南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Mitigating the Increasing Risks of Urban Flooding in Central Shanghai: Options and Analysis

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SCCRC 上海市气候变化研究中心 | SOAS University of London | RAND CORPORATION | Met Office Hadley Centre | Deltares | TU Delft | Shanghai Normal University | East China Normal University

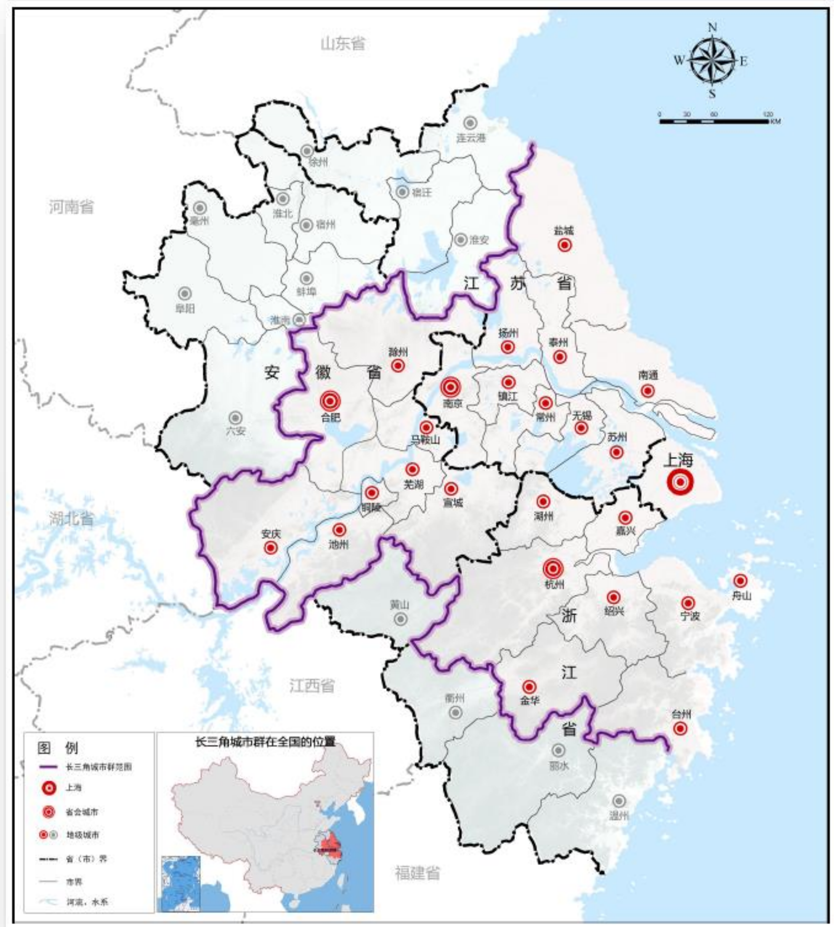
Outline

Shanghai Flood Backgroud

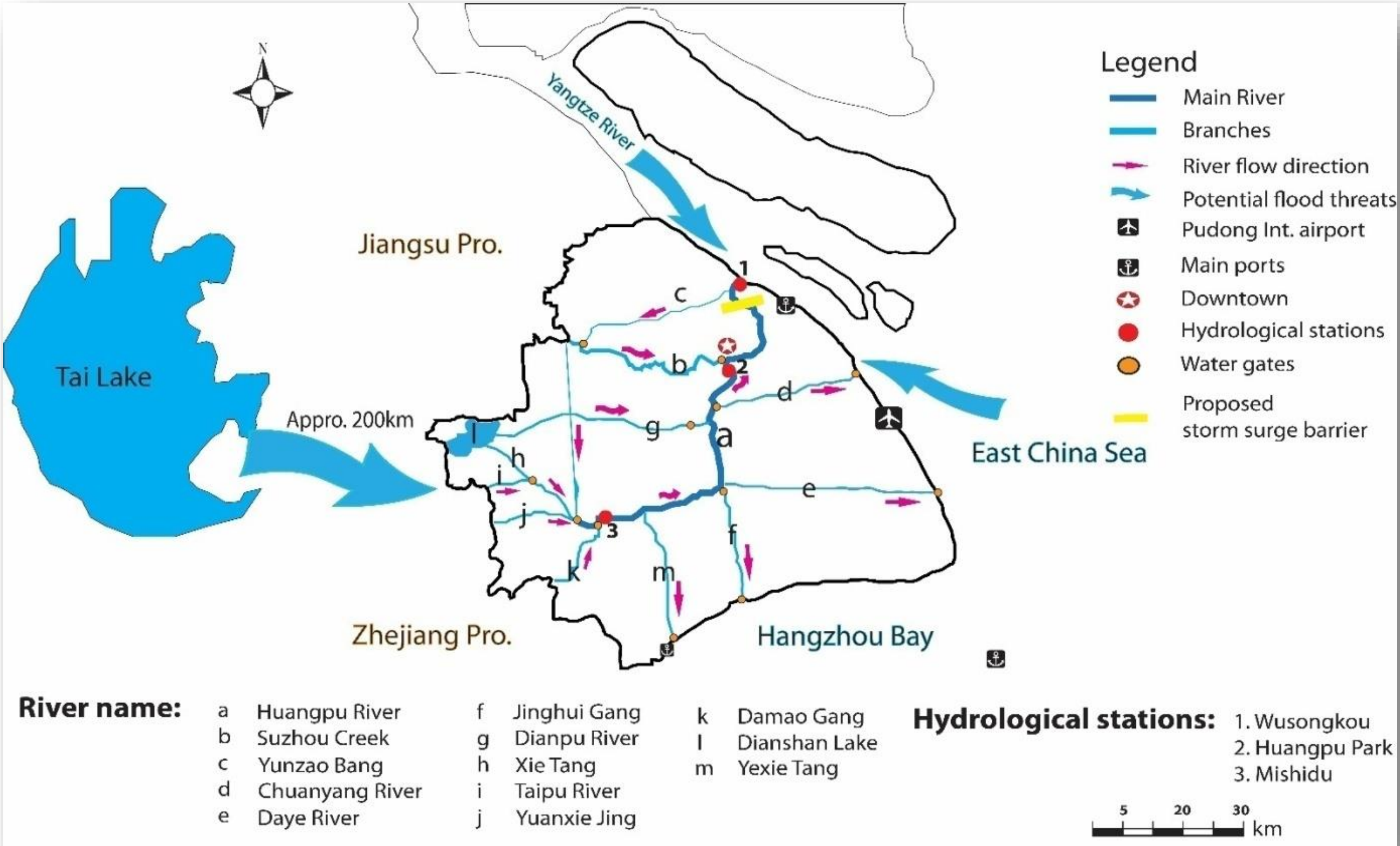
Shanghai Flood Risk Assessment

