safely is time after an evacuation information is announced until a disaster occurs, such as dike failure, overflowing and flood, or until the highest water level is reached (Figure 12). Lead time required for safe evacuation is estimated by distance between home and shelters [9] and walking speed while evacuating [10]. As a result, necessary lead time turned out to be about 1.4 hours during daytime for people who need a longer time to walk, and 0.6 hours for others (Table 20). Because walking speed is almost halved during night [11], lead time for people who need a longer time to walk is about 2.8 hours, and about 1.2 hours for others (Table 21).

Necessary lead time is, therefore, assumed to be approximately 3 hours for residents to evacuate safely, including those need a longer time to walk. Further research is, however, required with more details in the future, because many residents chose car to evacuate in the recent floods and then the speed to evacuate can be quite different.

Figure 12 Concept of lead time

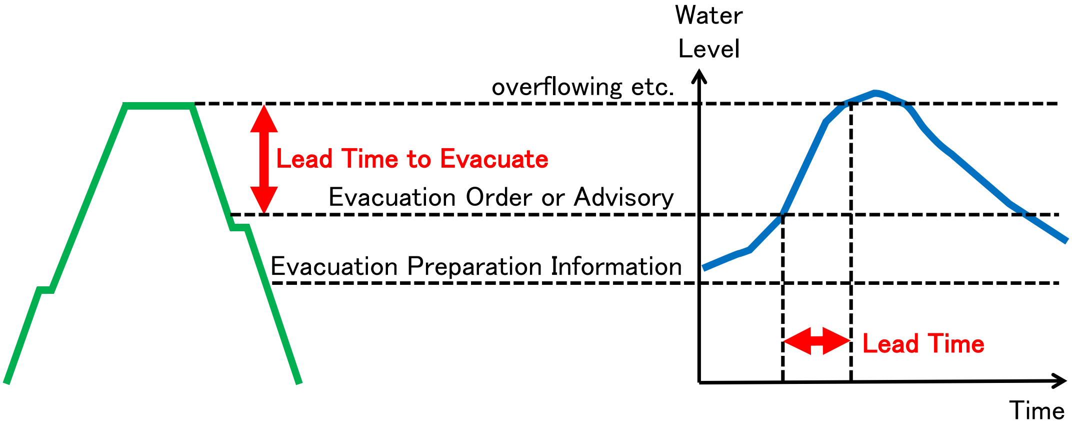


Table 20 Draft of lead time for citizens (daytime)

Target person	Distance	Walking speed（daytime）	Time required
People who need a longer time to walk	Max. 2,000m [9]	0.4m/s (Assumed to be about 40% of the below based on references [10])	1.4 hours
Others		1.0m/s [10]	0.6 hours

Table 21 Draft of lead time for citizens (night, Walking speed halved

Target person	Distance	Walking speed（daytime）	Time required
People who need a longer time to walk	Max. 2,000m [9]	0.2m/s (Assumed to be about 40% of the below based on references [10])	2.8 hours
Others		0.5m/s [10]	1.2 hours

5.5 Results

Based on 3 hours of necessary lead time determined as the above, evacuation rates of collected 86 cases are classified. The cases with Short lead time (less than 3hours) are spread out in wide range between minimum 7.1% and maximum 81% as shown in Figure 13 and Table 22. Evacuation rate with long lead time (3 hours and more) is higher by 10-15%, between minimum 17.3% and maximum 96%. Average rate of Long lead time is 43.8%, slightly higher than 40.9% with Short lead time.

Figure 13 Classification of evacuation rates based on lead time

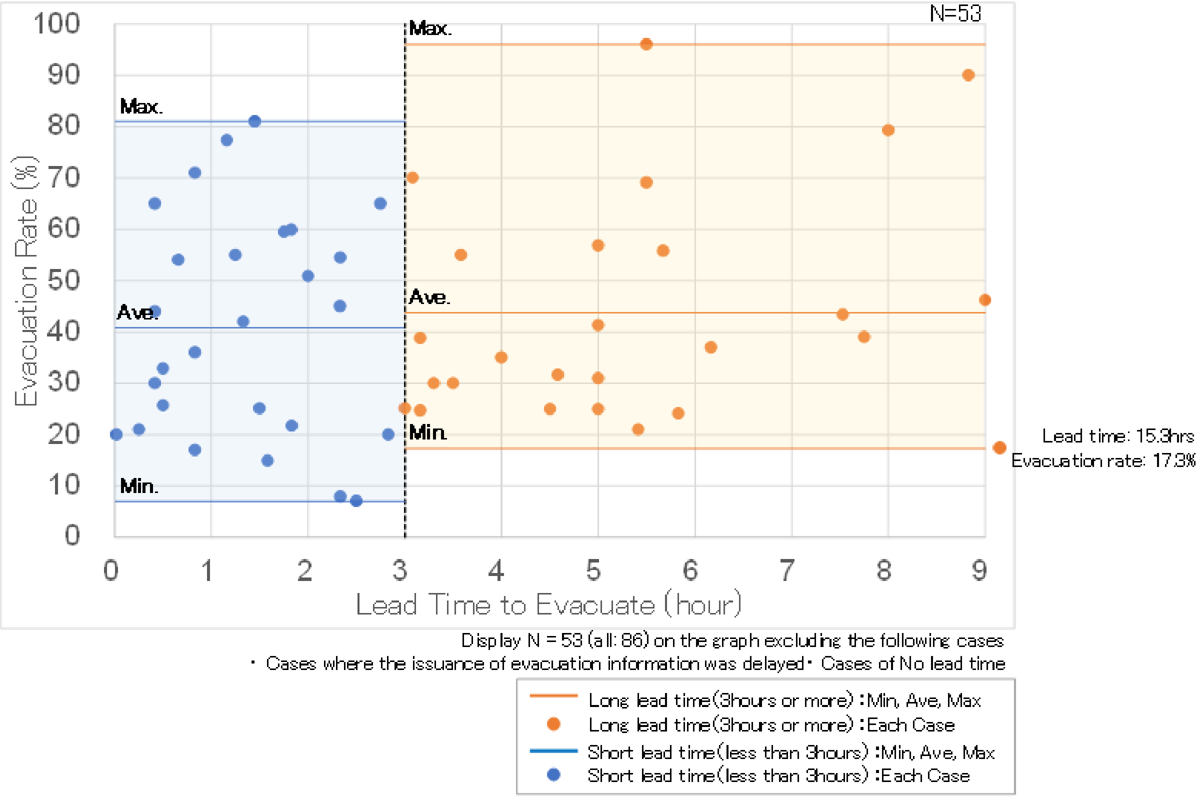


Table 22 Evacuation rate when lead time is short or long

Lead Time	Minimum	Average	Maximum
Short lead time （less than 3hours）	7.1%	40.9%	81%
Long lead time （3 hours and more）	17.3%	43.8%	96%

Relationship between Evacuation Rate and Flood Experience

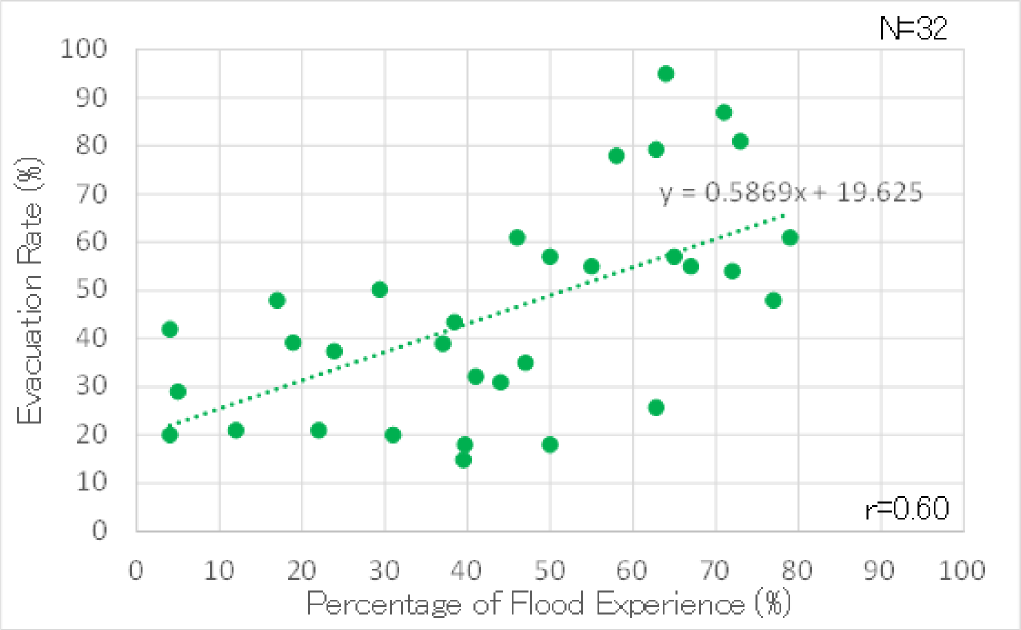
This project provides a correlation between evacuation rate and various elements. Among them, this project introduces the relationship between the evacuation rate and the percentage of people who have experienced floods before, where a positive correlation appeared.

Here, the percentage of people who have experienced floods before indicates the percentage of damage experience and evacuation experience in past floods. The reason why there are few applicable cases is that many questionnaire surveys do not have question items related to flood experience. When the relationships between the evacuation rate and the percentage of people who have experienced floods before were grasped in all 32 cases, positive correlation (correlation coefficients r = 0.60) was obtained as shown in Figure. This indicates that residents with a damage experience or evacuation experience have a crisis awareness of floods, and tend to have a higher possibility to evacuate. Based on this, it is possible to derive an evacuation function (linear function) with the flood experience as a parameter as shown below.

$y = 0.5869x + 19.625$

Where, x: the percentage of flood experience (%), y: evacuation rate (%). From the intercept of this function, it can be seen that an evacuation rate of at least about 20% can be expected in areas that have experienced floods. With this evacuation function, it is possible to set the evacuation rate that more reflects the regional characteristics by estimating the evacuation rate corresponding to any x (percentage of people who have experienced floods).

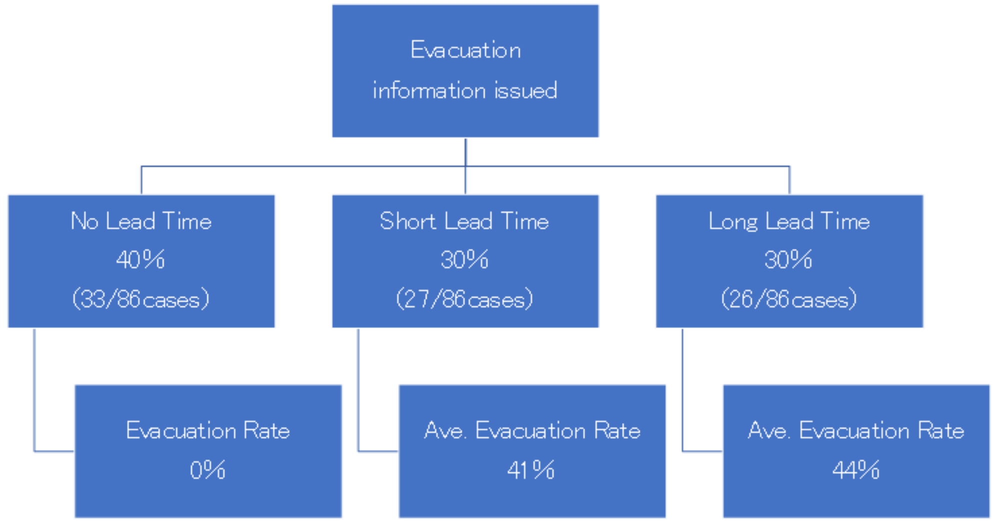
Figure 14 Evacuation function with the flood experience as a parameter



5.6 Evacuation Rate

Figure 15 shows a simple event tree, created according to lead time. Each ratio of the middle layer, No lead time, Short lead time (less than 3 hours) and Long lead time (3 hours and more), indicates ratio per scenario with population parameters of cases collected for this project. The lower layer shows evacuation rate per scenario. Here, if there is no lead time or the evacuation information is announced late, it is assumed that the residents cannot evacuate safely, and the evacuation rate is set to 0%. The evacuation rates were 41% and 44%, respectively, when the lead time was short and when there was long lead time. Overall Average rate (expected value) is 26%. This project estimates fatality of the flooded area, by calculating remaining population (exposure) in flooded area, determined by the evacuation rate. In order to improve the evacuation rate, actual record of Hurricane Katrina Disaster at New Orleans city, 80%, is added. This project proposes the above method of determining evacuation rate and values of evacuation rates.

