Taiwan International Water Forum

Building a resilient society to cope with water-related disasters intensified by climate change

October 2025

President, Foundation of River & Basin Integrated Communications (FRICS)
President, Japan Society of Civil Engineers (JSCE)
Emeritus Professor, The University of Tokyo

Koji IKEUCHI, Ph.D.

Self-introduction (Koji IKEUCHI)

1982 – 2001 Ministry of Construction (The predecessor of MLIT）

2001 – 2006 **MLIT（Ministry of Land, Infrastructure, Transport and Tourism）**

2006 – 2009 Director for Earthquake, Volcanic and Large-scale Flood Disaster Management, **Cabinet Office**

2009 – 2013 Director, River Planning Division, Water and Disaster Management Bureau, **MLIT**

2013 – 2014 Director General, Kinki Regional Development Bureau, **MLIT**

2014 – 2015 **Director General, Water and Disaster Management Bureau, MLIT**

2015 – 2016 **Vice Minister for Engineering Affairs, MLIT**

2016 – 2023 **Professor**, Department of Civil Engineering, School of Engineering, **The University of Tokyo**

2023 – Present **President, Foundation of River & Basin Integrated Communications(FRICS)**

Emeritus Professor, The University of Tokyo

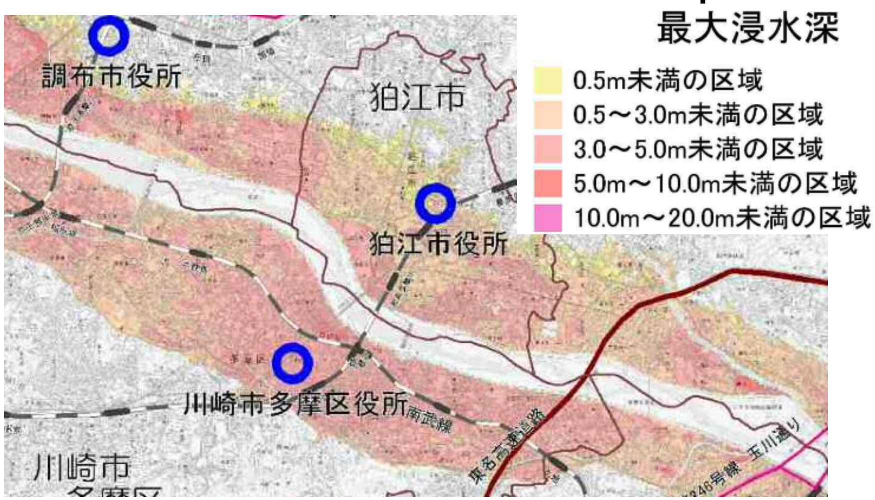
2025 – Present **President, Japan Society of Civil Engineers(JSCE)**

Outline

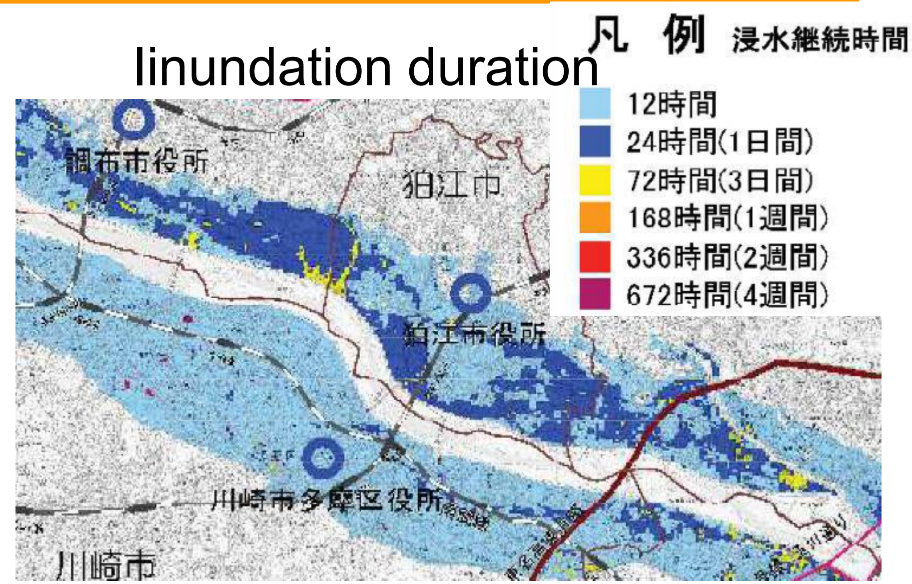
1. Currently available flood risk information
2. Characteristics and lessons of recent flood disasters
3. SIP project – Subtopic B
4. Conclusion

Example of an Inundation Assumption Area Map (Tama River)

Maximum inundation depth

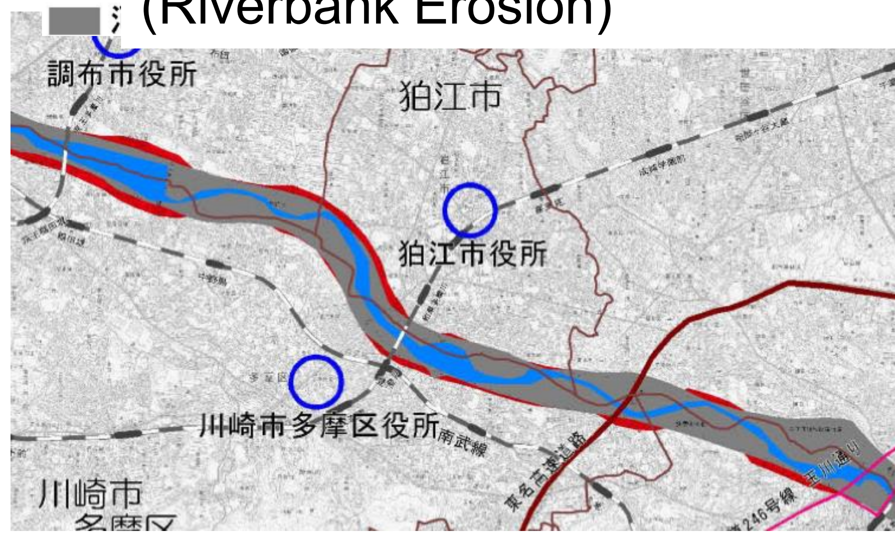


Iinundation duration

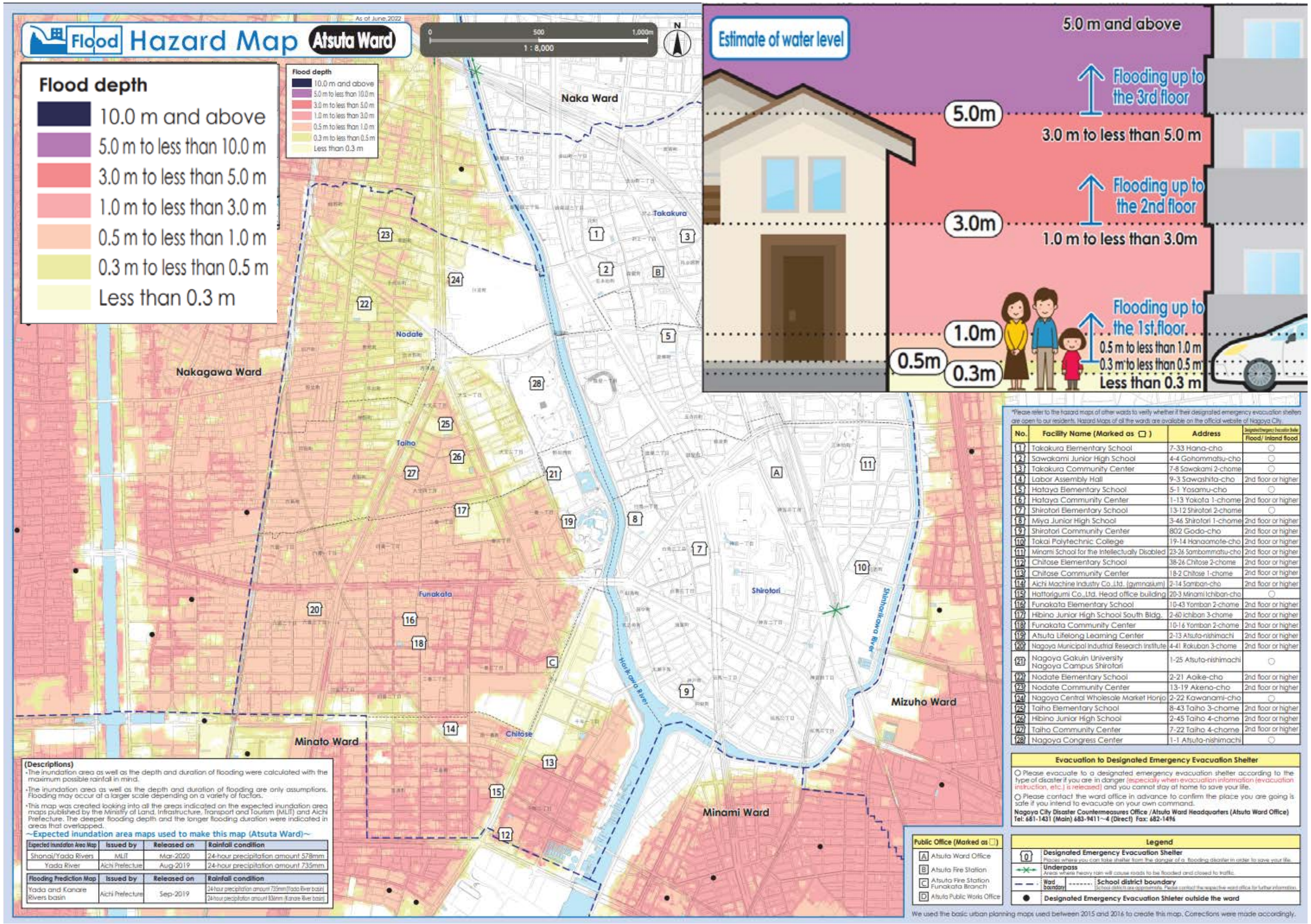


Areas at Risk of House Collapse (Flood Flows)

Areas at Risk of House (Riverbank Erosion)

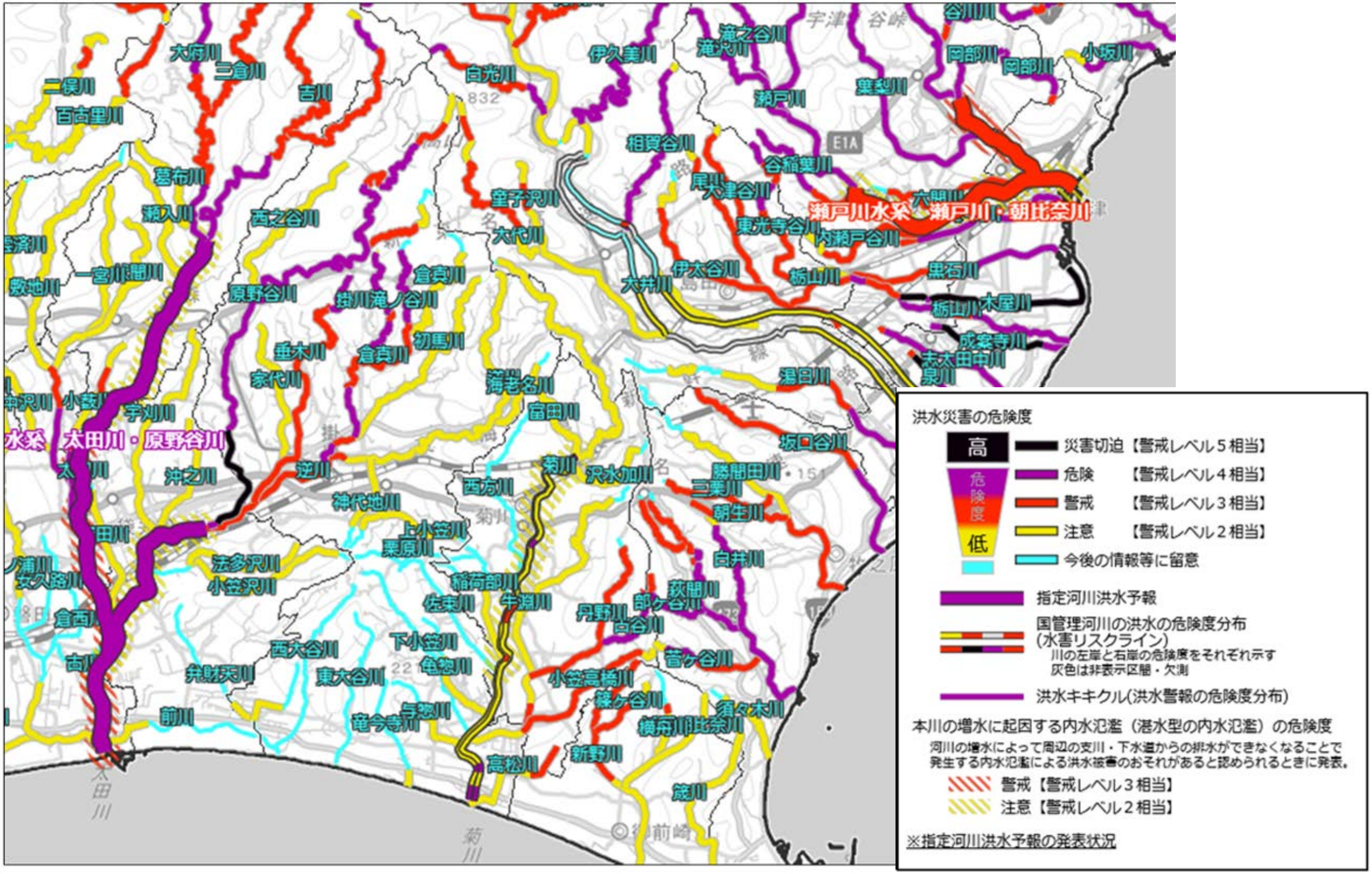


Hazard Map (Nagoya City)



出典：名古屋市ＨＰ
https://www.city.nagoya.jp/bosaikikikanri/cmsfiles/contents/0000153/153568/hm-e-kozui09atsuta_english.pdf

Kikikuru (Hazard Level Distribution)

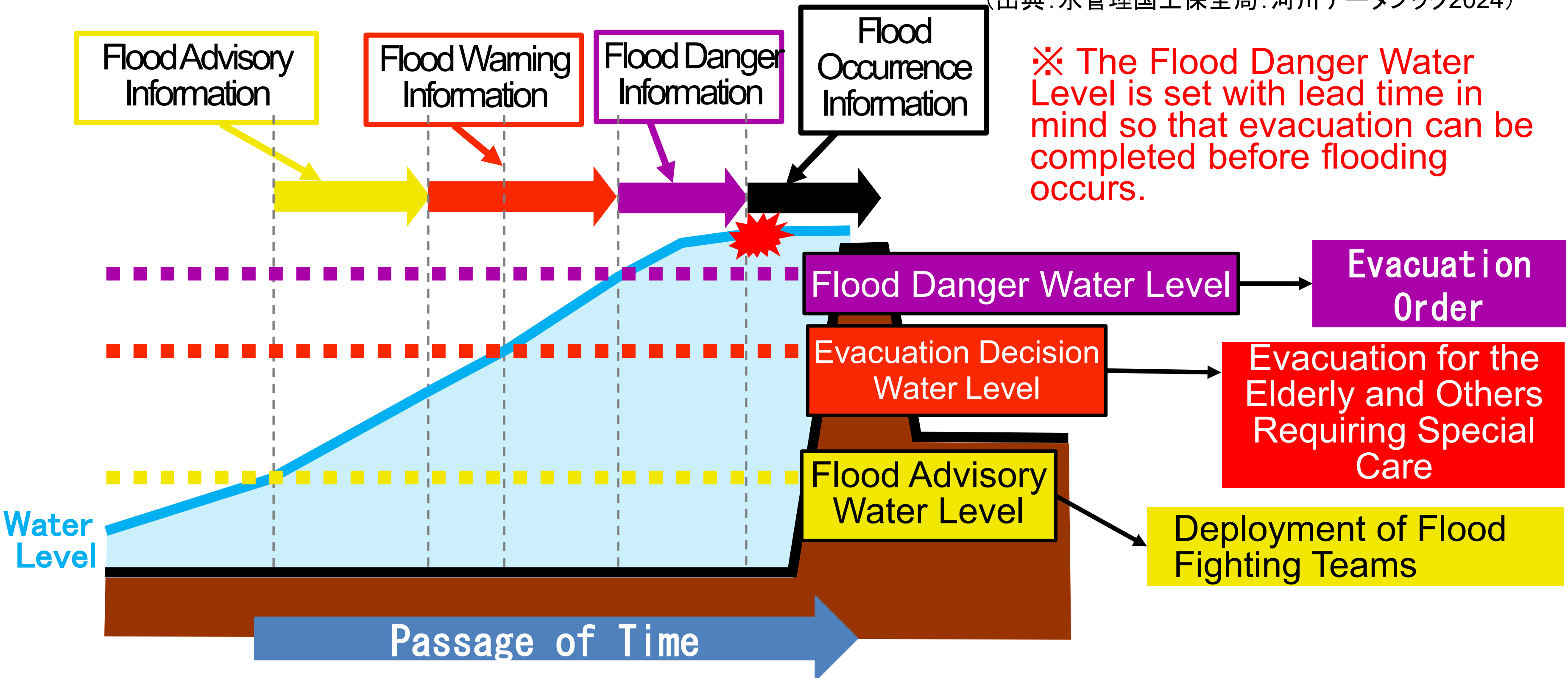


Japan Meteorological Agency(JMA) https://www.jma.go.jp/jma/kishou/know/bosai/riskmap_flood.html

Flood Forecast (MLIT and JMA)

- Announces the current water level and forecasts of future water levels.
- Targets rivers with relatively large basin areas where forecasting is technically feasible.
- Jointly conducted by river administrators and the Japan Meteorological Agency.
- 298 rivers managed by the national government and 131 rivers managed by prefectural governments are designated (as of March 31, 2023).

（出典：水管理国土保全局：河川データブック2024）



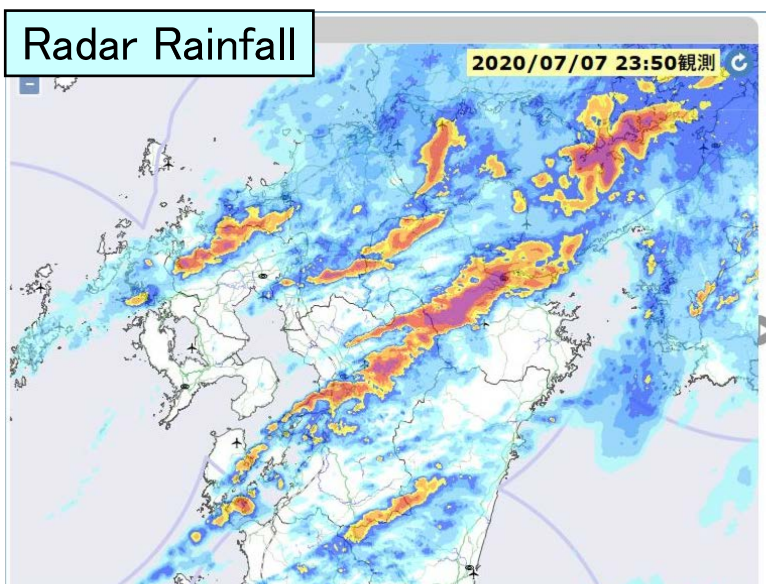
＊出典: 社会資本整備審議会河川分科会 大規模氾濫に対する減災のための治水対策検討小委員会（第1回）資料4「各課題に関する国土交通省等におけるこれまでの取組状況」（平成27年10月30日）

River Disaster Prevention Information (MLIT)

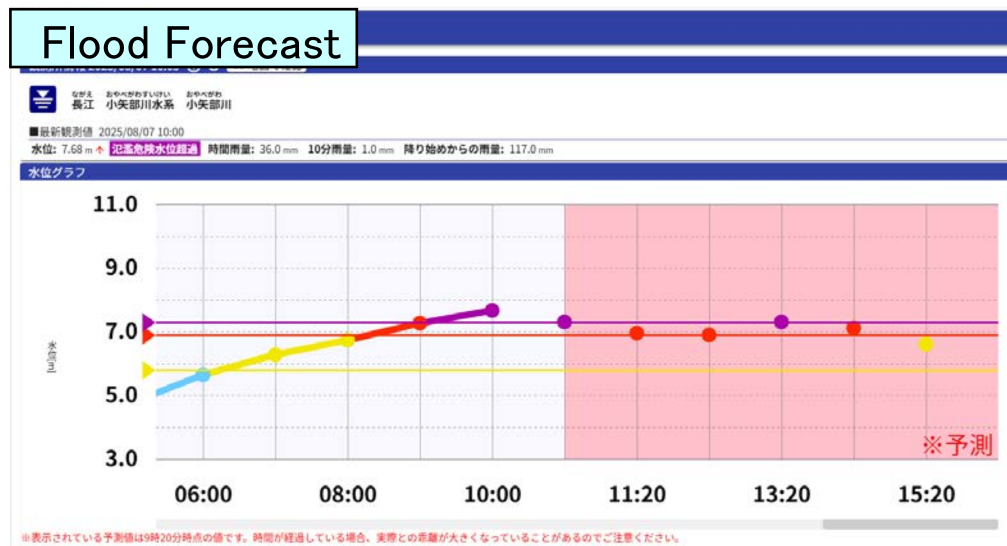
River Monitoring Camera

Water Level Information

Radar Rainfall



Flood Forecast



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Recent Major Flood Disasters

Mogami River and Koyoshi River Flooding（2024）

Kuma River Flooding（2020）

Typhoon Hagibis（2019）

Western Japan Heavy Rain （2018）

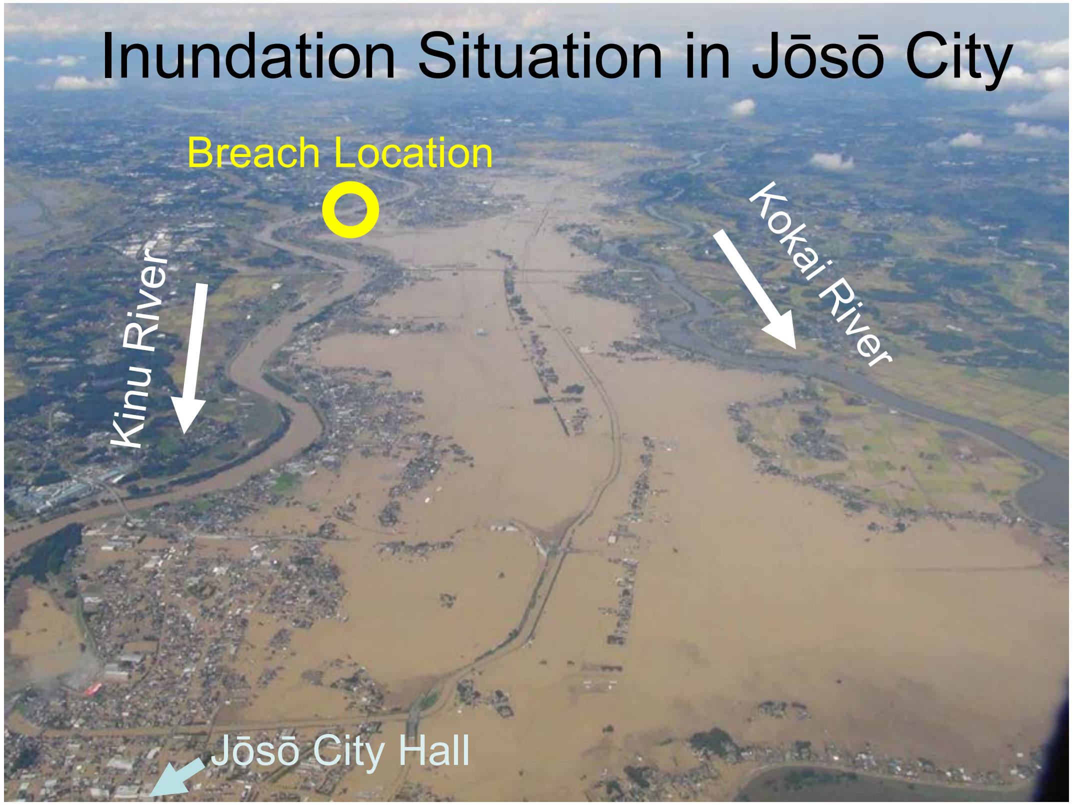
Northern Kyushu Heavy Rain（2017）

Kinu River Flooding（2015）

（出典：国土交通省資料、内閣府資料等）

Kinu River Levee Breach (2015)

- In 2015, the Kinugawa River, which flows through the Tokyo metropolitan area, experienced flooding that exceeded its discharge capacity, causing a levee breach and inundating approximately 40 square kilometers.
- The disaster resulted in 2 fatalities and damage to about 8,800 houses.
- A large number of people were stranded, and approximately 4,300 individuals were rescued by helicopters, boats, and other means.
- The Jōsō City Hall was flooded, and lifelines such as electricity, water supply and sewerage systems, and railway services were cut off.



Over 60% of the victims were found at home after failing to evacuate. (Kuma River Flood, 2020)

- During a series of record-breaking heavy rains, 65 people died in Kumamoto Prefecture.
- A summary by the prefectural government on where the victims were found revealed that more than 60%—41 people—were discovered inside their homes or within their premises.
- In addition, 12 people were found outdoors away from their homes, and 7 were found at sea or on beaches. (Based on NHK summary, July 13, 2020)

球磨川右岸側 人吉市紺屋町

7月4日朝撮影

球磨川右岸側 人吉市

7月4日午前中撮影

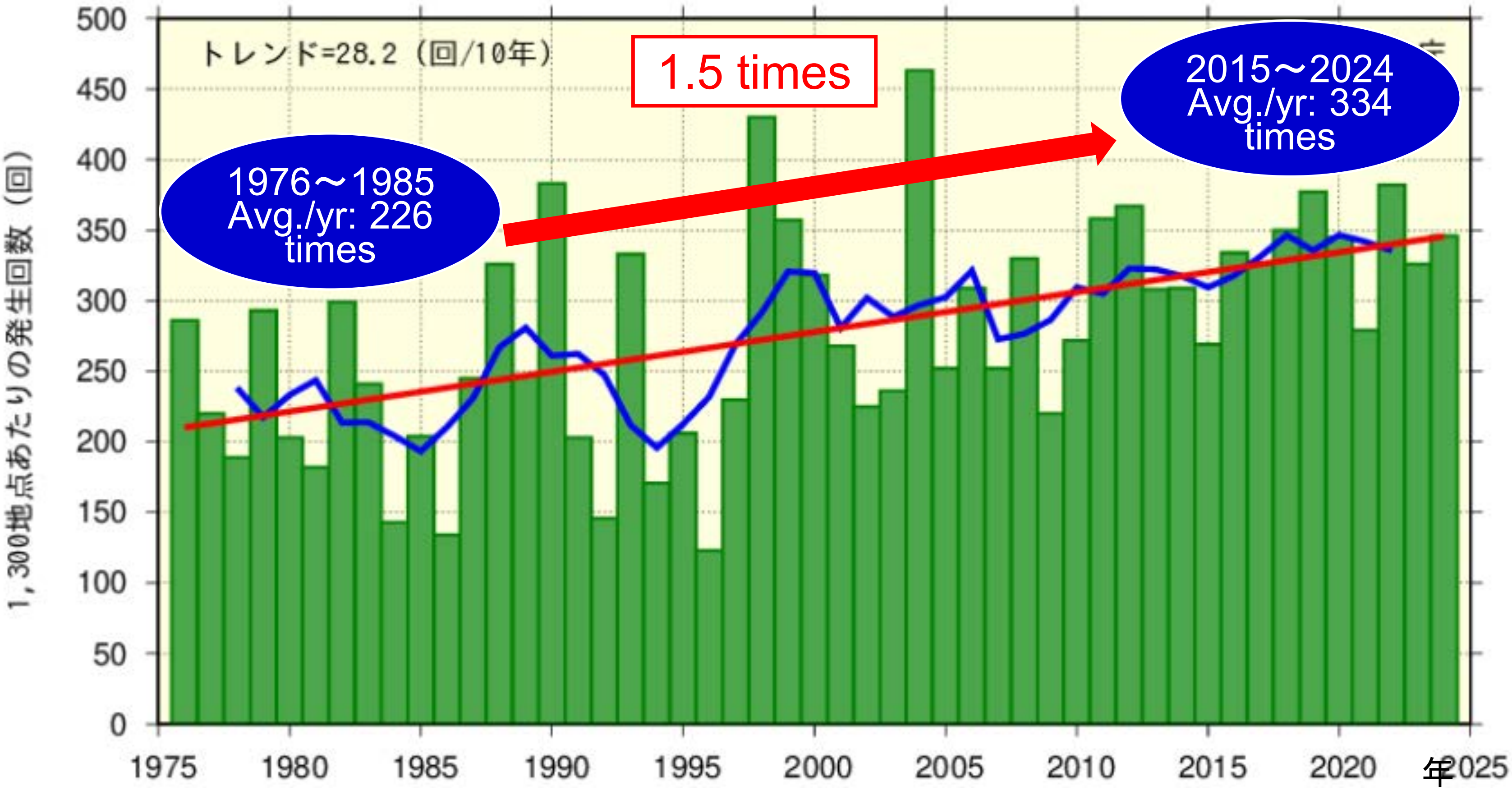
球磨川右岸側 人吉市上青井町

7月4日朝撮影

（写真：国土交通省提供）

Increase in the Number of Heavy Rainfall Events of 50 mm or More per Hour

The average annual number of occurrences in the most recent 10 years (2015–2024), about 334 times, has increased by approximately 1.5 times compared to the average annual number in the first 10 years of the statistical period (1976–1985), about 226 times.



Annual number of occurrences of hourly precipitation of 50 mm or more

（気象庁資料に加筆） https://www.data.jma.go.jp/cpdinfo/extreme/extreme_p.html

Changes in Rainfall and Flood Frequency Due to Climate Change

Climate Change Scenario	Rainfall	River Flow	**Flood Frequency**
2℃ rise (RCP2.6)	~1.1×	~1.2×	**~2×**
4℃ rise (RCP8.5)	~1.3×	~1.4×	**~4×**

2℃ rise (RCP2.6): Paris Agreement target; assumes achieving net-zero greenhouse gas emissions in the second half of this century.

4℃ rise (RCP8.5): Scenario with the greatest degree of warming.

（Recommendations from a study group of MLIT）

国土交通省・気候変動を踏まえた治水計画に係る技術検討会:「気候変動を踏まえた治水計画のあり方 提言（改訂版）」(2021年4月)

Summary of Characteristics and Lessons from Recent Heavy Rain Disasters

- Record-breaking rainfall has caused frequent flooding damage across various regions.
- In large-scale flood disasters, water has reached the eaves of two-story houses, resulting in many casualties and stranded individuals due to delayed evacuation.
- Flood damage to businesses has caused direct losses as well as secondary disasters from the inundation of facilities, having severe impacts on regional socioeconomic activities.
- In the future, flood frequency is projected to increase to about two to four times the current level.
- Strengthening preparedness for flood disasters across society is an urgent priority.

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    - Sub-subtopic B3
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Subtopic B, “Promotion of Disaster Prevention Actions through Risk Information.”

- Despite the availability of flood hazard maps during normal times and the provision of various information during heavy rainfall—such as disaster risk levels, river water levels, and flood forecasts—flood damage has not decreased.
- In recent flood disasters, residents have failed to take appropriate evacuation actions, resulting in many isolated individuals and casualties.
- Companies have also not implemented adequate disaster prevention measures, and flooding has caused not only severe direct damage but also serious impacts on local communities through ripple effects such as the suspension of business activities and secondary disasters.
- At present, neither residents nor companies recognize flood damage as their own problem, and preparedness for disasters remains insufficient.

This project aims to provide information that enables people to recognize the danger of flooding in a realistic way, so that residents and companies see flood damage as a matter directly concerning them and are able to take appropriate disaster prevention actions.

Subtopic B, "Promotion of Disaster Prevention Actions through Risk Information."

- Provide information that enables people to recognize the danger of flooding in a realistic and concrete manner during both normal times and disasters. Normal times: (B-1, B-2) Disaster times: (B-3)
- Provide quantitative information on the future frequency and scale of floods under climate change, which is necessary for companies when making investment decisions. (B-1, B-2)

Normal times

- B-1 Basin-scale prediction technology for wind and flood damage impacts
- B-2 Visualization technology for water-related disaster risks and damage impacts

Disaster times

- B-3 Technology for evaluating and generating real-time disaster risk information that promotes disaster prevention actions

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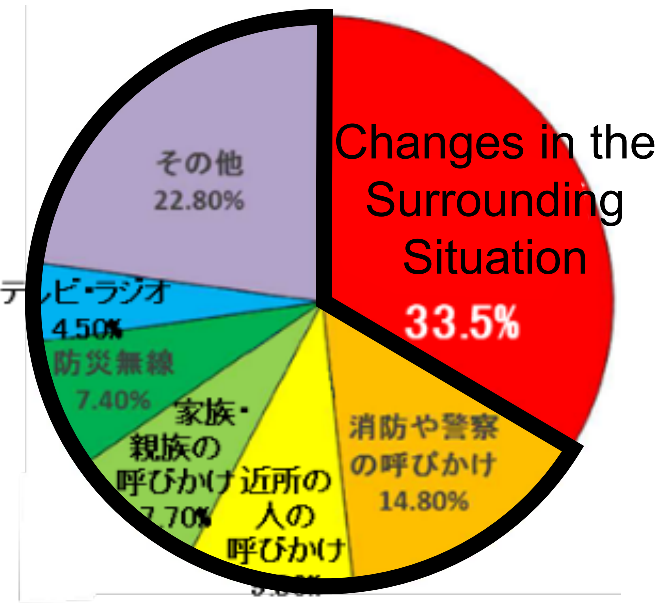
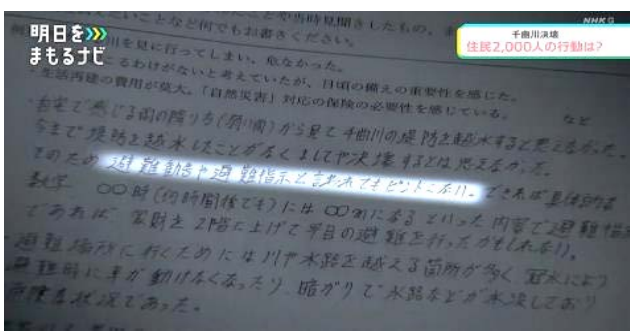
Information That Triggers Evacuation During a Disaster



- About one-third of people said that their "trigger for evacuation" was real and concrete information such as "changes in the surrounding situation."

(Survey of survivors of the 2018 Western Japan Heavy Rain Disaster)

- However, evacuating only after flooding is imminently approaching carries a high risk of being too late.



- If they had had information on "when and to what extent the location they were in would be flooded," they might have evacuated earlier.

(Comment from a survivor submitted to NHK)

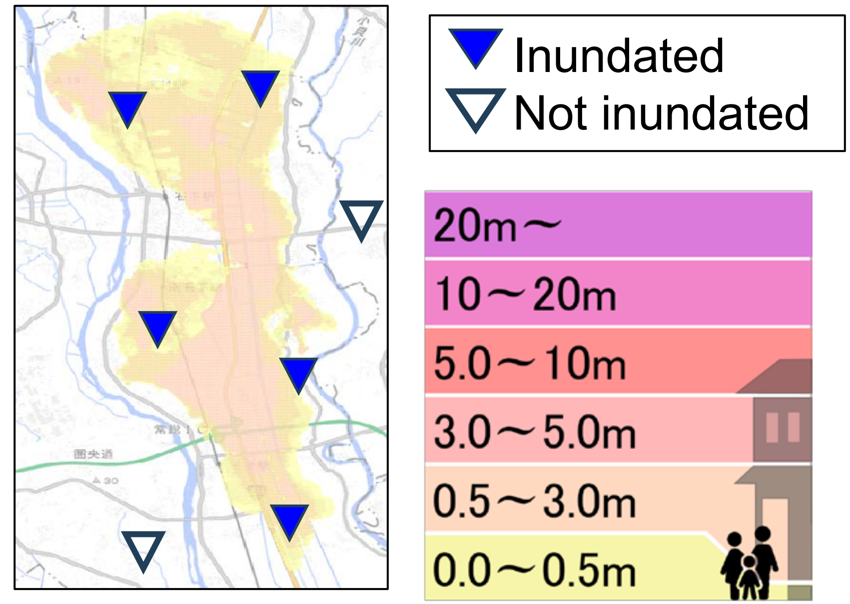
It has been shown that real, concrete, real-time information is effective as an evacuation trigger.

B-3 Technology for the evaluation and generation of real-time disaster risk information that promotes disaster prevention actions

Generation of real-time inundation and prediction information

Real-time identification of actual inundation extent

- Collect on-site inundation occurrence information and generate real-time inundation information (inundation extent, inundation depth).



Real-time inundation prediction

- Generate highly accurate inundation prediction information by performing data assimilation using high-speed computation and real-time inundation information.

Development of a tool that enables residents to grasp specific inundation risks in real time

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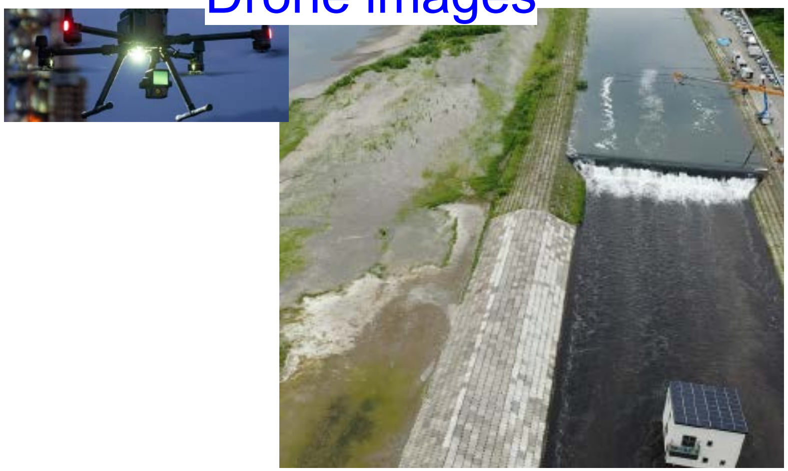
Real-time identification of actual inundation extent

- Flood occurrence information is identified using river patrol drones.
- Inundation information in urban areas is collected using inundation sensors, abnormal vehicle flow detection, drone images, helicopter images, and home appliance sensors.

Drone images

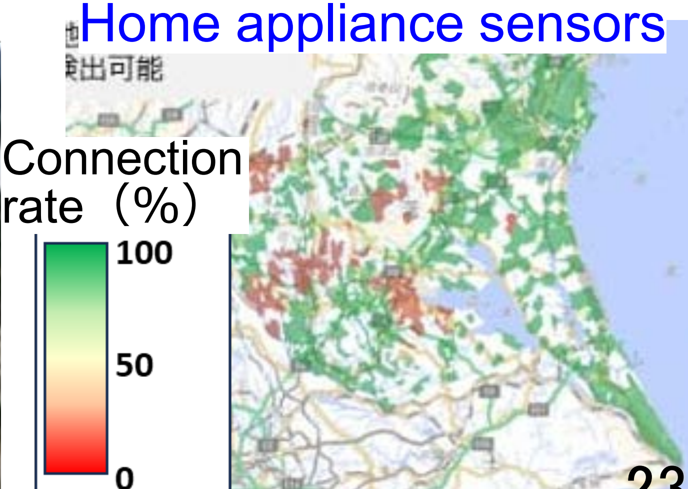


Inundation sensors

Abnormal vehicle flow detection

Helicopter images

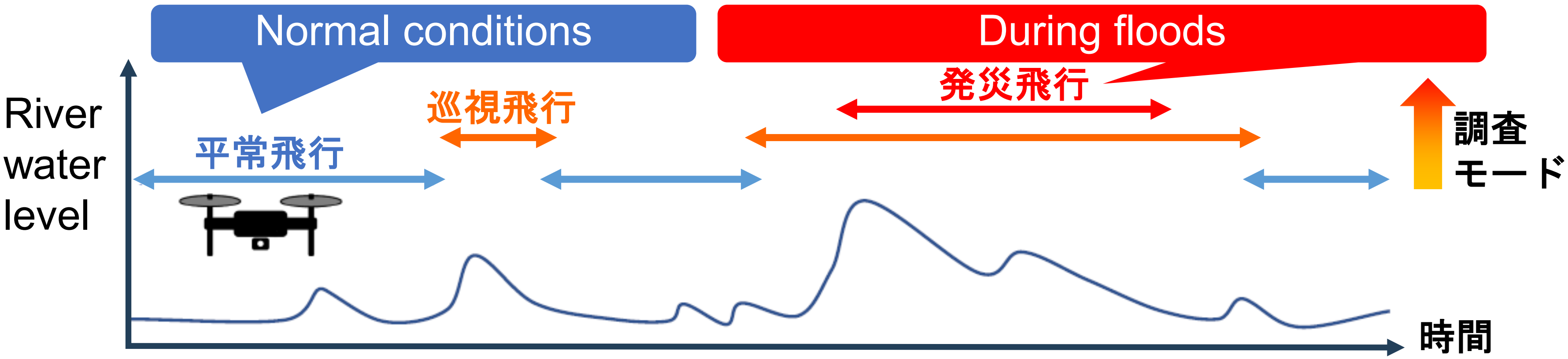
Home appliance sensors



Utilization of Drone-Captured Images

(Kitami Institute of Technology / The University of Tokyo)

- They are developing technology that uses drone-captured images to generate flood occurrence and inundation extent information, including AI-based automatic levee breach detection from full-scale experimental footage.
- They are also building a drone operation system usable in both normal and flood conditions, with charging-port-equipped drone tests conducted on the Fushikobetsu River in Hokkaido.



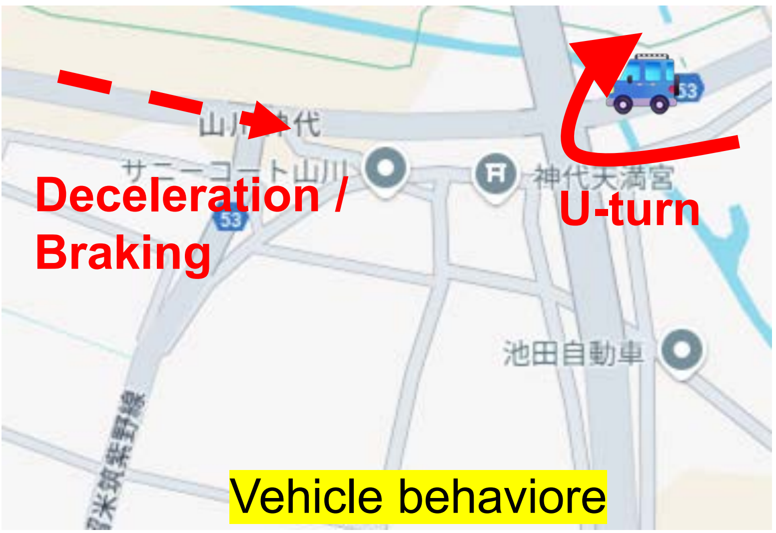
Drone with charging port

Levee breach experiment

Utilization of Vehicle Flow Data

➢ We are developing technology to collect vehicle flow data and use AI to generate real-time inundation occurrence information.

●Image of inundation area estimation



Generation of real-time inundation information

By detecting anomalies in real time from vehicle behaviors such as U-turns, sudden braking, and speed reduction, and overlaying this data with simultaneously collected disaster prediction information, we can identify inundation occurrence conditions.

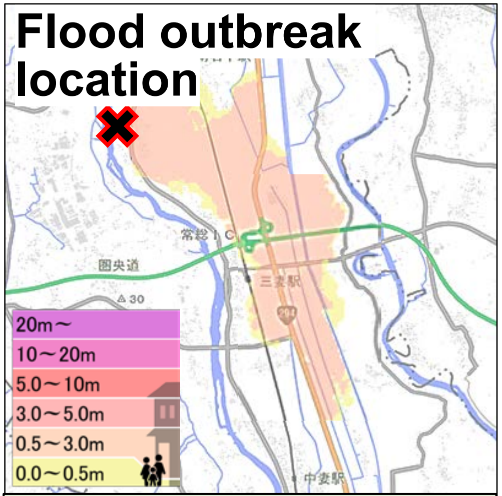
Real-time inundation prediction

- In Japan's river basins, inundation areas can change within hours, requiring high-speed computation for timely predictions.
- Using the Dynamic Mode Decomposition (DMD) method, we achieved inundation simulations about 100 times faster than conventional methods, and developed a data assimilation technique to correct parameters using real-time inundation data.

Inundation Occurrence

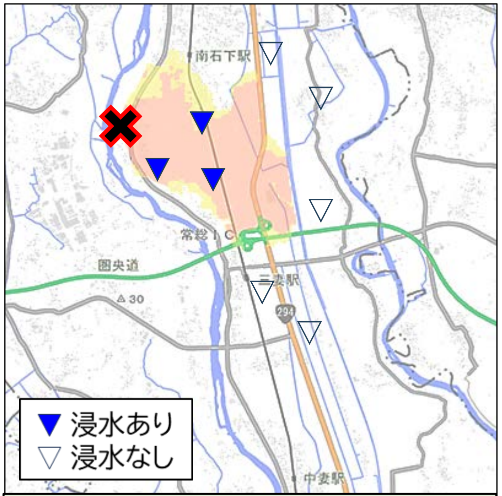
Upon receiving inundation occurrence information, perform high-speed inundation simulation (within 10 minutes).

Generation of Prediction Information



3h後の氾濫予測

Corrections by data assimilation



3h後の氾濫予測(再計算)

DMD(Dynamic Mode Decomposition)

Originally developed in the field of fluid dynamics, it is now applied in a wide range of fields including geotechnical engineering, traffic engineering, and economic/financial engineering. Notably, there have been no previous applications to inundation analysis or prediction.

In conventional physical simulations, it is necessary to solve complex partial differential equations, which requires significant computation time.

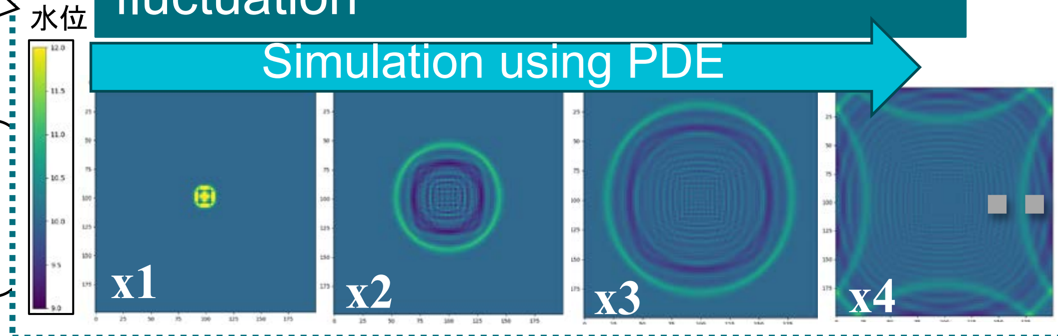
$X_{t+1} = AX_t$ If the linear transformation A is known, there is no need to solve complex partial differential equations.

