# Flood Risk and Climate Change Hokkaido

Joined project of Japan and the Netherlands

Client

RVO, Partners for Water

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## Joined project of Japan and the Netherlands

Final report


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# Preface

I would like to congratulate all the experts from the participating Japanese and Dutch universities, research institutes and companies with the performed flood risk analysis for Obihiro City within the Tokachi river catchment. All the work that has been done and despite of the covid-19 restrictions. When I returned home from our visit to Hokkaido in November 2018 (on which I still look back with nice memories), I would not have thought that the further cooperation would be so successful!

A new risk-based approach has been developed by integrating Japanese climate projection models and Dutch flood risk approach. Japanese and Dutch experts worked closely together on the different topics, like (i) extreme rain fall and river discharge, (ii) levee failure probabilities and (iii), flood consequences (damage, life loss) and flood risk. Not only discussing results and methods but also applying these methods together and really trying to understand the details to generate the results. By working in this way a mutual understanding and trust is created to have a good foundation for the added value of the project results.

For the Netherlands it has been very valuable that our flood risk approach has been 'reviewed' by Japanese high level experts. In depths discussions resulted in useful suggestions for further improvement. We can learn from Japanese methods and models, like we can learn from the Japanese enormous experience on emergency response and flood fighting as well.

Proposals already have been made for further cooperation next years. Rijkswaterstaat looks forward to participate in a new research project, for example on how to deal with extreme weather within a changing climate and flash floods in particular. This summer we experienced a very unusual flooding along the tributaries of the Meuse river in Limburg, as a result of exceptional precipitation over a very large region in Belgium, Germany and the Netherlands. This resulted in catastrophic flash floods in Germany and Belgium with many casualties. Since Limburg is less mountainous, we only experienced a lot of damage fortunately. But we were not well prepared for such a (limited) flash flood. And the current version of the precipitation generator in our GRADE instrument could not reproduce the observed peak flows on the Meuse river.

I believe that the Netherlands can learn much from experiences in Japan especially on flash floods and I hope we can work further together on flood protection within a changing climate. I look forward to participate with our Japanese partners in a new research project.

Finally I would like to thank the Netherlands Enterprise Agency for funding this 'Partners for Water' cooperation.

Durk Riedstra
Senior Advisor Flood Risk Management
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# 1 Introduction

## 1.1 Climate change is already happening

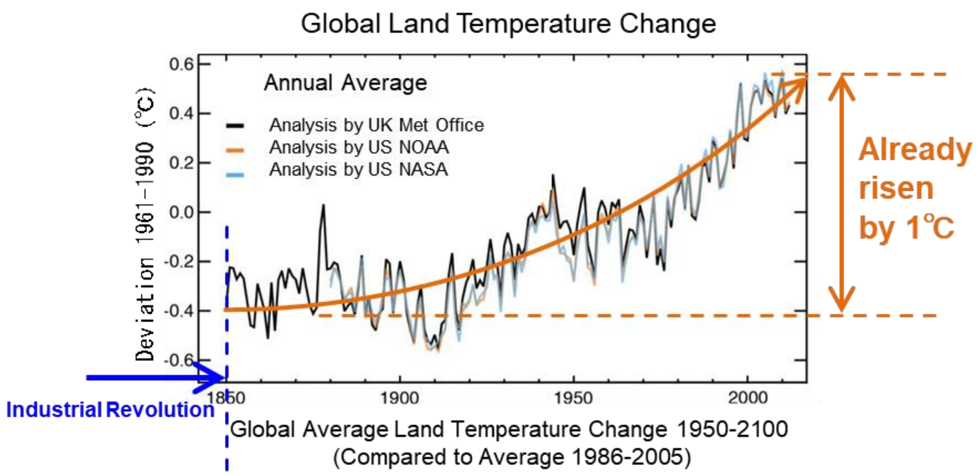
The history between the Dutch and Japanese water sector goes a long way back. In previous century, the Dutch approaches for water management and flood prevention have been adopted by Japanese water sector. Johannes de Rijke is world famous in Japan because of his work since 1890. Since then, both countries went their own way and developed and fine-tuned their methods to their own situation. Until recently when Hokkaido was hit by several typhoons, causing major floods and damage to people and the agricultural sector. This was reason for Japan to reinvest in the relation and knowledge exchange with Netherlands water experts from Rijkswaterstaat, HKV, Deltares and Delft University.

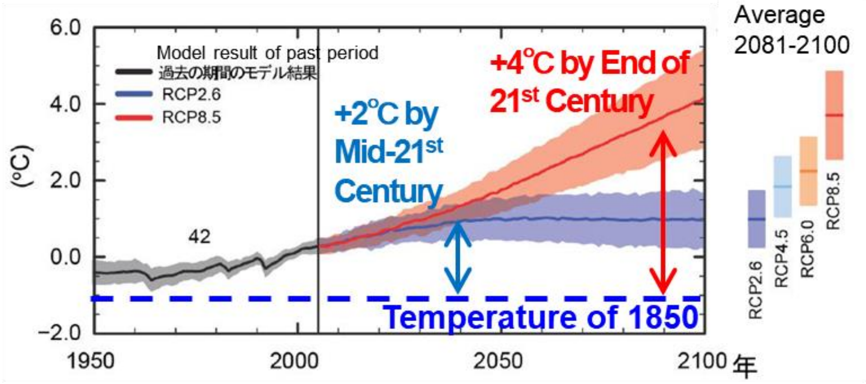
The consequences of climate change are already happening in the world, and as the predictions of the IPCC show the consequences of climate change will increase. This results in an increase in flood risk, but the flood risk can also be mitigated by prevention and flood control measures, smart urban planning or disaster management. In this chapter we give some example of the consequences of climate change in Japan and The Netherlands with regard to flooding.

### 1.1.1 Global, Japan and Asia

According to the 5th Assessment Report by IPCC, there is no doubt of global warming and the world average temperature has already risen by 0.85 degree, compared to 1850 before Industrial Revolution. It is certain that the main cause of this is human activity, associated with increase of greenhouse gas density, such as $CO_2$. It is forecasted that the temperature will rise further. Impact of global warming could extend not only to temperature rise, but to increase of frequency and intensity of extreme events, such as see level rise and heavy rain. It is highly expected by the end of this century to see extreme rainfall more intense and more frequent in most of mid-latitude land area and humid tropical area.

*Figure 1 Climate change*






(Made by Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, based on WG1 Report of IPCC's 5th Assessment Report)

The observed data of the last decades indicates that temporal and intense rainfall will increase in Japan, the target area of this project. Every year record rainfall causes disasters, associated with Typhoon/Seasonal front with heavier rainfall. Temperature rise leads to higher moisture in the air, and there is a growing concern that the frequency and intensity of rainfall would continue to increase.
The increasing trend of frequent and intense rainfall is not only occurring in Japan, but also other Asian countries suffer from heavy rain and severe flood.

*Figure 2 Recent floods in different places in Japan*

**August 2016 Heavy Rain in Hokaido**

Minami-Furano-town, Hokkaido

Hokkaido Regional Development Bureau HP
https://www.hkd.mlit.go.jp/ab/tisui/v6dkjr000000021d-att/v6dkjr000000023w.pdf

**July 2018 Heavy Rain in West Japan**


Ministry of Land, Infrastructure, Transport and Tourism HP
https://www.mlit.go.jp/common/001323940.pdf

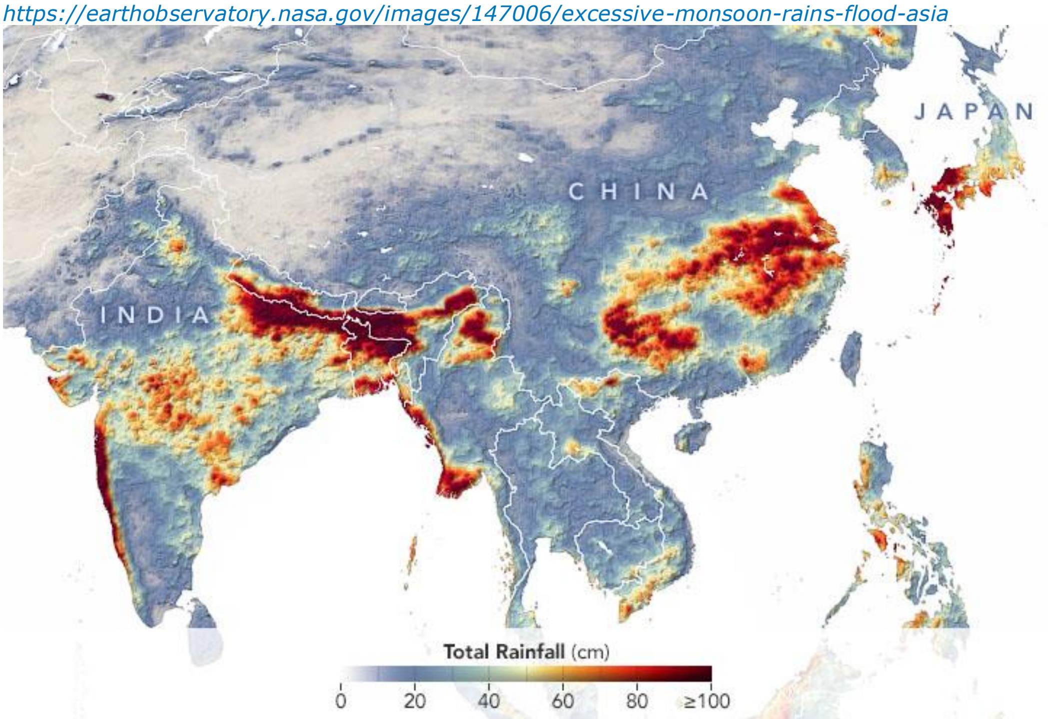
**2019 Typhoon No. 19**


Cabinet Office HP
https://www.cao.go.jp/minister/1909_r_takeda/photo/2019_006.html

**2020 Rainy Season Front**


Kyushu Regional Development Bureau
http://www.qsr.mlit.go.jp/sendai//////bousai_info/ryuuikitisui/images/s1-1.pdf

*Figure 3 Assumed Rainfall by Remote Sensing from Satellite (June 1st to July 20th, 2020)*
*https://earthobservatory.nasa.gov/images/147006/excessive-monsoon-rains-flood-asia*




### 1.1.2 The Netherlands

Also the Netherlands have to face the consequences of climate change. The sea level is expected to rise, the average temperature rises, rainfall patterns change which cause more heatwaves and drought but also more extreme rainfall. In the field of flood risk management there are several policy lines to deal with climate change, some examples:

- Levee Reinforcement. The levee is designed takin into account the future hydraulic conditions including climate changes.
- Delta Program spatial adaptation. This program stimulates the adaption of the build environment to be less vulnerable for the consequences of climate change.
- Knowledge program Sea Level Rise. In this program a better understanding is created about the possible sea level rise for the Netherlands, the impact and possible mitigations strategies.

The need for this research is illustrated by the summer of 2021 in which the area of Limburg faced a period of extreme rainfall which was related to the impact of climate change. Below is a summary of the flood event based on the fact finding research which was executed by ENW. A full description can be found at: https://www.enwinfo.nl/publicaties/.

Precipitation accumulated to 160 to 180 mm in two days over a large region. Similar heavy precipitation events in this area are rare and furthermore have never been registered in the summer season. The probability of occurrence is much smaller than can be directly derived from observations of past events, although a combination of measurements from past event with a large ensemble of model simulations indicates the probability of the Meuse two-day rainfall and peak discharge is on the order of 1:100 to 1:1000 per year.

Extreme rainfall was experienced simultaneously in a large area that included several tributaries of the Meuse in Belgium and the Rhine in Germany and Luxembourg. Due to the hilly terrain, the rain runoff immediately entered the rivers. Several villages in narrow valleys close to the Vesdre, Ahr and Sauer rivers were heavily affected and partially destroyed. Infrastructure (buildings, bridges, road, rail) was completely washed away. Hundreds of thousands of inhabitants were affected and more than 200 people died. The damage is estimated to be in the order of tens of billions of euros. In Belgium and Germany, damage and losses were the largest and only in these countries were fatalities recorded. The flood event in these countries was catastrophic, amongst others due to even larger rainfall amounts, steeper terrain and fast-flowing rivers.

In the Netherlands recorded peak discharges on the Meuse at Eijsden and regional tributaries were the highest ever recorded. Water levels on the Meuse downstream of Roermond were lower than in previous peak events and also lower than would be expected based on available model results. The lower water levels result from implementation of the large scale room for the rivers programme, 'Meuse Works', as well as a strong flood wave flattening in the downstream parts of the system. The probability of occurrence of the recorded water level is around 1:200 per year for the Meuse at Borgharen and decreases to 1:15 per year downstream. The main flood defences along the Meuse river in the Netherlands performed well and did not breach.

In the tributaries in Limburg the probabilities of occurrence of the recorded water levels vary widely: at many locations along the rivers Geul, Geleenbeek and Roer, probabilities are estimated to be between 1:100 and 1:1000 per year.

The floods in the Netherlands led to severe economic damage and losses in the affected area. A first estimate shows that more than 2.500 houses, more than 5.000 inhabitants and around 600 businesses are affected. Physical damage to houses and businesses, business interruption, damage to infrastructure and crop losses are the most significant. The observed damage to individual structures (residential and commercial) is highly variable. The estimated damage in the affected area is clearly larger than for the river floods in 1993 and 1995 (converted to 2021 prices: around € 200 million and € 125 million, respectively, excluding damage due to business interruption). It is important to note is that the largest damages and losses occurred in the regional rivers, mainly in the Geul floodplain, while in 1993 and 1995 most damage and losses were recorded in the main Meuse floodplain.

Around 50,000 people along the flooded rivers have been evacuated. Along the river Geul, specifically in Valkenburg, most people were not evacuated before the flood arrived, with the exception of some campgrounds and 193 people in health care institutions. Along the river Meuse, most people were evacuated before the arrival of the peak discharge. Finally, no fatalities were reported in the Netherlands and the majority of the people evacuated themselves.

The majority of healthcare workers – around two thirds - reported an increase of patients with psychological complaints (i.e. stress, concerns, and anxiety). The impact of the floods on the drinking water extraction for the Dunea water supplier was limited, but substantial for suppliers Evides and WML. The drinking water well of the Maas and Eyserbeek were temporarily closed due to chemical and microbiological contamination. The reserve capacity was sufficient to prevent shortages of drinking water supplies, also due to the wet and mild summer. The province Limburg had the highest COVID-19 risk ratio among provinces of the Netherlands and also had the largest increase of new cases after the floods. The flooded municipality Valkenburg aan de Geul showed a risk ratio of >5 (and is within the top 5 of Limburg), suggesting that the floods may have contributed to SARS-CoV-2 transmission. However, the differences appear to be small and may have only occurred locally.

## 1.2 The need for joined research

Japan has been suffering from flood caused by the record heavy rain every year, and it is clear that we are confronting the impact of climate change. Ministry of Land, Infrastructure, Transport and Tourism (later referred to as MLIT) has changed its policy, introducing "River Basin Disaster Resilience and Sustainability by All," because of the recent increase of external factors and frequent flood occurrence associated with climate change, while it used to be satisfactory enough by maintaining flood control facilities, such as levees and dams.

River Basin Disaster Resilience and Sustainability by All is an approach to reduce flood risk of the whole basin, by building up the cooperation by all the relevant organizations around the basin. It requires a quantitative understanding, for instance, time-space distribution of flood and its probability assessment. This is why a new approach developed by this project, integrating Hokkaido and Dutch Models, could be an excellent tool to assess quantity of flood risk change due to climate change.

Most of the surrounding countries have the similar challenges, for example, confronting climate change and flash floods because of rapid rainfall. It is, therefore, potential to make this case an advanced example to prevent and reduce damages of frequently occurring floods.

In addition, Europe including the Netherlands experienced unprecedented heavy rainfall disasters in July 2021, and the risk of disasters due to increased precipitation and localized heavy rainfall associated by climate change is increasing.

Japan's wealth of knowledge on how to respond to rapid runoff and disasters caused by localized heavy rain is highly beneficial to European countries, including the Netherlands.