Figure 15 Simple event tree based on lead time



Overall Ave.(Expected Value) =0.4 × 0% + 0.3 × 41% + 0.3 × 44% = 26%

5.7 Uncertainties in evacuation

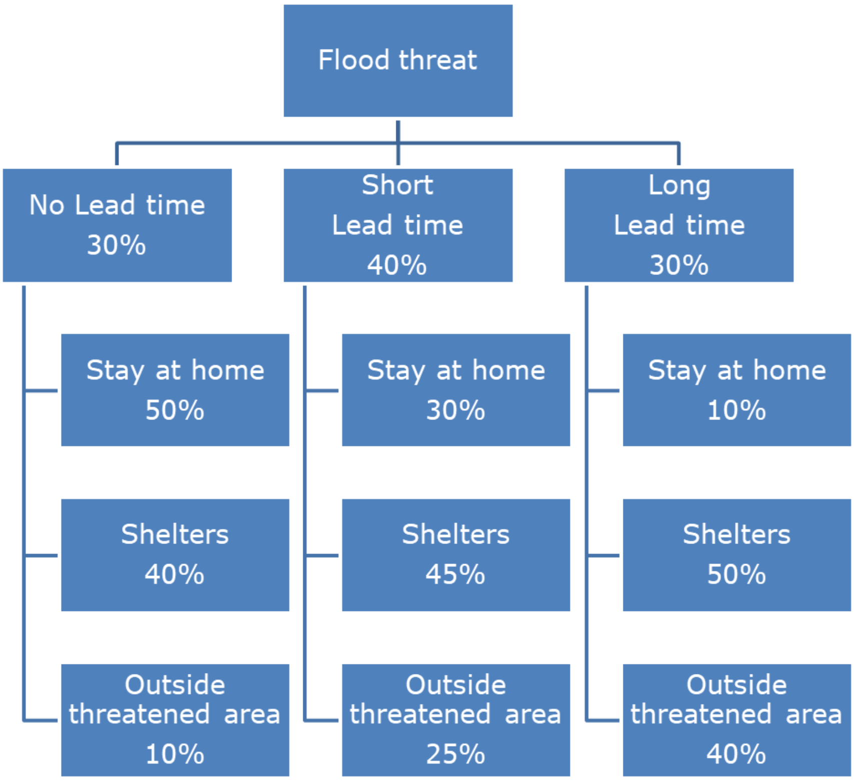
Evacuation is an aspect that is subject to several uncertainties, because human behaviour plays a major role in the effectiveness. Communication, previous experiences, available time, people’s awareness, preparedness, road capacity, are all aspect that influence the outcome of the effectiveness of the evacuation. Also the difference between preventive evacuation outside the threatened area and evacuation to shelters nearby have a large impact on the determination of the percentage of people that reach a save location. Therefore, this is a topic that needs further investigation to improve understanding of the evacuation effectiveness and the potential it can have in reducing the flood risks.

5.8 Proposal improve evacuation model

Further detailed study and examination are required as future issues. As the main study content in the future, since large-scale floods occur frequently in Japan, the latest information (evacuation rate, lead time, etc.) is added, and the event tree and loss of life due to floods are estimated based on it. It is necessary to update the evacuation rate used for. In addition, in this project, we focused on lead time as an element that can be estimated in common for all cases, but in reality, we have to focus on elements that correlate with the evacuation rate, such as flood experience, and estimated the evacuation rate immediately before the occurrence of a disaster. The contents of future studies including these are shown below.

- Create an event tree based on the latest information.
- Reexamination of lead time that allows residents to evacuate safely based on the results of the Great East Japan Earthquake etc.
- Understanding the correlation between elements other than lead time (flood damage experience, hazard map understanding rate, participation rate in disaster prevention drills, etc.) and evacuation rate. Analyze which element (uncertainty) contributes most to the evacuation rate.
- Based on the above, create an event tree that further reflects regional characteristics.
- Examining how to set the target evacuation rate.

Figure 16 Improved evacuation model



5.9 References

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6 Loss of Life

6.1 Loss of Life due to Recent Floods in Target Area

As described above, the center of Obihiro city, the target area of this project, did not suffer from damage due to overflowing in the event of Hokkaido Heavy Rain Disaster 2016. The record high water level at Tokachi River Obihiro Reference Point (1955-2015) [1] shows that 2016 was the second highest. It also indicates that the record high water level before 2016 was 1981, 35 years back in time. This is, therefore, an area with no flood damage in recent years, nor fatalities due to flooding.

Table 23 Tokachi River Obihiro Reference Point, record high water level [1]

Ranking	Flood date	Highest water level(m)
1	1962.8.4	38.12
2	2016.8.31	38.07
3	1981.8.5	37.54
4	1957.9.19	37.05
5	1961.7.26	37.00
5	1972.9.17	37.00
7	1955.9.8	36.88
8	1958.8.28	36.60
9	1964.8.26	36.49
10	1962.9.9	36.22

6.2 Method of Loss of Life Estimation

6.2.1 Japanese Method

In order to estimate loss of life in the flooded area in Japan, LIFESim model [2] is employed, by which United States Army Corps of Engineers (USACE) verified loss of life around New Orleans city when Hurricane Katrina hit there [3][4]. This model determines mortality dependent on water depth, taking into account age of victims (65 years and older/younger than 65 years). When a victim is 65 years and older, it is assumed that they can evacuate vertically to their top floor, and when younger than 65 years, the ceiling of the top floor is assumed to be reached by vertical evacuation (Figure 17). Fatality is then estimated by multiplying mortality classified into 3 areas (Table 24), Danger Water Level with maximum water depth from floor, Near Critical Water Level and Safety Water Level, by number of people in danger dependent on which floor in building. Ikeuchi et al. [3] estimated loss of life in large-scale flood of Arakawa river etc. based on a confirmation that there is no significant difference between Japan and the United States, in terms of floor height of residence, height of each story, or average height of people.

Figure 17 Overview of LIFESim model [3][4]

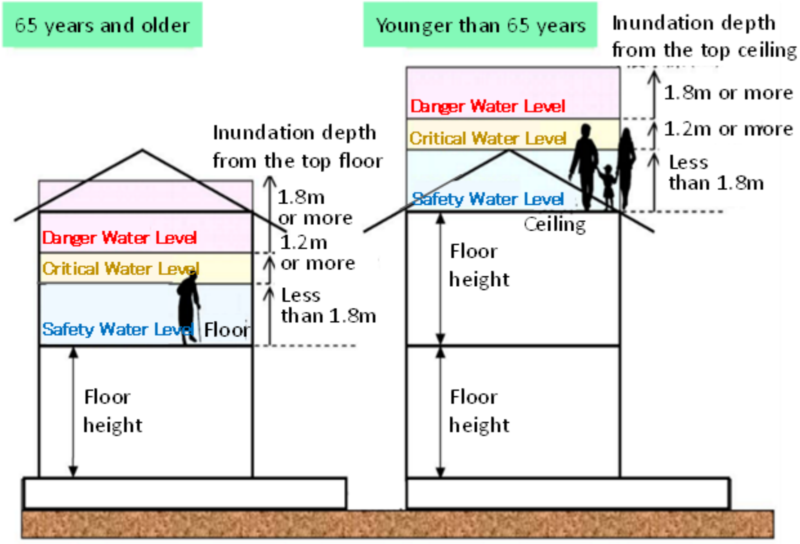


Table 24 Mortality according to water depth [3][4]

Classification of danger level	Mortality
Danger Water Level	91.75
Near Critical Water Level	12.00
Safety Water Level	0.023

6.2.2 Dutch Method

There is a model to estimate loss of life of the flooded area in the Netherlands, with mortality function related to flood characteristics [5][6]. S.N. Jonkman [5] divided flooded area into three hazard zones (breach zone, zone with rapidly rising water, remaining zone) and employed mortality function with parameter of water depth in each zone to estimate mortality in the event of flood. B. Maaskant et al. [6] improved the model of S.N. Jonkman , dividing flooded area into four zones, since majority of fatality was classified/assumed in two zones (zone with rapidly rising water and remaining zone) in the risk analysis of "The National Flood Risk Analysis for the Netherlands "VNK2 (Floris2)" [7]. Boundary conditions and mortality function per zone are explained as follows.

The breach zone
d·v≥7m^2/s and v≥2m/s

$$F_{D,B} = 1$$

The zone with rapidly rising water
$(d \cdot v < 7m^2/s$ and $v < 2m/s)$ and $(d \geq 2.1m$ or $w \geq 4m/hr)$

$F_{D,Rise}\ (d) = \Phi_N\left(\frac{\ln(d)-\mu N}{\sigma N}\right)$ $\mu_N=1.46$, $\sigma_N=0.28$

The transition zone
$(d \cdot v < 7m^2/s$ or $v < 2m/s)$ and $(d \geq 2.1m$ and $0.5m/hr \leq w < 4m/hr)$

$F_D = F_{D,Remain} + (w - 0.5)\frac{F_{D,Rise}-F_{D,Remain}}{3.5}$

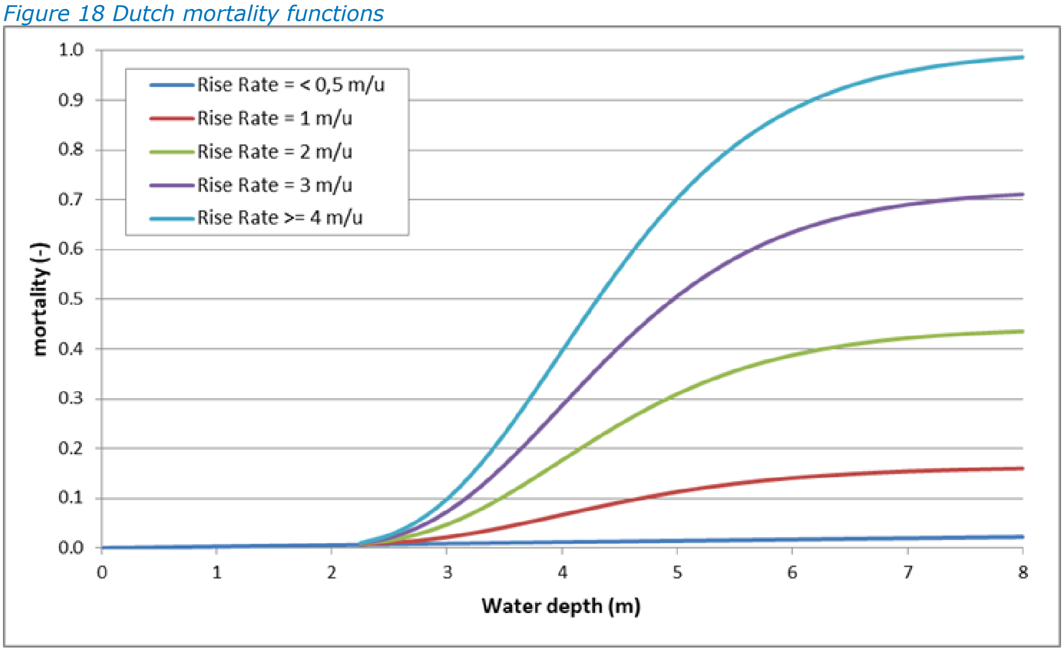
The remaining zone

（$w < 0.5m/hr$ or ($w \geq 0.5m/hr$ and $d < 2.1m$）) and （$d \cdot v < 7m^2/s$ or $v < 2m/s$）

$F_{D,Remain}(d) = \Phi_N\left(\frac{\ln(d)-\mu N}{\sigma N}\right)$ μ_N=7.60, σ_N=2.75

where, d: flood depth(m), v: flow velocity(m/s), w: rise rate of water(m/h), F: mortality, Φ: cumulative probability density function of standard normal distribution, μ: average value of h, σ: standard deviation of h.

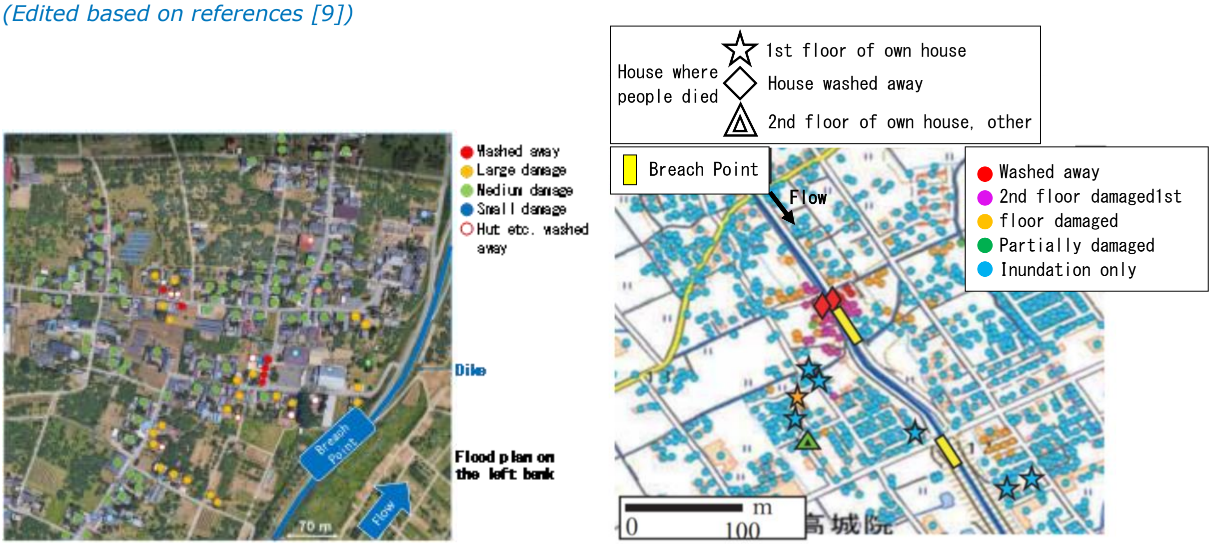
Figure 18 Dutch mortality functions



6.2.3 Selection of application method

Rivers in Japan are steeper than in the Netherlands, and their basins are generally steeper. For this reason, when a river floods, Figure 19 indicates that houses around the breaching point are frequently washed away or collapsed by a significant fluid force in Japan [8][9]. According to the research by Nihei and Shinohara [10][11], there are cases that people died during evacuation or before taking an action of evacuation due to rapidly rising water（Two examples are as follows: Max. water rise rate: 0.5m/h in Joso city, Ibaraki prefecture in the event of Heavy Rain Disaster in Kanto-Tohoku Regions in September, 2015. Max. water rise rate: higher than 1.0m/h in Mabi-cho, Kurashiki city, Okayama Prefecture in the event of Heavy Rain Disaster in July, 2018.) Sato et al. [12] and Tsukada and Ikeuchi [13] report that majority of the victims were senior citizens or person requiring support. An accurate loss of life caused by flood in Japan should be estimated, dependent on flooding and damage characteristics, taking into account hydraulic conditions, such as flow velocity, fluid force, and water rise rate, and age of victims.

