



**TEDEN SREDOZEMSKÉ OBALÉ  
IN MAKROREGIONALNIH  
STRATEGIJ**

Izola, Slovenija  
15. – 17. september 2025

**MEDITERRANEAN COAST  
AND MACRO-REGIONAL  
STRATEGIES WEEK**

Izola, Slovenia  
15 – 17 September 2025



# **DEVELOPMENT OF A METHOD FOR ASSESSING SEA LEVEL RISE AND FLOOD DAMAGE TO CULTURAL AND ARCHITECTURAL HERITAGE SITES IN THE SLOVENIAN ISTRIA REGION**

**ANDREJ KRYŽANOWSKI**

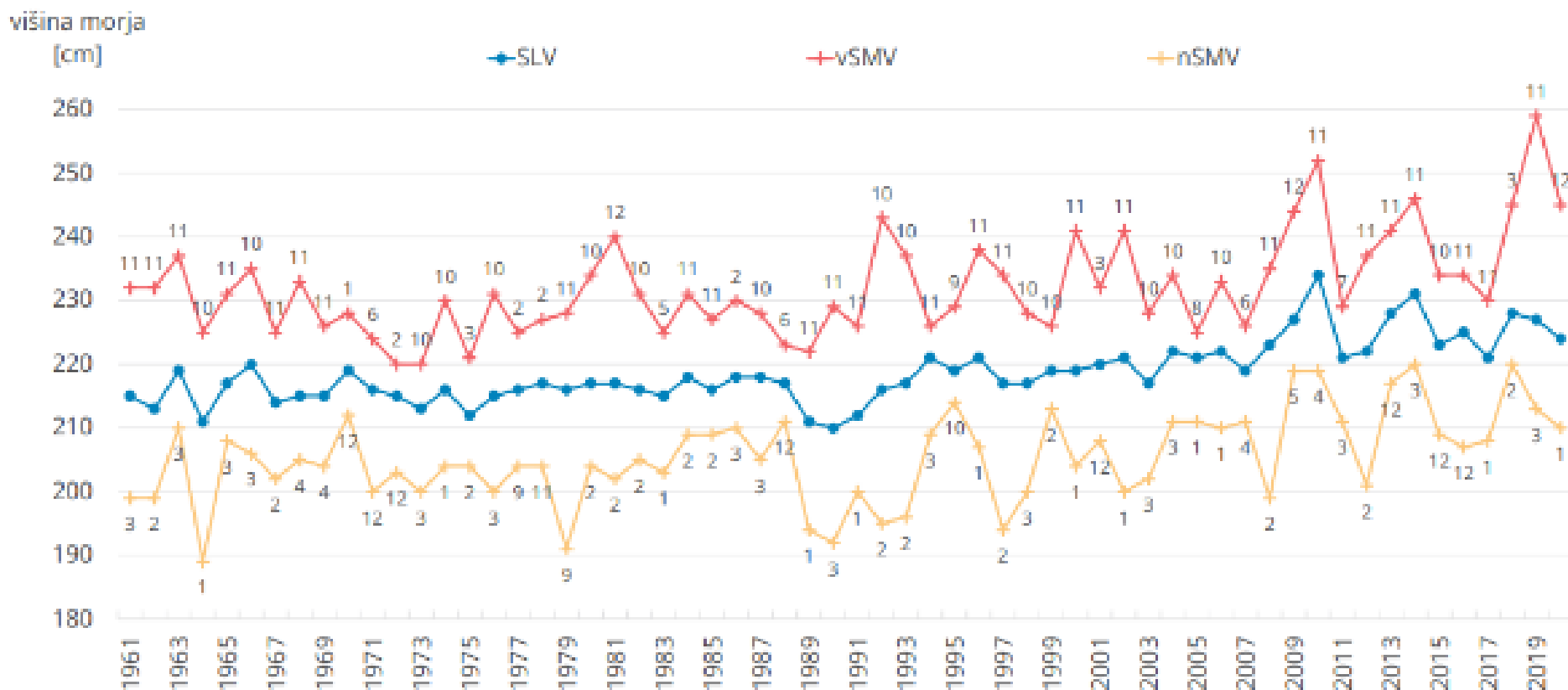
**UL FACULTY OF CIVIL ENGINEERING AND GEODESY**



