

Time-Varying Assessment of Urban Flood Resilience considering Cascading Infrastructure Effects

Case Study of Neihu District, Taipei

Yi-Ting Cheng and Hao-Che Ho

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Cascading Effects in FRI

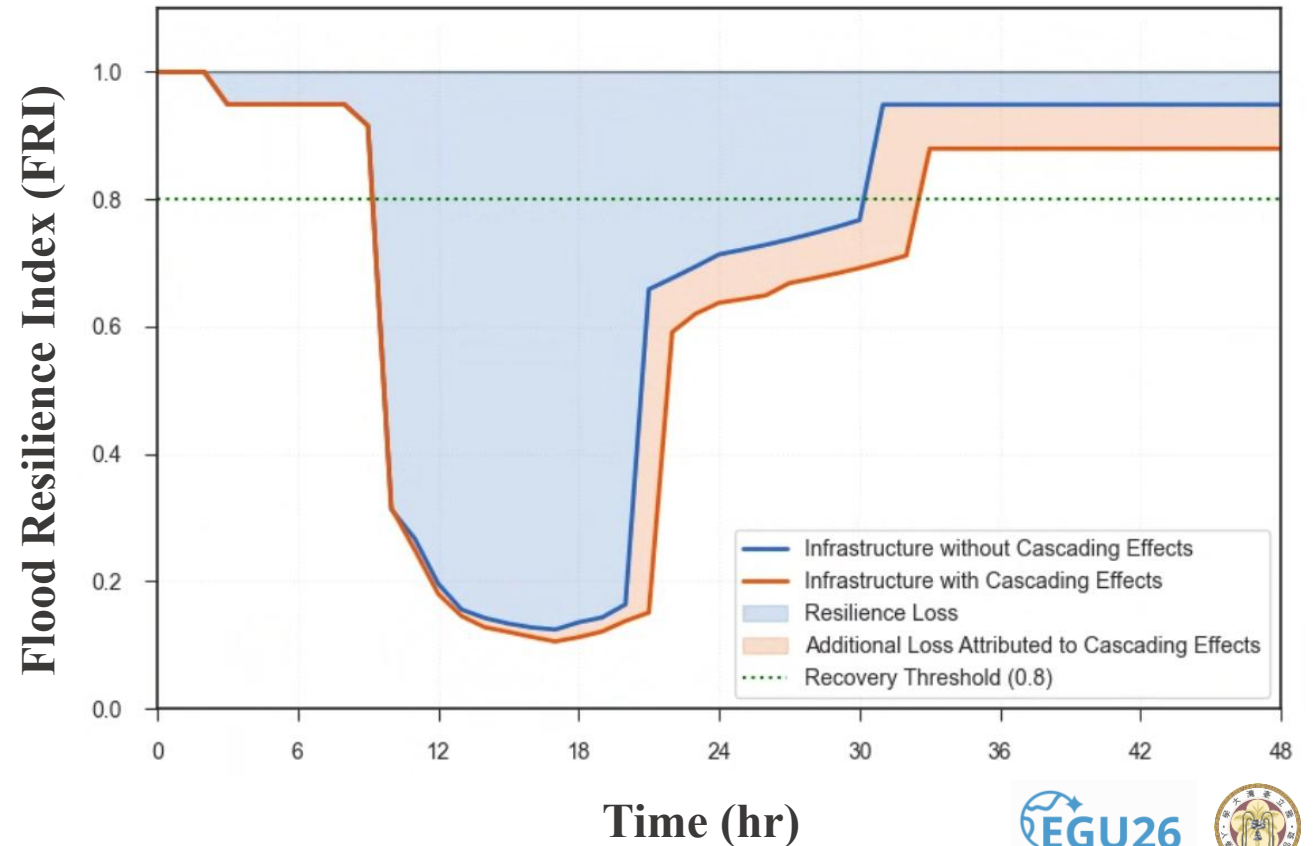
How to model cascading effects in infrastructure networks?

01 Structure Control in 3Di

02 Dependency Matrix β_{ij}

	E	C	W	T
Substation	1	0	0	0
Base Station	1	1	0	0
Pumping Station	1	1	1	0
MRT System	1	1	0	1