Figure 19 (Left) Damaged houses collapsed near the breaching point of Chikuma River（in Tsuno, Nagano city, Nagano prefecture, Typhoon No.19 in October, 2019）（Edited based on references [8]), (Right) Damaged houses near the breaching point of Suemasa River (Mabi-cho, Kurashiki city, Okayama prefecture in July, 2018) (Edited based on references [9])



Based on recent flood damage in Japan, loss of life estimation of urban area in Obihiro city needs to take into account hydraulic conditions, such as flood depth, flow velocity, fluid force and water rise rate. In addition, vulnerability of victims should be also considered. As described above, the method to apply mortality function is effective to reflect diverse hydraulic conditions. On the other hand, LIFESim model is remarkable in giving mortality per flood depth (classification of danger level), though concerned hydraulic condition is limited only to flood depth, and its feasibility of vertical evacuation, including age of victims (65 years and older/younger than 65 years.).

There are still significant challenges to apply the above model in practice to existing rivers in Japan, while mortality function is applied considering horizontal load condition, such as flow velocity and fluid force around the breaching point, and rapidly rising water caused by accumulating water in low-lying area or being surrounded by dike. This project, therefore, introduces an improvement of the loss of life estimation model (section 6.5).

6.2.4 Mortality

Based on the complexity of the Japanese situation and the challenges ahead, the choice has been made to use the Dutch mortality functions for the Obihiro case study. When the improved method is available an update can be made using the new mortality functions. The next section describes the loss of life using the Dutch mortality functions.

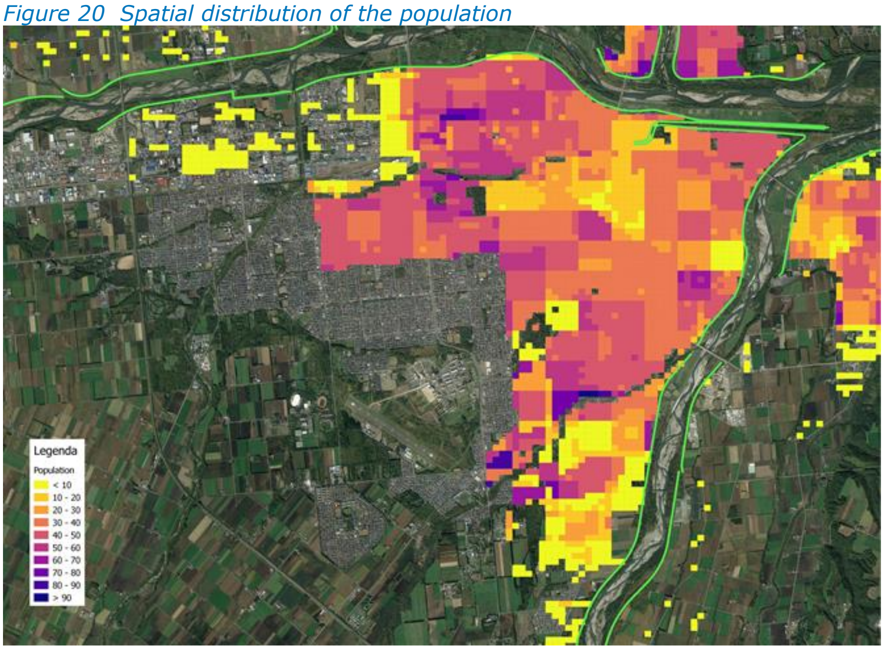
6.3 Loss of Life case Obihiro

Based on the method described in section 6.2 and the choices that have been made the loss of life for the Obihiro case can be determined. In the following section the calculation of loss of life is described.

6.3.1 Population

The total population in the case study area is approximately 28,800. These are the inhabitants of the area at risk. In the figure below the distribution of the population of the area is shown.

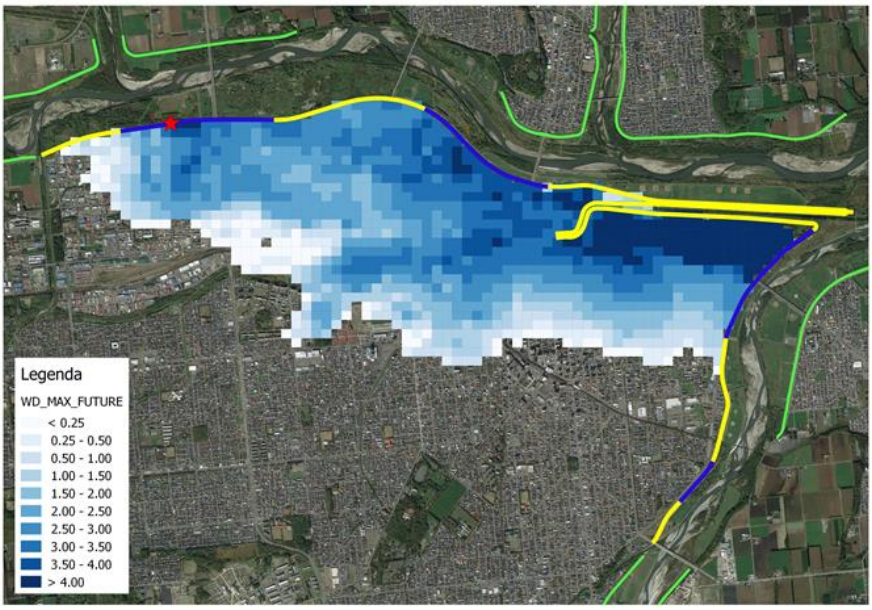
Figure 20 Spatial distribution of the population



6.3.2 Mortality

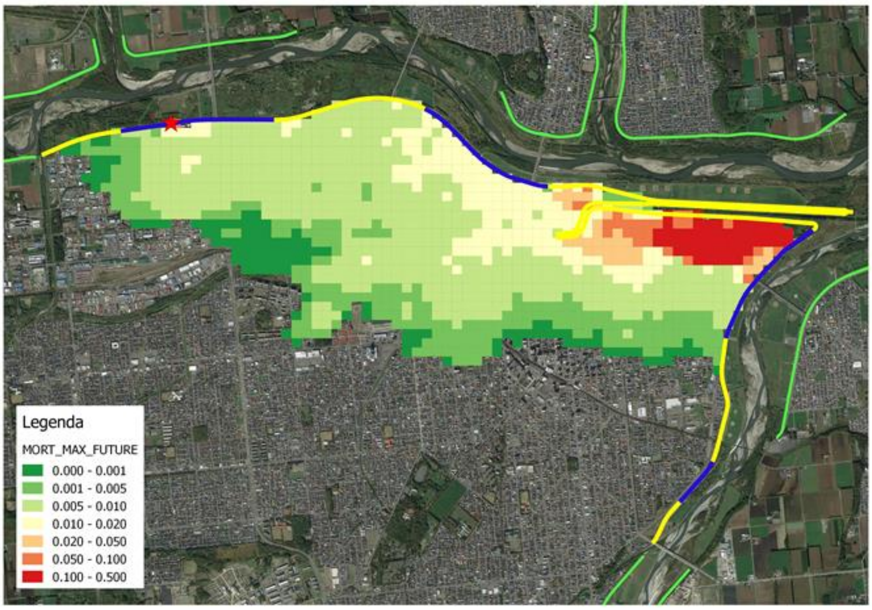
To determine the mortality the water depth, rise rate and flow velocity are combined using the mortality functions from section 6.2.4. The mortality is calculated for all breach locations and all inundation patterns. In this section one locations is described to illustrate the determination of the mortality. In the figure below the water depth is shown for breach location KP61.4 for the Max Scenario.

Figure 21 Water depth MAX scenario KP61.4



This maximum water depth in combination with the maximum rise rate during the flood scenario are used to calculate the mortality. This leads to a mortality rate per meshcode shown in Figure 22, the mortality varies between less than 0,1% to more than 10% in the deeper parts. This can be explained by the fact that, in general, the greater water depths lead to a higher mortality.

Figure 22 Mortality MAX scenario KP61.4



6.3.3 Loss of life

Loss of life for each breach scenario is calculated by multiplying the mortality by the population including evacuation. Incorporating evacuation can lead to different numbers for loss of life based on the included evacuation percentages. In the table below the loss of life is given for the different flood scenarios (Max, Min, MaxVol) and three evacuation percentages, one for the situation with no evacuation (0%), one for the overall average percentage (expected value) 26%, and one upper limit of 80 percent. Because of the different flood extents between the flood scenarios also the exposed population varies, this is also included in the table.

Table 25 Overview Loss of Life for all scenarios

Location		Max				Min				MaxVol			
		Exp	0%	26%	80%	Exp	0%	26%	80%	Exp	0%	26%	80%
Past	Satsunai_KP4_2	4076	17	13	3	4076	17	13	3	4076	17	13	3
	Satsunai_KP5_2	7830	23	17	5	7830	23	17	5	7830	23	17	5
	Satsunai_KP6_4	15594	56	42	11	9358	9	7	2	15594	56	42	11
	Satsunai_KP7_0	13930	28	21	6	10445	2	2	0	13930	28	21	6
	Tokachi_KP56_4	13411	186	139	37	5985	27	20	5	12427	118	88	24
	Tokachi_KP58_0	21555	162	121	32	14200	47	35	9	20769	127	94	25
	Tokachi_KP59_6	26884	340	253	68	23204	134	100	27	25533	225	168	45
	Tokachi_KP61_4	30421	337	251	67	28893	218	162	44	30283	289	215	58
	Tokachi_KP62_4	28880	179	133	36	26558	76	57	15	28880	179	133	36

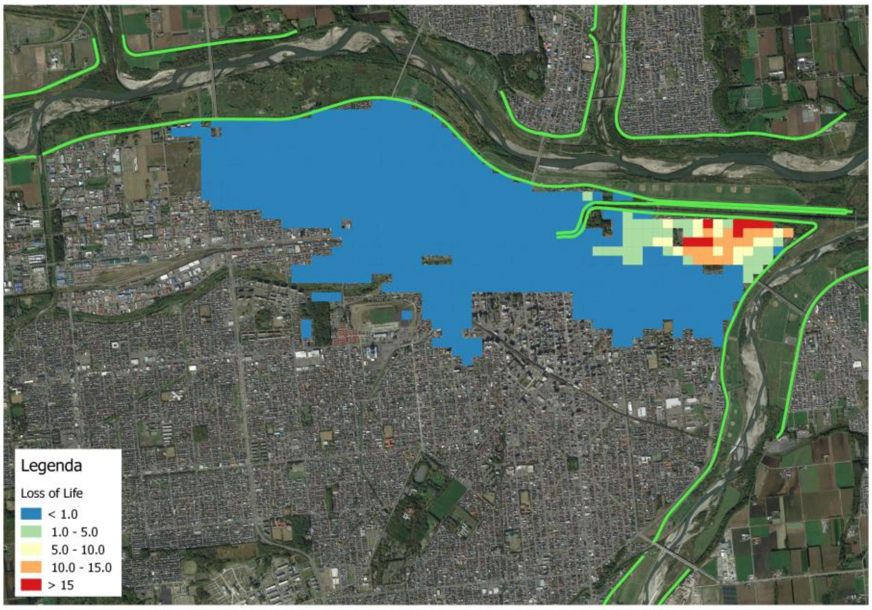
Future	Satsunai_KP4_2	11289	40	30	8	3906	14	11	3	7619	36	27	7
	Satsunai_KP5_2	13861	58	43	12	6638	17	13	3	13575	57	42	11
	Satsunai_KP6_4	20556	100	74	20	8946	6	5	1	16335	53	39	11
	Satsunai_KP7_0	20179	67	50	13	10539	3	2	1	18326	51	38	10
	Tokachi_KP56_4	35769	365	272	73	5366	22	17	4	21006	165	123	33
	Tokachi_KP58_0	36646	566	422	113	13526	41	31	8	26538	169	126	34
	Tokachi_KP59_6	37052	879	655	176	23014	115	86	23	30825	310	231	62
	Tokachi_KP61_4	39174	834	622	167	28380	164	122	33	33886	352	262	70
	Tokachi_KP62_4	34274	414	308	83	25887	60	45	12	35913	514	383	103

The loss of life analysis shows that largest loss of life is caused by levee breaches along the Tokachi river. This is due to the fact that the Tokachi river has a larger discharge than the Satsunai river and therefore leads to a larger flood extent and more people exposed.

In comparison to the calculated damage the loss of life is more sensitive to the hydrograph shape of the discharge that runs through the river. The difference between the “max” scenario and “maxvol” is relatively small, factor 2. But the difference with the “min” scenarios are relatively large, it can be up to a factor 20.

In the figure below the distribution of the loss of life over the case study area is shown for the KP61.4 Max scenario for the situation without evacuation. This gives information on the location where the loss of life is largest.

Figure 23 Spatial distribution of the loss of life for the max scenario KP61.4



6.4 Uncertainties in Loss of Life calculation

Determining loss of life is also subject to many uncertainties. In the case study the Dutch loss of life model is used. This method is based on the 1953 flooding in the Netherlands and is mostly applicable to larger flooded areas and “average” out differences between states. Other methods aiming to capture more local processes and effects, which will lead to differences in outcomes.

The methods are also sensitive to peoples location during a flood event. If a large percentage of the population is in a shelter this has an impact on the use of the loss of life model. So the combination and interaction between the evacuation and loss of life models is essential for a good estimation and understanding of the loss of life calculation.

Local situations also have a large impact on the loss of life determination, type of building constructions, age distribution of population, weather conditions.

Given these uncertainties it is necessary to further research this topic to get a better insight in the potential loss of life and the flood risks.