The flood risk assessment model (hereinafter referred to as Dutch Model), developed by Floris Project in the Netherlands, is an advanced model to analyze different flood scenarios comprehensively, assessing the distributions of human risk and economic risk quantitatively and stochastically. Dutch model has a solid reliability, being already introduced all over the Netherlands as the basis of risk based approach.

On the other hand, the climate projection model developed in Hokkaido, Japan (herein after referred to as Hokkaido Model), is extremely elaborate and large data of climate projection, based on ensemble climate projection data of past 3,000 years, future 3,240 years by 2 degree rise, and future 5,400 years by 4 degree rise, physically downscaled to 5km horizontal resolution, by means of regional climate model with reputation in weather forecast in Japan. This model makes it possible to reproduce metrological phenomena with high accuracy, such as topographical rainfall due to the steep topography of Japan. In addition, it enables statistical analysis, since it covers wide range of physically possible rainfall phenomena in the past and the future.

Hokkaido Model with rich probability information based on physics simulation and Dutch Model with excellent flood risk assessment are complementary to each other. A new approach developed by this project, combining both knowledge, is highly potential to apply for many different rivers worldwide.

Hokkaido has built up a continuous technical exchange with Dutch experts, and based on the knowledge obtained, studies have been initiated with reference to Dutch methods such as fatality estimation.
In January 2018, Hokkaido members visited the Delta Commission, Rijkswaterstaat, KNMI, HKV, and others to exchange opinions, which marked the beginning of technical exchange between these two countries. In November 2018, Dutch experts were invited to the Japan-The Netherlands Flood Control Seminar in Hokkaido, and a special session was held at the 63rd Conference on Hydraulic Engineering of the Japan Society of Civil Engineers. In June 2019, Hokkaido members paid the second visit to the Netherlands and exchange their perspectives again.

Based on the background of these technical exchanges, a consortium of experts from both countries was formulated to solve the technical issues mentioned above.

This consortium consisted of an existing network of Japanese and Dutch universities, research institutes, companies and governments. This network was developed in the last two years after recent floods in Hokkaido based on the need to cope with climate change. The top experts are involved in this network, since only they can give the added value to fill the requirement of Japan. These experts can be called knowledge entrepreneurs. This approach enables Dutch expertsto get connected to Japan and creates the (once in a lifetime) opportunity for further upscaling.

We have a mix of Dutch and Japanese top experts from universities, research institutes, consultants and governments:

- Universities (Safety and Security, Civil Engineering): Delft University and Hokkaido University
- Private organizations and research institutes (consultants), with a strong R&D focus on flood risk management: HKV, Deltares, Docon Co., Ltd, River Center of Hokkaido
- Government as counterparts: 1) Rijkswaterstaat and 2) Hokkaido Regional Development Bureau as a part of the MLIT

The Dutch partners are complementary to each other. They are all specialized in flood risk analysis with different focuses. HKV as a consultant will manage the project, is expertized in risk analysis and has much experience in developing and applying the Dutch methods to flood safety assessment in the Netherlands. Deltares as a water knowledge institute facilitates access to a large variety of relevant researches and models, and has much experience in the application of the Dutch flood risk methods to many countries around the world. TU Delft supports in depth knowledge development, review and quality control. Through their network in Japan and South East Asia we can also disseminate the result of the project.
The Japanese partners are also complementary. The River Centre of Hokkaido is responsible for the coordination of the water safety research, and Hokkaido University has expertise on the projections of quantified change of rainfall due to climate change of typhoons and the rainfall. Docon Co., Ltd has expertise on flood risk and relevant technical development.
The River Centre of Hokkaido, Docon Co., Ltd and Hokkaido University work together to establish a new flood risk assessment method, by scientifically evaluating flood risk increase based on projection of quantified change of rainfall due to climate change.

## 1.3 Objective of the study

The long-term missions of this study are as follows

1. Technical development of a new flood risk approach in Hokkaido by integrating flood risk analysis and failure probabilities of both countries. The integration of Dutch and Japanese approaches is the first step in the long term ambition to upscale the method to other regions around the world. The next step after this project aims to adopt the approach in entire Japan and the last step to explore the potential to use in South East Asia.
2. Sustainable relation between Dutch and Japanese researchers and experts resulting in joint proposals for research programs (as Horizon2020 in the Netherlands), publication of thesis for Japan Society of Civil Engineers, PhD positions, and knowledge development in national research programs of Rijkswaterstaat (as NKWN, WBI) and technical proposal for MLIT.

To realize these ambitions, roadmaps for business and research will be developed during the project to upscale the approach.

To make sure of the above opportunities, it is required to achieve the following.

- Ensure the clear achievement of this project.
- Clarify technical challenges of this project to make a proposal for the following term with the solutions.
- Generalize the result of this project to other rivers in Japan.
- Share the information and understanding with the stakeholders, who would be involved with the next project and other rivers to apply its results.
- Disseminate the results of this project by means of academic conferences.
- Develop cooperation between the Netherlands and Japan through this project, by building up a sustainable structure of technical and human exchange.

## 1.4 Cooperation between team members in joined project

This consortium builds on an existing network of Japanese and Dutch universities, research institutes, companies and government which started in 2018. after recent floods in Hokkaido and the need to cope with climate change. For the entire consortium the joined project was a key element to develop a sustainable network and improve methods and insights During the project we have worked in combined project teams of Japanese and Dutch experts. A project team was formed to define the hydraulic loads based on the rainfall, a team for assessment of the levees and a team for the risk and loss of life assessment. For the interaction between these topics we had physical meeting and, because of COVID-19, online meetings. During these meetings we had in depths discussion about these topics, and the application of the methods to the case study. During the physical meetings we also had social activities which contributed to a better understanding of each other. The joined project had added value for all partners and individual experts, which for example was shown in the project team which also had no changes.

The experts in Hokkaido, as part of the consortium but also the Japanese civil engineering community is open to develop this relation now. The "seminar for Water Management in the Netherlands and Japan on 29th November 2018" was attended by many civil engineers (>200) and there was a lot of interest in the Dutch method (see item newspaper). This proposal is the next step after the joined meetings in 2018 in the Netherlands (January) and Hokkaido (November) which included the open seminar for the Japanese water sector initiated by the Japanese partners. We have a mix of Dutch and Japanese top experts from universities, research institutes, consultants and government:

- Universities (Safety and Security, Civil Engineering): Delft University and Hokkaido University

- Private organizations and research institutes (consultants), with a strong R&D focus on flood risk management: HKV, Deltares, Docon Co., Ltd, River Center of Hokkaido
- Government as counterparts: 1) Rijkswaterstaat and 2) Hokkaido Regional Development Bureau as a part of the Ministry of Land, Infrastructure, Transport

The consortium partners cover the entire field of flood risk modelling (in depth knowledge of civil engineering, statistics and governance). From early warning and climate change modelling, hydrologic, hydraulic and morphologic processes as well as the assessment of damage, loss of life, evacuation and the use of cost benefit and multi criteria analyses.

The Dutch parties are complementary to each other. They are all strong in flood risk analyses but focus on different subjects. HKV as a consultant will manage the project HKV is expert in risk analyses and has much experience in development and application of the Dutch methods for flood safety assessment in the Netherland. Deltares as a water knowledge institute facilitates access to a large variety of relevant research and models and has much experience in the application of the Dutch flood risk methods in many countries around the world. TU Delft supports in depth knowledge development, review and quality control.

The Japanese parties are complementary. The River Centre of Hokkaido is responsible for the coordination of the water safety research, the Hokkaido University has expertise on the projections of climate change of typhoons and the rainfall. Docon Co., Ltd has expertise on flood risk and relevant technical development.

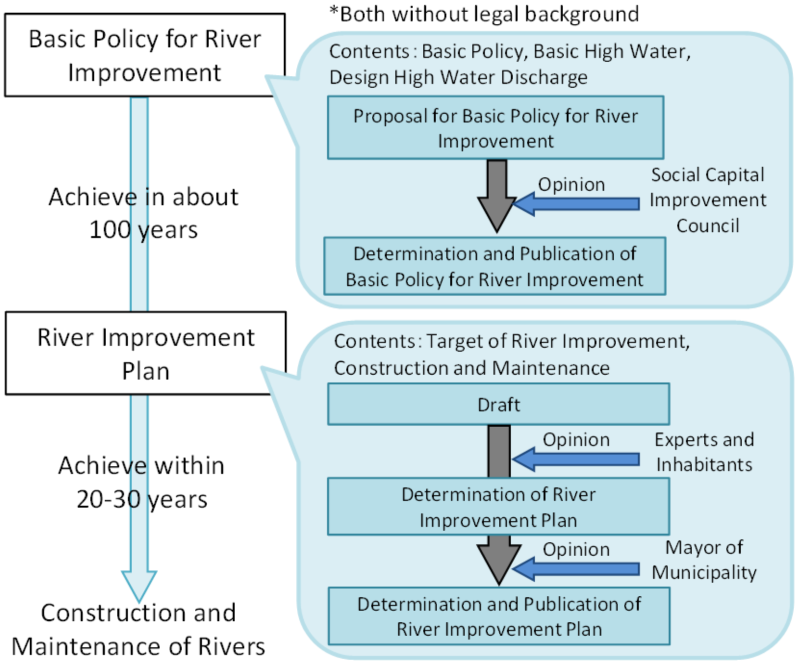
The advantage of involving both Japanese and Dutch parties with a high knowledge level is that both parties can learn a lot from the project, and have the availability to apply this knowledge for different goals.

# 2 Introduction in Flood risk management in Japan (Hokkaido) and the Netherlands

## 2.1 Japanese Flood risk policy

The current flood control scheme of Japan estimates extreme rainfall events, such as annual exceedance probability 1/150, by statistically analyzing observed data over the past several decades. The outliers are excluded from the analysis to express the probability rainfall deterministically (on the assumption that a rainfall for a given annual exceedance probability is determined).
Based on the long-term basic river maintenance policy, dependent on the characteristics of each river basin, runoff is calculated for several rainfall sets estimated for a given annual exceedance probability. This determines the design runoff for each tributary and reference point. This is called the basic high water, and its guidelines are described in "The Japanese Ministry of Land, Infrastructure, Transport and Tourism Technical Criteria for River Works" [1)]. In addition, a river improvement plan is formulated with specific targets to be achieved within a period of about 20 to 30 years, and river channel excavation, flood control facilities, levees, and other facilities are maintained for each river to keep the water level below the design high water level during floods.

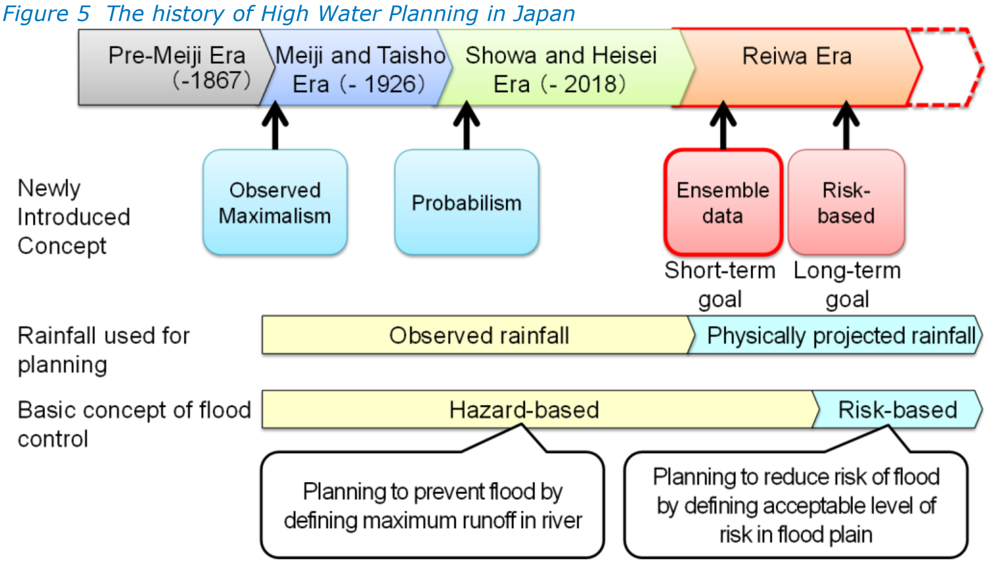
*Figure 4 The flood control scheme of Japan*




Source:"New Planning System for River Improvement" Sapporo Development Construction Department, Hokkaido Regional Development Bureau of MLIT, https://www.hkd.mlit.go.jp/sp/kasen_keikaku/kluhh4000000ft54.html

Reflecting the history of Japan's flood control policy, Dutch engineers came to Japan in 1870 to introduced modern river engineering. The target runoff for river maintenance was determined based on the observed maximum flood runoff in the past. The first version of "Technical Criteria for River Works," formulated in 1953, established a probabilistic method to set up a standard high water according to the annual exceedance probability, as described above.
Furthermore, the ensemble climate projection database d4PDF (Mizuta et al, 2017) has recently been developed in Japan. This database made a large amount of projected information available, for the past 3,000 years (60 years x 50), for 3,240 years (60 years x 54) by 2°C rise in the future, and for 5,400 years (60 years x 90) by 4°C rise in the future. This information is based on a large number of detailed physical simulations using supercomputers of past and future possible weather phenomena (including rainfall events that have never been experienced before), which makes it more reliable to estimate of probability rainfall.
Though the hazard-based flood control planning according to observed rainfall has been used in Japan, it is required to shift to a flood control planning based on projections, due to the growing climate change impacts.

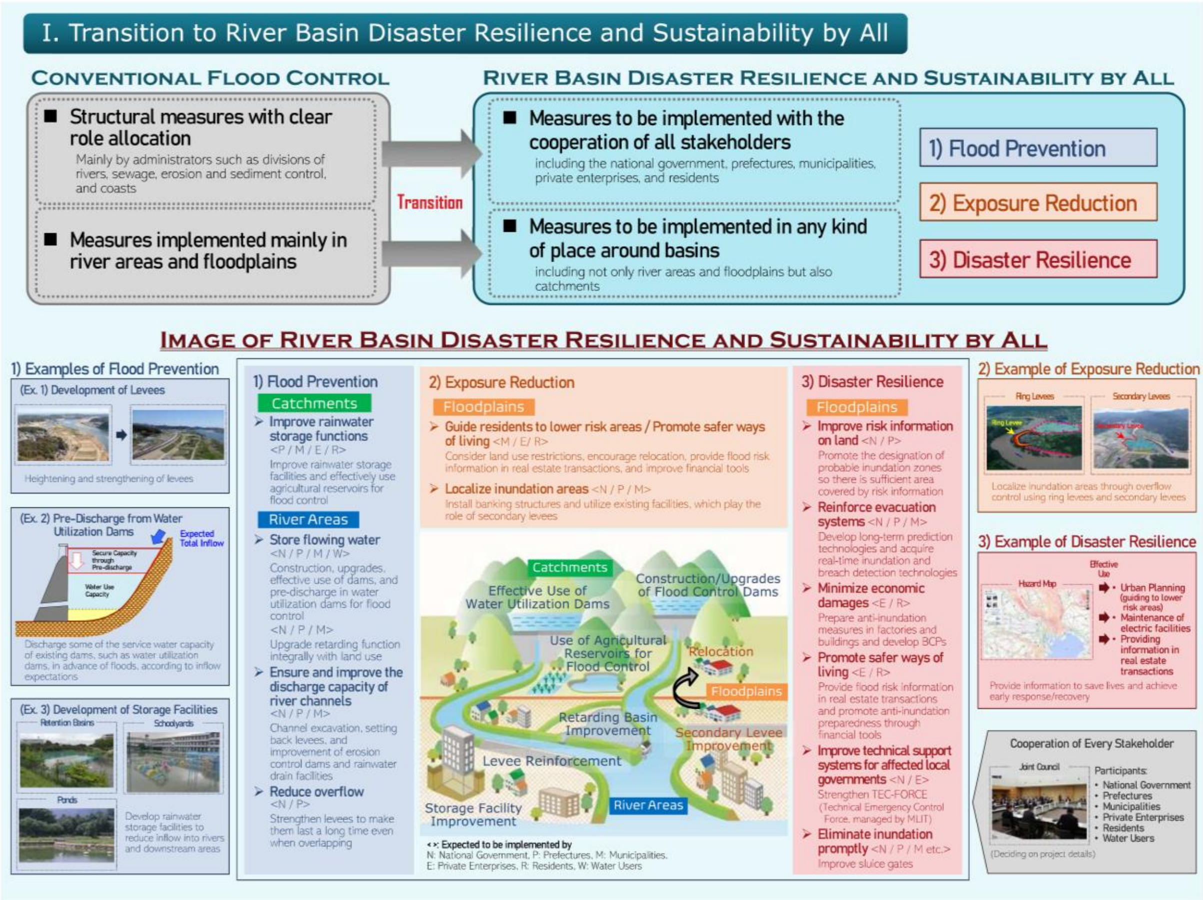
*Figure 5  The history of High Water Planning in Japan*




Adapted from "Historical Study on Institutionalization of Basic High Water", S. Nakamura, https://repository.dl.itc.u-tokyo.ac.jp/records/7541#.YbhbvVlUthE

In 2020, MLIT has announced a shift to "River Basin Disaster Resilience and Sustainability by All," which aims to reduce damage through collaboration among all parties involved with the basin, in light of the increasing frequency and severity of disasters in recent years. In contrast to the conventional river planning, which mainly focuses on river management facilities to keep floods below the design scale to ensure safety, River Basin Disaster Resilience and Sustainability by All is a comprehensive and multilayered approach that considerswatershed, river area, and flood prone area as a single basin in order to reduce damage of floods even beyond the estimated level. River Basin Disaster Resilience and Sustainability by All also covers tips to live in the flood prone area and to control flood flows. The risk-based approach is beneficial to quantitatively assessing flood risk and to understand the effects of measures. The attempt of this study to integrate scientific climate change projection and probabilistic risk assessment will be an extremely important knowledge to improve future safety of flood control in Japan.