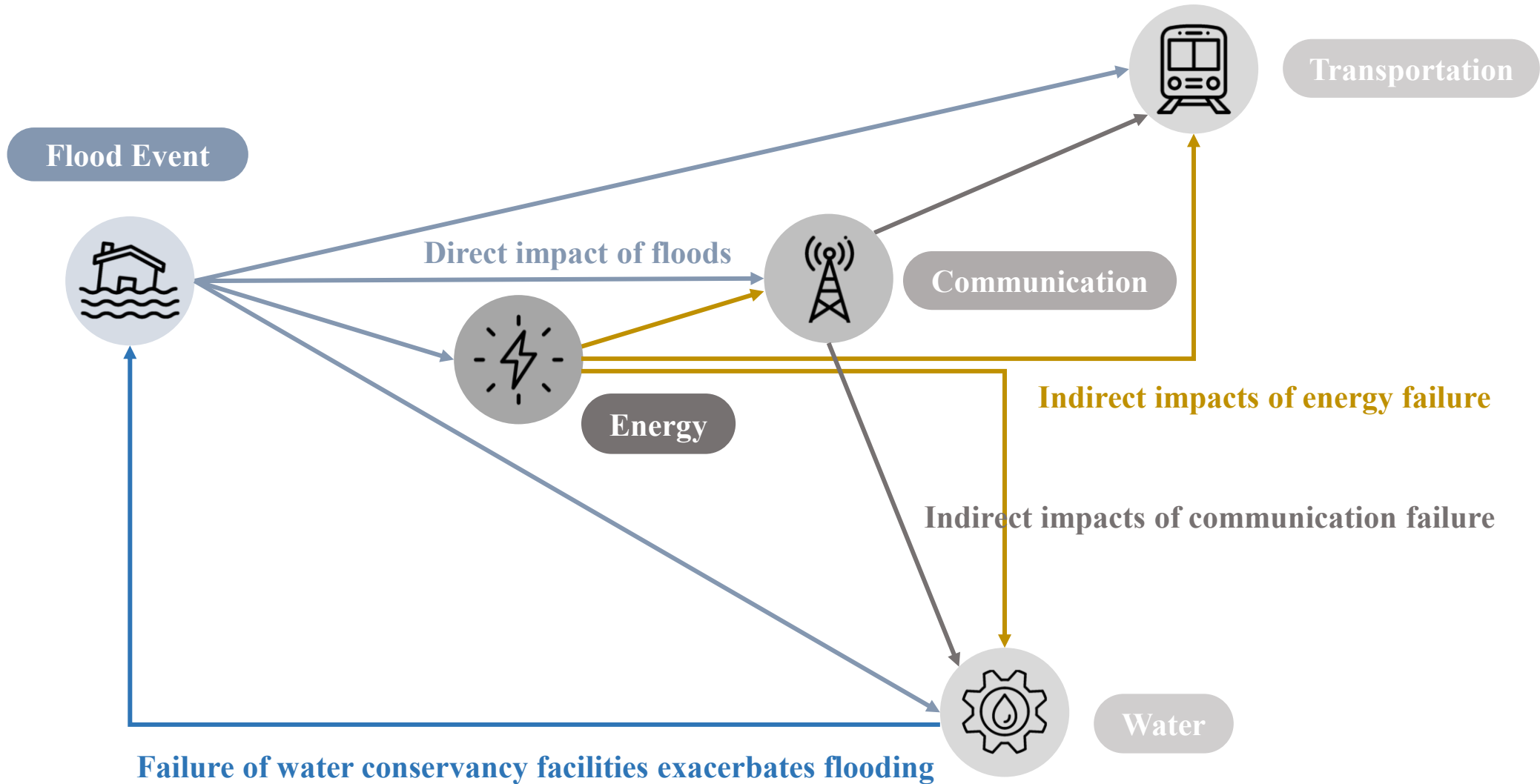
Comparing differences in flood resilience