Although A is a very complex matrix, its approximate value can be obtained from its eigenvalues and eigenvectors (modes).

重要度（寄与率）の低いモー
外できる

Numerical analysis of water surface fluctuation

Simulation using PDE

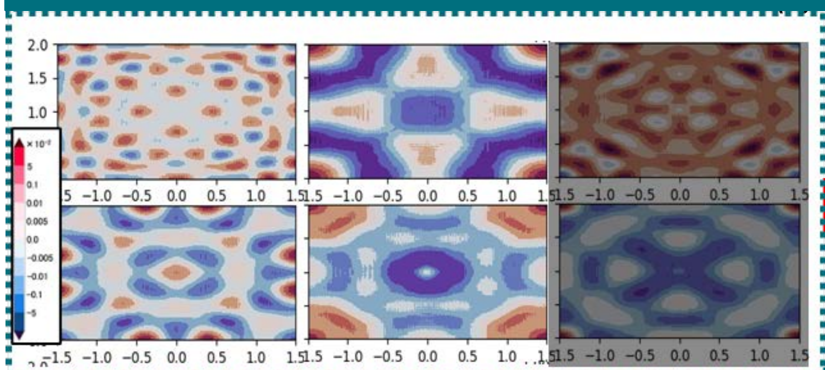


Xt

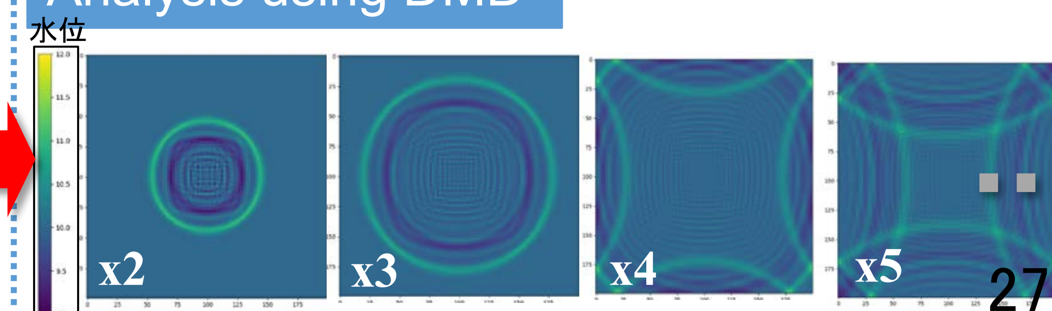
Linear transformation A

Xt+1

Extraction of Eigenvectors (Modes)



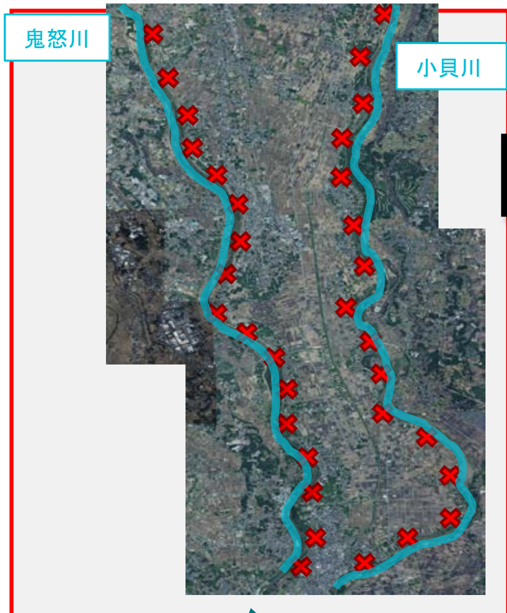
Analysis using DMD



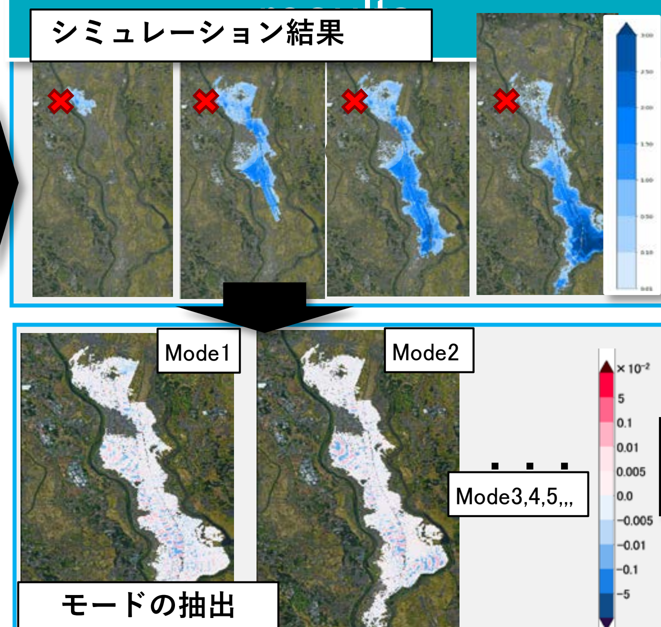
Flow of Inundation Analysis Using DMD

※Cooperating organization: Laboratory of Professor Tadashi Yamada, Chuo University

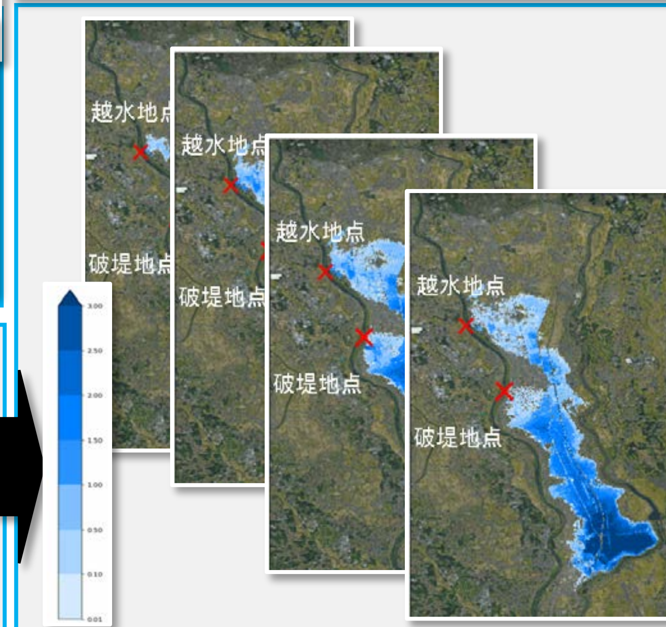
Inundation simulation



Mode extraction from inundation analysis results



Inundation analysis using DMD (modes)



✖ **Inundation occurrence location**

A large number of inundation simulation analysis results are required to build a DMD model.

By using DMD, high-speed analysis is possible.

Parameter Adjustment Using On-site Inundation Information

To adjust the constructed DMD model to match observed inundation data, parameters are introduced.

【DMD Model】

$$x(t) = \varphi\, exp\{\, \Omega t \,\}$$

t:Time

$x(t)$:Inundation depth distribution at time t

φ: Spatial mode of DMD

$exp\{\, \Omega t \,\}$: Temporal evolution mode of DMD

$$x(t) = \boxed{a}\, \varphi\, exp\{\, \Omega \boxed{b}\, (t - \boxed{c}) \,\}$$

a: Parameter for adjusting inundation depth

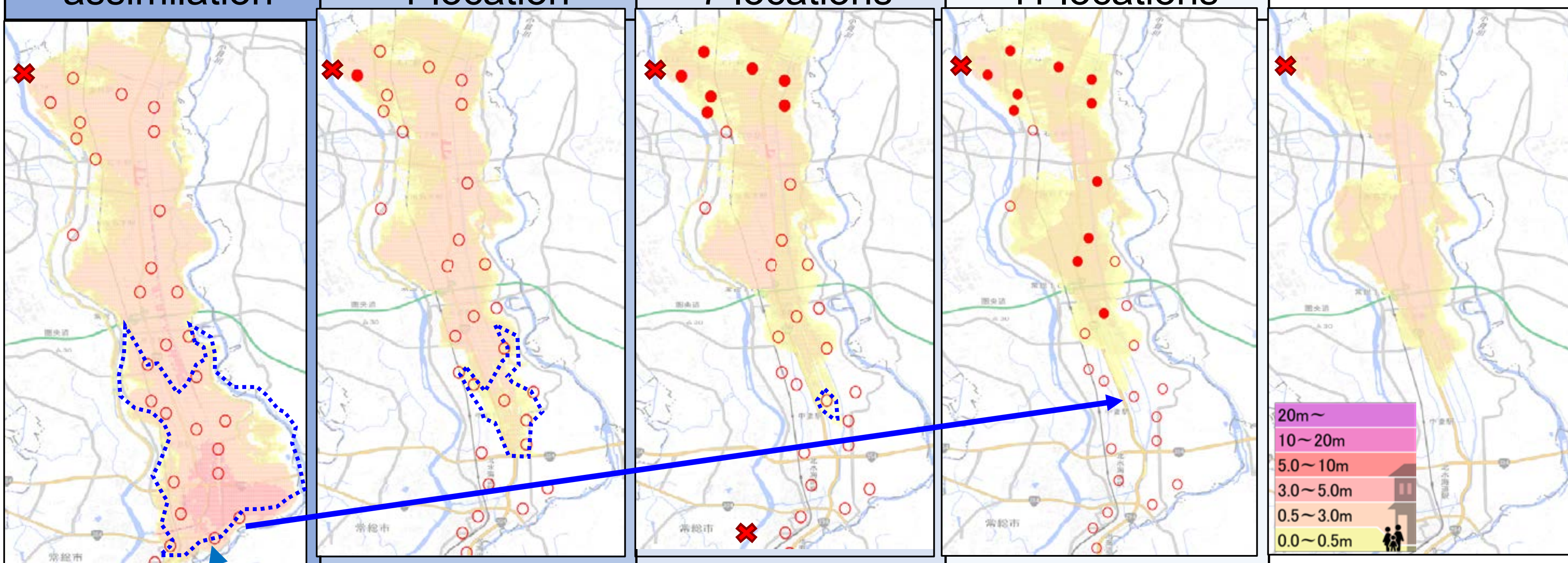
b: Parameter for adjusting the expansion speed of inundation

c: Parameter for adjusting the inundation start time

The parameters are adjusted so that the model can reproduce the observed inundation information, enabling inundation prediction.

Example of Flood Prediction Calculation Using DMD (Kinu River)

(Predicted area of inundation at 14:00)				
Calculation at 6:00 immediately after flood outbreak — without data assimilation	Calculation at 7:00 — data assimilation using on-site inundation information from 1 location	Calculation at 10:00 — data assimilation using on-site inundation information from 7 locations	Calculation at 13:00 — data assimilation using on-site inundation information from 11 locations	Reference data (flood prediction at **14:00**)



Area larger than reference data

✖ Flood outbreak location

● Location where inundation was confirmed

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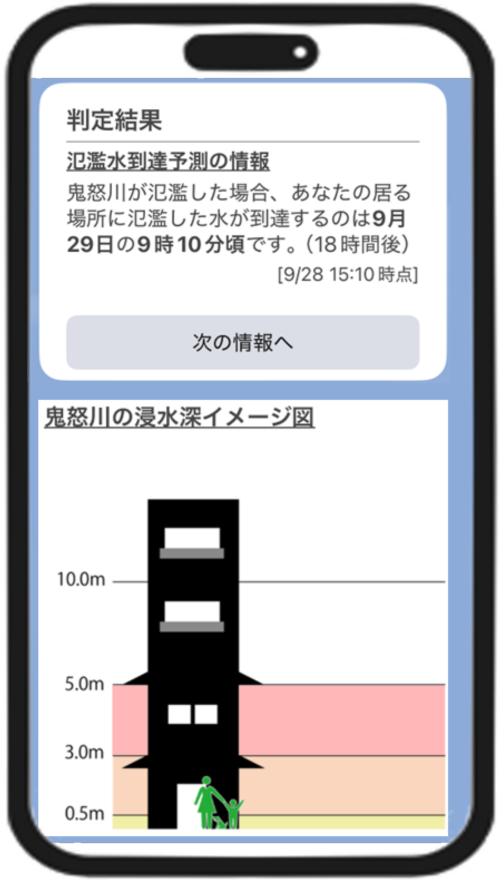
Development of a system that enables residents to grasp specific inundation risks in real time

- We are developing a tool that provides realistic inundation occurrence and prediction information in real time through the LINE app on smartphones.
- By registering one's current location via GPS (or entering an address, etc.), residents can specifically understand "when and to what extent inundation will occur."
- In addition, if evacuation is necessary, the tool allows users to check the nearest evacuation site.



Hearing at the Joso City flood prevention drill venue

At the venue of the Joso City flood prevention drill held in April 2025, we explained the details of the system under development using a demo screen and posters, and conducted hearings to gather feedback on effective utilization methods and points for improvement.

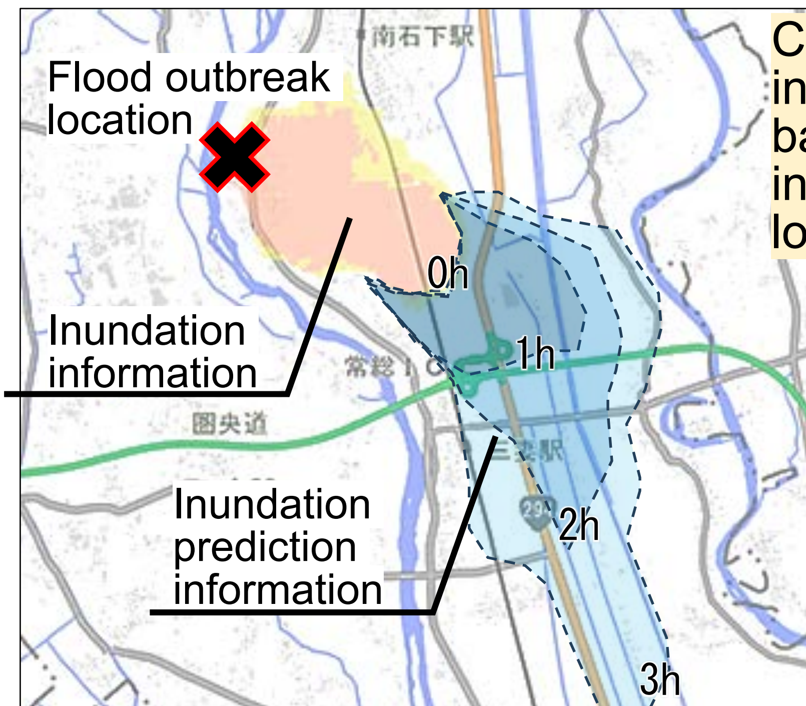
住民がリアルタイムで具体的な浸水リスクを把握できるシステムの実証実験

- 2025年6月に、常総市民による実地利用実験を実施し、使い勝手や機能に関する意見を収集。
- 得られた意見を踏まえ、システムの改良を継続中。

Social implementation of R&D results

Real-time inundation information / prediction information

Implementation target:
“River Disaster Prevention Information,”of MLIT



Convert to information based on the individual’s location

Tools enabling residents to grasp concrete flood risks in real time

Implementation target: Municipal LINE accounts

Danger level of one’s current location

Nearest evacuation sites

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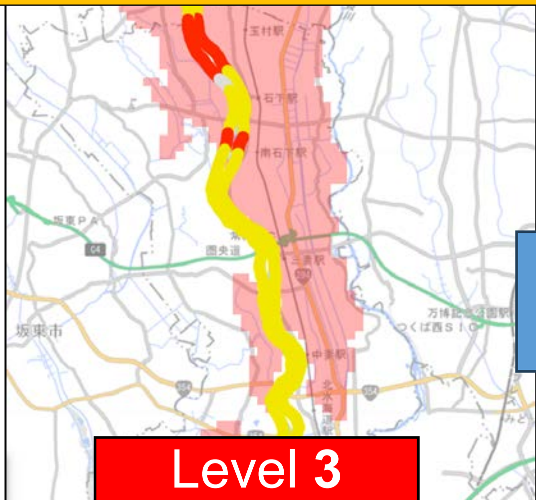
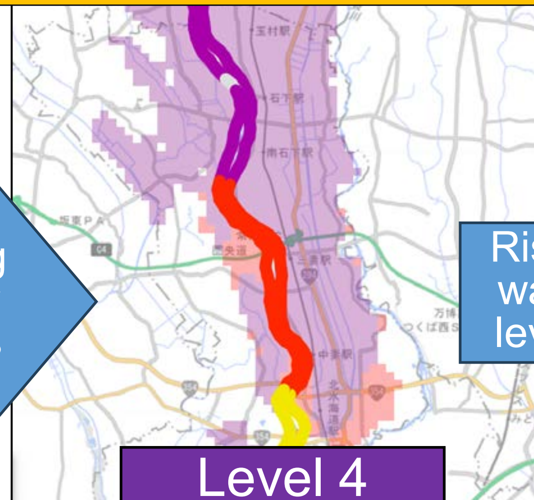
Provision of Inundation Risk Information Before and After Inundation is Detected

Provision of Information Before Inundation is Detected

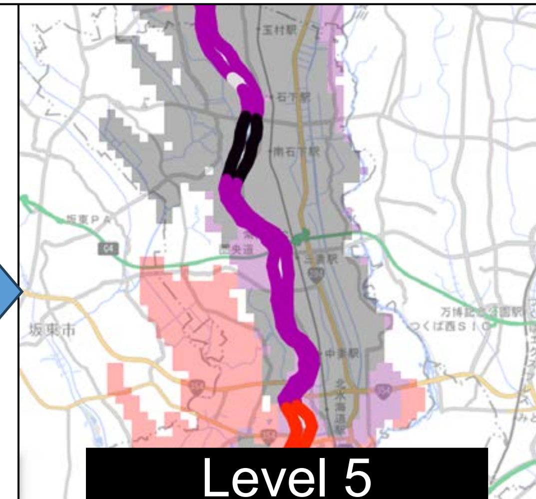
BRIDGE Project: IDR4M



Rising water levels

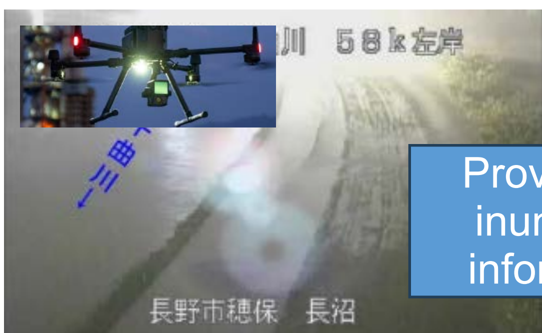


Rising water levels



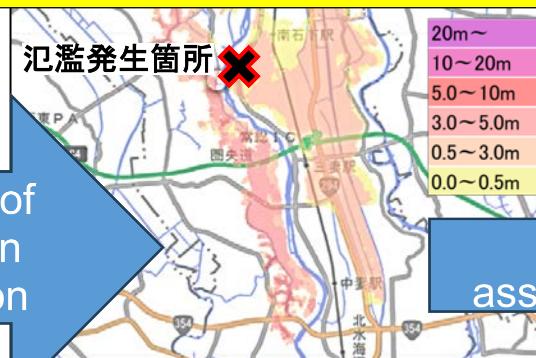
Provision of Information After Inundation is Detected

SIP Phase 3 Project



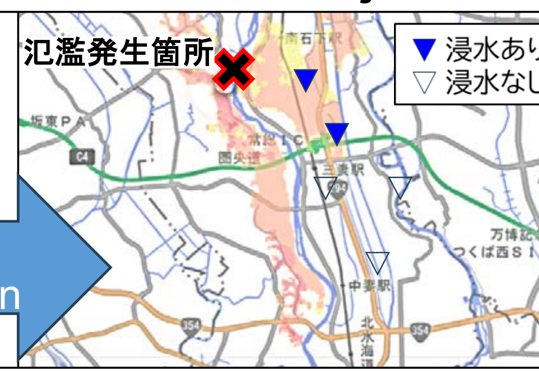
Drones collect information on flood occurrence

Provision of inundation information



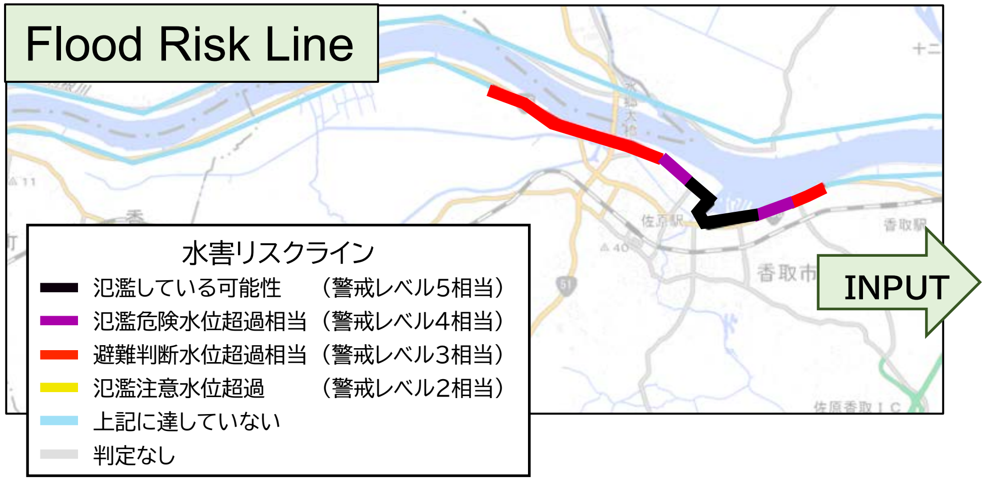
Rapid flood simulation to provide flood prediction information

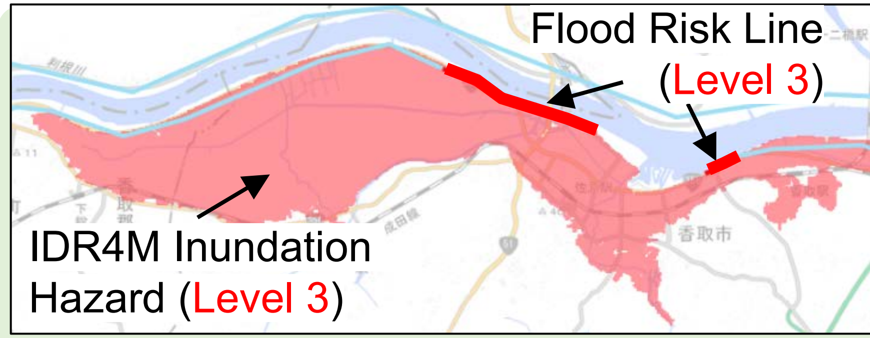
Data assimilation

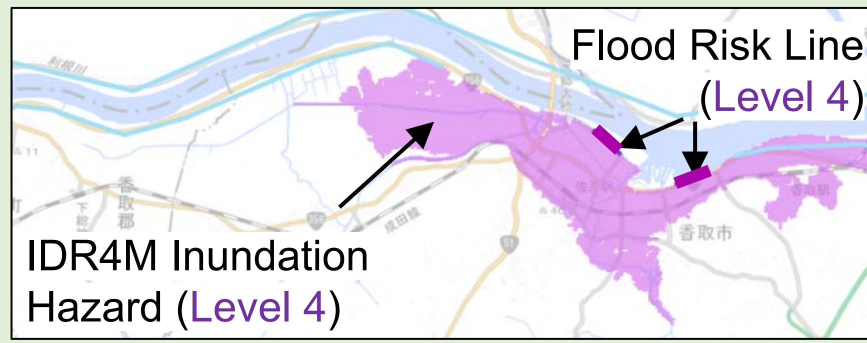


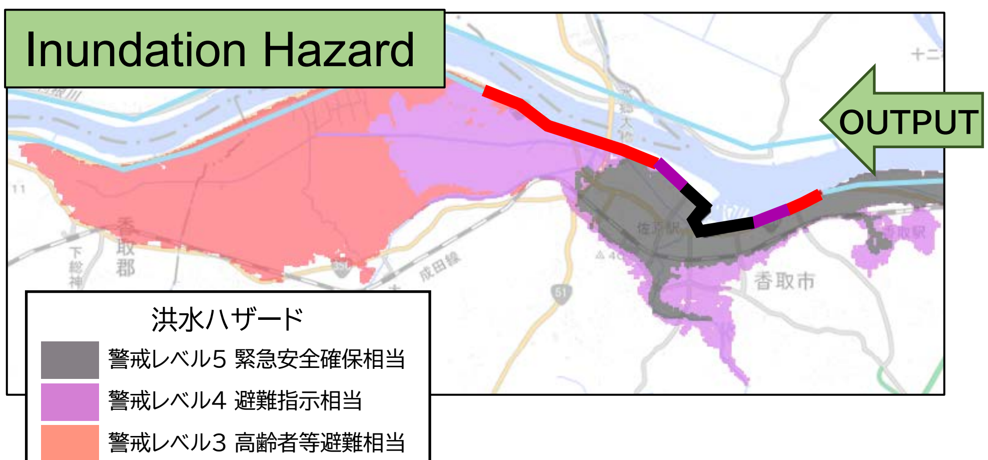
Data assimilation with on-site inundation information to provide corrected data

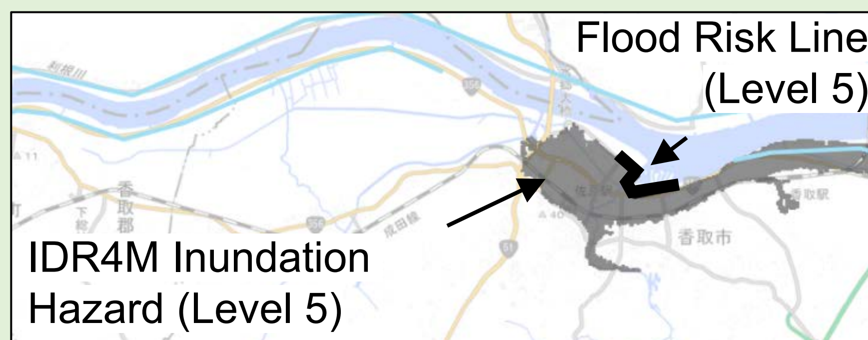
Inundation hazard information by IDR4M　(1)







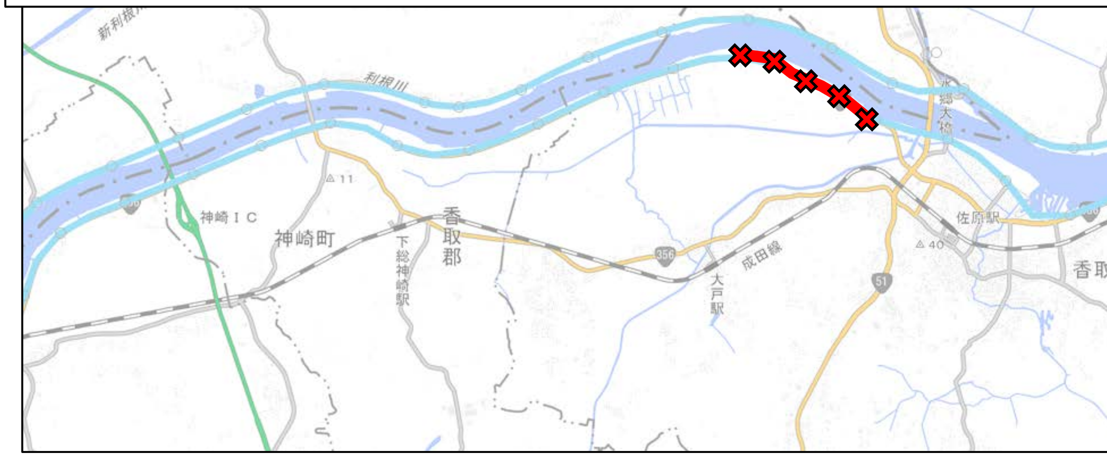


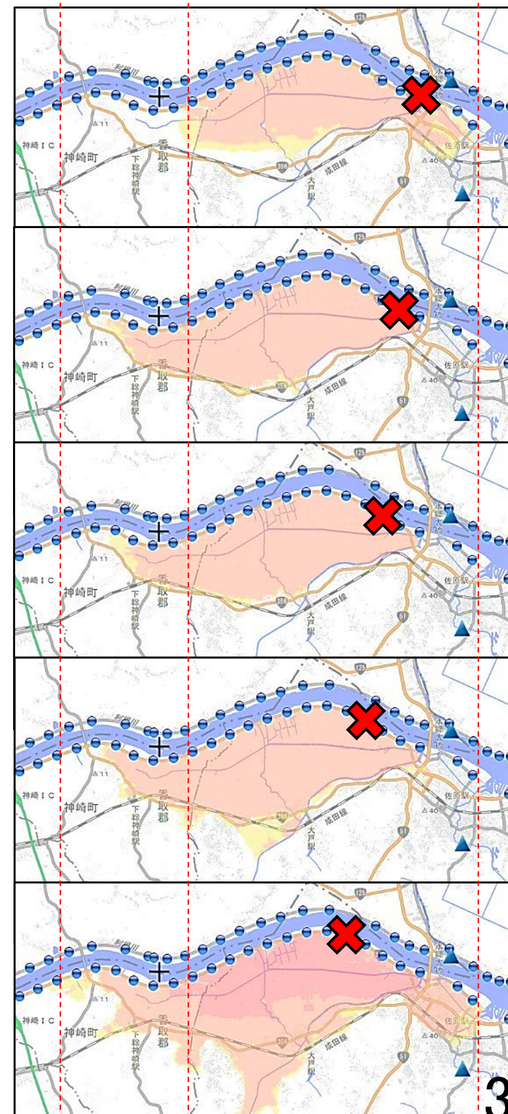


Inundation hazard information by IDR4M (2)

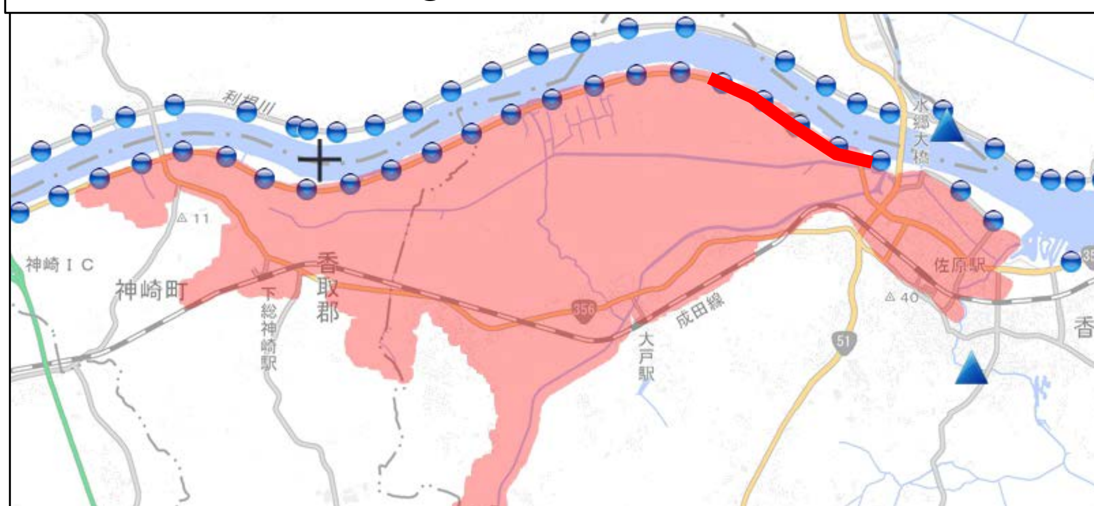
Collection of data from Inundation Navi

Occurrence of flood risk lines (5 locations, Level 3)





Overlay of inundation areas from Inundation Navi, colored according to the flood risk line levels



Outline

1. Currently available flood risk information
2. Characteristics and lessons of recent flood disasters
3. SIP project – Subtopic B
4. Conclusion

Conclusion

- While hazard maps and disaster information are provided during emergencies, the evacuation actions and disaster response of residents and businesses remain insufficient.
- One of the most important reasons is that "people do not perceive flood disasters as their own concern."
- Purpose of Technology R&D
  - Provide information that allows people to realistically recognize the dangers of flooding, both in normal times and during disasters.
  - Provide information that quantitatively indicates future flood risks under climate change.
- Current Status
  - Developing a prototype of the information provision system.
  - Conducting demonstration experiments in the field.
- Goal
  - Introduce the system to national and municipal governments.
  - Build a framework that enables society as a whole to adapt to flood disasters.

Thank you for your attention.

Flood Risk - Analysis and Management on Watershed Scale in Times of Change

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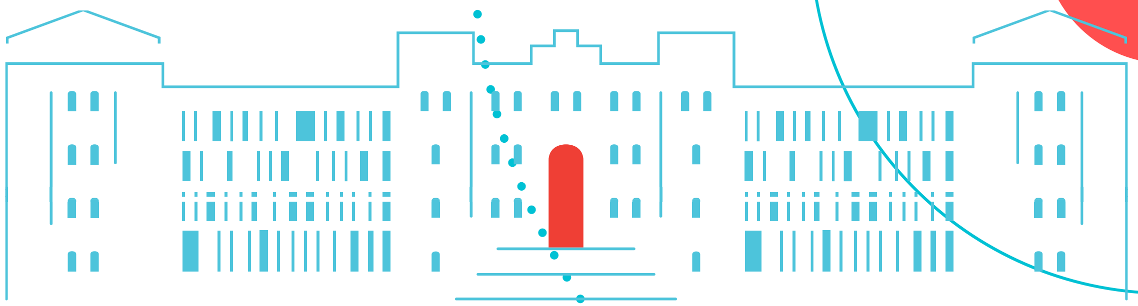
29.10.2025



Prof. Peter Fröhle
Oxana Karatnik

Session: Systematic Watershed Management and Smart Disaster Prevention

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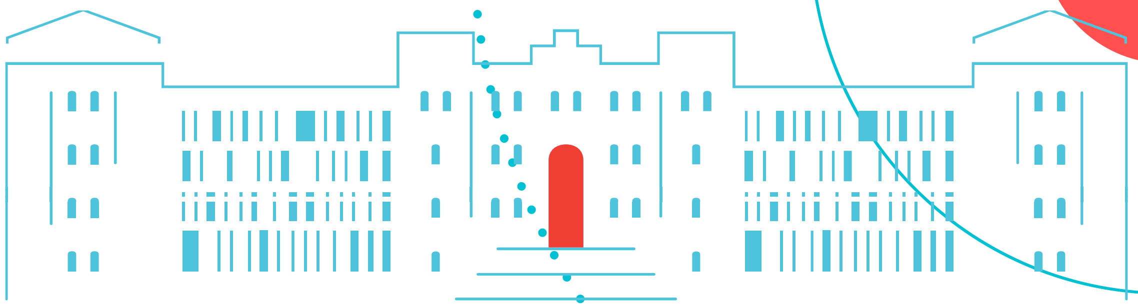


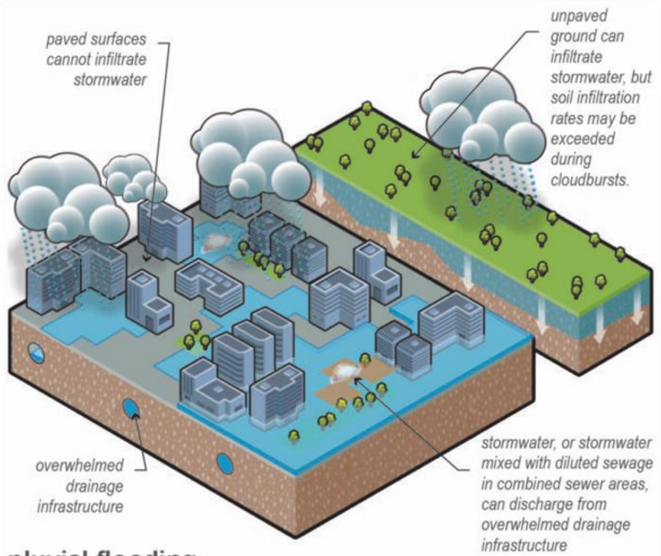
Prof. Peter Fröhle
Oxana Karatnik

Contents

1. Introduction - Flood Risk(s) and future Change(s)

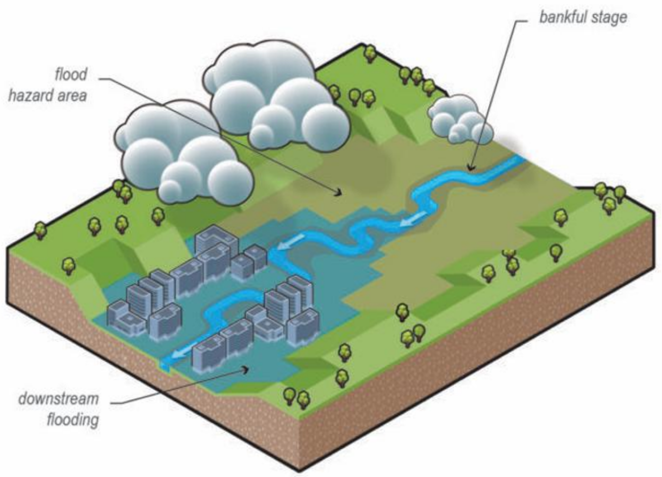
Flood risk(s)

- Pluvial Floods
- Fluvial Floods
- Coastal Floods
- Groundwater Floods
- Compound Floods



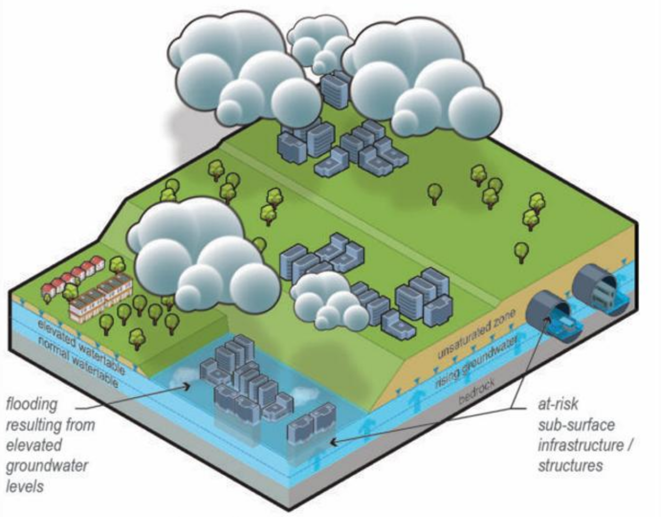
pluvial flooding

flooding that occurs when the intensity of precipitation exceeds the capacity of the land surface to infiltrate it and / or when the rate of runoff exceeds the conveyance and / or storage capacities of natural and engineered drainage systems. Pluvial flooding is commonly described as 'urban' flooding since it is a particularly important type of flooding in cities.



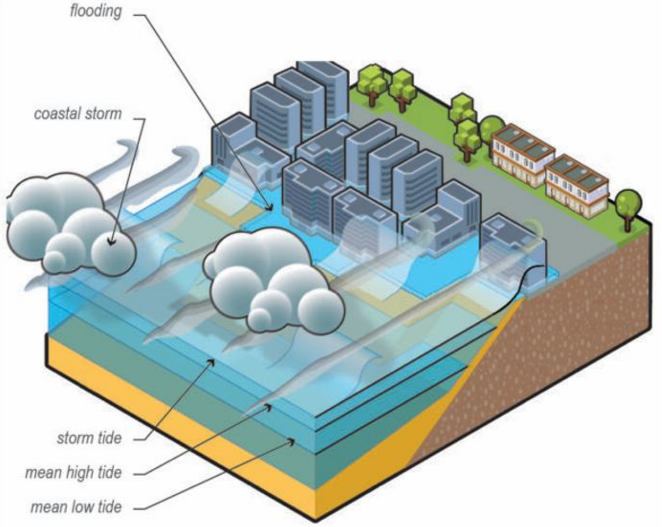
fluvial flooding

flooding caused when the stage of a river, creek, or stream exceeds the elevation of its banks; also known as river flooding.



groundwater flooding

flooding caused when the water table rises to levels that cause inundation of the land surface or subterranean property.



coastal flooding

flooding caused by high tides and storm surge. This type of flooding will be exacerbated by sea level rise.

www.climateassessment.nyc

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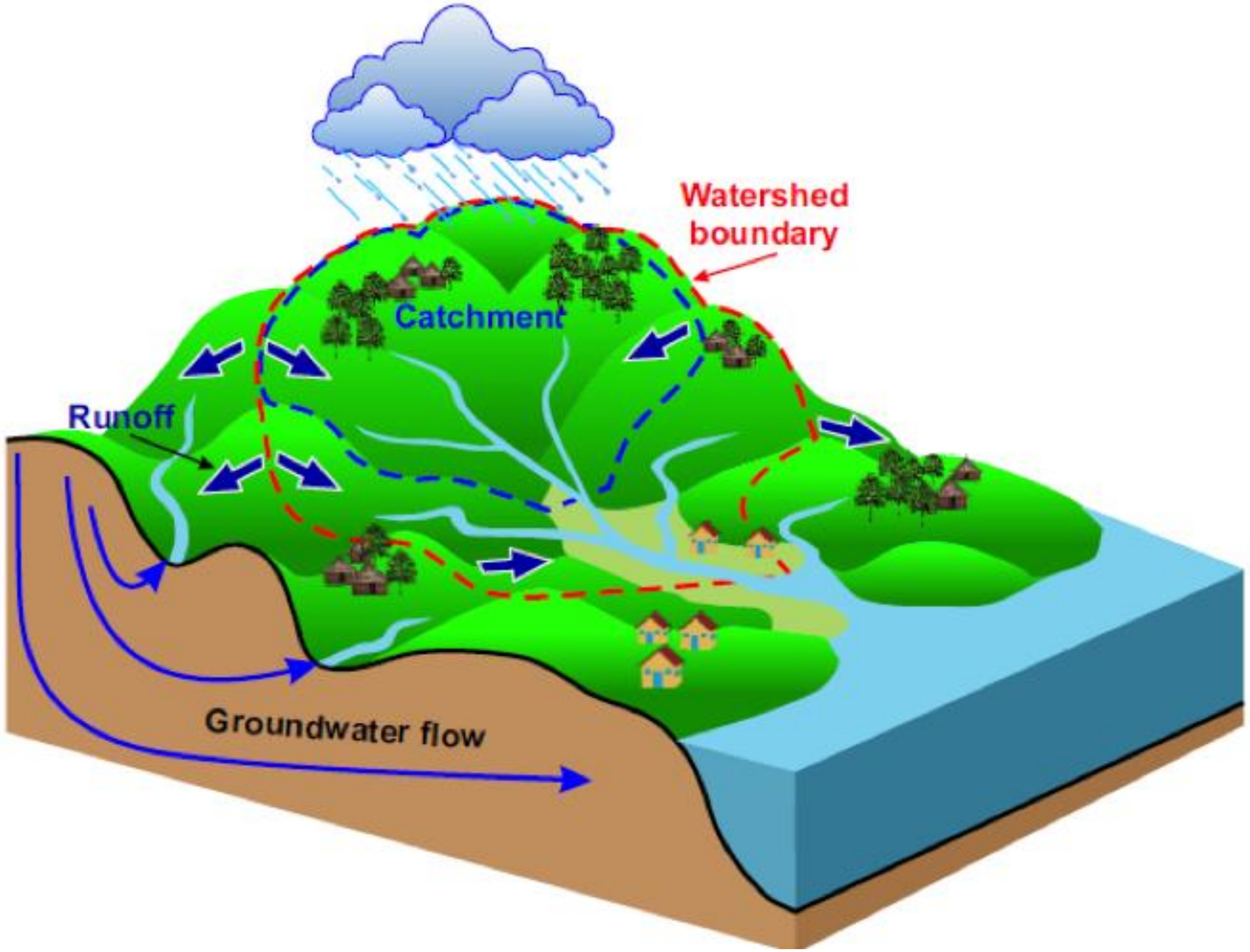
Future change(s)

- Climate Change
- Change in Geomorphology
- Societal requirements
- Technological developments
- …

2. Interactions on the watershed-scale

Catchment Scale

- Measures and Changes within the catchment influence the water system upstream and downstream
  - Flow reduction, water retention and upstream floods
  - Increase of flow velocities and downstream floods
  - …
- Holistic water management approach is inevitably necessary



www.geosports.org

3. Measures and (Smart) solutions

Measures - Three Pillars of Flood Protection

Modern Flood Protection

- Flood Preparedness
- Technical Flood Protection Measures
- (natural) Water Retention

Smart solutions and innovation (selection)

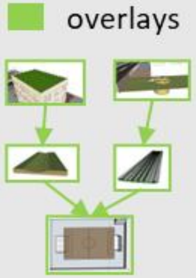
Innovations

- Digital Twin => Integration of data and models
- Development and integration of innovative structures
- Adaptation of existing technical infrastructure to reduce risks and to improve resilience and to adapt to the consequences of climate change gaining additional co-benefits (environment + social)
- Holistic approaches and nature based solutions

Kalypso - an open source modeling system for numerical simulations in water management

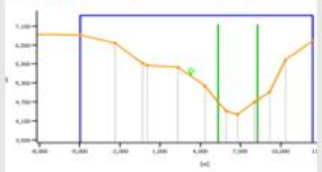
KalypsoHydrology

- Semi-distributed hydrological model



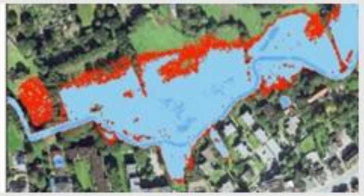
Kalypso1D2D

- Hydraulic modelling



KalypsoFlood

- Flood model



HQ100

HQ100 (Szenario 2050)

KalypsoRisk

- Risk model

Results:

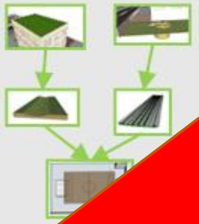
- Specific damage values for flood events.
- Annual expected damage values.