Trade-off Analysis of Flood Control Solution

Location of Shanghai

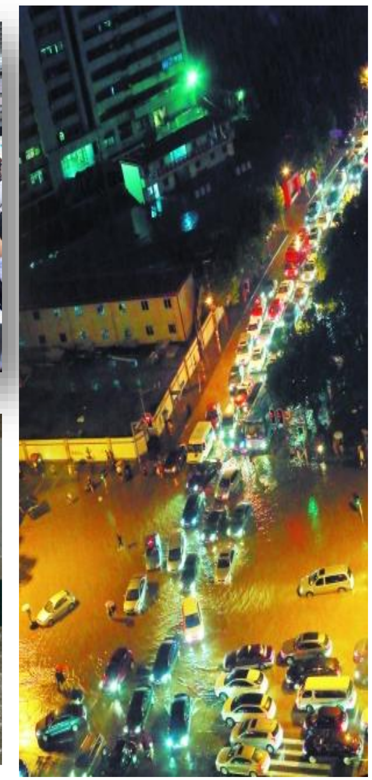


Flood Threats in Shanghai



Shanghai - A Flood Hazardous City

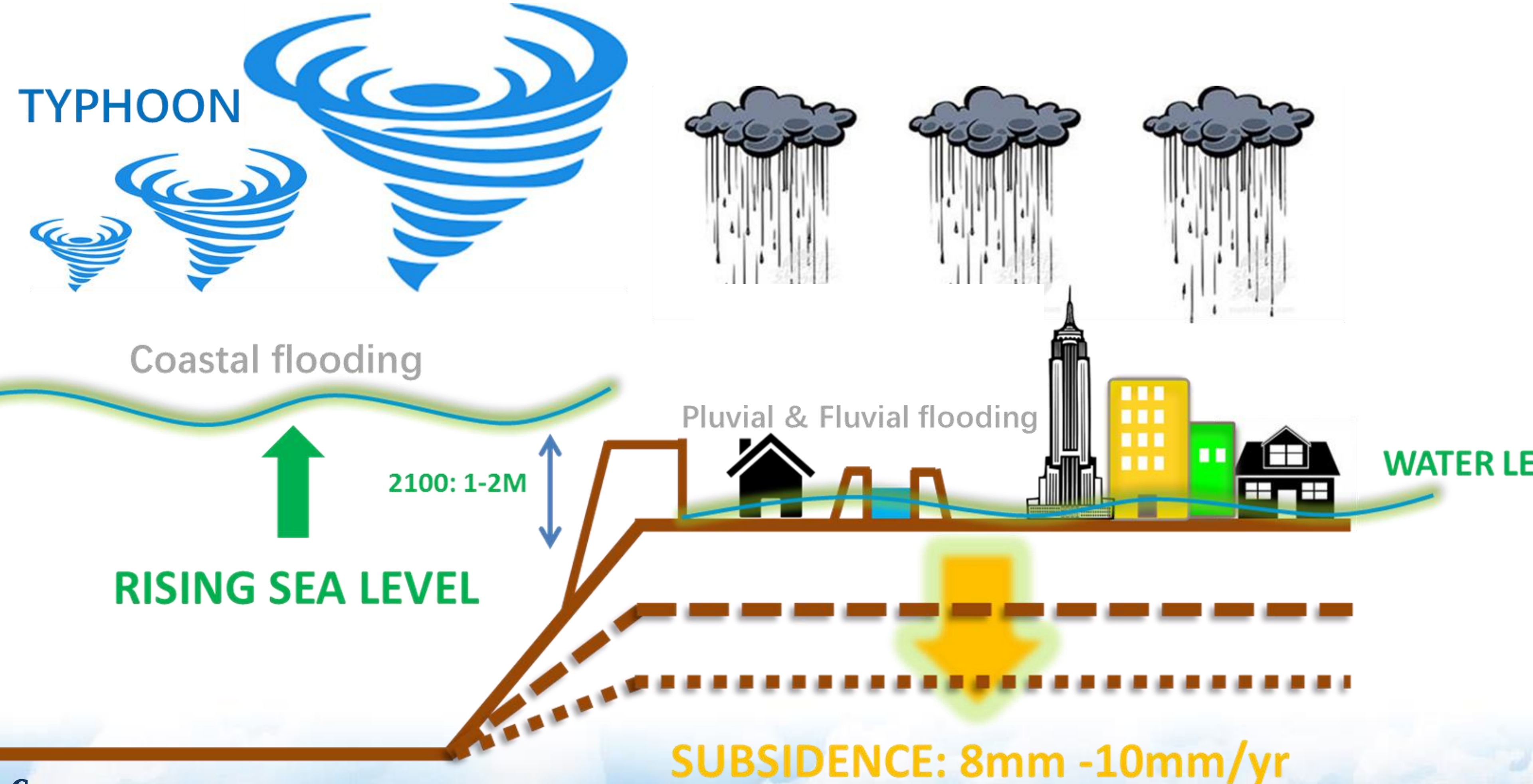
Rainstorm in 2013



Upstream flooding in 1991

Shanghai Compound Flood Risks

Extreme Rainstorms, Astronomical High Tides, Storm Surge, and Upstream Floods



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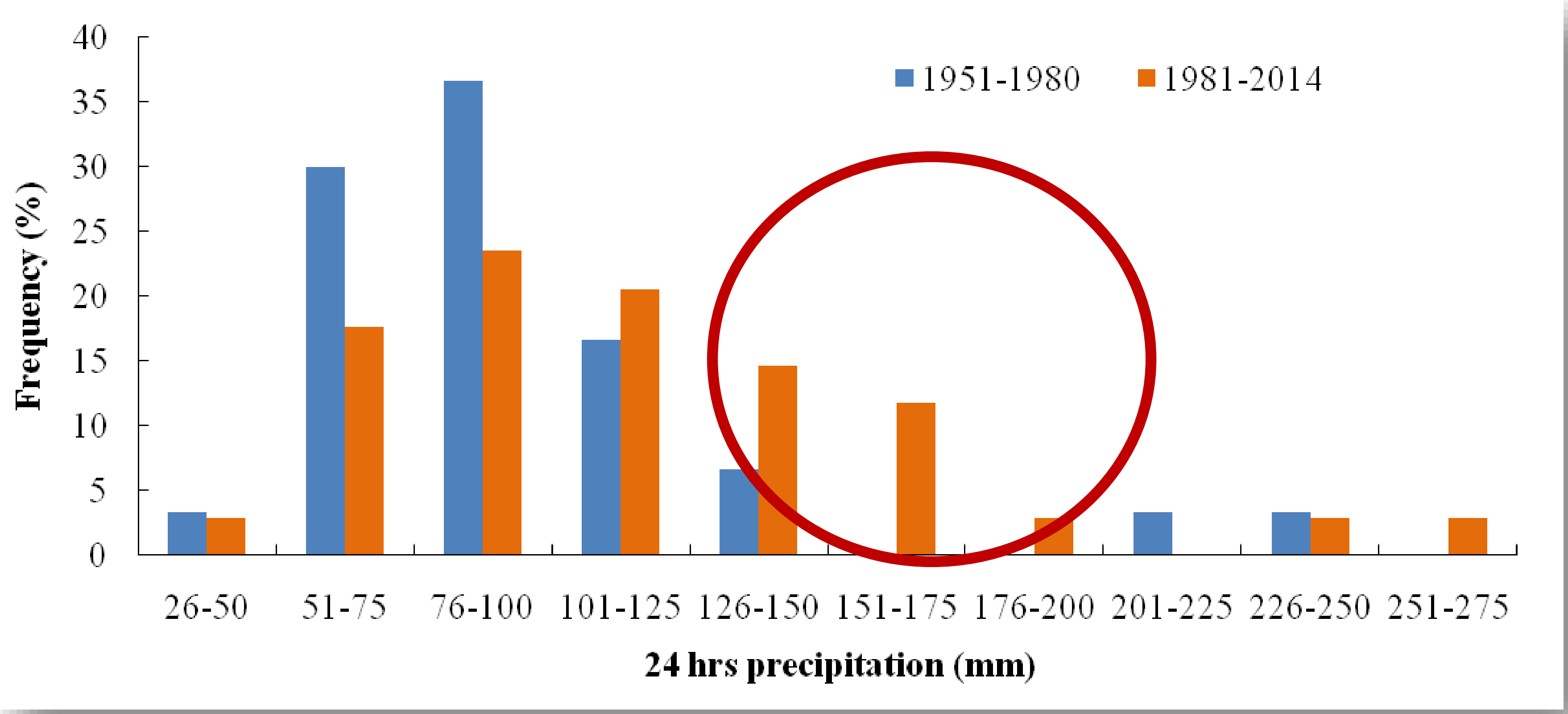
Increasing Trend of Precipitation