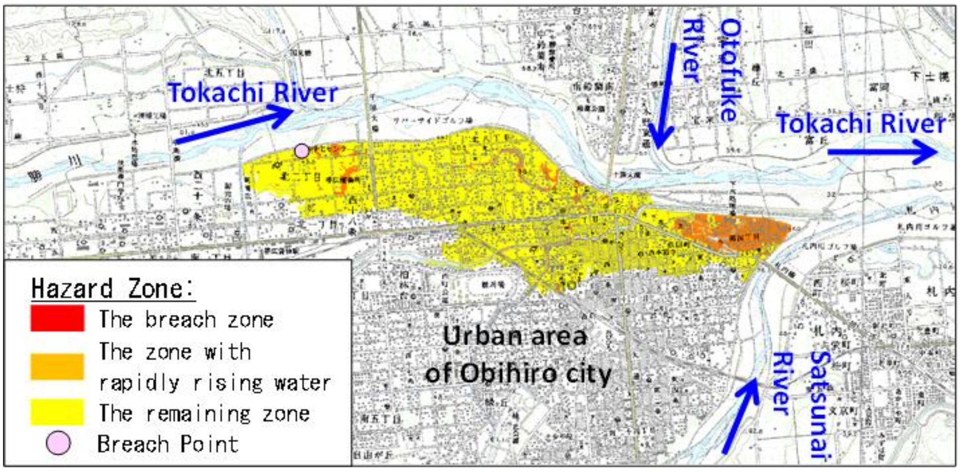
6.5 Proposal new loss of life model

During this project, engineers and experts from both countries joined diverse discussions concerning loss of life estimation model and estimation method, targeting Japan. As a result, this project employed a method to apply mortality function, to take into account fluid force in the event of dike failure and rapidly rising water due to accumulation. In order this method to be applied in Japan, however, requires model calibration, with adjustment to flooding and damage characteristics in Japan. This is why a new loss of life estimation model is proposed as a result of this project. In the future, applicability of this model has to be verified.

6.5.1 Point of View

According to Tomura and Masuya et al. [14], no area was classified in (The breach zone), even by external force considering climate change (+4K simulation) as indicated in Figure 24. As described above, however, damaged houses in recent years are significantly washed away/ collapsed around the breaching point. It is necessary to correctly assess loss of life classified in (The breach zone) to estimate loss of life of the flooded area. This project focuses on (The breach zone).

Figure 24 +4K simulation: Mortality zone map [14]



Concept of [The breach zone] is based on the assumption that people die 100% (FD,B= 1) when masonry and brick houses totally disrupt. Boundary condition, therefore, employs collapse criteria of masonry and brick houses (Figure 25) [15][16], which is implemented in majority of European countries including the Netherlands.

On the other hand, most of the houses in Japan is made of wood (Figure 26) [17]. Wooden houses are considered to be more vulnerable to fluid forces than masonry and brick houses, and are expected to suffer more damage. In order to estimate house damage in the event of a large-scale earthquake, houses are classified dependent on structure (wooden/non-wooden) and age (old/middle/new) based on fixed assets book data, which provides estimation of total destruction rate of houses, using damage rate function [18]. It is obvious that vulnerabilities are caused by different structure and age of houses. Especially in assessment of house damage in the event of a large-scale earthquake, old wooden houses are the most vulnerable. This can be explained by actually reported many cases of extremely severe and wide range of damage caused by earthquake, such as Great Hanshin-Awaji Earthquake in 1995 and Great East Japan Earthquake in 2011, which made it possible to assess vulnerability of houses based on actuality. House damage due to floods, however, is by far less than house damage due to large-scale earthquake, though it tends to increase in recent years. This is why this project focuses on boundary condition of [The breach zone] and determines collapse condition of wooden houses based on review of past studies.

Figure 25 Collapse criteria of masonry and brick houses15)

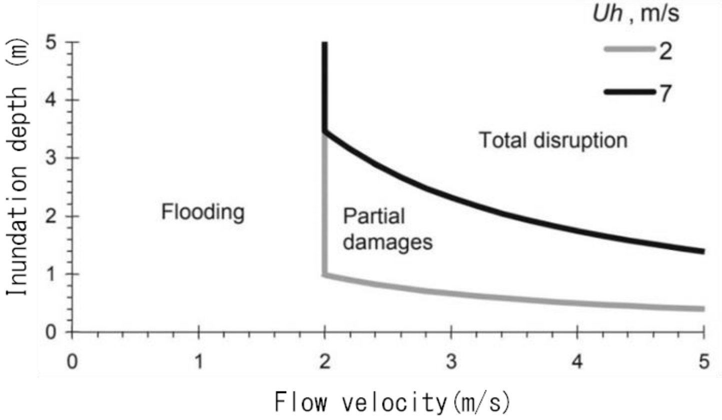
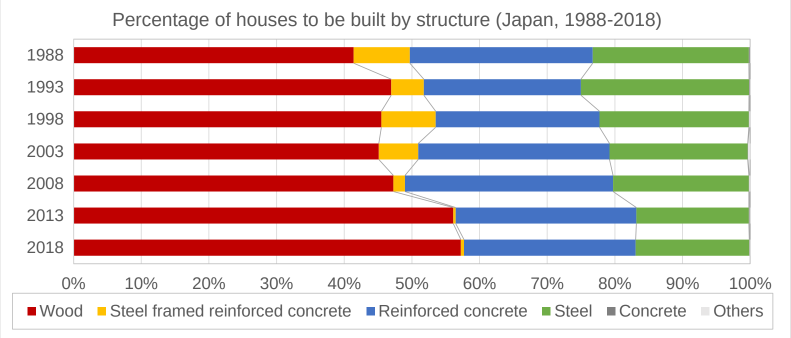
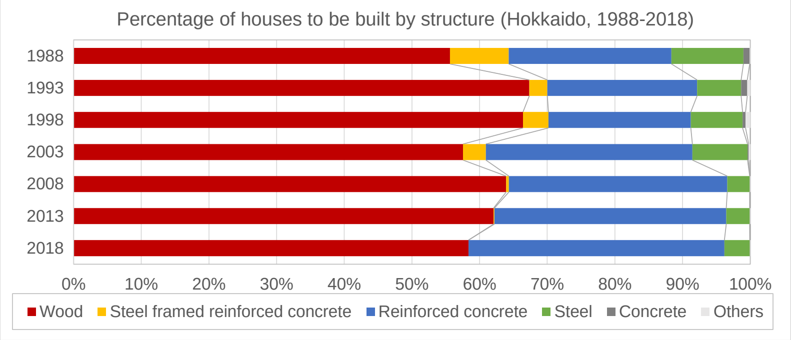


Figure 26 Percentage of houses to structure in Japan, (Left) All over Japan, (Right) Hokkaido17.





The Focus of This Study

Do you know the fairy tale “The Three Pigs” [19] published in the late 18th century? The outline of the story is as follows. One day, Three Pigs decided to build their own houses. The first little pig built his house out of straw. The second little pig built his house out of sticks (wood). Then the third little pig built his house with bricks.

A hungry wolf arrives there and blows away each house one after another, but the brick house made by the third little pig did not collapse. Eventually, the wolf enters the brick house from the chimney and gets hurt.

In proposing a new loss of life estimation model in this project, we got important inspiration from this story. The force a wolf blows houses can be replaced by flow velocity or fluid force (a horizontal force,) etc. Only the brick house made by the third little pig did not break under almost the same horizontal force. European houses, including the Netherlands, can be seen as the third little pig’s house, and Japanese houses can be seen as the second little pig's house.

In order to estimate loss of life due to floods in Japan, we thought it was necessary to evaluate whether the house of the second little pig’s house would be destroyed. This is the focus of this study.

6.5.2 Comparison of Collapse Condition

In order to determine appropriate boundary conditions of 【The breach zone】 in Japan, results of studies and literature were collected, related to collapse condition of wooden houses in Japan. Table 33 indicates collapse condition of houses derived from damage in the past floods. In Japan, a lot of studies assess washed away/collapsed houses by index of fluid force of flood flow (v2d, v: flow velocity and d: flood depth). On the other hand, in the Netherlands, the same index of fluid force (v2d) is reflected, which is derived from flood depth product (vd) related to moment and flow velocity (v), a horizontal force causing houses to collapse.

Though a lot of house damage due to Tsunami is reported in Japan, a Tsunami causes significant fluid force twice: incoming wave and dilatational wave. This is the reason why Table 33 does not include Tsunami, which is a different phenomenon from river flooding causing house damage.

Table 26 Collapse condition of wooden house (d: flood depth(m)、v: flow velocity(m/s))

No.	Target house structure	Collapse condition	Source
1	Two storied wooden house （Sliding）	$0 \leq d < 2.6,\ v = \sqrt{\frac{35.76}{d}}$ $2.6 \leq d < 3.2,\ v = \sqrt{\frac{122.95-33.53h}{d}}$ $3.2 \leq d,\ v = \sqrt{\frac{15.65}{d}}$	Flood Control Planning Room, River Environment Division and Flood Disaster Prevention Division, River Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transportation and Tourism, Manual for Creating a Flood Forecast Area Map（4th edition）, 2017. 20)
2	Two storied wooden house (new seismic criterion since 1981)	$1.65 < d,\ v = \sqrt{\frac{5.83}{(d-1.650)}}$	Flood Control Planning Room, River Environment Division and Flood Disaster Prevention Division, River Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transportation and Tourism, Manual for Creating a Flood Forecast Area Map（4th edition）, 2017. 20)
3	Two storied wooden house (old seismic criterion since 1950)	$1.65 < d,\ v = \sqrt{\frac{1.56}{(d-1.650)}}$	Flood Control Planning Room, River Environment Division and Flood Disaster Prevention Division, River Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transportation and Tourism, Manual for Creating a Flood Forecast Area Map（4th edition）, 2017. 20)

4	One-story wooden houses	Large damage: $v^2d = 10$ Washed away: $v^2d = 20$	Yagi, R. and Kure, S., Proposal of Vertical/Horizontal Evacuation Zone Classification based on Flood Inundation Analysis and Risk Rank Evaluation for the Joganji River and Jinzu River, 2020. 8)
5	Unknown	Damage occurs: $v^2d = 1.5$ An uninhabitable house appears: $v^2d = 2.5$	Kawata, Y. and Nakagawa, H, Flood Disasters in the Misumi River, 1984. 21)
6	Wooden houses	Houses may be damaged（based on houses survey results in New Zealand） $vd = 1$	Sato, S. et al., Numerical Simulation of Flood and Damage to Houses -A Case of the Yoshida River due to Typhoon No.8610, 1989. 22)
7	Unknown	Houses are washed away and large-scale damage occurs $2 < v$ and $2 < d$	Tabata, K. et al., On Flood Risk Reduction by Integrating Analysis of Flood Flow and Inundation in the Kinugawa River during 2015 Large Flood, 2018. 23)

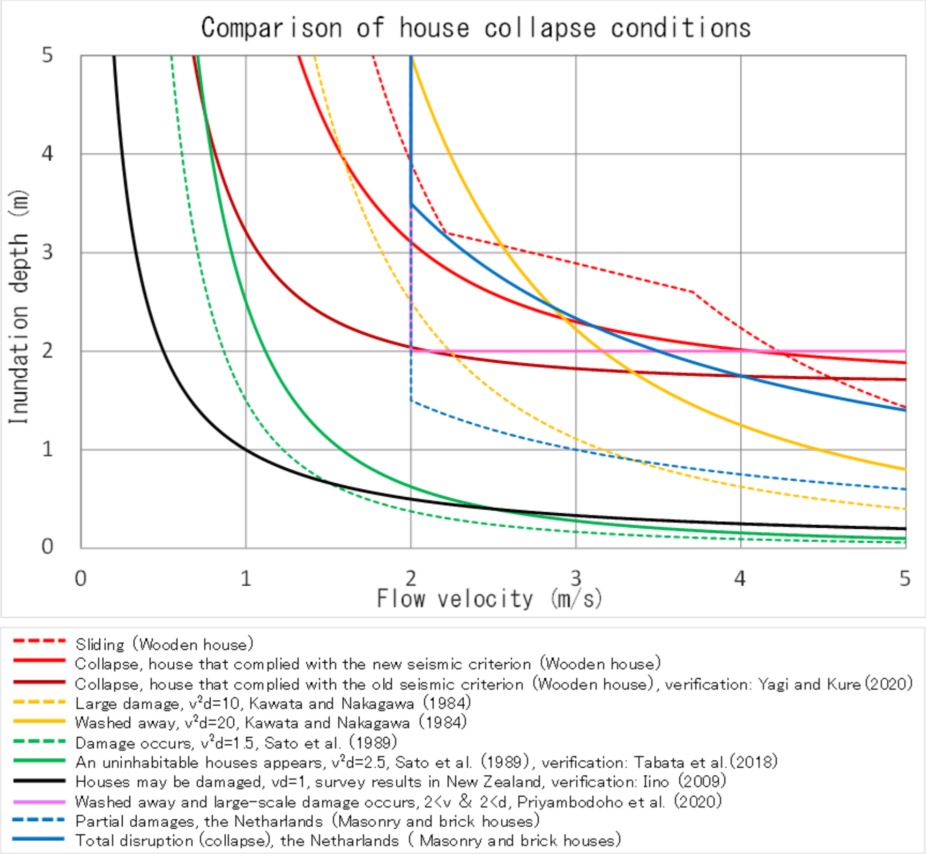
Collapse conditions in Table 33 are compared in Figure 27. It is quite clear that Dutch masonry and brick houses（total disruption）and Japanese wooden houses（houses that complied with the new seismic criterion*, collapse）are similar [19]. This is because houses that complied with the new seismic criterion has the similar ultimate shear strength（It collapses when fluid force equals to ultimate shear strength.） as Dutch masonry and brick houses.

