Assessing the direct economic costs of sea level rise and storm tide damage in coastal communities using tide gauge data and depth-damage functions

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Thesis structure

I. Incorporate tides into sea level rise damage estimates

A methodology for assessing sea level rise inundation costs in coastal communities using local tide gauge data and depth-damage functions

II. Consider storm tides and damages in a probabilistic framework

Assessing the costs of storm tide flooding in coastal communities

III. Add sea level rise

Assessing the future costs of storm tide flooding with sea level rise in coastal communities

Presentation outline

1 Introduction

2 Detailed model of coastal flooding damages

3 Tides in sea level rise damage and loss estimates

4 Storm tides in a probabilistic framework

5 Storm tide damages with sea level rise

6 Conclusions

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Local level coastal flooding damages

Climate change → Sea level rise → Coastal flooding → Economic damages and losses

- People are affected by climate impacts at the local level, and it is appropriate to introduce solutions to target a large number of people (Jabeen et al 2010)

- Grounding climate change at the local level provides benefits of making associated risks and opportunities more relevant to the public and private agents responsible for designing and implementing responses (Hunt and Watkiss 2011)

Aim: quantify potential future impacts of sea level rise and storm flooding at the local level to inform planners and decision makers of economic risks and thereby facilitate management

Literature

- Early economic studies on SLR projected national or global scale costs (e.g. Yohe 1989, Darwin and Tol 2001)
- Studies by Yohe at al. (e.g. Yohe 1989; Gary Yohe, Neumann, and Ameden 1995) provide a conceptual basis for estimating social costs
- More recent shift in the literature on SLR towards the local and regional economic impacts (e.g. Michael 2007; Neumann et al. 2010; Hallegatte et al. 2011; Lichter and Felsenstein 2012)

Research gap

- There is a need to assess the economic impacts and climate change response policy at the local scale (Hallegatte et al. 2010), and specifically to refine the method of estimating the increasing costs of coastal flooding (Michael 2007)
  - Bespoke tools have been developed to deal with particular micro situations, and aggregate, analytic frameworks have been created to deal with macro scale issues, but there is a vacuum of applicable approaches grounded in readily available platforms that can provide local level information for communities coping with climate change (Lichter and Felsenstein 2012)
- Little consideration has been given to the choice of water level used in assessments of SLR damages and losses

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Costs of coastal flooding

Direct economic damages – occur due to the physical contact of property, people, or any other objects with flood water, while indirect damages are induced by the direct damages but occur outside, temporally or spatially, of the flood event

- Direct flood damages to land and structures
- Current stock of land and buildings
- Costs of inaction; adaptation is not considered

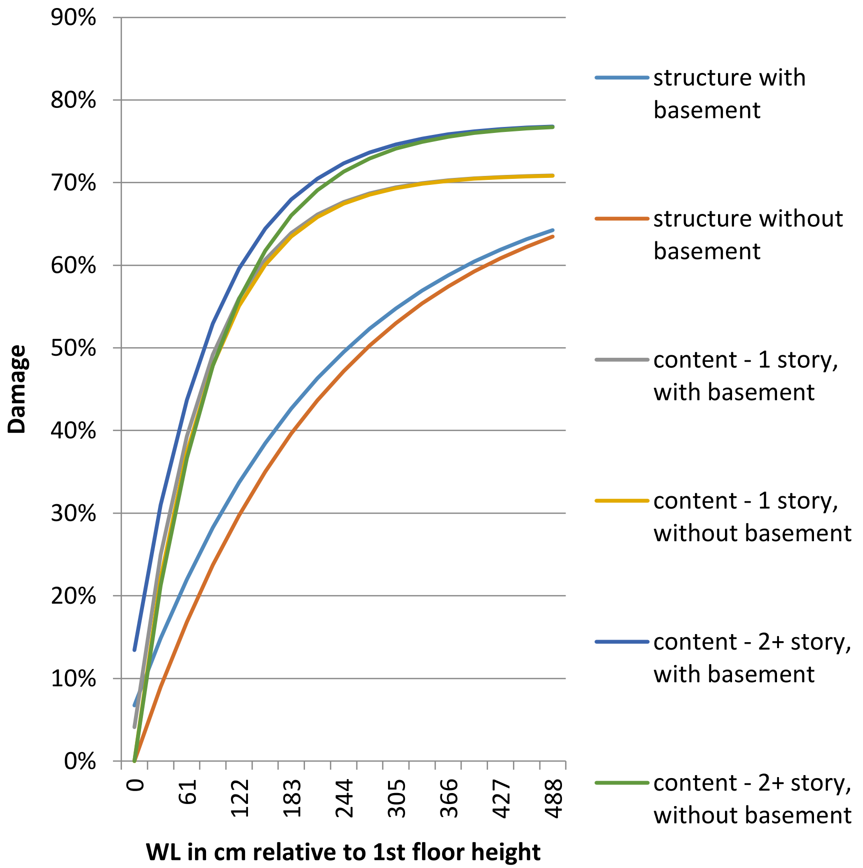
Flood damage assessment (Merz et al. 2010; de Moel and Aerts 2011):

1. **Inundation depth**
2. **Land use**
3. **Value of elements at risk**
4. **Susceptibility of elements at risk to hydrologic conditions**

Depth-damage functions

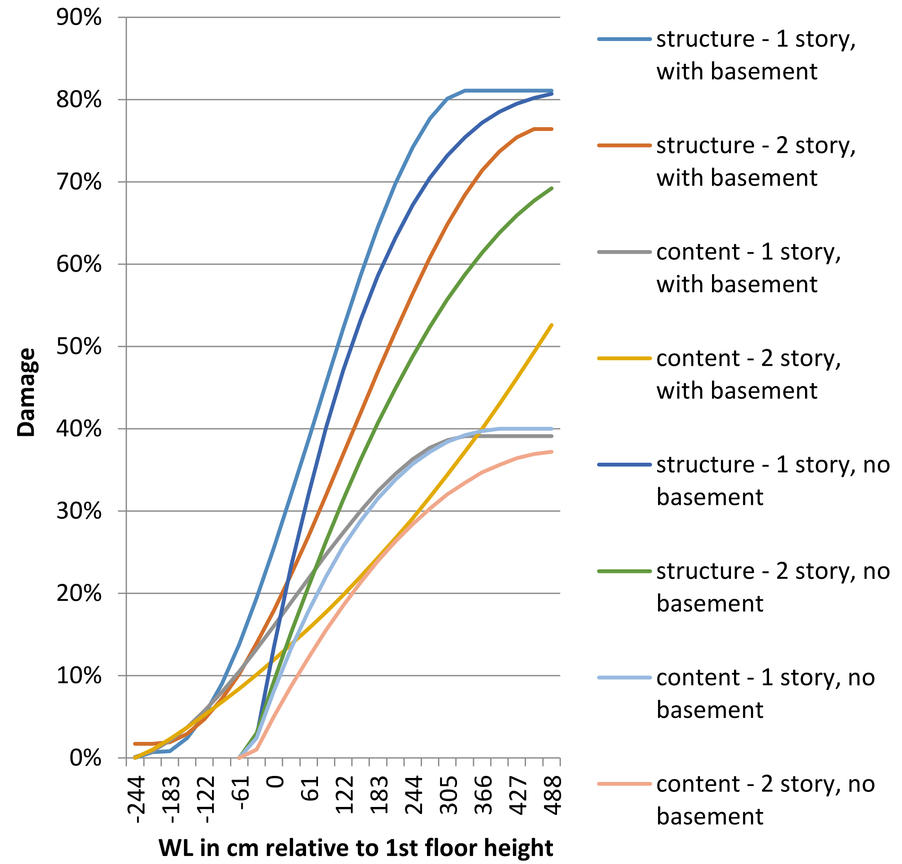
Non residential

- Generic depth-damage functions for use in USACE flood damage reduction studies (Kiefer & Willett 1996)



Residential

- Generic depth-damage data for use in USACE flood damage reduction studies
  - Basement (Dawson 2003)
  - No basement (Johnson 2000)



Data requirements

- **Elevation of land and structures** – DEM from CT DEEP, parcel and structure locations from the municipal GIS office
- **Water level** – NOAA tides and currents, tide gauge analysis
- **Value of land**
- **Value of structures**
- **Land use type**
- **Number of stories**
- **Basement**

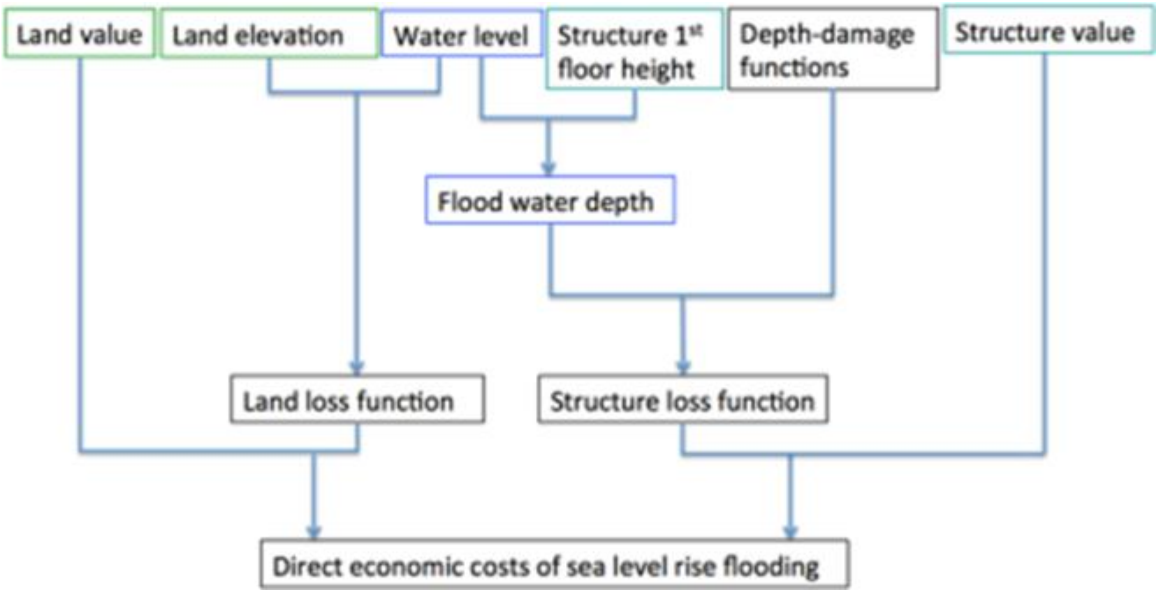
} Municipal property data

- **Value of structure contents** – content-to-structure value ratio: 50% for residential, 100% for commercial, 150% for industrial, and 100% for public land use