1

Cascading Effects of CI

CI Interdependencies



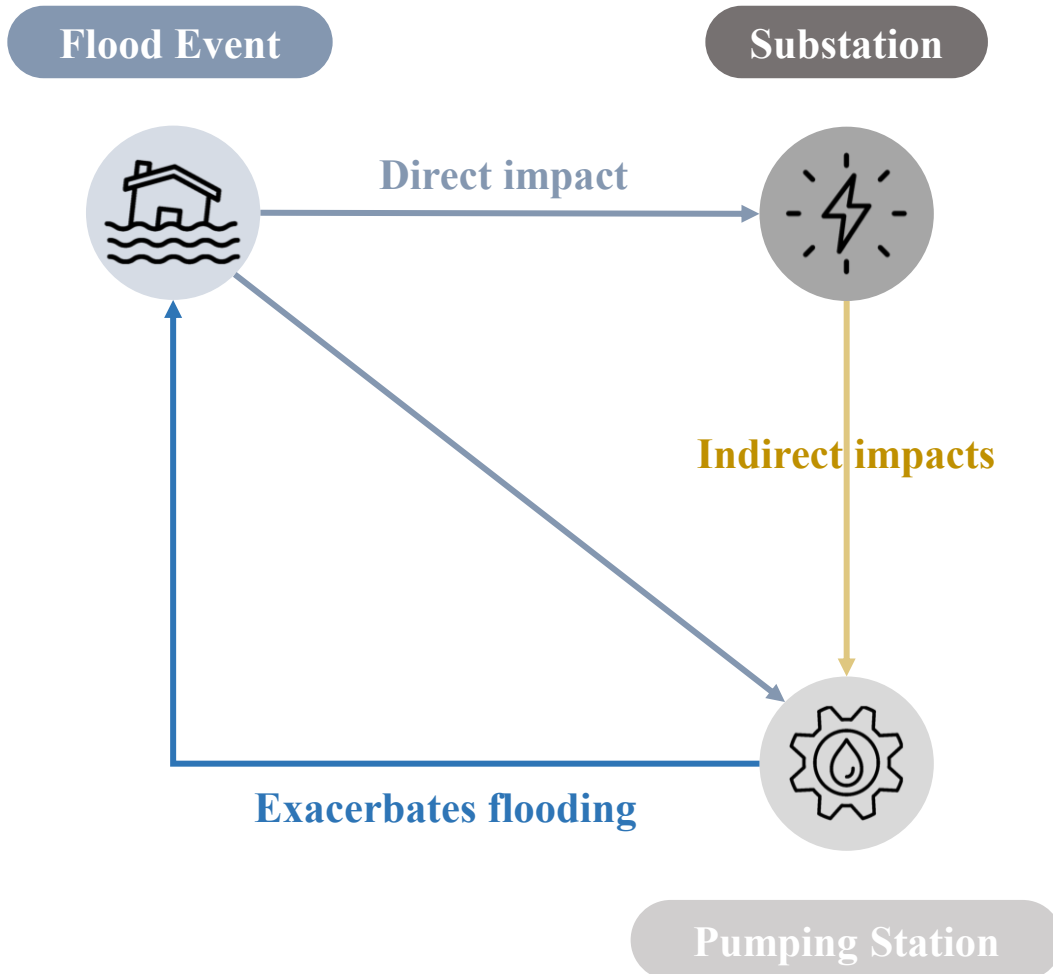
Critical Infrastructure



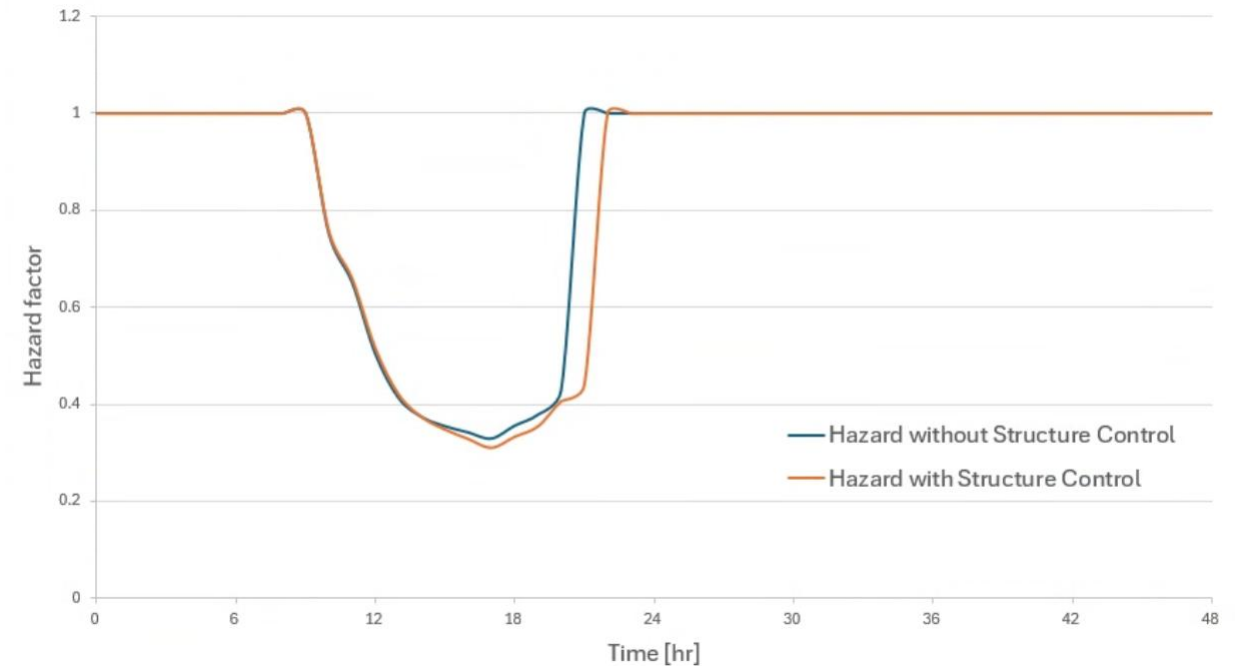
Critical Infrastructure	Energy	Communication	Water	Transportation
Representative Facilities	Substation	Base Station	Pumping Station	MRT System
Failure Thresholds	Water Depth \geq 0.3m	-	Water Depth \geq 0.5m	Water Depth \geq 0.25m