Aging of Japanese wooden house is, however, not taken into account, this can be, therefore, considered that new or comparable structure is assumed. This could be applicable if loss of life is estimated targeting new residential area, but it could underestimate damage in the area with many old houses. Collapse conditions of houses that complied with the old seismic criterion [19] are verified by Yagi and Kure [20] with the case of flood in recent years, targeting damaged houses due to dike failure at Chikuma river in the event of Typhoon No.19 in October, 2019. It is, however, possible to underestimate damage because aging is not taken into consideration just like the above mentioned houses that complied with the new seismic criterion.

Concerning a study of a border of "uninhabitable houses" by Sato et al. [22], it is verified by Tabata et al. [23] targeting damaged houses due to dike failure at Kinugawa river in the event of Heavy Rainfall Disaster in Kanto-Tohoku Regions, September 2015. What Sato et al. named a border of "uninhabitable houses" is described by Tabata et al., "risk of house washed away," which suggests a possibility to determine conditions of house washed away and collapse in Japan. Concerning a border of "houses may be damaged" based on houses survey results in New Zealand [24], its applicability is verified by Iino [25], targeting 4 rivers in Japan (wooden houses, over 20 years old). A border of "houses may be damaged" derived from practice in New Zealand might overestimate house collapse as Figure 27 indicates, because damage status of house is not clear enough.

Japanese seismic criterion;
In Japan, seismic criterion for houses are set so that they can withstand a certain amount of external force in the event of an earthquake. The Building Standards Law has revised the seismic criterion by verifying the damaged houses after the occurrence of a large earthquake in the past. The Building Standards Law was enacted in 1950, and the seismic criterion was revised in 1971, 1981, and 2000. The current seismic criterion was mainly revised in 1981 and is generally called the "new seismic criterion". On the other hand, before 1981, it was called the "old seismic criterion".

Figure 27 Comparison of house collapse conditions derived from past studies



6.5.3 Proposal for the Future

In comparison of collapse conditions in past studies, the results shown in Table 27 were obtained. It is considered that the most suitable condition is currently a border of “uninhabitable house” $v^2d=2.5$ studied by Sato et al. [22], because there are descriptions of “house washed away” and “collapse” and it is verified by flood damage in recent years.

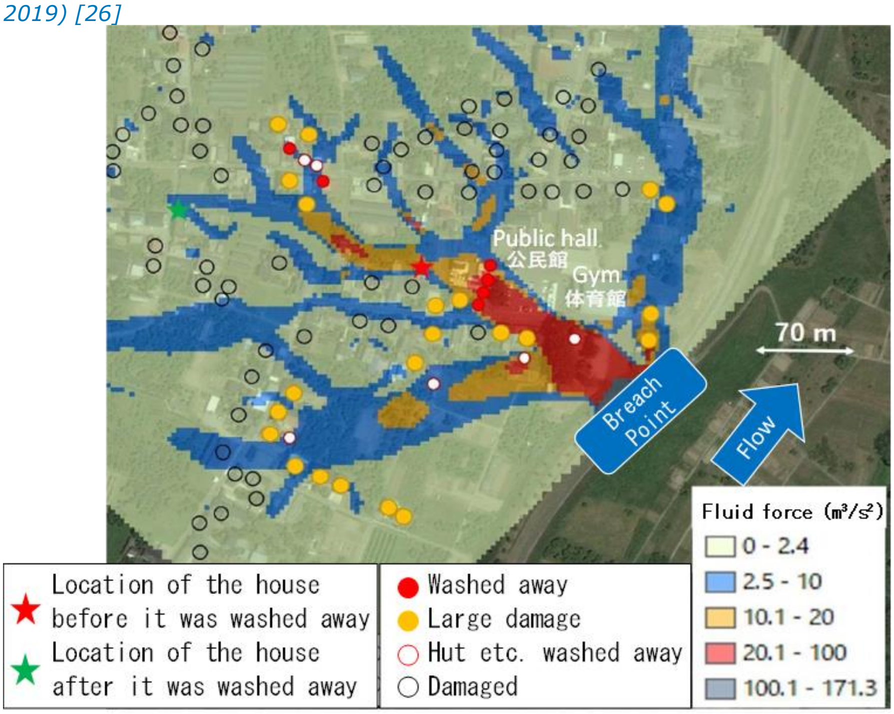
Table 27 Collapse conditions of Japanese houses and consideration

No.	**Target house structure**	**Collapse condition**	**Evaluation of aging deterioration**	**Target phenomenon**	**Verification in recent floods**	**Remarks**
1	Two storied wooden house (Sliding)	$0 \le d < 2.6,\ v = \sqrt{\frac{35.76}{d}}$ $2.6 \le d < 3.2,\ v = \sqrt{\frac{122.95-33.53h}{d}}$ $3.2 \le d,\ v = \sqrt{\frac{15.65}{d}}$	Only for new construction	Sliding	×	
2	Two storied wooden house (new seismic criterion since 1981)	$1.65 < d,\ v = \sqrt{\frac{5.83}{(d-1.650)}}$	Only for new construction	Collapse	×	
3	Two storied wooden house (old seismic criterion since 1950)	$1.65 < d,\ v = \sqrt{\frac{1.56}{(d-1.650)}}$	Only for new construction	Collapse	○	
4	One-story wooden houses	Large damage: $v^2d = 10$ Washed away: $v^2d = 20$	Partially (Including other than new construction)	Washed away	×	

5	Most suitable Unknown	Damage occurs: $v^2d = 1.5$ An uninhabitable house appears: $v^2d = 2.5$	Partially (Including other than new construction)	Washed away	○	
6	Wooden houses	Houses may be damaged（based on houses survey results in New Zealand） $vd = 1$	Partially (Including other than new construction)	Damaged	○	The target phenomenon (assumed damage to the house) is unclear.
7	Unknown	Houses are washed away and large-scale damage occurs $2 < v$ and $2 < d$	Partially (Including other than new construction)	Washed away and large-scale damage	○	Collapse conditions derived from the results of Typhoon No. 19 in 2019

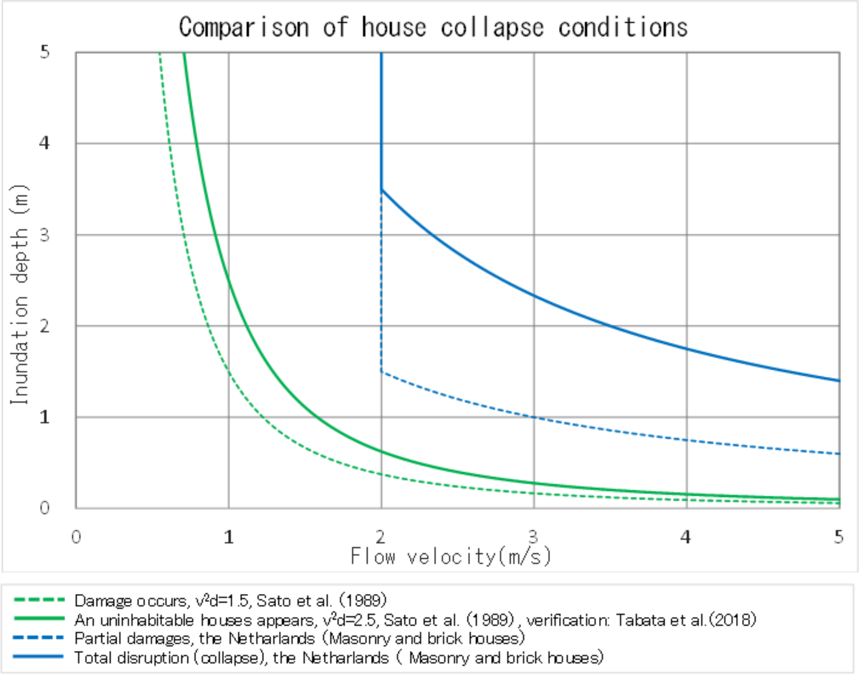
In addition, the collapse conditions of Sato et al. (An uninhabitable house appears: v2d = 2.5) have already been verified for the damaged houses due to dike failure at Kinugawa river in the event of Heavy Rainfall Disaster in Kanto-Tohoku Regions, September 2015, but they are detailed. It was compared with the reported fluid force (based on flood simulation) and damage situation [26] due to dike failure at Chikuma river during the heavy rain of Typhoon No. 19 in 2019. As shown in Figure 7.7, it can be seen that the blue range where the fluid force v2d is 2.5 or more and the location where the house was washed away shown in the red plot are almost the same. Based on this, it is considered that the collapse conditions of Sato et al. (An uninhabitable house appears: v2h = 2.5) are generally appropriate from the two recent floods.

Figure 28 Maximum fluid force and damaged houses in Nagano city, Nagano prefecture (Typhoon No. 19 in 2019) [26]



If collapse condition by Sato et al. is supposed to be a representative collapse condition of Japan and compared to Dutch collapse criteria of masonry and brick houses, it is obvious that there is a significant difference due to structure. Further research and verifications are required in the future.

Figure 29 Comparison of collapse conditions of Japanese and Dutch houses



As a result of this project, a new loss of life estimation model is proposed for future study as follows.

【The breach zone】

$v^2 \cdot d \geq 2.5m^3/s^2$

$$F_{D,B} = 1$$

【The zone with rapidly rising water】

$v^2 \cdot d < 2.5m^3/s^2$ and ($d \geq 2.1m$ or $w \geq 4m/hr$)

$$F_{D,Rise}\,(d) = \Phi_N\left(\frac{\ln(d)-\mu N}{\sigma N}\right) \qquad \mu_N=1.46,\ \ \sigma_N=0.28$$

【The transition zone】

$v^2 \cdot d < 2.5m^3/s^2$ and ($d \geq 2.1m$ and $0.5m/hr \leq w < 4m/hr$)

$$F_D = F_{D,Remain} + (w-0.5)\frac{F_{D,Rise}-F_{D,Remain}}{3.5}$$

【The remaining zone】

($w < 0.5m/hr$ or ($w \geq 0.5m/hr$ and $d < 2.1m$)) and ($v^2 \cdot d < 2.5m^3/s^2$)

$$F_{D,Remain}\,(d) = \Phi_N\left(\frac{\ln(d)-\mu N}{\sigma N}\right) \qquad \mu_N=7.60,\ \ \sigma_N=2.75$$

where, d: flood depth(m), v: flow velocity(m/s), w: rise rate of water(m/h), F: mortality, Φ: cumulative probability density function of standard normal distribution, μ: average value of h, σ: standard deviation of h.

6.5.4 Future activities

The following study is required as activities in the future. In order to verify reproducibility, it is necessary to grasp applicability to Japan by study on damage cases and large/full scale model experiment of, for example, Heavy Rain Disaster in July, 2018 (Mabi-cho, Kurashiki city, Okayama prefecture), Typhoon No.19 (Nagano city, Nagano prefecture), and Heavy Rain Disaster in July, 2020 (Kuma village, Kumamoto Prefecture).

【The breach zone】

- Verification of reproducibility in recent multiple floods. Verification of applicability to Japan.
- Elucidation of the house collapse mechanism from a mechanical point of view based on past studies.
- Understanding the relationship between collapsed houses and age. Consideration of age for house collapse conditions.
- Introduction of house damage function based on actual damage in recent years.
- Construction of a mortality function derived from past floods.

【The zone with rapidly rising water】 【The remaining zone】

- Understanding and organizing the mechanism of death occurrence in each zone.
- Setting of boundary conditions and Construction of mortality function for each zone based on past floods.
- Consideration of water rise rate observed or calculated by flood simulation.
- Consideration of victim age.
- Consideration of differences in height of house and person between the two countries.

How to consider age of houses

This project provides a comparison of houses that complied with the old seismic criterion（wooden）and collapse condition determined by Sato et al. in order to understand aging of houses. If the target of collapse condition determined by Sato et al. is wooden house, both conditions are wooden houses. The study of Sato et al. targets Yoshida River Basin in the event of Flood in August, 1986. It is highly possible that these houses are those that complied with the old seismic criterion (1950) or those built before implementing seismic criterion, since majority of these houses are older than 10 years old, according to the relationship between maximum fluid force and aging (Figure 30). On the assumption that it complies with old seismic criterion, collapse condition of newly built houses that complied with the old seismic criterion can be comparable to rather aged collapse condition of Sato et al.. The difference (Figure 31) can be assumed to be the change of yield strength due to aging.