Estimating damages and losses

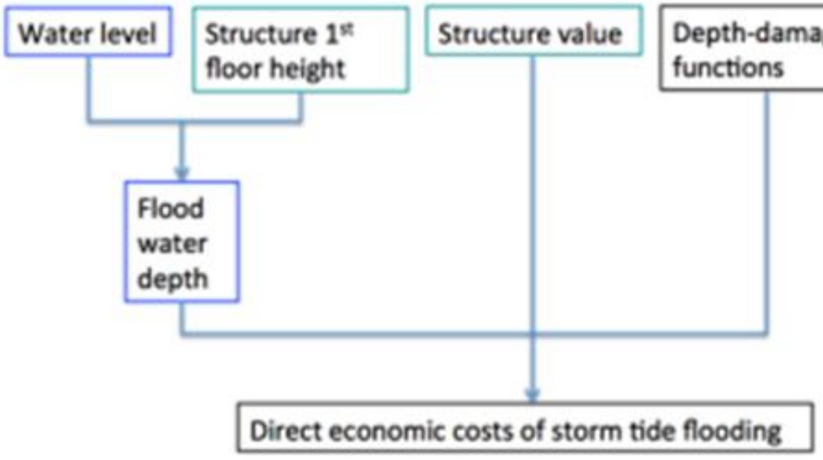
When is a property 'lost' to SLR?

- Land elevation < water level
- Structure 1st floor height < water level and damages > 10% of structure value



When is it damaged by storms?

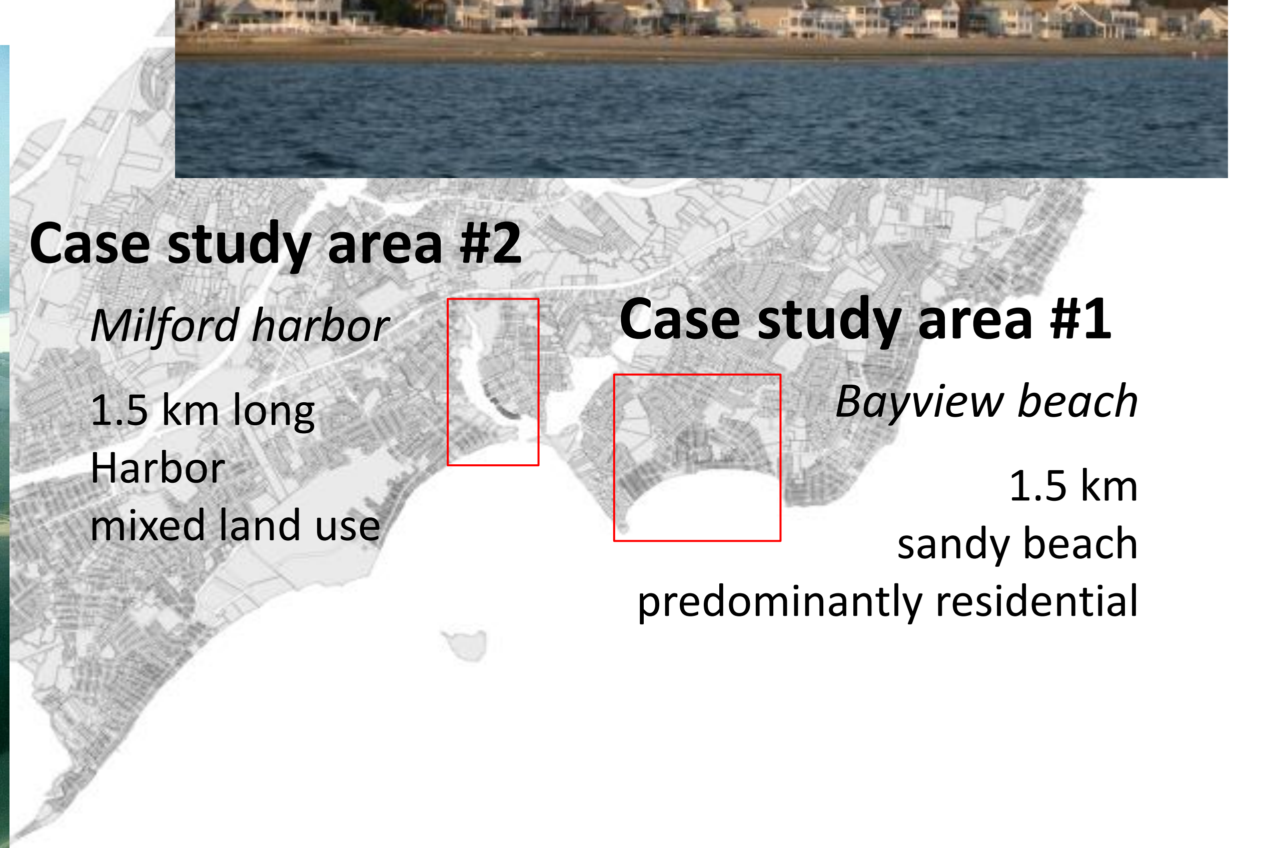
- Anytime floodwater contacts structures or contents of structures
- Land value is not lost to storms



Case study areas

Milford, Connecticut, USA

27.7 km coastline
52,000 population



Case study area #2

Milford harbor

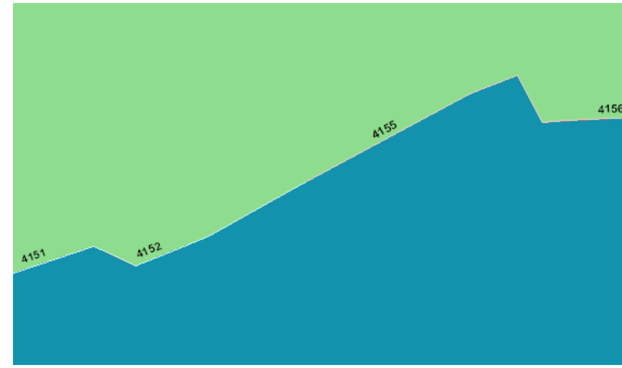
1.5 km long
Harbor
mixed land use

Case study area #1

Bayview beach

1.5 km
sandy beach
predominantly residential

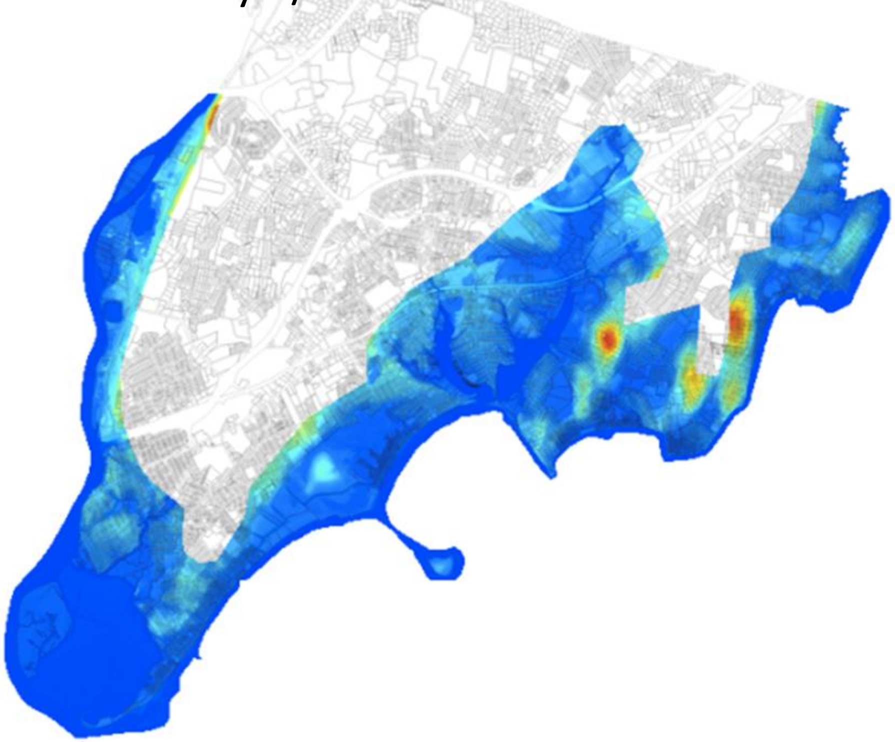
High resolution data



Digital elevation model:

Coastal Connecticut 3ft LiDAR data

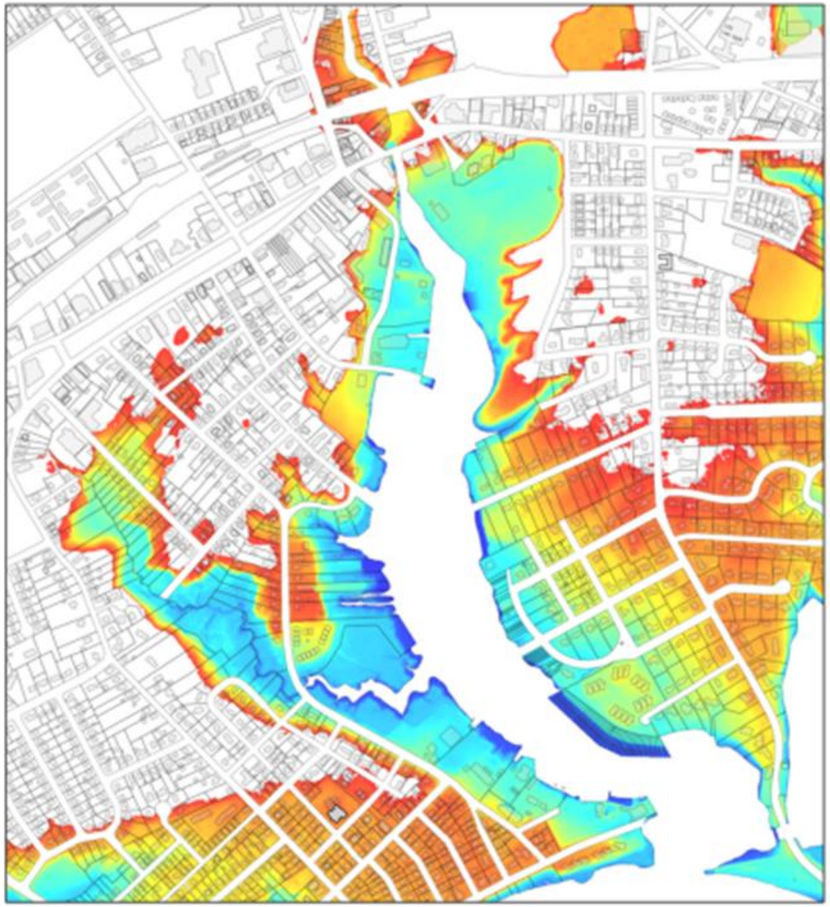
- CT DEEP, elevation data collected by FEMA in 2006
- Vertical accuracy +/- 1 foot, horizontal accuracy +/- 3 feet

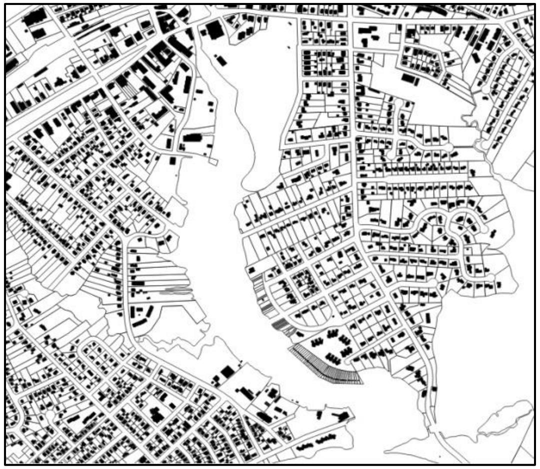


High resolution data

Spatial data:

Municipal GIS maps of properties and structures





Municipal property data:

- **Value of land**
- **Value of structures**
- **Land use type**
- **Number of stories**
- **Basement**

High resolution data

Results

- Sea level rise losses calculated using **land** (**A**), **structure** (**B**), and **land and structure** (**C**) elevation points
- Using both land and structure elevation points takes advantage of the most detailed data and provides the most accurate loss estimates

Datum & year	Damage function	Bayview land loss $	Bayview structure loss $	Harbor land loss $	Harbor structure loss $
MPST 2025	A	7,716,290	8,937,980	10,503,220	2,475,960
	B	739,740	1,022,420	-	-
	C	7,716,290	1,022,420	10,503,220	-
MPST 2050	A	10,821,050	12,267,320	12,661,579	6,113,212
	B	1,522,670	2,281,160	-	-
	C	10,821,050	2,281,160	12,661,579	-
MPST 2075	A	12,318,040	13,694,260	15,256,479	6,428,722
	B	3,381,200	4,522,915	-	-
	C	12,318,040	4,522,915	15,256,479	-
MPST 2100	A	16,218,320	17,190,610	23,770,273	9,898,797
	B	5,721,185	7,263,014	1,029,760	223,090
	C	16,218,320	7,263,014	23,770,273	223,090

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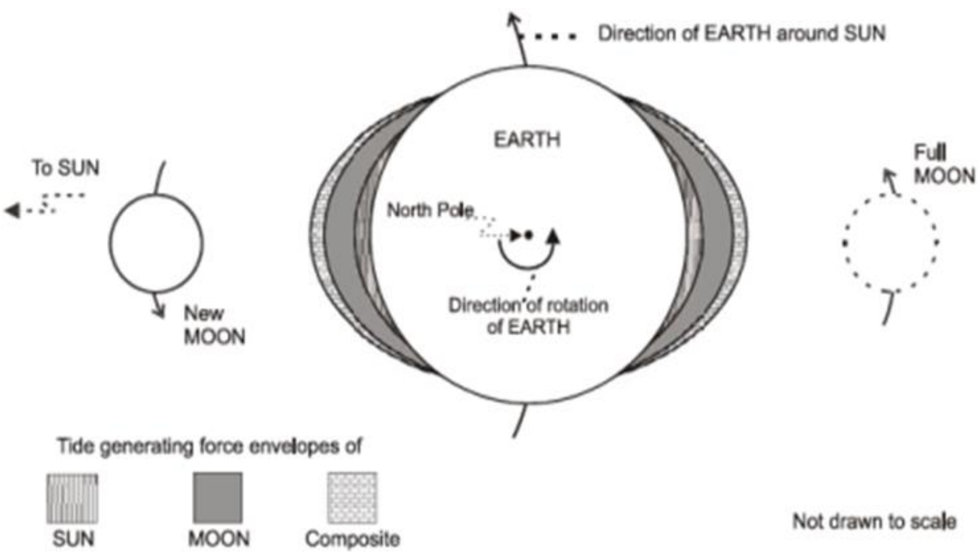
The role of tides

- Tidal variability



Conditions determining how much tides rise and fall:

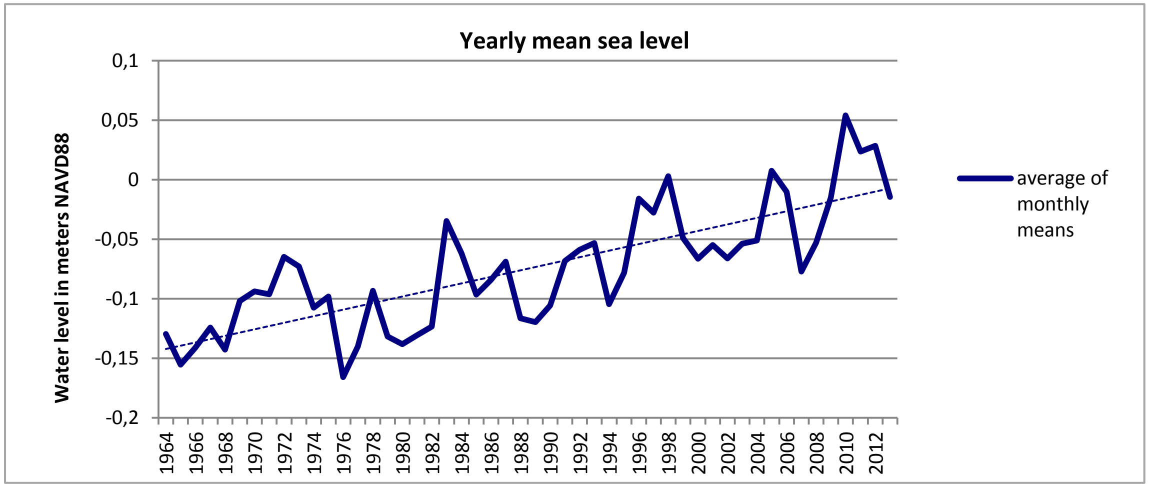
1. Phase of the moon
2. Moon's distance from earth in its elliptical orbit
3. Moon's declination to the north or south
4. Other factors: geography and shape of a shoreline, underwater topography, the speeds of traveling ocean waves, local winds and weather patterns

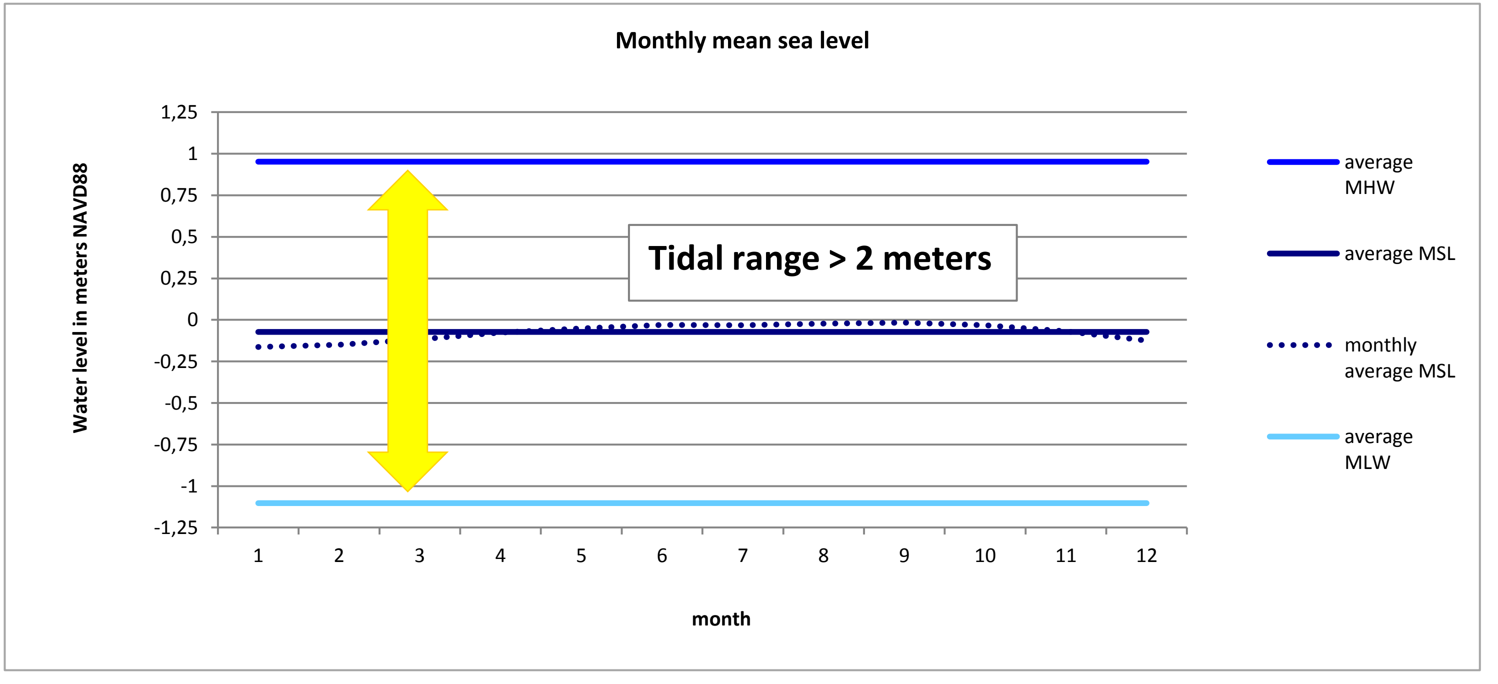
- Tide gauge data
  - Data available for Bridgeport, CT:
    - Monthly mean (1964-present)
    - Daily (1996-present)
    - H/L tide (1996-present)
    - Hourly (1996-present)