Innovation: Integration of data and models → digital twin

Kalypso - an open source modeling system fo imulations in water management

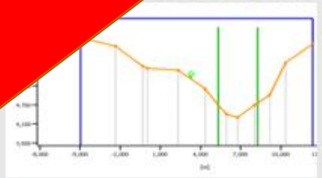
KalypsoHydrology

- Semi-distributed hydrological model



Kalypso1D2D

- Hydraulic modellin



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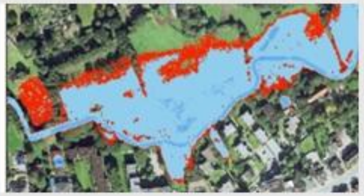
- ood model



KalypsoRisk

- Risk model

Results:

- Specific damage values for flood events.
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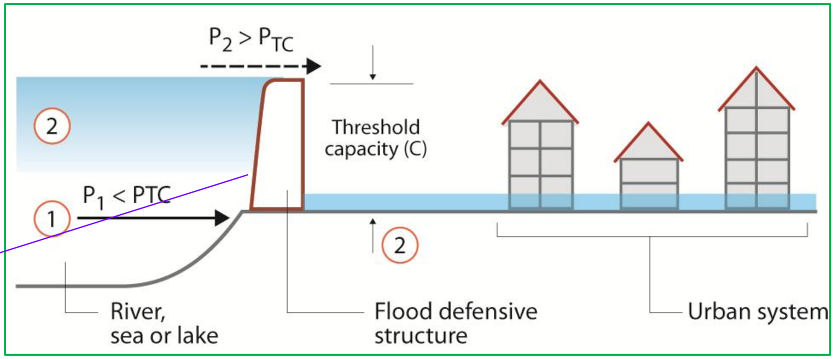
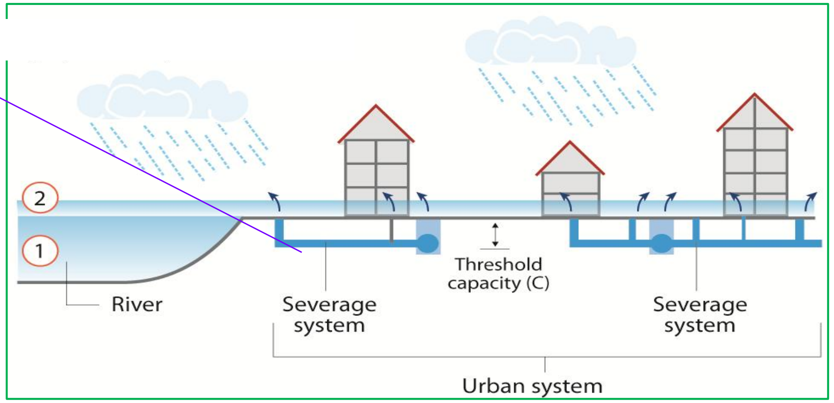
Risk reduction through protection

Risk= Probabaility x Consequences

Reducing the probability of floods



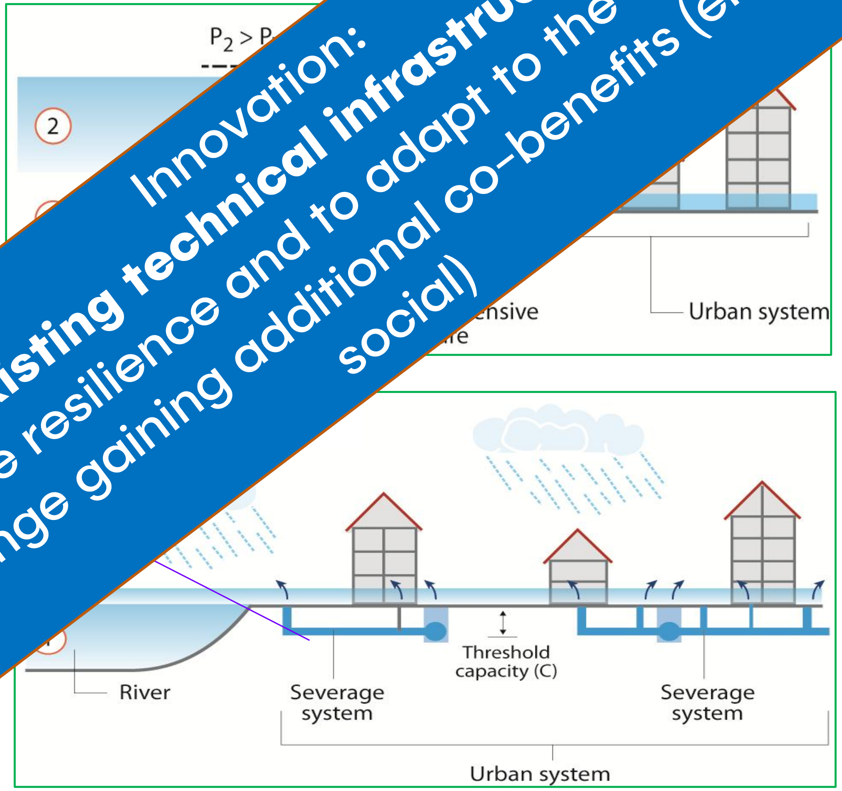


Risk reduction through protection

Risk= Probabaility x Conse

Reducing the probability of floods

Innovation:
adaptation of existing technical infrastructure to reduce risks and to improve resilience and to adapt to the consquences of climate change gaining additional co-benefits (environment + social)



Options of Flood Protection

Risk of Flooding = Probability of flooding x consequences (damages)

- Limit risks => Reduce (minimize) consequences
  => Improve resillience of systems

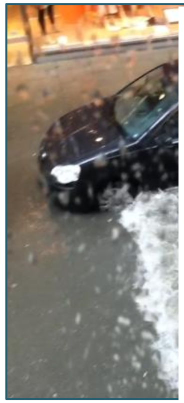
  - Reduce consequences / damages / damage potentials => water adapted constructions (living with water)

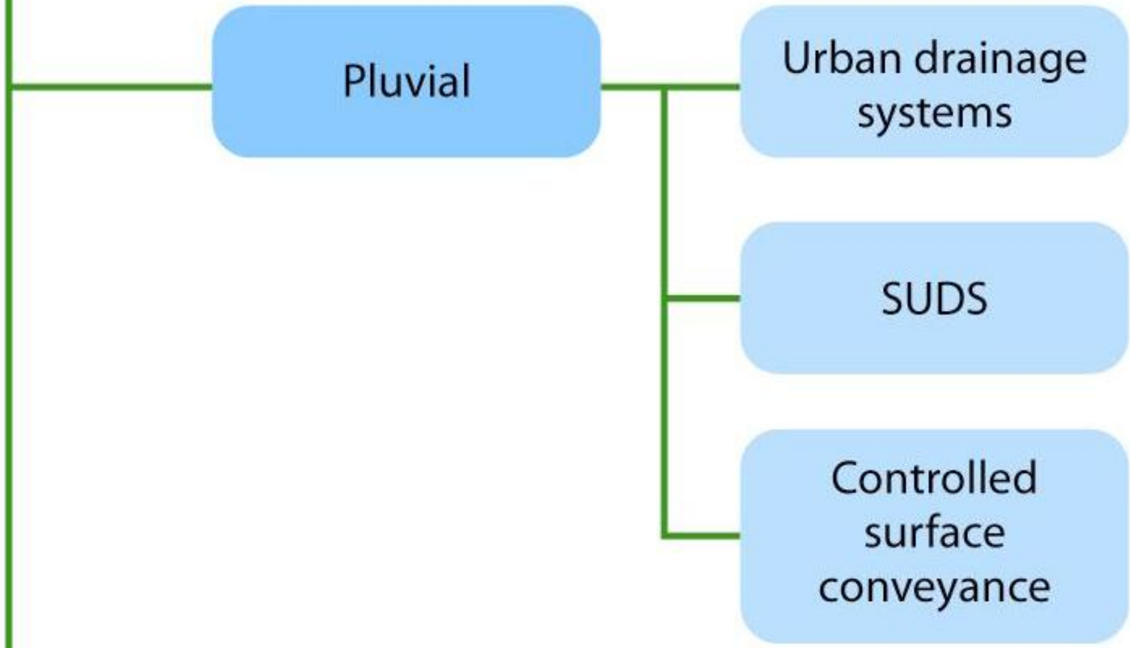
- Limit risks => reduce probability of occurance
  => improve protection level

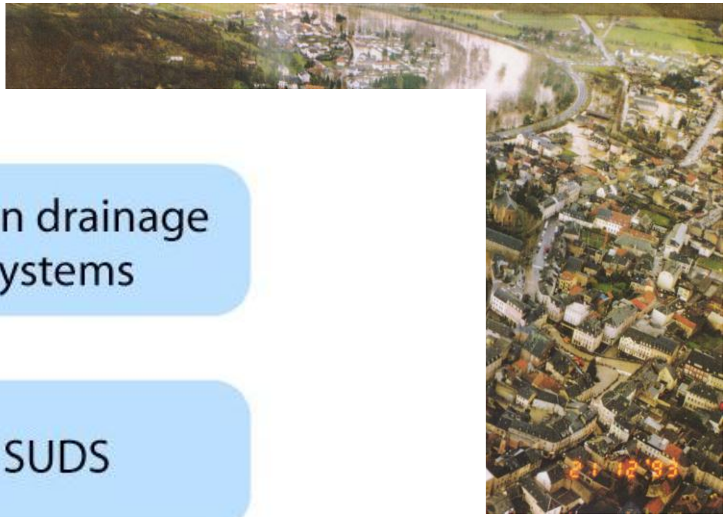
  - Reduce storm water levels
  - Increase height of flood protection measures

4. Example a: Urban Drainage

Overview of Flood Risk Mitigation Measures







SUDS – overview of technologies

Source control measures:

- Green roofs

- Rainwater reuse

- Permeable pavements

Infiltration techniques:

- Filter trenches, drains and strips
- Soakaways
- Rain gardens

Detention structures:

- Swales
- Ponds
- Wetlands
- Bioretention areas

Application of SUDS in Drainage Systems

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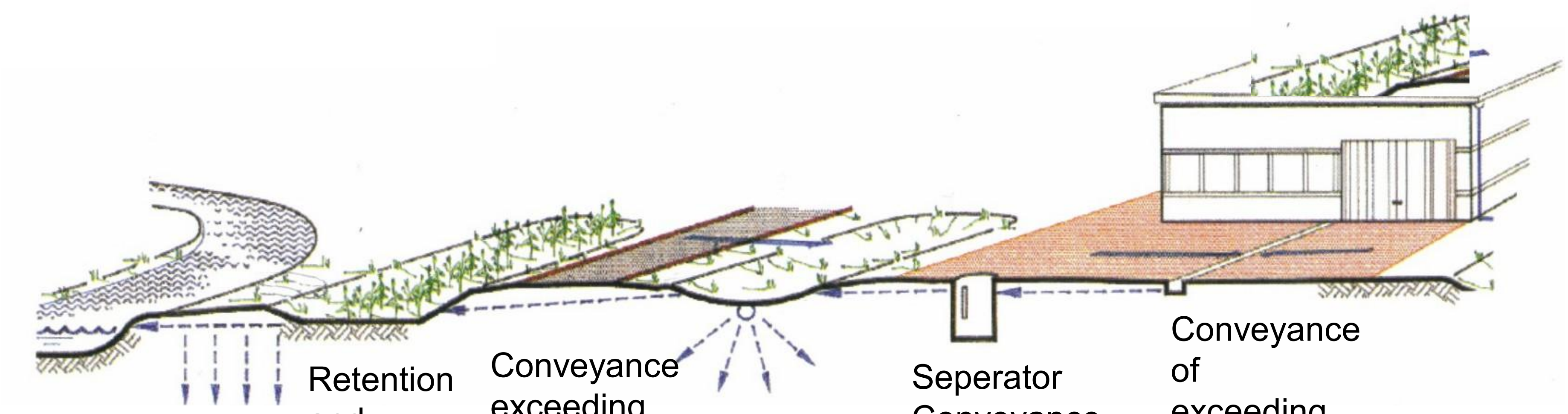
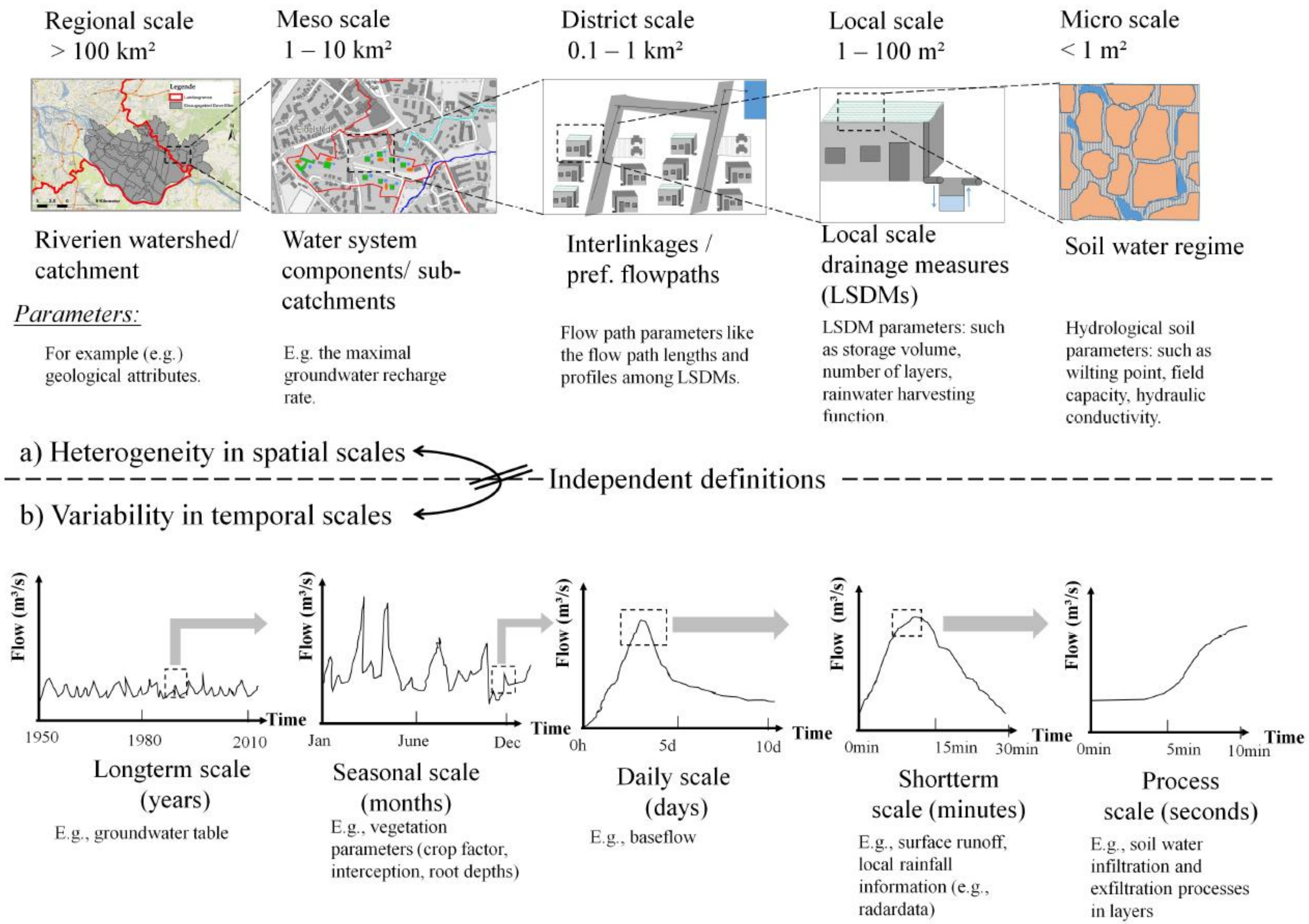
→ Integrated approach of application SUDS



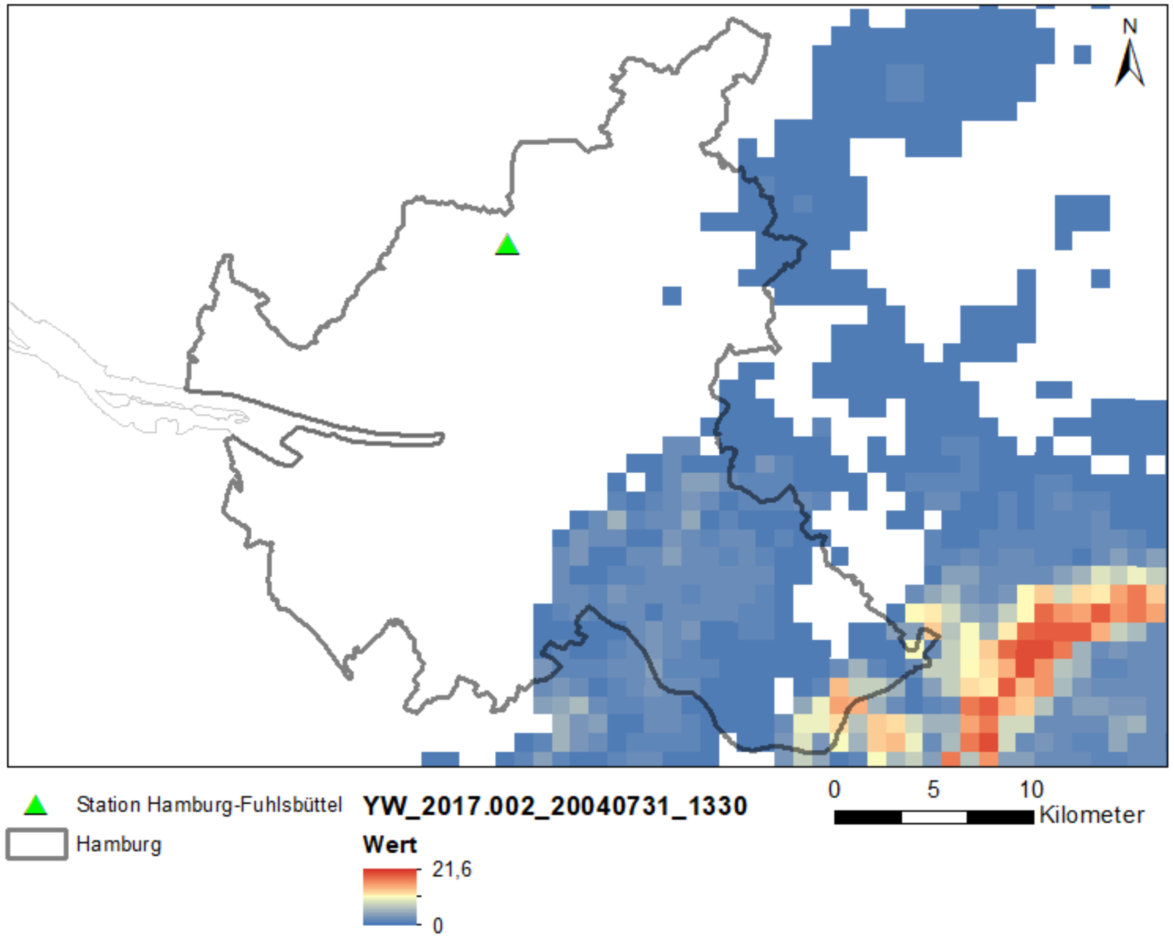
Conveyance and diversion structures for the run-off

SUDS and spatial and temporal scales in hydrology



From: Hellmers, S. (2020): Integrating local scale drainage measuresin meso scale hydrological modelling of backwater affected catchments, after Hellmers & Fröhle (2017)

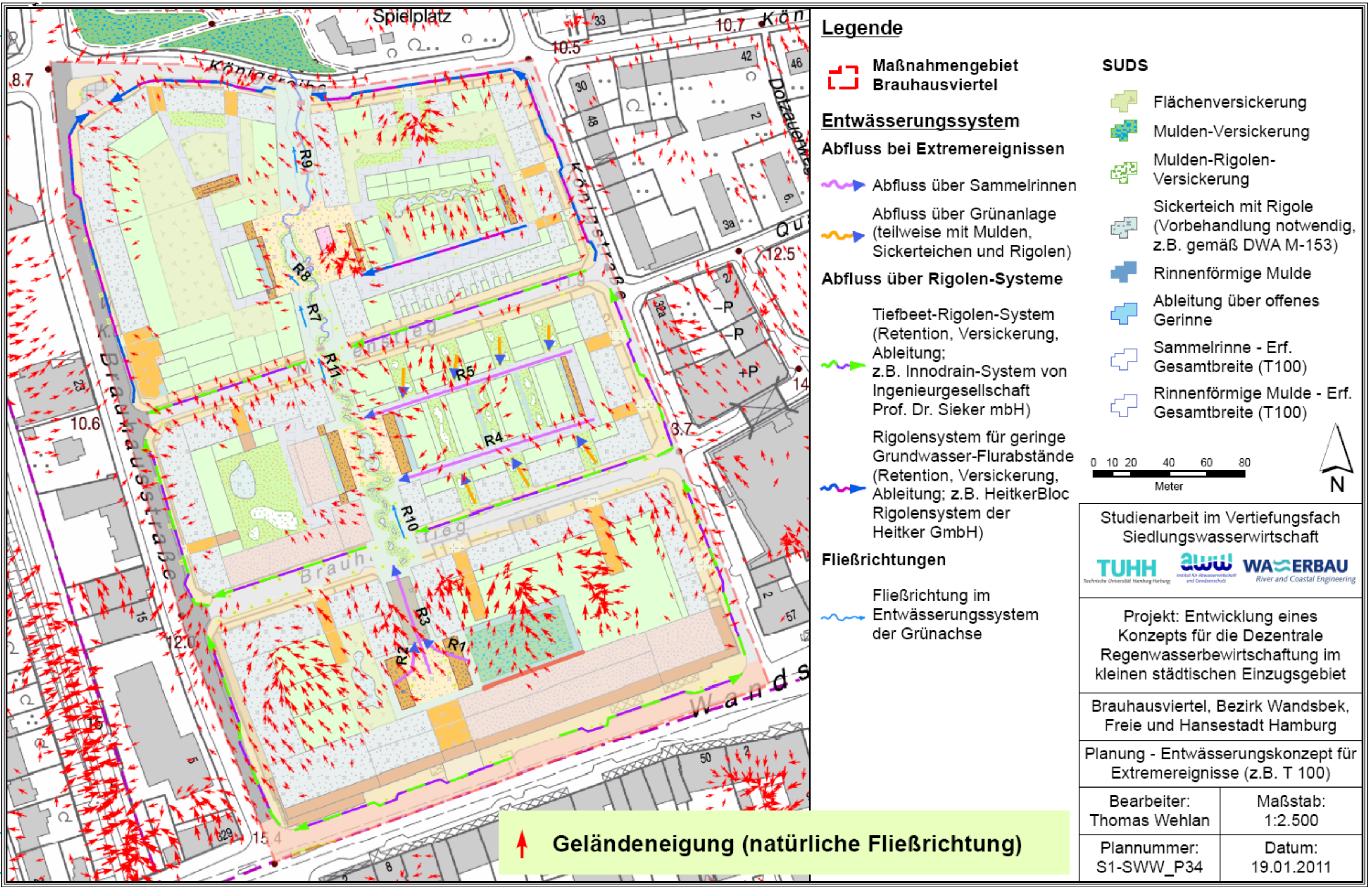
Integration of data
➔ RADKLIM precipitation climatology - event 31.07.2004



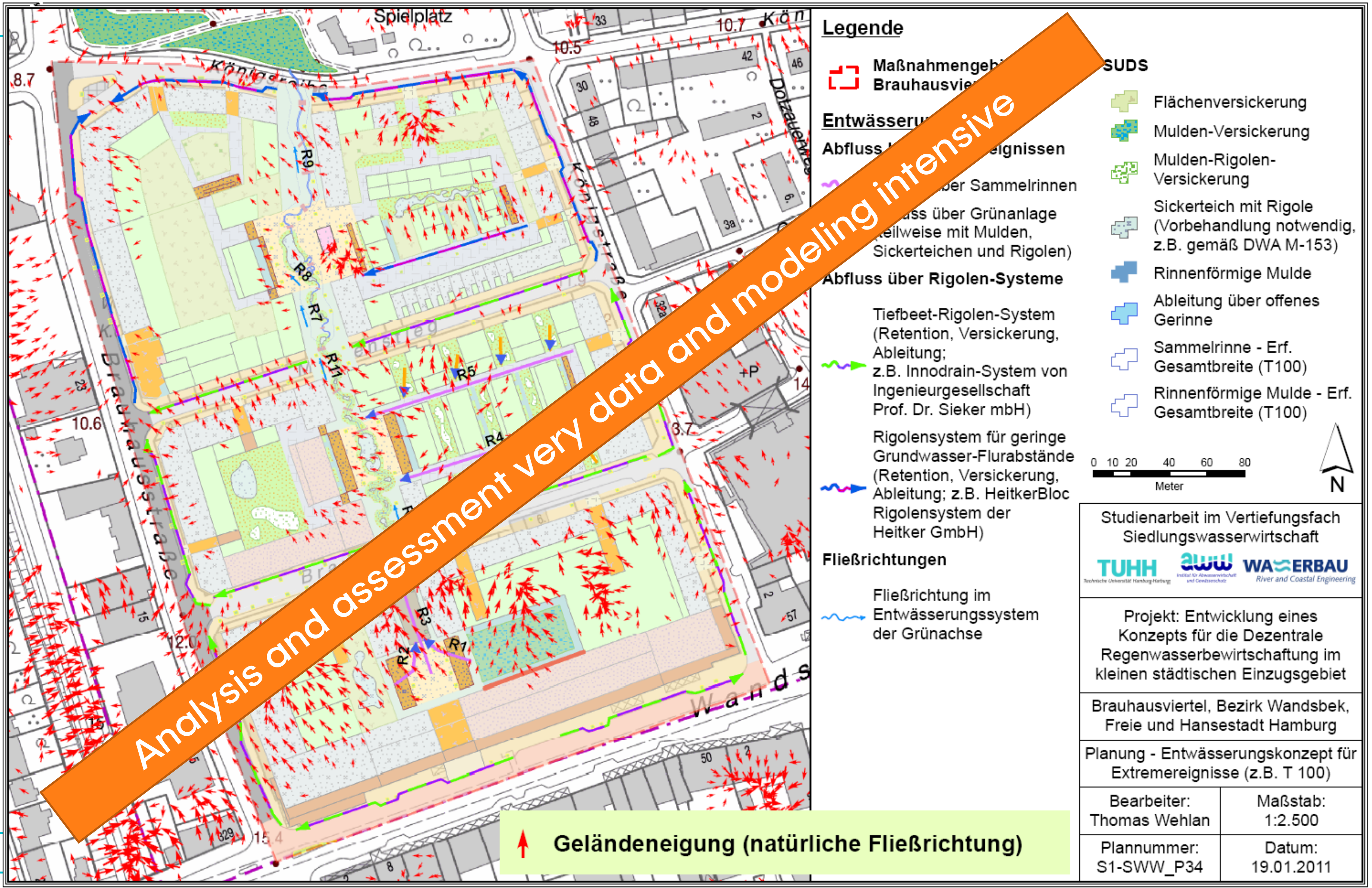
Dayly average Station Fuhlsbüttel: 0,7 mm/day

Intensity: 10-20mm/5min

SUDS- the planning aspects



SUDS- the planning aspects

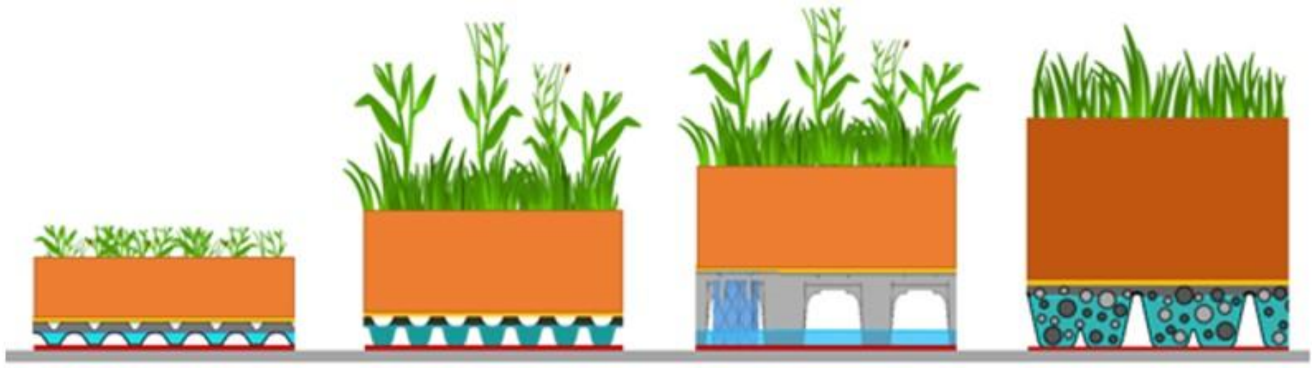


Analysis and assessment very data and modeling intensive

Green – roofs – storage capacity

Local and de-centralized retention of stormwater

- **Green-roofs**
- cisterns
- Multifunctional spaces (sport-area / streets / playgrounds / etc.)



	(1) Spardach	(2) Naturdach	(3) Retentionsdach	(4) Gartendach
Height	6 cm	10 cm	10 cm	15 cm
Storage capacity	5 l/m²	8,7 l/m²	28,5 l/m²	23 l/m²
Type of greening	extensiv	extensiv	extensiv	intensiv

Green – roofs – storage capacity

Local and de-centralized retention of stormwater

- **Green-roofs**
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Green roofs:
adaptation of existing technical infrastructure to reduce risks and to improve resilience and to adapt to the consequences of climate change gaining additional co-benefits (environment + social)

(1) Spardach	(2) Naturdach	(3) Retentionsdach	(4) Gartendach
6 cm	10 cm	10 cm	15 cm
5 l/m²	8,7 l/m²	28,5 l/m²	23 l/m²
extensiv	extensiv	extensiv	intensiv

Hamburg – Green roof strategy ➔ upscaling of solutions

Bild: © Visualisierung: TH Treibhaus Landschaftsarchitektur, Luftbild: Matthias Friedel

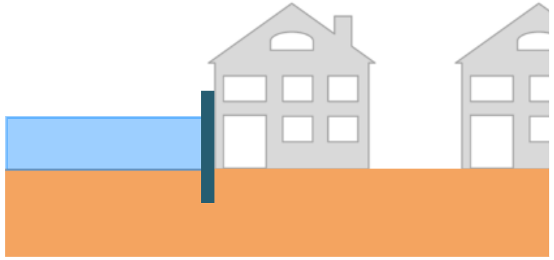
4. Example b: Adapted Constructions and Uses

Reduce consequences: Adapted Constructions and Uses => HafenCity Hamburg Flood Adapted Constructions

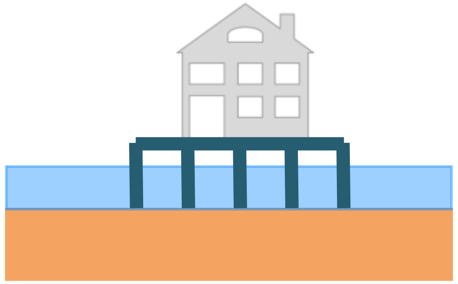
Building or **infrastructure**

- as water tight construction

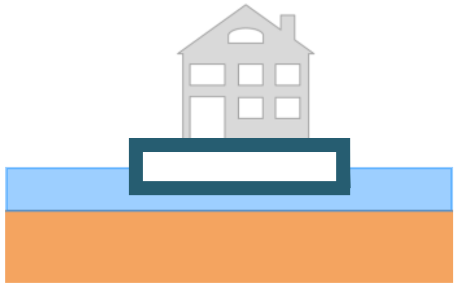
- as flood protection wall or dike



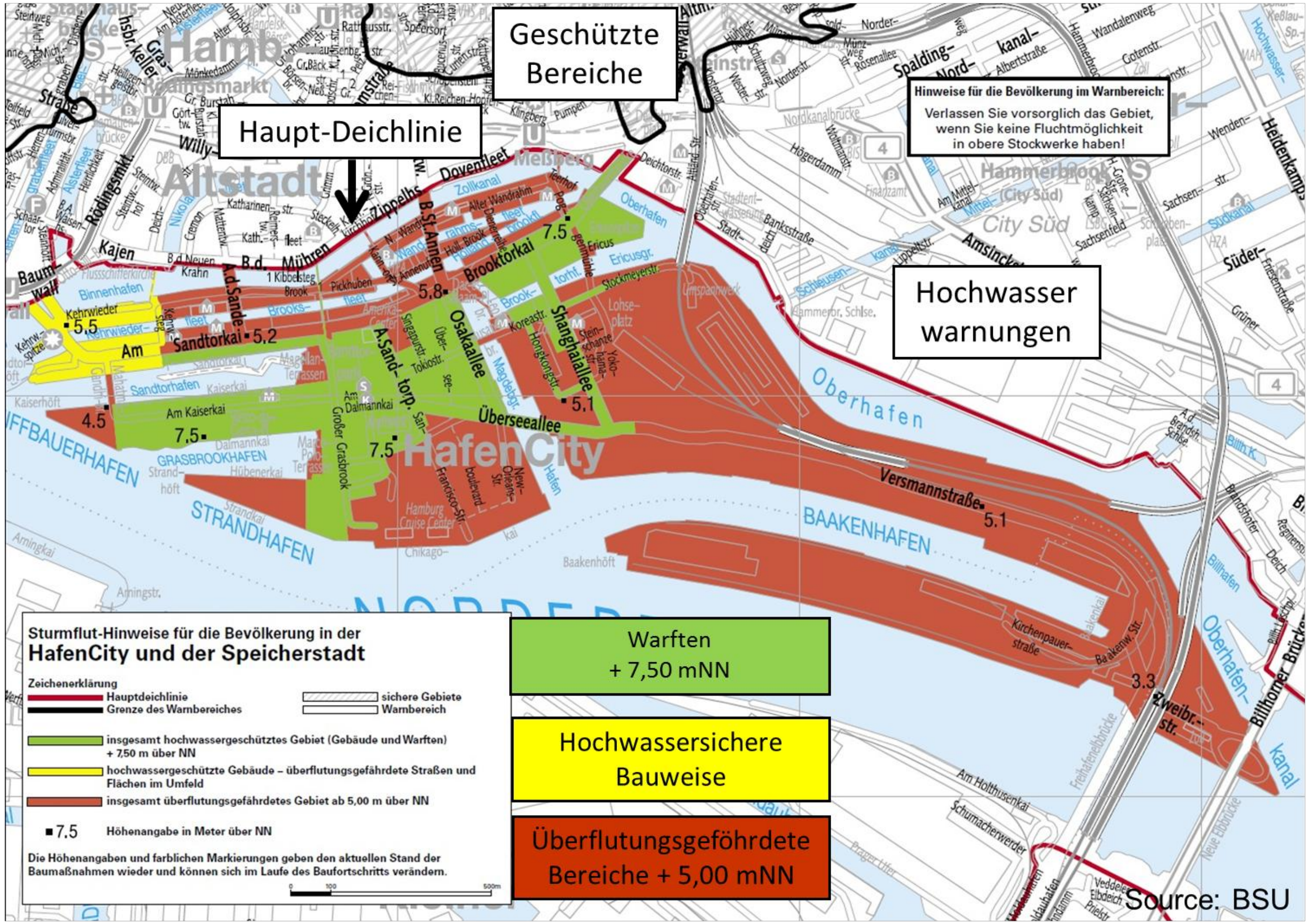
- on stilts



- amphibious or floating



Living with water: Flood adapted constructions – HafenCity Hamburg



Living with water: Flood adapted constructions – HafenCity Hamburg

Flood adapted constructions – water tight constructions HafenCity - Hamburg

Flood adapted constructions – water tight constructions HafenCity - Hamburg


Quelle LSBG

Flood adapted constructions – water tight constructions HafenCity - Hamburg

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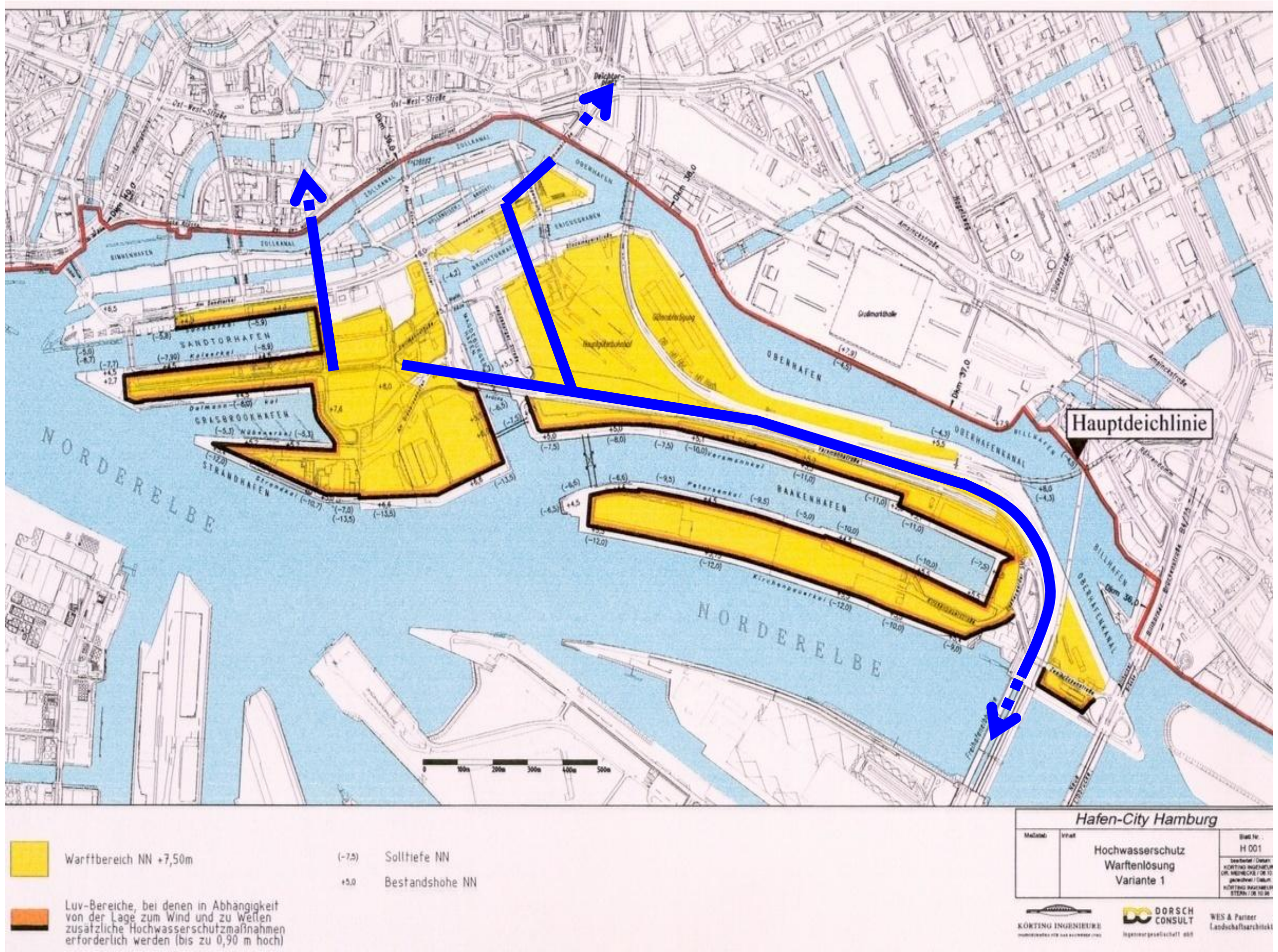
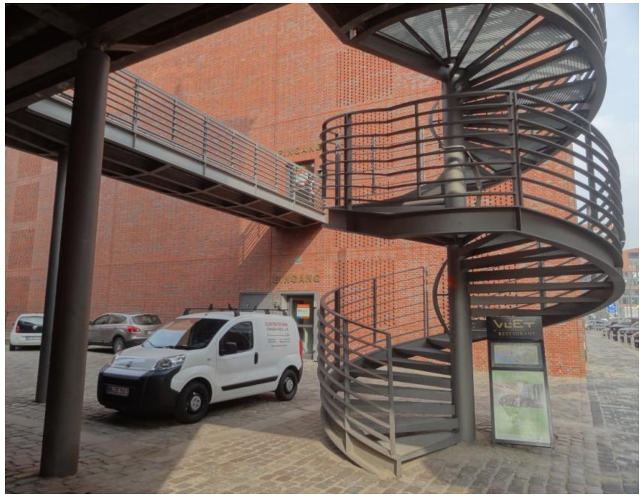
Flood adapted constructions – escape routes



Flood adapted constructions – escape routes

Flood adapted constructions – escape routes

Flood adapted constructions – escape routes



Flood adapted constructions – Constructions as flood protection wall - Fluttore / Example Landungsbrücken HH

4. Example c – Preparedness: Flood Protection of the Future: **Elbe Estuary** and **Schlei Area**

Main Objective

Identify and **analyze** the **potential options** for **future flood protection** in the **catchment** of the Elbe and the Schlei

evaluate them **comparatively** from a

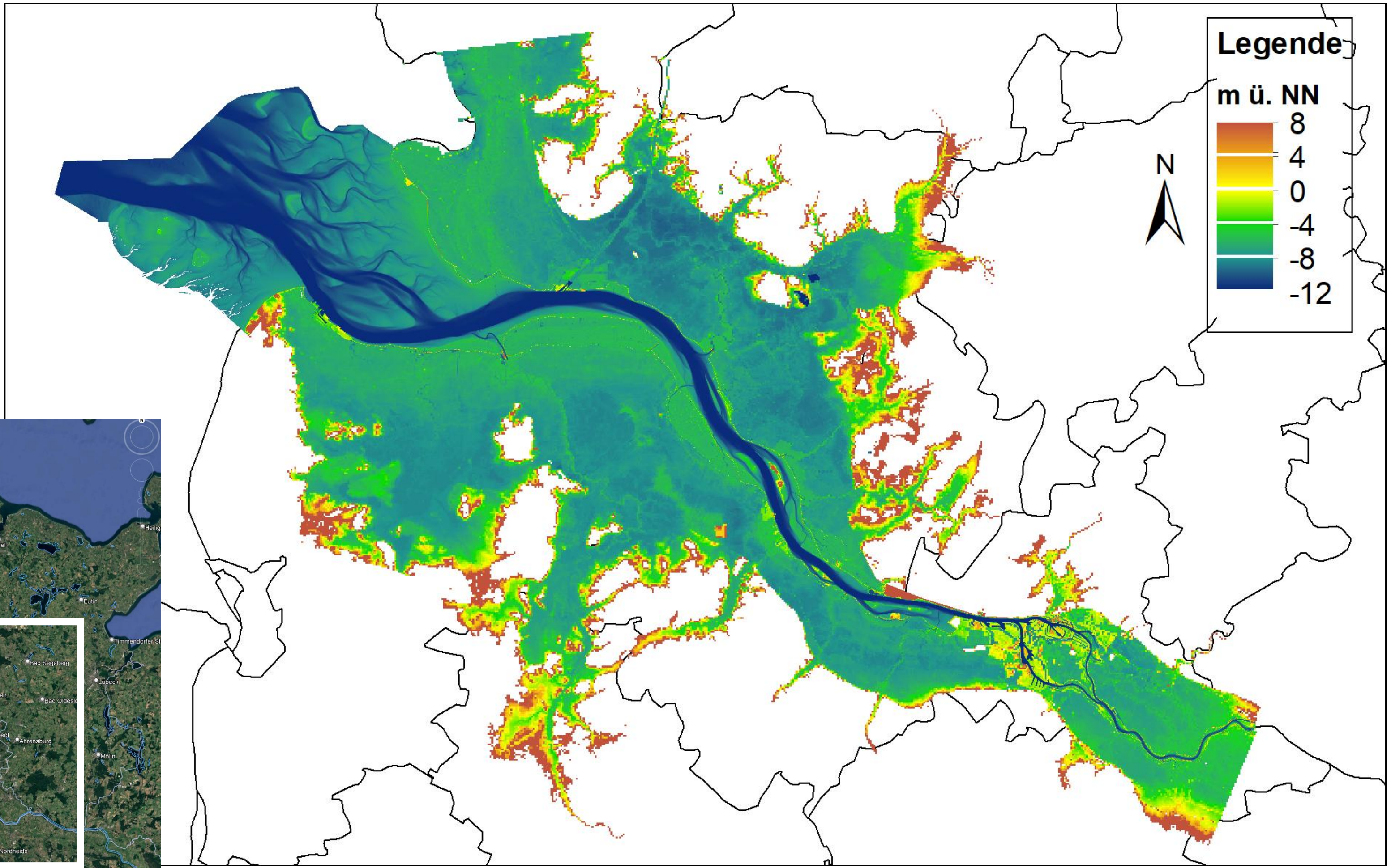
- **Hydraulic engineering**
- **Water management**
- **Ecological**
- **Economic**

perspective.