Figure 30 Relationship between Max. fluid force and age of houses (Edited based on references22）)

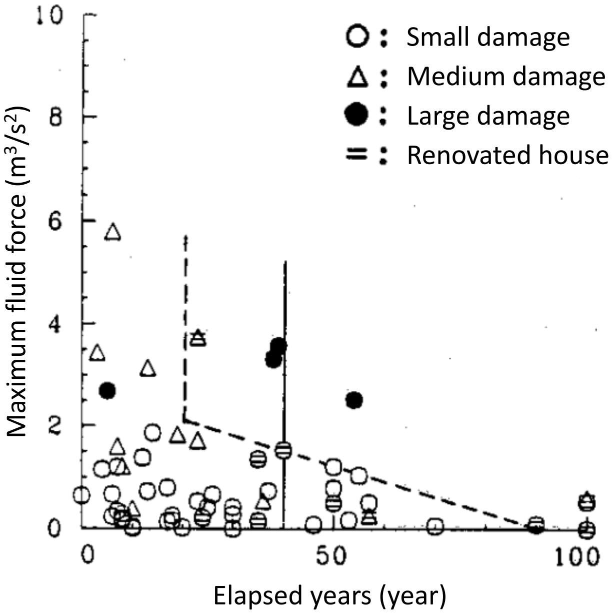
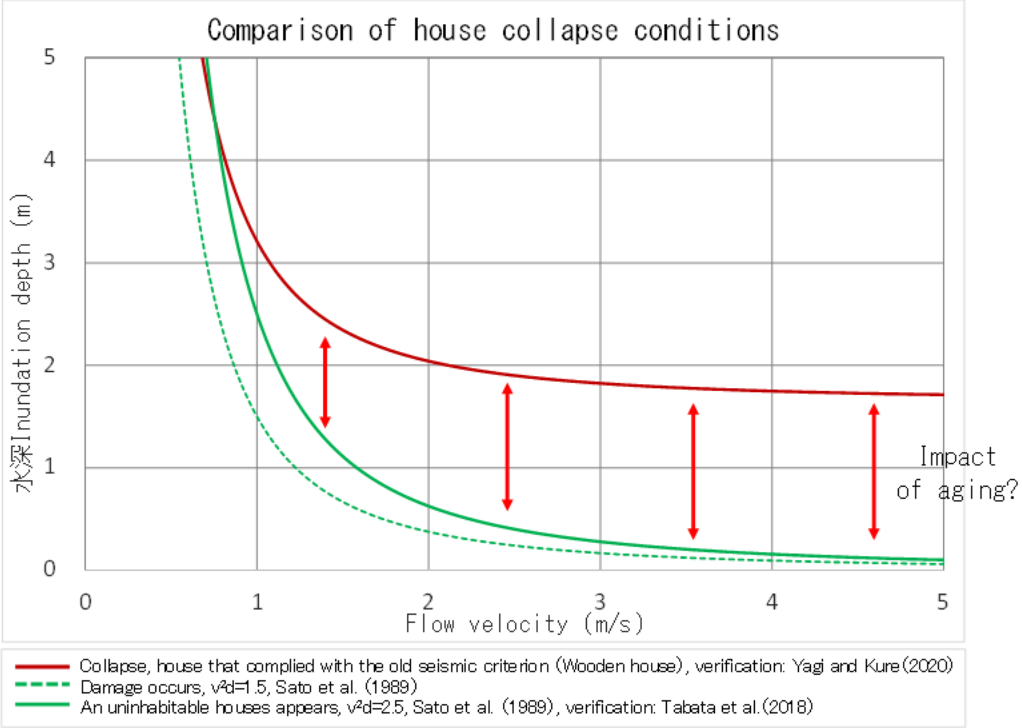


Figure 31 Comparison of wooden houses that complies with the old seismic criterion



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e8%b1%aa%e9%9b%a8%e7%81%bd%e5%ae%b3%e8%aa%bf%e6%9f%bb%e5%a0%b1%e5%91%8a%e6%9b%b8%ef%bc%88%e4%b8%ad%e5%9b%bd%e5%9c%b0%e5%8c%ba%ef%bc%89.pdf . (Japanese Only)

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7 Flood probabilities

In WP2 the flood probabilities are determined, which are used in the flood risk calculation. In these flood probabilities the dependence between the levee section is incorporated, the "scenario flood probability". The table below shows the difference between section and scenario flood probability. The latter is used for the flood risk assessment, as it is corrected for potential upstream flooding. The next sections give an overview of how these flood probabilities are calculated, and how the dependencies are taken into account.

Table 28 Section and scenario flood probabilities, for the average discharge statistics under future climate. The most upstream sections are highlighted as they are unaffected by upstream flooding and therefore have the same failure probability

Location	Section flood probability	Scenario flood probability (Future)
Satsunai_KP4_2	1/16358	1/29708500
Satsunai_KP5_2	1/3063	1/363030
Satsunai_KP6_4	1/703	1/1530
Satsunai_KP7_0	1/1130	1/1130
Tokachi_KP56_4	1/13	1/60
Tokachi_KP58_0	1/73	1/3900
Tokachi_KP59_6	1/65	1/480
Tokachi_KP61_4	1/105	1/174820
Tokachi_KP62_4	1/180	1/180

7.1 Overview of steps leading to failure probability per section

The method for calculating the flood probability is extensively described in the report WP2. In this section, a short overview of the steps is given to provide context for the flood probabilities used in the flood risk calculation.

- In WP1, the exceedance probabilities of the discharges for Satsunai and Tokachi river are determined. This information is combined with rating curves, to determine the exceedance probabilities of water level for all considered breach locations.

- Fragility curves give a relation between a water level and a failure probability, conditional to that water level. It is therefore a measure of the strength of the dike. In WP2 these curves are calculated for the failure mechanism overtopping. We take into account:
    - The duration of overtopping, which affects the failure probability.
    - The uncertainty in the revetment quality, revetment height, and the water levels. With a Monte Carlo simulation these uncertainties are incorporated in the fragility curve.

  Integrating these fragility curves with the water level exceedance probabilities gives a failure probability per dike segment. Calculating these is the main goal of WP2.

- A lot of dike segments will cause similar flooding when breached. These *segments* with similar consequences are grouped into dike *sections*, for which a failure probability is determined. We assume that the different dike segments belonging to a section are dependent, so the segment with the highest failure probability is normative for the dike section.

- Nine dike sections are considered in this study, five along Tokachi river and four along Satsunai river. If an upstream sections fails, water will flow from the river, into the area, reducing the downstream water levels. We assume that the reduction of the water levels is of such a magnitude that downstream sections will no longer fail during that event. This dependency of the failure probability to upstream sections is the last step from section failure probability to scenario failure probability. The next section will explain this further.

7.2 From section probability to scenario probability

Last section briefly explained how the failure probability per dike section is calculated. The failure probability of downstream section is however lower than the section failure probability itself, as upstream breaches will prevent downstream failures. We call this updated failure probability the *scenario failure probability*, or $P_{f,scenario}$. This probability is used to avoid overestimating the consequences of a flood.

To calculate this failure probability, some assumptions are made on the dependence between flood characteristics. We assume:

- The discharge per river branch (Satsunai and Tokachi) are dependent. This means that during an event, the same peak discharge occurs at every dike along a river branch. Note that Tokachi river has some confluences along Obihiro. We assume that the discharge on these tributaries is also dependent on the main branch. For example, a once per 100 year discharge will remain a once per 100 year discharge downstream of the confluences (which means the discharge increases).
- The segment failure probabilities are dependent, as explained in the section 7.1.
- Failure probabilities of sections (conditional to the discharge) are considered independent, but we consider the order of the sections. When an upstream section has failed, we assume the water level to be reduced such that the downstream dikes cannot fail anymore during this event.

Let $P_{f,section}$ be the section failure probability, and $|q$ conditional to discharge q. The scenario failure probability of section n during in event, is calculated in upstream to downstream order (1, 2, 3, …, n):

$$P_{f,scenario,1}|q = P_{f,section,1}|q$$
$$P_{f,scenario,2}|q = P_{f,section,2}|q \cdot [1 - (P_{f,scenario,1}|q)]$$
$$P_{f,scenario,3}|q = P_{f,section,3}|q \cdot [1 - (P_{f,scenario,1}|q + P_{f,scenario,2}|q)]$$
$$P_{f,scenario,n}|q = P_{f,section,n}|q \cdot [1 - sum_i^{n-1}(P_{f,scenario,n}|q)]$$

$P_{f,scenario,n}|q$ is the *scenario* failure probability, which is corrected for potential upstream failures. This number is used to calculate the flood risk, by multiplying it with the consequences of a flood scenario.

For the most upstream section, the scenario and independent failure probability are equal, as no flooding further upstream is considered. For the second section, the failure probability is reduced, since failure can only take place when the upstream section has not failed. For the third section, both upstream sections reduce the flood risk, etcetera.

7.3 Scenario probabilities

In the basic scenario for the flood probabilities are calculated with the average exceedance probability of the discharges for the “future” situation, so including climate change. These probabilities are shown in Table 29.

Table 29 Scenario flood probability, Future average

Location	Scenario flood probability (Future average)
Satsunai_KP4_2	1/29708500
Satsunai_KP5_2	1/363030
Satsunai_KP6_4	1/1530
Satsunai_KP7_0	1/1130
Tokachi_KP56_4	1/60
Tokachi_KP58_0	1/3900
Tokachi_KP59_6	1/480
Tokachi_KP61_4	1/174820
Tokachi_KP62_4	1/180

The impact of climate change can be analysed by comparison the “future” situation with the “past” situation. In Table 30 the flood probabilities for the “past” situation are shown. The flood probabilities are smaller than the “future” situation.

Table 30 Scenario flood probability, Past average

Location	Scenario flood probability (past average)
Satsunai_KP4_2	1/1533756680
Satsunai_KP5_2	1/6906020
Satsunai_KP6_4	1/26380
Satsunai_KP7_0	1/39570
Tokachi_KP56_4	1/90
Tokachi_KP58_0	1/22290
Tokachi_KP59_6	1/1870
Tokachi_KP61_4	1/1007420
Tokachi_KP62_4	1/7100

Another aspect that influences the flood probability is the uncertainty in the exceedance probability of the discharges. In the basic analysis the average exceedance probability is used, when the 95% upper limit of the exceedance probability is used the flood probabilities will increase. In Table 31 the flood probabilities are shown for the 95% upper limit of the exceedance probability of the discharges. Note that the 95% upper limit is the upper limit of the 95% confidence interval, which is actually the 97.5th percentile in the probability distribution.

Compared to the flood probabilities in Table 29 the probabilities are significantly larger due to the increase in exceedance probabilities of higher discharges.

Table 31 Scenario flood probability, Future 95%

Location	Scenario flood probability (Future 95%)
Satsunai_KP4_2	1/2863600
Satsunai_KP5_2	1/35000
Satsunai_KP6_4	1/160
Satsunai_KP7_0	1/70
Tokachi_KP56_4	1/50
Tokachi_KP58_0	1/1770
Tokachi_KP59_6	1/290
Tokachi_KP61_4	1/63760
Tokachi_KP62_4	1/20

8 Flood Risk

The flood risk is determined by multiplying the calculated flood probability by the flood consequences. The risks are expressed in economic risk and risk of loss of life. In this chapter the flood risks are calculated and shown for the Obihiro case study area. In the risk analysis the difference in risks between "past" and "future" are shown and also the impact of the different hydrographs shapes on the results.

8.1 Economic Risk

8.1.1 Expected value of economic damage

The expected value of the economic damage is calculated by multiplying the flood probability per scenario by the economic damage and then combing it over the flood scenarios. To determine the impact of climate change the results are shown for the "past" and "future" scenarios. In Table 32 the economic risk for the "past" scenarios is given.

The economic risk is calculated by the following formula:

$$Economic\ risk = \sum_{1}^{n} P_{f,scen,n} \cdot Damage_{scen,n}$$

$$n = breach\ locations$$

The expect value of the economic damage is approximately 3,700 million Yen/year. This economic risk is dominated by breach location KP56.4 and is caused by a relatively high probability of failure.

When climate change is taken into account, the failure probability and the amount of damage increases and therefore the economic risk increases as well, Table 33. The expect value of the economic damage increases to 20,464 million Yen/year. This is an increase by a factor 5.5, 50% of the difference is caused by the increase in failure probability and 50% by the increase in economic damage.

In the basic analyses the "Max" hydrographs are used as flood scenarios. As an sensitivity analysis the different hydrographs shapes are used to calculate the economic risk. For the "past" scenarios the impact is relatively small, max 10 percent between "Max" and "Min". This is due to the fact that there are a limited number of hydrographs in the "past" dataset that lead to overtopping and failure of the levee, so there is a limited variation in the economic damage. This is consistent with the damage calculation in section 4.4.

Table 32 Economic Risk for each breach location and the total economic risk for the "past" situation

Location	Flood probability (Pf)	Damage (million Yen)	Economic Risk (million Yen/yr)
Satsunai_KP4_2	1/1533756680	83200	0.00
Satsunai_KP5_2	1/6906020	170400	0.02
Satsunai_KP6_4	1/26380	362700	13.75
Satsunai_KP7_0	1/39570	308000	7.78
Tokachi_KP56_4	1/90	311300	3296.58
Tokachi_KP58_0	1/22290	465600	20.89
Tokachi_KP59_6	1/1870	568200	304.38
Tokachi_KP61_4	1/1007420	641300	0.64
Tokachi_KP62_4	1/7100	606800	85.51
Total			**3,729**

For the "future" scenarios the variation between the different hydrographs "Max", "Min" and "MaxVol" are larger so the impact on the economic risk will also be larger than for the "past" scenarios. As stated above the economic risk in the table below is calculated with the "Max" hydrographs. When the "Min" scenarios are used for the "future" situation the damage will decrease to approximately million 6,400 Yen/year, this is a reduction with a factor 3.

Table 33 Economic Risk for each breach location and the total economic risk for the "future" situation

Location	Flood probability (Pf)	Damage (million Yen)	Economic Risk (million Yen/yr)
Satsunai_KP4_2	1/29708500	268983	0.01
Satsunai_KP5_2	1/363030	330438	0.91
Satsunai_KP6_4	1/1530	483160	314.83
Satsunai_KP7_0	1/1130	480609	426.26
Tokachi_KP56_4	1/60	833980	13346.00
Tokachi_KP58_0	1/3900	855874	219.20
Tokachi_KP59_6	1/480	865033	1791.73
Tokachi_KP61_4	1/174820	917039	5.25
Tokachi_KP62_4	1/180	798407	4359.83
Total			**20,464**

The economic risk shown above are calculated with the average exceedance probability of the discharges. When the upper limit of exceedance probability (95%) is used for the flood probability calculation, the flood probabilities and flood risk increase. In Table 36 the economic risk is shown for that situation. The economic risk increases by a factor 3.5, to an expected value of the economic risk of 71,618 million Yen/year.