NOAA TIDES & CURRENTS

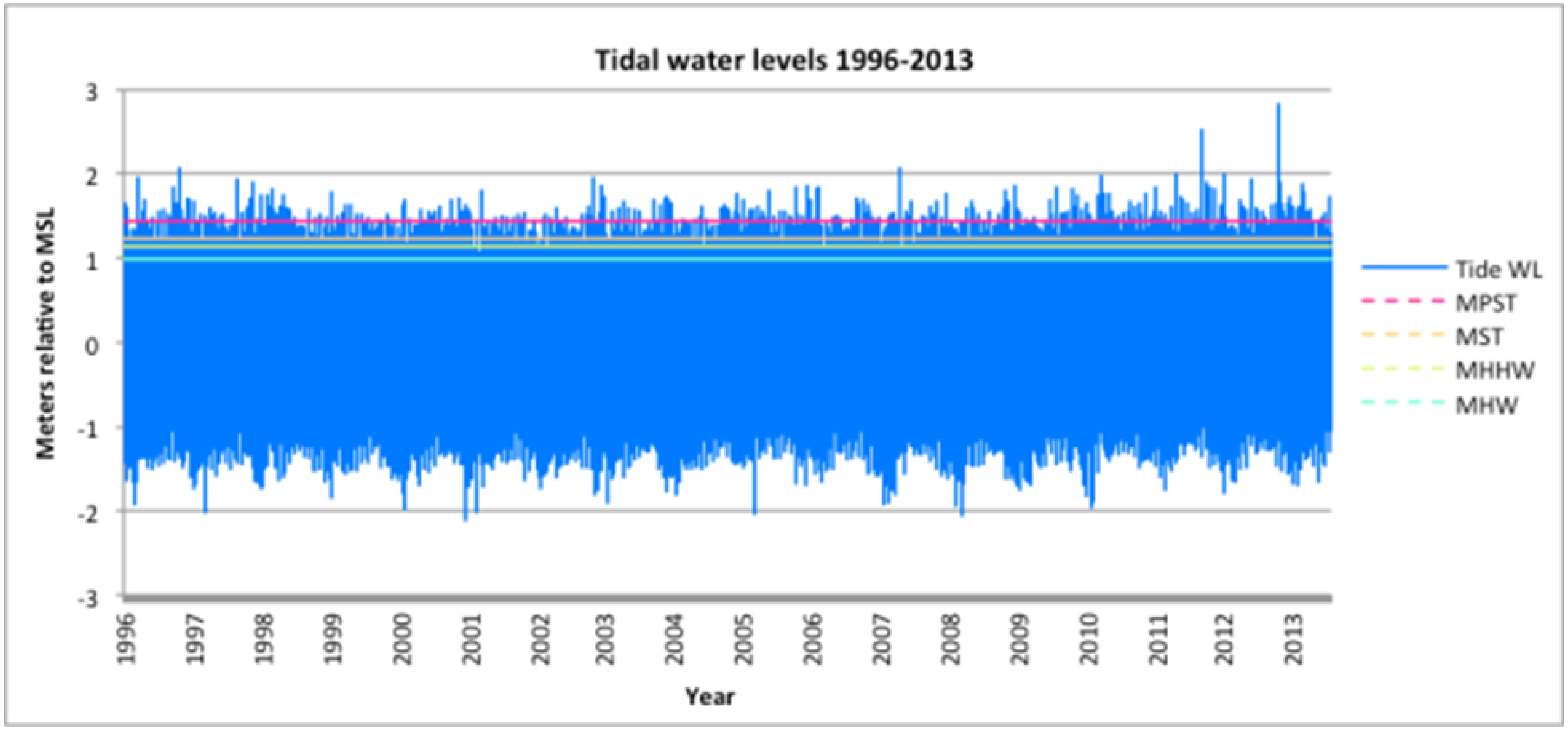
Tides

- Monthly data
  - Sea level rise
  - Mean tidal levels

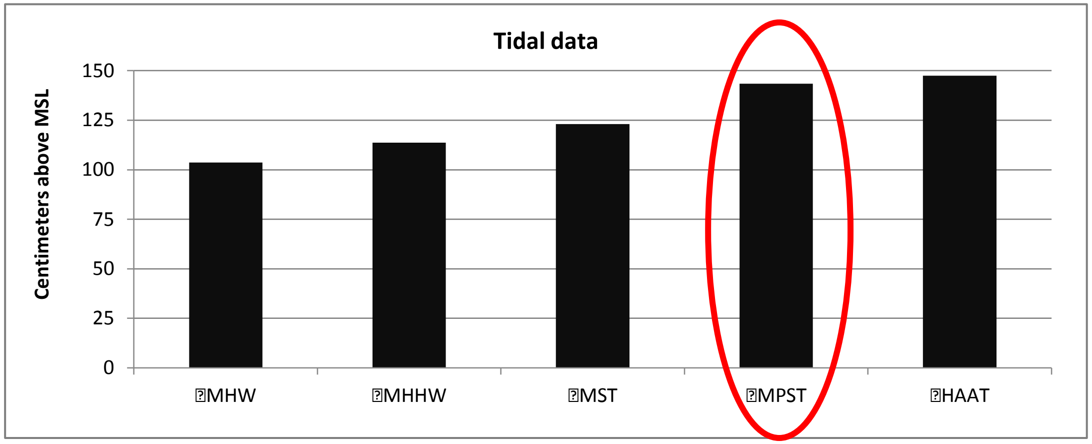




Tides

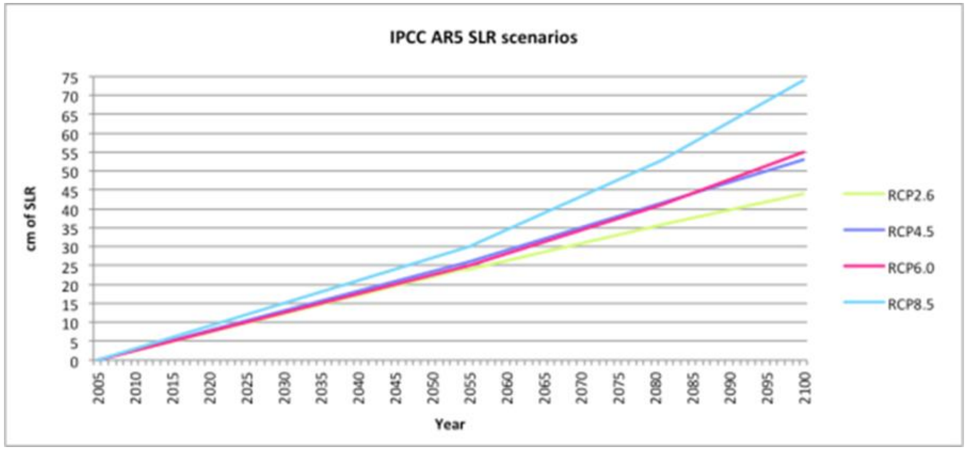


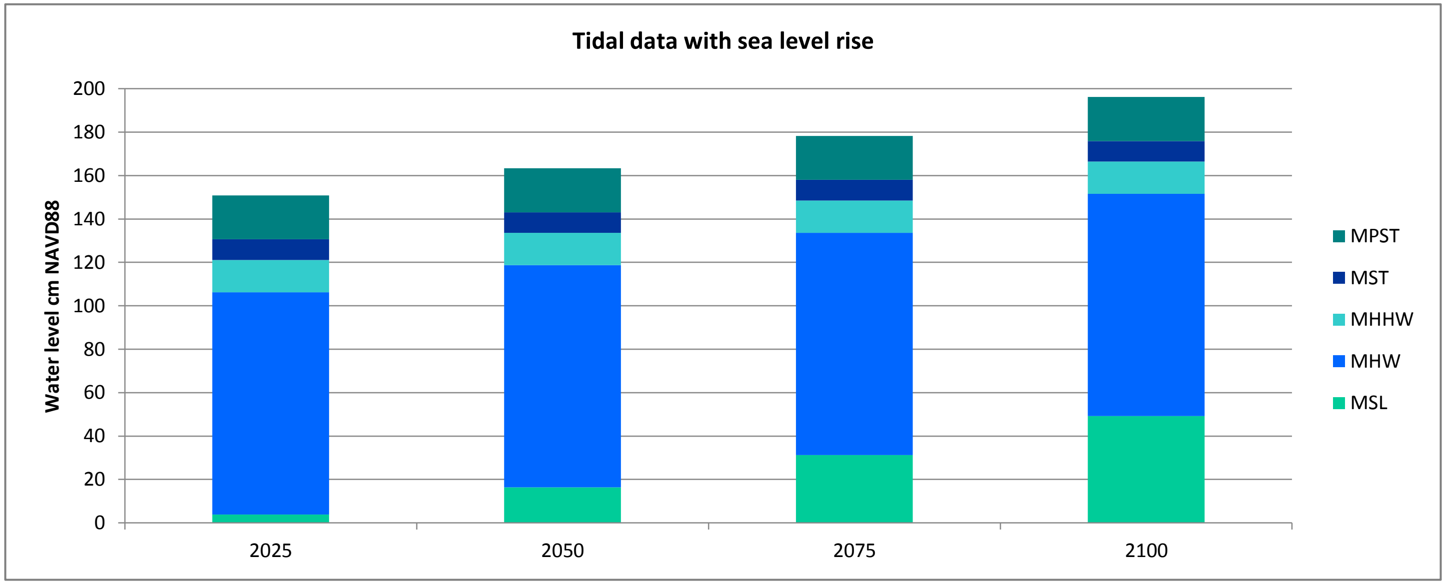
- High tide/low tide data
  - High tide water levels
  - Probability of high tide water levels



