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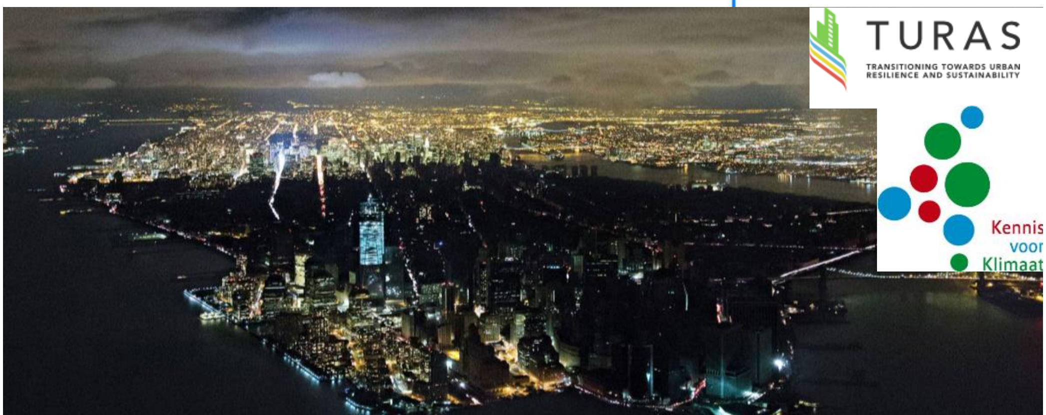
VU UNIVERSITY AMSTERDAM

TURAS TRANSITIONING TOWARDS URBAN RESILIENCE AND SUSTAINABILITY

Kennis voor Klimaat



Hurricane Flood Risk in New York City

Spatial cost-benefit analysis of measures

Hans de Moel,
Ning Lin, Kerry Emanuel, Nathan van der Dussen, Wouter Botzen and Jeroen Aerts

Deltas in Times of Climate Change II, September 2014

Introduction

POLICYFORUM

CLIMATE ADAPTATION

Evaluating Flood Resilience Strategies for Coastal Megacities

Integration of models for storms and floods, damages and protections, should aid resilience planning and investments.

Jeroen C. J. H. Aerts,[1*] W. J. Wouter Botzen,[1] Kerry Emanuel,[2] Ning Lin,[3] Hans de Moel,[1] Erwann O. Michel-Kerjan[4*]

Recent flood disasters in the United States (2005, 2008, 2012); the Philippines (2012, 2013); and Britain (2014) illustrate how vulnerable coastal cities are to storm surge flooding (*1*). Floods caused the largest portion of insured losses among all catastrophes around the world in 2013 (*2*). Population density in flood-prone coastal zones and megacities is expected to grow by 25% by 2050; projected climate change and sea level rise may further increase the frequency and/or severity of large-scale floods (*3–7*).

reducing flood occurrence in large parts of the city. However, as in other cities, some of these large-scale engineering options have

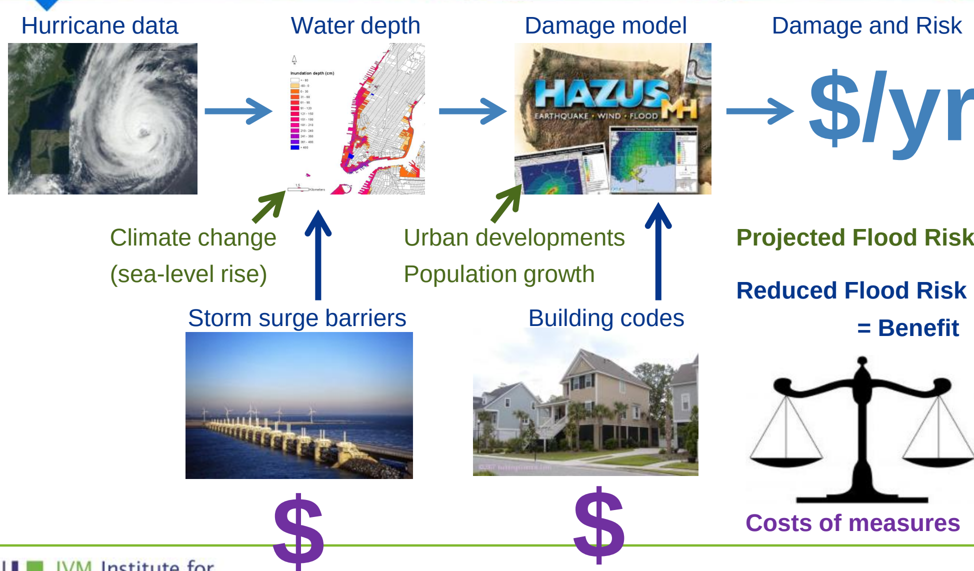
return flood zones (defined by the U.S. Federal Emergency Management Agency), with protection of critical infrastructure to reduce economic loss due to business interruption. S3 includes moderate local flood protection measures, such as levees and beach nourishment that are also part of S2c. The local protection measures and building codes for new structures are adjustable to future climate change, as they can be upgraded if flood risk increases in the coming decades.