Elbe estuary and flood prone areas

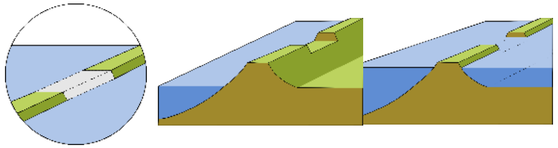
Google Earth

Elbe estuary and flood prone areas

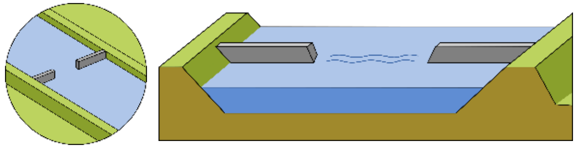


Individual Measures for Flood Protection in the Estuary

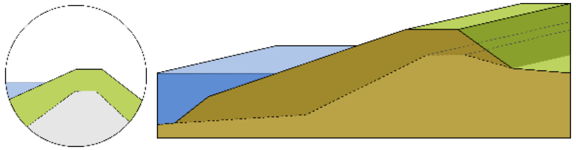
Flood-Polder (1P)



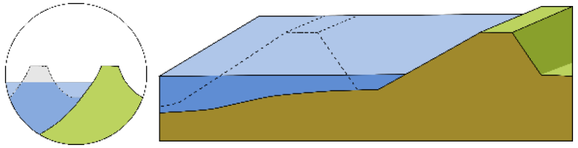
Reduction of Cross-section (2Q)



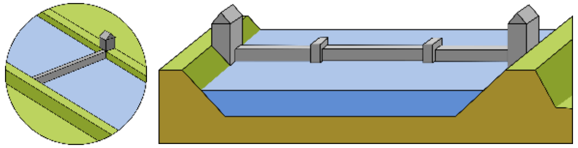
Strenghtening (3V)



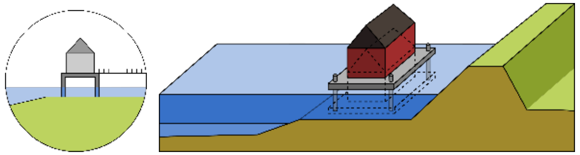
Dike re-alignment (1L / 1G)



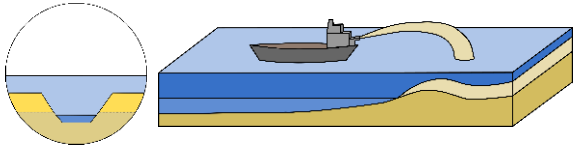
Storm-surge barrier (2S)



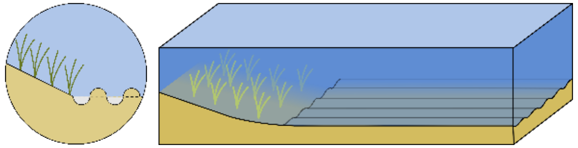
RESILIENT Constructions (4R)



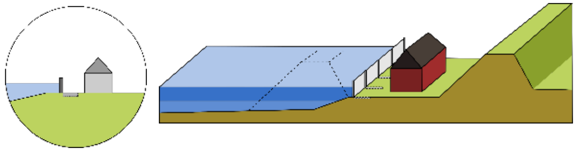
Enhancement of Wadden Sea (1W)



Increase of Dissipation (2D)



Adapted constructions (4A)



Individual Flood-Protection in the Lower Elbe Catchment – polder-solutions

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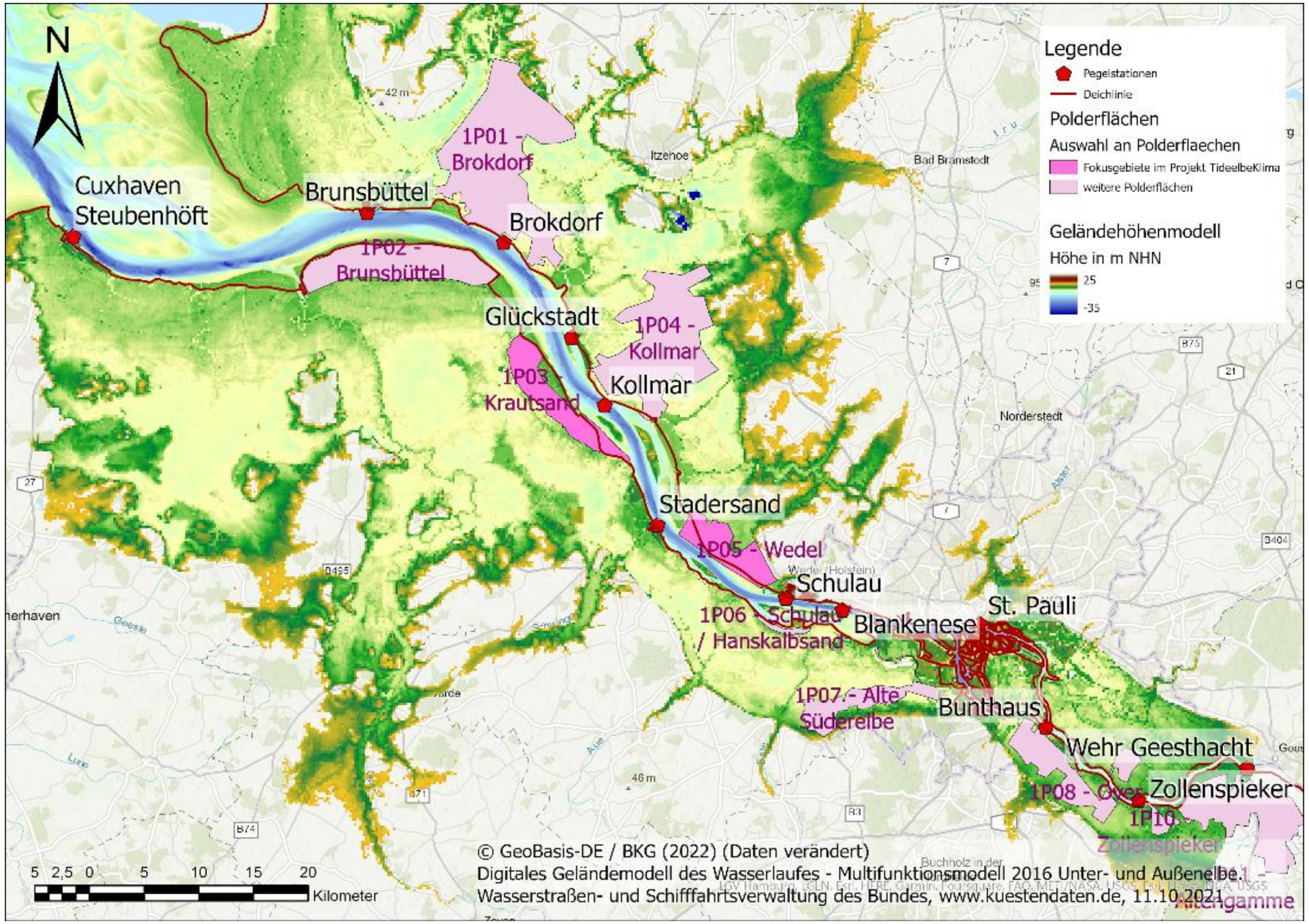
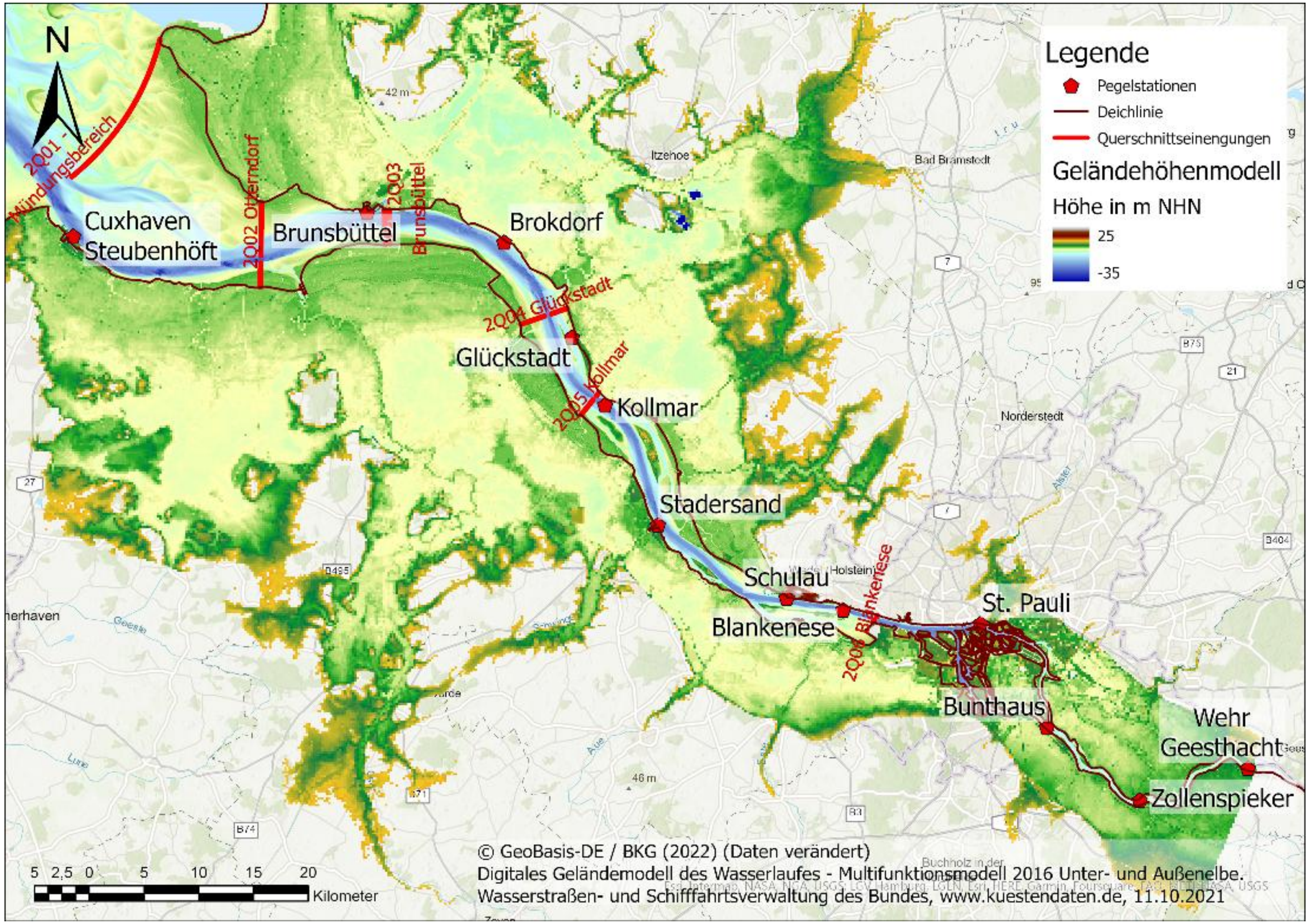
- 12 Polder – Locations
  in the Lower Elbe catchment



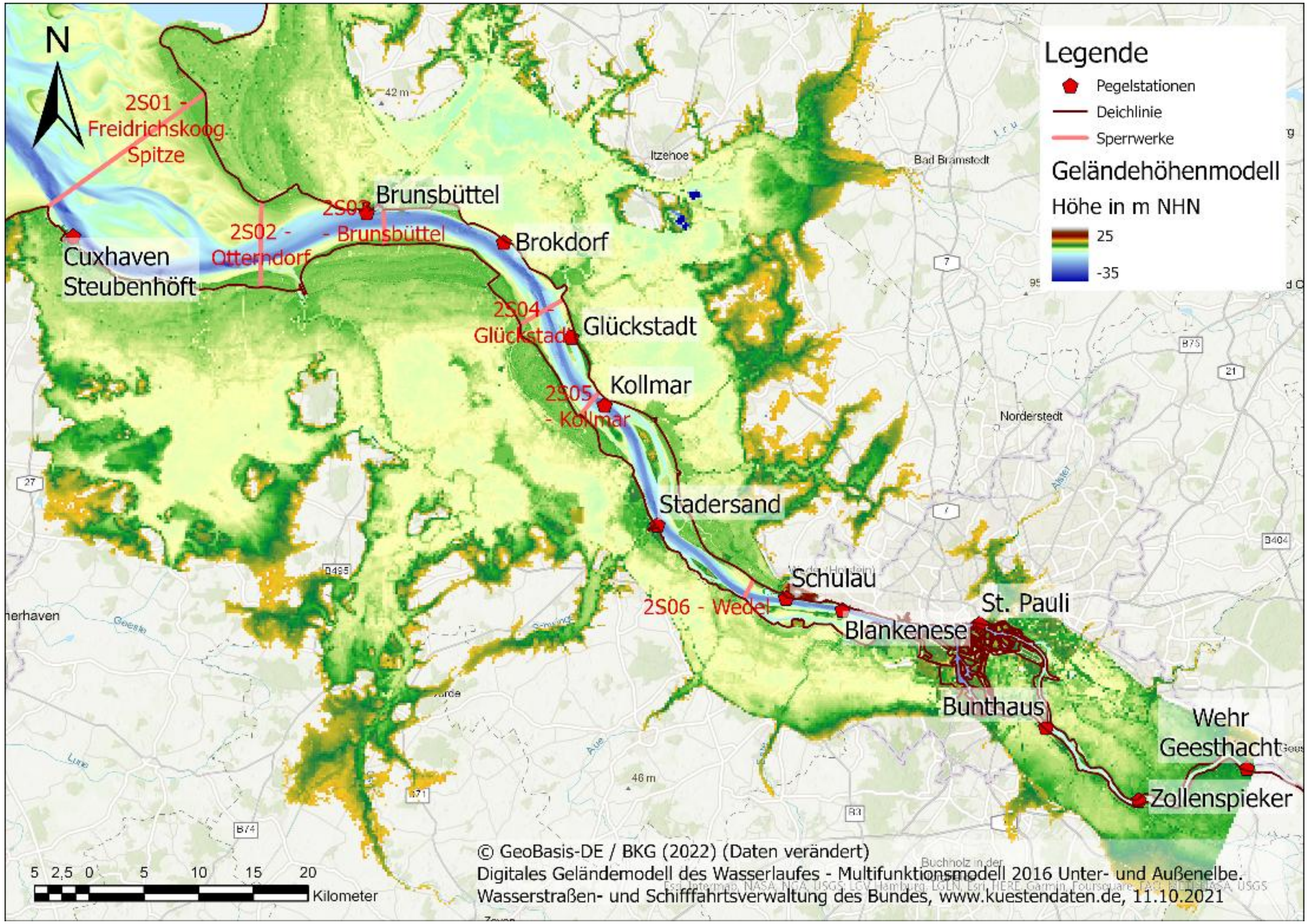
Individual Flood-Protection in the Lower Elbe Catchment – reduced cross-section

- 6 possible locations for **reducing cross-section** area in the Lower Elbe catchment

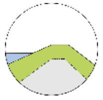
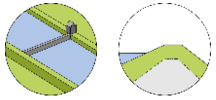
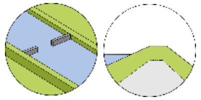
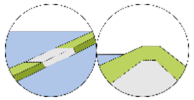
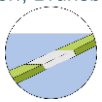
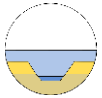
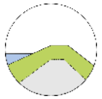


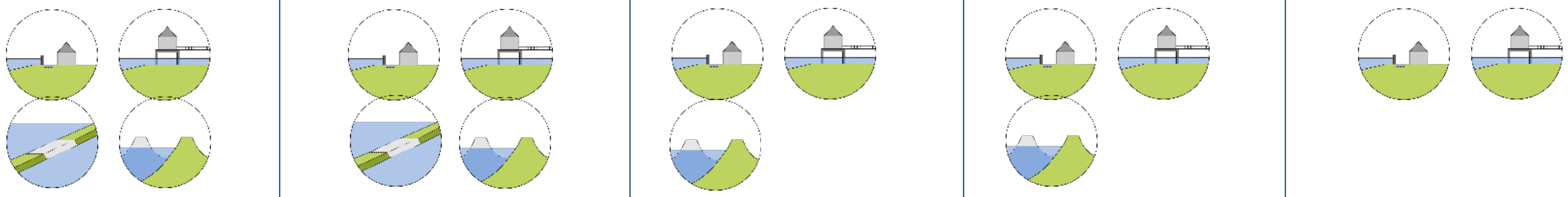
Individual Flood-Protection in the Lower Elbe Catchment – storm-surge barriers

- 6 possible locations for **rstorm-surg-barriers** in the Lower Elbe catchment



Combination of individual measures into packages

	Package VI „Gray Walls and Concrete or Asphalt Dikes.“	Package I „Maintaining proven concepts.“	Package II „A Storm-Surge-Barrier for the Elbe.“	Package III „The Hybrid Solution“	Package IV „Space for the Elbe.“	Package V „Removing coastal protection structures to create a natural Elbe landscape. “
PACKAGE	Keine weitere Betrachtung dieses Paketes.					
VARIATIONS			Where? → a: Friedrichskoog Spitze → b: bei Brunsbüttel	Where? → a: Friedrichskoog Spitze → b: Otterndorf, Brunsbüttel & Kollmar + 	Where? → a: all possible locations → b: all possible locations + 	Where? → a: dike re-alignment by 500 m +  → b: Complete removal
OPTIONAL						



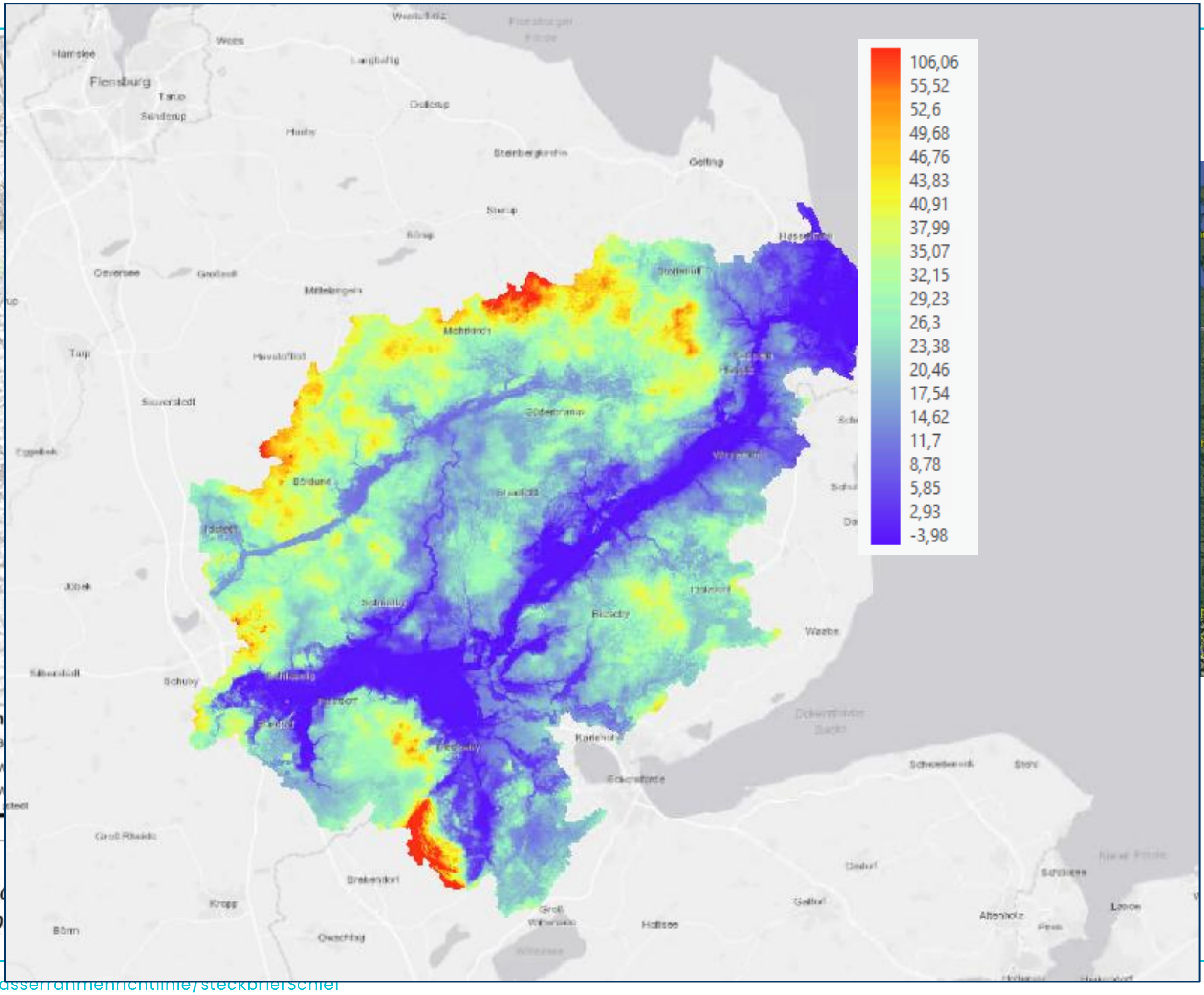
4. Example d: Preparedness Flood Protection of the Future for the Schlei Area => Baltic Sea

Catchment of the Schlei

Area: 63.000 ha
Water courses: 1.390 km

- Two cities
- 18 water boards

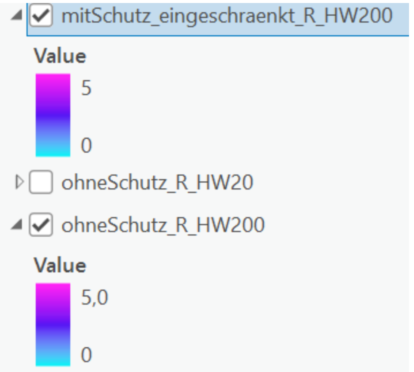
Abbil
nie/D

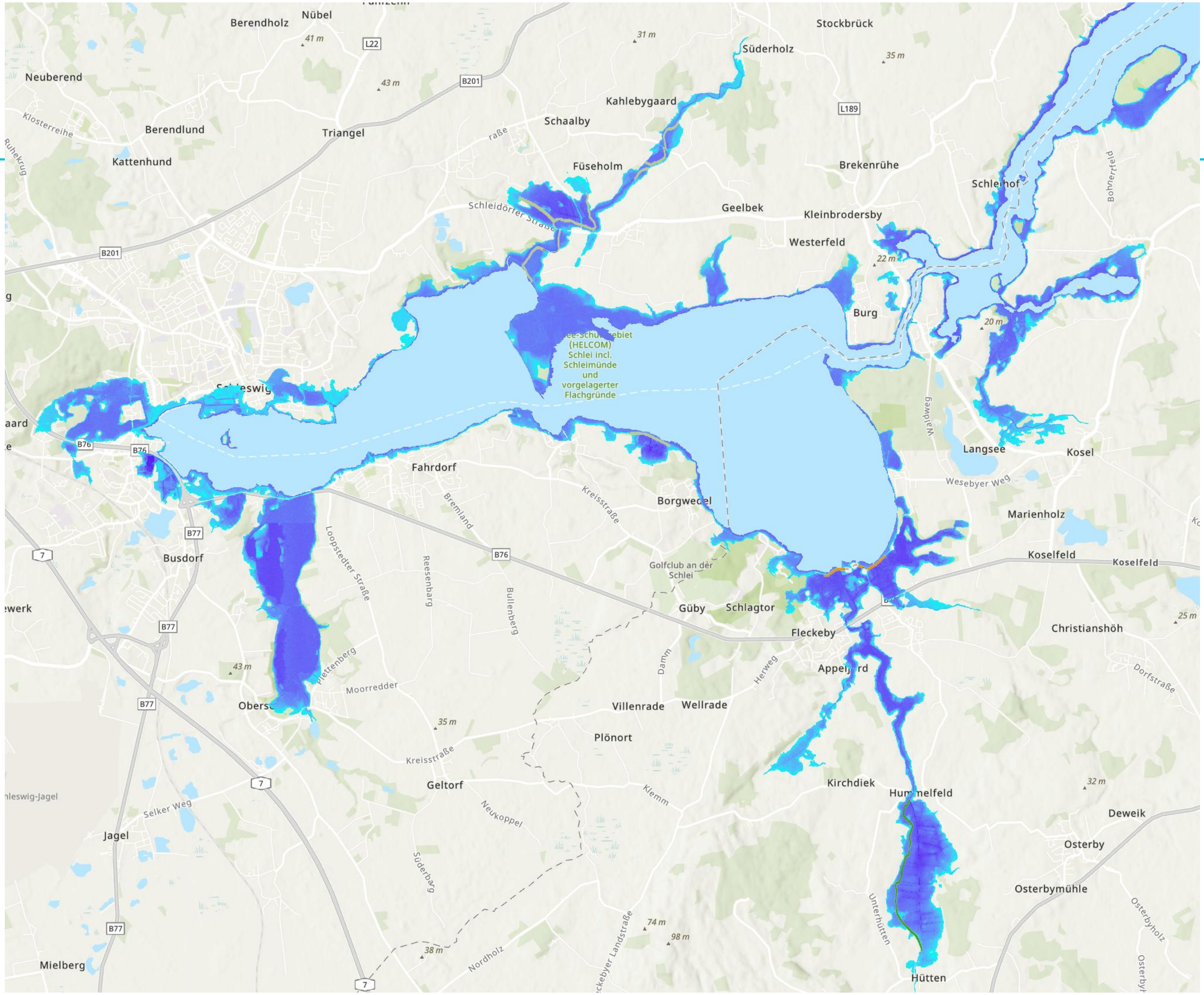


https://www.schleswig-holstein.de/DE/fachinhalte/W/wasserrahmenrichtlinie/steckbriefschlei

Hazard maps

- Innere / westliche Schlei

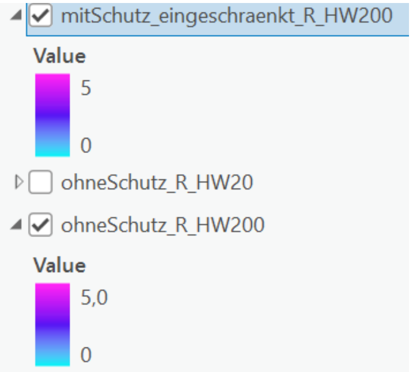


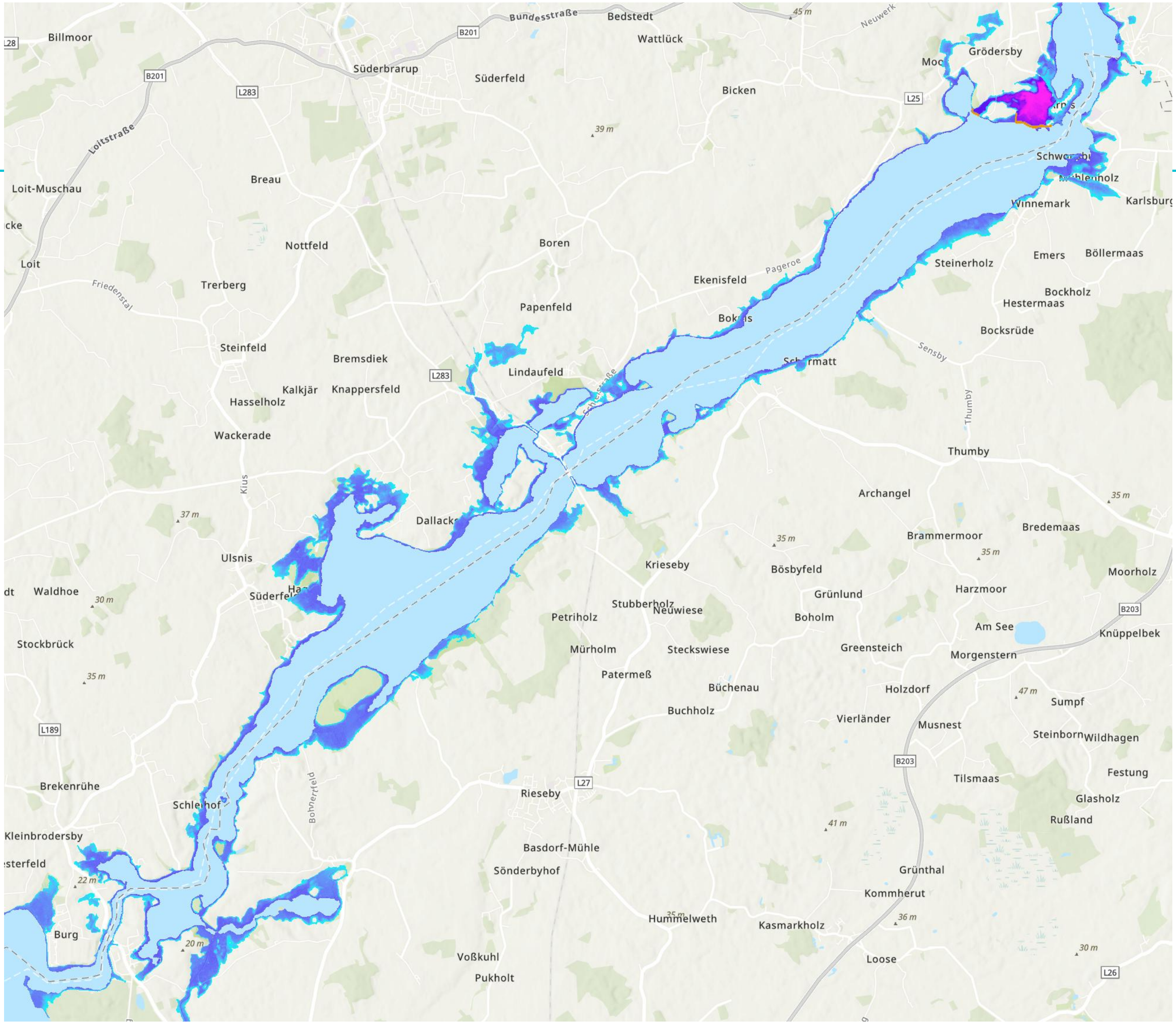


UmweltGeodienste Schleswig-Holstein

Hazard maps

- Mittlere Schlei



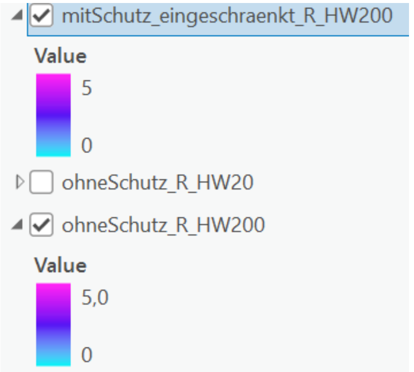


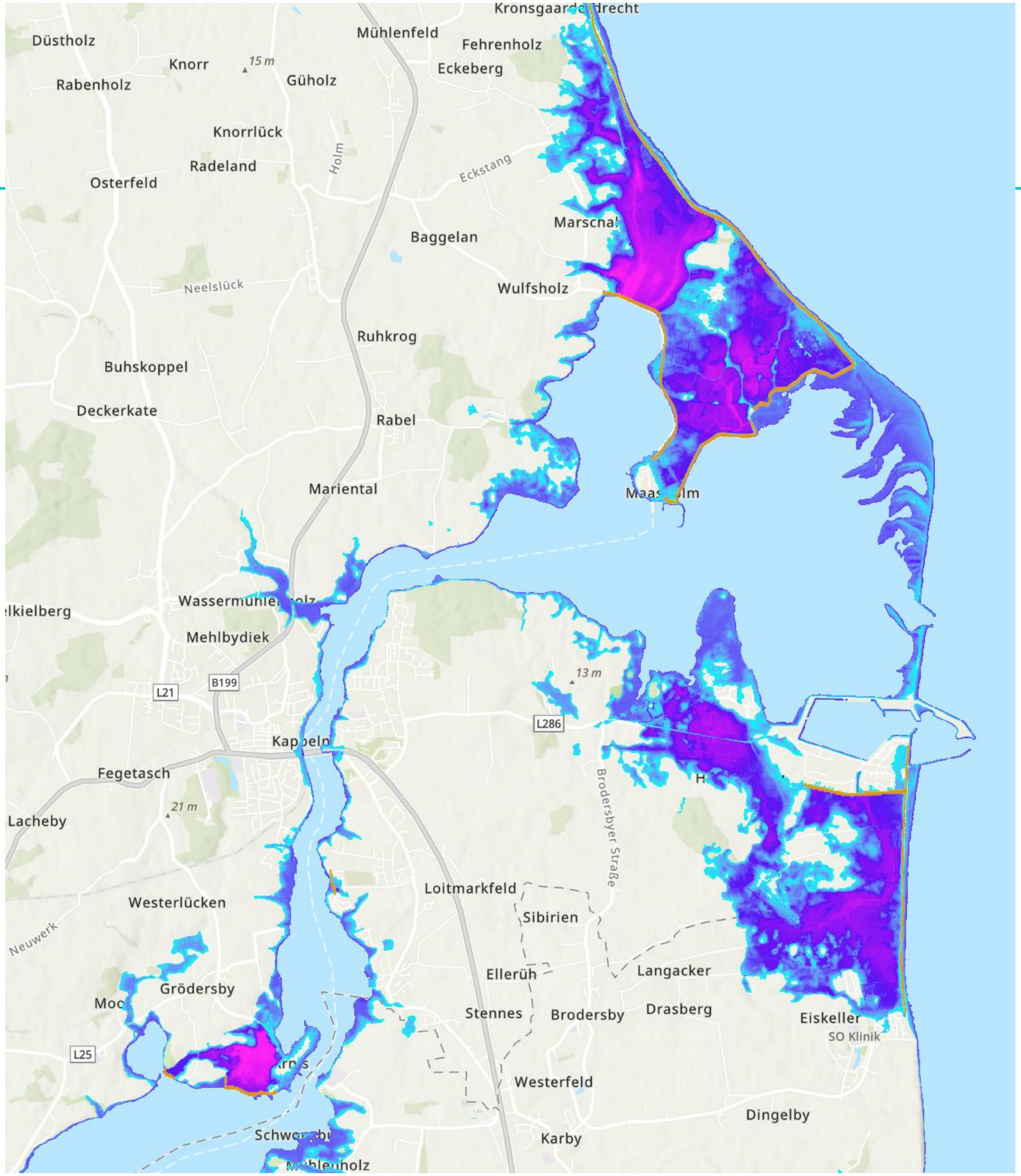
UmweltGeodienste Schleswig-Holstein

TUHH
WASSERBAU
River and Coastal Engineering

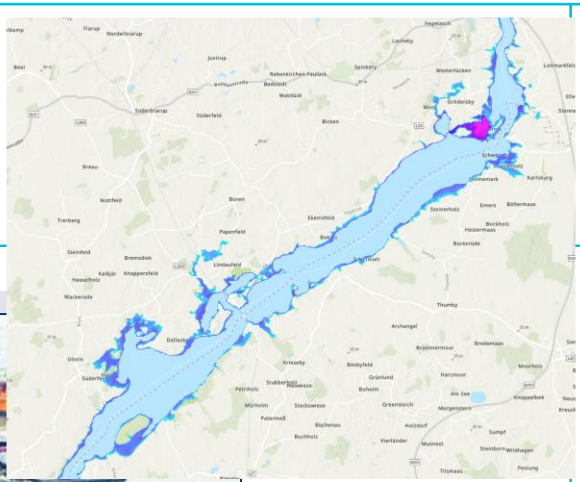
Hazard maps

- Äußere / östliche Schlei



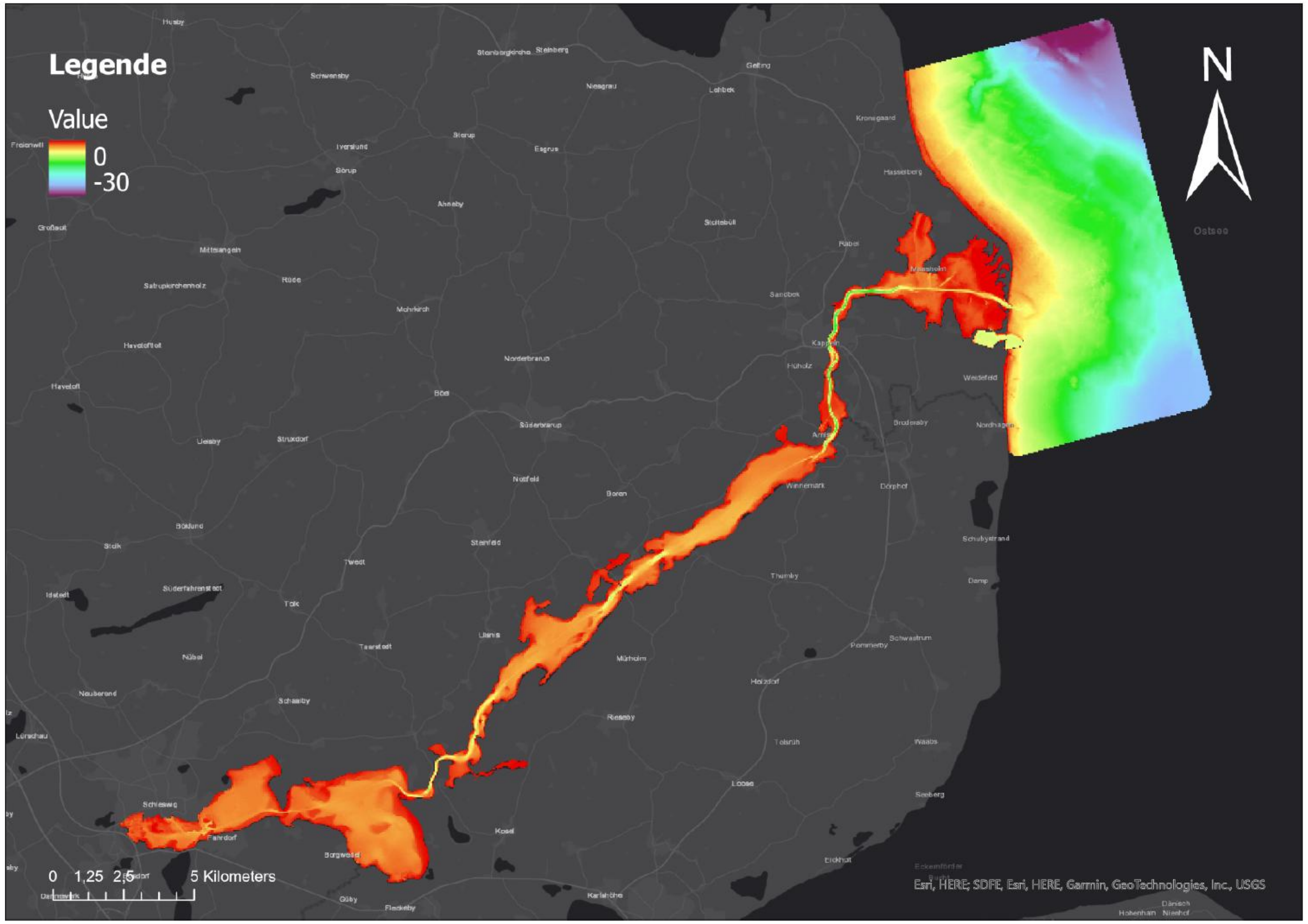


Dike breach Arnis October 2023

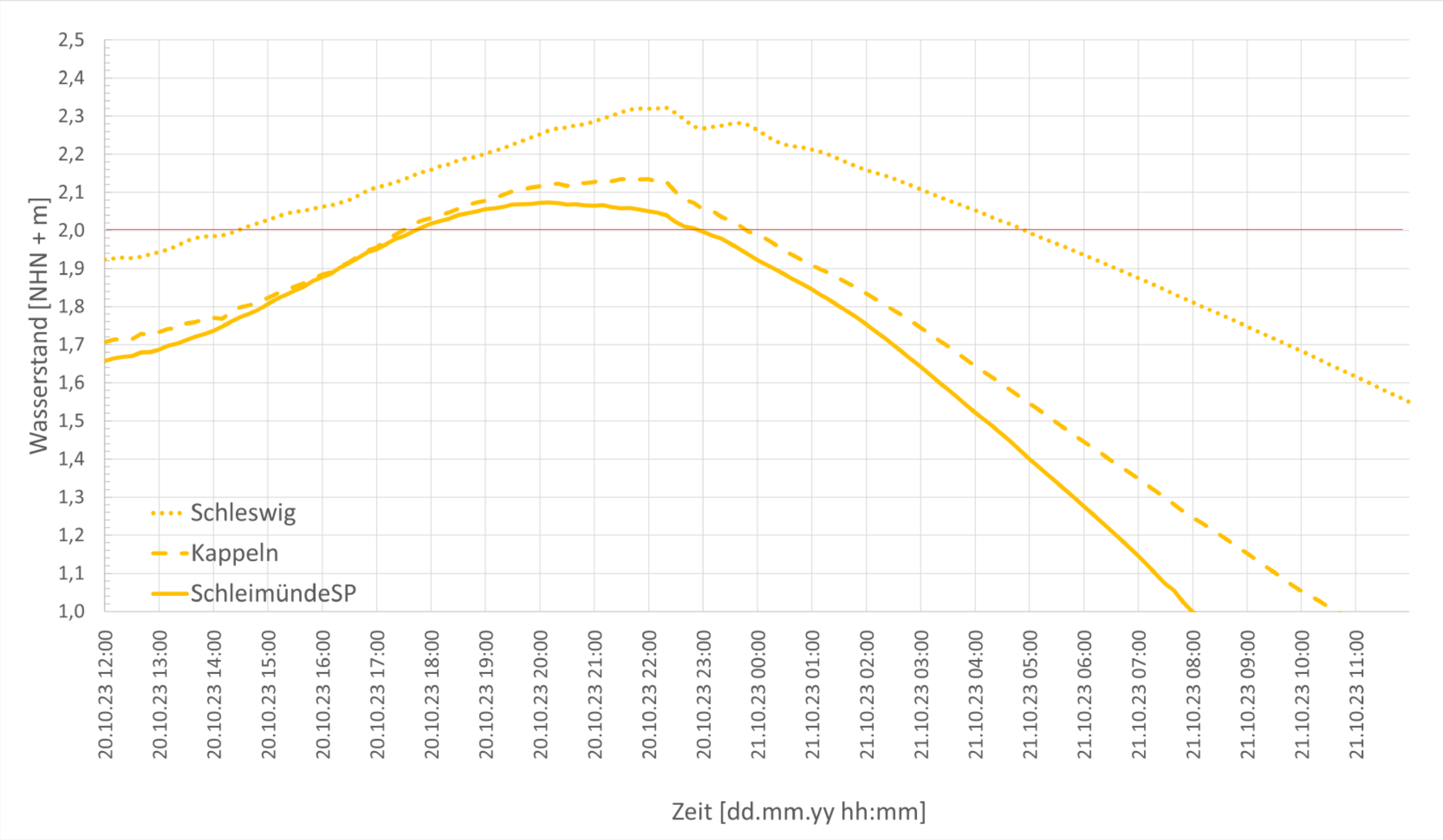


www.shz.de (Foto Benjamin Nolte)

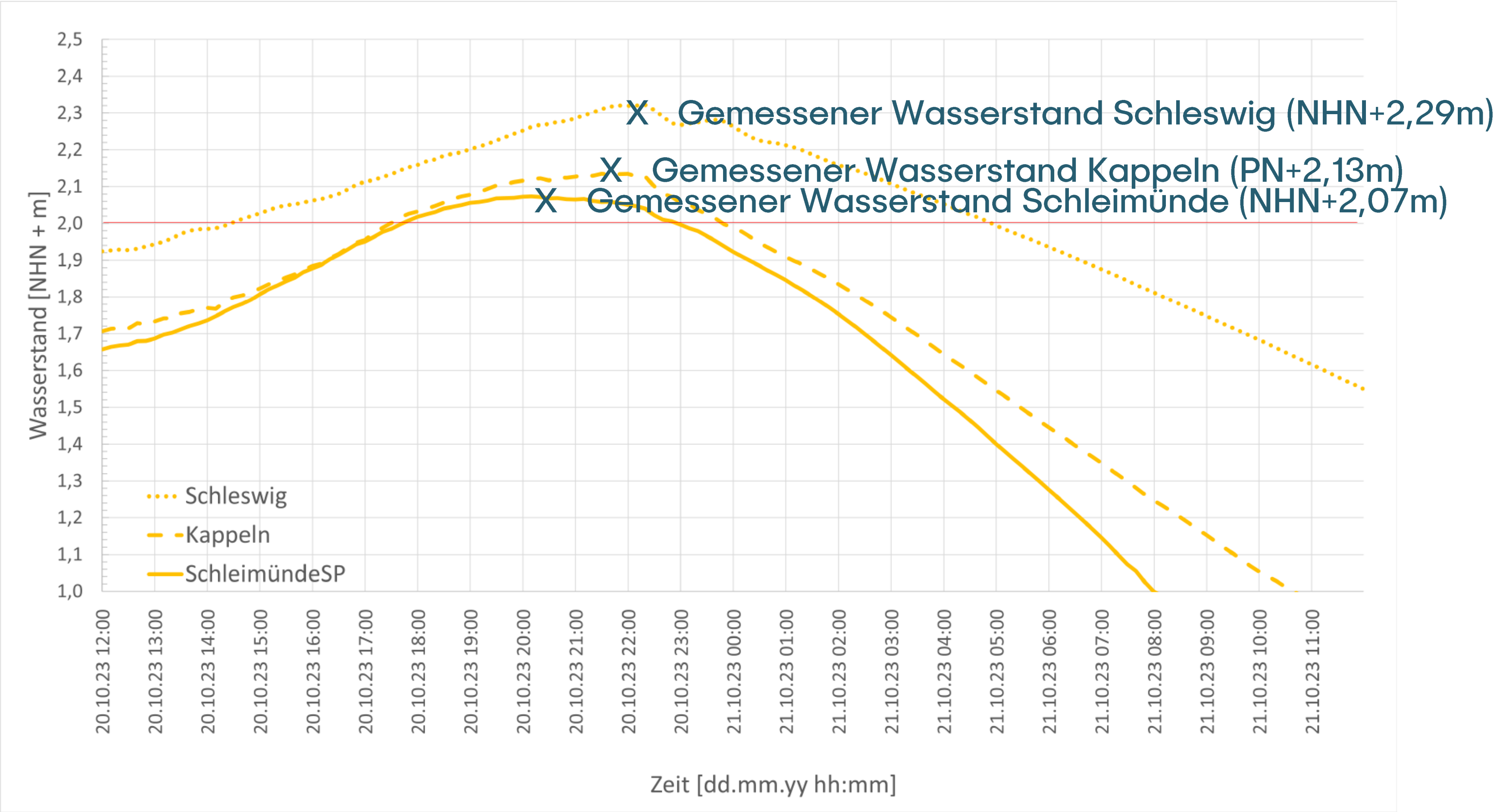
Hydrodynamic-numerical model of the Schlei



Model results



Model results



5. Conclusions

Conclusions

Water is like a young child

- We have to foresee possible actions and reactions of water
- Water needs guidance
- Avoid that water is coming into an area where it may cause damages

Resilient and climate proof urban water systems need

- process understanding
- Information and data
- models and

→ **integration into a digital twin**

- innovative (technical and nature based) measures

to quantify effects and effectivity as basis for planning and decision making

Conclusions

Water management is like educating a (young) child

- We have to foresee possible actions and reactions of water
- We need to provide Water the necessary guidance
- We have to avoid that water is coming into an area where i… damages

Resilient and climate proof water systems need

- process understanding
- Information and data
- models and

…gration into a digital twin

- innovative (technica… based) measures

to quantify effects and ef…ctivity as basis for planning and decision making

Detailed Analyses in the (complete) catchment are necessary since the effects of measures have a spatial scale

Danke!