Table 34 Economic Risk for each breach location and the total economic risk for the "future" situation and 95% upper limit exceedance probability of the discharges

Location	Flood probability (Pf)	Damage (million Yen)	Economic Risk (million Yen/yr)
Satsunai_KP4_2	1/2863600	268983	0.09
Satsunai_KP5_2	1/35000	330438	9.44
Satsunai_KP6_4	1/160	483160	3029.52
Satsunai_KP7_0	1/70	480609	7082.86
Tokachi_KP56_4	1/50	833980	15709.33
Tokachi_KP58_0	1/1770	855874	484.17
Tokachi_KP59_6	1/290	865033	2993.99
Tokachi_KP61_4	1/63760	917039	14.38
Tokachi_KP62_4	1/20	798407	42294.25
Total			**71,618**

8.1.2 Spatial distribution of expected value economic damage

The expected value of the damage (section 8.1.1) is a total risk for the entire area. This expected value of economic risk can also be distributed over the area. In Figure 32 the spatial distribution of the “past” scenario is given. It shows the location with higher economic risk. The impact of climate change is shown in Figure 33. It clearly shows the increase in economic risk. This increase is a combination of the larger flood probability and the larger flood extent and flood characteristics.

Figure 32 Spatial distribution of the “past” economic risk (million Yen/yr).

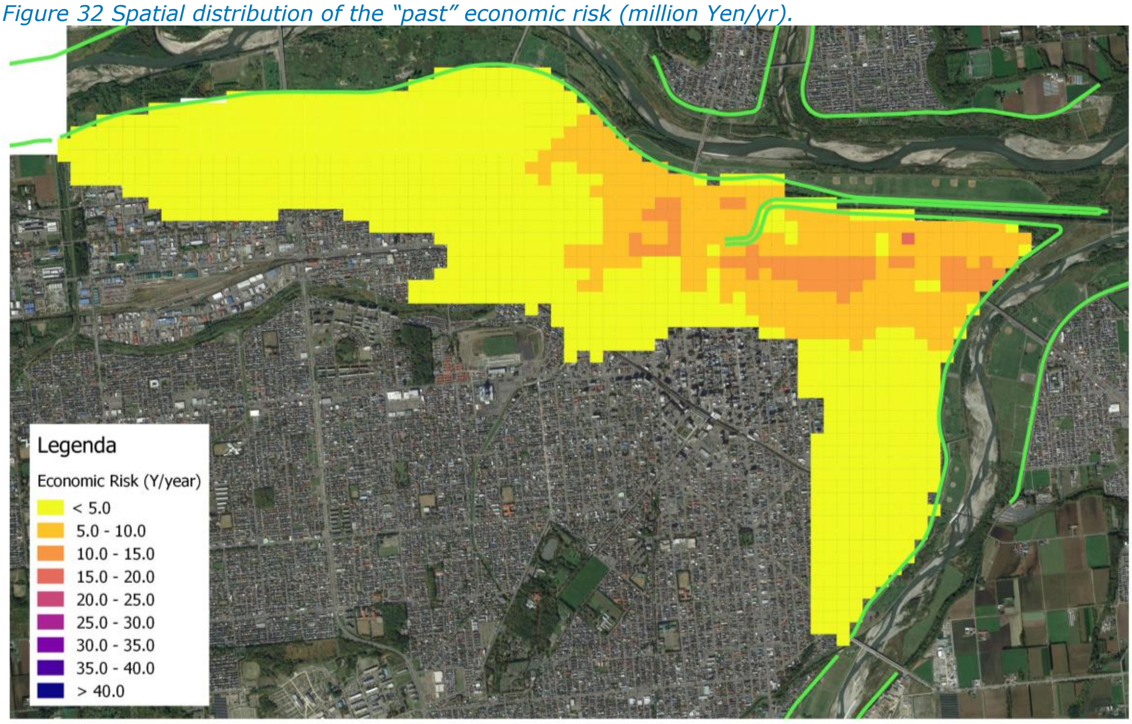


Figure 33 Spatial distribution of the “future” economic risk (million Yen/yr).

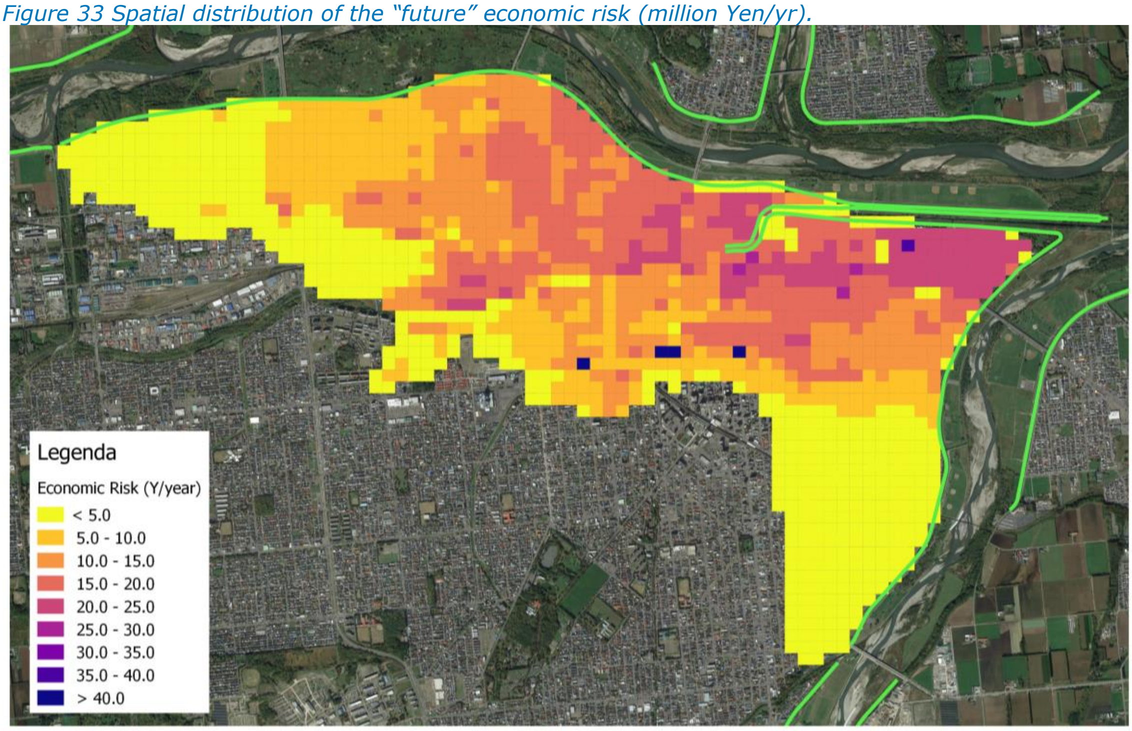


Figure 33 shows that the economic risks are highest in the areas with the largest water depths. This can be explained by the fact that that area is the lowest part and that all inundation scenarios have the largest water depth in that area. It is also interesting that some local areas in the central part of Obihiro have a higher economic risk, this can indicate that high value infrastructure is present. An example of such a location is shown in Figure 34.

Figure 34 One of the locations with higher economic risk

8.2 Risk Loss of Life

8.2.1 Expected value of Loss of Life

The expected value of loss of life gives insight in the average number of fatalities per year due to flooding. In all analysis regarding loss of life the average evacuation percentage of 26 percent is used. To determine the impact of climate change the results are shown for the “past” and “future” scenarios. In Table 35 the the expected value of loss of life for the “past” scenarios is given. The expect value is approximately 1.63 fatalities/year. This risk of loss of life is dominated by breach location KP56.4 and is caused by a relatively high probability of failure.

When climate change is taken into account, the failure probability and the loss of life increases and therefore the risk of loss of life increases as well, Table 36. The expect value of loss of life increases to 7.6 Fatalities/year. This is an increase by a factor 4.5, 50% of the difference is caused by the increase in failure probability and 50% by the increase in loss of life.

Table 35 Expected value of loss of life for each breach location and the total expected value of loss of life for the "past" situation

Location	Flood probability (Pf)	Loss of Life	LoL Risk
Satsunai_KP4_2	1/1533756680	13	0.00
Satsunai_KP5_2	1/6906020	17	0.00
Satsunai_KP6_4	1/26380	42	0.00
Satsunai_KP7_0	1/39570	21	0.00
Tokachi_KP56_4	1/90	139	1.47
Tokachi_KP58_0	1/22290	121	0.01
Tokachi_KP59_6	1/1870	253	0.14
Tokachi_KP61_4	1/1007420	251	0.00
Tokachi_KP62_4	1/7100	133	0.02
Total			**1.63**

Table 36 Expected value of loss of life for each breach location and the total expected value of loss of life for the "future" situation

Location	Flood probability (Pf)	Loss of Life	LoL Risk
Satsunai_KP4_2	1/29708500	30	~0
Satsunai_KP5_2	1/363030	43	~0
Satsunai_KP6_4	1/1530	74	0.05
Satsunai_KP7_0	1/1130	50	0.04
Tokachi_KP56_4	1/60	272	4.35
Tokachi_KP58_0	1/3900	422	0.11
Tokachi_KP59_6	1/480	655	1.36
Tokachi_KP61_4	1/174820	622	0.00
Tokachi_KP62_4	1/180	308	1.68
Total			**7.60**

The risk of loss of life shown above are calculated with the average exceedance probability of the discharges. When the upper limit of exceedance probability (95%) is used for the flood probability calculation, the flood probabilities and flood risk increase. In Table 37 the risk of loss of life is shown for that situation. The risk increases by a factor 3.5, to an expected value of the economic risk of 25.16 fatalities/year.

Table 37 Expected value of loss of life for each breach location and the total expected value of loss of life for the "future" situation and 95% upper limit exceedance probability of the discharges

Location	Flood probability (Pf)	Loss of Life	LoL Risk
Satsunai_KP4_2	1/2863600	30	0.00
Satsunai_KP5_2	1/35000	43	0.00
Satsunai_KP6_4	1/160	74	0.46
Satsunai_KP7_0	1/70	50	0.74
Tokachi_KP56_4	1/50	272	5.12
Tokachi_KP58_0	1/1770	422	0.24
Tokachi_KP59_6	1/290	655	2.27
Tokachi_KP61_4	1/63760	622	0.01
Tokachi_KP62_4	1/20	308	16.32
Total			**25.16**

8.2.2 Local Individual Risk

The local individual risk gives insight in the annual probability that an individual will die at a particular location, including the effect of evacuation. The local individual risk is a combination of the scenario flood probabilities, the mortality and the evacuation percentage. For the evacuation percentage the average value of 26 percent is used.

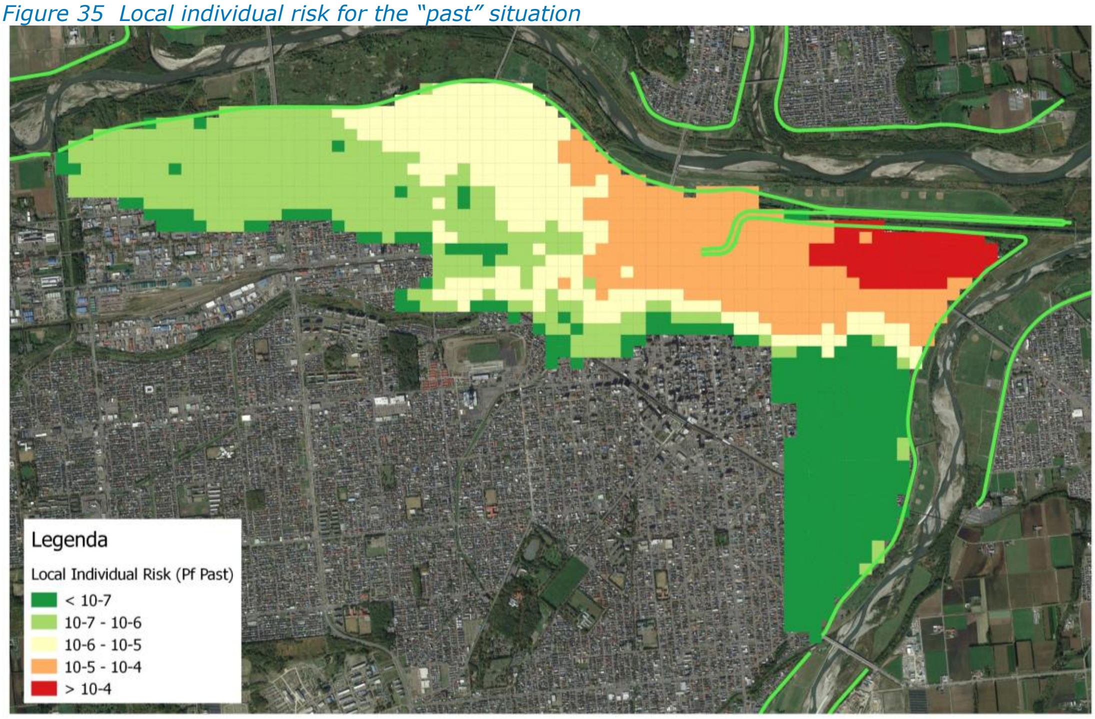
The local individual risk is calculated by the following formula:

$$Local\ individual\ risk = \sum_{1}^{n} P_{f,scen,n} \cdot Mort_{scen,n} \cdot (1 - evac.percentage)$$

$$n = breach\ locations$$

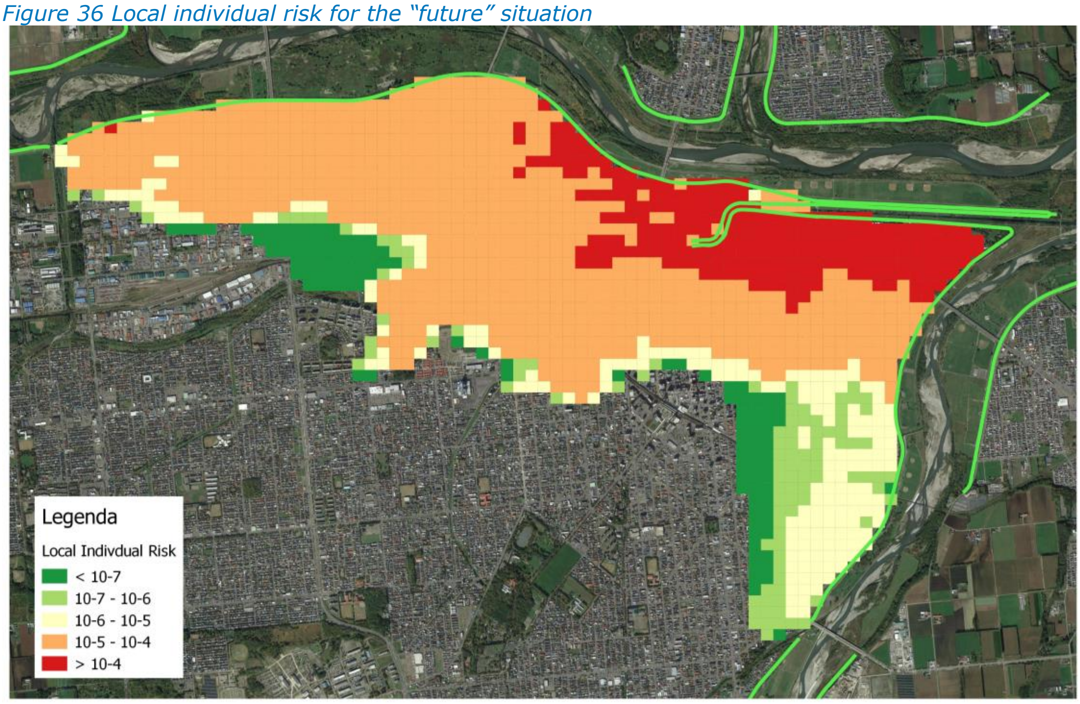
The figure below shows the local individual risk for the "past" situation. The riskier places are situated in the deeper parts of the case study area and are consistent with economic risks.