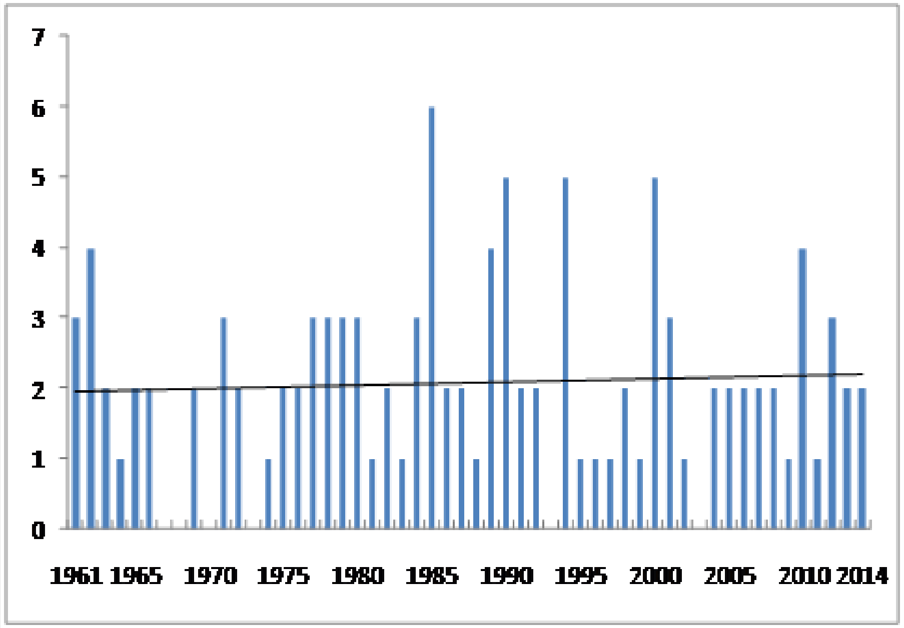
The changes of frequency of 24-hour precipitation at Xujiahui station



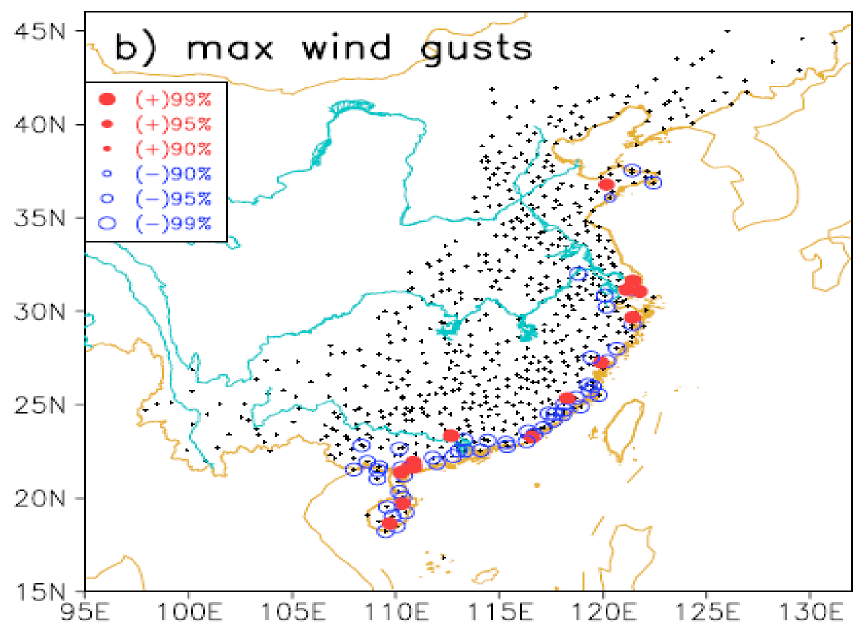
The frequency in the range of more than 100mm/24hr heavy rain has dramatically increased in recent 30 years.