*Figure 6 River Basin Disaster Resilience and Sustainability by All, MLIT, Source : https://www.mlit.go.jp/river/kokusai/pdf/pdf21.pdf*




## 2.2 Dutch Flood risk policy

The Netherlands is a small country, lying in the delta of several rivers (Rhine, Meuse, Scheldt) and bordering the North Sea. As a result, the Netherlands is prone to flooding, especially because climate change and the rising sea level will be causing increasingly frequent higher water levels and more extreme discharges.

Without flood defences, such as levees and storm surge barriers, 60 percent of The Netherlands would be inundated on a regular basis. These areas accommodate some nine million people and some seventy per cent of our gross national product is earned here. Consequently, adequate flood risk management is vitally important.

The flood risk policy is being co-designed and developed within the Dutch National Delta Programme.

**The Dutch National Delta Program** (source: Deltaprogramma.nl)

The government seeks to protect the Netherlands, now and in the future, against flooding and to secure a sufficient supply of fresh water. Furthermore, the government seeks to render our country climate-proof and water-resilient. The plans to this end are set down in the Delta Programme.

The aim of the Delta program is to ensure that our flood risk management, freshwater supply, and spatial planning will be climate-proof and water-resilient by 2050, so that our country will continue to be able to cope with the increasing weather extremes. This time around we will try and prevent a disaster, rather than devise measures on the aftermath.

By 2050, the Netherlands must be climate-proof and water-resilient. This means that our flood risk management, freshwater supply, and spatial planning must be up to par. Only then will our country continue to be able to cope with the impact of climate change.

Along with its partners, the government has adopted a new approach to working on the delta:

- New flood protection standards have been implemented. Rather than focusing on the probability of flooding, the government also considers the potential impact of a flood (risk-based approach). The stringency of the standards is determined by the scope of the potential impact;
- More insight will be provided into the availability of fresh water for agriculture, industry, and nature;
- Spatial planning in the Netherlands will be more climate-proof and water-resilient.

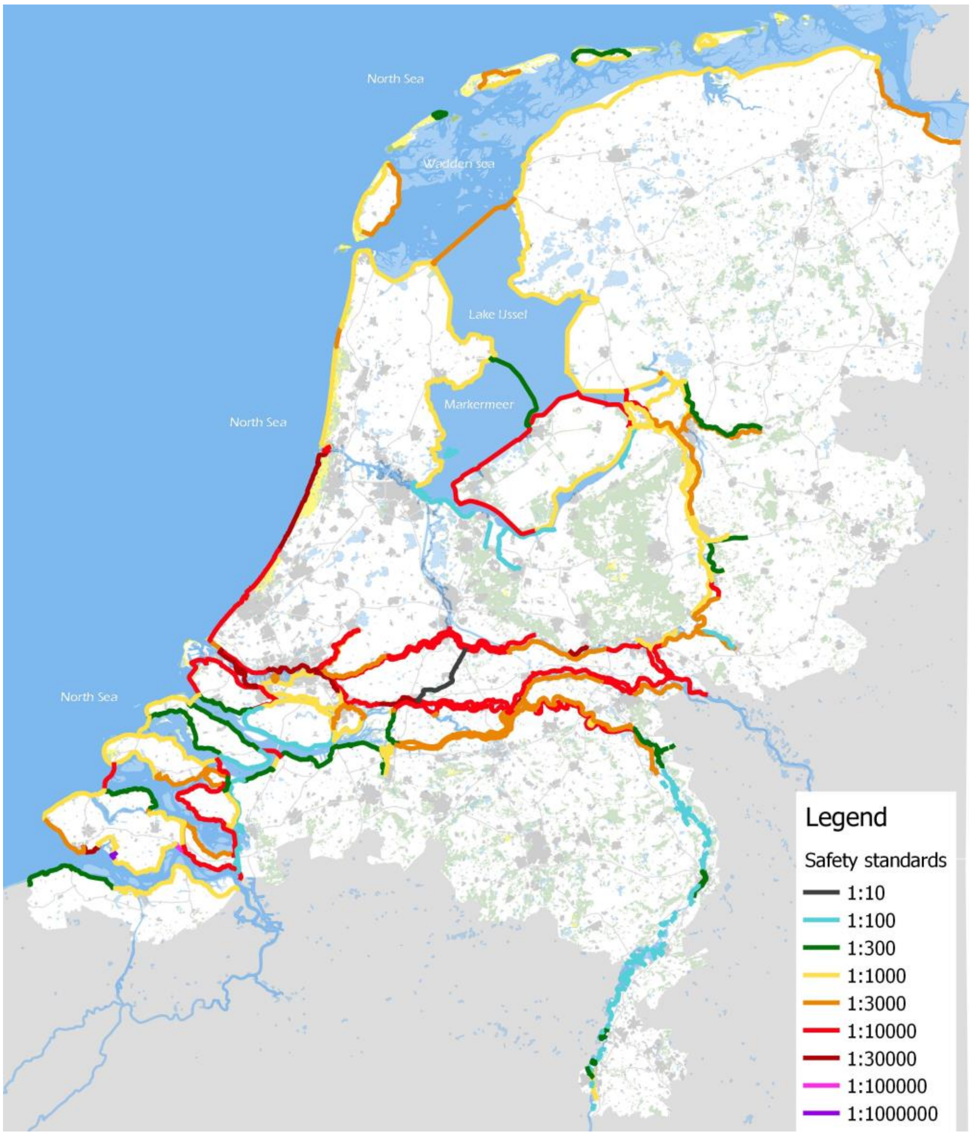
One of the Delta decisions is on flood risk management. The essence of the Delta Decision on Flood Risk Management is that by no later than 2050, the probability of fatality due to flooding must not exceed 1 in 100,000 per annum (or 0.001 %) for every resident living behind the dykes. This is the so-called tolerable individual risk.

The Delta Decision on Flood Risk Management is underpinned by a risk-based approach. This enables more targeted investments in the flood protection of the Netherlands. Every resident living behind the dykes will have the same minimum level of flood protection. At locations where a flood would have a major impact (e.g., many casualties, great economic damage, and/or damage to vital infrastructure of national significance), the protection level will be raised.

Between 2015 and 2020, great progress has been made in the implementation of the Delta Decision on Flood Risk Management. For example, the protection targets have been translated into standards for the primary flood defences: the dykes, dunes, dams, and storm surge barriers that protect our country against flooding from the sea, the major rivers, and the major lakes. These standards have been set down in the Water Act, which came into force on 1 January 2017, Figure 7.

The first National Round of Assessments of these primary flood defences commenced in 2017. A new set of statutory instruments is available to this end: a set of agreements and methods for the assessment of the primary flood defences. By no later than 31 December 2022, the Minister of Infrastructure and Water Management will report to the Senate and the House of Representatives on the condition of the primary flood defences, on the basis of the first National Round of Assessments. The second National Round of Assessments will run from 2023 to 2034;

*Figure 7 Dutch Safety Standards*




Furthermore, the Flood Protection Programme has been rolled out. In this Programme, the 21 district water boards of the Netherlands and the central government are collaborating on the largest dyke improvement operation since the Delta Works. The Flood Protection Programme is aimed at ensuring that the primary flood defences managed by the district water boards will meet the standards by 2050. This involves nearly 1,300 kilometres of dykes and nearly 500 sluices and pumping stations. Many dyke improvement projects are already under way.

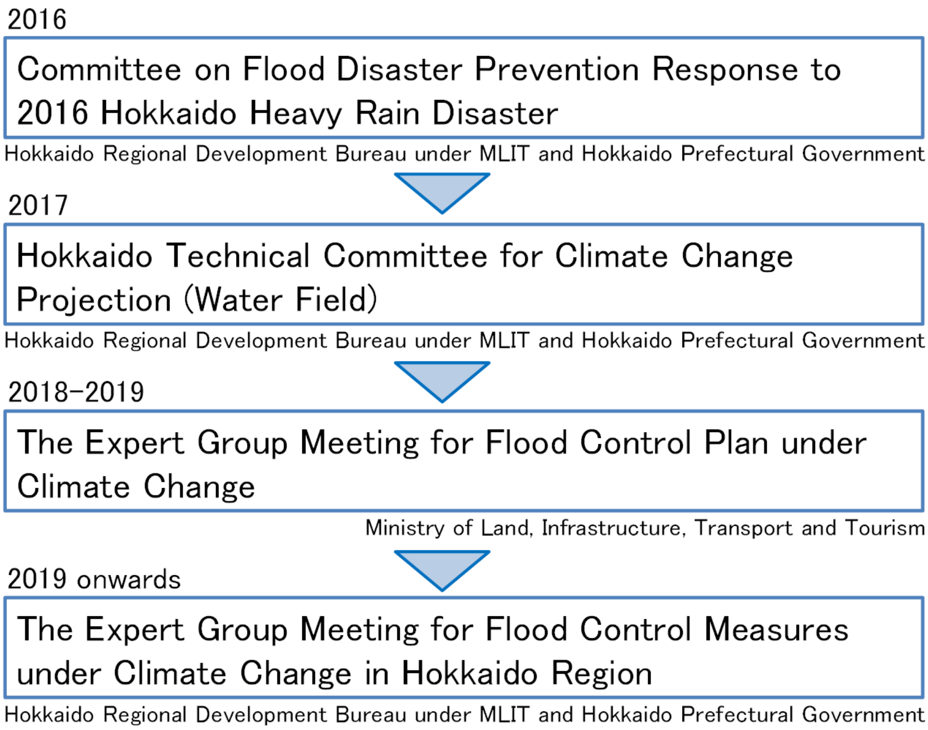
The Dutch National Delta program gives a good overview of the Dutch Policy on flood safety and the implementation of the risk-based approach on coping with flood risks.

## 2.3 Challenges with regard to climate change

### 2.3.1 Japan

August 2016 Heavy Rain Disaster in Hokkaido triggered Hokkaido Regional Development Bureau, MLIT, and Hokkaido Prefecture established the expert committee [1], in order to review the disaster and consider future flood prevention measures. The committee concluded that "predictions and concerns about intensified flood damage due to the impact of climate change have been recognized as a reality", and that "the impact of climate change should be scientifically predicted," and "flood control measures should implement specific risk assessments".
In response to this report, climate change impact projections and flood risk assessments based on large ensemble climate data [2] were conducted in 2017. This has led in 2018 – 2019 to the study of flood control plan associated with climate change by MLIT,[3] and the adaptation measures to be social implemented for a river basin in Hokkaido.[4] The large ensemble climate data covers diverse meteorological phenomena that can physically occur in past and future climates, allowing quantitative assessment of extremely rare heavy rainfall events, based on their occurrence probability. These studies are not only the first of their kind in the country, but have also attracted global attention, as they were reported at the regular meeting of the United Nations Framework on Climate Change held in Bonn, Germany on 20 June 2019 [5] [6].

*Figure 8 Challenges with regard to climate change in Japan*




1) Committee on Flood Disaster Prevention Response to 2016 Hokkaido Heavy Rain Disaster, 2017, https://www.hkd.mlit.go.jp/ky/kn/kawa_kei/ud49g7000000f0l0.html
2) Hokkaido Technical Committee for Climate Change Projection (Water Field) , 2018, https://www.hkd.mlit.go.jp/ky/kn/kawa_kei/splaat000000vdyw.html
3) The Expert Group Meeting for Flood Control Plan under Climate Change, 2019, https://www.mlit.go.jp/river/shinngikai_blog/chisui_kentoukai/index.html

4) The Expert Group Meeting for Flood Control Measures under Climate Change in Hokkaido Region, 2019, https://www.hkd.mlit.go.jp/ky/kn/kawa_kei/splaat000001offi.html
5) Tomohito Yamada, Adaptation measures for extreme floods using huge ensemble of high-resolution climate model simulation in Japan, Bonn Climate Change Conference, 2019, https://unfccc.int/sites/default/files/resource/2.5Tomohito_Yamada_presentation_ver1.5plus.pdf
6) Tomohito Yamada, United Nations Framework Convention on Climate Change（UNFCCC）The 50th sessions of the UNFCCC Subsidiary Bodies（SB 50）Participation Report」,2019, https://www.hkd.mlit.go.jp/ky/kn/kawa_kei/splaat000001ofky-att/splaat000001pcj9.pdf

### 2.3.2 Netherlands

Within the National Delta program the Delta decision on flood risk management lead to an update of the Dutch Safety standards and a more risk based approach on dealing with flood risks. But challenges remain and circumstances change:

- The sea level is rising (possibly at an increasingly faster rate), while the soil is subsiding;
- Torrential rains are increasing in frequency and intensity;
- The temperature is rising;
- The climate is becoming drier.

Due to all these changes and the economic growth a flood would have a greater impact today than it would have had in 1953 when the last large flood occurred in the Netherlands. Key knowledge issues pertain to the rising sea level and extreme rainfall events.

For the rising sea level a Sea Level Rise Knowledge Programme is established and conducts research into the pace at which the sea level will be rising from the second half of this century onwards. The program present its final results in 2026.

In the summer of 2021 an extreme rainfall event in the Netherland, Belgium and Germany lead to extreme discharges on the regional and primary hydraulic systems. In the Netherlands the primary system was exposed to extreme water levels but levee breaches did not occur. This was not the case for the regional system. The regional system was overloaded due to the extreme rainfall and the rapid discharge to the regional rivers causing water to overflow the regional levees leading to large amounts of damage in the southern part of the Netherlands, luckily there were no casualties. This event lead to new research questions on how the Netherlands will have to deal with these extreme rainfall events and what measures are possible to deal with these events.

# 3 Methodology of the flood risk analyses

## 3.1 General approach

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 calculated.

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.