Modeling Flood Risks, Estimating Costs

The heart of the method is a probabilistic flood-risk model developed for the city (*12–*

Aerts et al., 2014. Science 344, 473-475. doi:10.1126/science.1248222

Modeling frame



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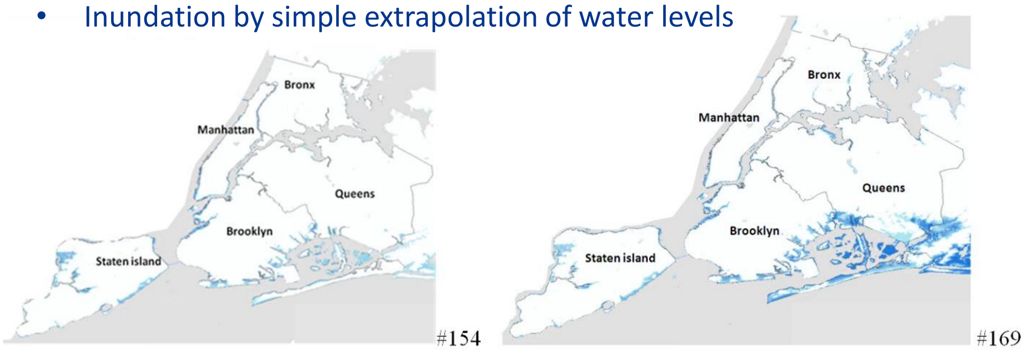
Modeling frame

Hurricanes / inundation

- 549 storms
- Derived from a much larger set, but only most extreme ones (at Battery, Manhattan)
- Inundation by simple extrapolation of water levels



Aerts et al., 2013 – Risk Analysis

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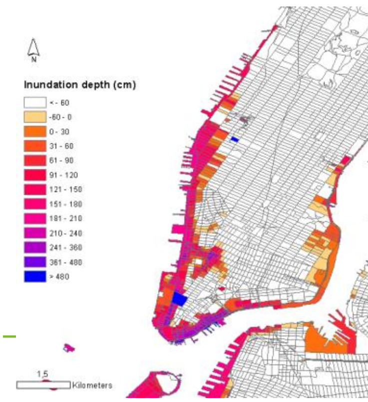
Modeling frame

Damage model

- Based on HAZUS-MH4
- Damage to **buildings** (residential, commercial, etc.) and **vehicles**
- At census **block level**



Code	Description	Value at risk ($/building)			Measure implemented					
					Existing Buildings			New Buildings**		
		Structure	Content	Inventory	Elevation	Dryproof*	Wetproof*	Elevation	Dryproof*	Wetproof*
RES1	Single Family Dwelling	182492	91246	0	Y	Y	Y	Y	Y	Y
RES2	Manuf. Housing	356421	178211	0	Y	Y	Y	Y	Y	Y
RES3A	Duplex	186630	93315	0	Y	Y	Y	Y	Y	Y
RES3B	Triplex / Quads	282573	141287	0	Y	Y	Y	Y	Y	Y
RES3C	Multi-dwellings (5 to 9 units)	873207	436604	0	N	Y	Y	Y	Y	Y
RES3D	Multi-dwellings (10 to 19 units)	1546338	773169	0	N	Y	Y	Y	Y	Y
RES3E	Multi-dwellings (20 to 49 units)	3714867	1857433	0	N	Y	Y	Y	Y	Y
RES3F	Multi-dwellings (50+ units)	18707261	9353631	0	N	Y	Y	Y	Y	Y
RES4	Temporary Lodging	11991508	5995754	0	Y	Y	Y	Y	Y	Y
RES5	Institutional Dormitory	7019251	3509626	0	Y	Y	Y	Y	Y	Y
RES6	Nursing Home	8067754	4033877	0	Y	Y	Y	Y	Y	Y
COM1	Retail Trade	571211	571211	41339	N	Y	Y	N	N	N
COM2	Wholesale Trade	1466010	1466010	127395	N	Y	Y	N	N	N
COM3	Personal and Repair Services	342290	342290	0	N	Y	Y	N	N	N
COM4	Professional/Technical Services	11381918	11381918	0	N	Y	Y	N	N	N
COM5	Banks	2370537	2370537	0	N	Y	Y	N	N	N
COM6	Hospital	81553944	122330915	0	N	Y	Y	N	N	N
COM7	Medical Office/Clinic	4904708	7357062	0	N	Y	Y	N	N	N
COM8	Entertainment & Recreation	2260999	2260999	0	N	Y	Y	N	N	N
COM9	Theaters	6015389	6015389	0	N	Y	Y	N	N	N
COM10	Parking	180913	90457	0	N	Y	Y	N	N	N
IND1	Heavy	1677769	2516654	585357	N	N	N	N	N	N
IND2	Light	4095922	6143882	422805	N	N	N	N	N	N
IND3	Food/Drugs/Chemicals	0	0	0	N	N	N	N	N	N
IND4	Metals/Minerals Processing	0	0	0	N	N	N	N	N	N
IND5	High Technology	0	0	0	N	N	N	N	N	N
IND6	Construction	0	0	0	N	N	N	N	N	N
AGR1	Agriculture	0	0	0	N	N	N	N	N	N
REL1	Churches and Other Non-profit	1982996	1982996	0	N	N	N	N	N	N
GOV1	General Services	18290701	18290701	0	N	N	N	N	N	N
GOV2	Emergency Response	2874692	4312038	0	N	N	N	N	N	N
EDU1	Grade Schools	7797433	7797433	0	N	N	N	N	N	N
EDU2	Colleges/Universities	27175914	40763870	0	N	N	N	N	N	N

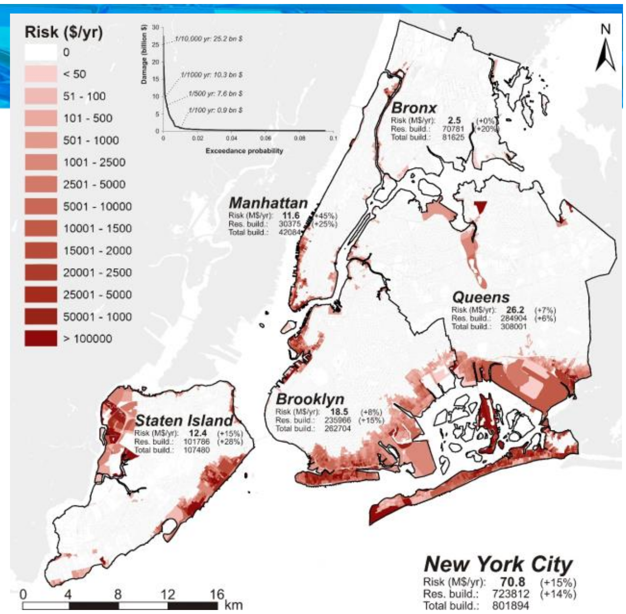
Notes: *Not implemented in V-zone;
**Assumed being built without basement.