Tides with SLR

Sea level rise scenario	Sea level rise rate 2006-2055 (cm/yr)	**Sea level rise 2046-2065 (cm)**	Sea level rise rate 2056-2080 (cm/yr)	**Sea level rise rate 2081-2100 (cm/yr)**	**Sea level rise 2100 (cm)**
RCP2.6	0.48	24	0.4165	0.44	44
RCP4.5	0.52	26	0.5615	0.61	53
RCP6.0	0.50	25	0.5819	0.74	55
RCP8.5	0.60	30	0.8812	1.12	74





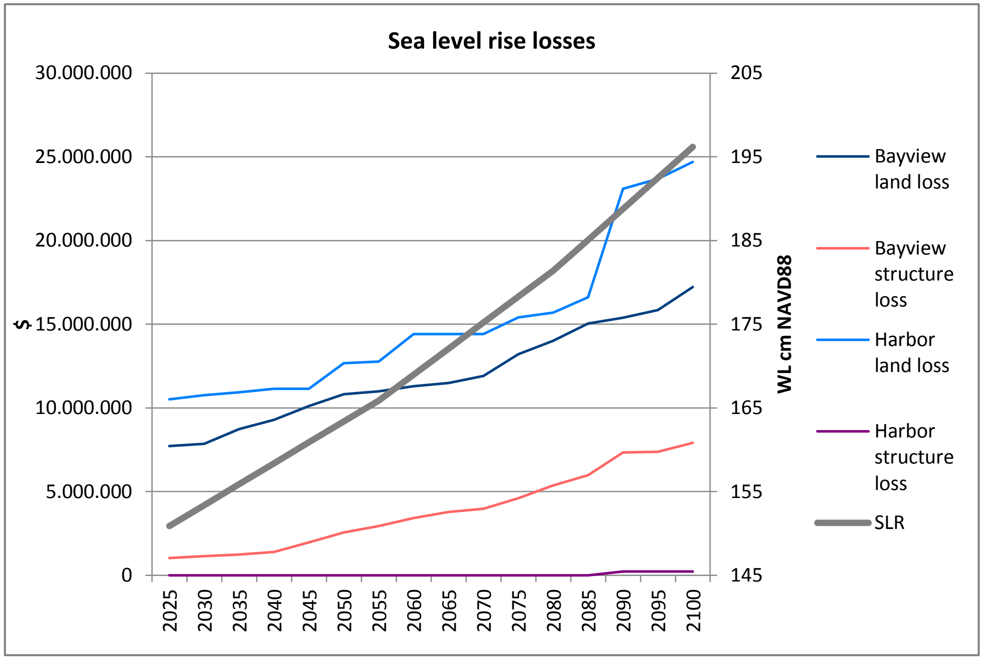
Including tides in flood damage estimates

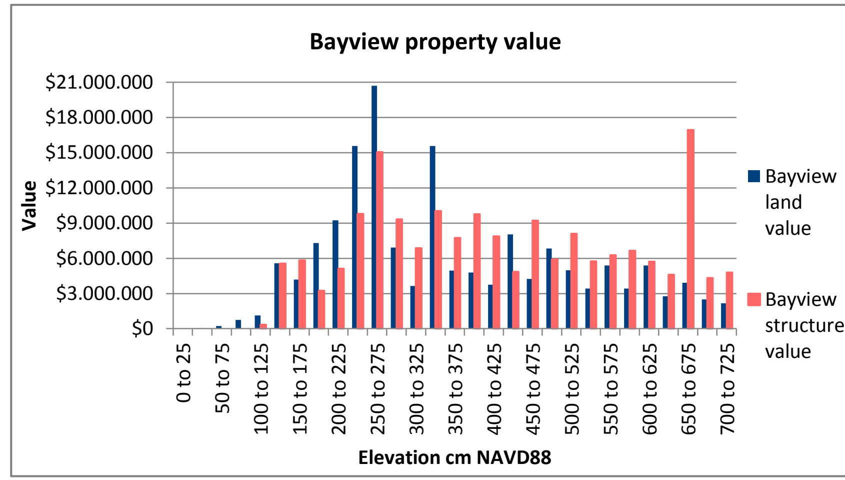
Results

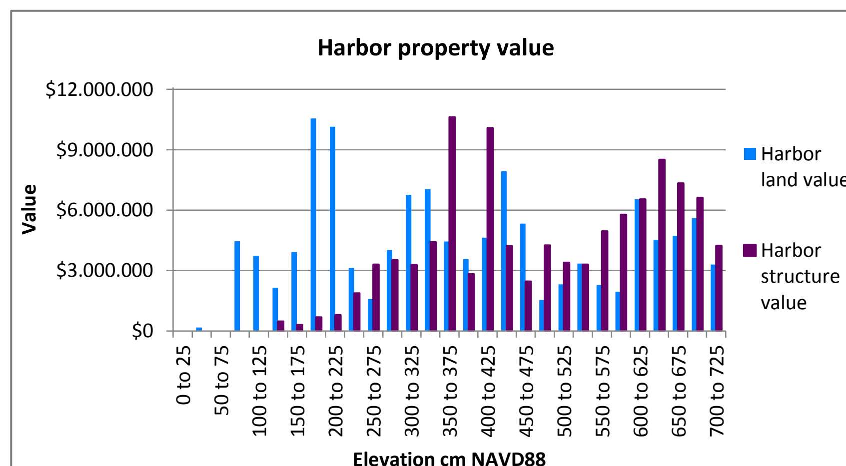
- Results highlight the difference between using MSL to assess damages as opposed to including the role of the tides
- Damage depends on where a property is actually located, not on the definition of sea level, however some damages may not be captured when insufficient consideration is given to the choice of water level

Year	Datum	Bayview land loss $	Bayview structure loss $	Harbor land loss $	Harbor structure loss $
2025	MSL	-	-	1,660	-
	MHW	1,023,220	96,170	5,204,150	-
	MHHW	1,574,540	254,240	7,861,750	-
	MST	2,967,890	258,310	8,416,550	-
	MPST	7,716,290	1,036,570	10,503,220	-
	HAAT	7,860,110	1,149,490	10,766,310	-
2050	MSL	-	-	1,660	-
	MHW	1,135,760	254,240	7,671,750	-
	MHHW	3,315,920	258,310	8,416,550	-
	MST	5,834,010	892,090	9,095,480	-
	MPST	10,821,050	2,558,785	12,661,579	-
	HAAT	10,988,110	2,944,355	12,764,569	-
2075	MSL	-	-	1,660	-
	MHW	3,315,920	258,310	8,416,550	-
	MHHW	7,017,040	899,540	9,604,420	-
	MST	9,281,710	1,243,850	11,136,310	-
	MPST	13,201,340	4,597,515	15,406,479	3,040
	HAAT	14,011,240	5,368,707	15,696,479	3,040
2100	MSL	2,700	-	176,290	-
	MHW	7,716,290	1,036,570	10,503,220	-
	MHHW	10,988,110	2,944,355	12,764,569	-
	MST	12,318,040	4,180,915	15,256,479	3,040
	MPST	17,221,340	7,917,365	24,698,558	223,090
	HAAT	19,210,760	8,691,018	24,976,208	223,090

Future SLR losses (with tides)