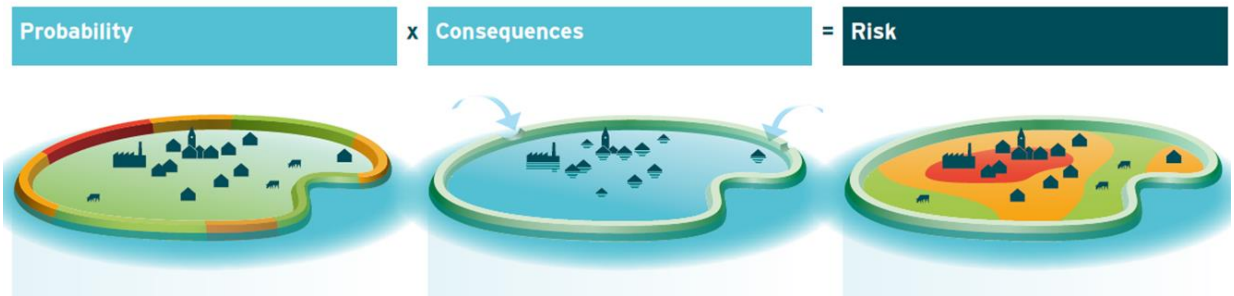
Uncertainty plays an important role in calculating the failure probability of flood defences and in determining the consequences of flooding. For example, It is not known what the maximum load will be in a given year or what the exact flooded area will be given a levee breach.

It is, however, generally possible to assign probabilities to the possible loads and strengths, on the basis of statistics and expert judgment. And for the consequences it is possible to generate different scenarios to determine bandwidths of possible flood consequences.

The failure probability of a flood defence is the overall probability of all combinations of loads and strengths at which the flood defence will fail. The probabilistic approach allows us to explicitly address the uncertainties surrounding the actual values for loads and strength properties when considering the level of safety afforded by the flood defences.

Combining the calculated flood probability and the potential flood consequences lead the determination of the flood risk.

*Figure 9 Brief overview of risk approach (VNK2, The method in brief)*



### 3.1.1 Flood scenarios

An area can be flooded from different locations and a breach can occur everywhere. However, it is not necessary to identify the consequences of flooding for every possible breach location for a sufficiently accurate risk analysis. A system can be divided into segments where the flood pattern will be approximately the same, regardless of the precise location of the breach within that segment. So based on the characteristics of an area and the hydraulic system different breach locations are defined for which the failure probability and flood consequences are determined.

Additionally to the selection of the breach locations, choices have to made regarding the shape of the discharge wave or the shape of the storm surge set-up. Different shapes will lead to differences in inflow through a breach at a certain location. So it is important to consider different type of shapes of the hydraulic loads to get insight in the possible flood extent and flood characteristics.

### 3.1.2 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 segments with a breach location
- Producing flood propagation models
- Defining flood scenarios
- Consequence estimates for each scenario
    - Economic damage
    - Evacuation
    - Loss of Life

These consequences give an insight in the potential damage that can occur due to a levee breach.

### 3.1.3 Flood probability

The failure probability of a flood defence is the overall probability of all combinations of loads and strengths at which the flood defence will fail. The hydraulic loads are derived from extreme rainfall to discharges in rivers or extreme wind conditions can lead to high water levels and high waves along the coast. These conditions for different systems are translated into probabilities of exceedance of certain hydraulic loads.

The probability of exceedance of hydraulic loads are combined with the strength of the levee to determine the flood probability of a considered segment of the levee system.

For some systems, mainly river systems, breaching of a levee can have an impact on the hydraulic loads for the more downstream situated levees. So there is some dependency between the upstream and downstream breach locations. Given that a more upstream breach location has failed the hydraulic loads will decrease and the probability of failure of the more downstream situated breach location is getting smaller. This effect has to incorporated in the flood probability calculation in order to prevent an overestimation of the failure probability of the downstream levees.

### 3.1.4 Flood Risk

The flood risk is calculated based on the flood probabilities and the flood consequences of each scenario. Every scenario contributes to the flood risk and the sum of the contributions gives the total flood risk.

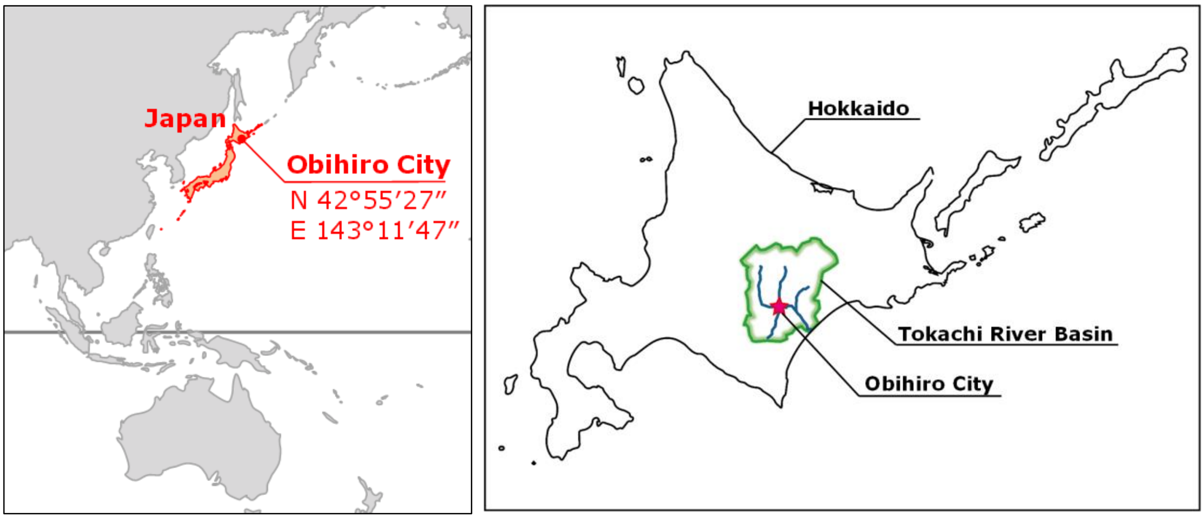
The flood risk can be expressed and represented in various ways and all measures of risk can be calculated on the basis of the flood probabilities and their flood consequences. The measures of risk are:

- Annual expected value of economic damage
- Spatial distribution of the annual expected value of economic damage
- Annual expected value of number of fatalities
- Local individual risk
- Societal risk

## 3.2 Case study area

- The target area of this study is Obihiro City, around mid-stream of Tokachi River basin in Tokachi Plain, south-east of Hokkaido.
- The Tokachi River is a first class river with a channel length of 156 km and a basin area of 9,010 km$^2$. It originates from the 2,077-meter-high Tokachi-dake mountain in the Daisetsuzan mountain range and flows through Obihiro City with numerous tributaries into the Pacific Ocean. The river is surrounded by 2,000-meter-high mountains on the north and west sides of the basin, and dependent on weather conditions, such as typhoons, it can cause large amounts of precipitation due to orographic rainfall and rapid flush into the river.

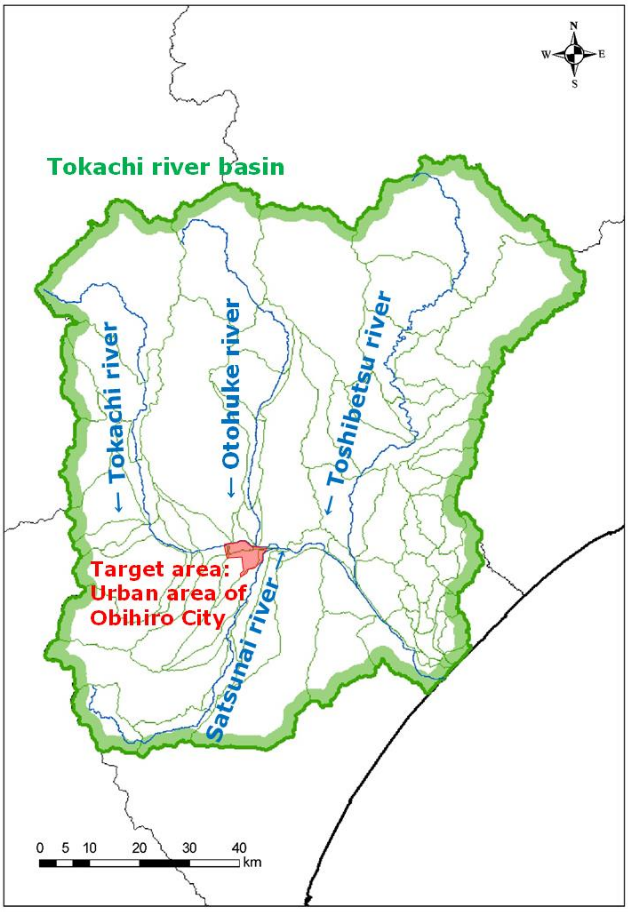
*Figure 10 Location of Hokkaido and Obihiro City*




**-** The risk assessment of this study is targeted to the urban area of Obihiro city, where the core functionalities are concentrated. Obihiro City is a hub of the Tokachi region, known as one of the largest food supply bases in Japan. Its population is approximately 170,000 people, and 100,000 of them live in the city center with many important regional facilities such as the city hall, hospitals, and centers for commerce, industry, energy and distribution.

Obihiro urban area is located at the confluence of Tokachi River and Satsunai River, the second largest tributary of the Tokachi River system, and is, therefore, a highly probable to be flooded. After experiencing major floods in 1922, 1962, and 1980, the area has been spared from inundation damage, thanks to the progress in river maintenance, though there is a fear for increasing food risk due to revealing climate change impact.

*Figure 11 The target area in Tokachi River Basin*




- Hokkaido is one of the most advanced regions in Japan for climate change adaptation in the field of flood control, and the Tokachi River has more than 10,000 cases of detailed meteorological simulations and flood simulations of physically possible heavy rainfall events in the past and future, based on the Japanese climate projection database d4PDF (Mizuta et al, 2017). This study attempted to develop a new risk assessment method by combining a large number of Japanese physical simulations and Dutch probabilistic flood risk assessment.

## 3.3 Part 1: extreme rainfall and river discharges

### 3.3.1 Flood damage estimation based on observation and climate projection dataset

In August 2016, three typhoons landed in Hokkaido region, Japan within a week. After landing of these typhoons, typhoon No. 10 approached near this region. These typhoons caused record-breaking rainfall in many parts of Hokkaido, resulting in river flooding, landslides, road and bridge washouts, and extensive damage to agricultural land, the main industry in the region (Reference; Ministry of Land, Infrastructure and Transport, Nguyen and Yamada 2017). The research group led by the leader of Japanese side in this joint research project has conducted large-scale climate simulations using a regional climate model that covers the period from the middle of the 20th century to the end of this century using a domestic supercomputer (earth simulator) and developed climate change projection database which have quite large ensemble members with high spatial resolution (Yamada 2020, Hoshino et al., 2020). The validity of the scale and occurrence probability of large-scale heavy rainfall revealed by the predicted information was demonstrated using mathematical and statistical theory (Shimizu et al., 2020). The advantage of using this data is that the probability of occurrence and intensity of possible extreme rainfall event can be estimated. In addition, the data enables to estimate the future changes of these phenomena. We have analyzed the spatio-temporal characteristics of heavy rainfall and associated flood inundation characteristics based on the results of climate change projections over several thousand years and quantified the risk of human and economic damage associated with potential large-scale floods in the current climate and in the future climate, when global warming progresses (Yamada 2020). This research has contributed to a shift from the traditional hazard-based flood control planning based on past rainfall observations to a new risk-based planning considering extremely large floods in the future climate.

In the field of flood control, hydrological models (rainfall-runoff and inundation models etc.) that describe the processes from rainfall-runoff to inundation play a fundamental role in setting the design conditions. On the other hand, the parameters of the model are subject to uncertainty due to the finite number of observed flood event in the past. In "working package 1" of this joint research, the relation between rainfall and peak discharge expressed by each model is considered to develop a method for estimation of peak discharges in the Tokachi river basin. The advantage of the quantification of rainfall-peak discharge relation enables estimation on uncertainty of characteristics of different hydrological models. Introducing rainfall-peak discharge relation expressed by models, future change of spatial-temporal characteristics of extreme rainfalls with low frequency and large-magnitude can be considered, and peak discharge is calculated under these extreme rainfalls by dynamical simulation and statistical methods. Here, the methodology constructed in working package 1 is purposed to estimate probability distribution of peak discharge with return period of design level by using the input from extreme rainfall distribution with the same level and rainfall-peak discharge relation derived from a hydrological model. Advantages of this methodology is that estimated peak discharge as output is subject to update in accordance with the differences and sophistication of climate models and rainfall-runoff models. This technical report describes the methodology and results developed in working package 1.

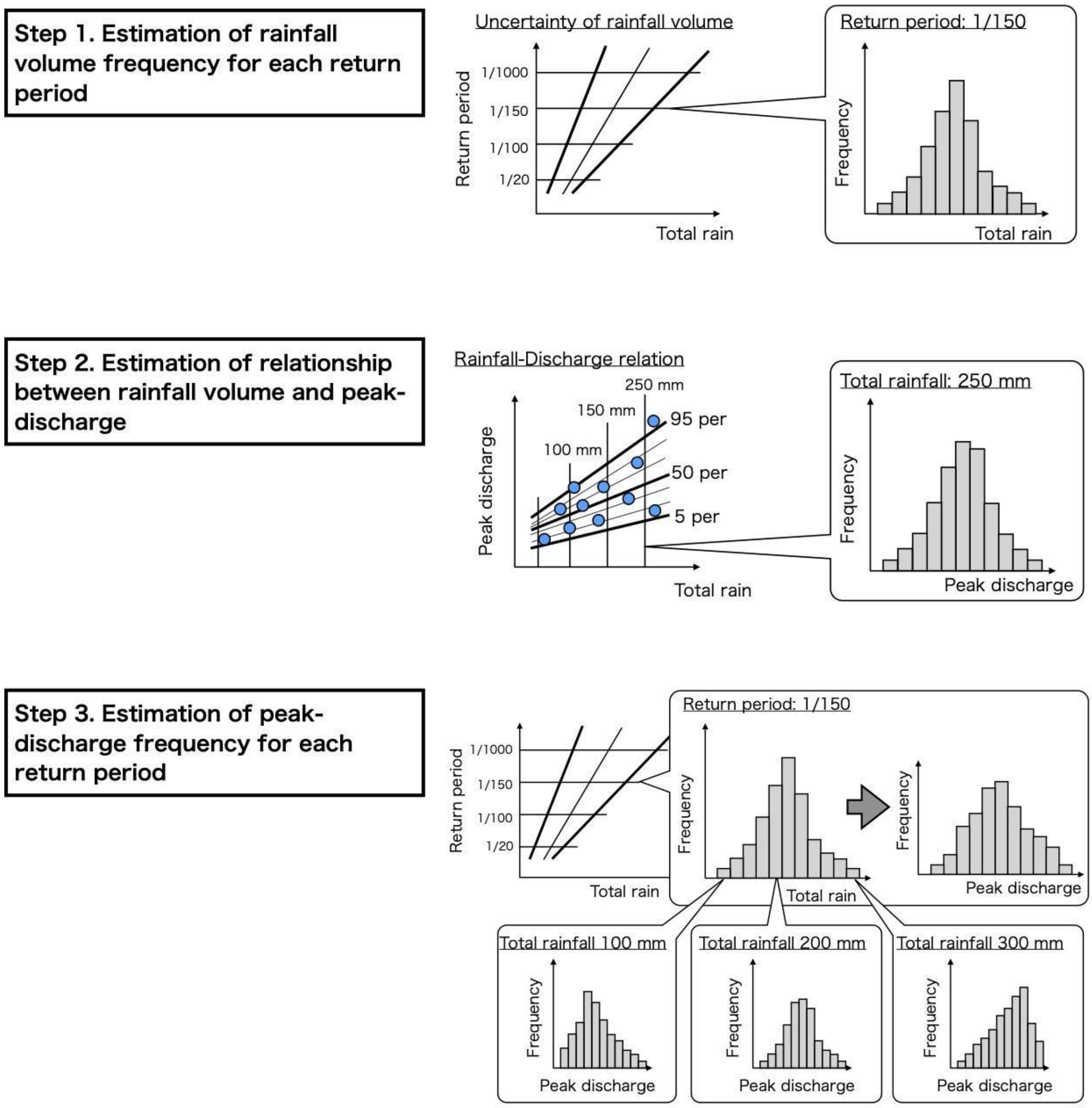
### 3.3.2 Estimation method for peak-discharge distribution for each return period

The estimation method for peak discharge frequency for each return period consists of three steps as shown in Figure 12. The first step is the estimation of rainfall volume frequency for each return period using ensemble climate datasets with resampling technique. By using this process, frequency distribution of rainfall with arbitrary return period, here, a range of arbitrary probability distribution is defined as a confidence interval.