Aerts et al., 2014

Risk estimates

71 M$/year

- 6% vehicles
- 12% V-zone
- 82% A-zone
- Queens and Brooklyn most damage (65%)
- Residential: 43%

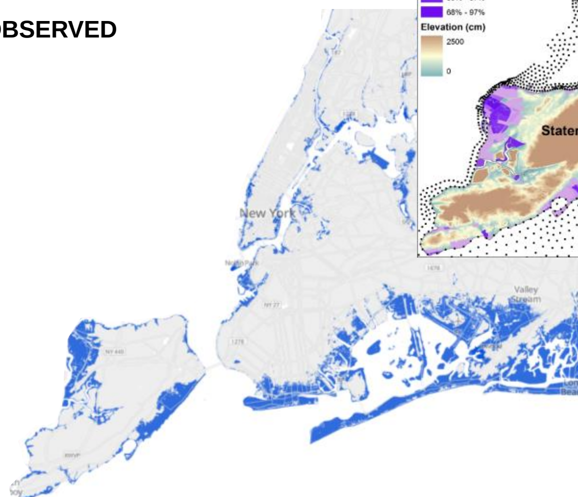


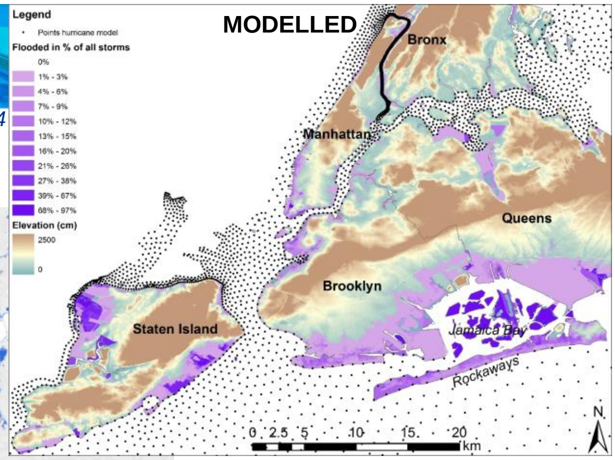
Aerts et al., 2014

Validation Sandy

Aerts et al., 2014

OBSERVED





http://project.wnyc.org/flooding-sandy-new

Damage Sandy

- NYC roughly **$21 billion**
- **1/500 - 1/1000** per year

Modelled return period

- **1/660 – 1/1250** per year

Future Risk estimates

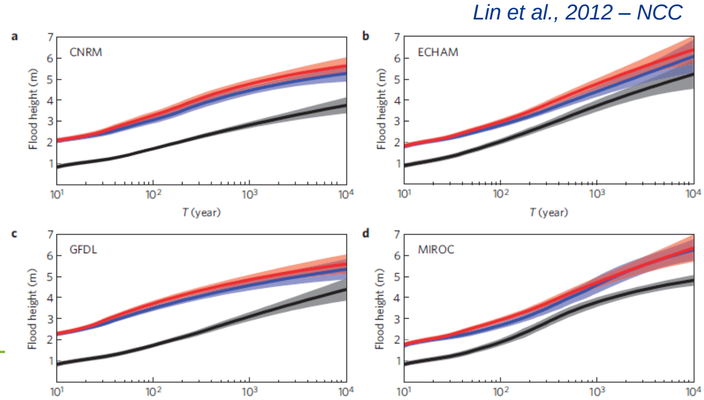
Population growth (2050)

- Projection of city

Climate change (2050+2080)

- Four GCMs
  - *SLR*
  - *Frequency*

Lin et al., 2012 – NCC

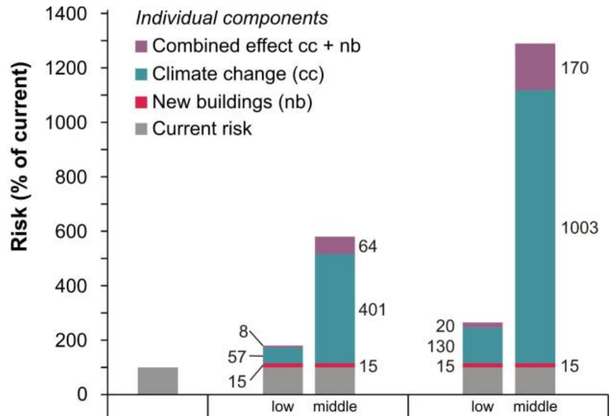


SLR 2050 is 30cm
SLR 2080 is 60cm

Future Risk estimates

Population growth:
- +15%

Climate change:
- Low (only SLR)
- Middle (SLR+freq)



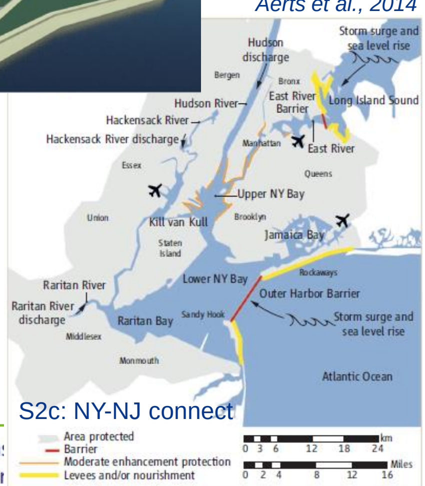
	Current	2050s	2080s
Risk (%)	100%	180% - 580%	266% - 1289%