Slightly Increased in the Numbers of Landing Typhoon

There was no significant change in the number of typhoons in Shanghai

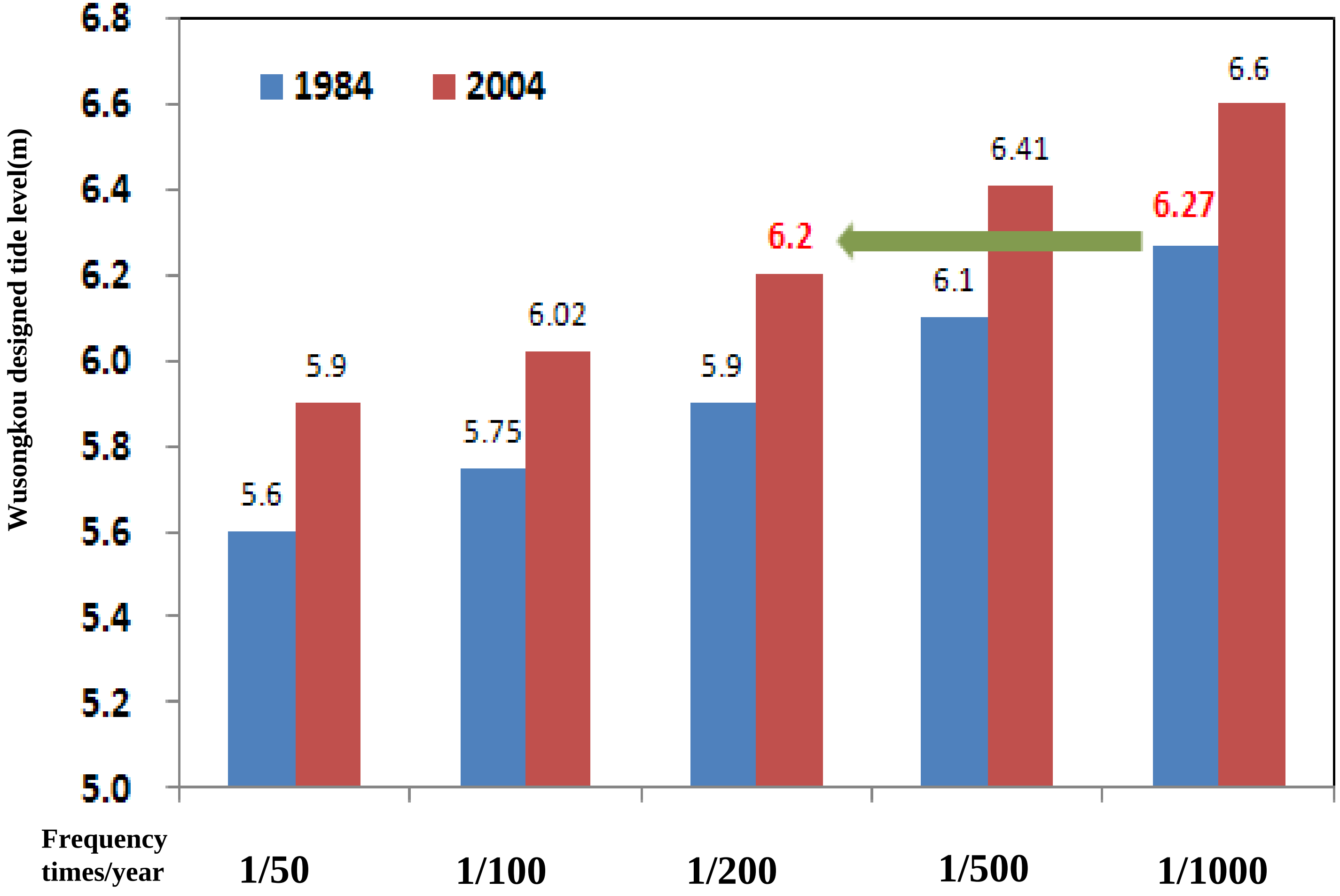


Reference: Shanghai Climate Change Monitoring Bulletin,2015



Reference: Assessment Report on Impacts of Climate Change on Tropical Cyclone Frequency and Intensity in the Typhoon Committee Region,2012