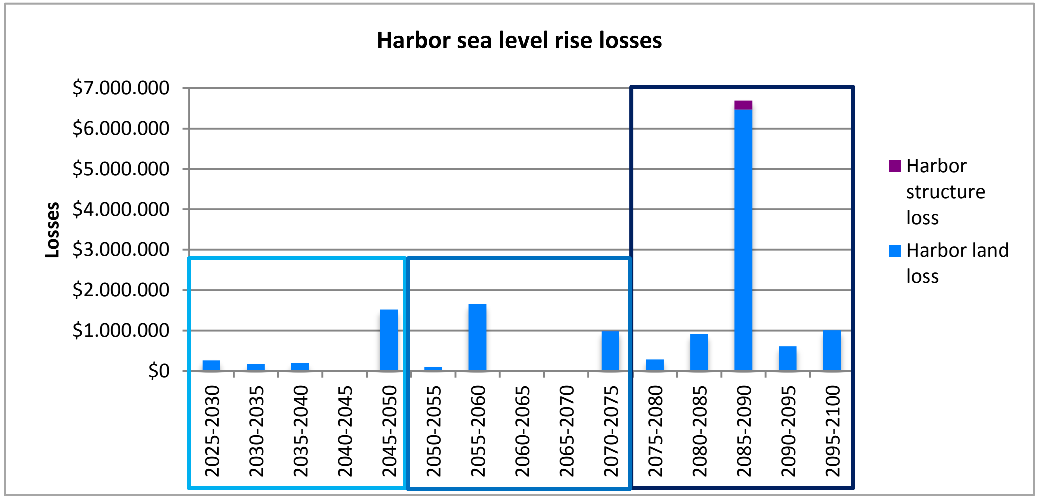


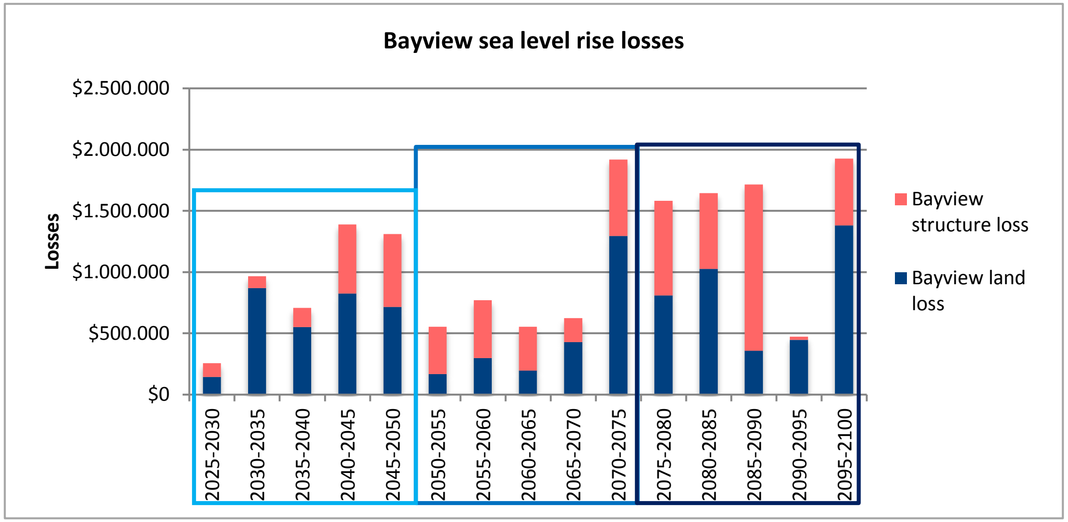




Year	Bayview land loss	Bayview structure loss	Harbor land loss	Harbor structure loss
2025	5%	1%	5%	0%
2050	7%	1%	6%	0%
2075	9%	2%	7%	0.001%
2100	11%	4%	12%	0.092%

Future SLR losses (with tides)





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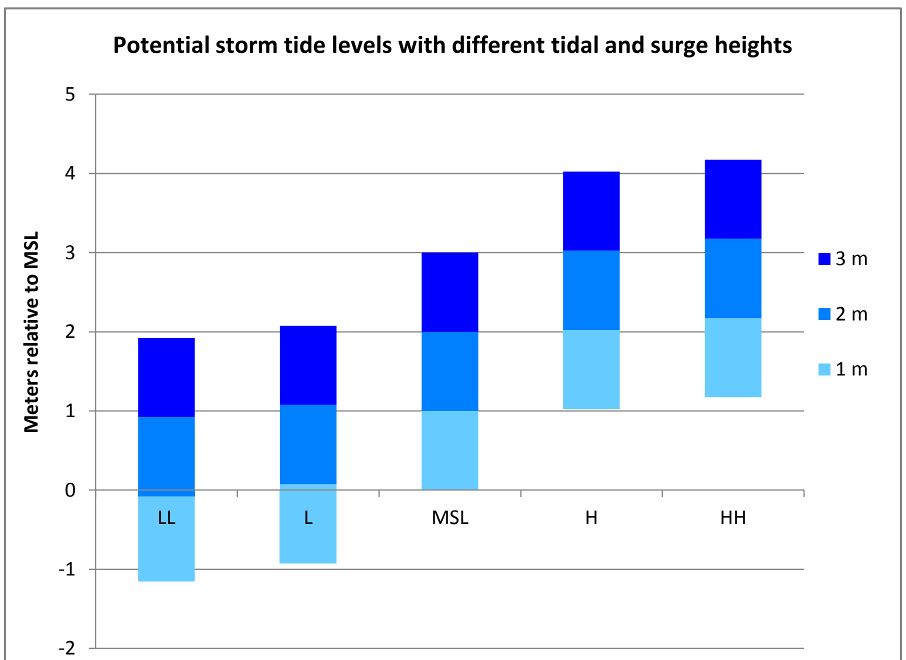
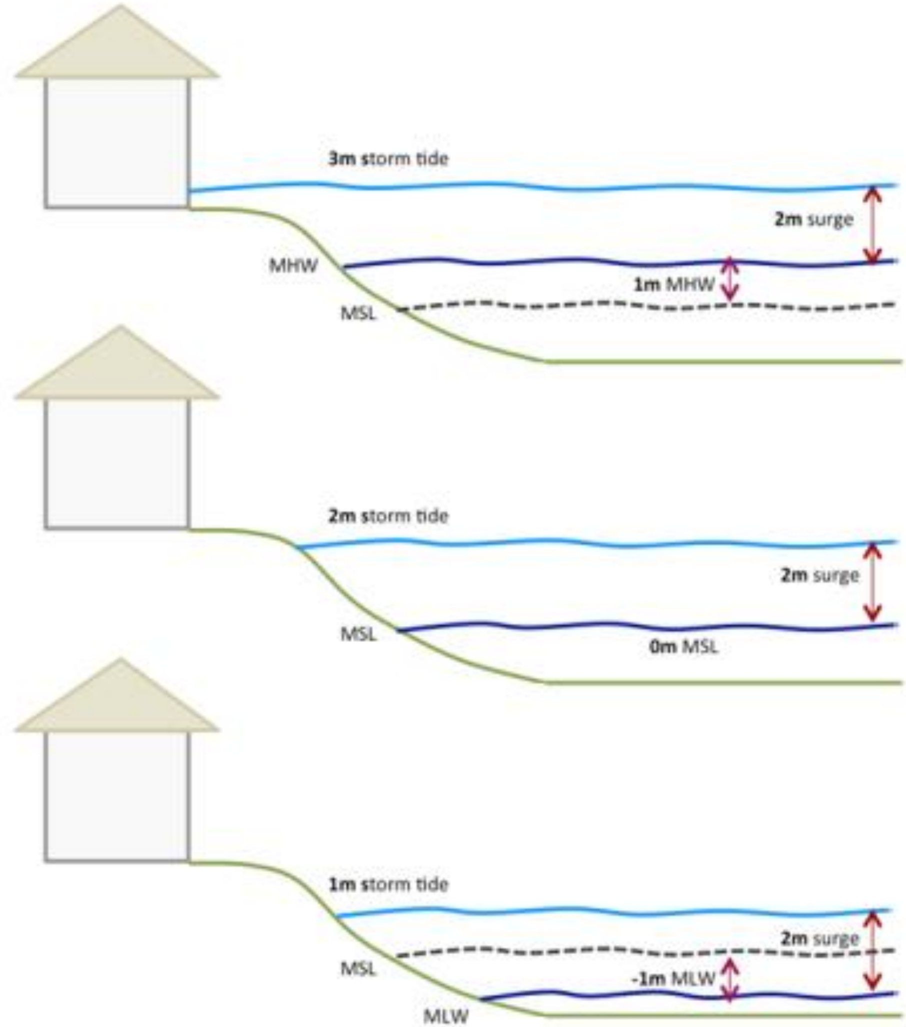
Storm tides

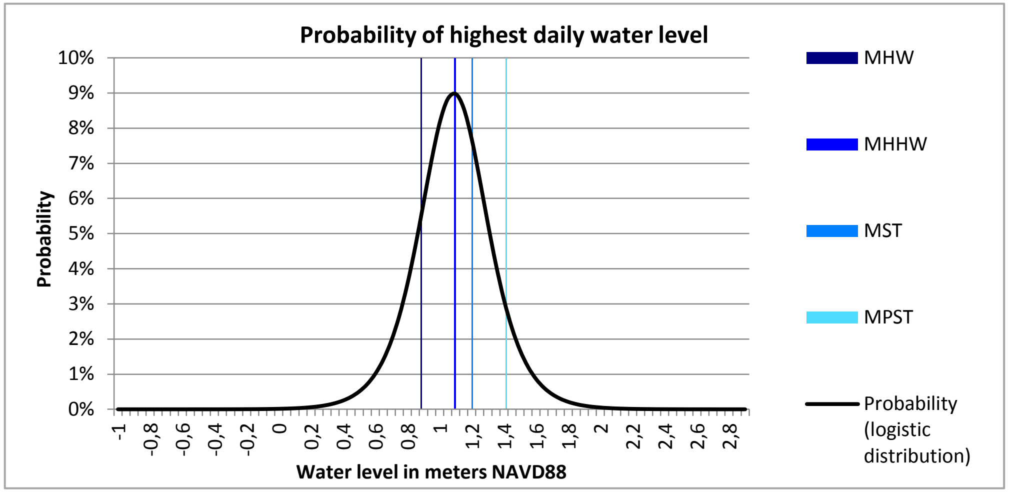
- Hurricanes & nor'easters
- Storm surge vs storm tide
- Importance of tidal level
- Probability of storm arriving at high, low, or mid tide