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TUHH

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River and Coastal Engineering

Disaster Forecasting Models and Data Visualization: Applications in Early Warning System Platforms

Analyzing Disaster Mechanisms and Developing Intelligent Early Warning Systems

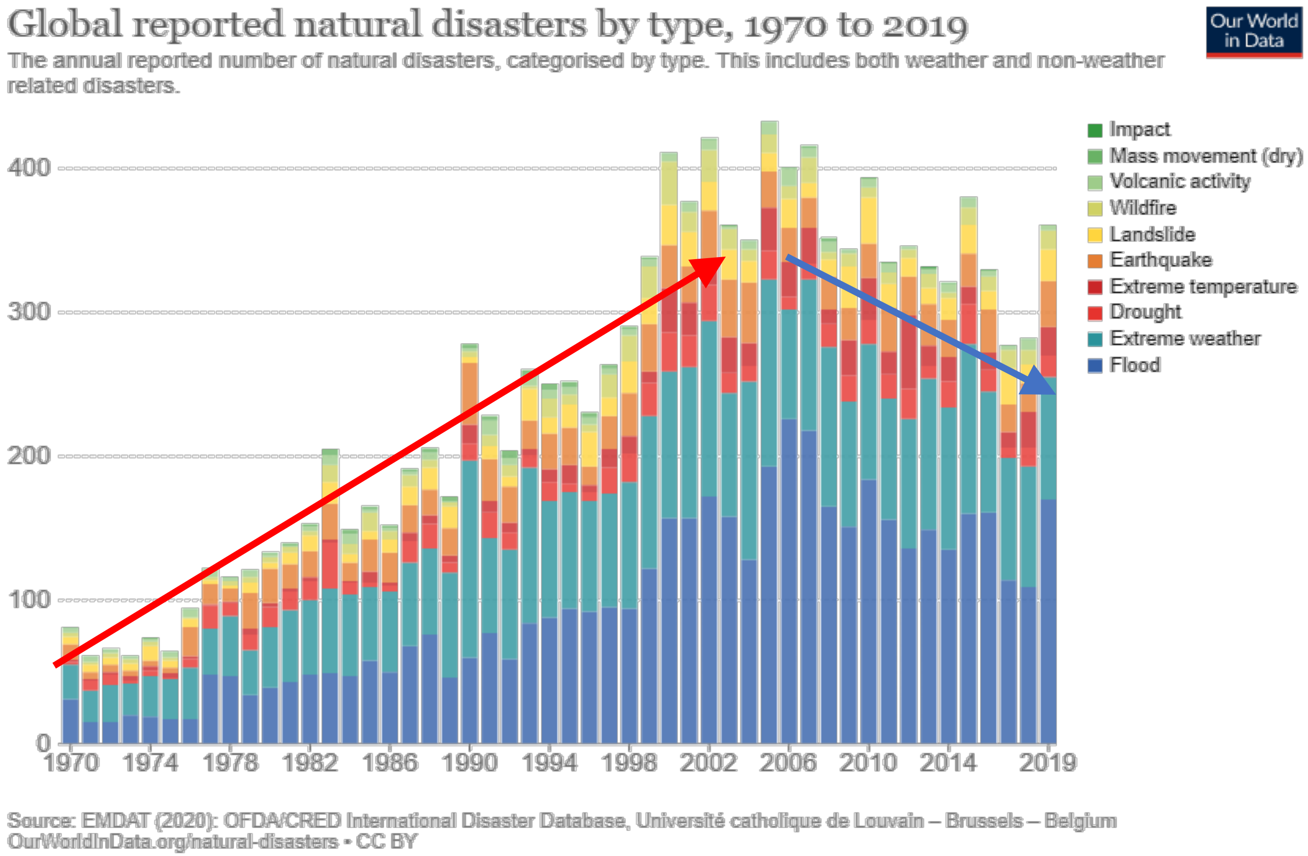
Speaker: Hao-Che (Howard) Ho
Associate Professor, Department of Civil Engineering,
National Taiwan University

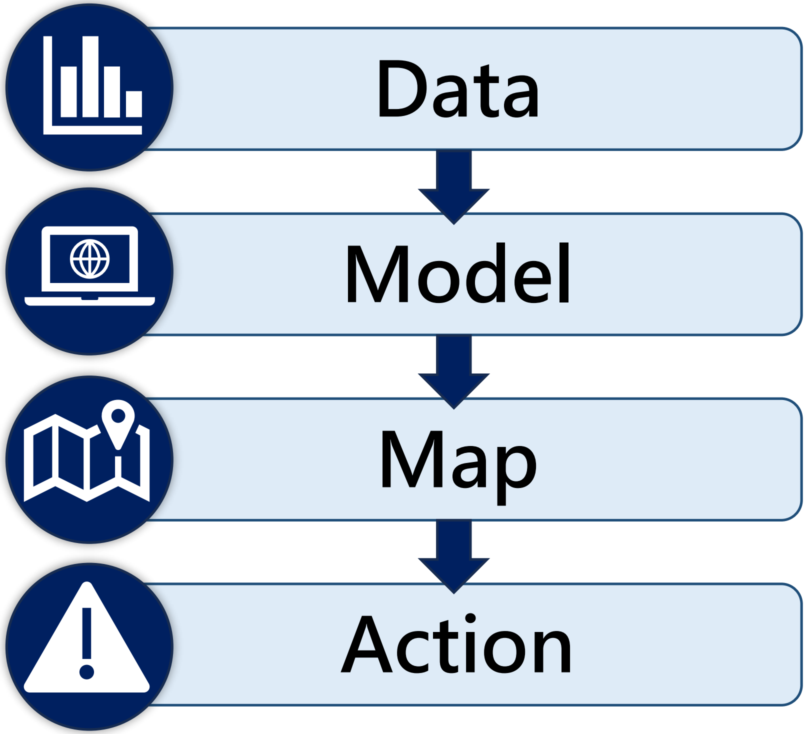
Why Conduct Disaster Forecasting?

Extreme Climate Events

The Importance of Disaster Forecasting and Data Visualization

- Through computational modeling and data visualization, we can transform complex climate events into understandable information.
- This not only improves the efficiency of early warnings but also enables decision-makers to take action before disasters happens.





The Importance of Disaster Time Scales

➢ Different disasters occur over different time scales, and understanding these patterns helps in designing effective monitoring and early warning strategies.

Short-Duration Disasters

- ✓ Require real-time monitoring.
- ✓ Require fast response, e.g., heavy rainfall and flash floods.

Moderate-Duration Disasters

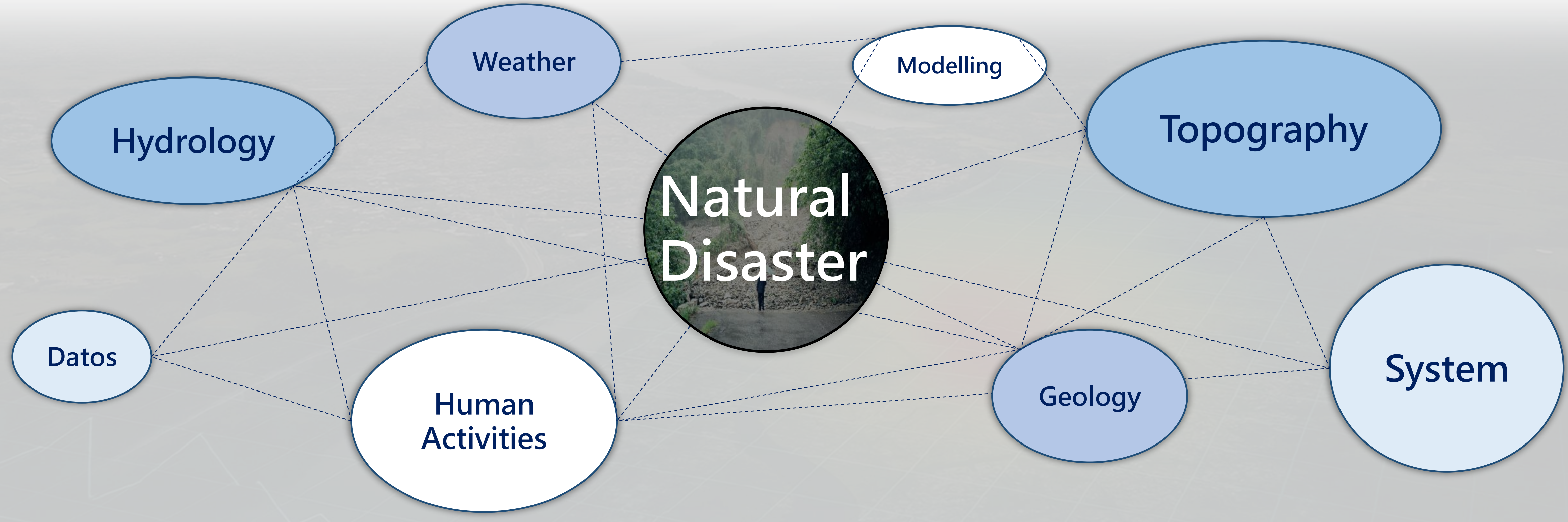
- ✓ Require integration of rainfall forecasts with watershed modelling.
- ✓ Examples include river floods, and dam-breaks from landslide-dammed lakes.

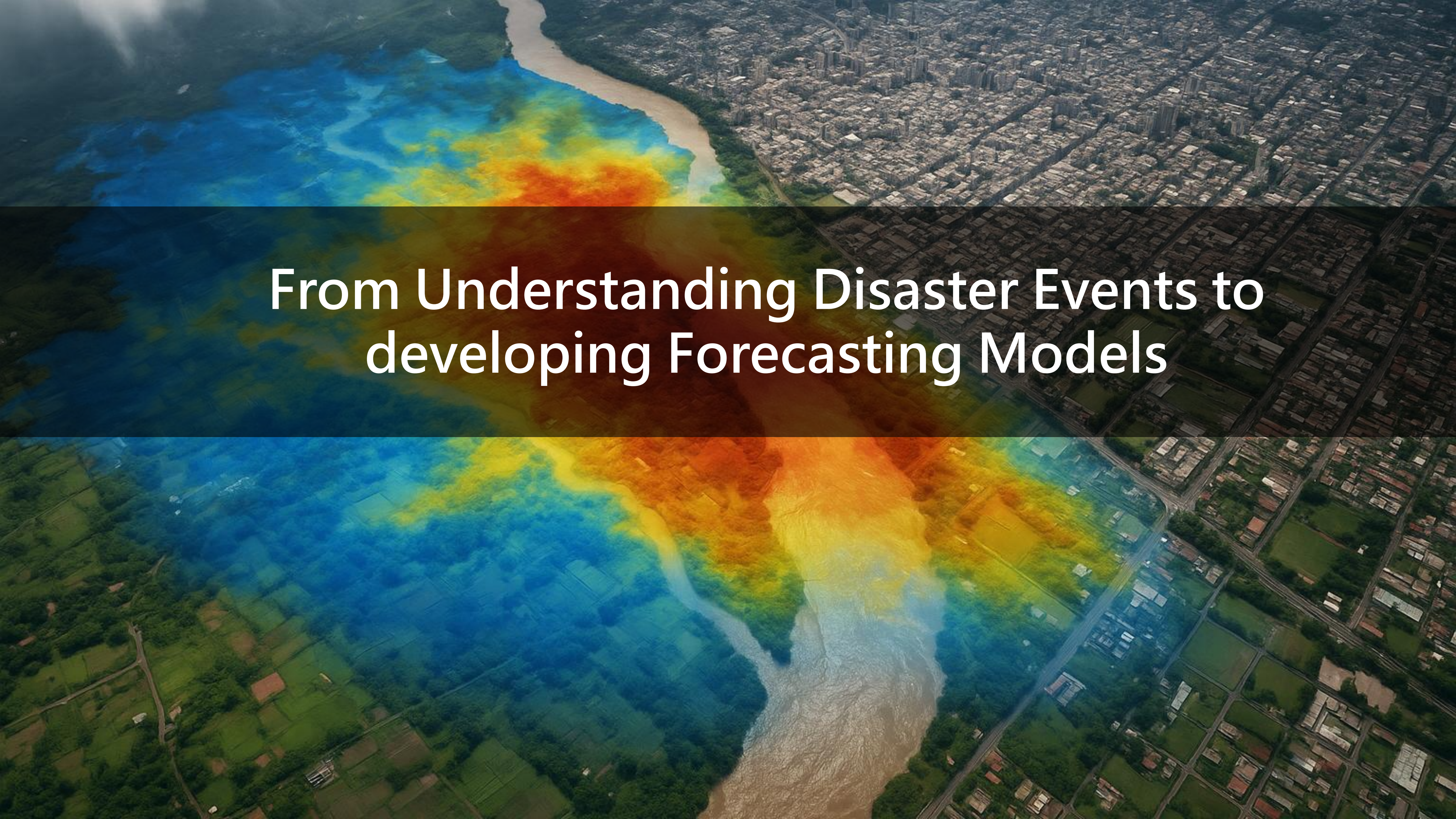
Long-Duration Disasters

- ✓ Require continuous monitoring.
- ✓ Require trend analysis for forecasting, e.g., landslides and slope failures.

Why Its Important to Understand Disaster Mechanisms

- Disasters are not caused by a single factor; they result from the combined effects of climate, topography, geology, and human activities.
- Only by understanding how these factors interact can we develop scientifically grounded forecasting models.
- Grasping these mechanisms not only allows us to predict disasters but also to mitigate risks at their source.





From Understanding Disaster Events to developing Forecasting Models

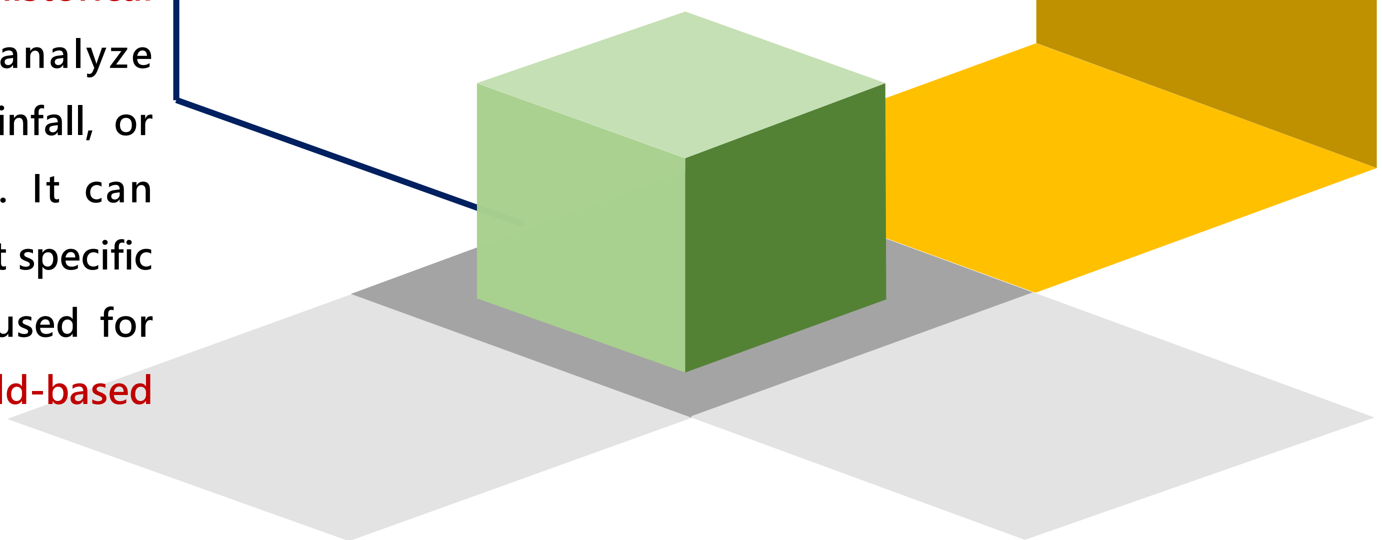
Types of Disaster Forecasting Models

Space-Time Model

Considers both temporal and spatial variations, simulating the dynamic processes of disaster formation, propagation, and recession. It can simulate flood propagation and serves as a core foundation for intelligent disaster management systems.

Single Point Model

Focuses on forecasting at a single station or location, using historical and real-time data to analyze changes in water level, rainfall, or slope moisture content. It can quickly reflect risk trends at specific points and is commonly used for early warning and threshold-based assessments.

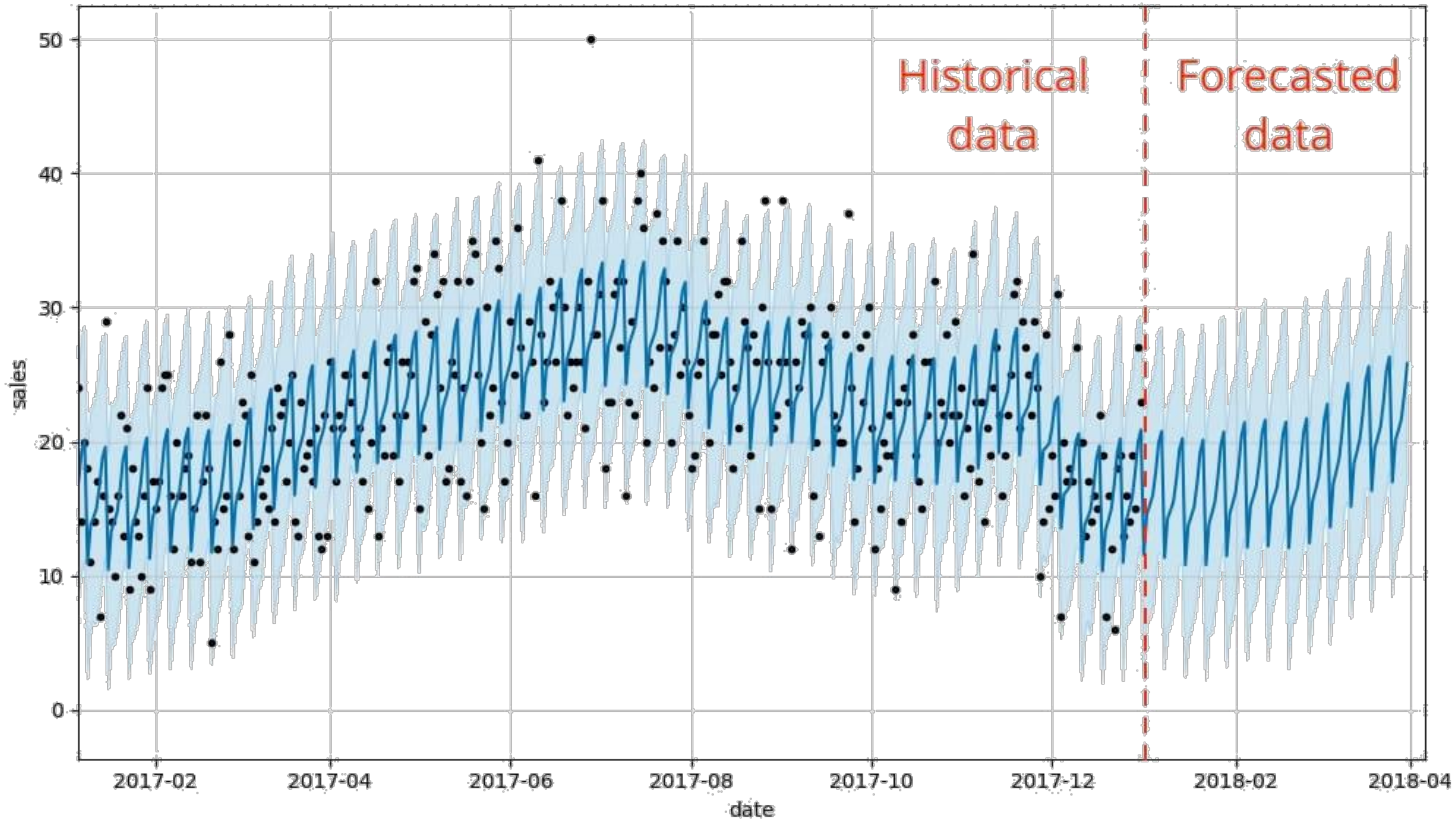


Surface Model

Simulates disaster distribution across an entire region by integrating spatial data such as topography, rainfall, and land use. It can depict flood extents, landslide susceptibility, or debris flow distribution, supporting regional disaster management and resource deployment.

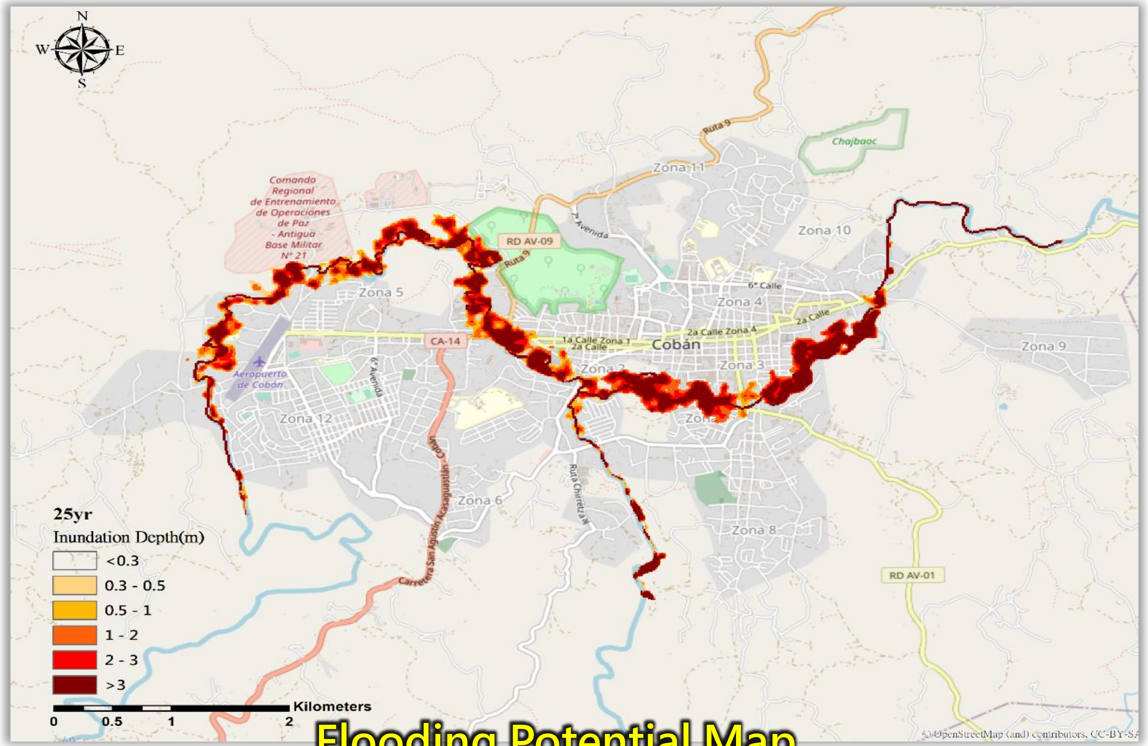
Single Point Model – Data-Driven Forecasting

- Point models use historical observational data from a single location to predict future trends through statistical or machine learning methods.
- These models do not require complex physical parameters, making them suitable for rapid development and use in real-time monitoring stations.
- However, they can only reflect local conditions and are limited in describing the spatial distribution of the overall disaster.

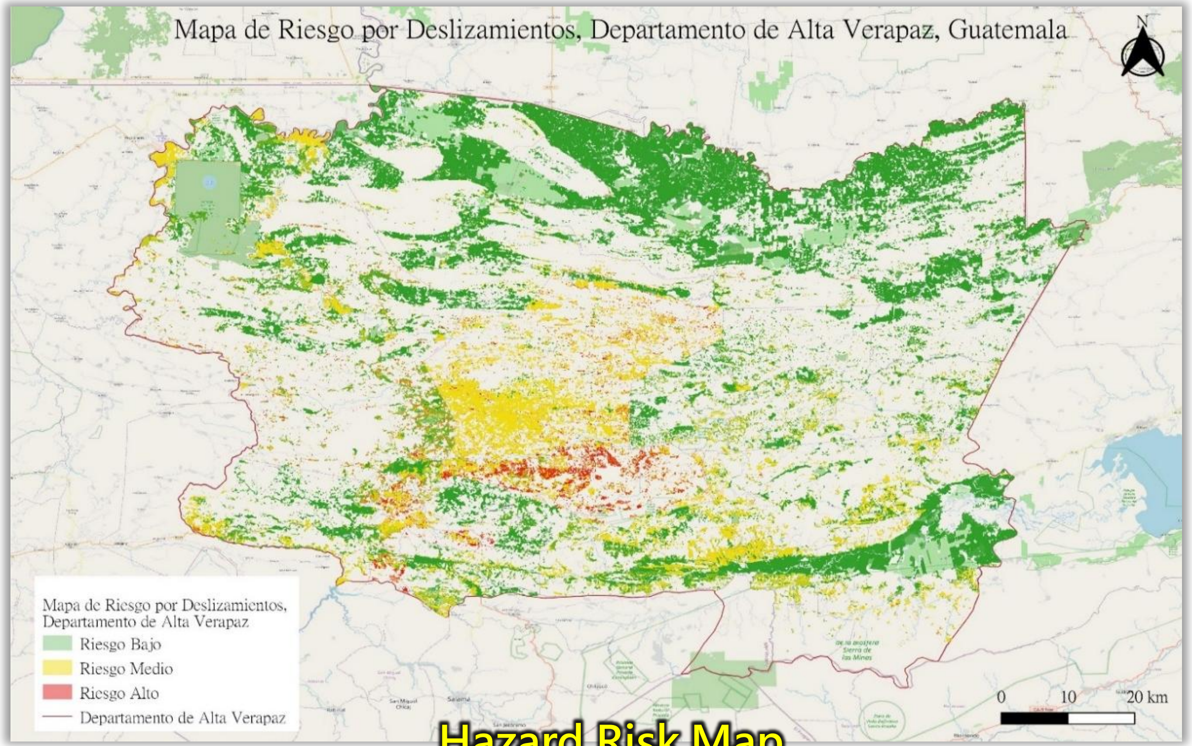


Surface Model – Regional-Scale Forecasting

- Surface models are based on geographic information and physical processes, simulating disaster behavior across an entire watershed or urban area.
- They integrate multi-layered data such as rainfall, topography, and land use to predict disaster distribution at different locations.
- Although these models require larger computational resources, they provide decision-makers with spatially meaningful information, such as flood extent maps or landslide susceptibility maps.



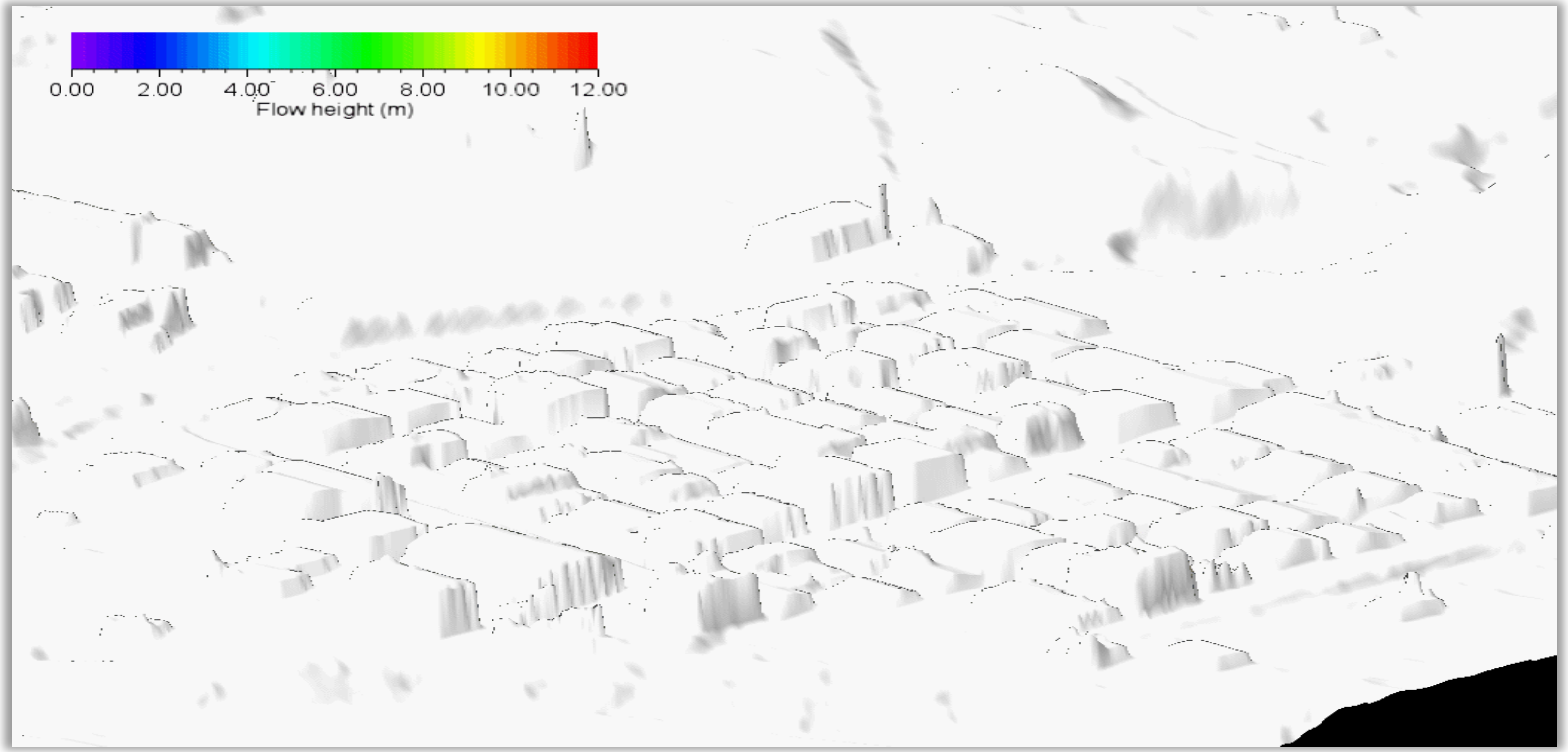
Flooding Potential Map

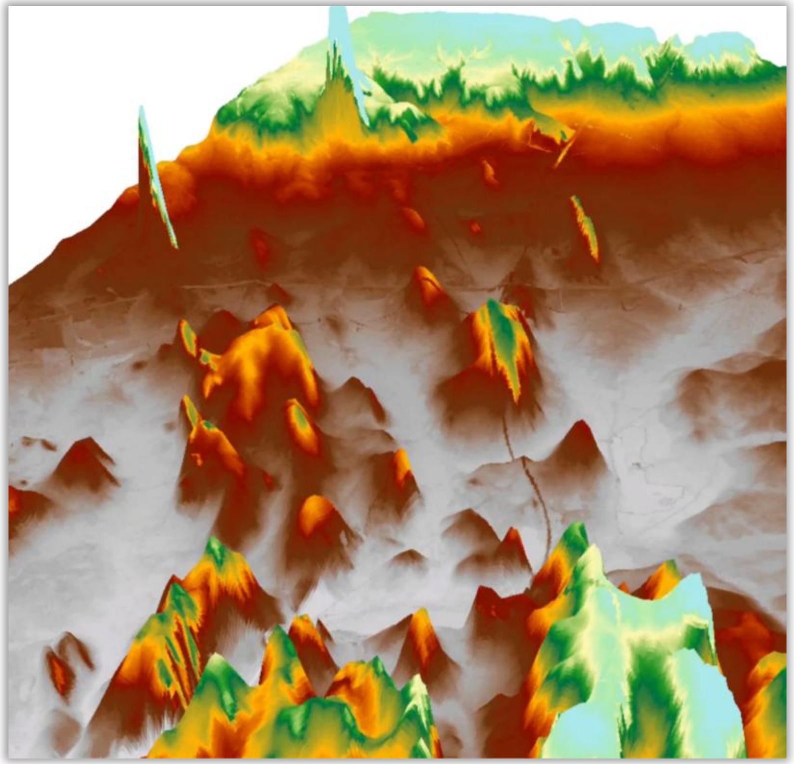


Hazard Risk Map

Space-Time Model – Dynamic Disaster Simulation

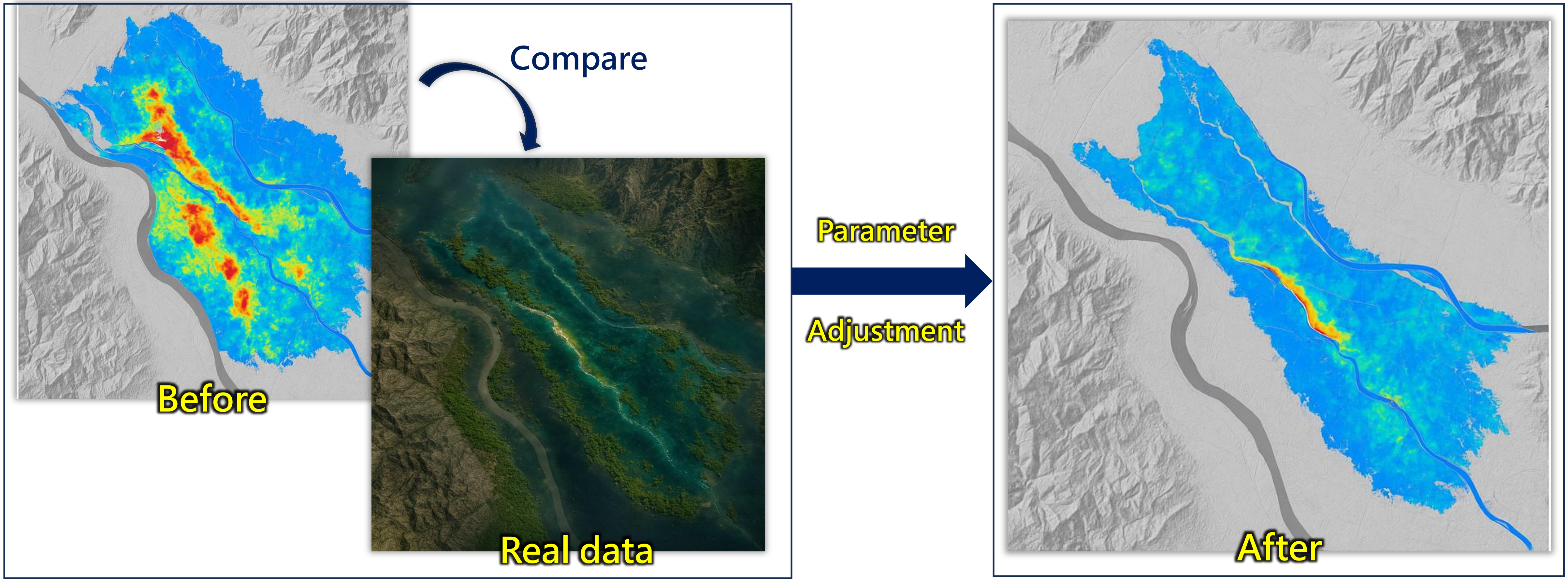
- Space-time models can simultaneously describe the spatial spread and temporal evolution of disasters, presenting a complete dynamic process.
- Through numerical simulations or deep learning architectures, they can reproduce the continuous states of disaster occurrence, development, and recession.
- These models are suitable for simulating rapidly changing events such as flood propagation, slope failures, or dam-breaks from landslide-dammed lakes.





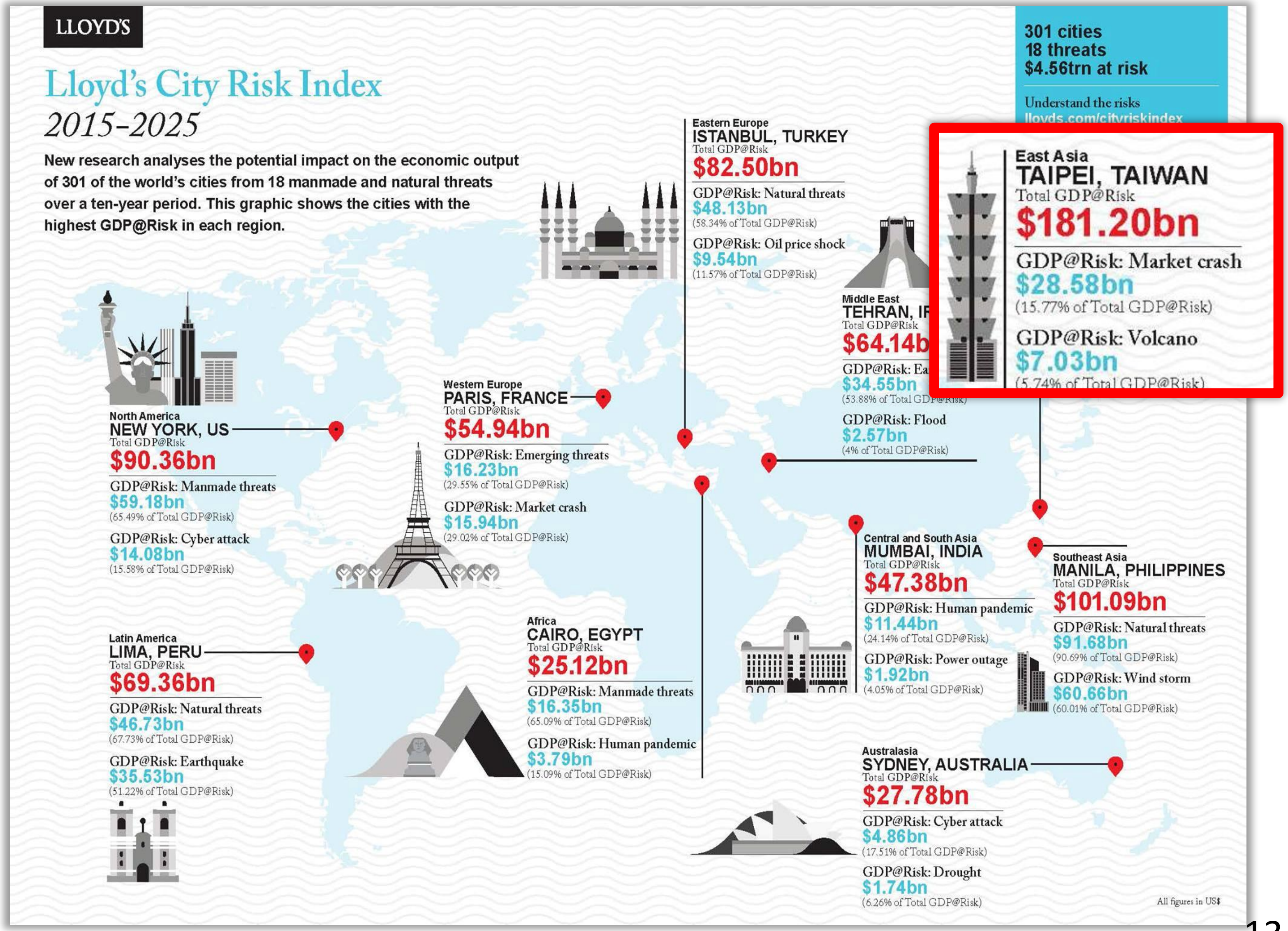
The Importance of Model Parameters

- Model parameters determine whether the forecasting results can accurately reflect local conditions.
- By adjusting these parameters, the model can "learn" the differences in characteristics such as topography, rainfall, and watersheds, allowing predictions to more closely match the actual occurrence and development of disasters.



Natural Disaster Cases in Taiwan

- According to the Urban Risk Index developed in collaboration between the University of Cambridge and Lloyd's, Taipei City ranks among the top three globally for disaster exposure.
- Taiwan's steep terrain and concentrated rainfall make it an important testing ground for flood and flash flood forecasting worldwide.

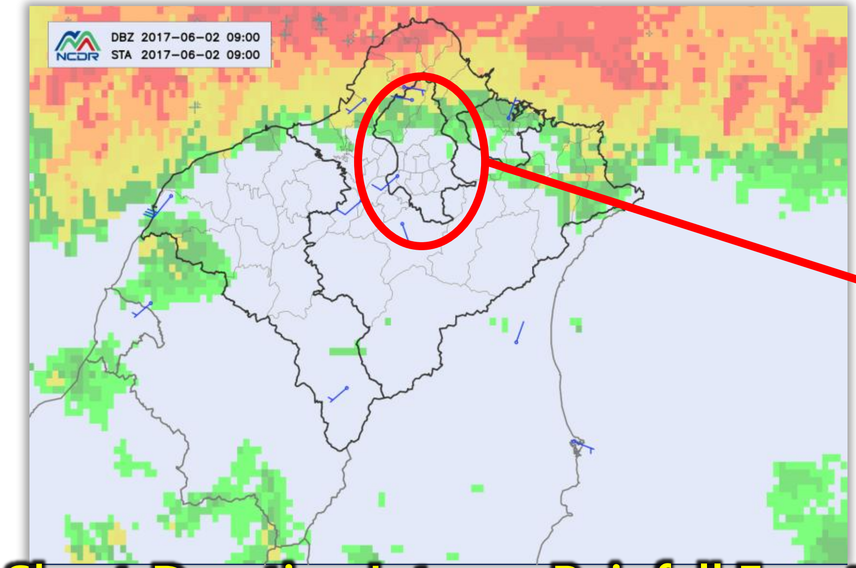


Natural Disaster Cases in Taiwan

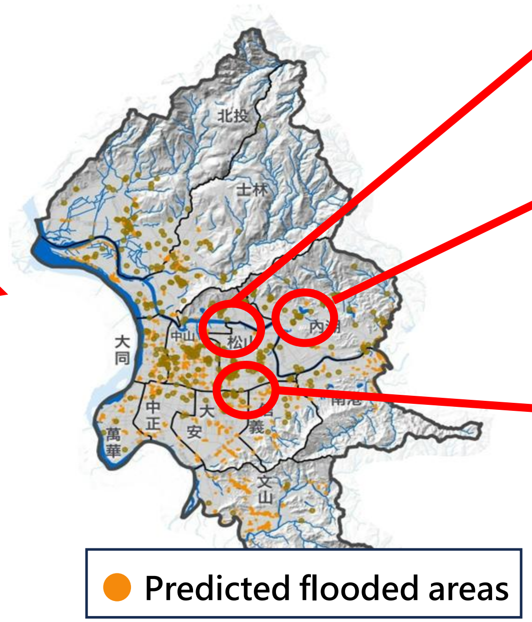
➢ 2017 Taipei Extreme Rainfall Event

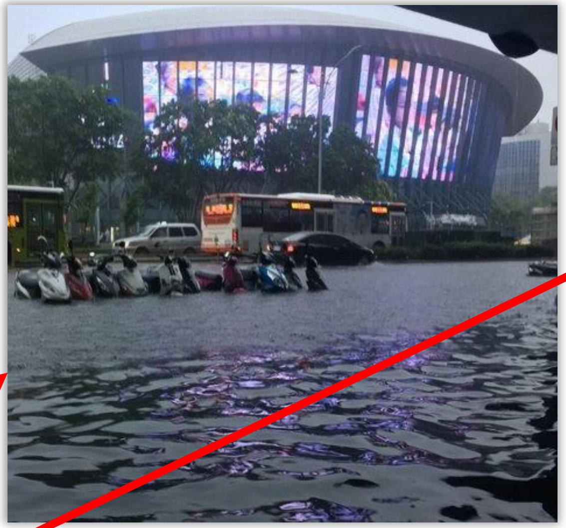
→ Simulated urban drainage and flood detention benefits using rainfall events of different return periods to evaluate the impact of terrain modifications on flood mitigation.

→ This case highlights the importance of 'detailed terrain adjustments' for simulation accuracy in urban inundation forecasting and provides empirical evidence for future standards on stormwater retention and outflow control.



Short-Duration Intense Rainfall Event



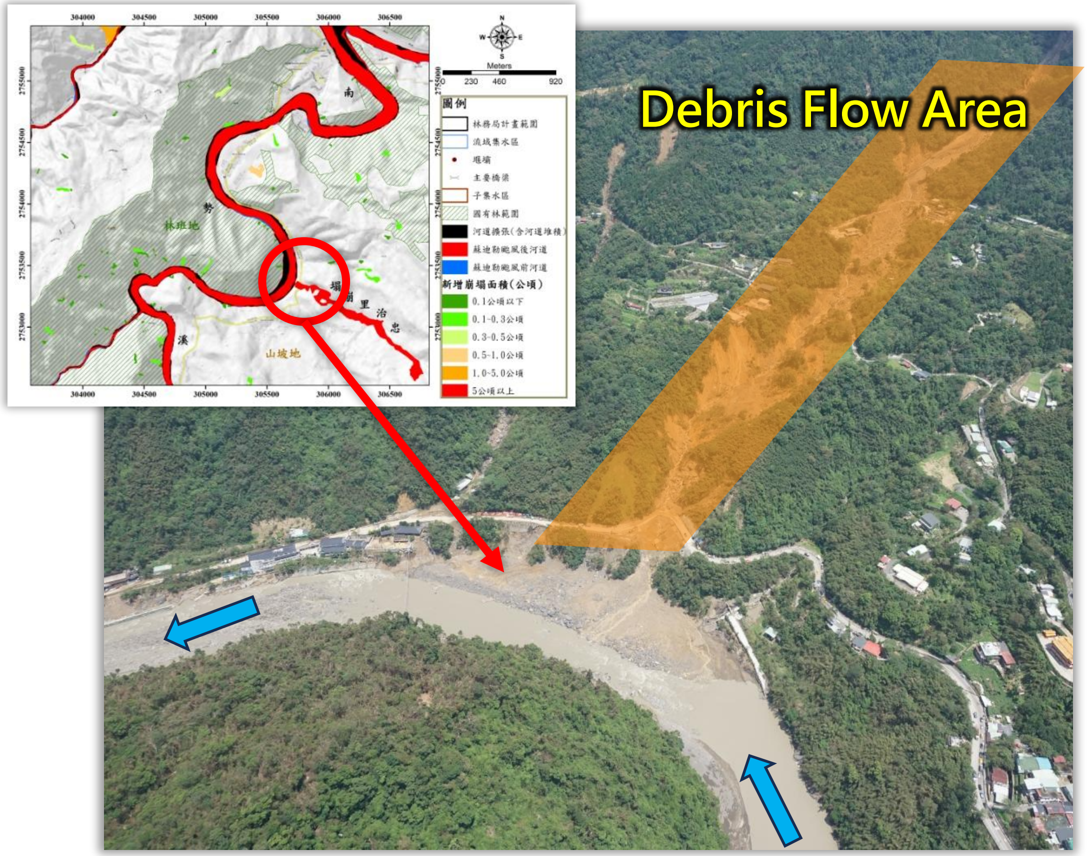


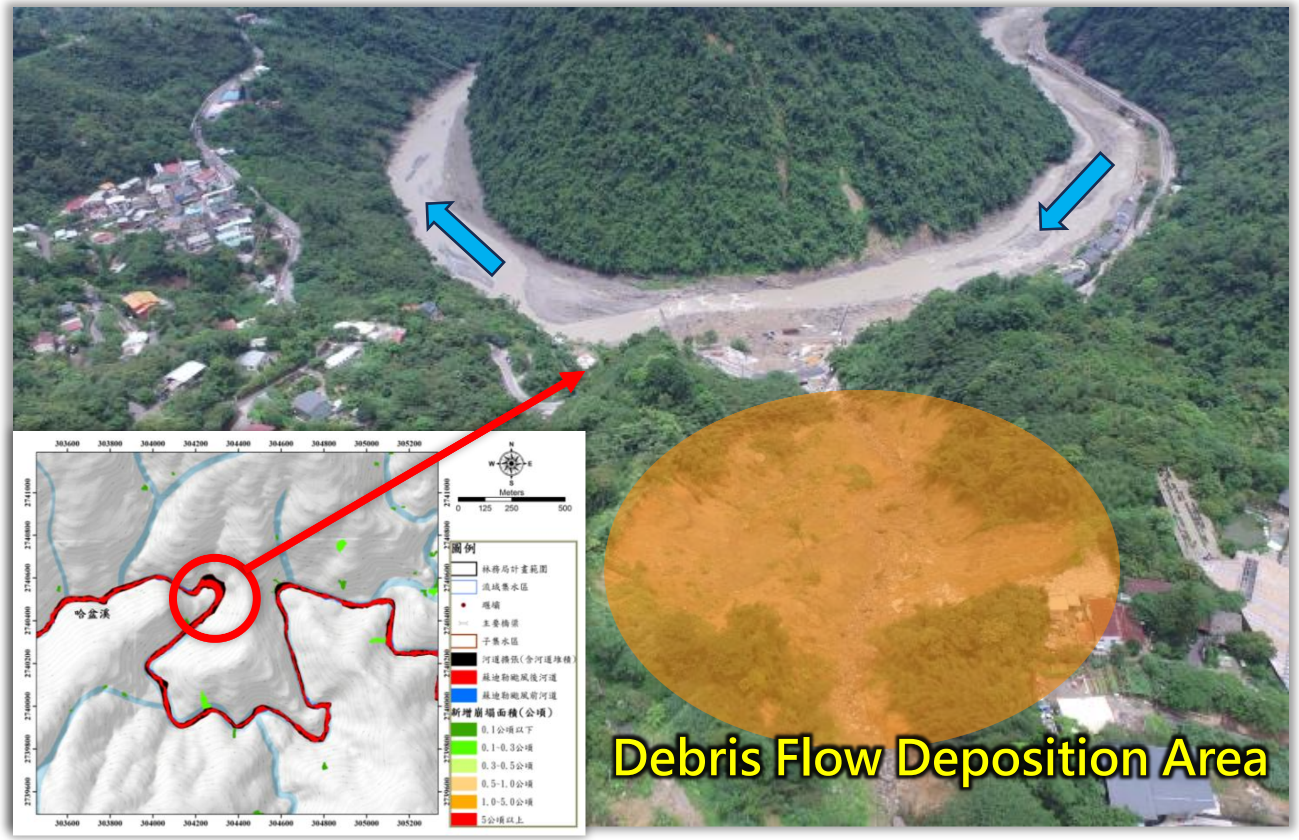
Natural Disaster Cases in Taiwan

➢ 2015 Typhoon Soudelor Debris Flow Event

→ During Typhoon Soudelor, the Nanshi Creek watershed experienced large-scale landslides and channel diversions due to continuous heavy rainfall, triggering secondary disasters such as debris flows.