The second step is the estimation of the relationship between rainfall volume and peak discharge by using rainfall-runoff model result. The rainfall-runoff simulations for several rainfall patterns which are included in the ensemble climate dataset were conducted to calculate peak discharges at target points. Next, quantile regression was applied to the relationship between rainfall volume and peak discharge in order to obtain relative frequency of peak discharge as a function of rainfall volume.

The third step is the estimation of peak discharge frequency for each return period. By using the frequency distribution of rainfall with target return period *T* derived from ensemble climate data, the occurrence frequency of peak discharge distribution, caused by a given rainfall amount, corresponding to conditional distribution, can be quantified. Then, taking a weighted average of the conditional distribution of peak discharge with *T*-year rainfall distribution derives probability distribution of *T*-year peak discharge. Detail of the method is described below.

*Figure 12 Estimation method for peak-discharge frequency for each return period*




3.3.2.1 Return period of rainfall

Design rainfall in the current flood control management of Japan is generally calculated by following steps. Firstly, observed annual maximum rainfall was fitted to several probability distributions which are candidate for estimation on design rainfall. Then, a probability distribution which has highest level of stability and goodness of fit is selected, and design rainfall as a quantile value corresponding to target annual exceedance probability "*p*" in this selected distribution is obtained. A probable rainfall corresponding to exceedance probability "*p*" means that occurrence probability of rainfall which exceeds this probable rainfall in a year becomes "*p*". Also, return period is defined as reverse inverse number of exceedance probability in an adopted probability distribution, and becomes an important index in flood control management. Flood control management of main river basins in Japan adopted a return period ranging from 100 year to 200 year as design level.

However, the observation period of hydrological quantity in major river basins of developed countries ranges from a few decades to more than a hundred years. It shows the observation period is shorter than the design return period of flood prevention facilities. In other words, when using the annual maximum data, the number of observed extremes ranges from a few dozen to a hundred at most, so that the estimation of design conditions in the conventional hydrological frequency analysis contains large uncertainty (estimation error). Since ensemble climate data provides a lot of samples of rainfall based on dynamical models which verifies physical feasibility of calculated meteorological phenomenon, the uncertainty of the probable rainfall can be quantified as a frequency distribution. To quantify the uncertainty, resampling to ensemble data was conducted in this study.

Resampling of annual maximum heavy rainfall obtained from a large ensemble climate dataset was conducted to clarify the frequency distribution of the probable rainfall. By applying resampling, 100,000 samples were generated in the climate experiment. For derivation of frequency distribution of T-year probable rainfall, Gumbel distribution was fitted to each of the 100,000 resampled samples from the past and the 4 degree Celsius warmer climate condition. In other words, we estimated 100,000 Gumbel distributions fitted to the maximum annual 72-hour rainfall for 60 years, which gives 100,000 sets of T-year probable rainfall for a given return period and allows us to estimate its frequency distribution. Because of using a climate model, introduced resampling method can be interpreted as a physical Monte Carlo experiment. Here, the cumulative distribution function of the Gumbel distribution is shown in equation (1).

$$F_X(x) = \exp\left[-\exp\left\{-\left(\frac{x-\mu}{\sigma}\right)\right\}\right] \qquad (1)$$

Where, $F_X(x)$ is cumulative density distribution of Gumbel distribution, $x$ is annual maximum rainfall, $\mu$ is location parameter, σ is scale parameter.

#### 3.3.2.2 Rainfall-Peak discharge relation

The frequency distributions of peak discharge as a function of rainfall volume were estimated by using quantile regression. The peak discharges have a range even if the same rainfall volume due to differences in spatio-temporal rainfall patterns. The relation between rainfall volume and peak discharge is represented as a function. The peak discharge range is quantified as percentile values using quantile regression and each quantile value from 1st to 99th percentile were extracted for each rainfall volume. The obtained 99 discharges were used to make frequency distribution of peak discharge. By applying quantile regression, the conditional probability distribution of peak discharge which is caused by an arbitrary amount of rainfall can be calculated.

#### 3.3.2.3 Return period of peak discharge

The frequency distributions of peak discharge for each return period were estimated. The frequency distribution of rainfall volume for each return period obtained by step 1 and the frequency distribution of peak discharge for each rainfall volume obtained by step 2 are used to calculate frequency distribution of peak discharge for each return period. Each bin (section in histogram) of rainfall volume has a frequency distribution of peak discharge. The frequency distribution of peak discharge is expressed as equation (2).

$$f_{Q_p}\left(q_p, T\right) = \int_r f_{Q_p}\left(q_p \mid r, T\right) f_R\left(r, T\right) dr \tag{2}$$

where $T$ is target return period, $Q_p$ is peak discharge, $R$ is rainfall volume, $f_{Qp}(q_p|r)$ is the conditional probability density function of the peak discharge that can occur under a given rainfall volume $r$, $f_R(r)$ is the probability density function of rainfall volume, and $f_{Qp}(q_p)$ is the probability density distribution of the peak discharge.

In this study, a Gumbel distribution is fitted to a set of probable rainfall values derived from the resampling method described above to construct a continuous distribution of a probable rainfall $f_R(r,T)$ for any given return period $T$. The Gumbel distribution is also applied to a set of calculated peak discharge values obtained for a given total rainfall value r, which can be derived from a relation between total rainfall in arbitrary period and calculated peak discharge, to construct the conditional distribution of peak discharge, $f_{Qp}(q_p|r)$. Equation (2) is the probability distribution of the peak discharge $f_{Qp}(q_p,T)$ under the total rainfall for a given return period $T$ as $f_R(r,T)$, which can be derived by a following process. $f_{Qp}(q_p,T)$ is weighted average of the conditional distribution of peak discharge under given rainfall value $f_{Qp}(q_p|r)$, which distribution of rainfall $f_R(r,T)$ is derived from d4PDF-5km.

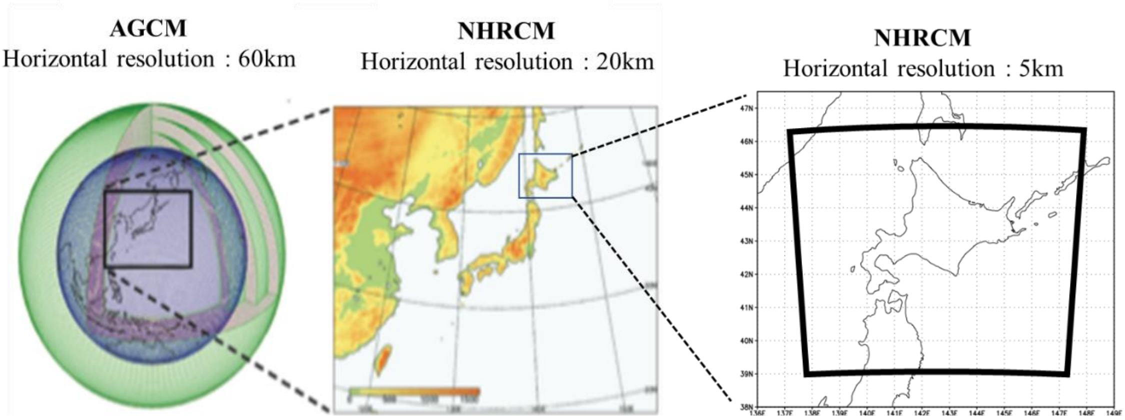
The above method for the probability peak discharge integrates the conditional distribution expressed by the relationship between the total rainfall and the peak discharge obtained from the rainfall-runoff model, and the distribution of the probable rainfall itself from the ensemble climate data. In other words, the method is capable of updating the probability distribution of the output peak discharge as the climate model and rainfall-runoff model differ or become more sophisticated.

### 3.3.3 Large ensemble climate data

In recent years, a large-ensemble climate simulation database (d4PDF) (Mizuta et al, 2017) has been created and utilized by the research project of the Ministry of Education, Culture, Sports, Science, Japan (SOUSEI, TOUGOU, SI-CAT, DIAS) and JAMSTEC Earth Simulator Special Promotion Projects. Using d4PDF and its extensive data on past, current and future climate, it is possible for the first time to assess the frequency of rare weather phenomena which lead to disasters. The original d4PDF is consisted of simulations from the atmospheric GCM (AGCM) called the Meteorological Research Institute AGCM, version 3.2 (MRI-AGCM3.2) (Mizuta et al, 2012) with a horizontal resolution of approximately 60 km (d4PDF-60km), and dynamical downscaling (DDS) from d4PDF-60km to a horizontal resolution of 20 km using the Regional climate model (RCM) targeted over Japan (regional experiment of d4PDF) (hereafter, d4PDF-DS20) (Figure 13). The experimental settings of d4PDF consist of a past climatic condition (hereafter past experiment; 50 ensembles×60 years (1951–2010)) and a 4 ℃ warmer climatic condition (hereafter +4K warmer experiment; 6 sea surface temperature patterns×15 ensembles×60 years), which has a 4 ℃ warmer global mean air temperature than the preindustrial period. The sea surface temperature

(SST) used in the past experiment was obtained from the Centennial Observation-Based Estimates of SST, version 2 (COBE-SST2) (Hirahara et al., 2014). Small perturbations based on SST analysis error were added to initial conditions of the SST to prepare ensemble members. The SST used in the +4K experiment consists of the six patterns based on RCP8.5 experiments conducted under the phase 5 of the CMIP5 (Taylor et al., 2012). The details of experimental settings of the d4PDF are presented in Mizuta et al. (2017). Moreover, dynamical downscaling (DDS) was applied to d4PDF-DS20 for conversion of annual maximum rainfall events from d4PDF-DS20 to a horizontal resolution of 5 km. The target rainfall event was defined as an event in d4PDF-DS20 for each year, between June 1 and December 1, where rainfall amounts reached the maximum value in 72 h over the Tokachi river Obihiro reference point basin. This study defined the rainfall events as annual maximum rainfall events. For DDS, we employed the NHRCM (Sasaki, 2008), which was used to make the d4PDF-DS20. We set the target area of the DDS to 800 800 km around Hokkaido (Figure 13). Furthermore, we set the number of calculation grids to 161 161 in the horizontal direction and 50 in the vertical direction. The Kain-Fritsch convective parameterization scheme (Kain et al., 1993) was used for the DDS. The other physical schemes, such as microphysics, land surface, and boundary layer schemes, were the same as those used in Kawase et al. (2018). The grid-mean topography was used in this study, while Kawase et al. (2018) used the envelope-type mountains. This study utilized values from the d4PDF-DS20 to set the initial and boundary conditions for the calculation. The target period for the DDS was set to 15 days, including the annual maximum rainfall occurrence period in each year. The DDS was performed for a total of 3000 events for the past experiment and 5400 events for the +4K experiment. Yamada et al. (2018) verified the validity of d4PDF-5km in terms of heavy rainfall characteristics.

*Figure 13 Downscaling process in d4PDF*




## 3.3.4 Hydrological model

This section describes the rainfall-runoff models selected by the two countries. The characteristics of rainfall and peak discharge represented by these physical models allow us to evaluate uncertainty of model calculation.

### 3.3.4.1 Wflow_sbm

Wflow_sbm is a physically based bucket-style hydrologic model based on simplified physical relationships and it uses kinematic wave surface and subsurface routing for lateral transport. The wflow_sbm model is a fully distributed hydrological model, allowing the use of high-resolution spatial input data. This makes the model well suited for the use of high-resolution climate model output. The wflow model is Open Source and freely available.

#### 3.3.4.2 MATSIRO

The Minimal Advanced Treatments of Surface Interaction and Runoff (MATSIRO) (Takata et al., 2003) is also used here. MATSIRO can simulate the exchange of water vapor, energy, and momentum between the land surface and atmosphere on a physical basis. The interaction between atmosphere and land surface can be simulated by this model with a general circulation model (GCM). MATSIRO has been used for various impact assessments of the hydrological cycle, such as the impact of human activities (Pokhrel et al., 2017) and groundwater impacts (Koirala et al., 2014). Recently, a system for estimating condition of land surface and river in real time has been developed and operated (Today's Earth). This system consists of MATSIRO and river routing model CaMa-Flood. Meteorological forecast and observation data are used as input data of the system to estimate the risk of water-related disasters on a global scale. MATSIRO solves the surface and sub-surface runoff by considering four runoff types; the base flow, the saturation excess runoff (Dunne runoff), the infiltration excess runoff (Horton runoff), and the over flow of the uppermost soil layer. The first three runoff types are calculated by applying a simplified TOPMODEL (Beven and Kirkby, 1979), which assumes the subgrid-scale slope profile.

#### 3.3.4.3 RRI model

The RRI model was employed to simulate flood inundation and identify flood-prone areas. The RRI model is a two-dimensional model that is capable of simulating rainfall–runoff and flood inundation simultaneously (Sayama et al., 2012, Sayama et al., 2015). At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell. The channel is discretized as a single line along its centerline of the overlying slope grid cell. The flow on the slope grid cells was calculated with the 2D diffusive wave model, whereas the channel flow was calculated with the 1D diffusive wave model. The RRI model simulates the lateral subsurface, vertical infiltration, and surface flows to better represent flood characteristics.

## 3.4 Part 2: Failure probability of levees

In flood control planning in Japan, calculations are based on the condition that a breach will occur if the water level exceeds the planned water level. The probability is evaluated as 0 or 1, whether the water level will be exceeded or not. However, the actual phenomenon of breaching is that the water level may reach the planned water level but not breach, or the water level may not reach the planned water level but breach occurs. This is due to various factors such as the mechanism of levee failure, strength of the levee, and temporal changes in hydraulic conditions. Probabilistic assessment of levee failure is essential for the correct assessment of flood risk.

In the Netherlands, flood risk has been assessed based on the probability of levee failure using a fragility curve, which has been introduced into policy. In this study, the Dutch method of calculating the probability of breaching is applied to the Tokachi River basin, and a method of creating a fragility curve is proposed, with some modifications based on the characteristics of floods in Japan.

There are several factors that can cause levee breaches. In Japan, the factors are generally divided into overflow, erosion/ scour, and seepage. In 2019, typhoon No. 19 caused floods in Japan and breaches of levees occurred in many places, including 14 on rivers managed by the national government and 128 on rivers managed by prefectural governments. According to the results of a survey on the causes of breaches, overflowing water was the main cause of 86% of the breaches.

In this study, the probability of levee breakage was calculated for overflowing water, which is one of the most frequently reported causes of levee breakage in Japan.

### 3.4.1 Overview of Approach

The method applied in this study is based on VNK2[2] and the Dutch method for dike safety assessment, called the BOI[3]. We did however improve some parts of the method:

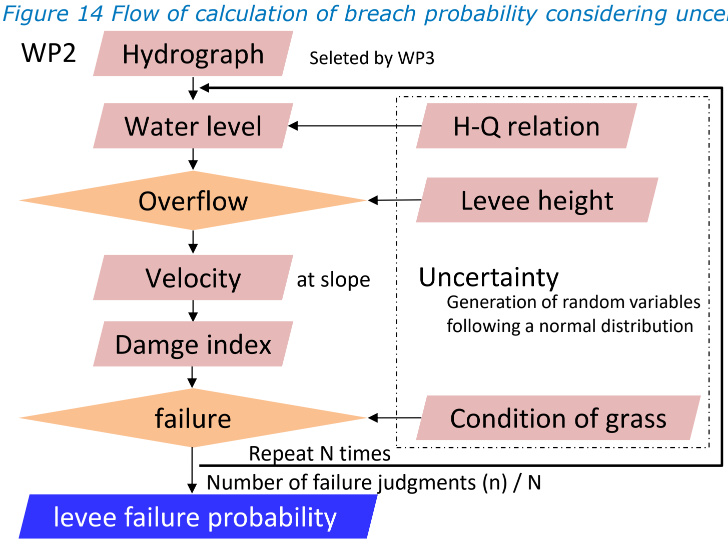
- Only the failure mechanism overtopping was considered, as it is considered the most important for Obihiro. We applied a cumulative damage approach, to take into account the duration of the hydrographs:

- Not only the probabilities of the peak discharges are considered, but also the shape of the hydrograph. A high water level with a long duration gives a higher failure probability, as it can cause more damage to the revetment.