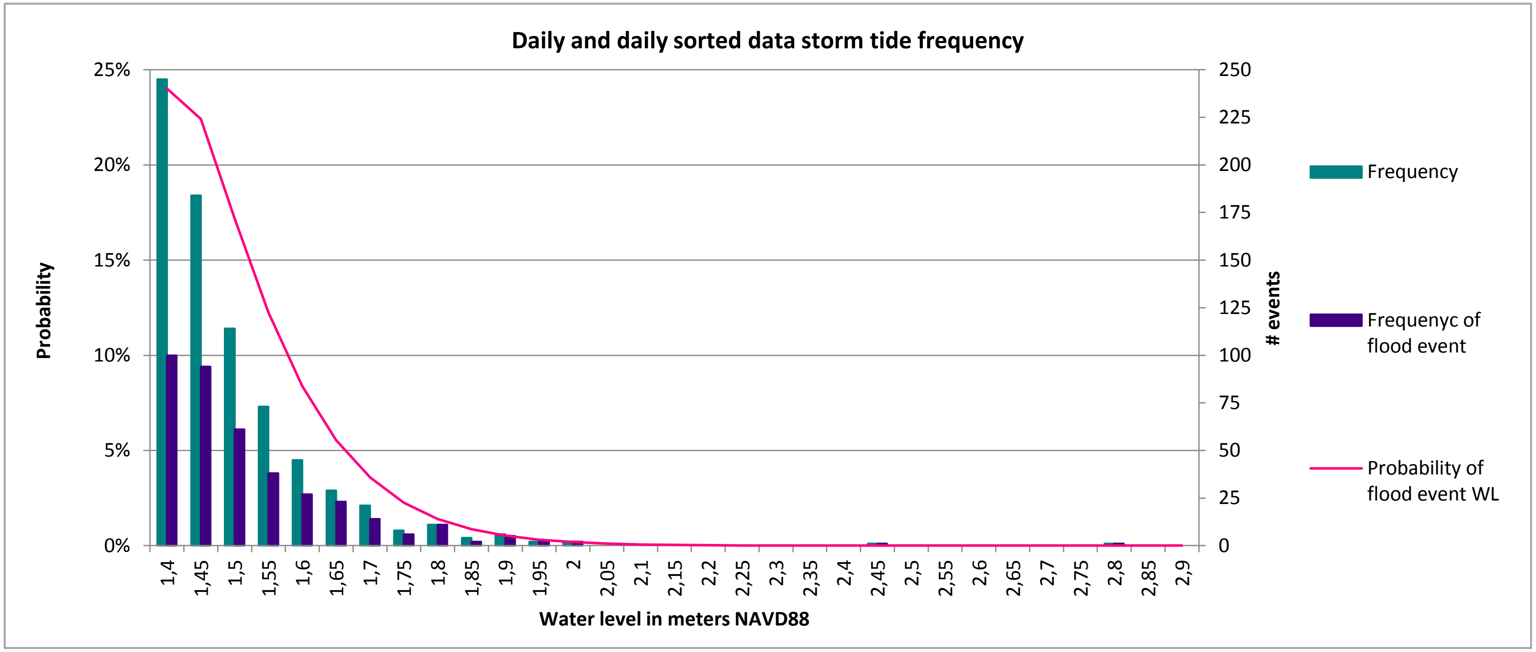




Storm tides

- High water events vs flood events
- Probability of occurring vs probability of causing damage

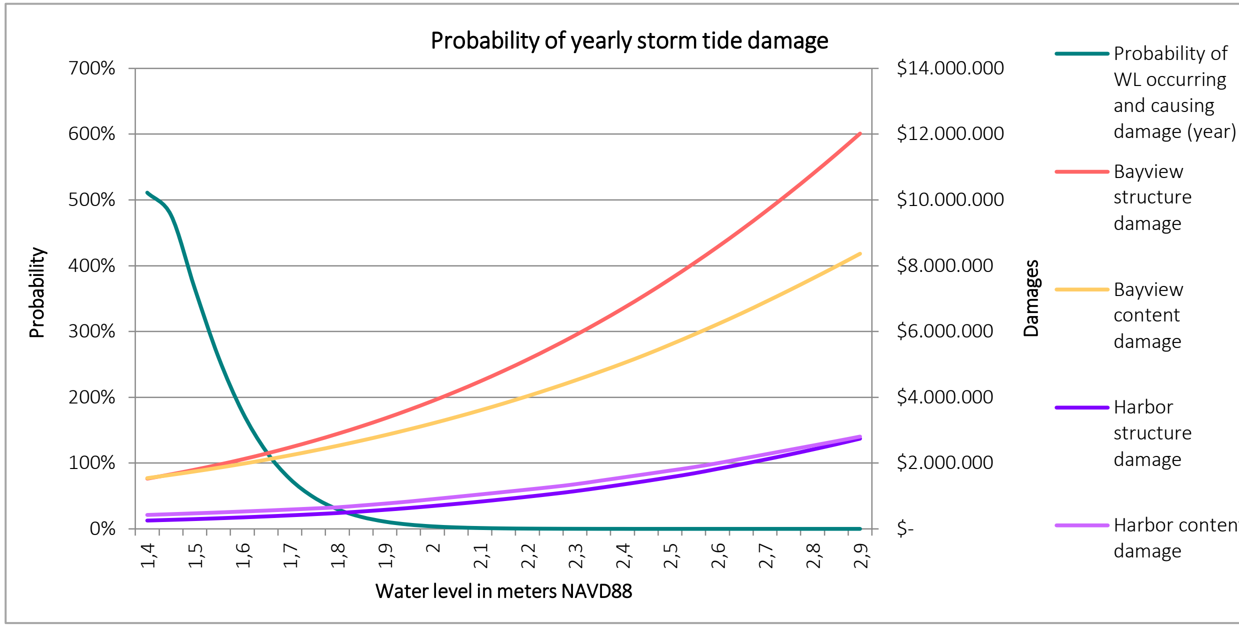


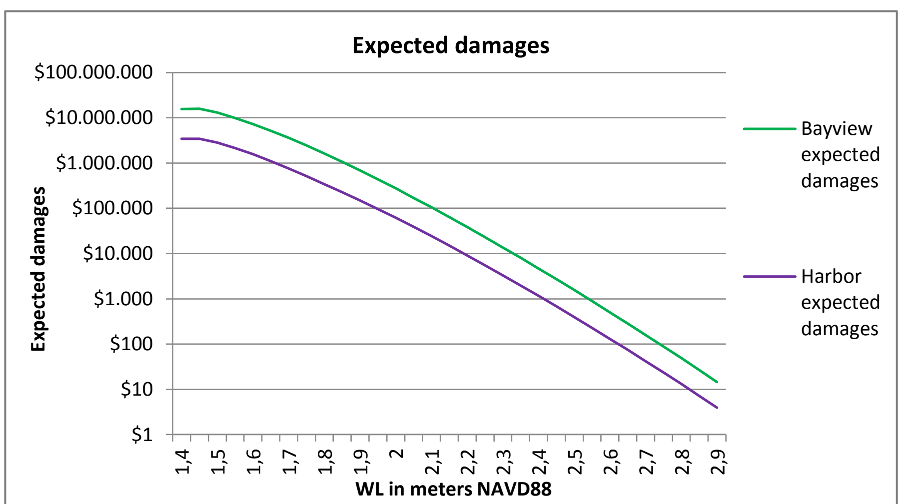


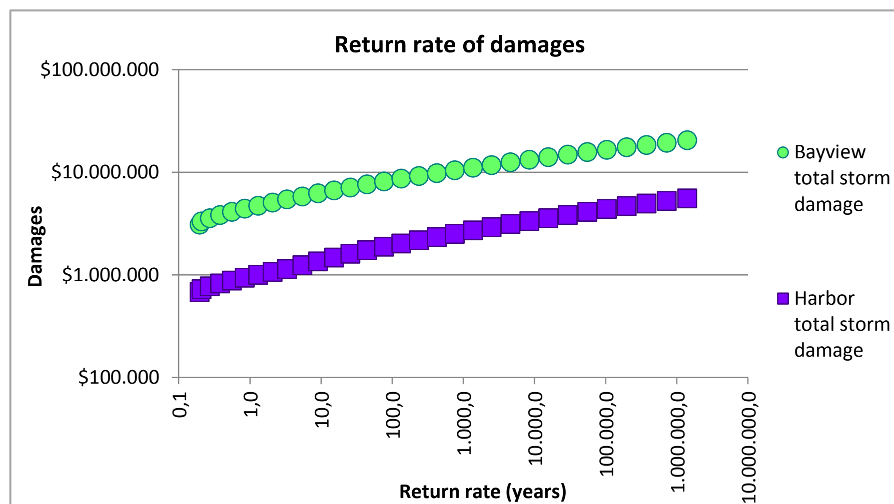
Storm tides

Results:

- Yearly probability of flood event and associated damages
- Return rate of damages
- Expected damages