The Local Designed Standards for High Tide Standards has getting lower under climate change



Comparison of design climaxes between 1984 and 2004 in Wusongkou station

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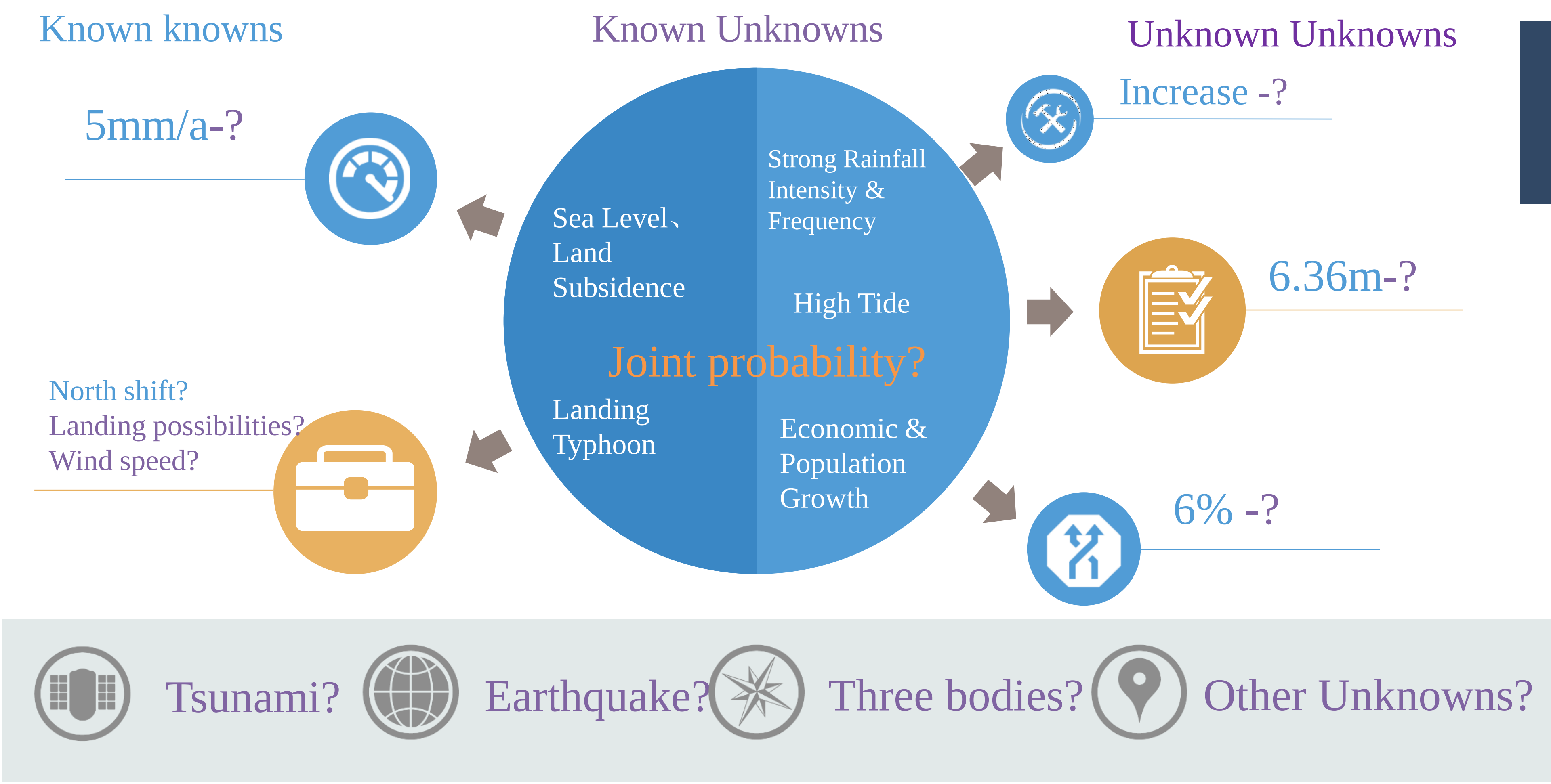
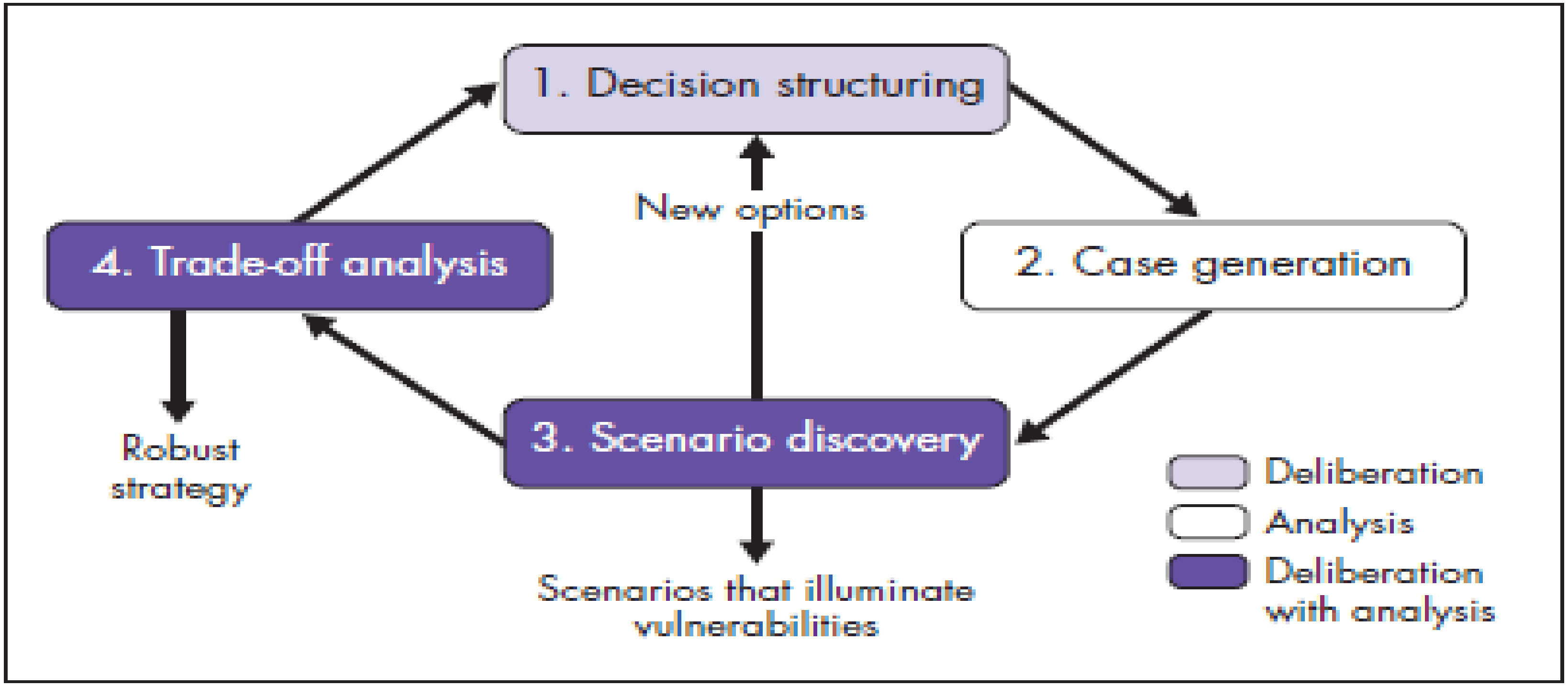
Deep Uncertainties in Shanghai