Structure Control

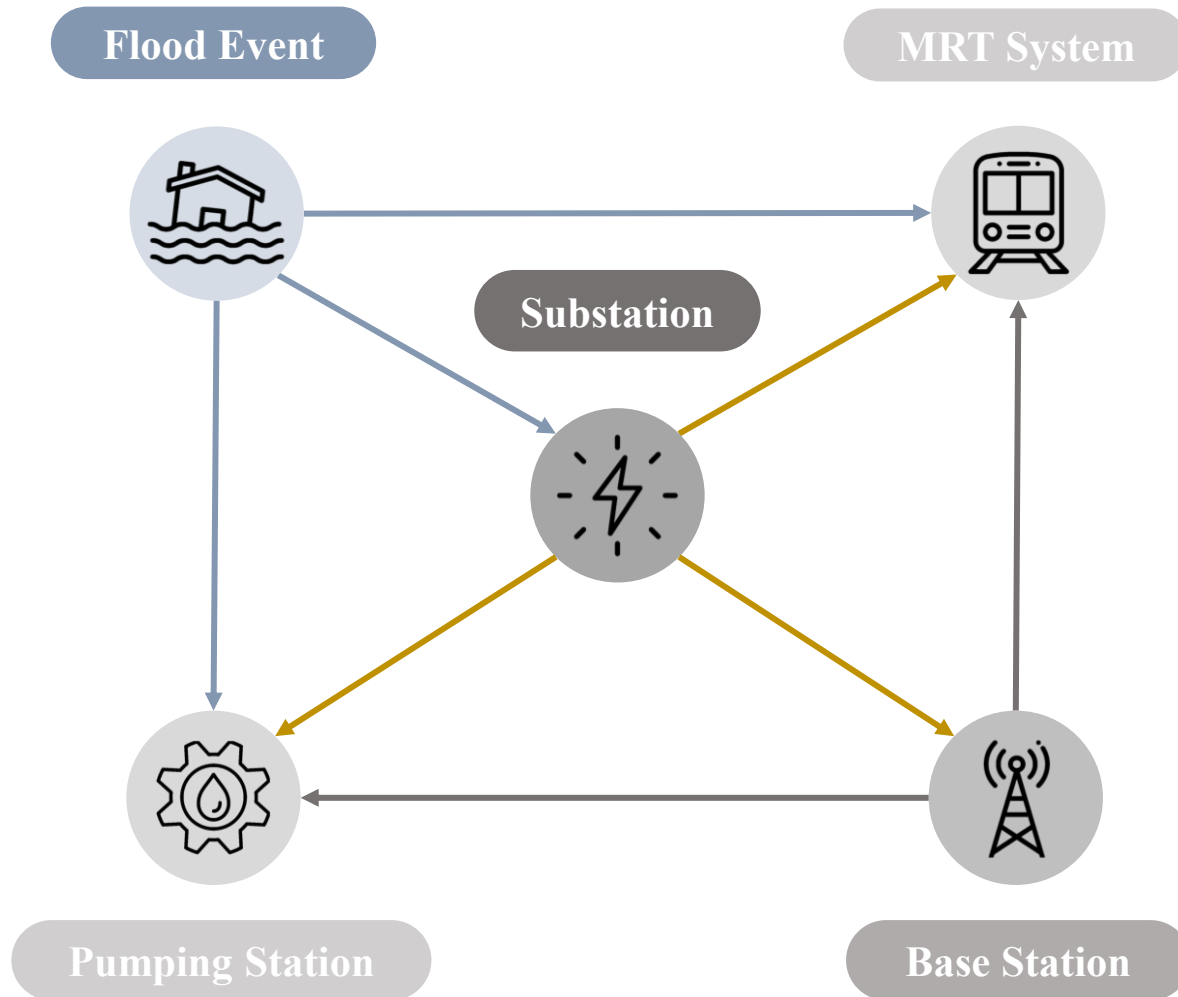


Using the **Structure Control** function in 3Di, pump stations are set to stop operating when the flood depth reaches a defined threshold.





Dependency Matrix



Using a Dependency Matrix β_{ij} to represent the interdependencies among systems.

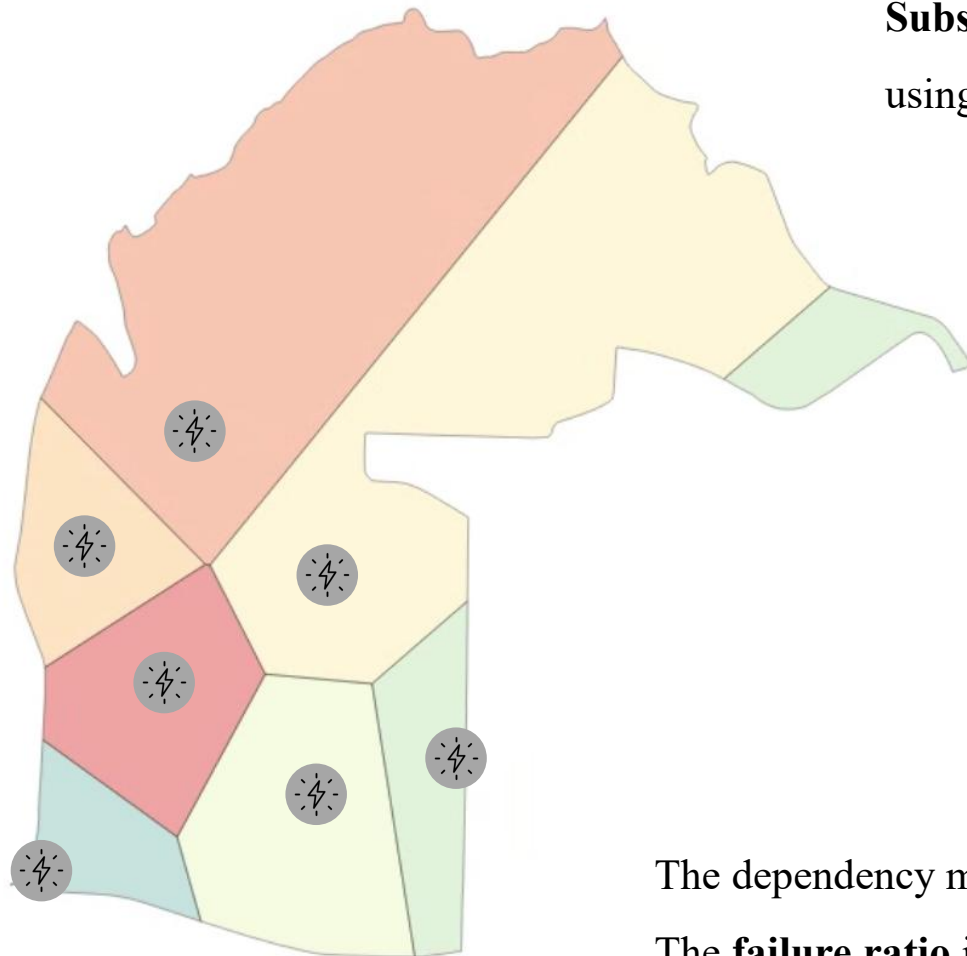
	Energy	Communication	Water	Transportation
Substation	1	0	0	0
Base Station	1	1	0	0
Pumping Station	1	1	1	0
MRT System	1	1	0	1