→ By comparing terrain and conducting slope stability simulations, the landslide and sediment transport processes were reconstructed, establishing a landslide–deposition–erosion chain mechanism for the watershed.



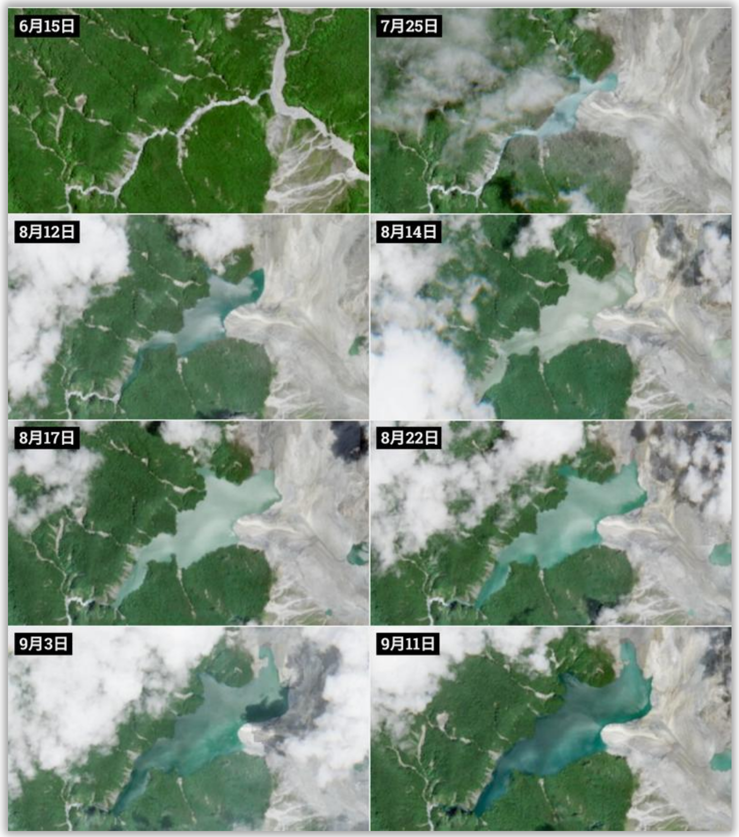


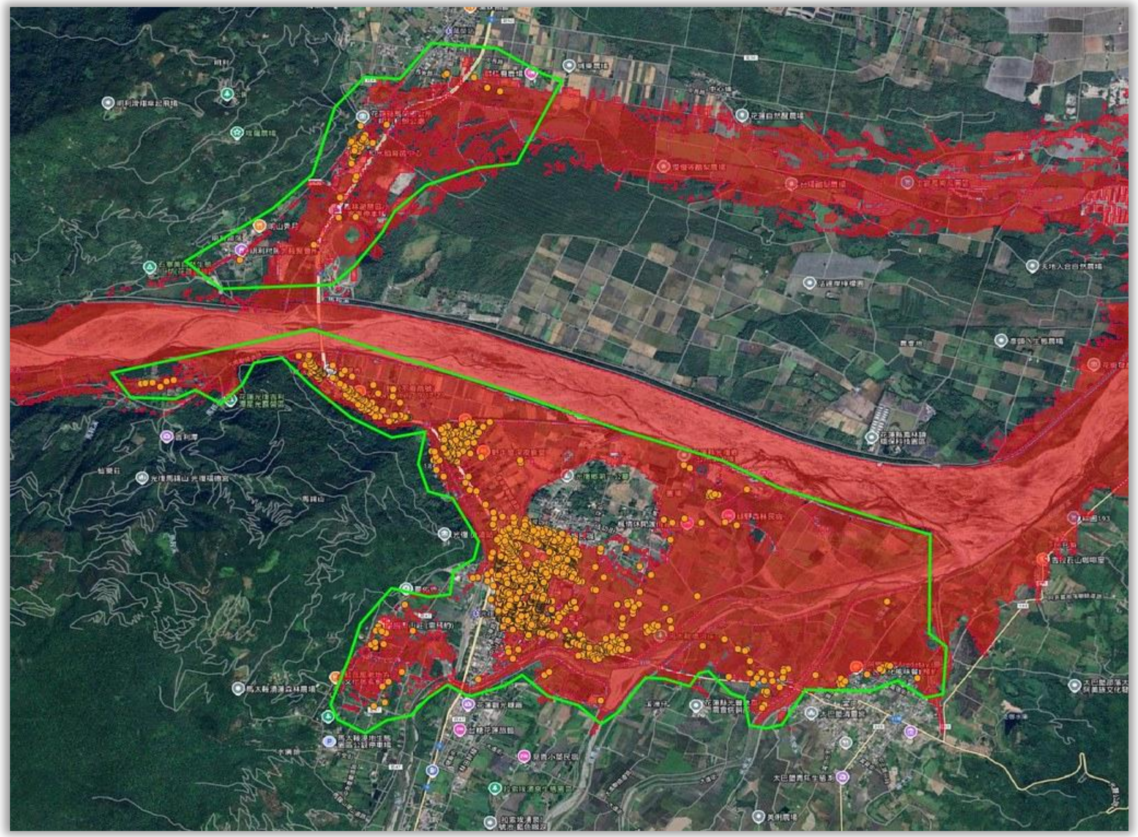
Natural Disaster Cases in Taiwan

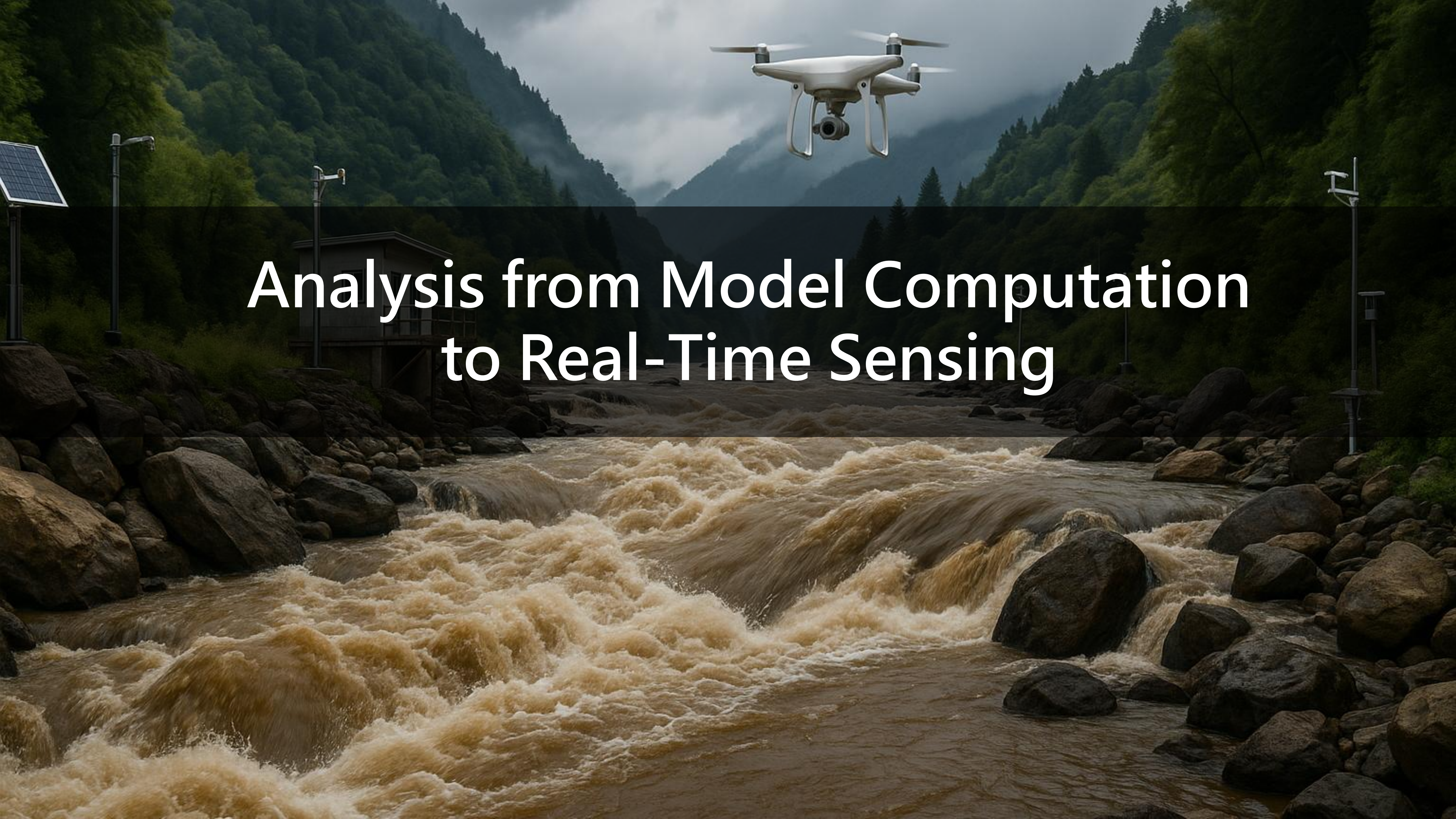
2025 Hualien Mataian Creek Landslide-Dammed Lake Dam-Break Event

→ Dam-break events of landslide-dammed lakes are among the most challenging scenarios in disaster forecasting. Rapid changes in water level and the sudden release from a dam-break can cause severe downstream flooding.

→ By simulating the collapse process of a landslide-dammed lake, it is possible to estimate the timing of the dam-break and the extent of its impact, enabling disaster management authorities to evacuate early and reduce losses.






Analysis from Model Computation
to Real-Time Sensing

Applications of IoT in Disaster Forecasting

- The Internet of Things (IoT) enables disaster monitoring to become real-time and high-density.
- Sensors can continuously collect information such as rainfall, water level, and soil moisture, and transmit it wirelessly in real time to early warning platforms, allowing models to be updated and adjusted instantly as the data changes.

Rain Gauge

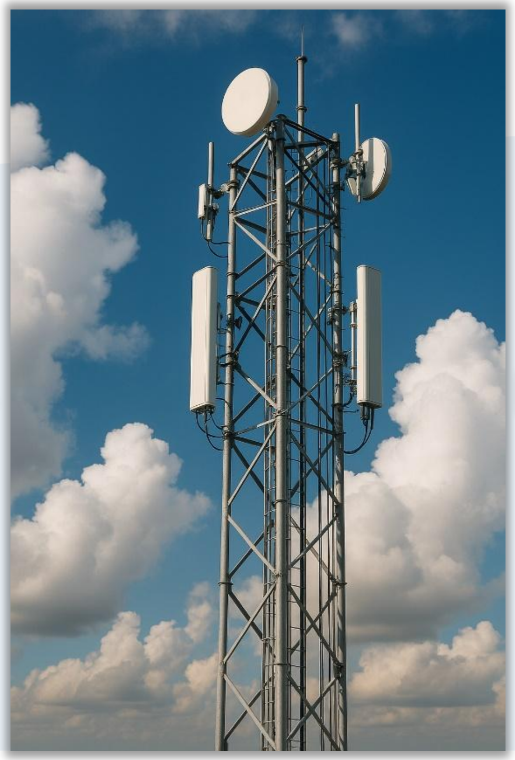
CCTV

Water Level Indicator

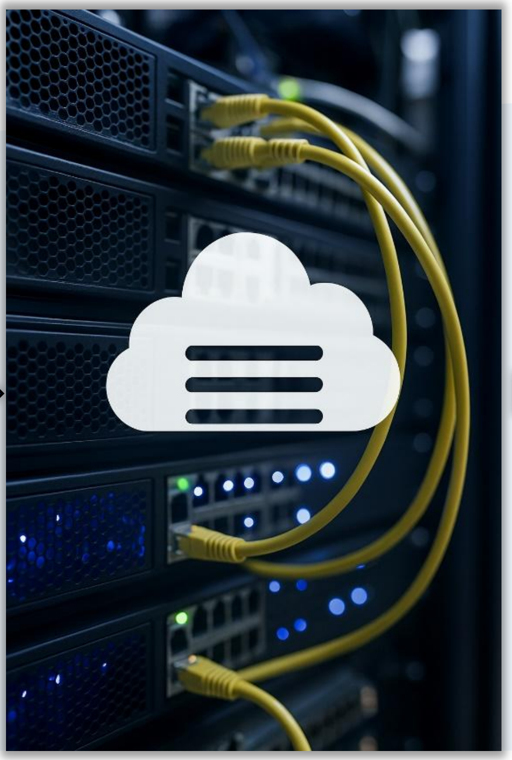
IoT System Architecture and Data Integration

- IoT systems integrate sensor networks, data transmission, and cloud analytics to consolidate monitoring information from various locations in real time, forming a comprehensive disaster monitoring network.
- These data are not only used for model computations but can also be directly converted into visualized information, enabling early warning platforms to issue alerts immediately.

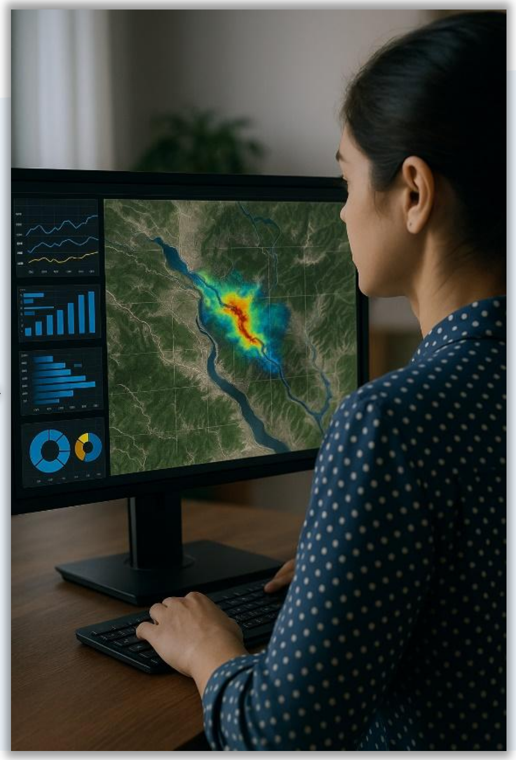
IoT Sensors



Communication Network



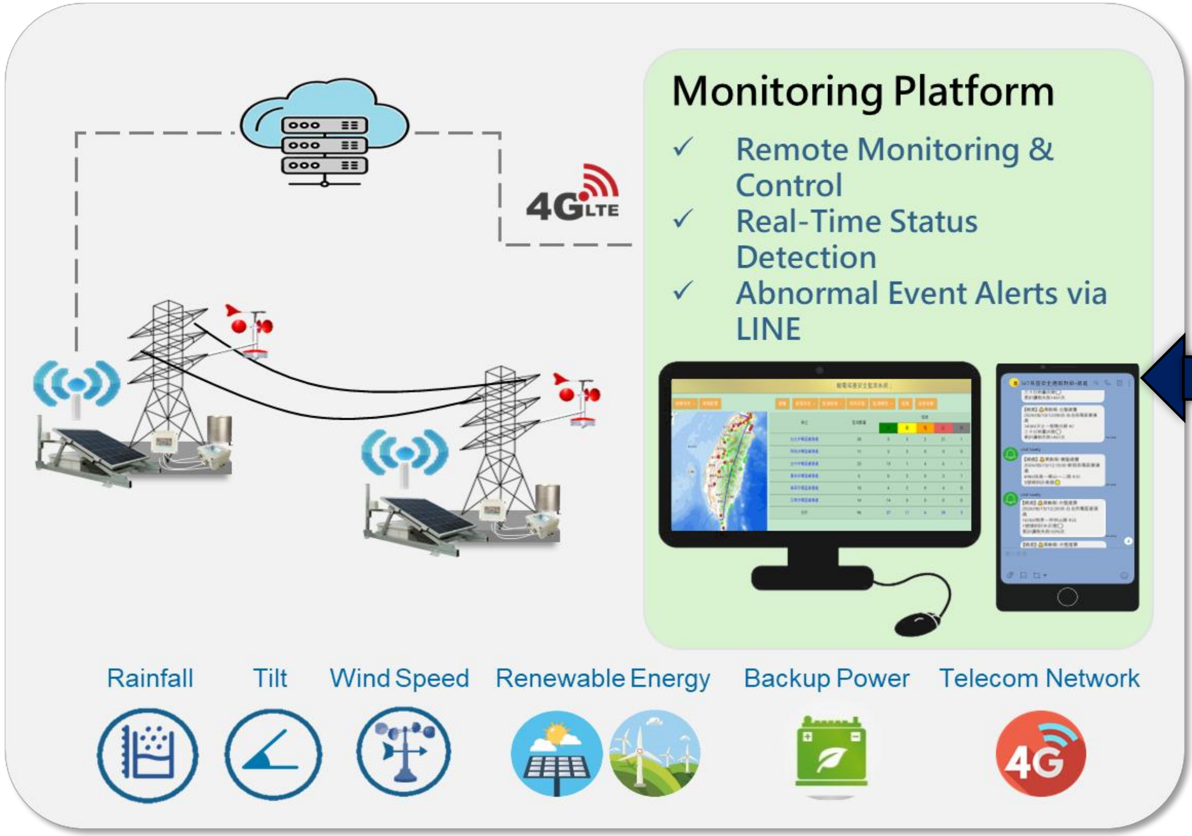
Cloud Platform

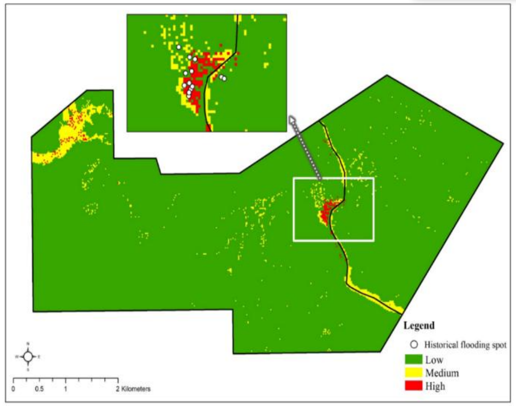


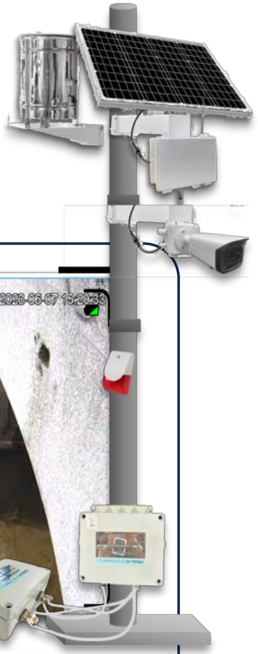
Visual Interface

Roles and Requirements of Early Warning System Platforms

- An early warning platform serves as the central bridge connecting "data, models, and actions."
- It must integrate multi-source data and present risks and trends in a clear manner.
- A well-designed platform not only issues alerts but also helps decision-makers understand "why action is necessary."





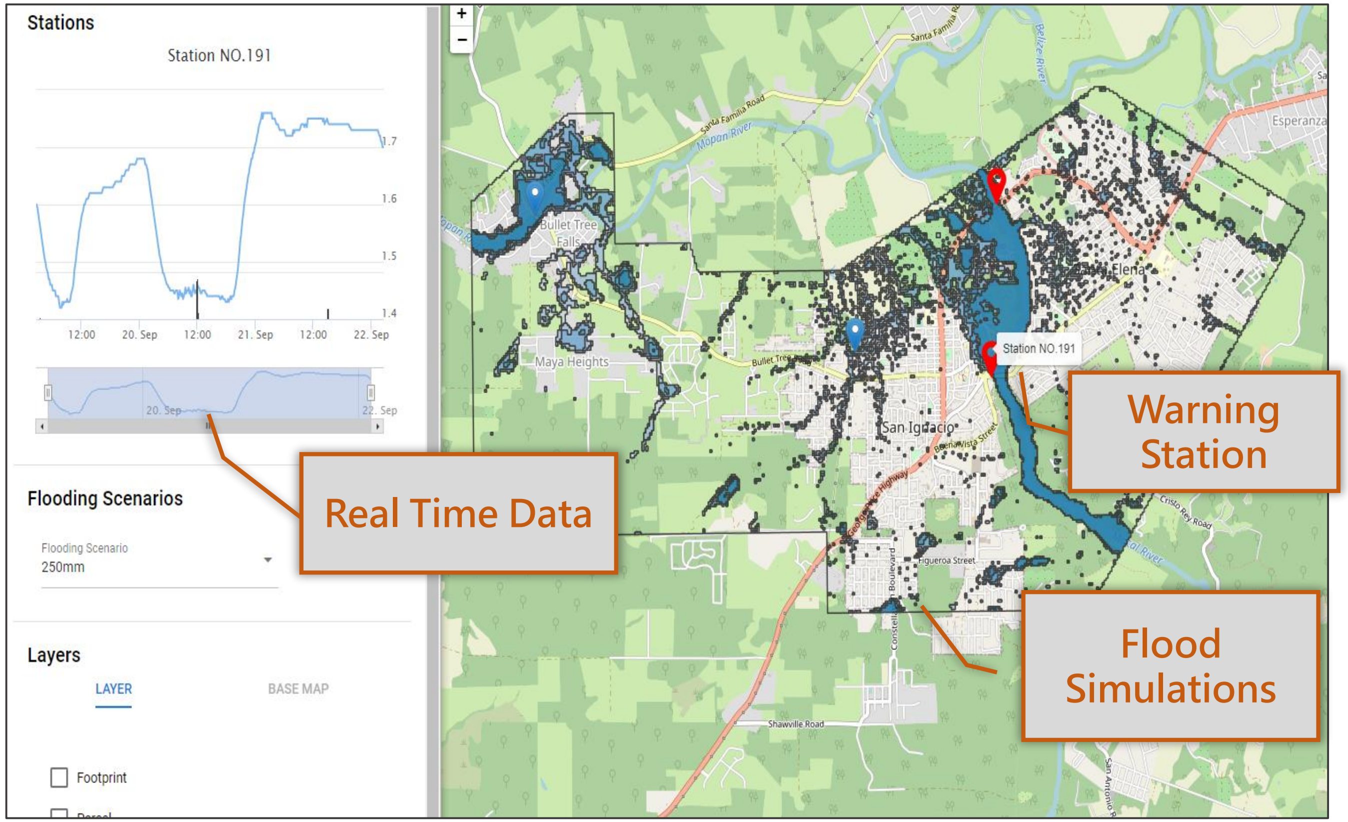


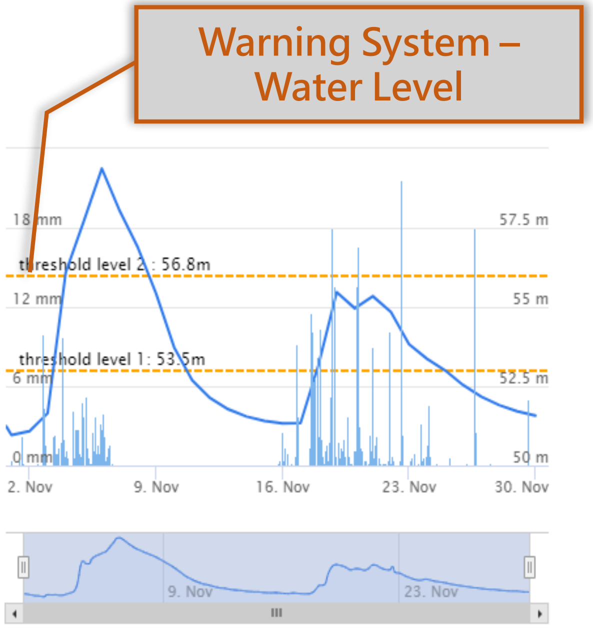
Design Principles of Early Warning System Platforms

- An effective early warning platform should simultaneously ensure accuracy, real-time performance, and understandability.
- Information must be clear and easy to read, enabling users to assess risks quickly.
- At the same time, the system should have a stable data update mechanism and multi-level alert notification functions to ensure critical information is delivered to the right people in the shortest possible time.

Functions

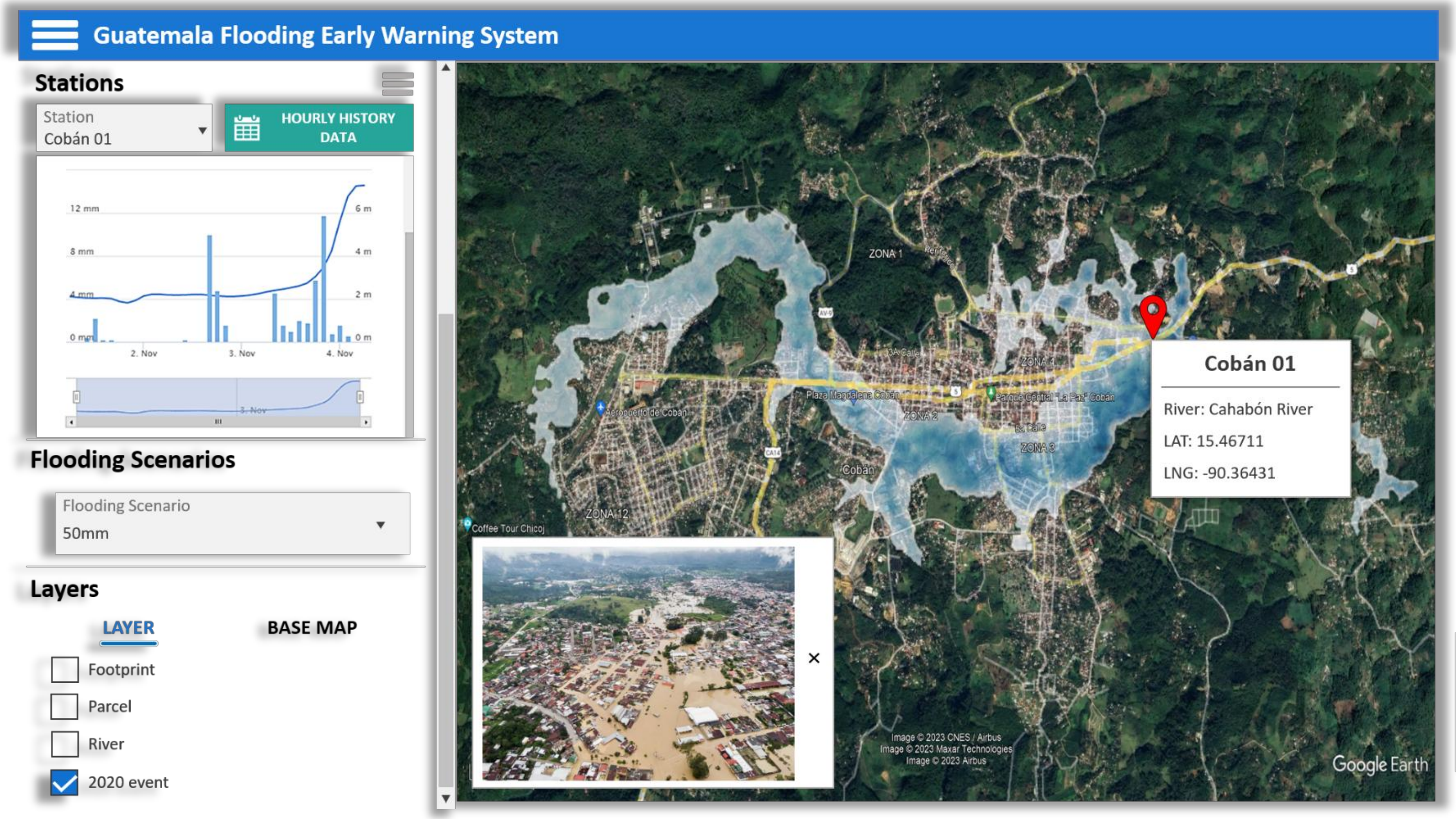
- Access
- Map Web
- Geospatial Data Management
- Early Warning
- Historical Data Query

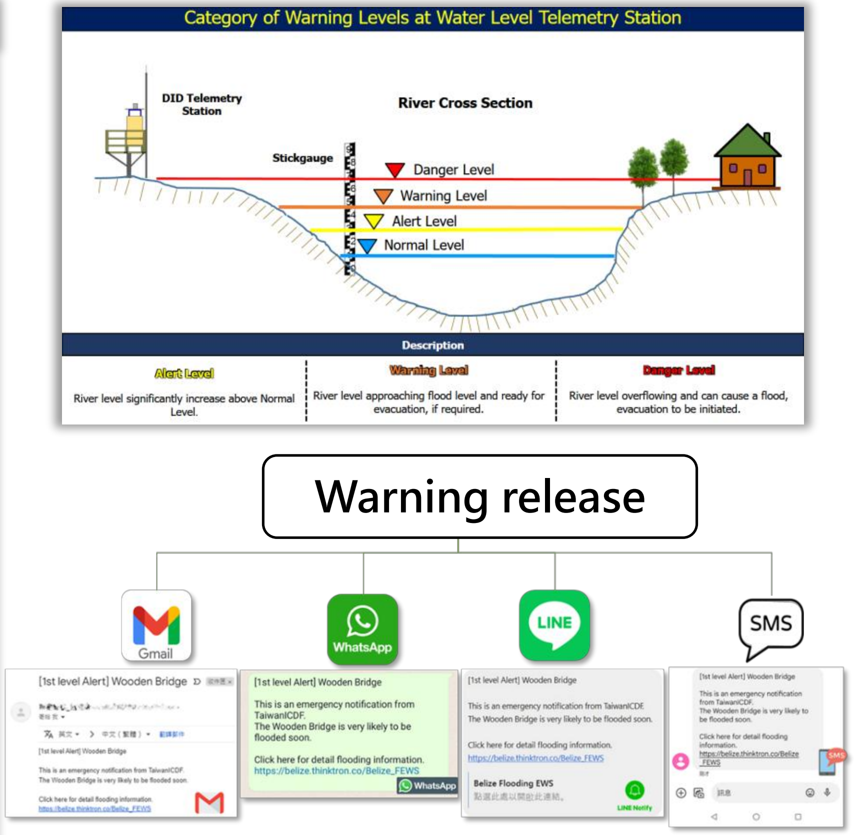




Applications of Data Visualization in Early Warning System

- Data visualization can transform complex model results into clear risk representations.
- Dynamic maps, timelines, and alert color scales allow users to quickly perceive disaster trends.
- Clear visual presentation significantly shortens decision-making time and enhances response efficiency.



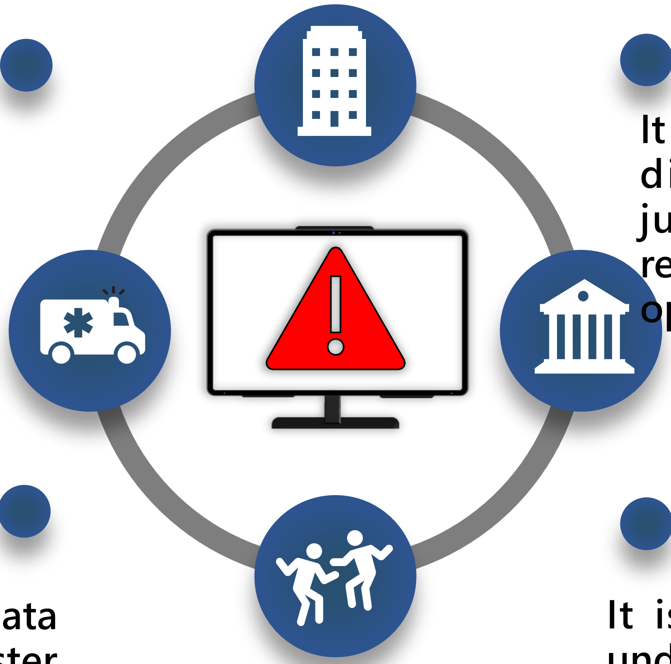


Users and Application Scenarios of Early Warning Platforms

- Different users play distinct roles in disaster response.
- Government agencies require comprehensive risk assessments, local teams focus on real-time notifications, and communities and the public rely on concise alert information to guide evacuation actions.
- Platform design must accommodate multi-level needs to ensure information is effectively used across all user levels.

Central Government"

It is necessary to integrate monitoring and forecasting data from across the country, conduct cross-regional risk assessments, and issue unified decisions and response directives.



Local Government

It is necessary to monitor rainfall, water levels, and disaster conditions in real time within their jurisdiction, and quickly deploy personnel and resources to carry out disaster prevention and rescue operations.

Disaster Management Agencies

It is necessary to obtain accurate monitoring data and model simulation results to assess disaster potential and establish appropriate alert and notification mechanisms.

Community and Residents

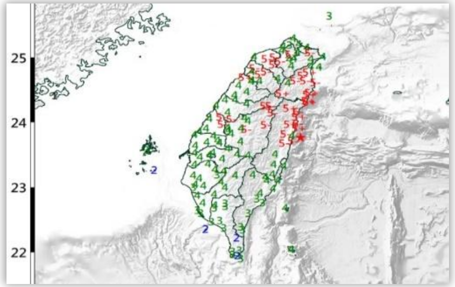
It is necessary to provide clear and easy-to-understand alerts and route guidance, enabling people to quickly grasp risk situations and take evacuation and self-protection measures.

Hualien Mataian Creek Barrier Lake Disaster Event

Event Timeline

2024/04/03

The magnitude 7.1 earthquake caused slope destabilization, raising concerns over potential geological instability.



2025/07-09

Frequent rainfall over two months caused a gradual rise in water levels, approaching the structural capacity limit of the dam body.

2025/07/25

Intense rainfall from Typhoon Wipha triggered a large-scale upstream landslide, resulting in the formation of a barrier lake.

Event Timeline

2025/09/23

14:50

Overtopping occurred at the dam crest, and within a short period, the dam breached, releasing a large volume of water and debris flow downstream.

16:00

The second wave of floodwaters fully inundated the Guangfu urban area, with first floors nearly completely submerged.

15:08

The first flood peak reached the Mataian Creek Bridge, and at approximately 15:30, the bridge collapsed, disrupting transportation.

Formation of a Barrier Lake

- Barrier Lake Data

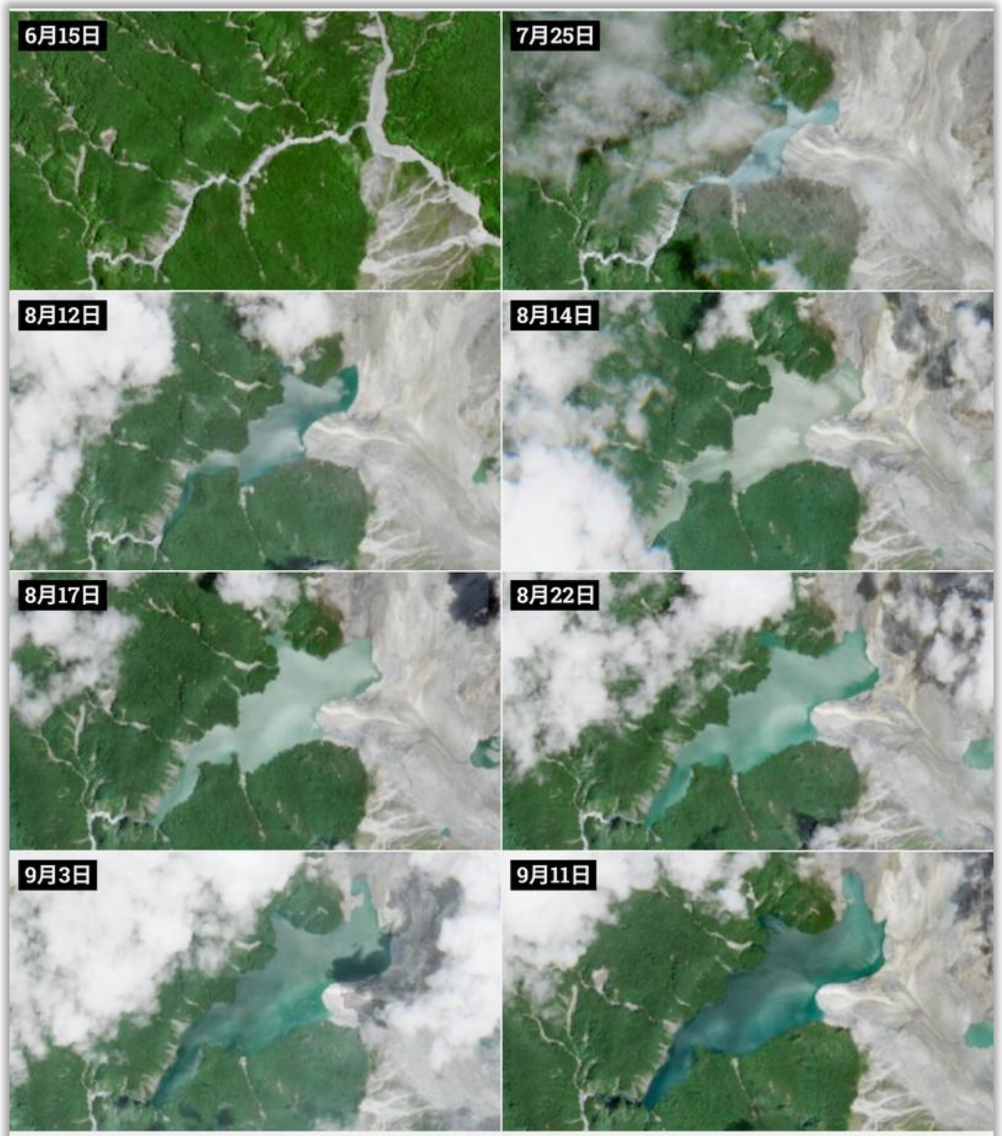
→ Location: Wanrong Township, Hualien County

→ Dam Height Before Overtopping: Approximately 250 meters

→ Lake Surface Area Before Overtopping: Approximately 137 hectares

→ Reservoir Volume Before Overtopping: 86.37 million cubic meters (full capacity ~91 million cubic meters)

→ Affected Area: 1,837 households (6,843 residents living there).



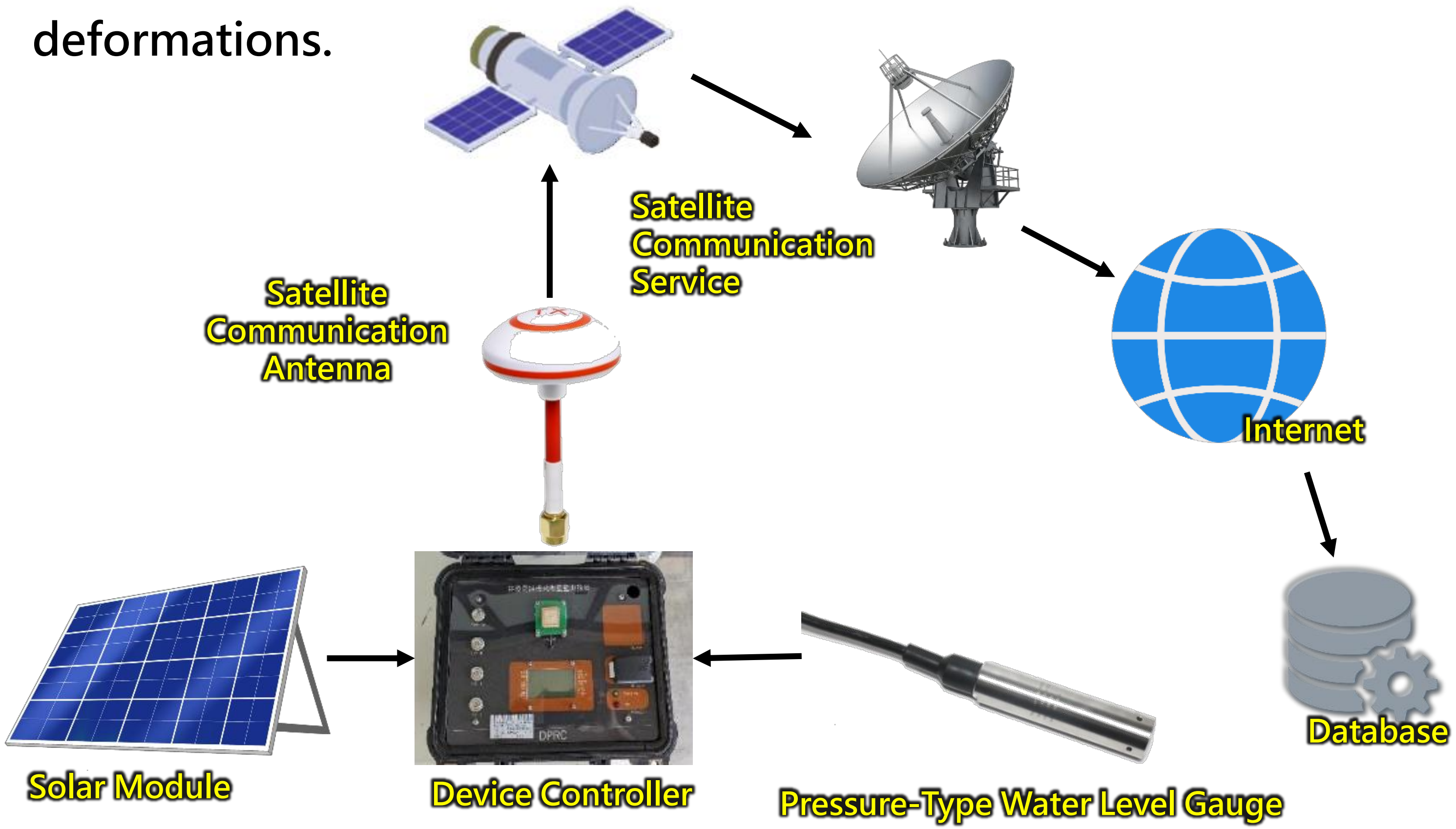
資料來源：European Union, contains modiiled Copemicus Sentinel data 2025 ｜ 資料整理：林奕甫 ｜ 製圖：江世民

IoT Monitoring System

➢ Establishment of a Monitoring System

→ Instruments such as satellite-based water level gauges, pressure-type water level sensors, UAV aerial photography, LiDAR, and micro-seismometers were employed.

→ Real-time data were transmitted to the Central Disaster Prevention Center to monitor water levels and slope deformations.



Disaster Response and Management

中央災害應變中心
Central Emergency Operations Center

Central Emergency Operation Center

農業部林業及自然保育署
Forestry and Nature Conservation Agency, Ministry of Agriculture

Forestry and Nature Conservation Agency

Deploy UAVs and aerial surveying for monitoring to track the barrier lake' s water levels and dam changes, and to assess the risk of dam breach.

Agency of Rural Development and Soil and Water Conservation

Analyze dam stability and breach simulations to support local access road and drainage planning.

經濟部水利署

Water Resources Agency

Notify downstream flood control units and initiate levee inspections and temporary heightening of protective structures.

Hualien

Local Government

Conduct emergency evacuation and sheltering, coordinating police, fire, and civil defense personnel to support the disaster area.

Research Institutions

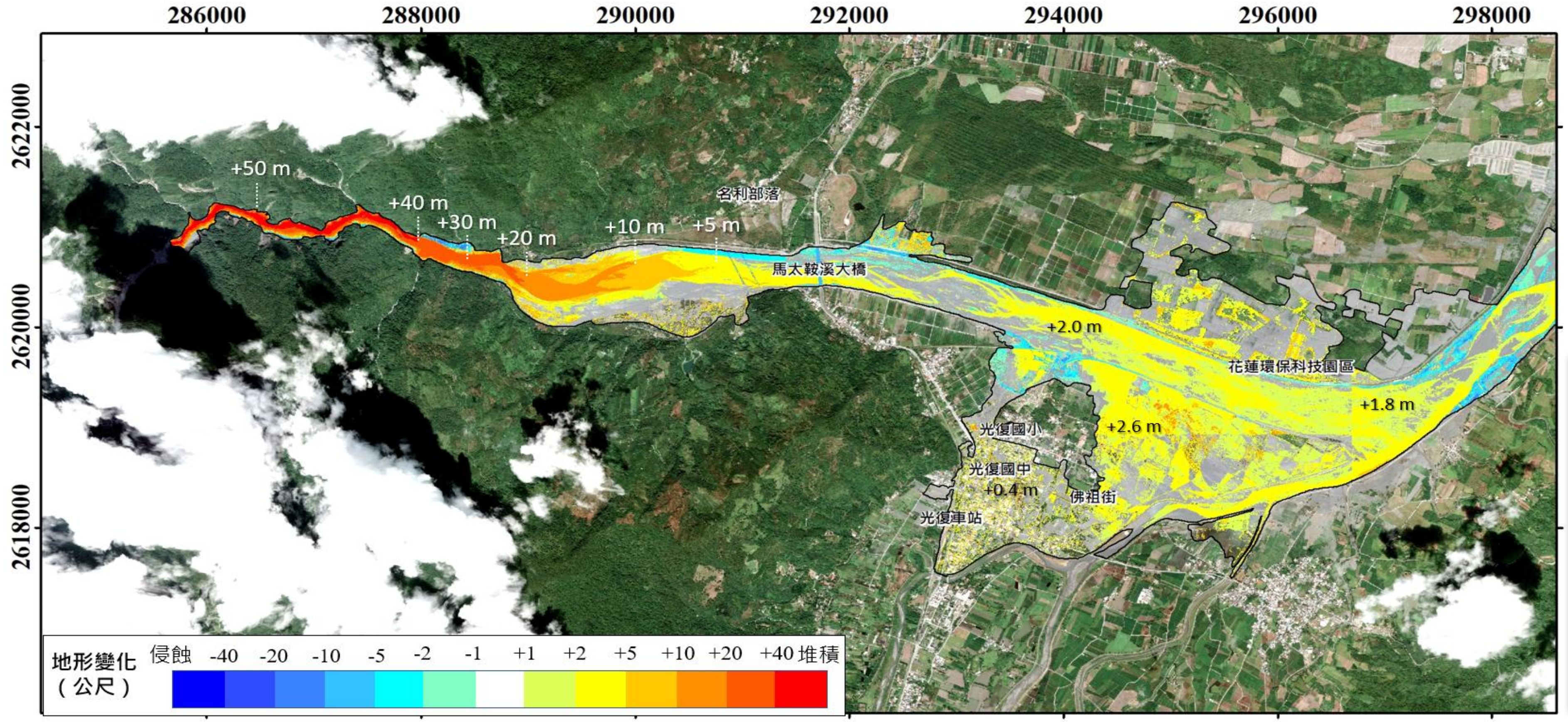
Perform real-time analysis of monitoring data to provide dam breach and hydrological simulation forecasts. Assist in the deployment of satellite water level gauges and AI-based early warning systems.