- When calculating the total failure probability for the area, we use a tailored approach to take dependencies between different dike sections into account.

  1. Failure probabilities are combined conditional to the discharge, as different sections would fail during the same high discharge conditions.
  2. For combining segments into section probabilities, the maximum segment failure probability per discharge is used, hence, the segments are considered dependent.
  3. When combining sections to river probabilities, the reducing effect of potential failure of upstream sections is taken into account.

*Figure 14 Flow of calculation of breach probability considering uncertainty.*

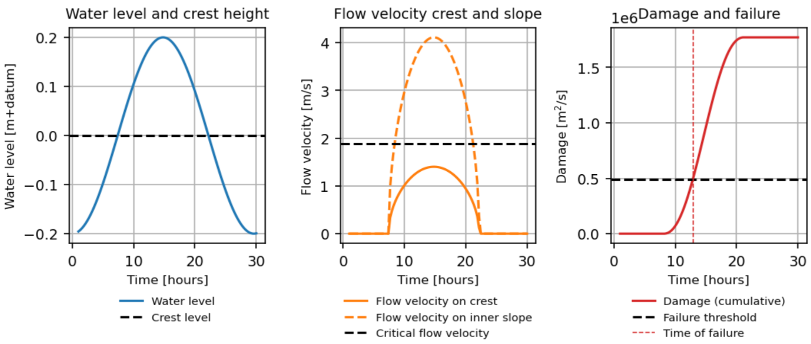



[2] Rijkswaterstaat VNK Project Office, The National Flood Risk Analysis for the Netherlands -FINAL REPORT, 2016, https://www.helpdeskwater.nl/publish/pages/131663/vnk-rapport-eng-lr.pdf .
[3] https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/beoordelen/nieuwsbrieven/nieuwsbrief-landelijke-beoordeling/nieuwsbrief-boi-oktober-2019/programma-boi-2023/

### 3.4.2 Fragility curve

In this study, we focused on the mechanism of levee failure caused by overflowing water and adopted a method to determine the occurrence of levee failure based on the damage caused by erosion of the levee slope by overflowing floodwaters.

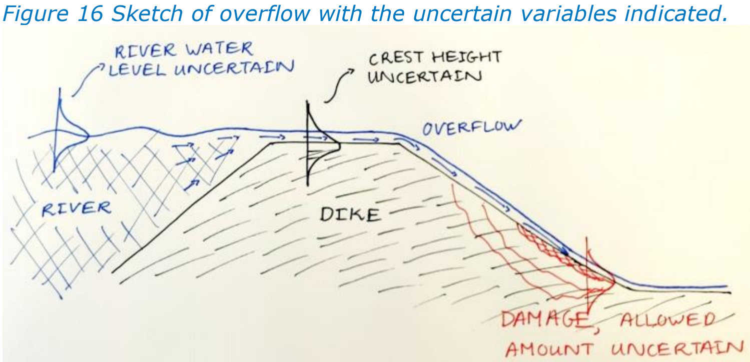
*Figure 15 Example of calculating damage due to overflow with a cumulative overtopping approach.*




### 3.4.3 Uncertainty

The following image shows the different uncertainties we want to take into account when considering the failure mechanism overflow: the damage (or critical overtopping velocity, as described in the last section), the water level and the crest height.

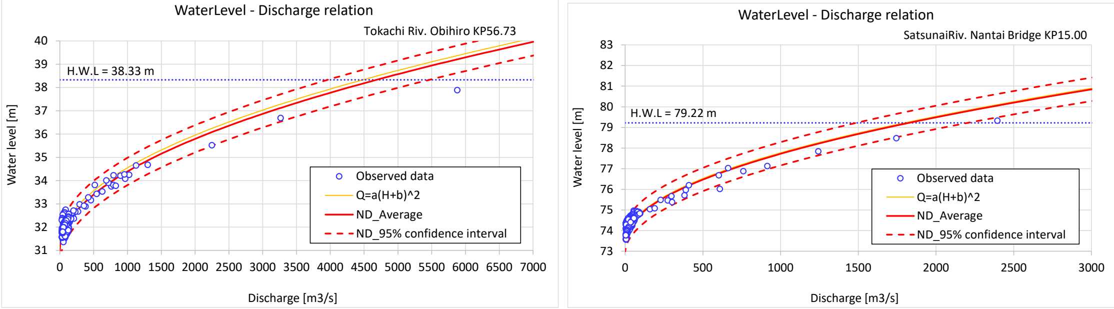
*Figure 16 Sketch of overflow with the uncertain variables indicated.*




1. Water levels

Uncertainty in river levels was evaluated based on the relationship between water levels calculated from HQ-relations and water levels observed in the field in the target river. Observations were collected at Obihiro, Tokachi River (KP56.73) and Nantaibashi, Satsunai River (KP15.00). The data are available for five years from 2014 to 2018. Observations were carried out once a week or during runoff. The difference between the observed water level and the water level calculated from H-Q-relation to the observed flow was calculated. The mean and variance of this difference were used to evaluate the uncertainty.

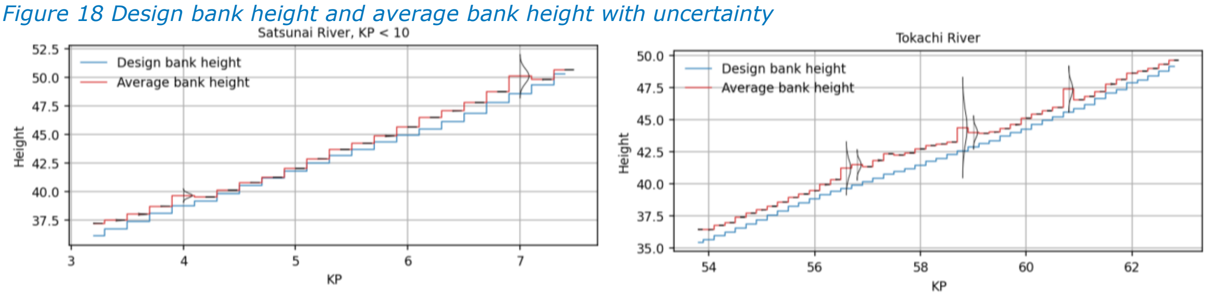
*Figure 17 Calculation of water level dispersion at Obihiro point (KP56.73) and Nantaibashi point (KP15.00)*




2. Bank Height

The planned high water level set in the river plans for the Tokachi River and the Satsunai River is defined as the "design bank height. The height of the top of the embankment is organized longitudinally based on the ground level data (LP data) obtained from aerial laser surveying, and the mean value and standard deviation are calculated every 0.2 km in the longitudinal direction of the embankment to be used as the uncertainty of the embankment height. The levee height and LP data in the plan were provided by the Hokkaido Development Bureau.

*Figure 18 Design bank height and average bank height with uncertainty*




3. Critical flow velocities

In the approach described above, provided by Dean et al. (2010), the standard deviations of the critical flow velocities are given. These can be used to quantify uncertainty on the strength side:

- For "plain grass - good cover": u_cu_c = 1.80, σ_(u_c ) = 0.38
- For "plain grass - average cover": u_c = 1.30, σ_(u_c ) = 0.12
- For "plain grass - poor cover": u_c = 0.76, σ_(u_c ) = 0.04

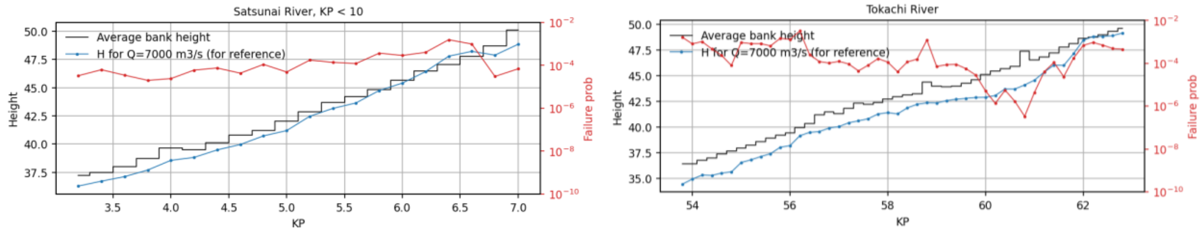
In our approach, the condition of plain grass is "good cover" because the dykes in the Tokachi River are properly managed.

The different uncertainties (random variables) can be combines into a single fragility curve. We used Monte Carlo simulations to calculate a fragility curve that takes into account uncertainty.

### 3.4.4 failure probability

The failure probabilities of levees in the Tokachi River and the Satsunai River were calculated. The failure probabilities were calculated at intervals of about 0.2 km. As a result, the failure probability of the levees of the Satsunai River ranged from about 10-5 to 10-3. The failure probabilities of the levees of the Tokachi River were in the range of 10-5 to 10-3, as in the case of the Satsunai River, although they varied greatly by location.

Figure 19 Failure probability per location (KP).




1. Combine segments to sections

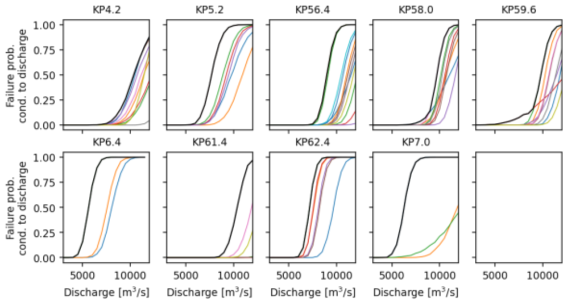
Until now, the failure probabilities where calculated for a levee segment. In this section we combine the failure probabilities from segments, to sections, to the whole of Obihiro. When doing so, we want to avoid counting the consequences of the same flood scenario multiple times. This means that a failure of one segment, reduces the failure probability of a next section, unless the conditions for which they fail are independent. Combing the failure probabilities thus means we make a realistic choice between combining probabilities dependent and independent.

- First of all, we combine the probabilities conditional to the discharge. This means we assume that a single high discharge causes a high water level along all flood defenses. This might be a little simplified for the two rivers (Satsunai and Tokachi), but is probably a very realistic simplification, as the high water levels are caused by the same rain event.
- Secondly, segments are grouped into sections based on similar consequences. Because these sections are close to each other, we assume the strength to be dependent. This means that the dike will always fail at the segment with the highest failure probability (for that discharge).
- Thirdly, sections are combined per river branch independently (still conditional to discharge), but we take the order of the sections into account. Sections are far enough apart for the strength of the dike to be considered independent. However, when an upstream sections has failed, we assume the water level to be reduced such that the downstream dikes cannot fail anymore during this event.

2. Combining segment probabilities to sections

The result of combining segment probabilities to sections is shown in the figure below. Per discharge the maximum failure probability is selected, resulting in the black curve. For most sections a single segment is dominant, only for section KP59.6 (lower left in Figure X) two sections result in a combined fragility curve.

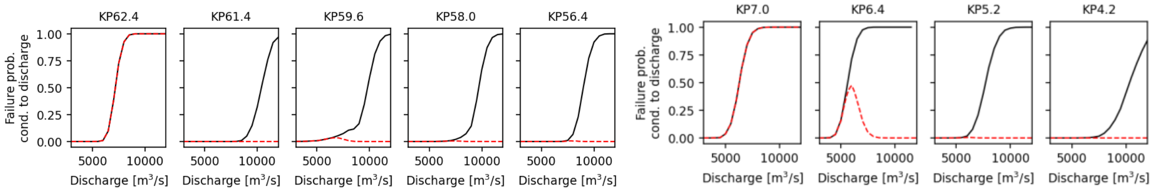
Figure 20 Fragility curves for all segments (coloured), and the combined section curve (black).



3. Combining section probabilities per river branch

The result of combining section probabilities per river branch, is shown in the two figures below. The black curves are the original section curves, independent of upstream sections. The red dashed curves are after taking potential failure of upstream sections into account. The highest discharges will certainly lead to upstream failure, reducing the conditional failure probabilities downstream for these discharges. Therefore, downstream sections will only fail at relatively low discharges, especially if the section has a higher failure probability.

*Figure 21 Fragility curves for all sections of Tokachi river, before and after taking the effect of upstream sections into account.*




## 3.4.5 Flood probabilities

The flood probability was calculated using the failure probability calculated and the probability of water level exceedance calculated in WP1. The flood probability was calculated for each section set in WP3.

*Table 1 Past, average/ Failure probabilities for the sections used in WP3. The scenario probabilities are the failure probabilities after correcting for upstream failure.*

| Location | Section failure probability | Scenario probability |
|---|---|---|
| Satsunai KP7.0 | 2.53e-05 | 2.53e-05 |
| Satsunai KP6.4 | 5.67e-05 | 3.79e-05 |
| Satsunai KP5.2 | 4.62e-06 | 1.45e-07 |
| Satsunai KP4.2 | 3.00e-07 | 6.52e-10 |
| Tokachi KP62.4 | 1.41e-04 | 1.41e-04 |
| Tokachi KP61.4 | 3.36e-04 | 9.93e-07 |
| Tokachi KP59.6 | 1.21e-03 | 5.36e-04 |
| Tokachi KP58.0 | 6.62e-04 | 4.49e-05 |
| Tokachi KP56.4 | 2.04e-02 | 1.06e-02 |

*Table 2 Future – average/ Failure probabilities for the sections used in WP3.*

| Location | Section failure probability | Scenario probability |
|---|---|---|
| Satsunai KP7.0 | 8.87e-04 | 8.87e-04 |
| Satsunai KP6.4 | 1.42e-03 | 6.52e-04 |
| Satsunai KP5.2 | 3.26e-04 | 2.75e-06 |
| Satsunai KP4.2 | 6.11e-05 | 3.37e-08 |
| Tokachi KP62.4 | 5.46e-03 | 5.46e-03 |
| Tokachi KP61.4 | 9.52e-03 | 5.72e-06 |
| Tokachi KP59.6 | 1.55e-02 | 2.07e-03 |
| Tokachi KP58.0 | 1.37e-02 | 2.56e-04 |
| Tokachi KP56.4 | 7.53e-02 | 1.60e-02 |

## 3.5 Part 3: Damage, evacuation, loss of life and flood risk

In part 3 the flood consequences for the Obihiro case study are shown. For all aspect, economic damage, evacuation, loss of life and flood risk an overview of the approach and results are given. The more extensive analysis and detailed description are included in report, "Flood Risk and Climate Change Hokkaido WP3, 2021".

### 3.5.1 Economic damage

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.

For the Obihiro Case study the damages are calculated for the current situation and the situation including climate change. In the situation with climate change more extreme discharges can occur leading to an increase in flood consequences. Next to the impact of climate change also the shape of the discharge wave has an impact on the flooding and the calculated damage. 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 current "past" situation and the lower figures for the situation including climate change "future". The three damage calculations per scenario show the impact of the difference in discharge wave. "Max discharge" means a discharge wave with a very high peak, the "Min discharge" means that the peak of the discharge wave is slightly above the levee height and the "Max Volume" is a discharge wave that is relatively wide.

*Figure 22 Damage (Satsunai Riv. KP4.2)*


The damage calculation has been done for all breach locations used in the flood risk analysis. In Table 3 the calculated damage per breach location is given. The table gives insight in the extent of the flood damage and the difference between the different locations and the impact of the different shape.

*Table 3 Economic damage for "past" and "future" scenarios*

| | 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 |

These economic damages are the potential damages that can occur when a levee breaches. He impact of climate change on the calculated damage is for the max scenarios a factor 1.5 - 3. For some breach locations the shape of the hydrograph has a similar effect on the calculated damage and for some location the impact of the shape of the discharge wave is even larger.