$\beta_{ij} = 0$: No direct dependency

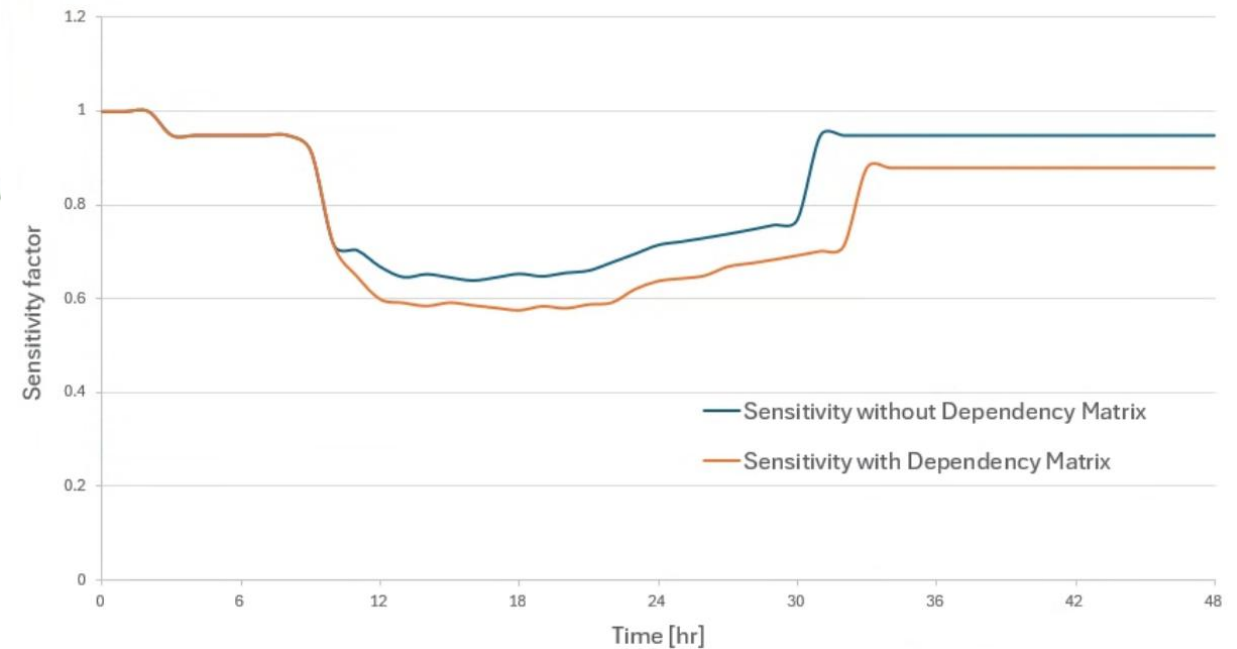
$\beta_{ij} = 1$: Dependency exists

The facility in column (j) requires the facility in row (i) to operate

Dependency Matrix



Substations act as central nodes; the study area is partitioned into sub-zones using **Voronoi Polygons**.



The dependency matrix calculates the number of **infrastructure failures** in each sub-zone. The **failure ratio** is then aggregated and used as the **Sensitivity factor** for the FRI.

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Flood Resilience Index



Three Components of Flood Resilience Index

→ Integrates socioeconomic factors

Population density

Business density

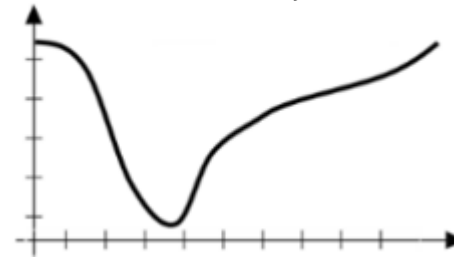
Infrastructure exposure

Flood depth

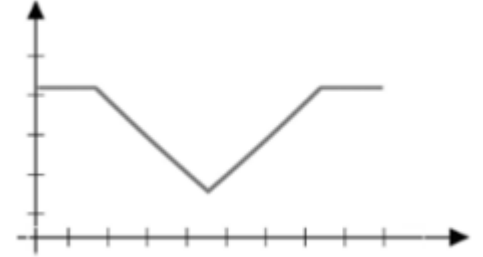
Flood area

Flood duration

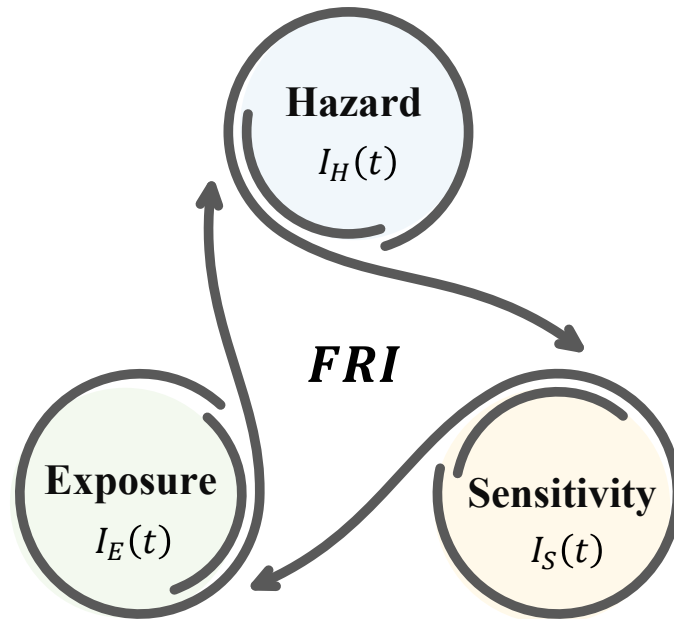
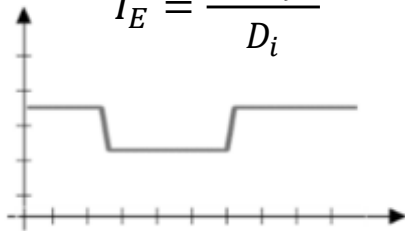
$$I_H = \frac{D_I(t)}{D_{ref}}$$