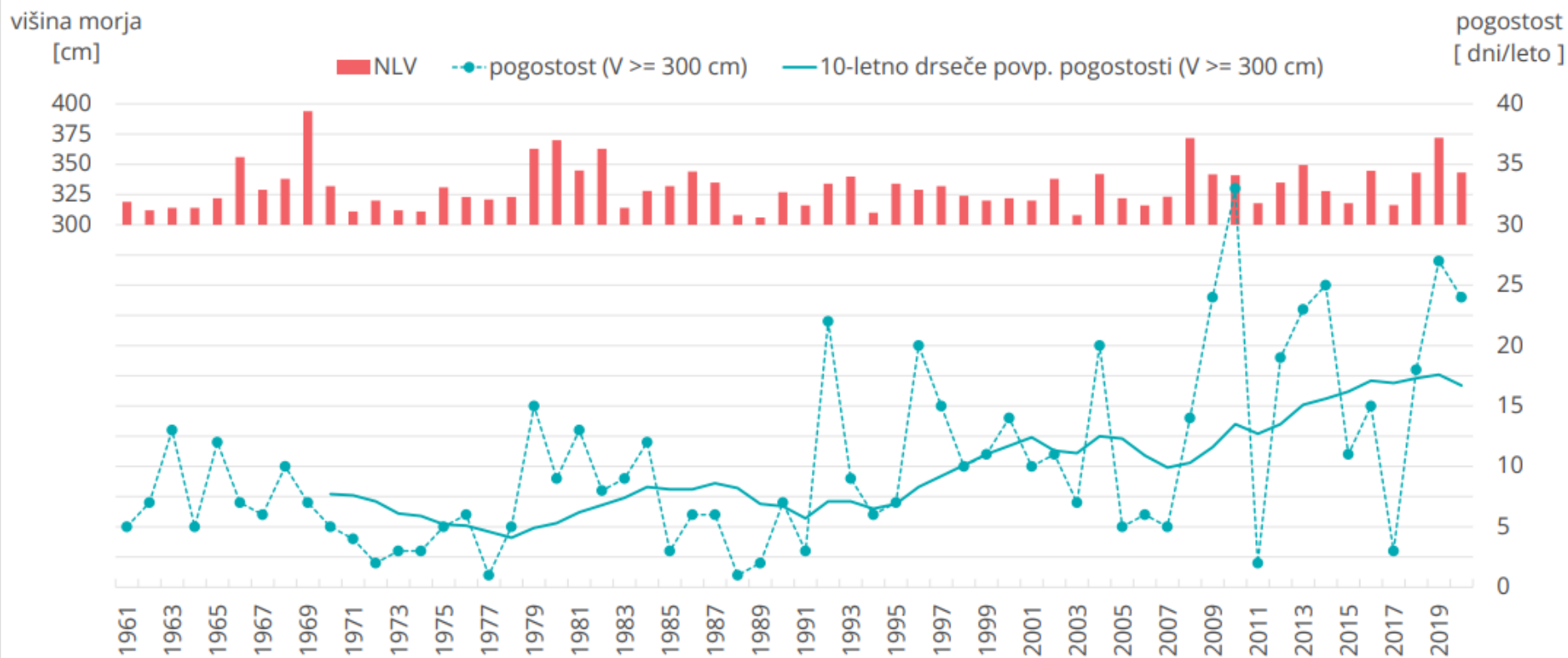
## PROJECT OBJECTIVES

1. Definition of characteristic flood events based on climate change scenario forecasts and actual records of extreme tidal events
2. Upgrade the existing methodology for calculating flood damage with the KR PAN application, which was developed for inland water flooding, to sea flooding, which differs significantly from inland water flooding in all sectors due to the numerous negative effects of seawater
3. Upgrading the methodology for determining flood damage to individual types of cultural heritage buildings and monuments, as well as cultural landscapes, as a result of sea flooding, taking into account the characteristic features of cultural heritage buildings and monuments in the coastal area of Slovenian Istria
4. Development of a special module in the KR PAN application for determining flood damage caused by the sea in areas of expected sea flooding, with the area of validity in the coastal area of Slovenian Istria

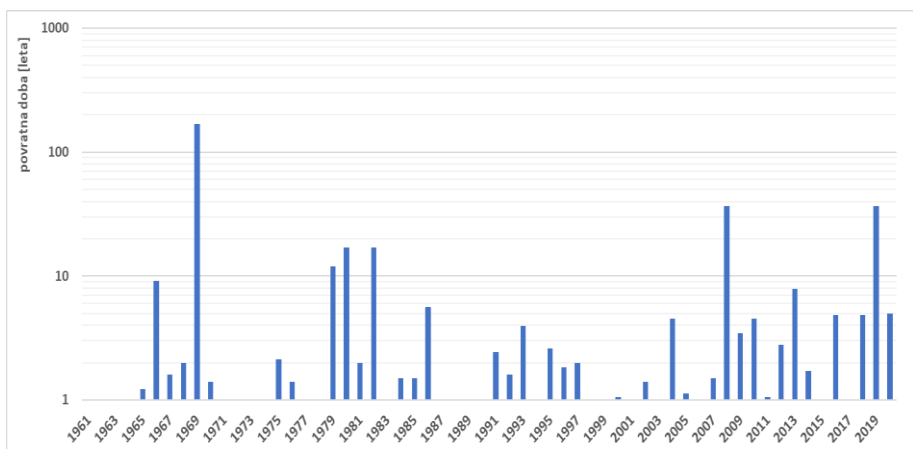
# DEFINITION OF CHARACTERISTIC FLOOD EVENTS - MSL