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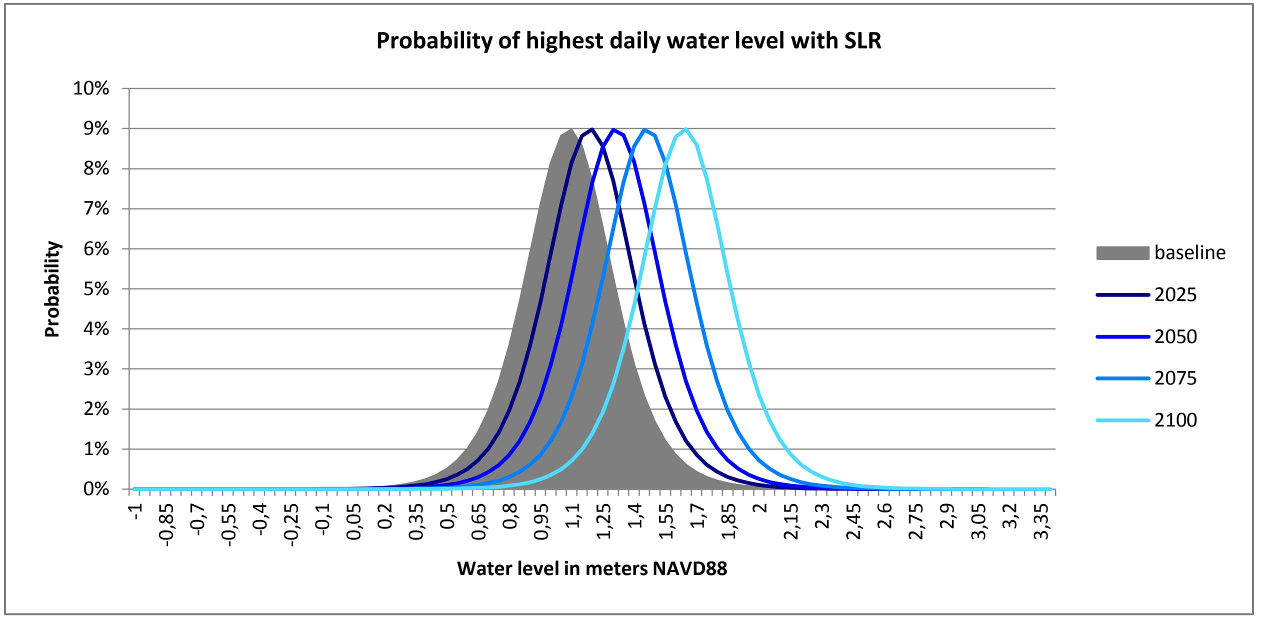
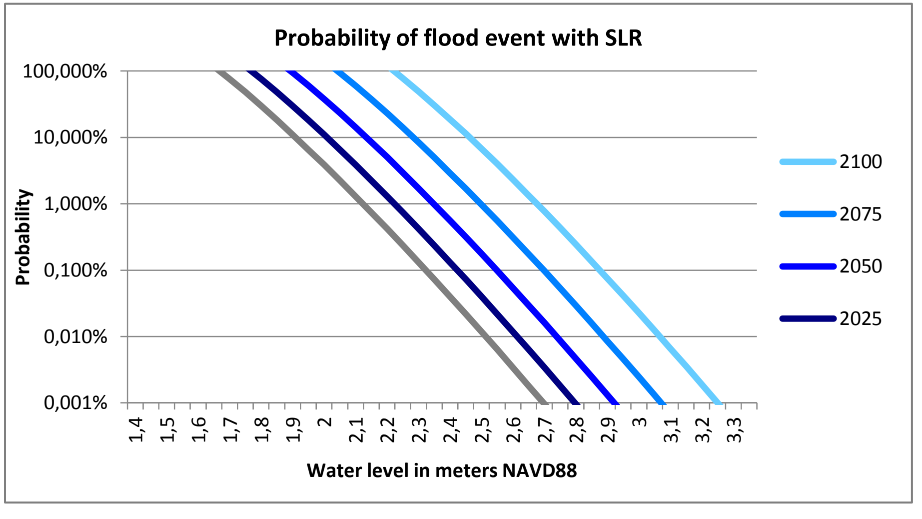
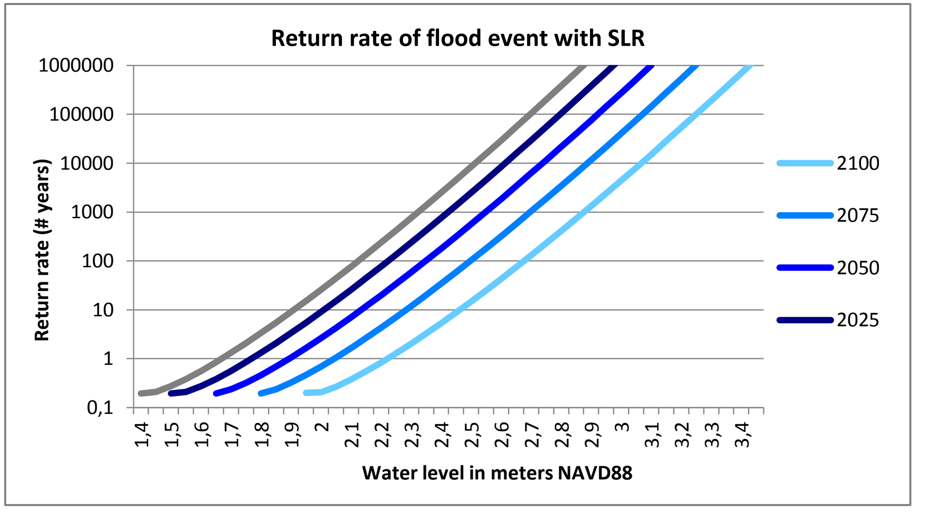
Storm tides with SLR

- Sea level rise
  - Probability of highest daily water level with SLR
  - Yearly probability of a storm tide occurring and causing damage
  - Return rate of flood event



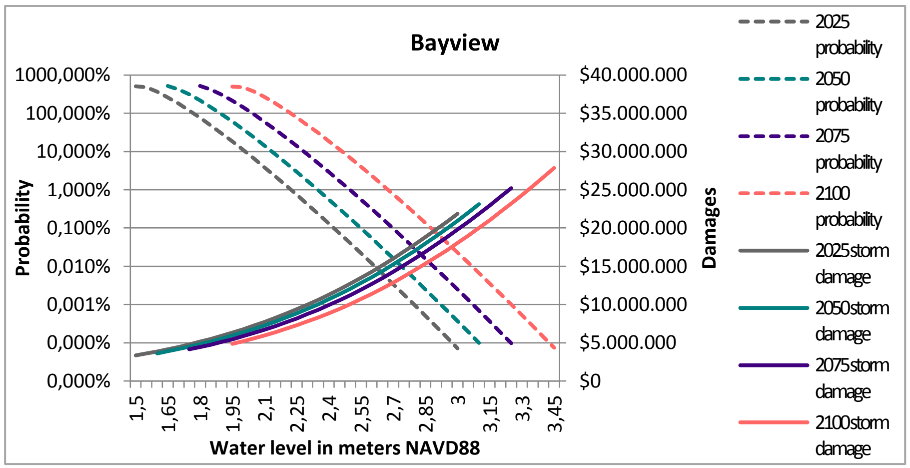


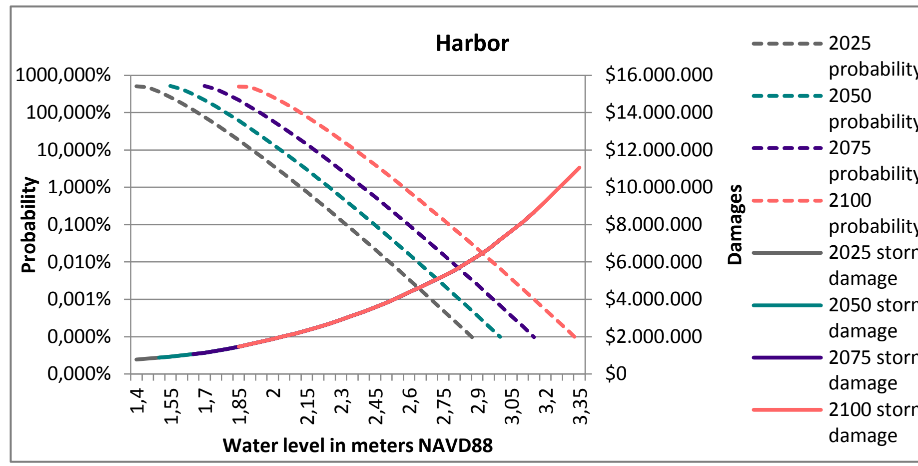


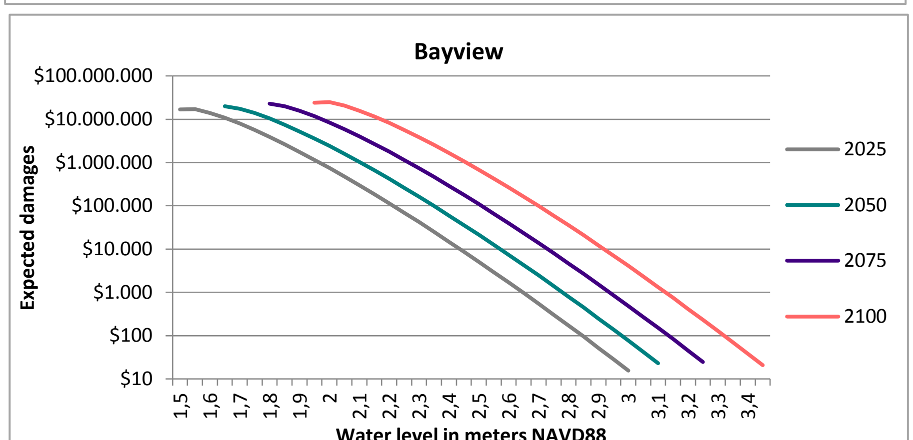
Storm tides with SLR

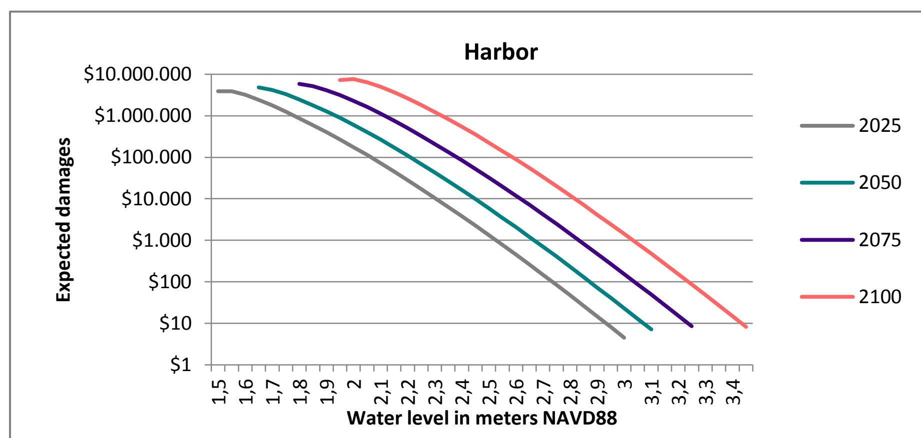
Results:

- Yearly probability of a flood event occurring and the potential damages
- Expected damages









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Conclusions

- Detailed model of coastal flooding damage
  - Incorporates tidal effects
  - Includes storms in probabilistic framework capturing distribution over time
  - Integrates effects of tides and storms
  - Includes sea level rise
- Amended flood damage assessment methodology to assess SLR losses, storm tide damages, and storm tide damages with sea level rise
  - Depth-damage functions
  - High resolution data
  - Tide gauge analysis

Thank you.

Questions or comments?

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