$$I_S = e^{\left(1 - \frac{D_i}{D_{ref}}\right)t}$$



$$I_E = \frac{D_{ref}}{D_i}$$



Local government disaster prevention budget

Household income

Business capital

Infrastructure failure ratio



Time-Varying Flood Resilience Index

Hazard

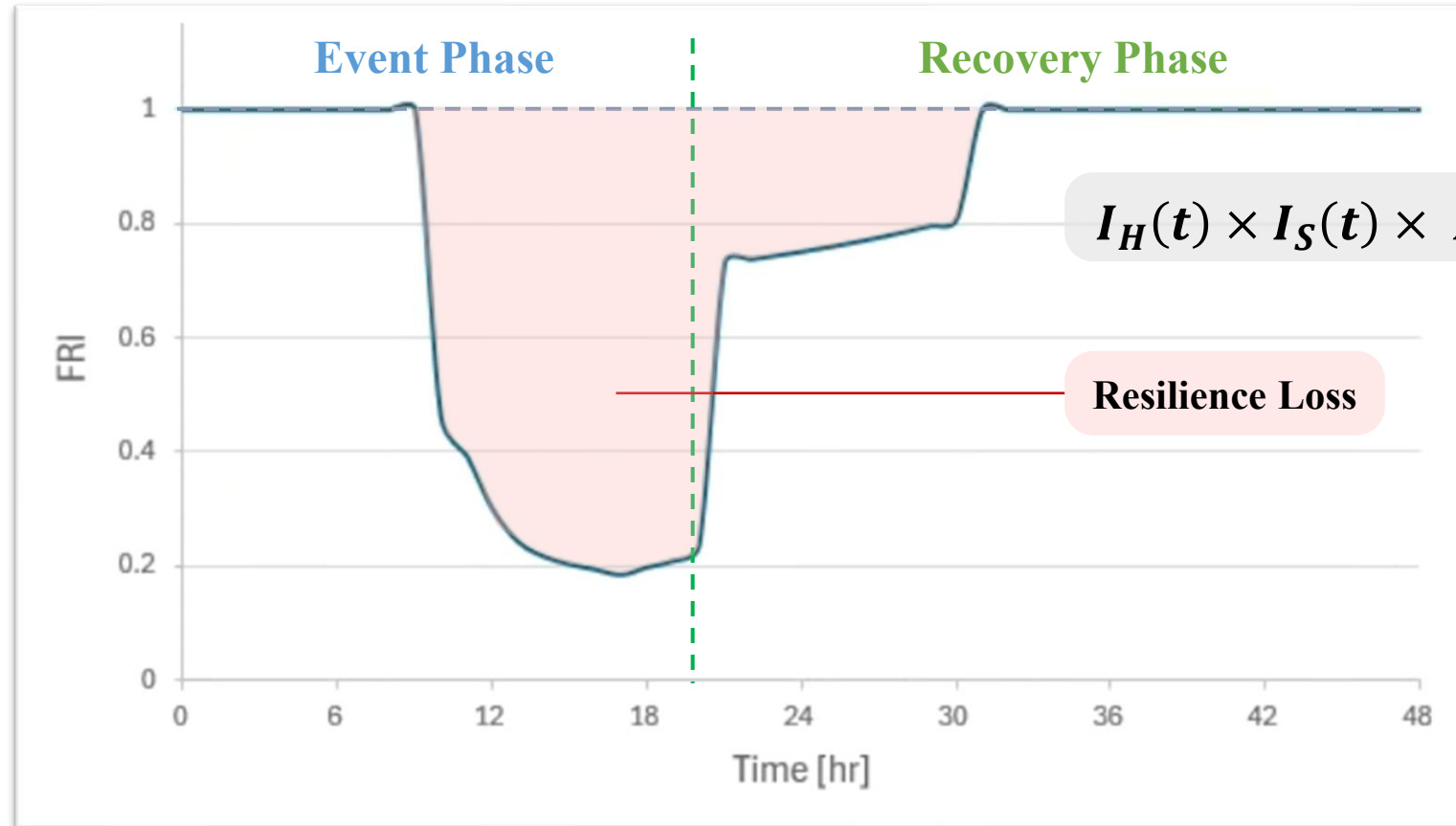
$I_H(t)$

Exposure

$I_E(t)$

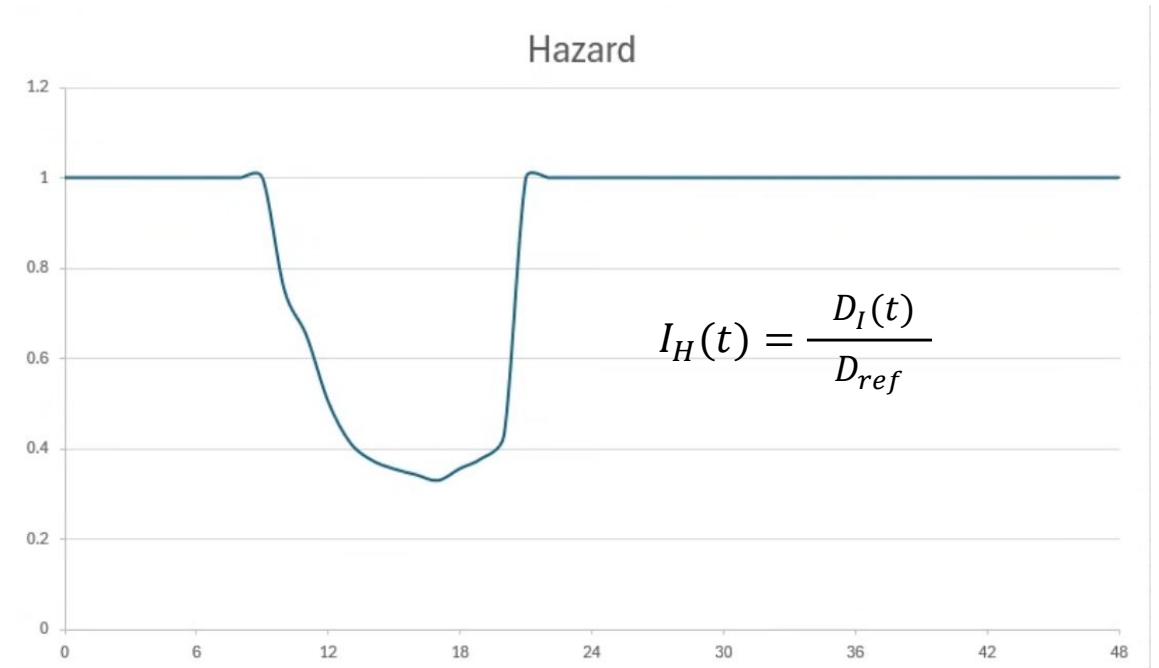
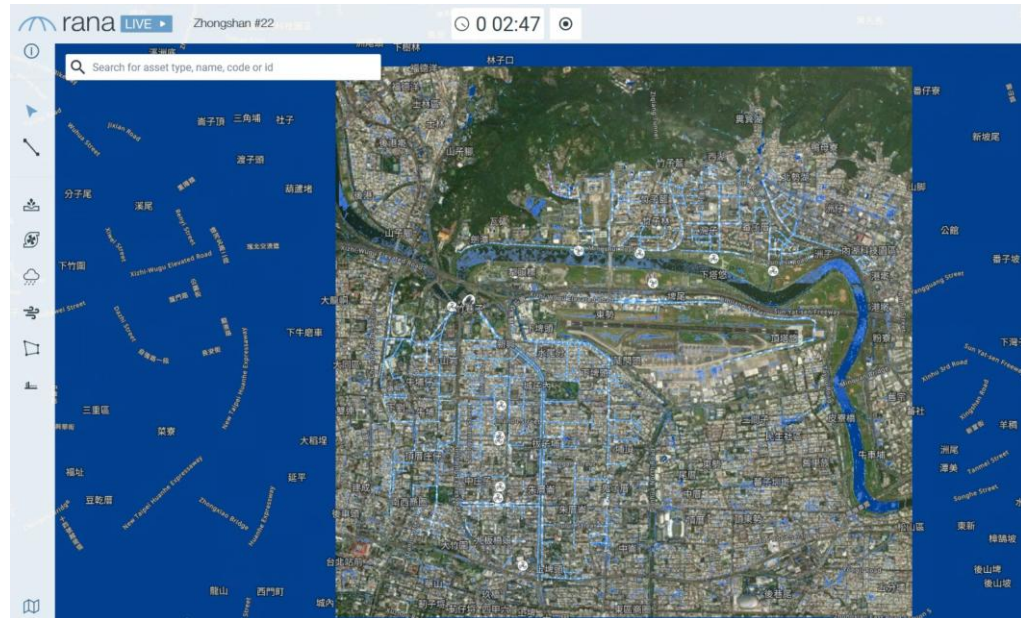
Sensitivity