Aerts et al., 2014

Scenarios of measures

S1: Building-scale measures

Aerts et al., 2014



S2c: NY-NJ connect

Costs

Elevation level	Cost based on Jones *et al.* per building category: RES1	RES2	RES3A	RES3B
+ 2 ft	$1,090	$1,445	$1,237	$1,856
+ 4 ft	$2,181	$2,891	$2,473	$3,711
+ 6 ft	$3,271	$4,336	$3,710	$5,567

New/existing

- Elevation
- Wet proofing
- Dry proofing

and maintenance costs for storm surge barrier strategies for NYC (in $ 2012 values)

	Barrier	Total span (m)	Span nav. parts (m)	Cost estimation Engineering firms: Construction (US$ bn)	Cost estimation Engineering firms: Maintenance (US$ mln/yr)	Cost estimation based on historical analyses (Table 5.1): Construction (US$ bn)	Cost estimation based on historical analyses (Table 5.1): Maintenance (US$ mln/yr)
Strategy 2a:	Arthur Kill	500	500	1.1		0.6–1.1	5.5
'Environmental	Verrazano Narrows	1820	1820	6.4	75	4.3–6.4	41
dynamics'	East River	1360	1360	1.9–2.1		2.6–3.0	31
Total				**9.4–9.6[a]**		**7.5–10.5[a]**	**77.5[a]**
Strategy 2c:	East River	1360	1360	1.9–2.1		2.6–3.0	31
'NY-NJ Connect'	Outer Harbor	9540	2500	5.9	72	6.5–9.4	72
Total				**7.8–8.0[a]**		**9.1–12.4[a]**	**104[a]**
Strategy 2b:	Arthur Kill	500	500	1.1		0.6–1.1	5.5
'Bay Closed'	Verrazano Narrows	1820	1820	6.4	75	4.3–6.4	41
	East River	1360	1360	1.9–2.1		2.6–3.0	31
	Jamaica Bay	1730	1730			4.1–6.1	39
Total				**9.4–9.6[a]**		**11.6–16.6[a]**	**116.5[a]**

[a]All summary cost tables are in US$ 2012 values. Indexing was applied using the Construction Cost Index and the Skilled Labor Index from ENR (Engineering News-Record, http://enr.construction.com/economics).

*Aerts et al., 2013. ANYAS 1294, 1-104. doi:*10.1111/nyas.12200

CBA of Scenarios

Recommendations:

- Elevate new buildings 4-6ft (NPV>0 in all scenarios)
- Consider flood proofing existing buildings (NPV>0 under moderate cc)
- Delay investment in surge barrier (depending on how cc unfolds)

	Where/ how much	Environ.dyn. S2a	Bay closed S2b	NJ-JY connect S2c	Hybrid solution S3
		Costs			
Total investment	NYC	$16.9–21.1 billion	$15.9–21.8 billion	$11.0–14.7 billion	$6.4–7.6 billion
Total investment	NJ	$2 billion	$2 billion	n/a	$4 billion
Total investment	NYC+NJ	$18.9–23.1 billion	$17.9–23.8 billion	$11.0–14.7 billion	$10.4–11.6 billion
Maintenance	NYC+NJ	$98.5 million	$126 million	$117.5 million	$13.5 million
		BCR for current climate			
BCR	4% discount	0.21 (0.11; 0.35)	0.21 (0.11; 0.34)	0.36 (0.18; 0.59)	0.45 (0.23; 0.73)
	7% discount	0.13 (0.07; 0.21)	0.12 (0.07; 0.20)	0.23 (0.12; 0.37)	0.26 (0.13; 0.43)
		BCR for middle climate change scenario			
BCR	4% discount	1.32 (0.67; 2.16)	1.29 (0.65; 2.11)	2.24 (1.14; 3.67)	2.45 (1.24; 4.00)
	7% discount	0.60 (0.30; 0.98)	0.60 (0.30; 0.97)	1.06 (0.54; 1.74)	1.09 (0.55; 1.78)

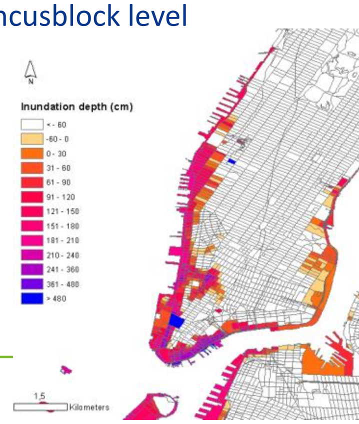
Building-scale measures

S1 often not cost-efficient as a whole under current climate, but:
- Maybe in specific places it is
- Maybe measure efficient in area A, but other measure in area B

→ **Spatial cost-benefit analysis** at the cencusblock level

Measures:
- Elevation 2ft/4ft/6ft
- Wet proofing 2ft/4ft/6ft
- Dry proofing 2ft/4ft/6ft

Scenarios:
- Current
- ECHAM 60cm (only SLR)
- GFDL 60cm (SLR + increase freq.)