### 3.5.2 Evacuation

Evacuation is an important factor when determining loss of life, because it gives insight in the location of people prior and during a flood event. For the case study the definition of the evacuation rate is the ratio of the people that reach a safe location. The destinations are not only shelters, but also other safe places, such as higher ground and relatives / friends' home.

An important factor is the lead time. The lead time describes the time available to reach a safe location. For the case study the lead time is determined by a standard throughout all available real cases (86), 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. Lead time required for safe evacuation is estimated by distance between home and shelters and walking speed while evacuating.

Figure 23 Concept of lead time

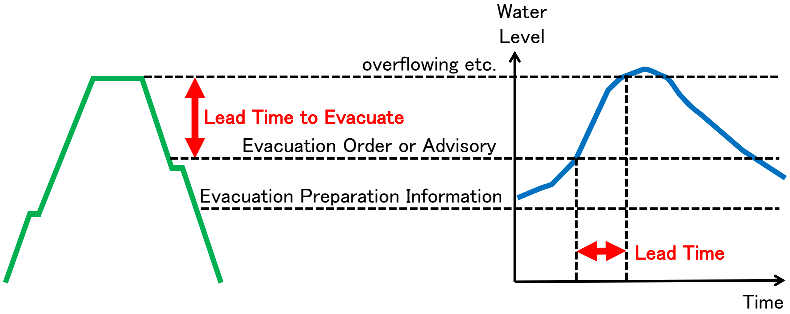
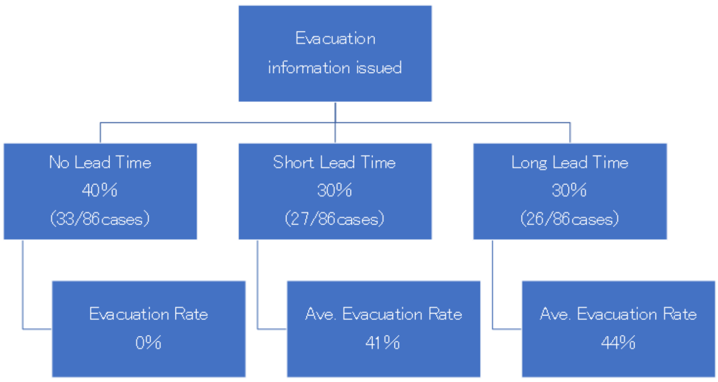



Figure 23 shows a simple event tree, created according to lead time. Each ratio of the middle layer, No lead time, Short lead time (less than 3 hours) and Long lead time (3 hours and more), indicates ratio per scenario with population parameters of cases collected for this project. The lower layer shows 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.

Figure 24 Simple event tree based on lead time




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

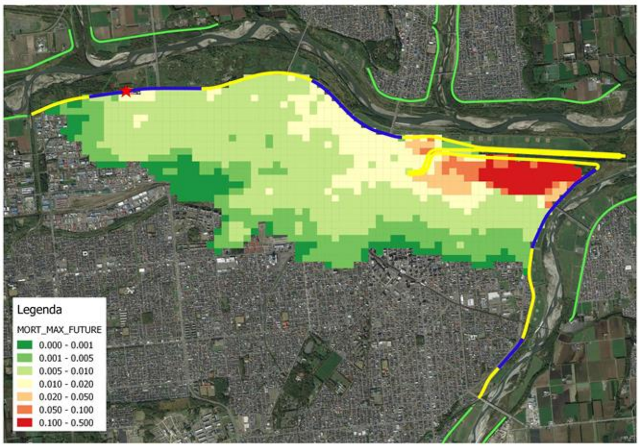
### 3.5.3 Loss of life

There are different models to calculate the loss of life for a flooded area. For instance there is the LIFESim model developed by the United States Army Corps of Engineers (USACE). This model determines mortality dependent on water depth, taking into account age of victims (65 years and older/younger than 65 years). Fatality is estimated by multiplying mortality classified into 3 areas, 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.

Another model is the Dutch model. This model sues mortality functions related to flood characteristics. The flooded area is divided 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. For the Obihiro case study the Dutch loss of life model is used.

For the different breach locations, the flood extent and flood characteristics are used to determine the mortality at the flooded area. This is used to determine the mortality at all locations. For breach location KP61.4 the mortality rate is shown in Figure 25, 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 25 Mortality MAX scenario KP61.4*




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 (Exp), this is also included in the table.

*Table 4 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 is larger than the Satsunai river and therefore leads to a larger flood extent and more people exposed.

### 3.5.4 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 the risk analysis the difference in risks between the current situation "past" and the situation including climate change "future" are shown and also the impact of the shape of the discharge waves on the results.

#### 3.5.4.1 Economic Risk

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.

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 Yen/year. This economic risk is dominated by breach location KP56.4 and is caused by a relatively high probability of failure.

*Table 5 Economic Risk for each breach location and the total economic risk for the "past" situation*

| Location | Flood probability (Pf) | Damage (Yen) | Economic Risk (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** | | | **3,729,38** |

When climate change is taken into account, the failure probability and the amount of damage increases and therefore the economic risk increases as well. The expect value of the economic damage increases to 20,464 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.

#### 3.5.4.2 Risk Loss of Life

The expected value of loss of life gives insight in the average number of fatalities per year due to flooding. To determine the impact of climate change the results are shown for the current situation "past" and the situation including climate change "future". The expect value for the current ("past") situation 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. In all analysis regarding loss of life the average evacuation percentage of 26 percent is used.

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. 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.

The local individual risk gives insight in the annual probability that an individual will die in a particular location, including the effect of evacuation probability. 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.

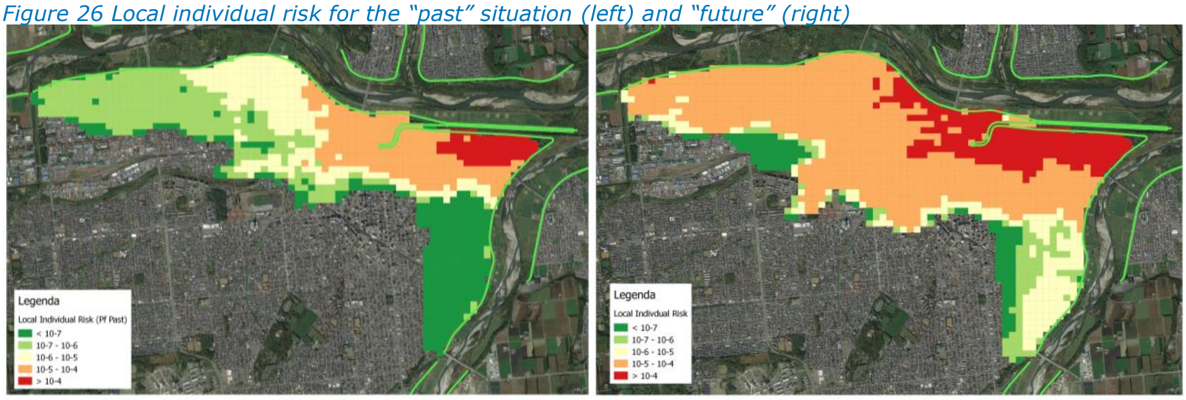
The local individual risk is calculated by the following formula:

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

$$n = breach\ locations$$

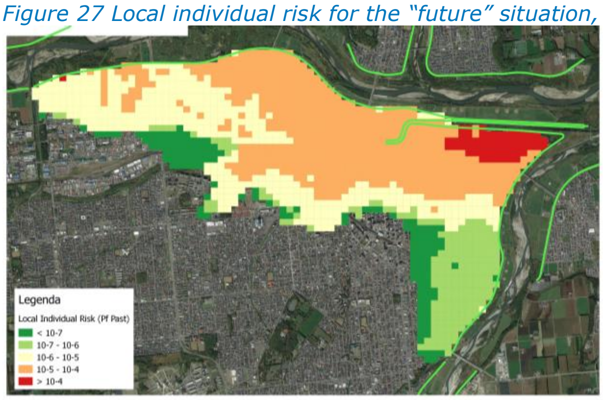
The figure below shows the local individual risk for the current "past" situation. The riskier places are situated in the deeper parts of the case study area and are consistent with economic risks. When climate change is included the scenario flood probabilities increase and also the flood extent and flood characteristics increases. The increase in flood extent and flood characteristics lead to an increase in mortality. The flood extent is larger than the "past" situation and also the risks are higher, this is shown in the right figure.

*Figure 26 Local individual risk for the "past" situation (left) and "future" (right)*




The local individual risk is in the basic analysis calculated with the average evacuation percentage, 26%. When this percentage increases the local individual risk will decrease. In Figure 27 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 27 Local individual risk for the "future" situation, 80 percent evacuation*



# 4 Main findings

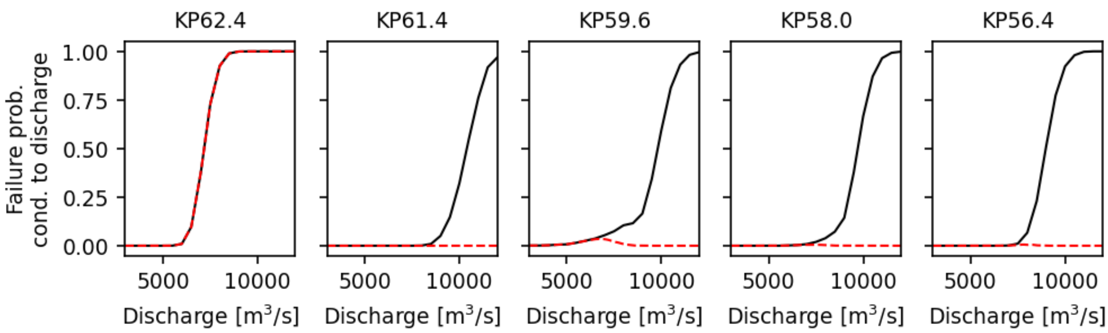
## 4.1 Application of the method

In the research we succeeded in compiling discharge statistics based on extreme rainfall, subsequently determining failure probabilities using fragility curves and mapping the consequences of a flood in terms of damage, casualties and risk. The method can be applied to other river and delta systems. In chapter 5 we also discuss some recommendations.

The main challenge in compiling the discharge statistics is dealing with uncertainties in the water system and rainfall patterns, which leads to a relatively large uncertainty band around the derived discharge statistics.

This uncertainty also has a direct influence on the determination of failure probabilities by means of fragility curves. The analysis determined the failure probability for erosion of the flood defense system as a result of overflow/overtopping. First, the fragility for the different breach locations without dependencies between the breach location was determined (black lines in Figure 28) and then the dependencies between the different breach locations were included (red lines in Figure 28). This means that the more downstream breach locations have a smaller chance because an upstream breach has a reducing effect on the chance of a downstream breach. Due to the inclusion of these dependencies, the probabilities vary between 1/100 per year for the more upstream breach locations to less than 1/100,000 per year for the more downstream locations.

*Figure 28 Fragility curves for one location*

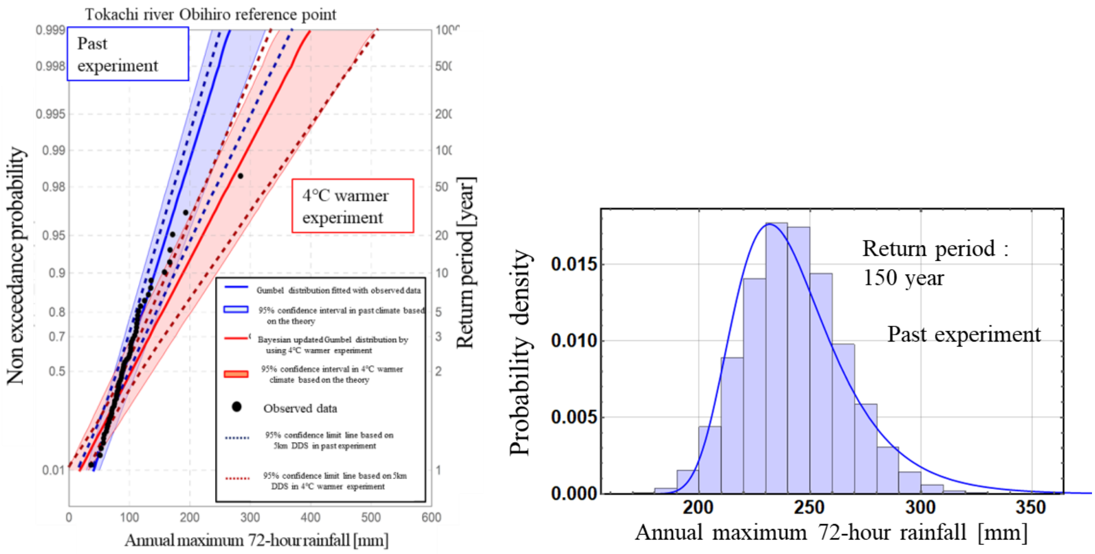



To determine the flood risks, the probabilities per breach locations are combined with the consequences of the floods. For this purpose, both the economic damage and the number of casualties per breach location were determined. In addition to the economic risk (euros per year) and the casualty risk (chance of casualties per year), the local individual risk (LIR) has also been determined. The LIR describes the chance at a certain location of becoming a victim of a flood. .

### 4.1.1 Hydrology and Hydraulics

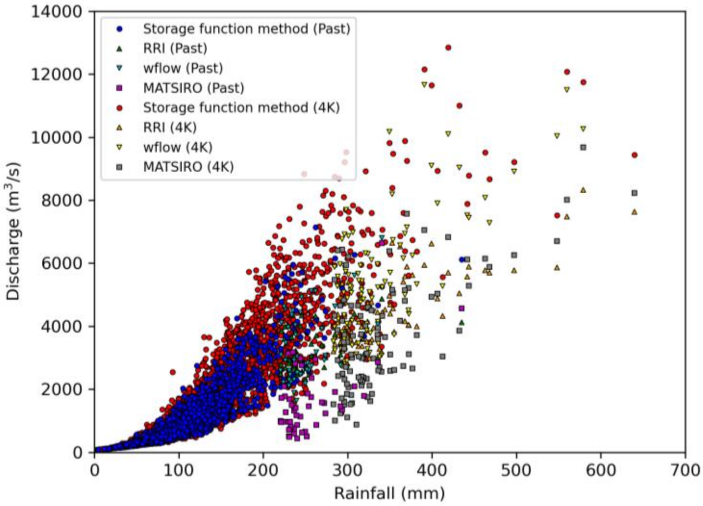
Figure 29 shows the confidence intervals of the probable rainfall in the Tokachi river basin for the past experiment and the 4K warmer experiment. In this figure, the black dots represent the observed maximum annual basin-averaged 72-hour rainfall, and the solid blue line is the Gumbel distribution that these observations are assumed to follow. In addition, the blue and red areas are the confidence intervals of the probable rainfall for the past and future climate, respectively. The confidence intervals for the past and future climates are constructed using a physical Monte Carlo method described in section 3.3.2. Number of calculated maximum annual rainfall in each sample is the same as observation. The existence of the purple overlapping area between the two intervals indicates that heavy rainfall events with the same return period, but with different frequency, can physically occur in both climates where the global average temperature differs by 4K. The results of the probability assessment based on ensemble climate data are also supported by statistical theory, and research results have been obtained to ensure its scientific validity (Shimizu et al., 2020). In this study, we adopted the probability limit method (Moriguti, 1995), which allows us to derive the statistical threshold of rainfall that can occur under the assumed probability distribution of maximum annual rainfall, and constructed confidence intervals based on this test. The blue and red dotted line in Figure 29. Figure 29 show the width of the confidence interval based on this theory. The figure shows that the confidence intervals based on the ensemble climate data and the confidence intervals based on probability limit method coincide with each other very well for both past and future climates. The coincidence of the confidence intervals constructed independently from the physical Monte Carlo calculations and the probability limit method supports the mathematical validity of the present study.