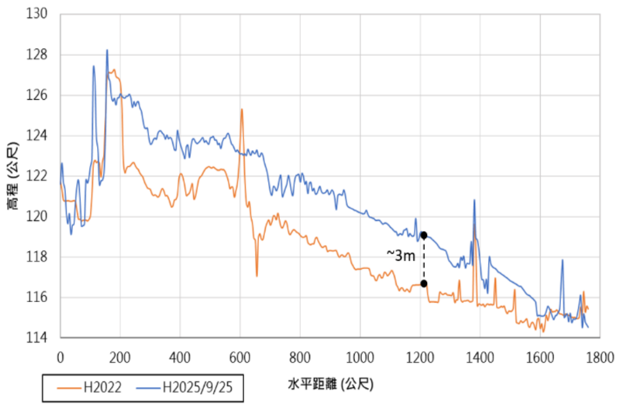
Disaster Overview

- On September 23, 2025, floodwaters surged within just 30 minutes, releasing an estimated 15 million cubic meters of water. Multiple bridges and levees were destroyed, and downstream settlements and farmland were severely inundated. The disaster resulted in at least 18 people were killed and several others went missing, disrupted transportation and communications, and damaged or buried hundreds of households.

Disaster Overview

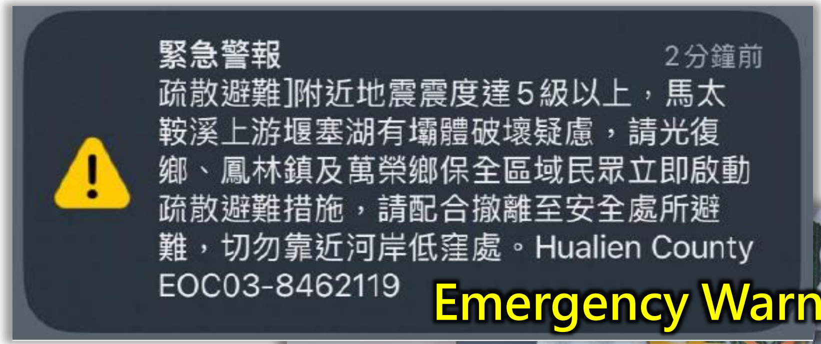
➢ A massive volume of collapsed debris moved downstream, severely impacting the mid- and lower-reach riverbeds, with localized elevation increases of 2–50 meters. The river cross-sections were reshaped, and the flow paths and flood discharge routes were significantly altered.





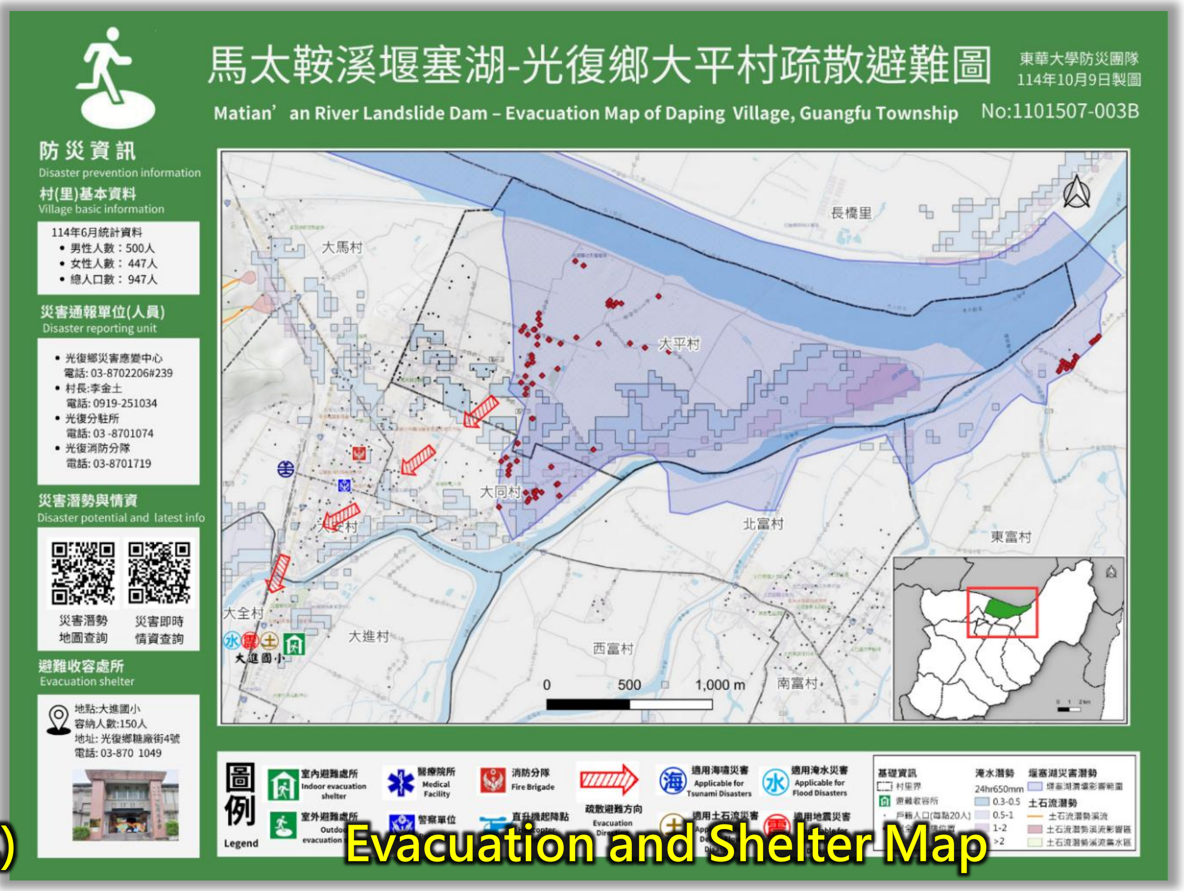
Warning and Reporting Procedures

- On September 21, a Yellow Warning was issued → upgraded to a Red Warning on September 22.
- The Central Emergency Operation Center (CEOC) coordinated unified command, immediately notifying downstream townships and initiating evacuation.
- Warnings were disseminated through multiple channels, including disaster prevention warning SMS, police radio broadcasts, and local disaster response groups.



Emergency Warning SMS

Central Emergency Operation Center (CEOC)

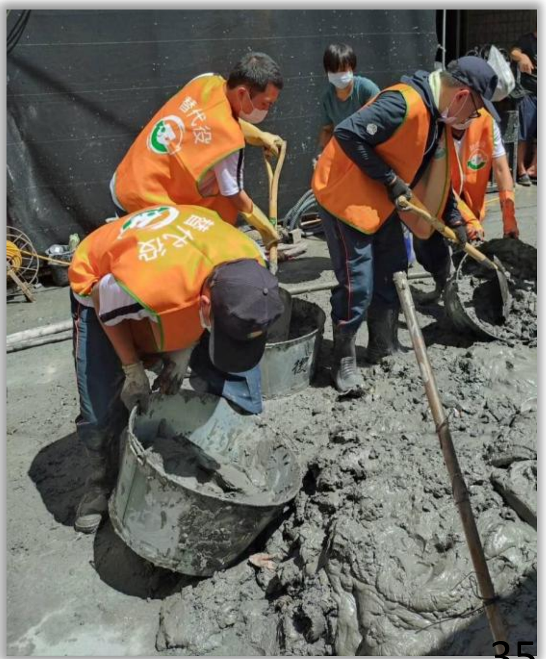


Evacuation and Shelter Map

Local Disaster Response Groups

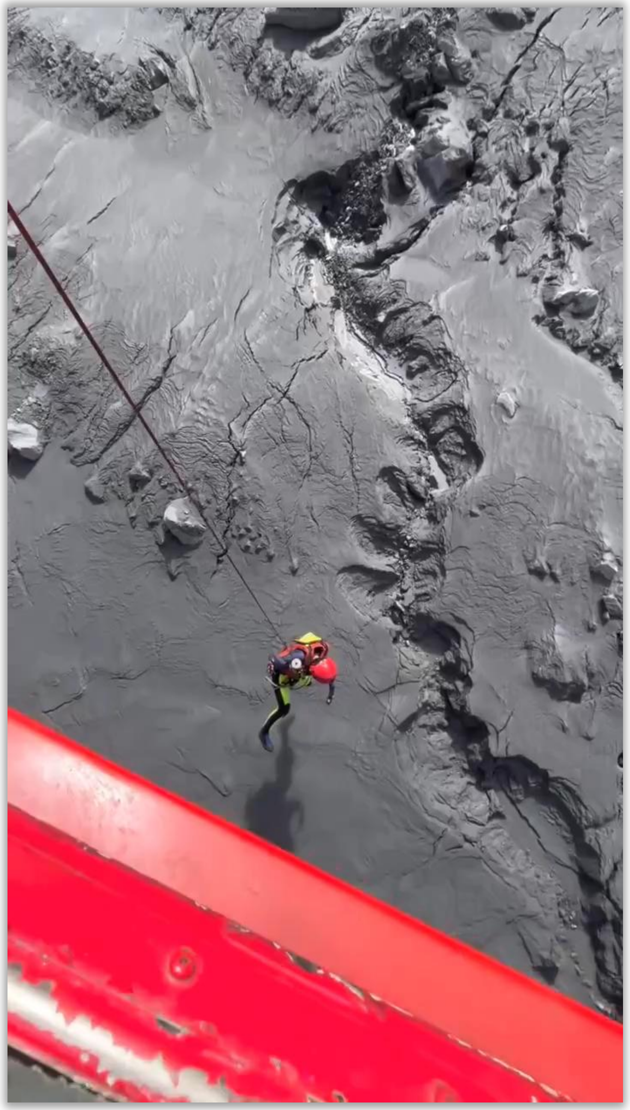
Resilience Community

Community Disaster Volunteers



Post-Event Challenges and Risks

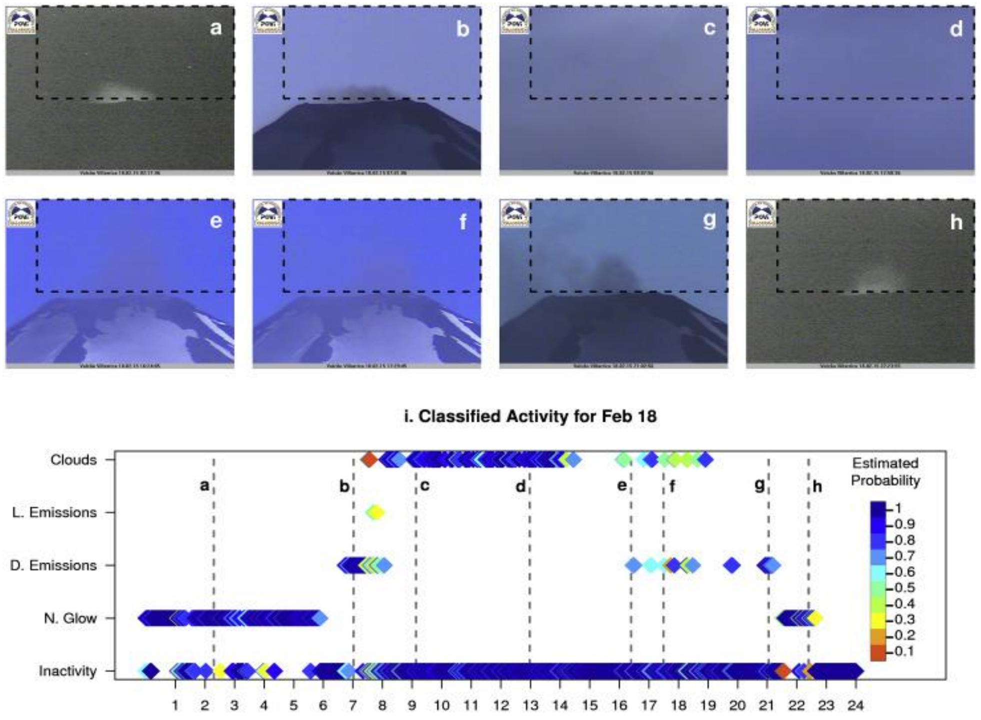
- High Geological and Climatic Uncertainty: Slopes remain unstable, potentially triggering secondary landslides or the reformation of a barrier lake.
- Engineering and Access Limitations: Severe mud conditions and difficult transportation on site restrict the deployment of heavy machinery.
- Inter-Agency Coordination and Long-Term Management Challenges: Integration of multiple disaster prevention agencies is required to ensure consistent monitoring and remediation objectives.



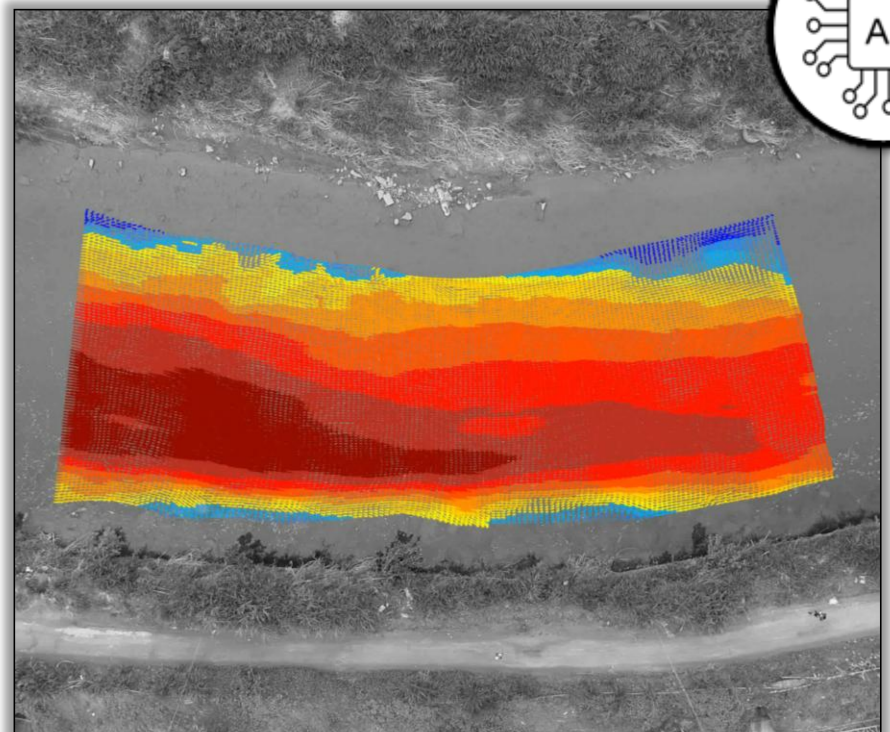
Analysis from Technological Applications to Disaster Management Vision

Future Outlook and Development Pathways

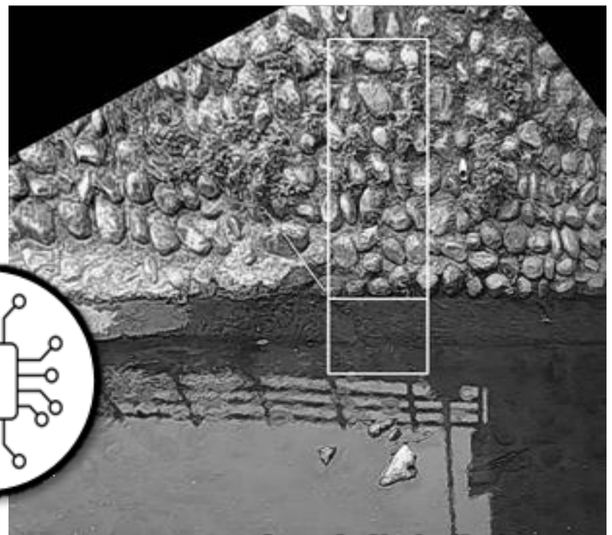
- Future disaster forecasting will integrate artificial intelligence, cloud computing, and denser sensor networks.
- Data will no longer serve merely as monitoring results but will become the basis for proactive warnings and decision-making.
- This will allow every disaster to be predicted earlier, observed by more people, and ultimately reduce disaster losses to the minimum.



AI-Based Volcanic Monitoring



AI-Based Hydrological Measurements



Water level digital recognition

AI-Based Flood Monitoring

International Collaboration and Sharing Taiwan Experience

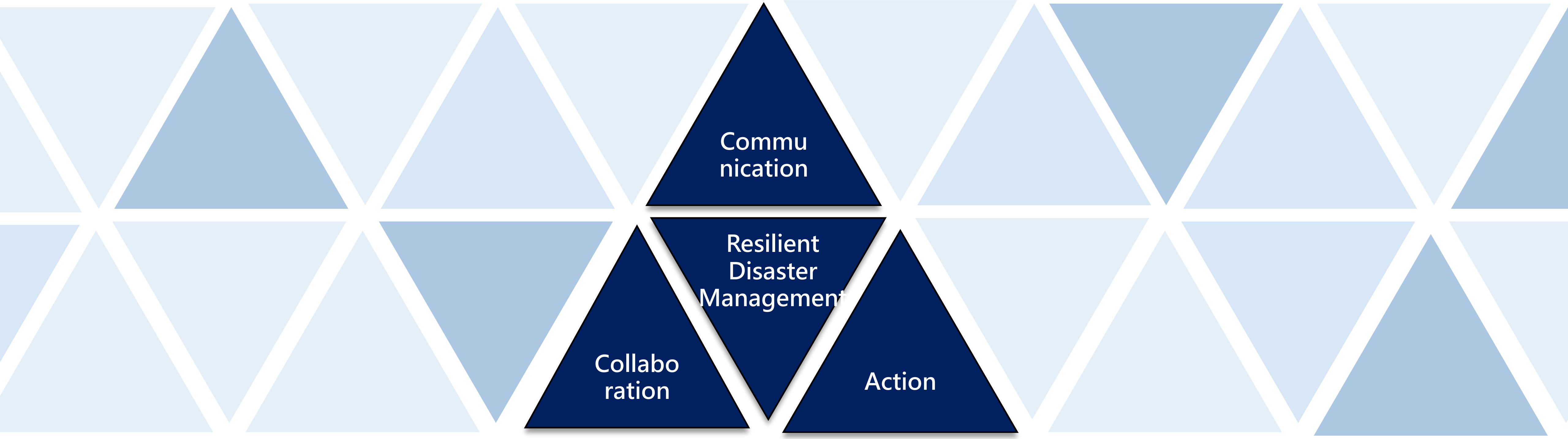
- Taiwan has accumulated extensive experience in the development of disaster monitoring and early warning systems. From real-time rainfall networks and watershed simulations to resilient communities, Taiwan possesses a comprehensive technical framework.
- These achievements are being shared through international collaboration with countries in Central America, such as Guatemala, to jointly promote regional disaster resilience capacity building and technology transfer.

Integrated Vision for a Transnational Disaster Management Platform

- Disasters know no borders, and transnational information integration is a key direction for future disaster management cooperation.
- By sharing meteorological data, real-time monitoring, and simulation results, countries can coordinate responses before disasters occur.
- Establishing a regional disaster management platform enhances transparency of early warning information, accelerates decision-making, and ensures that disaster management technologies truly serve as global public goods.

Conclusion and Outlook

- Disaster forecasting is not merely a technical issue; it is the integrated outcome of communication, collaboration, and action.
- From understanding temporal scales and applying models to constructing IoT systems and early warning platforms, each step brings us closer to the goal of "preparing in advance and minimizing losses."
- In the future, through data sharing and international collaboration, we aim to build a more resilient disaster management system.

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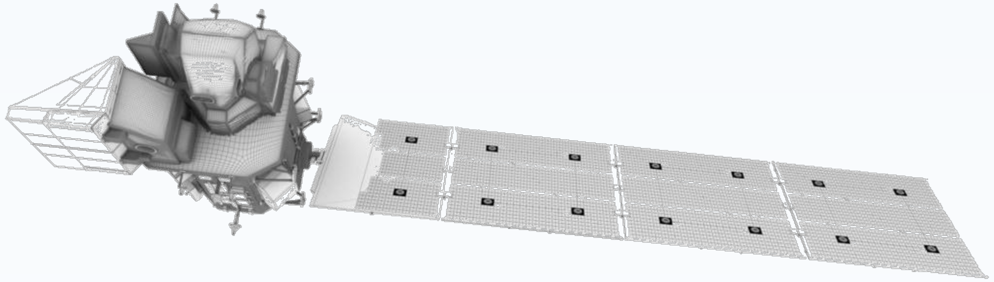
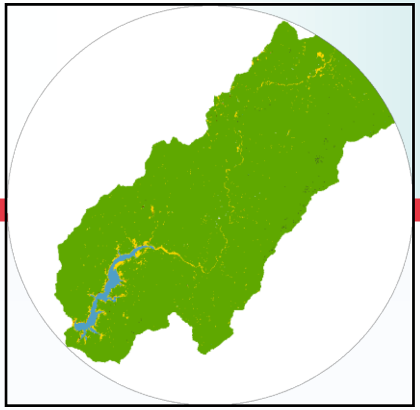
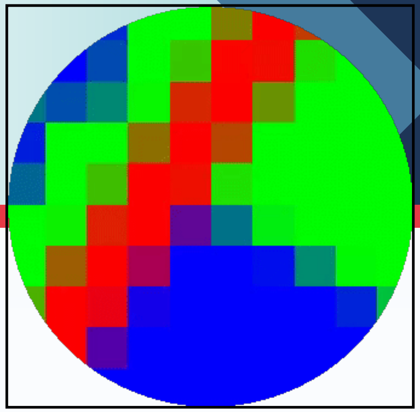
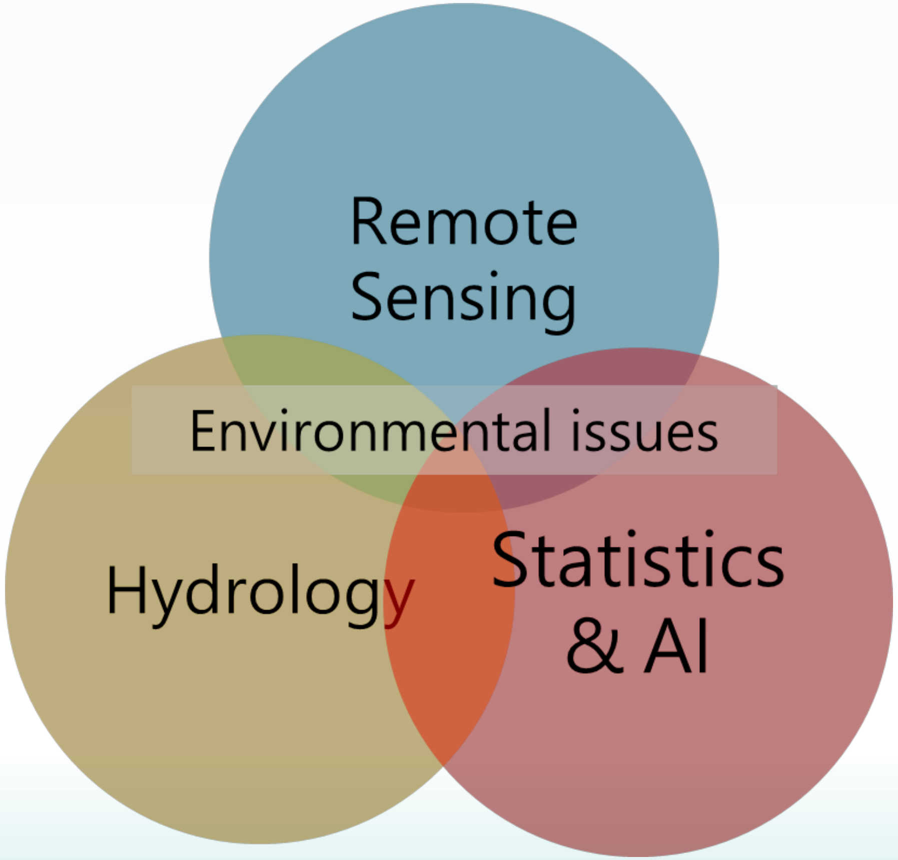
Taiwan Can Help
U



AI for disaster monitoring and future challenge of climate change

Presenter: Dr. Su, Yuan-Fong
National Taiwan Ocean University

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National Taiwan Ocea

Contents

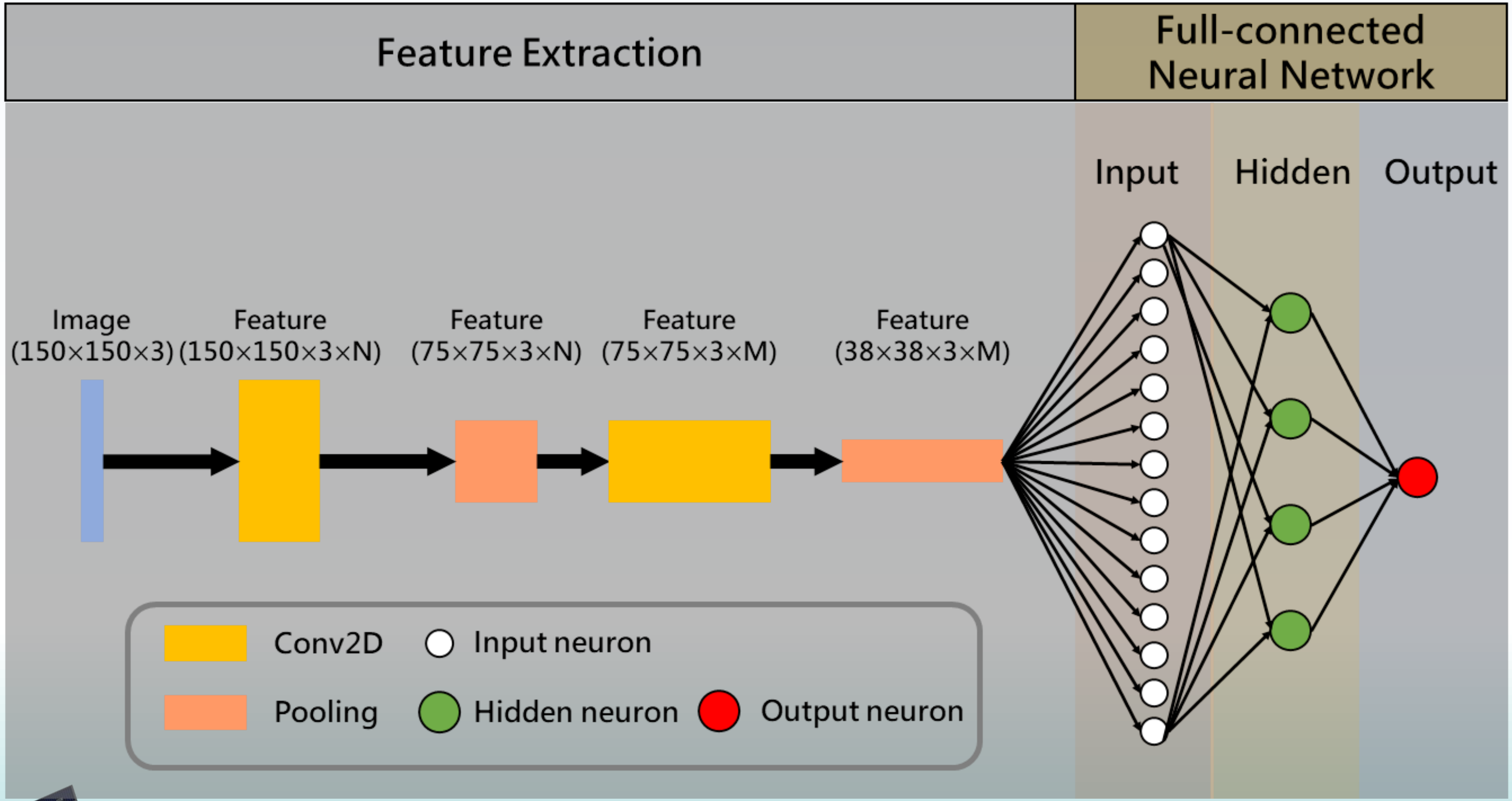
1. AI for near real-time flooding detection using CCTV in urban area
2. CCTV for shoreline monitoring using U-NET
3. AI and Cloud-based remote sensing for disaster monitoring
4. Future Challenge of Climate Change

AI for near real-time flooding detection using CCTV in urban area

Can we automatically detect flooding from all CCTV footages?

- In a small island, Taiwan, we have 100,000+ cctv footage.
- Every year we may have several flooding events result from storms and typhoons.
- It is impractical to monitor all cctv footages by people.
- Therefore, we need an algorithm to automatically detect flooding from all cctv footages.
- The algorithm we used is Convolutional Neural Network.

Convolution Neural Network (CNN)



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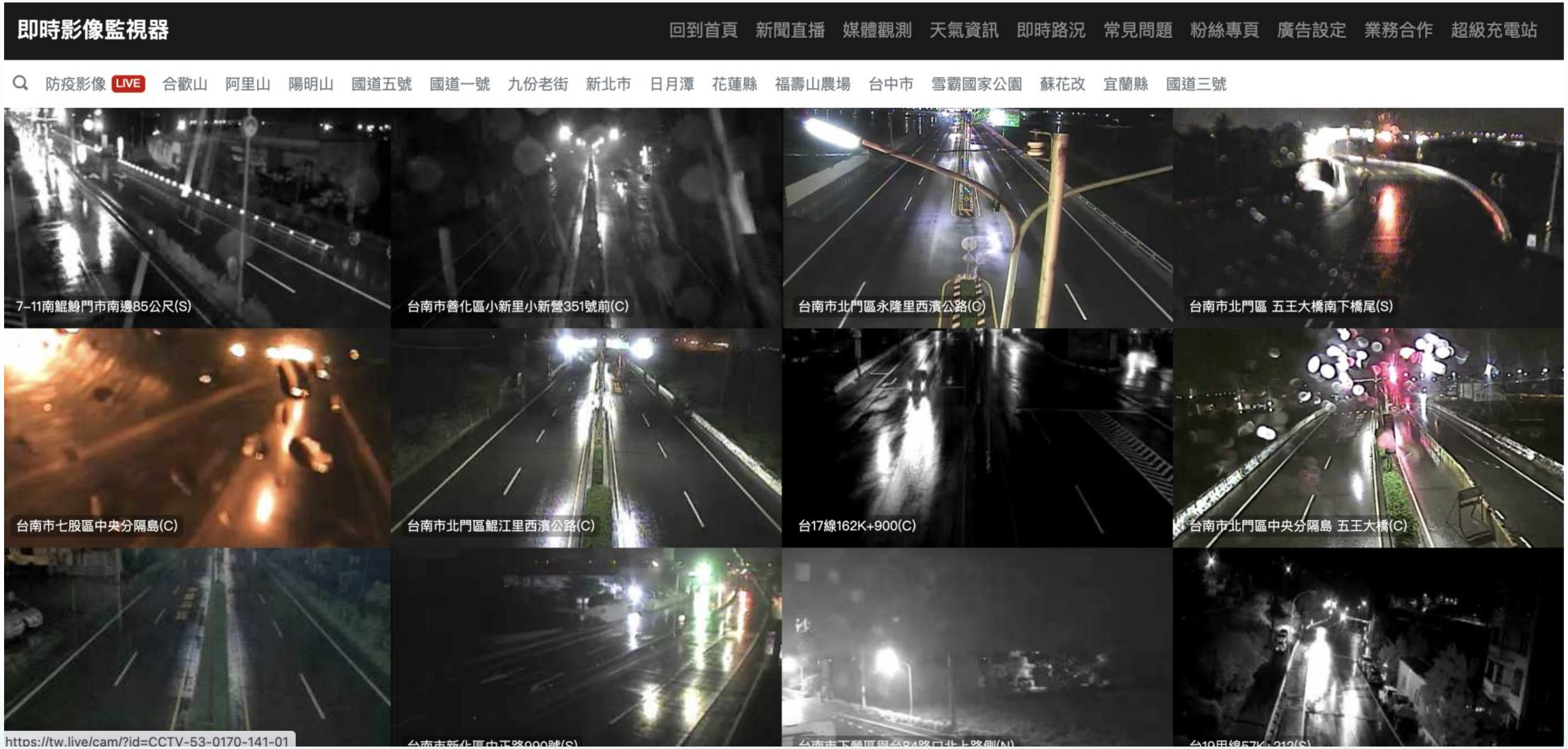
Training sample collection (From open CCTV)

- tw.live



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National Taiwan Ocean University

Training sample collection (From News)


ETtoday新聞雲 | 新聞雲APPS | 手機版

淹水 相關新聞

受到熱帶性低氣壓登陸及其外圍環流影響，臺灣中南部地區2018年8月23日出現強降雨，造成彰化、台南、高雄等地接出現淹水災情，

快訊／雨彈來襲「淹水警戒發布！」南投列一級「下班民眾注意！」

大雨特報雨彈來襲，經濟部水利署緊盯水情。水利署今（7）日下午五時針對南投縣、彰化縣發佈一級淹水警報，包括南投市及草屯鎮、彰化縣二水鄉等區域均納入警戒範圍，提醒周邊居民小心防汛，下班通勤民眾也要小心雨勢，才能確保人身安全。詳全文>>

大雨襲高雄時雨量破百！岡山、永安多處積水　水深一度達20公分

高雄市受午後熱對流影響，有短延時強降雨發生，中央氣象局於15時45分發佈高雄市豪雨特報，主要在永安區、路竹區、岡山區、湖內區及茄萣區一帶有明顯雨勢發生，經統計積淹水災情通報6件，於下午4時58分已全部退水，集中岡山區及永安區。詳全文>>

快訊／水利署發布淹水警報！「高雄這2區」列一級警戒

Image collection

- There are 134 photos are labeled as (1) for normal (not flooding).
- T ot (0) for

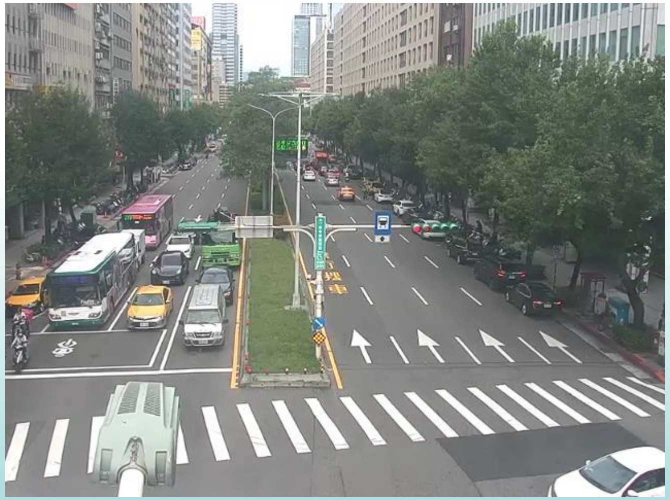


Image preprocess

- JPEG, JPG, TIFF convert to PNG
- Resize to 150x150
- Normalize to 0~1.
- Split to Training (80%) and Testing (20%) datasets

Convolution Neural Network (CNN)

➤ Using TensorFlow to construct a CNN.

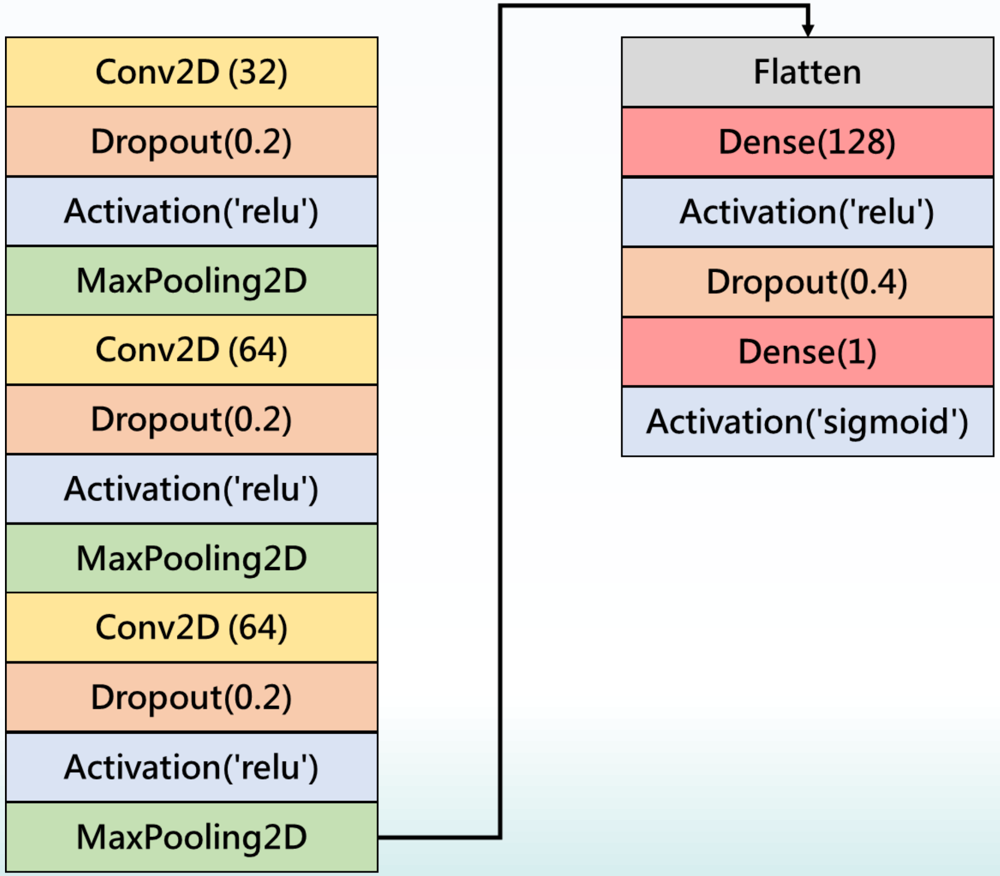
```
model = Sequential()
model.add(Conv2D(32, (3, 3), input_shape=INPUT_SHAPE))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))

model.add(Conv2D(32, (3, 3), kernel_initializer = 'he_uniform'))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))

model.add(Conv2D(64, (3, 3), kernel_initializer = 'he_uniform'))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))

model.add(Flatten())
model.add(Dense(64))
model.add(Activation('relu'))
model.add(Dropout(0.5))

model.add(Dense(1))
model.add(Activation('sigmoid'))
```



Epoch = 10

- Total parameters: 1,212,513
- Training time: 82 sec.
- Training accuracy: 100%
- Test accuracy: 81.25%
- Threshold: 0.59

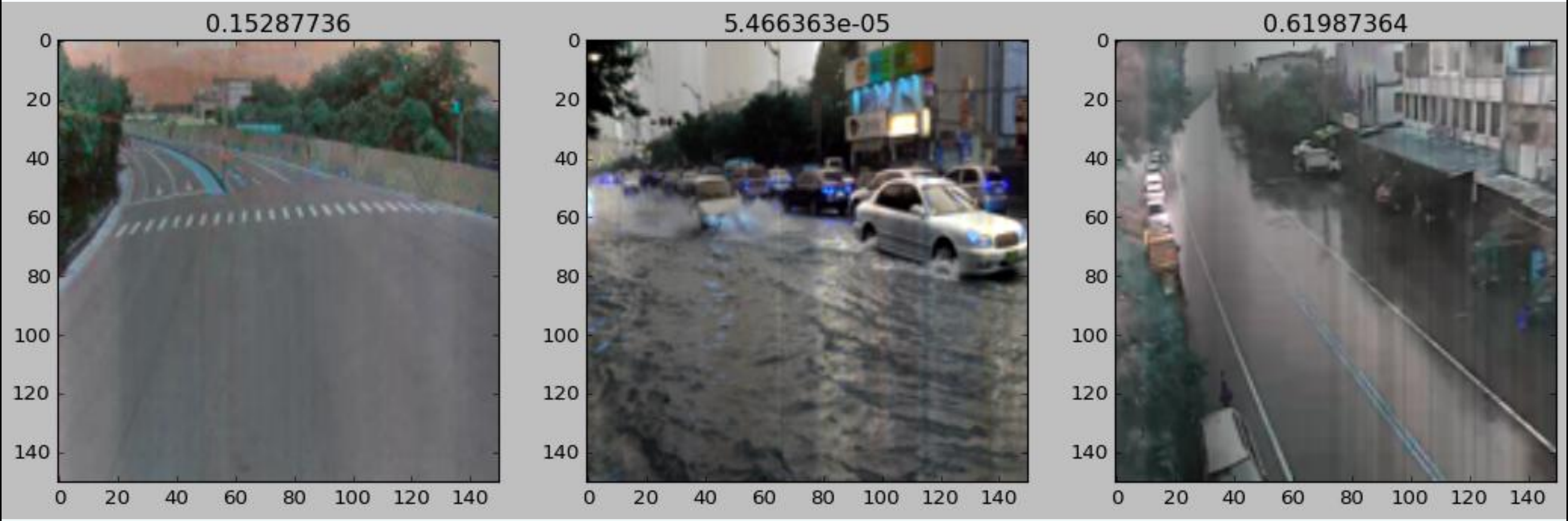
Testing		Labelled		
		Normal	Flooding	UA
Classified	Normal	24	3	89%
	Flooding	6	15	71%
	PA	80%	83%	OA=81.25%

Training		Labelled		
		Normal	Flooding	UA
Classified	Normal	104	0	100%
	Flooding	0	87	100%
	PA	100%	100%	OA=100%

國立

Nationa

Mis-classified (Threshold = 0.599)



X O O

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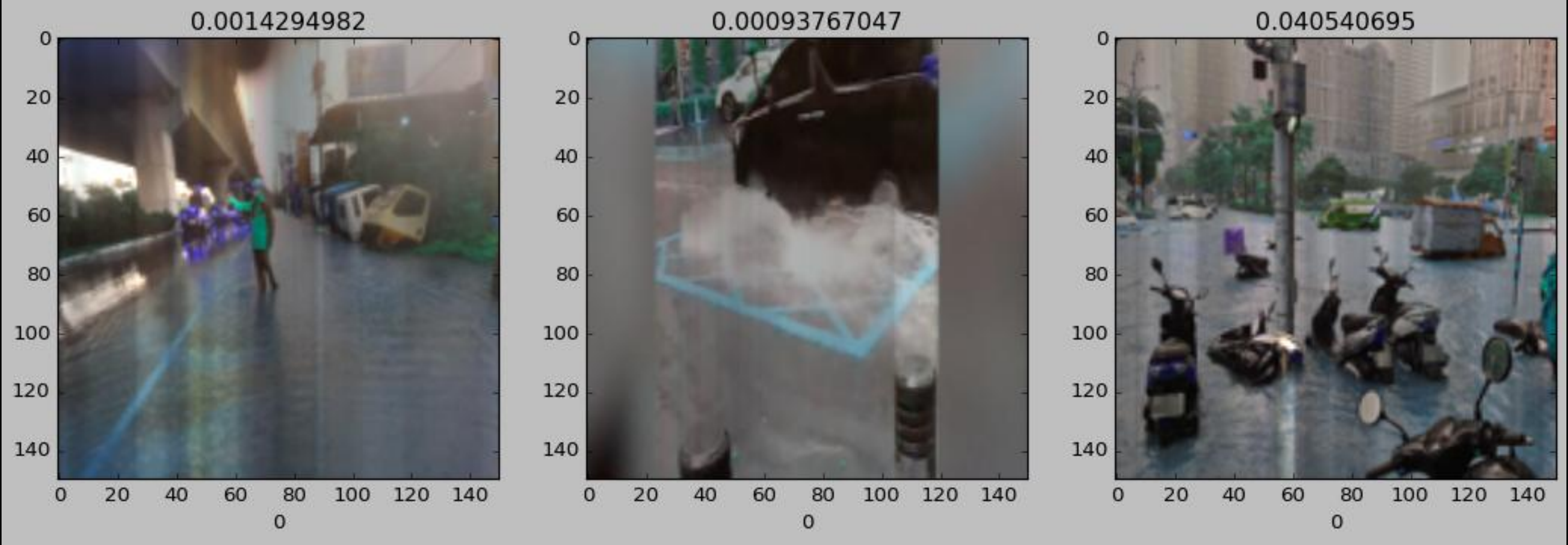
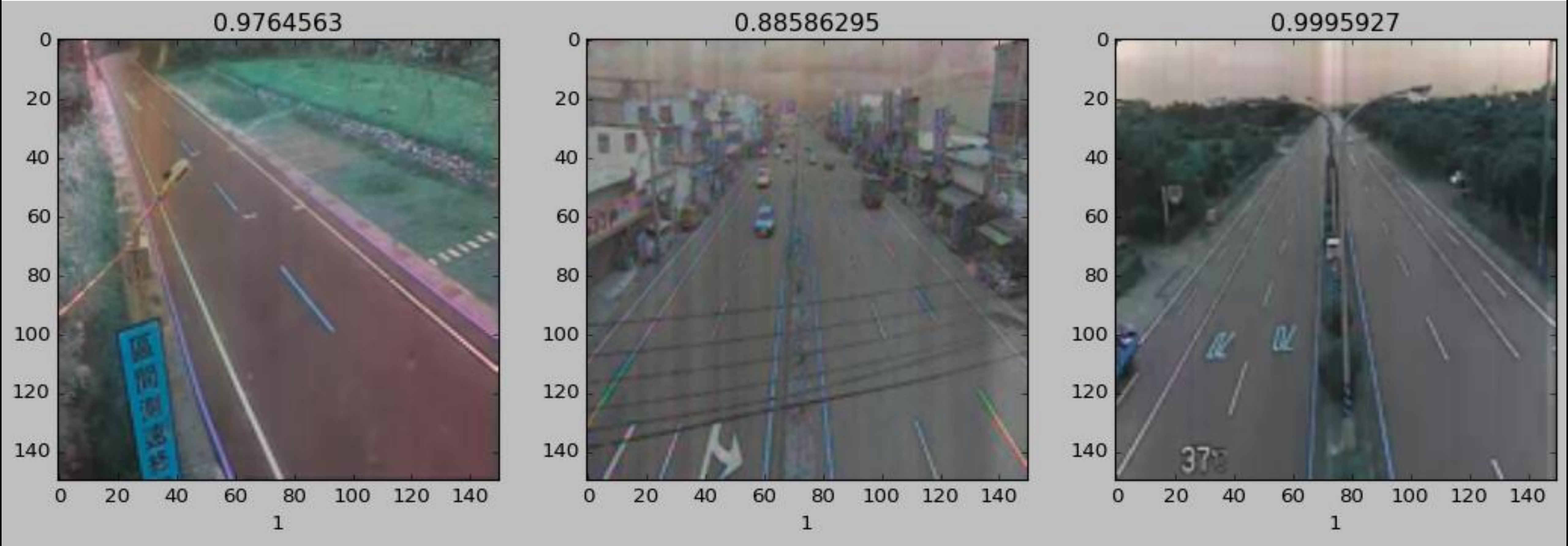
Threshold = 0.599



O O O

Threshold = 0.599



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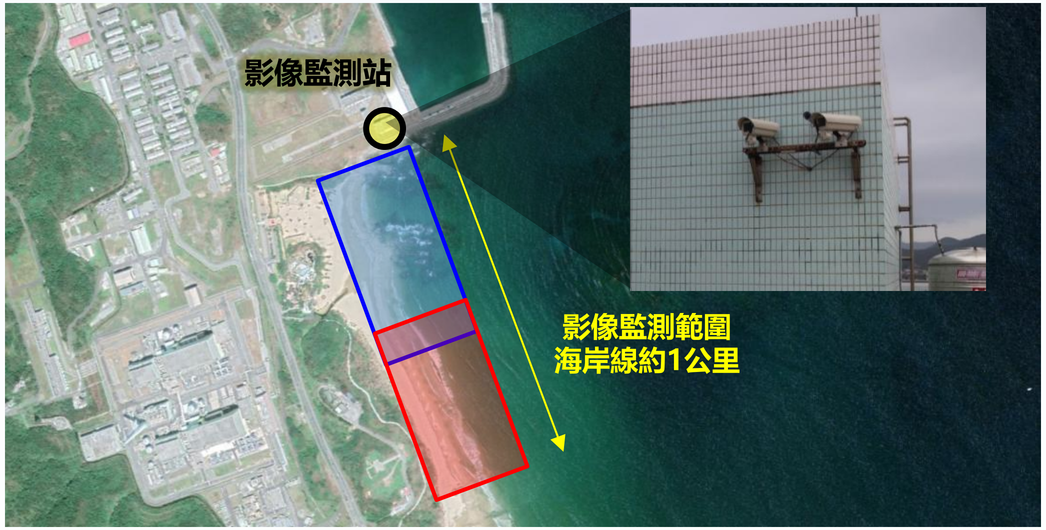
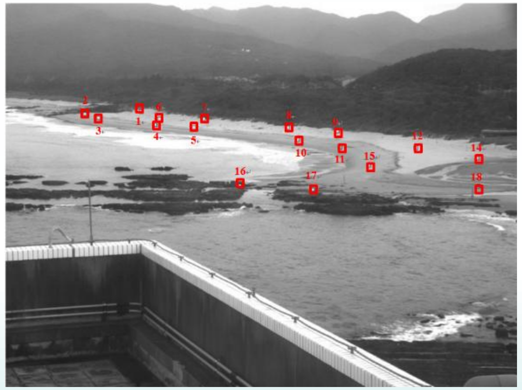
CCTV for shoreline monitoring using U-NET

Backgound

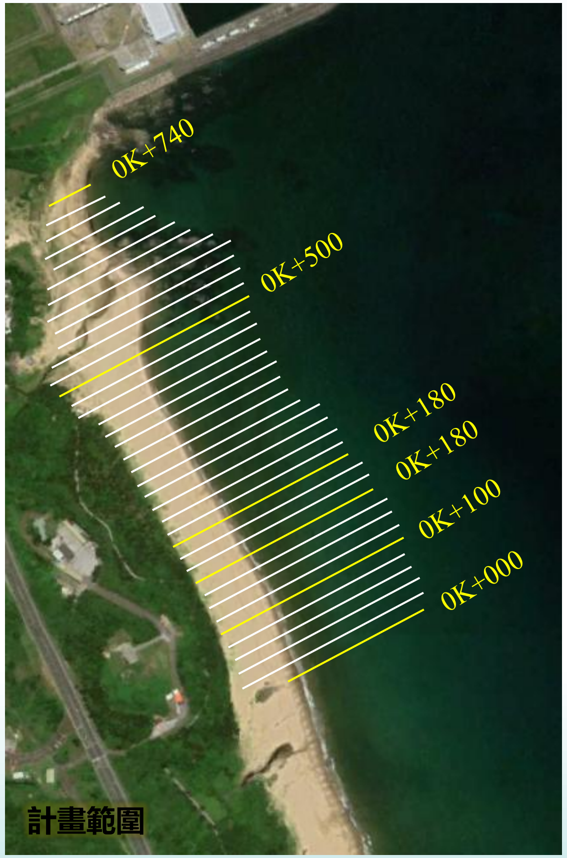
Study area and objective

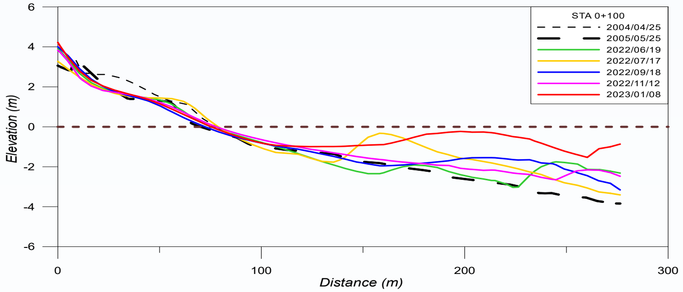
- Yan-Liao Beach at northern Taiwan.
- Collecting images since 2012.