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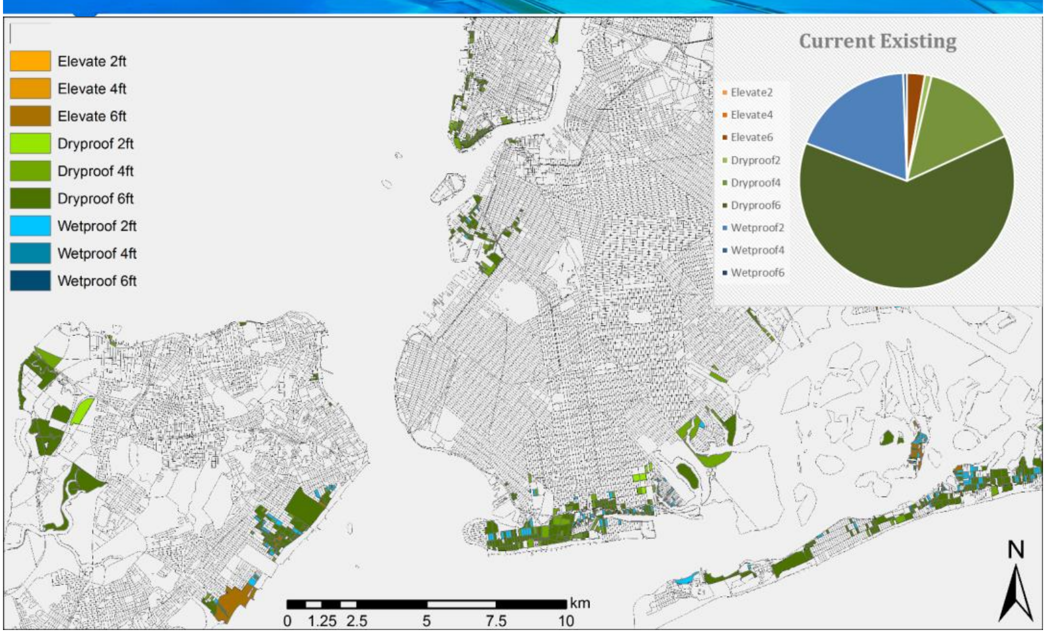
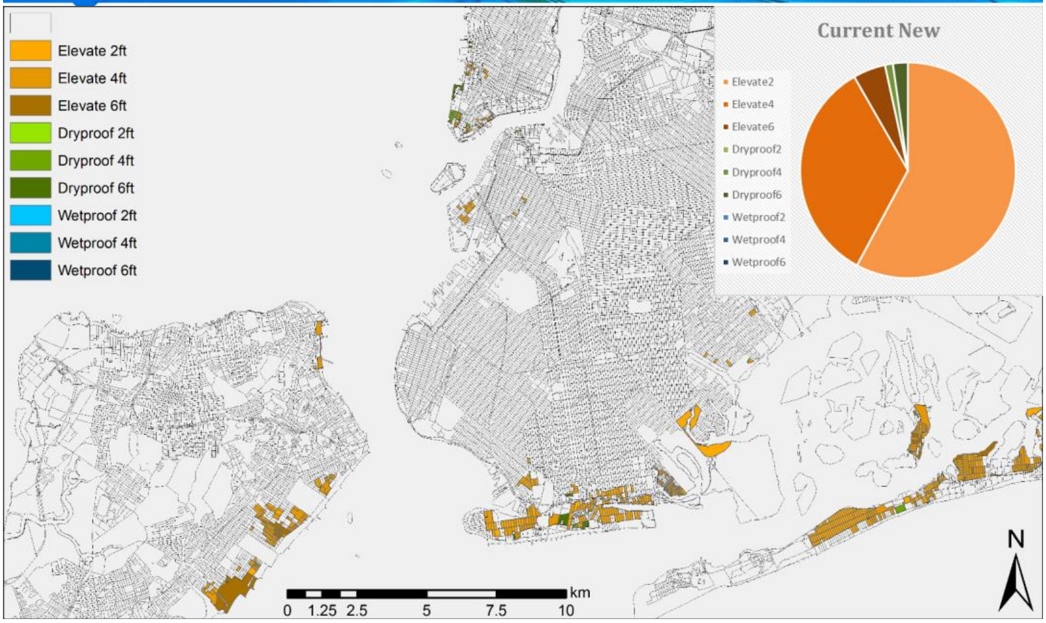
Spatial CBA