Robust Decision Making: Good Decisions under Divided Predictions & Opinions

Run the Analysis “Backwards”

Proposed strategy → Identify vulnerabilities of this strategy → Develop strategy adaptations to reduce vulnerabilities

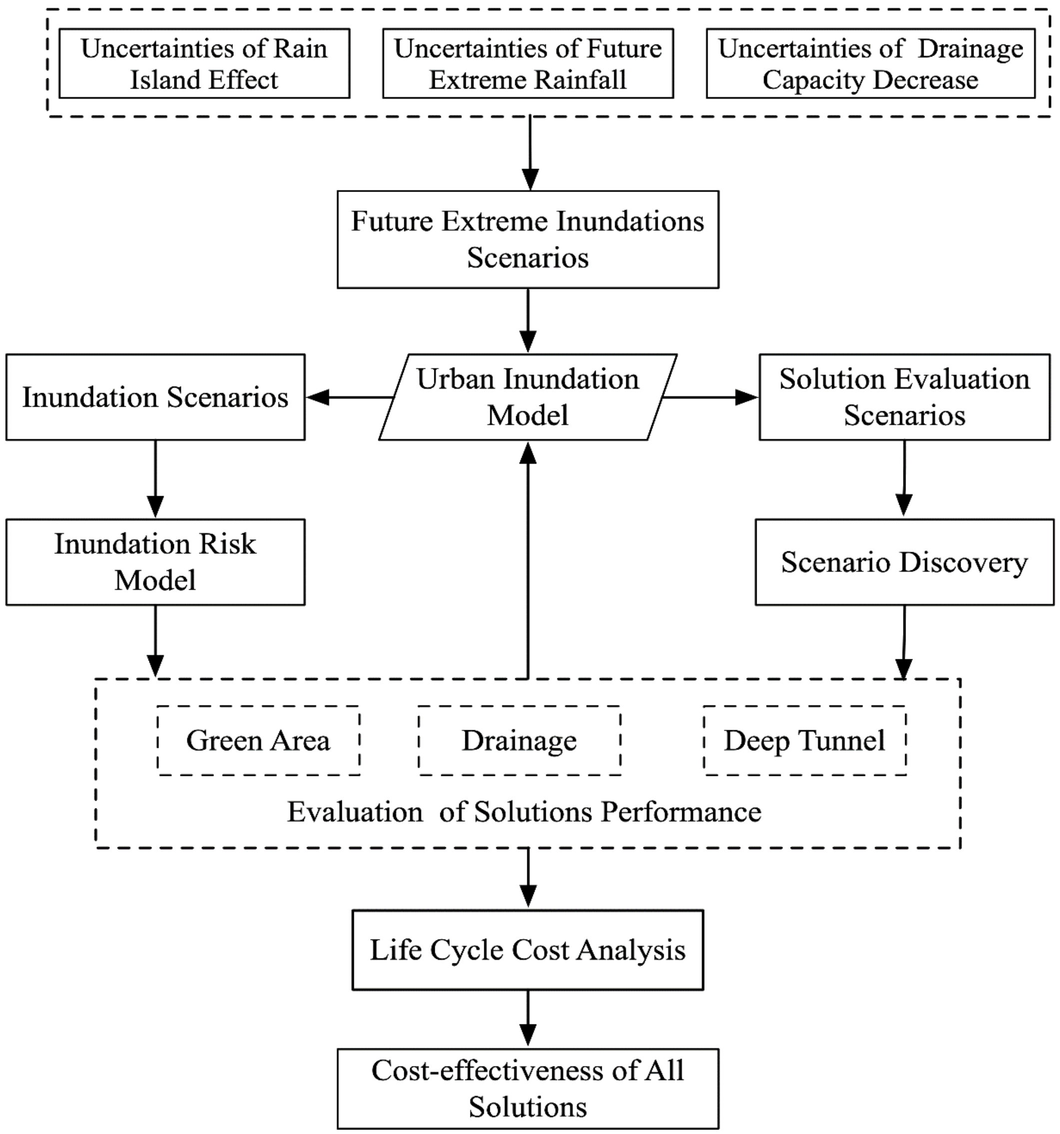


The XLRM Metric of Robust Decision Making Theory

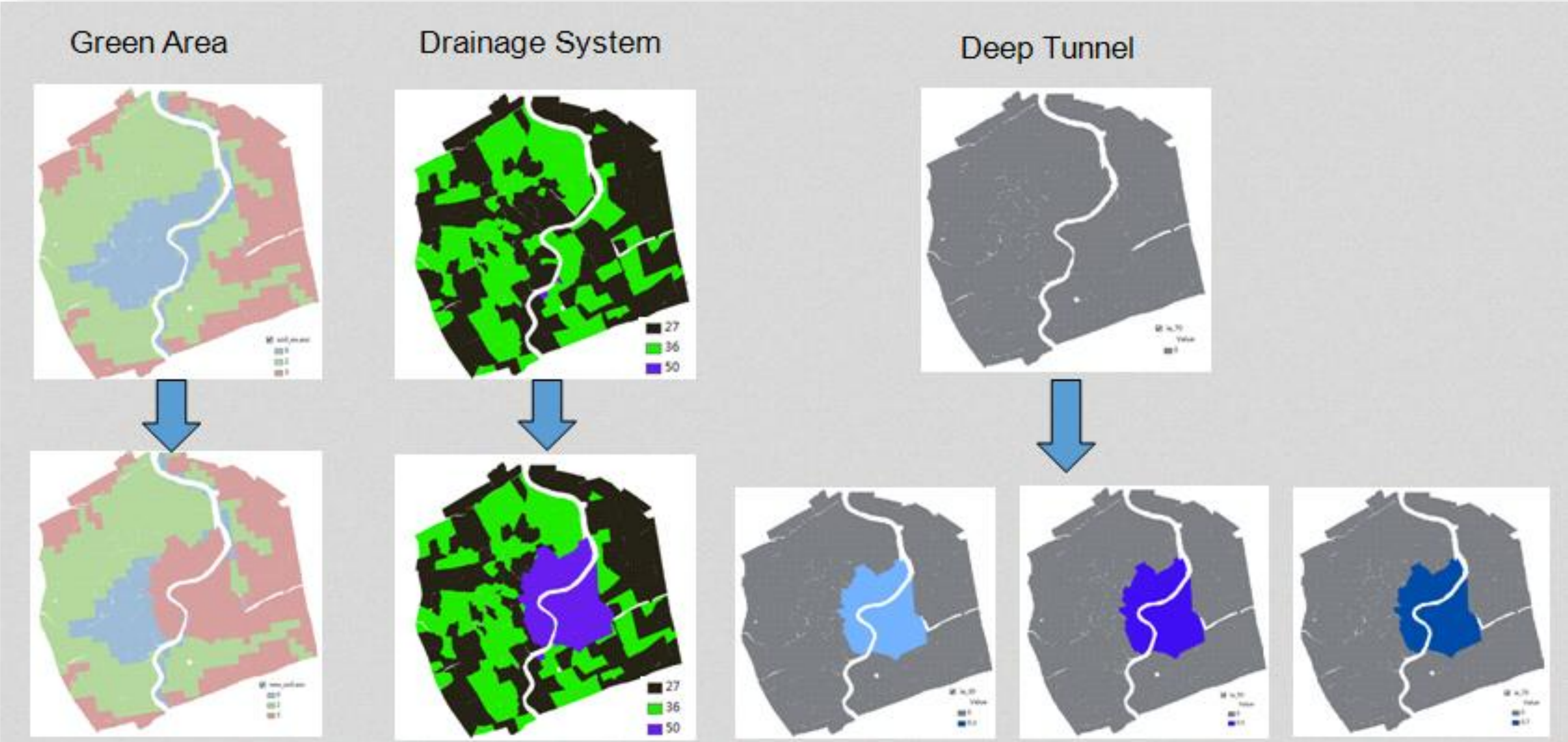
Exogenous Factors and Uncertainties (X)	Levers under Control (L)
Hazard - sea level rise - precipitation pattern (amount & spatial distribution) - future typhoon landfalls and associated storm surges - upstream flooding - high tide ***Urbanization*** - future population - critical infrastructure - future land use pattern ***Social economy*** - future scope and scale of the economy - change of industrial structure - commercial & business chain	***Baseline*** ***Non-structural adaptation strategy*** - relocate residents - flooding insurance subsidy - business zoning ***Structural adaptation strategy*** - retrofit seawall and embankment - construction of estuary tidal sluice - change building codes - improve drainage system standard - increase of green area - construction of deep tunnel
Relationships (R)	**Measures of Outcomes (M)**
- Global and Regional Climate Model(RCM & GCM) - Compound flood model (surge model & river model) - Future sea level prediction - Population prediction model - Economy prediction model - Risk model (direct loss) - Input/output model (indirect loss)	- Flood risk mitigation, measured by % reduction of total loss - Cost efficiency, measured by the amount of net benefit

Coupling flood model, risk model and evaluation model in many plausible scenarios: flow chart.

- The first major step of the process is to quantify three uncertain factors
- The second major step is to simulate the inundation depths and areas for both the baseline event and each of scenario using the Shanghai Urban Inundation Model.
- The third major step is to specify various mitigation measures and to evaluate the risk-mitigation performance of these measures
- The fourth major step includes the calculations of economic costs of various mitigation measures and then the comparative analysis of cost-effectiveness of all specified mitigation measures.