$I_S(t)$





Flood Resilience Index - Hazard



Derived from 3Di flood simulations →

Reference values →

Flood depth	Flood area	Flood duration
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0.5 m

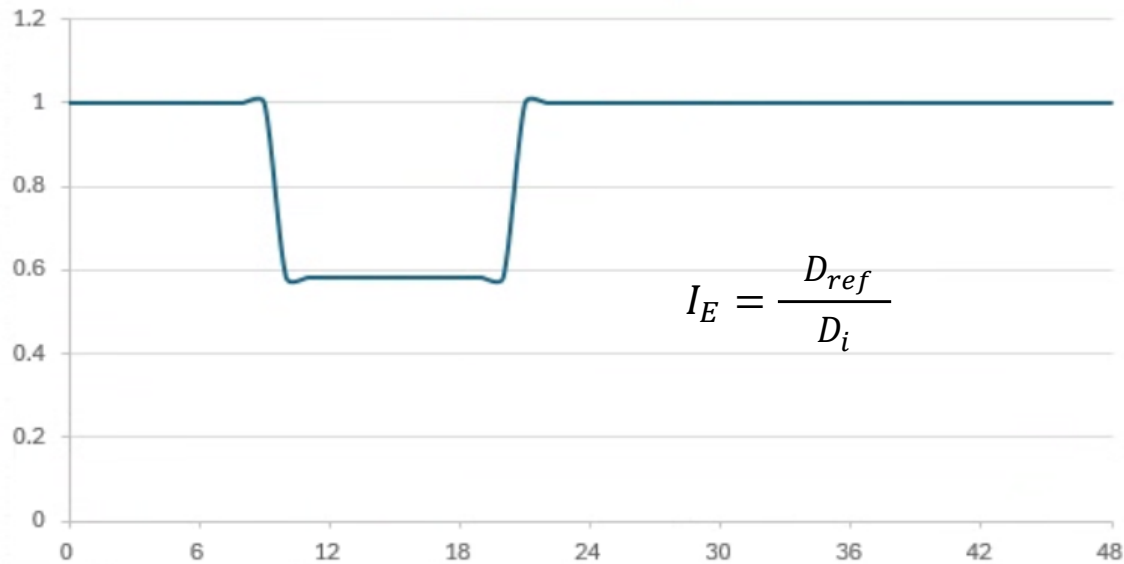
10 %

8 hr

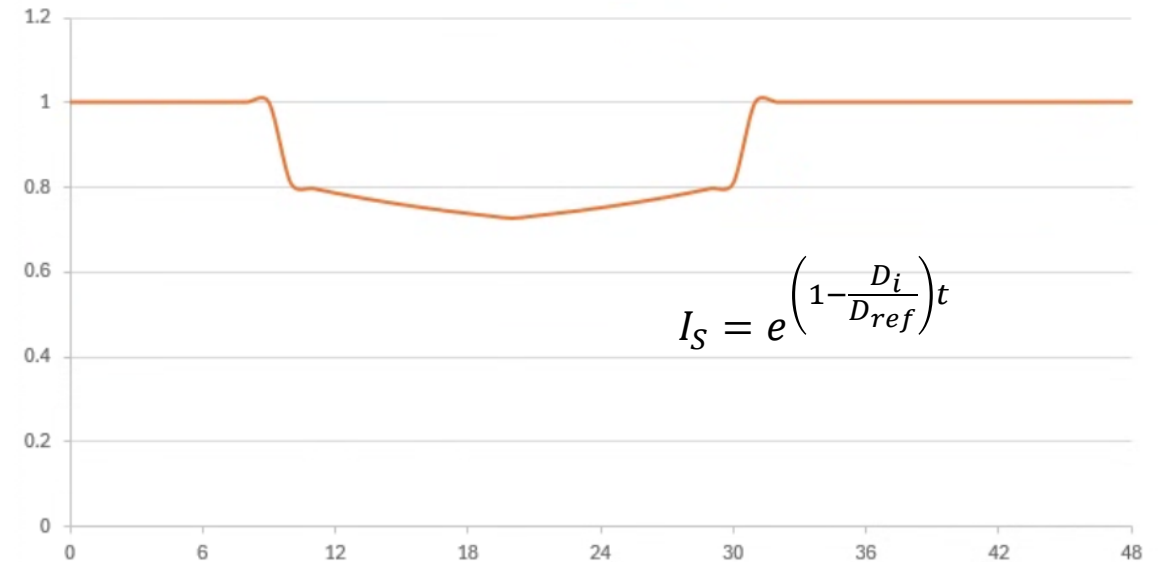


Flood Resilience Index – Exposure & Sensitivity

Exposure



Sensitivity



Population density

Business density

Infrastructure exposure

Household income

Business capital

Infrastructure failure ratio

Local government disaster prevention budget

The reference values for **exposure** are defined as **the first quartile** of Taipei City, while those for **sensitivity** are set as **the third quartile** of Taipei City.

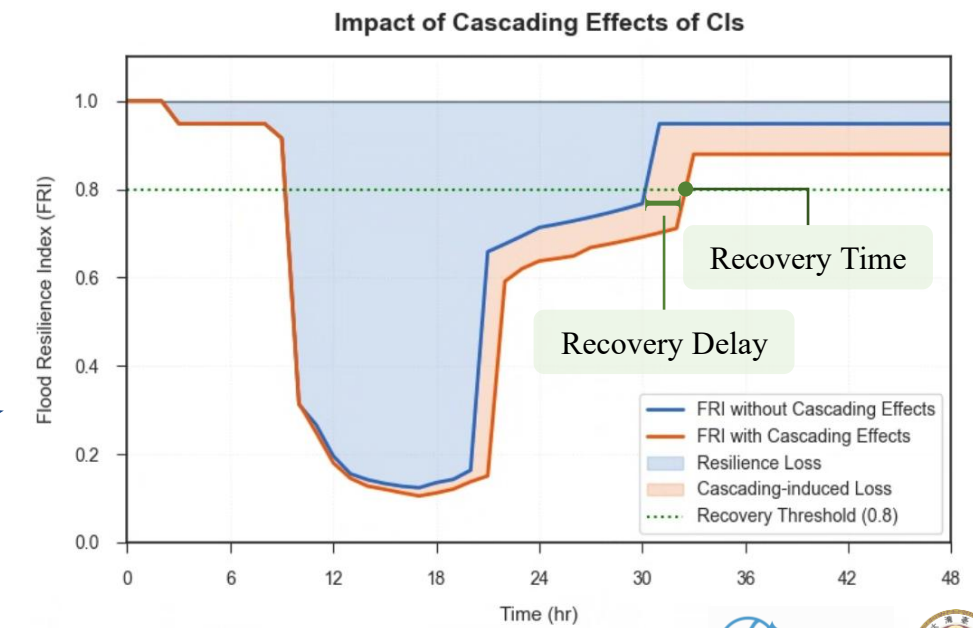