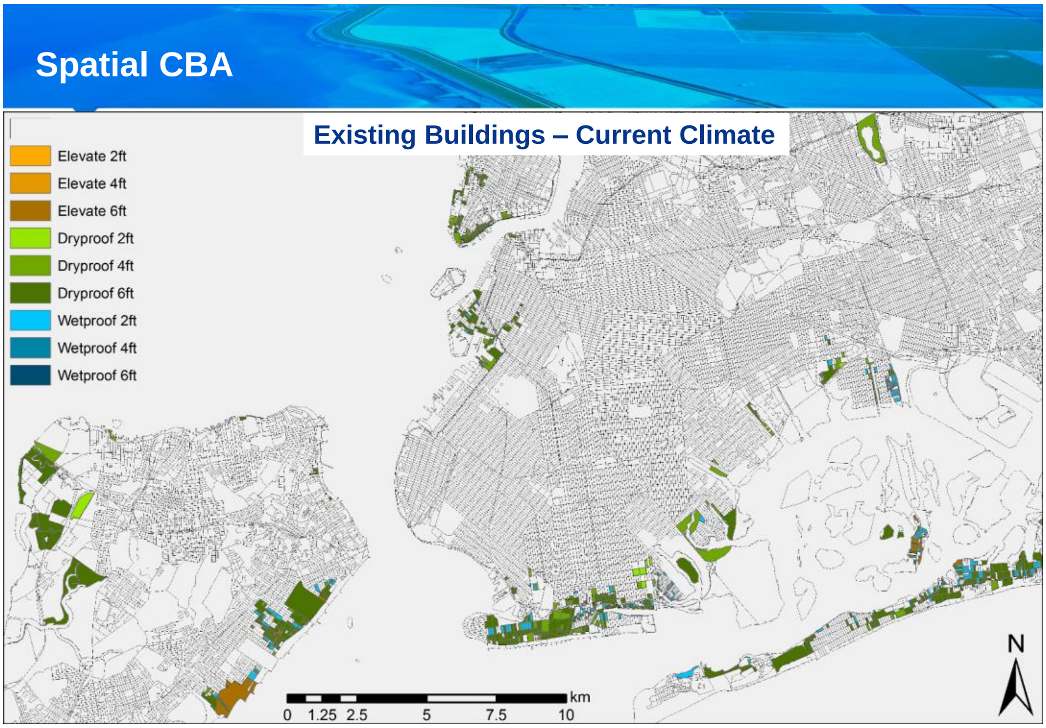


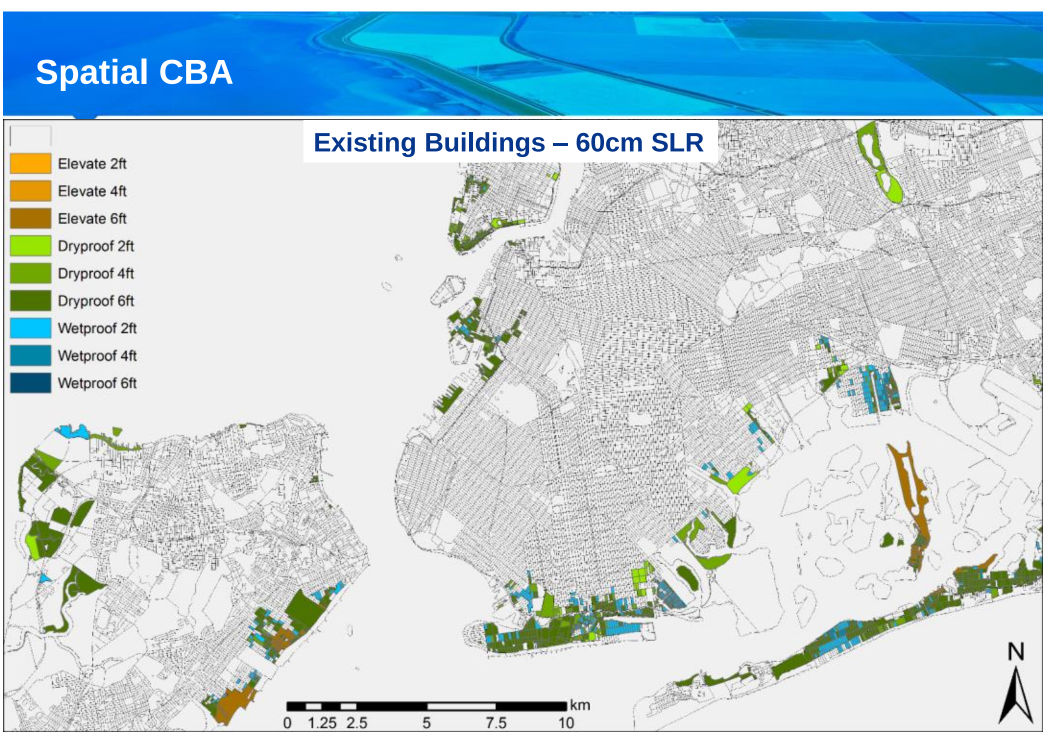
Spatial CBA

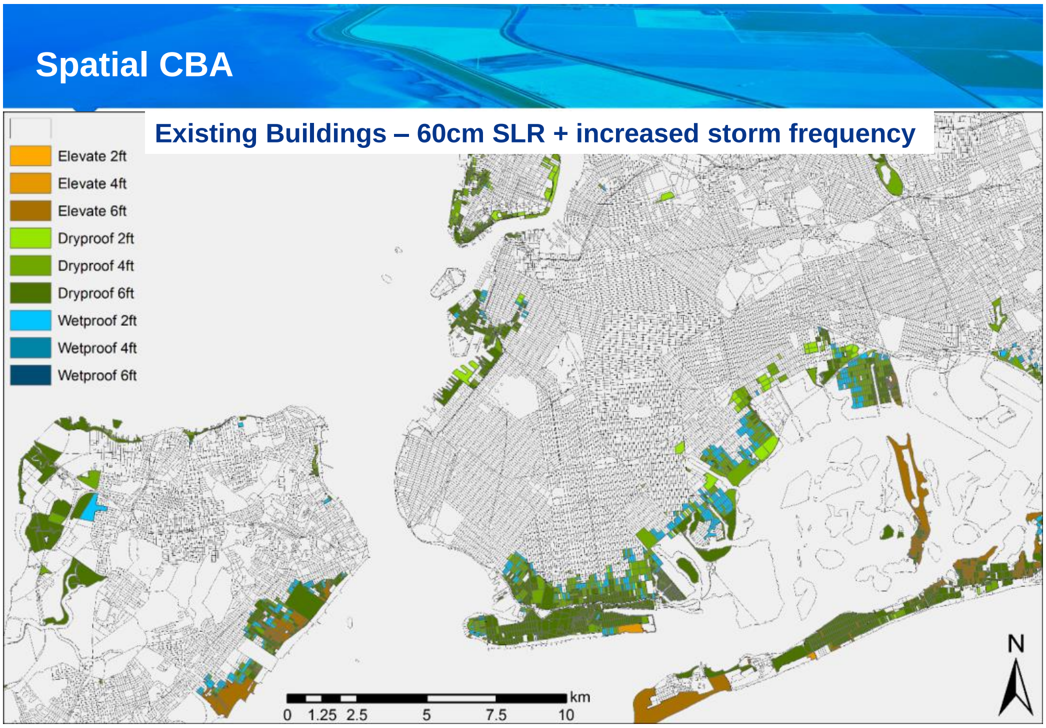


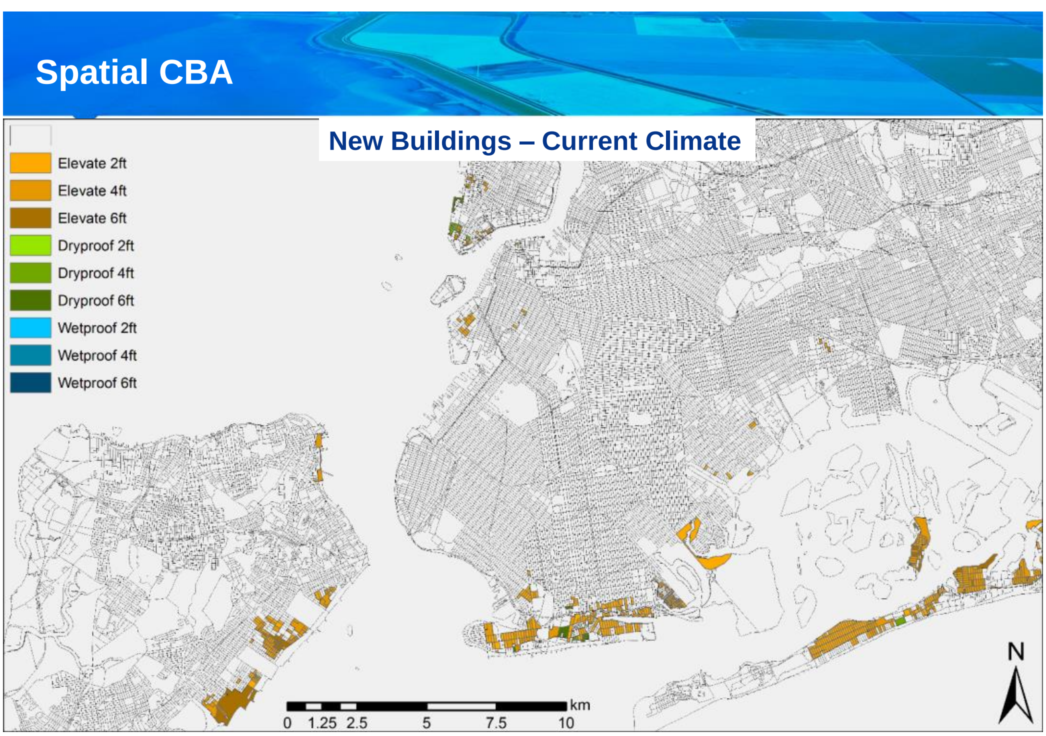
Spatial CBA

EXISTING	Current
Risk No Measure	71.0 M$/yr
Benefit Best Measure	28.5 M$/yr
% Benefit	40%
# Census blocks (5094)	891
NEW	
Risk No Measure	15.2 M$/yr
Benefit Best Measure	8.7 M$/yr
% Benefit	58%