*Figure 29 Left: Confidence interval of probable rainfall derived from d4PDF-5km (Shimizu et al., 2020). Right: Frequency distribution of 150-year annual maximum 72-hour rainfall in past experiments (blue bins) and the probability density function f R(r,150) of the Gumbel distribution fitted to the frequency distribution (solid blue line).*




The relationship between the rainfall volume and the peak discharge is determined based on spatio-temporal rainfall patterns and differences of runoff model and its parameters. The scatter plots of rainfall volume and peak discharge from different runoff models are shown in Figure 30. Note that the runoff models which described in 3.3.4 adopted default parameters and initial conditions. Although the parameters need to be adjusted for practical use, this setting was used because the purpose of this study was to propose a method to realize evaluation based on the differences in models. The proposed method can estimate peak discharge distribution at each return period in consideration of multiple runoff models by applying the regression curve to the rainfall-peak discharge relationship for each runoff model or for the combining result of runoff models. In the following part, the return period of the peak discharge is estimated according to the relationship between rainfall volume and peak discharge of single model.

Figure 30 Relationship between annual maximum 72-hour rainfall and peak discharge estimated by the different runoff models at the reference point in the Tokachi River basin




The relationship between the annual maximum 72-hour rainfall and the peak discharge for each experiment and the estimated quantile regression curves are shown in Figure 31. Figure 31 also shows derivation process of the probability distribution of the 150-year peak discharge in the past experiment and the 4K warmer experiment based on result of single model. Also, Figure 32 comparison of the probability density function of the 150-year peak discharge for the past experiment and the 4K warmer experiment. The shape of the probability distribution is shifted under different climatic conditions. The multiplier of future change is 1.88 for the expected value and 2.04 for the 95% upper confidence limit of the 4K warmer experiment and the past experiment.

The 150-year peak discharge based on this method were calculated at the Obihiro, Satsunai, Bisei and Otohuke River confluences point. These probable peak discharges can be used as a starting point for the evaluation of water levels caused by flows equivalent to the planned probability scale, the evaluation of the probability of overtopping and levee breaching, and the quantification of human and economic risks.

Figure 31 Process of deriving the T-year probability peak flow rate in the past experiment (left) and the 4K warmer experiment

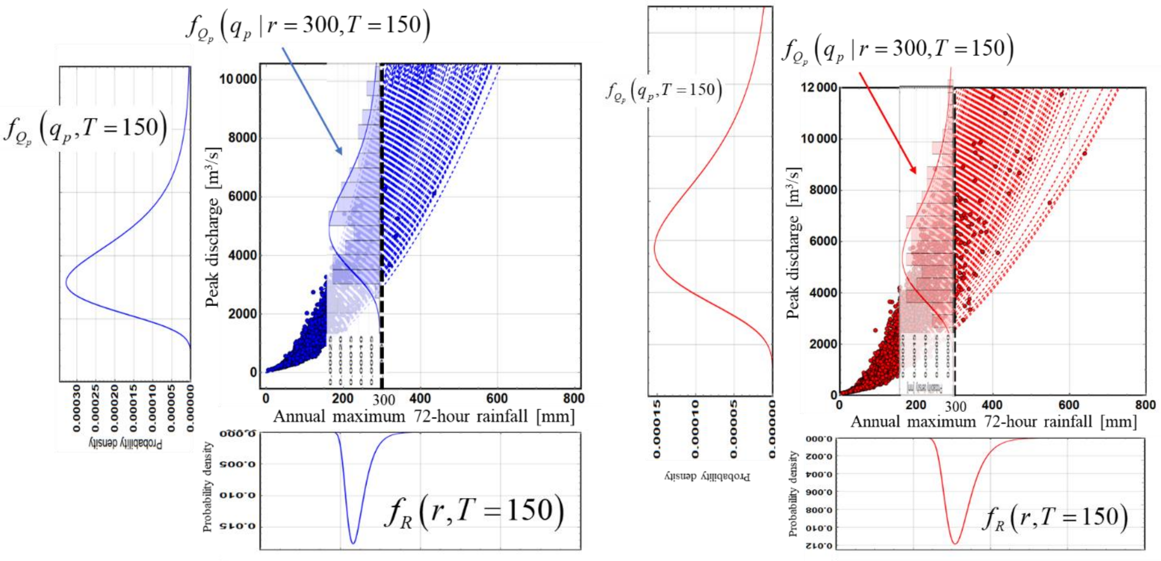
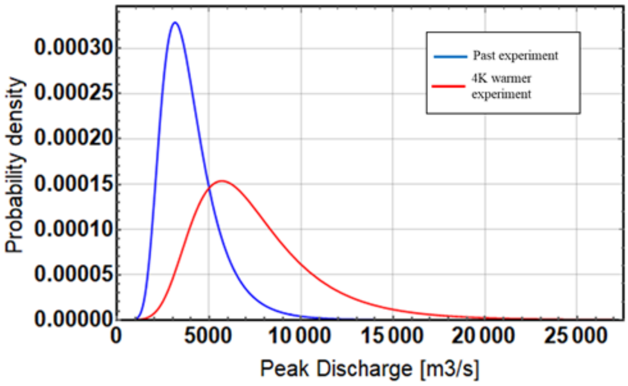


*Figure 32 Comparison of the probability density function of the 150-year probability peak flow rate for the past experiment and the 4K warmer experiment.*




### 4.1.2 Failure of Levees

According to the calculation results of the probability of levee failure, the probability of levee failure near KP60.8 of the Tokachi River is small, about $10^{-6}$. This may be due to the fact that this section includes a bridge and is relatively high compared to the sections before and after it. On the other hand, the probability of levee failure near KP58.8 of the Tokachi River is relatively higher than that of the sections before and after it. Although the average height of the embankment is high due to the inclusion of the bridge, the difference in the height of the embankment between the bridge and the section before and after the bridge is large, and the uncertainty of the height of the embankment within the section is thought to have influenced the increase in the probability of embankment failure. This point needs to be accurately evaluated in the future by assessing the uncertainty as only positive variability.

The results of the uncertainty sensitivity analysis indicate that the water level-flow relationship has a significant effect on the probability of levee failure at the target locations. The relationship between water level and flow is due to the temporal changes in the riverbed topography. It changes with each outflow as well as with time during the outflow. This result is considered to represent the flood characteristics of the target watershed, which is characterized by high flow velocity and large water level changes.

Three uncertainties are taken into account in the probability of levee failure. It is unclear how much influence this uncertainty has on the risk assessment in WP3. If the impact on the outcome of the risk assessment is small, the uncertainty here may be negligible. On the other hand, if the impact is large, it may be necessary to reconfirm the factors that cause uncertainty and conduct sensitivity analysis of the data. In the future, we believe that a sensitivity analysis of the uncertainty of the calculation results of each WP to the risk assessment results should be conducted.

As for the flood probability, within a section of the same river with the same planned size (discharge), the results showed that the levee failure probability was larger upstream and smaller downstream. For example, in the section of the Tokachi River after the confluence of the Shikaribetsu River (from KP59.6 to KP56.4), the return period was about 1.5×103 years upstream and about 4.5×106 years downstream. In the Satsunai River, the return period is about 3.0 x 103 years in the upstream side and about 4.9 x 106 years in the downstream side. This result is due to the fact that the failure probability of the upstream bank is deducted when calculating the failure probability of the downstream bank.

The hazard maps published in Japan show inundation damage based on the planned size of the river and the assumed maximum external force. The condition for a levee failure is an exceedance of the planned elevation. The results of the inundation analysis are superimposed on the results of the inundation analysis for all the assumed breach points. In other words, the level of safety of levees is uniform, and levee breaches are considered as independent phenomena. This method can provide residents with a safer assessment of the hazard. On the other hand, when quantifying damage for the purpose of flood risk assessment, there is a possibility of overestimation.

The approach in this study adopts a non-independent approach that expresses the probability of levee breaches at each location in a probabilistic approach and takes into account the occurrence of levee failures upstream. As a result, this method expresses the probability of flood occurrence in a more realistic way. In the future, quantitative flood risk assessment will be required to promote flood control measures in flood plains. By adopting the method proposed in this study, more accurate flood risk assessment will be possible.

### 4.1.3 Damage, evacuation, loss of life and Risk assessment

In chapter 3 the methods and application on the case study are shown. 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 and especially when high value assets do 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 to 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 resulting in a potential flash floods. One of characteristics of a flash flood is that there is relatively little time for evacuation and that is what also is the result in this case.

The potential flooding of the Obihiro case study area leads to large water depths with locally high rise rates. This can lead to potentially high numbers of loss of life. 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 flood risks are the product of the flood probability 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 increases and on the other hand the flood probability increases this leads 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 annum (or 0.001 %) for every resident living behind the levees. This is the so-called tolerable individual risk.

## 4.2 Dealing with uncertainties

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 integrated approach illustrated the impact of uncertainties and how it influences the final risk. The integrated approach also created a lot of insight in the consequences of choices made during the modelling. These consequences because clear because the complete chain of models were discussed during the project.

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.

In the flood risk analysis for the Obihiro case study the impact of these uncertainties are shown by presenting the bandwidths of the calculated flood risks and provide insight into the causes of the bandwidth. The insights in these bandwidths can be used to define the need to do more research to reduce the bandwidth. But in the case that the occur or lower limit to the bandwidth will not result in a different decision or measures it can also been concluded that the information is good enough to make these decisions.

## 4.3 Working together in a joined project

The greatest added value lies in the fact that the Japanese and Dutch experts were working closely together on the different topics. This involved collaboration between universities, knowledge institutes and companies, people from Japan and the Netherlands, and collaboration between the various tracks. Because analyses were actually performed and models have been applied, it was concrete, and it was everyone's responsibility to also solve problems such as imperfect data. Mutual coordination was also important, because others continued with outcomes that you had determined. These insights into the impact of each contribution, and to apply the methods has provided a lot of insight.

The success factor was that results and methods were not only discussed, but also applied these methods together and really tried to understand the details to generate the results. Working in this way creates mutual understanding and trust in order to have a good basis for the added value of the project results in practice. This resulted in an integrated risk framework, based on Japanese and Dutch experiences, which can be used for risk assessments and further developed.

During the project we, as everybody in the world, were confronted with the COVID-19 pandemic. This had a great impact on the project because we could not meet any more in Japan or the Netherlands. During the project however we adapted our way of working together and sharing information. We succeeded in the project because of the possibility to have online meetings, the contribution of Maki Masaki san as in interpreter, and the support of the Dutch Embassy with organising workshops in Japan. Draft results have been presented (digital) in a special session during the IAHR conference 2020 in Sapporro.

The project also contributed to a sustainable relation between the involved experts resulting in scientific papers, and interest in the way of living and working in both countries.

# 5 Recommendations

## 5.1 Extreme rainfall and discharges

In this case study, not all details of the method could be explored. Therefore, some shortcuts were made in the approach, that require attention in any follow-up research. The following improvements and recommendations can be made:

- Calibration of the models; The models used in this study were not calibrated. Only a quick assessment was made of the quality of the models. Based on a simple sensitivity analyses, the best model parameter set was selected. The quality of the models has impact on the outcome of WP1, the discharge statistics. Therefore, before using the output from WP1 for any real applications, the quality of the model needs to be further improved.
- Impact of initial conditions; An import uncertainty in the model is the initial state of the hydrological models. Since we are running the models on event basis, we also start each event with the same initial conditions. In reality, however, the initial conditions can be very different from event to event. Some events happen after a long time of rainfall, other events happen after dry conditions. The storage capacity in for example the soil and the reservoirs might be completely different, affecting the generated runoff. It is recommended to also included the initial conditions as an uncertain parameter in the simulations and include it in the uncertainty estimations given to WP2.
- Impact of reservoir operations; Reservoirs and their operation can have a significant impact on the downstream discharges. The reservoir operations are for now not included in the hydrological models. This is an important point on which to improve the models. It is also a complex point, since in many cases the real operations are not well known. More research in the operation of the reservoirs, and how to include it in the hydrological models, is recommended.
- Hydrograph shape; For now, not much focus was given to the derivation of the hydrograph shape. This needs more attention, since the shape (and volume) of the hydrograph have an impact on downstream flood levels and flood risk.
  Focus on mountainous areas; For now, a lot of attention was given to the urban areas and the impact of flooding there. During the many flood events on Hokkaido it was observed that also in the mountainous areas there was a lot of damage to roads, bridges and other (critical) infrastructure. Although the direct costs related to these damages is small compared to damages in the urban areas and associated loss-of-life, the cascading effect might also result in large additional damages and maybe even loss-of-live due to the fact certain areas can not easily be reached by emergency services.
- Also, climate change is most likely going to affect the mountainous areas stronger, resulting in potentially increasing damages in these areas. It is therefore recommended to also do an assessment of the flood risk in these areas.

Longer-term research is required to look at the impact of sediment behaviour on the flood risk in the Tokachi River Basin. It is known from earlier experience that sediment input and morphological changes in the riverbed during the event can have large impact on the simulated water levels and stability of the dikes. This effect is not included in the models, but can be added, albeit in a simplified manner. It is recommended to investigate this topic and think of a way sediment behaviour can be added to the overall methodology for flood risk assessment in the Tokachi River Basin and in general.

## 5.2 Failure probabilities

In this study, levee failure due to overtopping is the subject of evaluation. In this study, we focused on levee failure due to water overtopping, but there are some reports of levee failure due to erosion and piping in Japan. Therefore, the probability of levee failure due to other levee failure mechanisms should be evaluated in the future.

In this study, flood hydraulics are calculated assuming a model waveform. Flood runoff in Japan is characterized by various shapes of hydrographs, which are expected to affect the probability of levee failure and damage during inundation. Therefore, the flood probability should be evaluated taking into account the shape of the hydrograph.

## 5.3 Damage calculation

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.

A comparison of the two approaches would be useful to see the strengths of both methods. What are potential method gaps, where does one model perform better than another and where could the methods be improved.

## 5.4 Evacuation and loss of life

The current evacuation method uses only two destinations, people are either at a safe 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.

So an improvement of the evacuation modelling will lead to a much better insight in the location where people will go 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 a evacuation order is issued. Given the location 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 to 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 have an impact on the possibility of building collapse which will lead to a higher probability of casualties. This is also an aspect that can improved to the model to make the models more suitable for the Japanese situation.

# 6 Last words

I would first like to express my gratitude towards the project "Flood Risk and Climate Change Hokkaido," which gave us such a great opportunity to learn about the advanced climate adaptation approaches of the Netherlands in flood control and to work on developing a new risk assessment method throughout the joint research between Japan and the Netherlands.
The Netherlands' climate adaptation measure is quite advanced, valuable and essential for Hokkaido to improve its flood control. I deeply appreciate the generosity of Dutch experts for their cooperation, and the efforts by all the relevant persons to this study.

It has been long since increasing intensity and frequency of flood due to climate change was appealed in Japan. In recent years large scale floods occur every year, causing extreme damage, which threatens physical and mental safety of the citizens.
Hokkaido is a region surrounded by a rich natural environment, and many people enjoy the benefits of food supply nationwide and nature-related tourism.
On the other hand, such a rich nature caused historically also disasters. Especially large scale floods occur more frequently in recent years, though it used to be less extreme and less frequent compared to the rest of Japan.
Hokkaido is estimated to sustain the greatest impact by increasing flood risk due to climate change, in Japan. This is why the discussion has been initiated, based on the following key words.

- Hokkaido needs to take an initiative to establish new flood control measures for next generation, because it expects extremer impact by climate change than the rest of Japan.
- Flood control measures based on risk assessment should be taken, by scientifically estimated future impact of climate change.

Thanks to this project, we have achieved extraordinary results.
Hokkaido will facilitate to further develop this study, and repeat reflecting its results to our society. We believe this is our mission to challenge the impact of climate change step by step in order to secure the physical and mental safety of citizens, and eventually this will bring Hokkaido the future prosperity.
Research never ends. By deepening a research, it is necessary to continuously explore a new way of solution for upcoming challenges. It would be so encouraging if we could continue with technical exchange with the Netherlands to open up a new way together to confront such a huge challenge like climate change.

It has been about 150 years since Hokkaido was developed. Though there are accumulated challenges in front of us, it would be our great pleasure if we could proceed one step further to secure physical and mental safety of Hokkaido by improving future flood control.

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