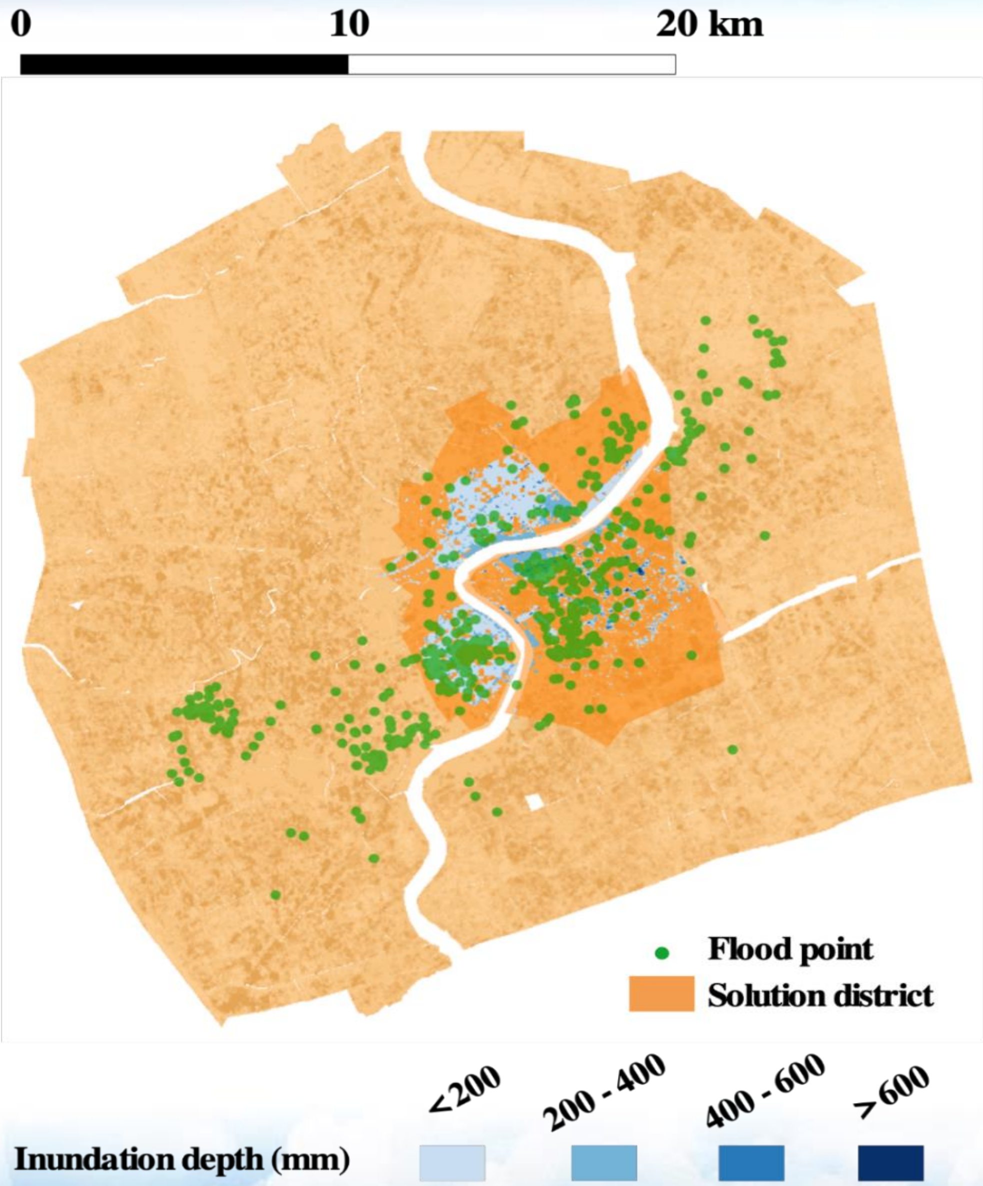
Study on Future Extreme Inundation Based on Future Rainstorm Scenarios



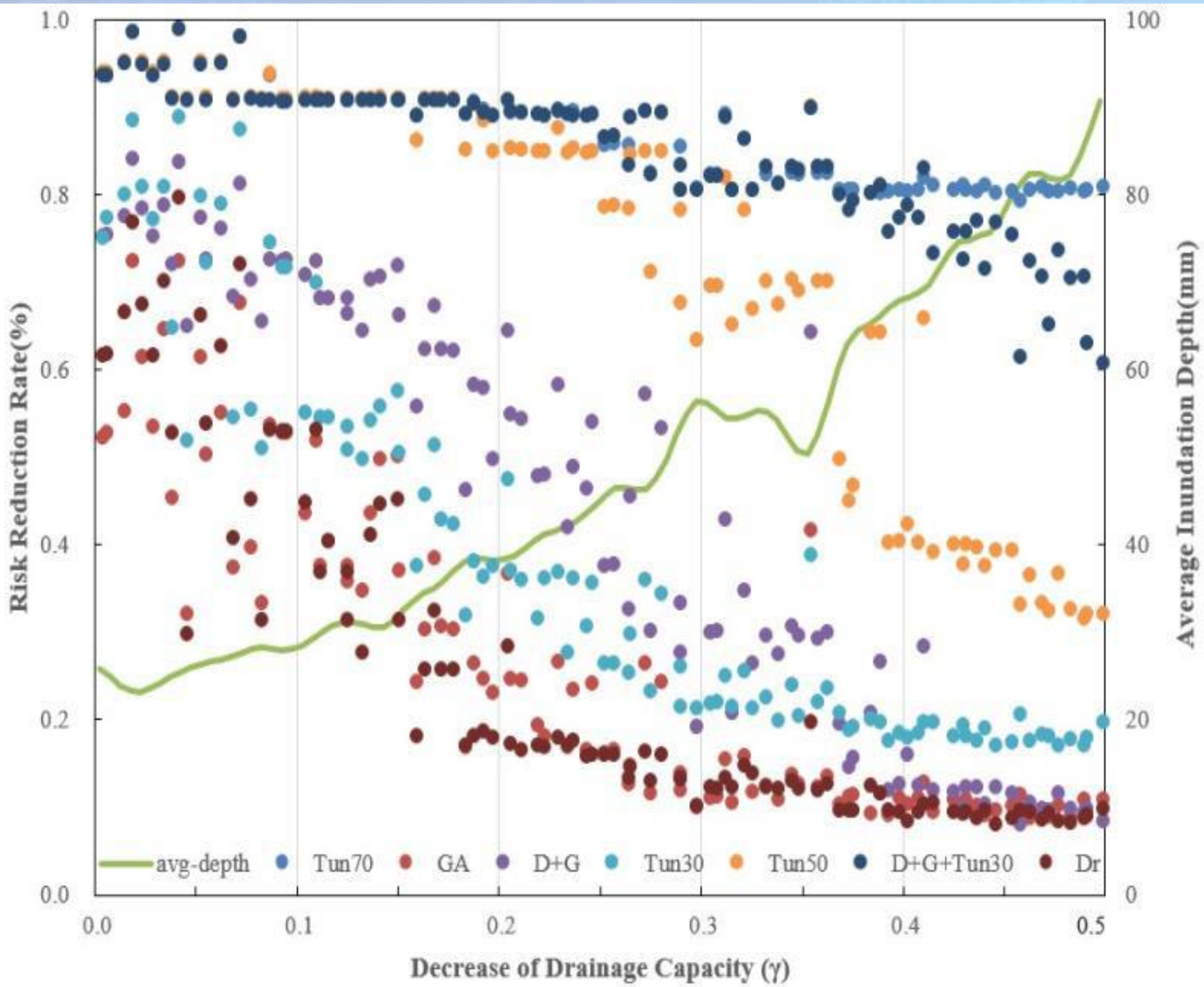
Application of Green Area, Drainage System and Deep Tunnel

Validation of the SUIM Simulation

Fig. 3 compares the spatial patterns of simulated inundation by the SUIM and the public-reported waterlogging points. It shows a very good match in the solution district.