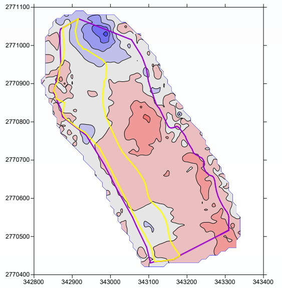


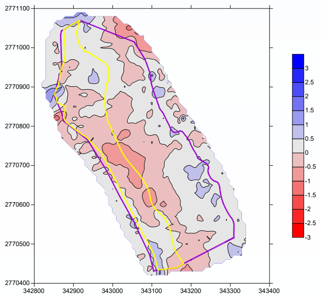


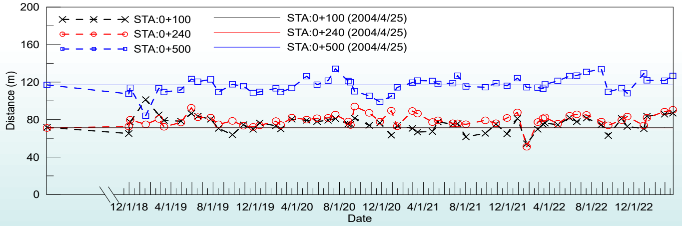
Coastal survey

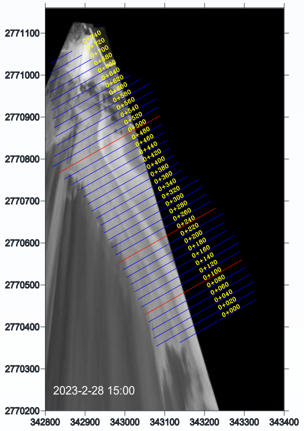


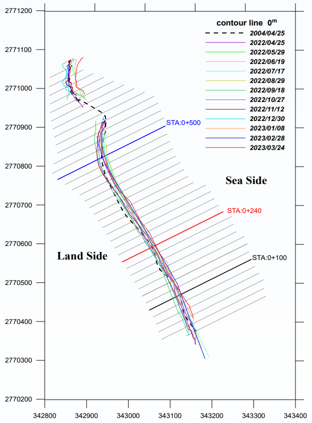


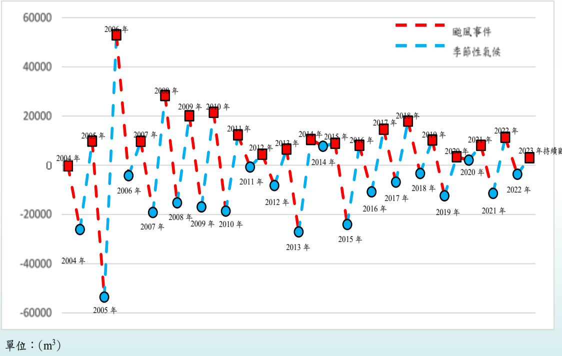












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National Taiwan Ocean University

Old method

- Old method utilized traditional edge detection algorithms and manually select coastal line from one of edges.

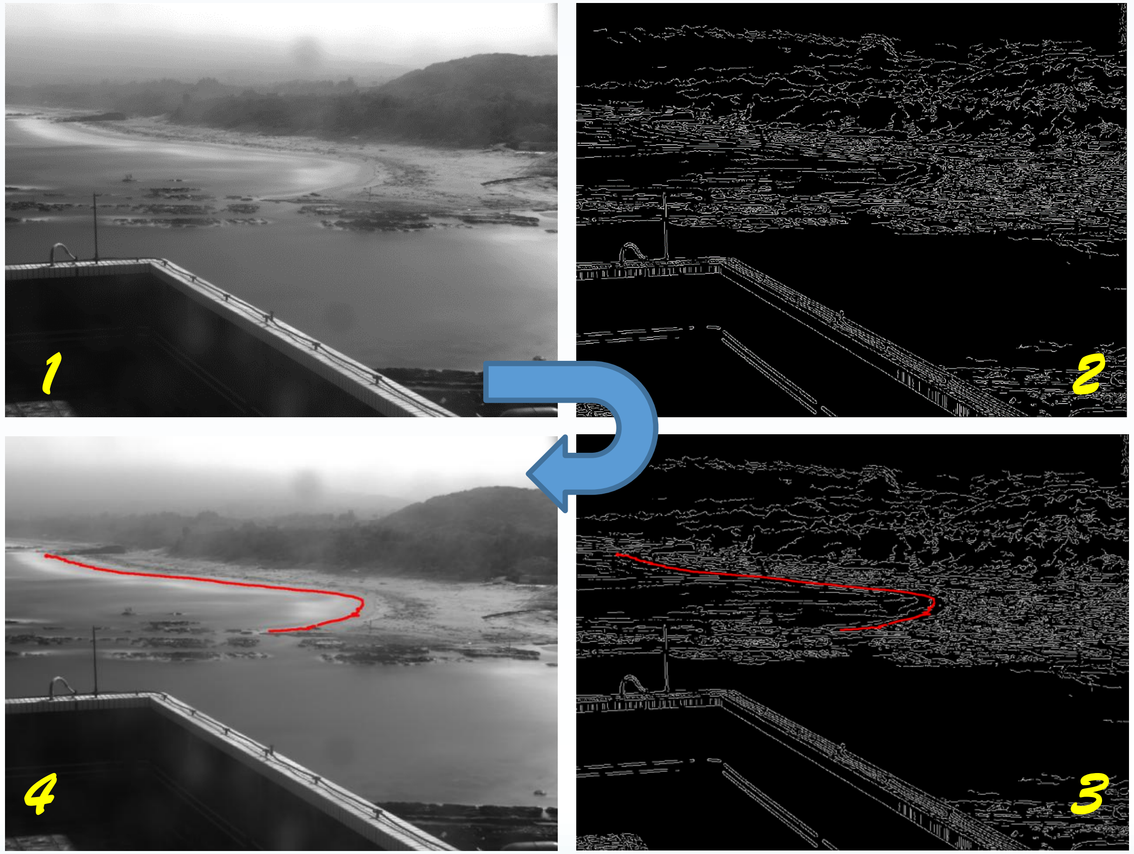
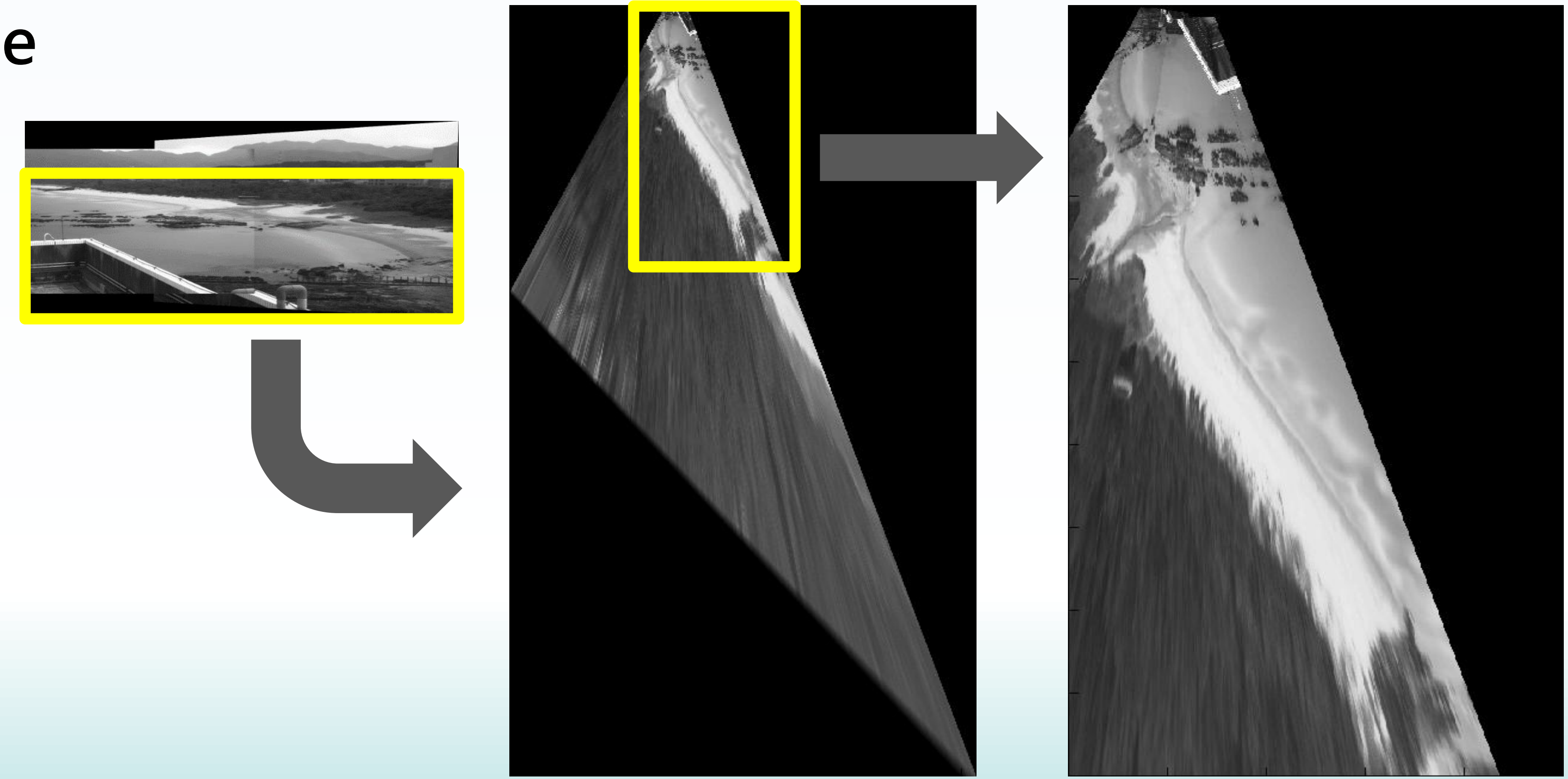
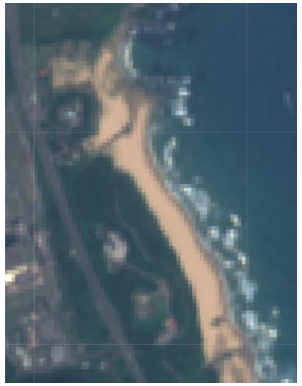


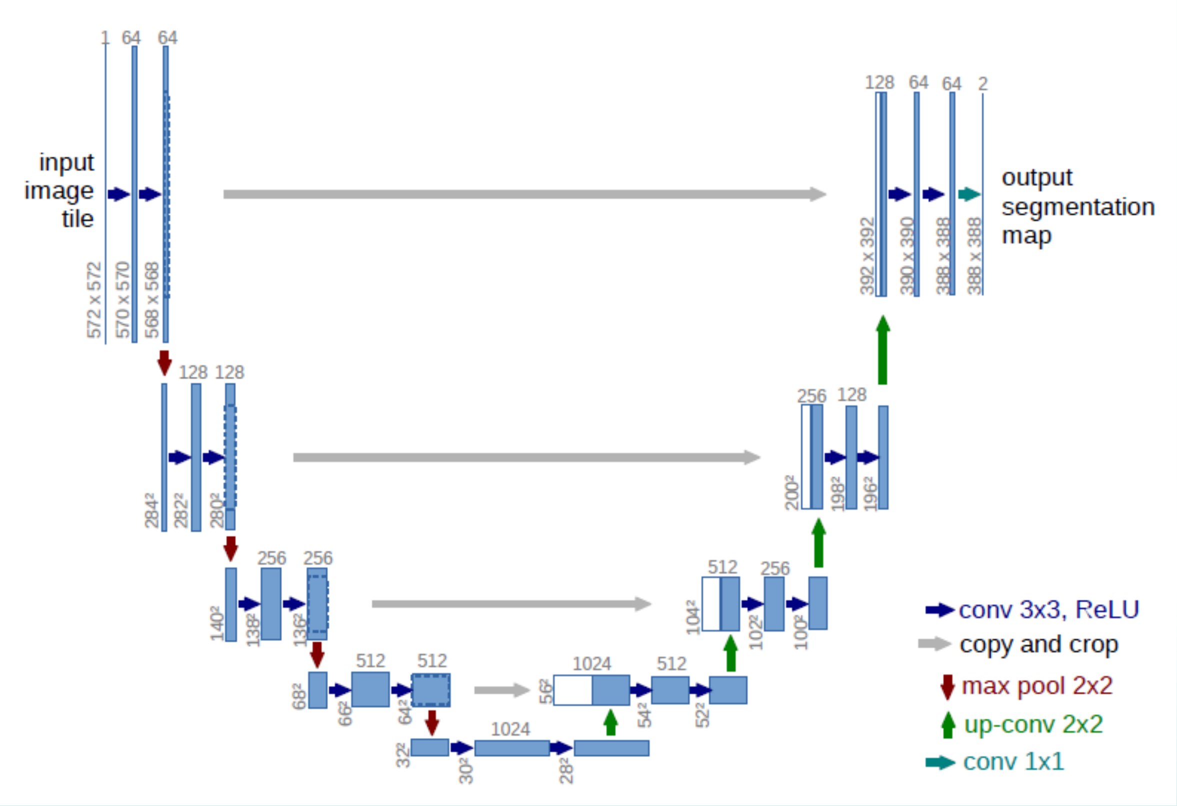
Image preprocess

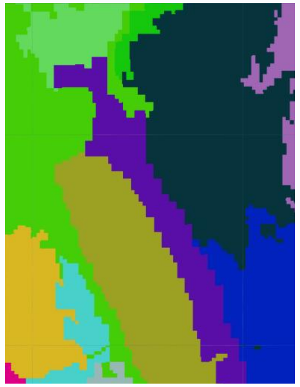
- Mosaic
- Georeference
- Image clip



AI model : U-NET







AI and Cloud-based remote sensing for disaster monitoring

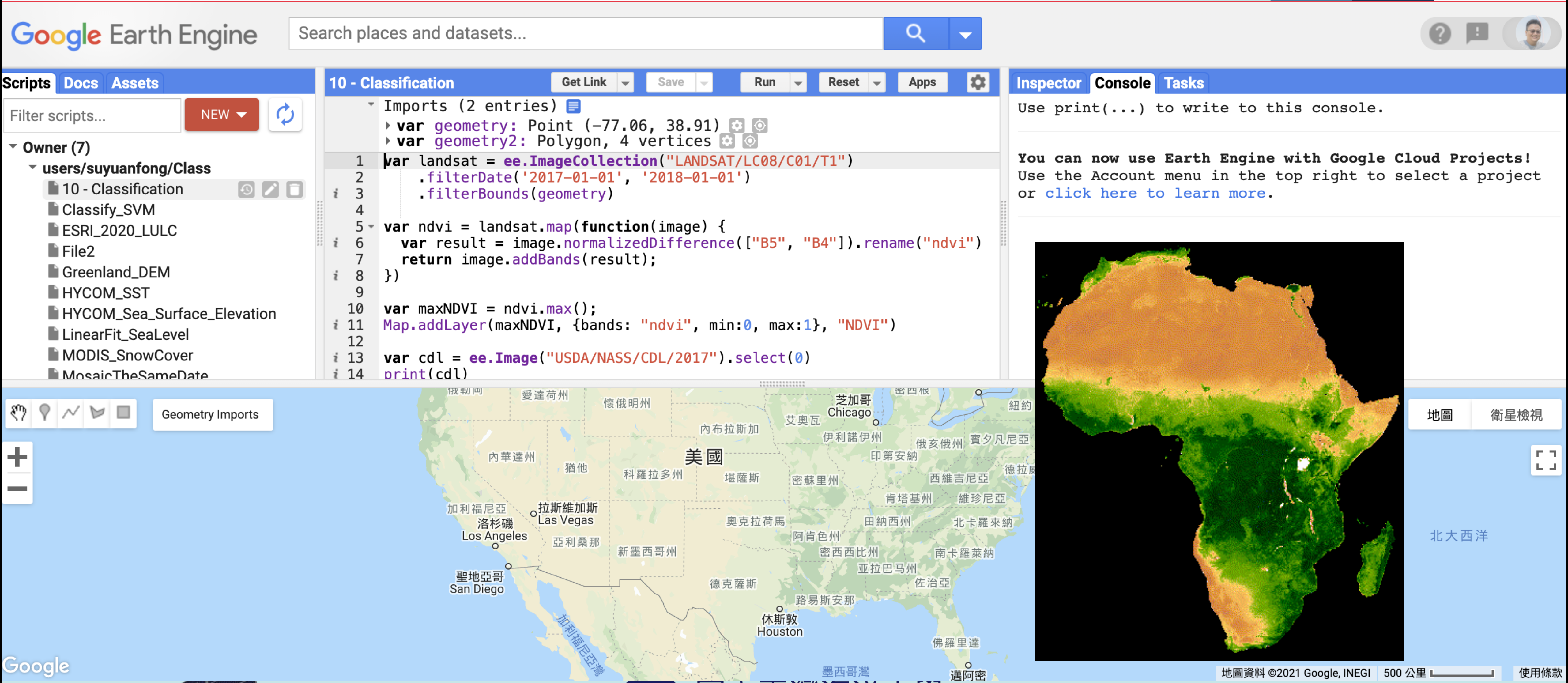
Cloud-based Remote Sensing

- Opendata
- Cloud-computing
- Freely accessible platform

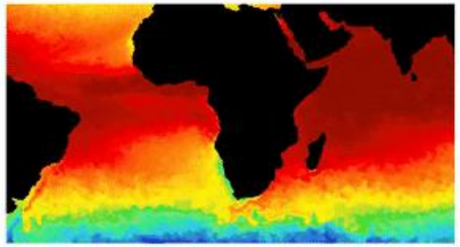
Request

Response

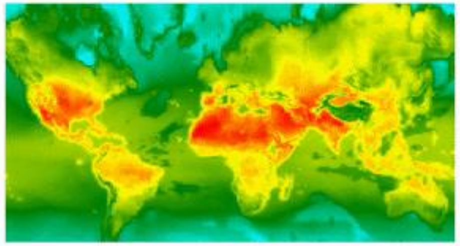
Google Earth Engine - Code Editor



Google Earth Engine Datasets



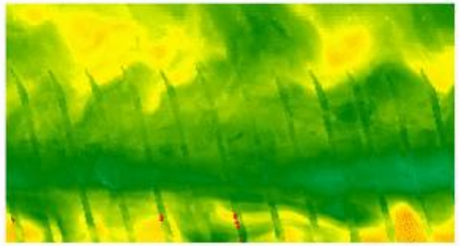
Surface Temperature
31 datasets



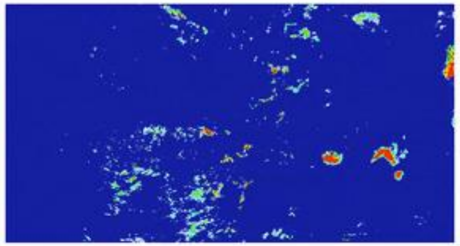
Climate
50 datasets

Landsat
5 dataset (from 1972)

Sentinel
4 datasets

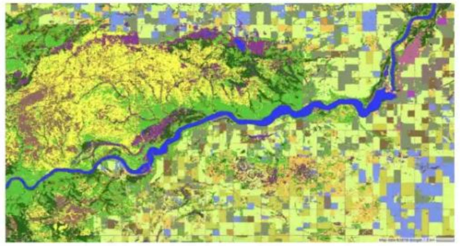


Atmospheric
6 datasets

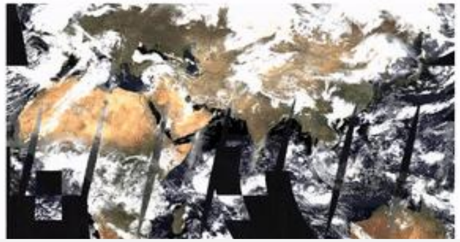


Weather
27 datasets

Terrain
36 datasets

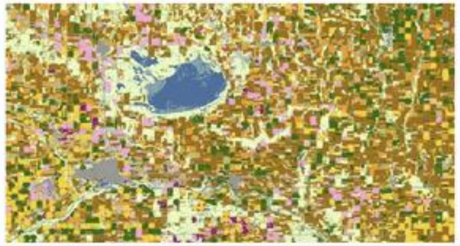


Landcover
20 datasets



MODIS
25 datasets

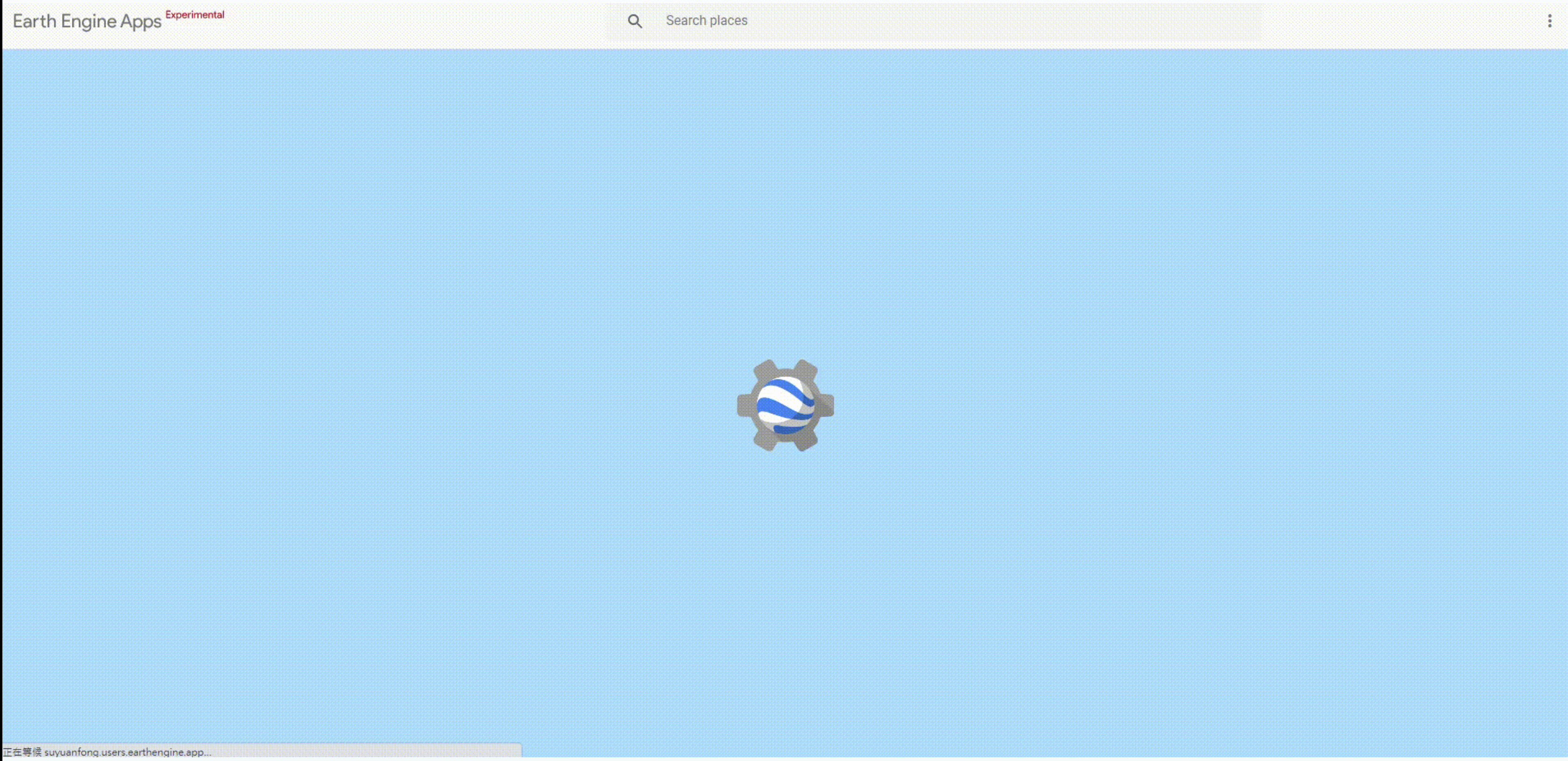
High-resolution imagery
3 datasets



Cropland
3 datasets

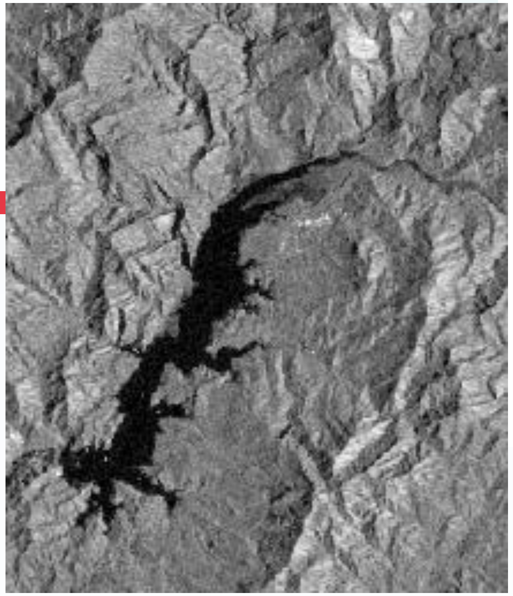
Other geophysical data

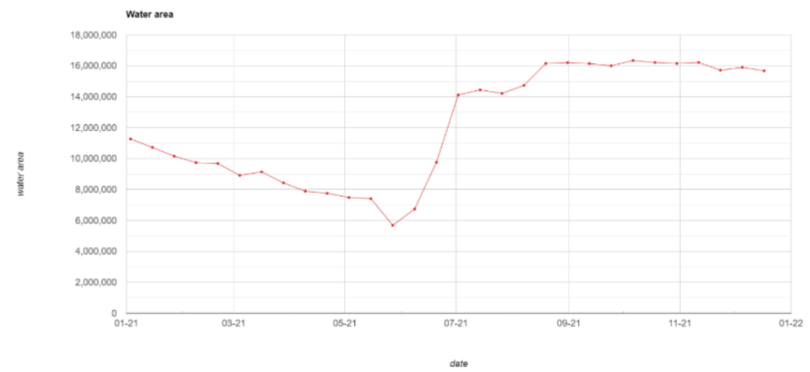
Large scale flooding monitoring

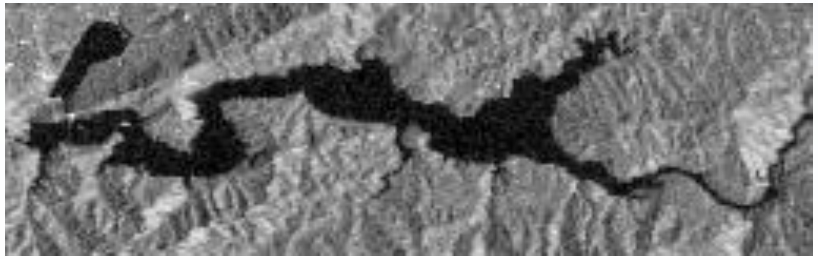


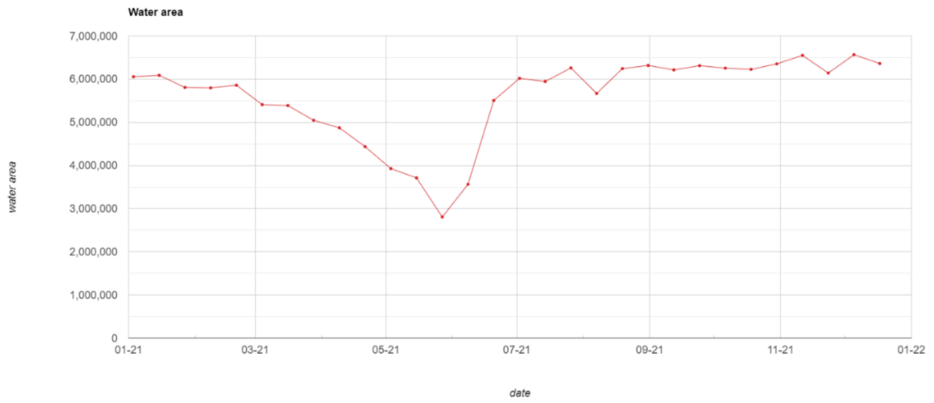
Flooding in central China, July 2021

2021 Drought





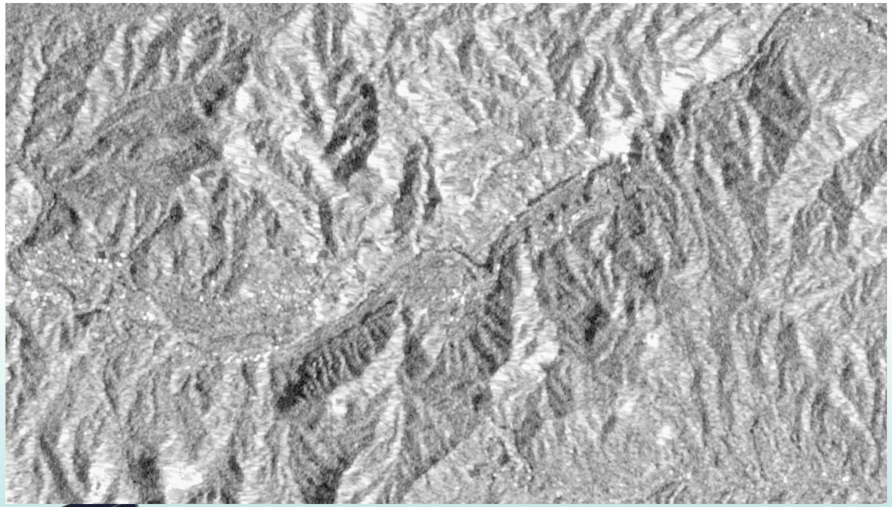


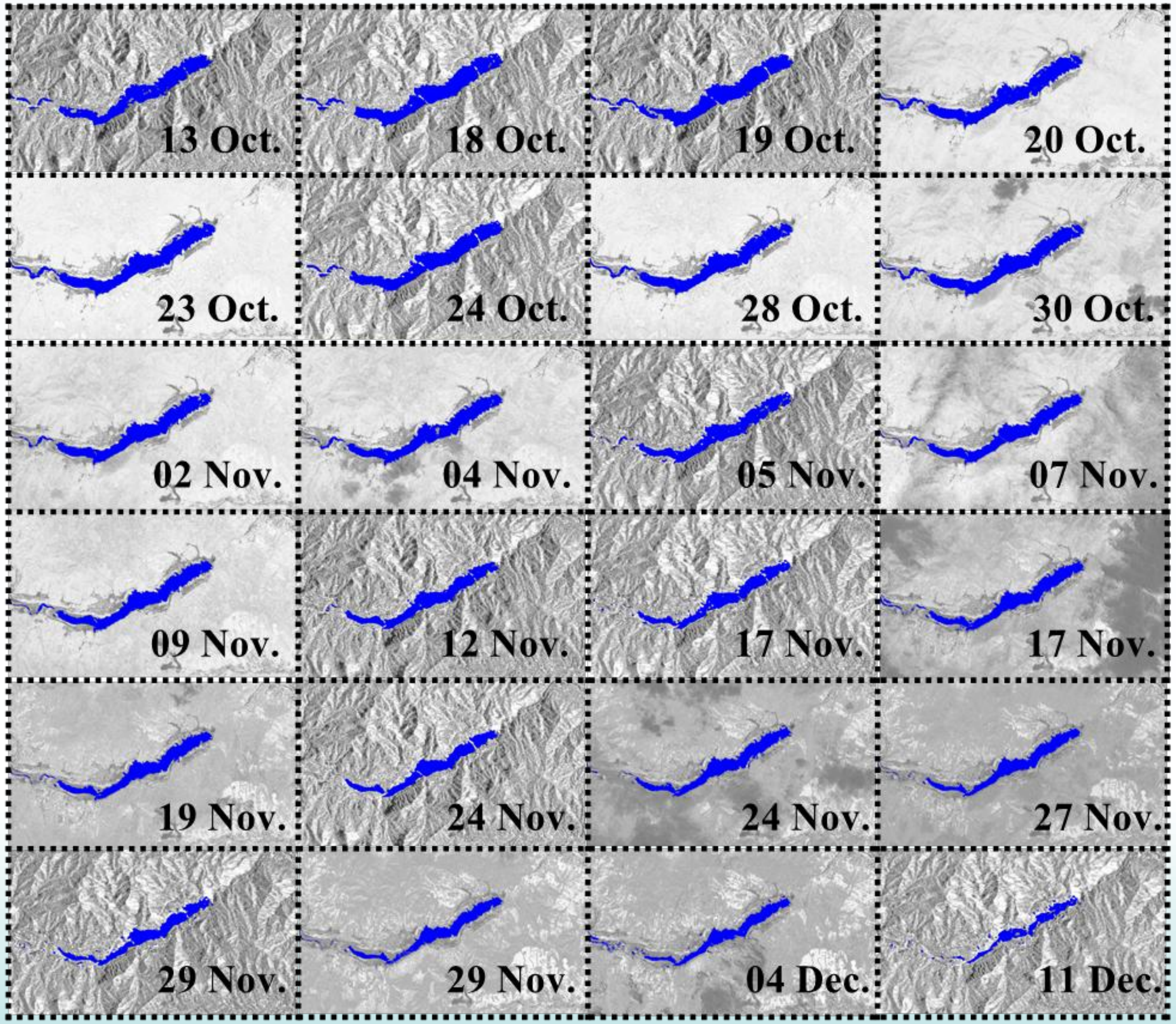


Source: udn.com

Yamba Dam in Japan

- Hagibis Typhoon in 2019
- Yamba Dam keep all rainfall in the catchment to prevent flooding in the downstream area.

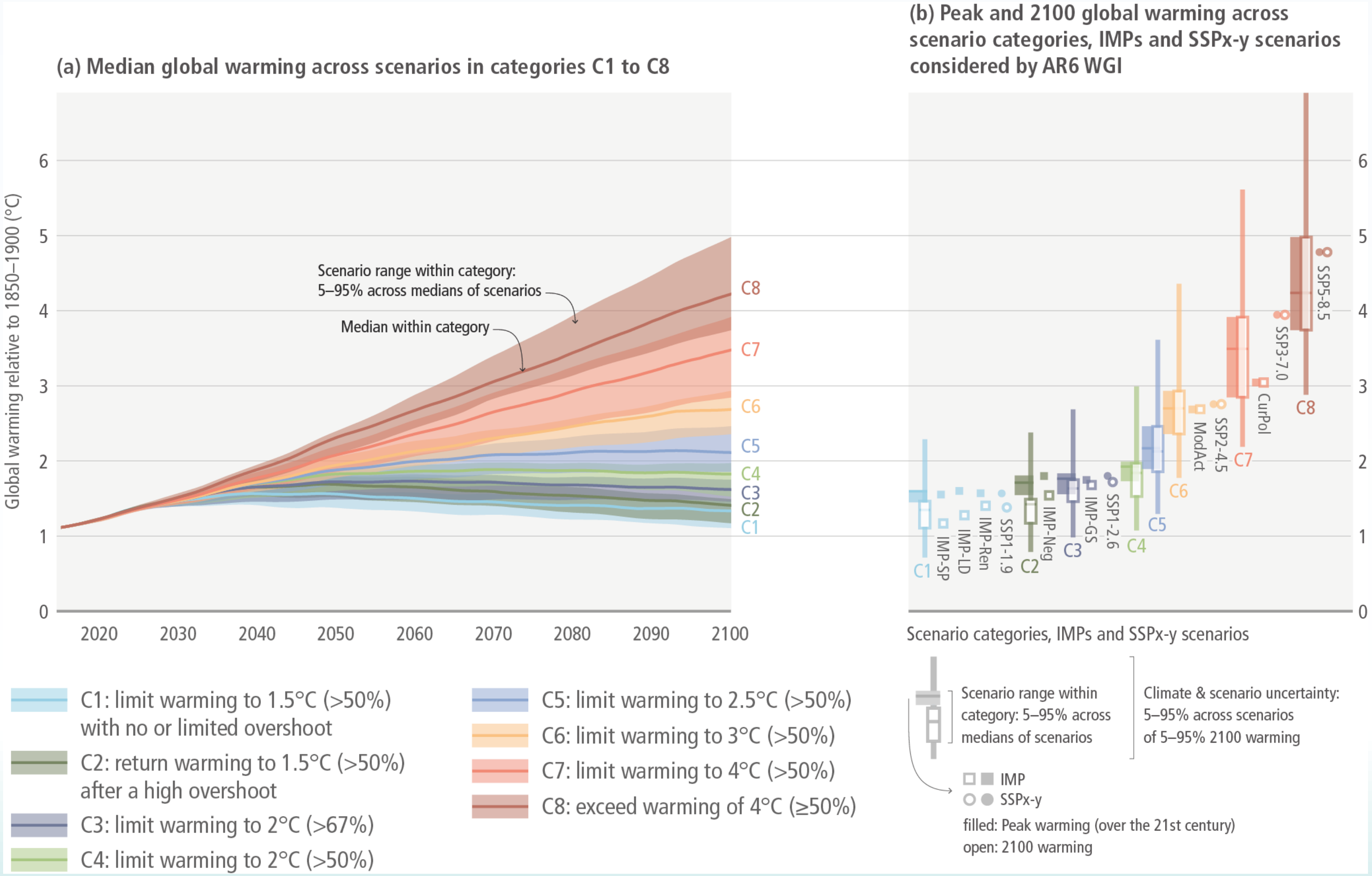




Future Challenge of Climate Change

We all know the concept.

- But to what extent?



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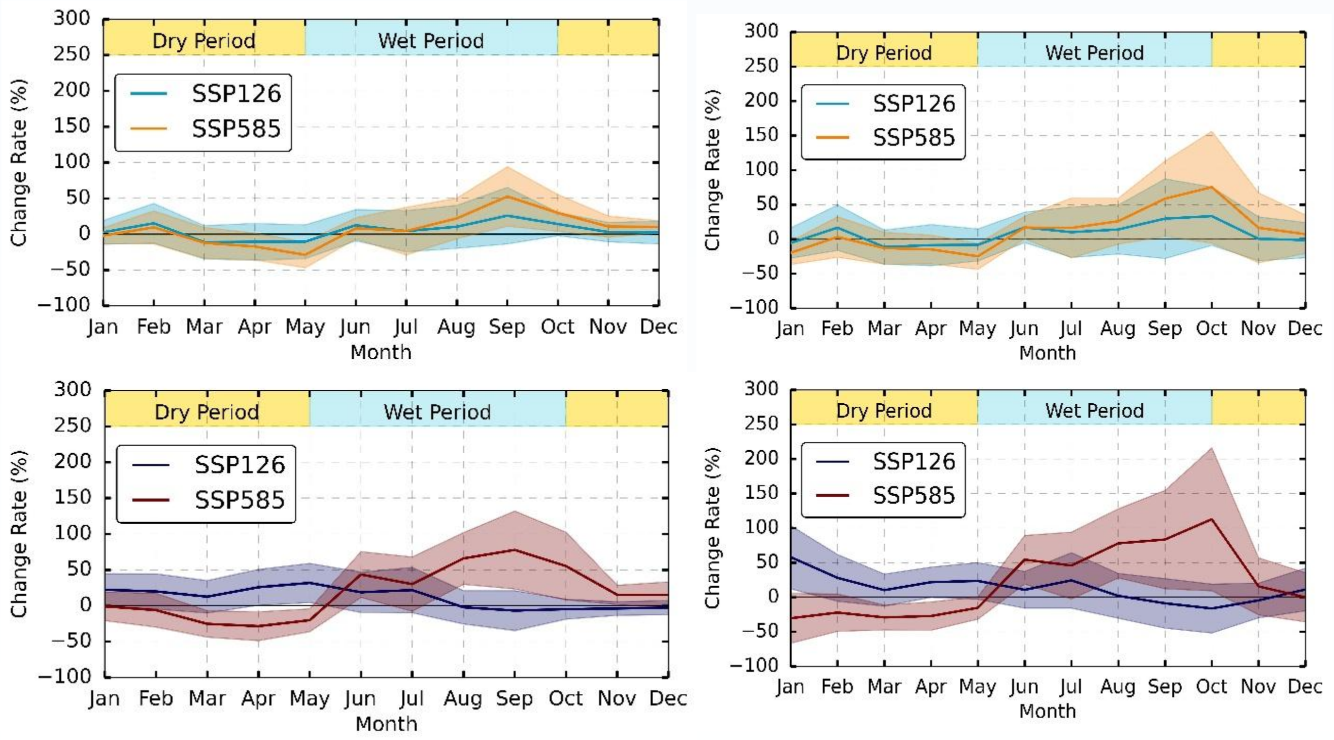
River flow changes in percetange.



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Conclusions

- Deep learning methods such as CNN, U-Net, Attention U-Net have great potential to enhance efficiency and accuracy compared to traditional methods for disaster monitoring.
- Cloud-based remote sensing allows us to monitoring various disaster globally.
- In the future, the return period of river flow may increase three-fold to ten-fold in Central Taiwan.

Questions?

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