# Census blocks (4908)	759

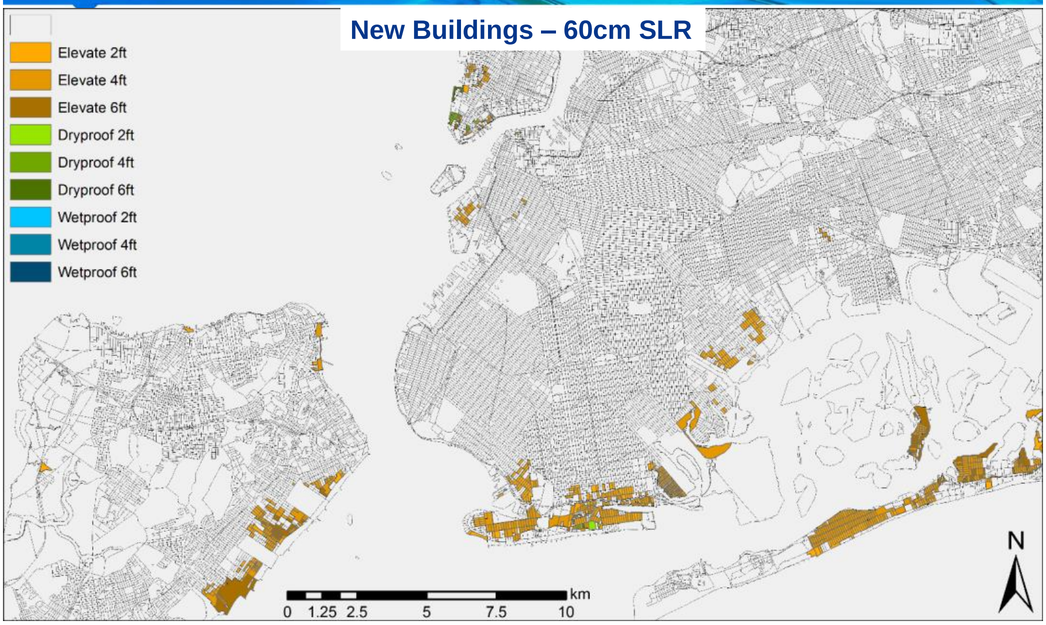

Spatial CBA
Existing Buildings – Current Climate
Elevate 2ft
Elevate 4ft
Elevate 6ft
Dryproof 2ft
Dryproof 4ft
Dryproof 6ft
Wetproof 2ft
Wetproof 4ft
Wetproof 6ft
0 1.25 2.5 5 7.5 10 km
N


Spatial CBA
Existing Buildings – 60cm SLR
Elevate 2ft
Elevate 4ft
Elevate 6ft
Dryproof 2ft
Dryproof 4ft
Dryproof 6ft
Wetproof 2ft
Wetproof 4ft
Wetproof 6ft
0 1.25 2.5 5 7.5 10 km
N