Figure 35 Local individual risk for the "past" situation



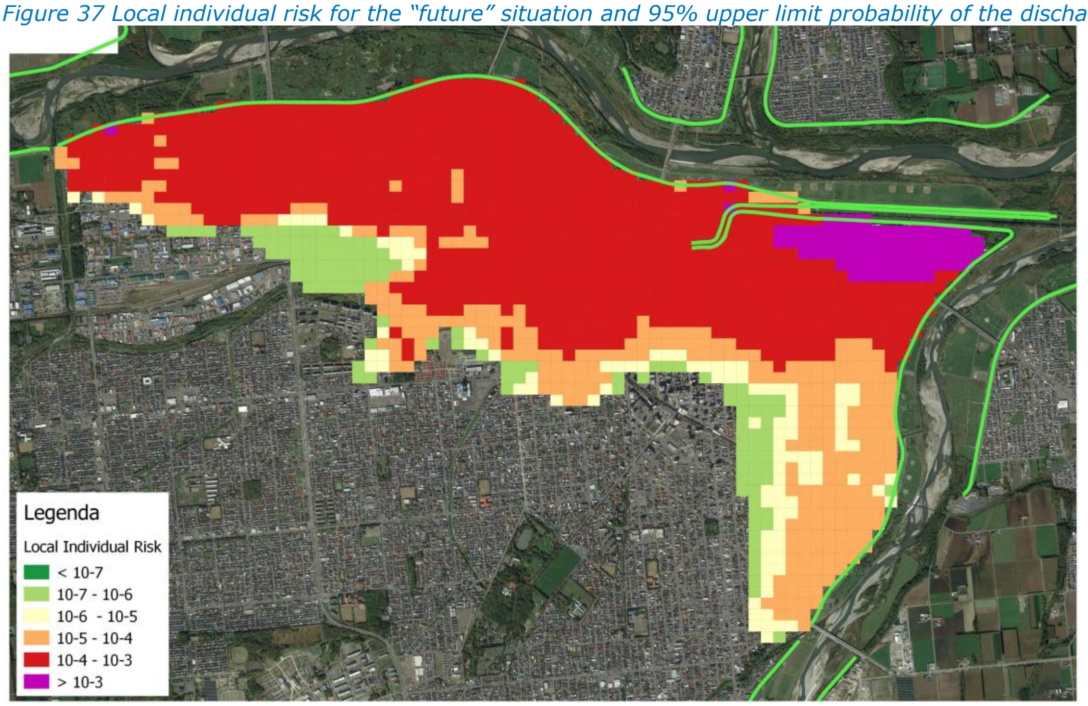
When climate change is included the scenario flood probabilities increase and also the flood extent and flood characteristics increases. The increase in flood extent and flood characteristics lead to an increase in mortality. Figure 36 shows the local individual risk for the "future" situation. The flood extent is larger than the "past" situation and also the risks are higher.

Figure 36 Local individual risk for the "future" situation



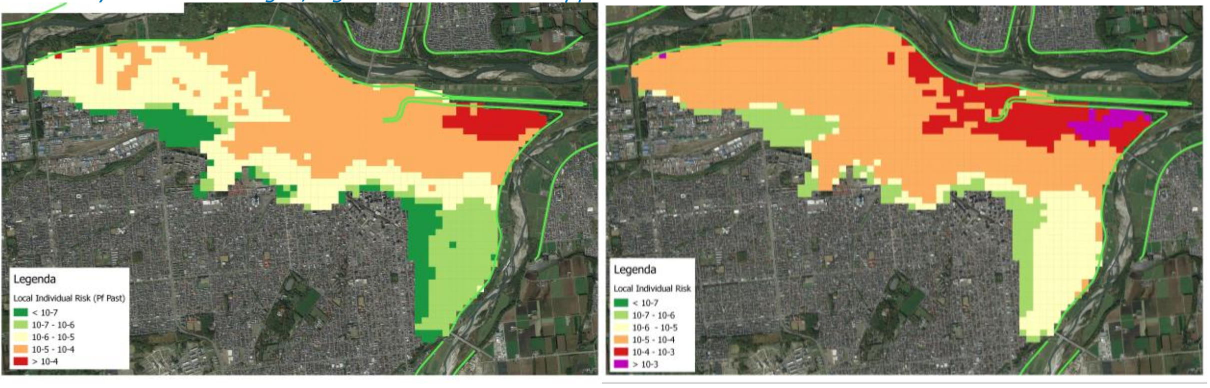
The local individual risk shown above is determined with the average exceedance probability of the discharges. When the upper limit of exceedance probability (95%) is used for the flood probability calculation, the flood probabilities and flood risk increase. In Figure 37 the local individual risk is shown for that situation. It leads to a significant increase in local individual risk, in some parts the local individual risk exceeds 1/1,000 per year.

Figure 37 Local individual risk for the "future" situation and 95% upper limit probability of the discharges



The local individual risk is in the basic analysis calculated with the average evacuation percentage of 26%. When this percentage increases the local individual risk will decrease. In Figure 38 the local individual risk is shown for the situation with an 80 percent evacuation. The decrease in risk is equal to the increase in evacuation percentage, from 26% to 80%, a factor 3.

Figure 38 Local individual risk for the "future" situation, 80 percent evacuation, left is the average exceedance probability of the discharges, right is with the 95% upper limit.



8.3 Uncertainties in Flood Risk

Uncertainties are inextricably linked to determining flood risk. In every step in determining the flood risk choices must be made on how to deal with uncertainties. The uncertainties in determining the flood risk are therefore a direct translation of the uncertainties of all steps in determining the flood risks.

Throughout the whole process of determining the flood risk the largest uncertainties are in determining the flood probability and in particular in the exceedance frequencies of the hydraulic loads.

9 Reflection, conclusions and recommendations

The results show that the flood consequences, economic damage and loss of life, and therefore also the flood risk are subject to uncertainties.

For the economic damage we have seen that the different type of discharge waves can have a large impact on the calculated damage. The flood extent differs between the different discharge waves. Especially when high value assets flood in one scenario and not in another scenario, this can lead to significant differences in the calculated damage. It is therefore important to conduct a proper analysis on the damage calculation and how the economic damage may be affected by local high value assets.

The average evacuation rate in the Obihiro case study is set at 26 percent. This is a relatively low percentage and is mainly caused by the short lead times. Due to the extreme rainfall the river discharges increase quite fast, potentially resulting in flash floods.

The current evacuation method uses only two destinations, people are either at a safe shelter location or people are at risk at home. In reality people are at different locations with differences in vulnerability. People outside the threatened area are not vulnerable, people at shelters in the threatened area are still vulnerable but less vulnerable than people staying at home.

- An improvement of the evacuation modelling will lead to better insight into the location where people will evacuate to, given a flood threat. A first draft of the improved evacuation method has already been described in the report of WP3.

- The improved method shows where people will, most likely, go to when an evacuation order is issued. Given the location where people are the vulnerabilities are different and the loss of life modelling has to be adjusted to these differences. Therefore also the loss of life modelling has to be improved to translate the evacuation strategies to the impact on the loss of life.

- Next to improvements of the loss of life modelling through considering the different locations where people evacuate to, the model can also be improved by incorporating the Japanese type of constructions. The current Dutch method is based on the Dutch type of constructions (concrete), the Japanese building construction consists mostly of wood, which can impact the possibility of building collapse, leading to a higher probability of casualties. This is also an aspect that can be improved in the model, to make them more suitable for the Japanese situation.

The flood risks are the product of the flood probabilities and the flood consequences. The results shows that the economic risk is highest in the locations with the larger water depths, but also high value assets have a large impact on the economic damage. It is wise to further analyse the locations in their vulnerability to flooding.

The impact of climate change is large, on the one hand the flood extent and flood characteristics increase. On the other hand the flood probability increases leading to a significant increase in economic risk.

The risk of loss of life is expressed by the expected value of loss of life and the local individual risk. The expected number of loss of life is dominated by the breach location with the highest flood probability. The scenarios with in potential larger number of fatalities are less important for the risk of loss of life due to a relatively low flood probability. In accordance with the economic risk, the impact of climate change is large.

The local individual risk gives insight in the annual probability that an individual will die at a particular location, including the effect of evacuation. For the Obihiro case study area the risks are in the deeper parts of the area larger than 1/10,000 per year and at some locations even larger than 1/1,000 per year. This is mostly due to a relatively large failure probability of some of the breach locations. In comparison, in the Dutch flood risk policy the probability of fatality due to flooding must not exceed 1 in 100,000 per year (or 0.001%) for every resident living behind the levees. This is the so-called tolerable individual risk.

9.1 Economic damage

In the case study the economic damage is determined with the Japanese method. The method is based on the value of different assets and the inundation depth, based on the inundation depth the damage rate is determined which is multiplied with the value of the asset. This approach is quite similar to the Dutch method of determining the economic damage.

The potential economic damage has a large variation between the different breach locations. The difference in economic damage can go up to a factor 8. The difference of the potential damage within one breach location due to differences in discharge waves is in the order of a factor 1.5 to 3.5.

Climate change has also an impact on the potential economic damage, due to the increase in discharges the flood probability, flood extent and flood characteristics increase as well. The impact on the potential damage varies between breach locations but is in the order of a factor 1.5 to 3.

9.2 Evacuation and loss of life

Given the data from 86 cases in Japan the average evacuation rate is set at 26 percent, with a bandwidth of 0 percent in case of no lead time up to 44 percent in case of “long” lead time (more than 3 hours).

Loss of life is determined with the Dutch mortality functions in combination with the evacuation rate. The mortality functions uses the flood characteristics (water depth, rise rate and flow velocity) to determine the mortality at all locations. The case study shows that, in accordance with the economic damage, that there is a large variation in potential loss of life between different breach locations. In several scenarios the number of casualties is in the hundreds, even when the expected value of the evacuation rate is taken into account. The difference in loss of life between the different breach locations can go up to a factor 20.

The difference in the loss of life within one breach location due to differences in discharge waves is also relatively large and is in the order of a factor 2.5 to 20. The factor 20 is caused by the fact that there is a large difference between the discharge waves.

Climate change also has an impact on the potential loss of life, due to the increase in discharges the flood probability, flood extent and flood characteristics increase as well. The impact on the potential loss of life varies between breach locations but is in the order of a factor 2 to 3.5.

So for the determination of loss of life the shape and height of discharge wave has a significant impact on the loss of life.

9.3 Flood risk

9.3.1 Economic Risk

The economic risk is calculated for the current situation ("past") and for the situation including climate change ("future"). The impact of climate change to the economic risk is approximately a factor 5.5, for which 50% of the difference is caused by the increase in failure probability and 50% by the increase in economic damage.

The basic economic risk calculation is done with the use of the flood probability which is determined with the average exceedance probability of the discharges. When the upper limit of the exceedance probability of the 95 percent confidence interval is used, the flood probability increases. This larger flood probability increases the economic risk by a factor 3.5.

When looked at the spatial distribution of the economic risk, in general the larger risks are in the deeper parts of the case study area. What stands out is that at some locations apparently high value assets are present because at these locations the economic risk is relatively high.

Therefore a further analysis of these high value assets and their vulnerability to floods is recommended.

9.3.2 Risk loss of life

In accordance with the economic risk the risk of loss of life is determined for the current situation ("past") and for the situation including climate change ("future"). The impact of climate change to the risk of loss of life is approximately a factor 4.5, for which 50% of the difference is caused by the increase in failure probability and 50% by the increase in economic damage.

When the 95 percent upper limit of the exceedance probability is used, the flood probability increases. This larger flood probability increases the risk of loss of life by a factor 3.5.

The local individual risk gives insight in the annual probability that an individual will die at a particular location, including the effect of evacuation. The Obihiro case study shows that the risks are in the deeper parts of the area larger than 1/10,000 per year and at some locations even larger than 1/1,000 per year. This is mostly due to a relatively large failure probability of some of the breach locations.

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