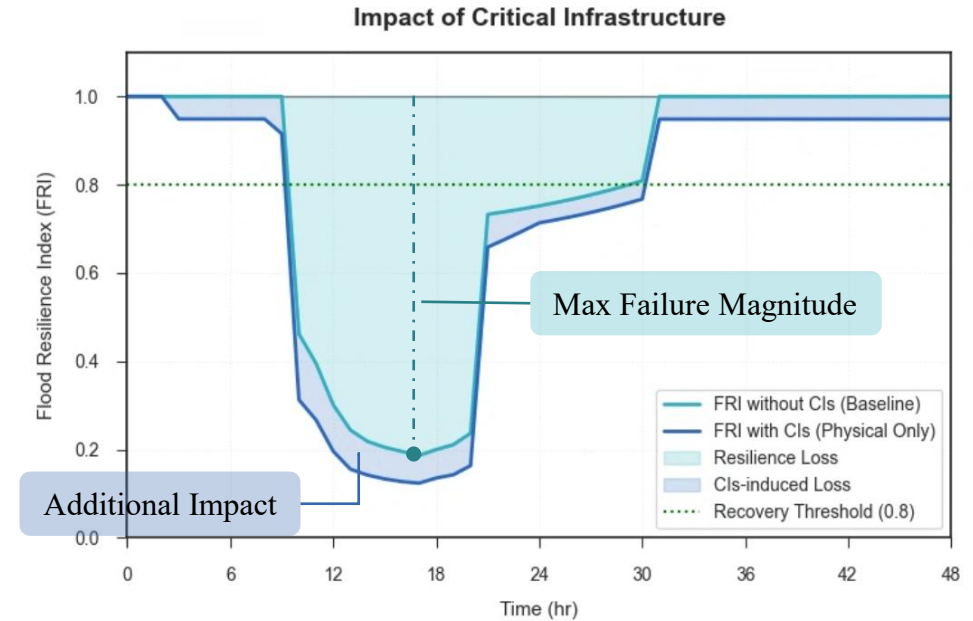
3

Results & Conclusions

Results

	Baseline (Without CIs)	FRI with CIs (Without Cascading)	FRI with CIs (With Cascading)
Resilience Loss	10.478	13.197	16.114
Max Failure Magnitude	0.813	0.876	0.895
Recovery Time (hr)	30	31	33

Compared to scenarios without cascading effects, cascading effects among critical infrastructures increased resilience loss by 22.1% and delayed recovery by 2 hrs.



Conclusions



01

Incorporating cascading effects in resilience assessment preventing the underestimation of risks.

02

The time-varying FRI captures the exact timing of cascading failures and recovery delays.

03

Identifying critical nodes enables targeted protection and smarter urban disaster strategies .