Performance of Solutions in Reducing Inundation

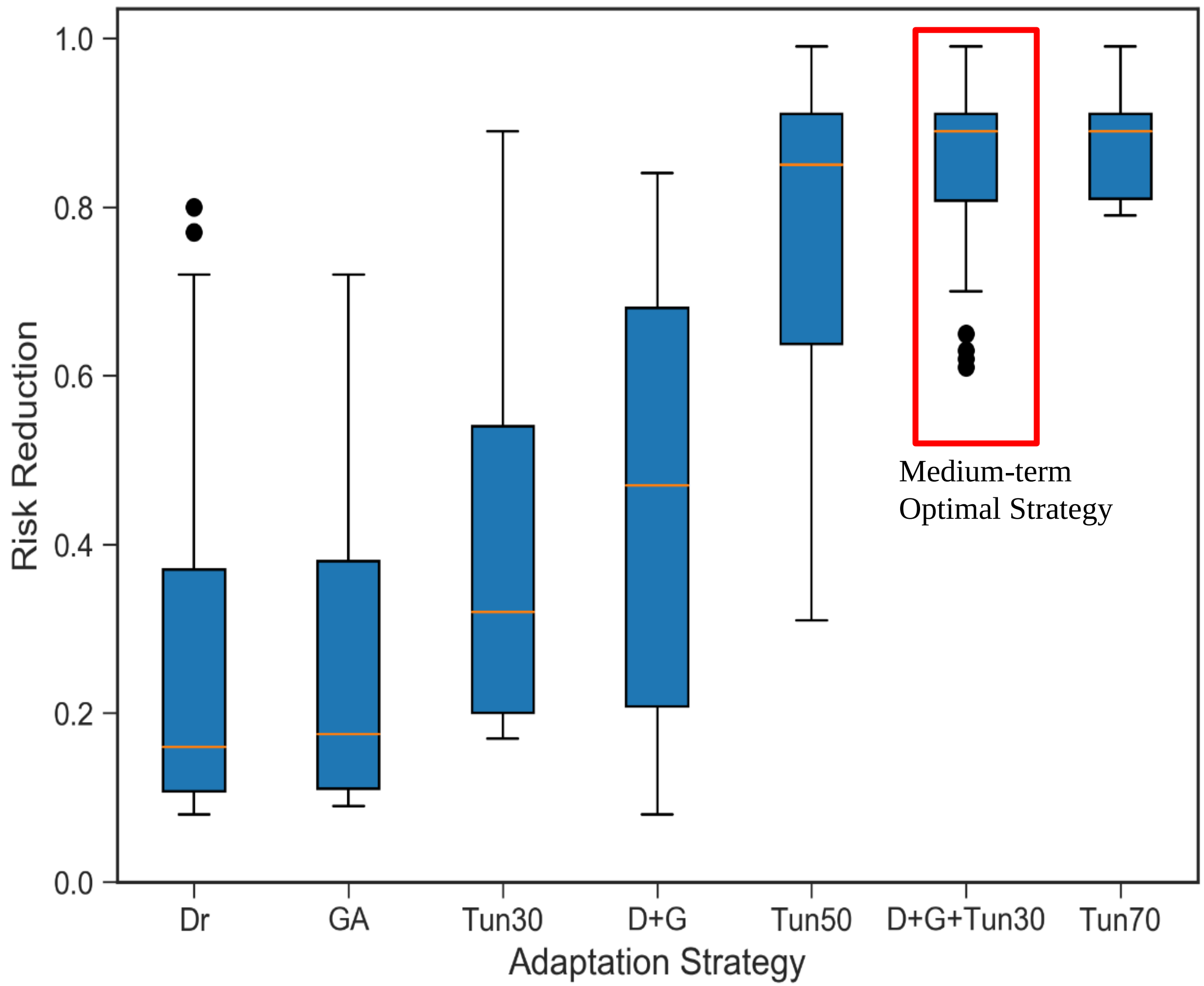


Box plots of potential risk reduction rates.

Dr: drainage capacity enhancement; GA: green area increase; Tun30: deep tunnel with 30% runoff absorbed; D+G: Dr + GA; Tun50: deep tunnel with 50% runoff absorbed; D+G+Tun30: Dr + GA + Tun30; Tun70: deep tunnel with 70% runoff absorbed

drainage capacity decrease caused by sea-level rise and land subsidence will play a dominant role in worsening future inundation risks in Shanghai.

Performance of Solutions in Reducing Inundation



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the solution of Drainage, Green Area and Tunnel with 30% precipitation absorbed is the medium-term optimal strategy for flood risk reduction.

Cost-Effectiveness Comparison

Table 1. Cost analysis of the five individual solutions

Solutions	Initial Cost (million RMB)	Unit (km/km^2)	Maintenance and operations	Life span (year)	Life cycle cost (million RMB)	Salvage Value (Million RMB)	Annual Average Cost (million RMB/y)
Drainage	100/km	117.6	2%	50	13,427	52	269
Green	600/km^2	30.0	2%	70	17,988	36	257
Tun30	300/km	22.2	5%	50	14,070	29	281
Tun50	300/km	37.0	5%	50	23,451	49	469
Tun70	300/km	51.8	5%	50	32,831	68	657

Note: Drainage: drainage capacity enhancement; Green: green area increase; Tun30, Tun50, Tun70: deep tunnel with 30%, 50%, 70% runoff absorbed, respectively.

Table 1 presents the comparative cost structure of the five basic solutions. The cost is accounted as the present value in 2013 RMB. The annual average cost (AAC) in the table indicates that the low impact solution of "green area expansion" has the lowest financial demand per year and the highest impact grey solution of Tun70 has the highest financial demand per year, respectively.

Cost-Effectiveness Comparison

Table 2. Cost-effectiveness of the solutions

	ARR (Average risk reduction rate, %)	PVC (million RMB/year)	ARR/PVC (percentage point/million RMB/year)
Drainage	25	269	0.093
Green area	26	257	0.101
Tun30	39	281	0.139
D+G	62	526	0.118
Tun50	74	469	0.158
D+G+Tun30	85	807	0.105
Tun70	87	657	0.132

Note: ARR: Average risk reduction rate. PVC: The present value of cost per year.

Tun50 has the highest effectiveness-cost ratio. If the criterion of solution choice is that the risk reduction rate should be at least 85% on average, Tun70 will have the highest effectiveness-cost ratio.

Summary

- The cost-effectiveness comparison in Table 2 brings up an important decision-making issue on the trade-offs between the grey infrastructure and the green solutions.
- Grey infrastructure usually possesses better protection standards in reducing inundation risks associated with the low return period events, but has a high level of negative impact on ecology and such negative impact is very difficult to be quantified (planners tends to under estimate the negative impact)
- Green solutions are typically effective in managing relatively high return period events, but beneficial to the local environment and ecology and such benefits are very difficult to be measured by monetary value (planners tends to under estimate these benefits)
- (D+G+Tun30) becomes preferable to the solution of "deep tunnel with 70% runoff absorbed" (Tun70).

Thanks

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