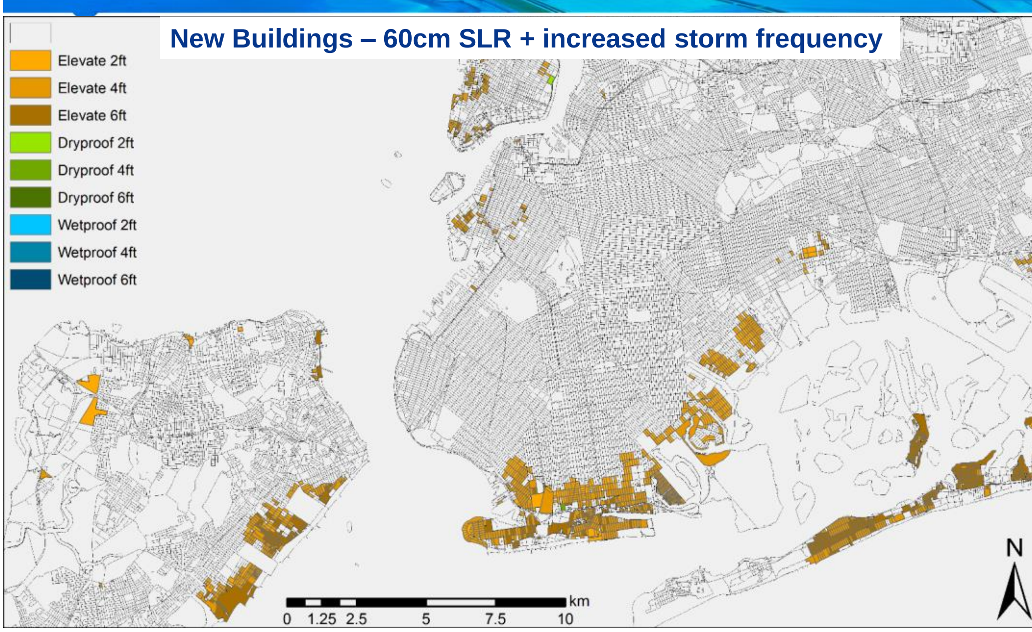

Spatial CBA
Existing Buildings – 60cm SLR + increased storm frequency
Elevate 2ft
Elevate 4ft
Elevate 6ft
Dryproof 2ft
Dryproof 4ft
Dryproof 6ft
Wetproof 2ft
Wetproof 4ft
Wetproof 6ft
km
0 1.25 2.5 5 7.5 10
N


Spatial CBA
New Buildings – Current Climate
Elevate 2ft
Elevate 4ft
Elevate 6ft
Dryproof 2ft
Dryproof 4ft
Dryproof 6ft
Wetproof 2ft
Wetproof 4ft
Wetproof 6ft
km
0 1.25 2.5 5 7.5 10
N

Spatial CBA



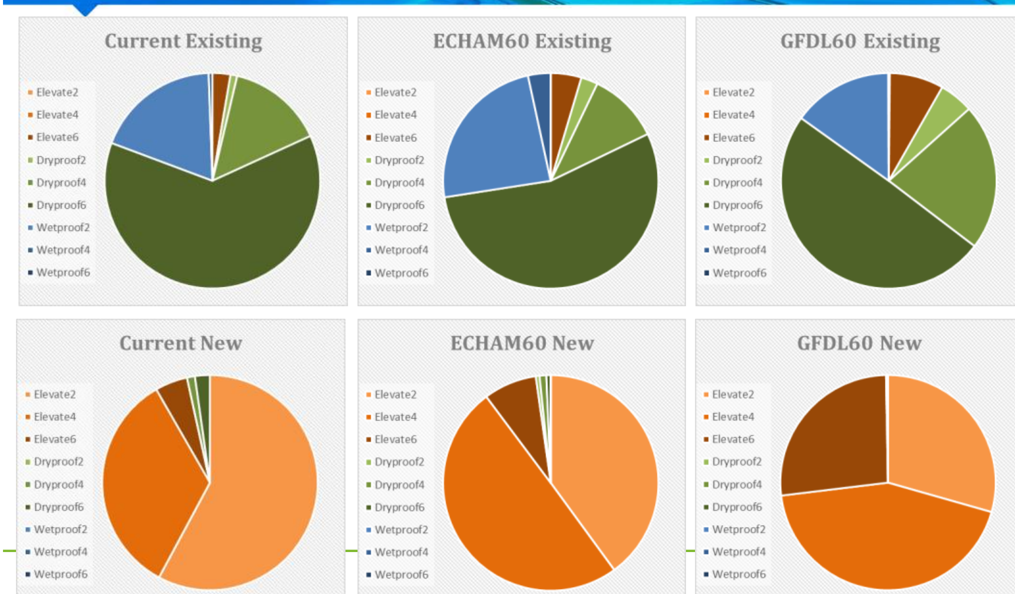
Spatial CBA



Spatial CBA

EXISTING	Current	SLR (60cm)	SLR + Freq.
Risk No Measure	71.0 M$/yr	164.2 M$/yr	787.7 M$/yr
Benefit Best Measure	28.5 M$/yr	79.6 M$/yr	440.0 M$/yr
% Benefit	40%	48%	56%
# Census blocks (5094)	891	1585	2700
NEW			
Risk No Measure	15.2 M$/yr	34.8 M$/yr	176.0 M$/yr
Benefit Best Measure	8.7 M$/yr	22.1 M$/yr	121.5 M$/yr
% Benefit	58%	63%	69%
# Census blocks (4908)	759	1076	1690

Spatial CBA



Concluding remarks

1. Even when applying a measure throughout the city is not cost-efficient; it can be **efficient in specific areas** (16%-17%)
    - Area increases considerably with climate change (up to 53%)
2. Substantial amount of **risk can be reduced** through an optimal mix of damage-reducing measure at building level.
    - Risk reduction of 40-56% for existing buildings
    - Risk reduction of 58-69% for new buildings
3. Type of measure to apply **differs spatially**
    - Most effective measure existing seems dryproofing 6ft
    - Most effective measure new seems elevating 2-6ft
    - But not *most* cost-efficient, doesn't mean not cost-efficient at all

Thank you for your attention!

hans.de.moel@vu.nl

Aerts et al., 2014. Evaluating flood resilience strategies for coastal megacities. Science vol.344, 2 May 2014, pp. 473-475. doi:10.1126/science.1248222

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