# DEFINITION OF CHARACTERISTIC FLOOD EVENTS – HIGHEST ANNUAL WATER LEVEL



# DEFINITION OF CHARACTERISTIC FLOOD EVENTS – HIGHEST SEA LEVEL



- The sea begins to flood the most exposed parts of the coast when the sea level at the tide gauge station in Koper is approximately **300 cm** (0.91 m) – this is the **yellow warning** level issued by ARSO.

- The sea begins to flood Tartini Square and the point in Piran when the sea level at the tide gauge station in Koper is **330 cm** (1.21 m), which corresponds to a two-year flood – this is the **orange warning** level issued by ARSO. The Piran marina is full.

- The sea completely floods Tartini Square in Piran when the sea level at the tide gauge station in Koper reaches **350 cm** (1.41 m), which corresponds to an eight-year flood – this is the level of the **red warning** issued by ARSO. The sea floods the Sečovlje and Strunjan salt pans, and the Piran peninsula and marina are under water.

Leto	Najvišja gladina morja [m]		Povratna doba [leta]	Leto	Najvišja gladina morja [m]		Povratna doba [leta]	Leto	Najvišja gladina morja [m]		Povratna doba [leta]
	vodomerna leta v Kopru	višina v državnem KS			vodomerna leta v Kopru	višina v državnem KS			vodomerna leta v Kopru	višina v državnem KS	
1961	3,19	1,10	1	1981	3,3	1,21	2	2001	3,11	1,02	1
1962	3,11	1,02	1	1982	3,61	1,52	17	2002	3,25	1,16	1
1963	3,14	1,05	1	1983	3,16	1,07	1	2003	3,05	0,96	<1
1964	3,13	1,04	1	1984	3,26	1,17	1	2004	3,42	1,33	5
1965	3,23	1,14	1	1985	3,26	1,17	1	2005	3,22	1,13	1
1966	3,52	1,43	9	1986	3,45	1,36	6	2006	3,16	1,07	1
1967	3,27	1,18	2	1987	3,09	1,00	<1	2007	3,26	1,17	1
1968	3,3	1,21	2	1988	3,05	0,96	<1	<b>2008</b>	<b>3,72</b>	<b>1,63</b>	<b>36</b>
<b>1969</b>	<b>3,94</b>	<b>1,85</b>	<b>168</b>	1989	3,2	1,11	1	2009	3,38	1,29	3
1970	3,25	1,16	1	1990	3,11	1,02	1	2010	3,42	1,33	5
1971	3,1	1,01	<1	1991	3,33	1,24	2	2011	3,21	1,12	1
1972	3,2	1,11	1	1992	3,27	1,18	2	2012	3,35	1,26	3
1973	3,14	1,05	1	1993	3,4	1,31	4	2013	3,5	1,41	8
1974	3,08	0,99	<1	1994	3,1	1,01	<1	2014	3,28	1,19	2
1975	3,31	1,22	2	1995	3,34	1,25	3	2015	3,18	1,09	1
1976	3,25	1,16	1	1996	3,29	1,2	2	2016	3,43	1,34	5
1977	3,2	1,11	1	1997	3,3	1,21	2	2017	3,17	1,08	1
1978	3,18	1,09	1	1998	3,2	1,11	1	2018	3,43	1,34	5
1979	3,56	1,47	12	1999	3,19	1,10	1	<b>2019</b>	<b>3,72</b>	<b>1,63</b>	<b>36</b>
1980	3,61	1,52	17	2000	3,21	1,12	1	2020	3,433	1,343	5



# DEFINITION OF CHARACTERISTIC FLOOD EVENTS – MSL RISE SCENARIOS

- S1** current situation – baseline,
- S2** sea level rise according to regional projections (NASA/IPCC) for a period of up to 10 years **0.05 m**,
- S3** SGM increase according to regional projections (NASA/IPCC) for a period of 10 to 30 years **0.1 m**,
- S4** SGM increase according to regional projections (NASA/IPCC) for a period of over 30 years **0.2 m**,
- S5** SGM increase according to regional projections (NASA/IPCC) for the period from 30 to 50 years **0.3 m**,
- S6** SGM increase according to regional projections (NASA/IPCC) for the period over 50 years **0.4 m**,
- S7** pessimistic greenhouse gas emissions scenario (RCP8.5): Compared to the average for the period 1986-2005, the expected minimum sea level rise along the Slovenian coast by the end of the century (2100) is **0.61 m**,
- S8** Pessimistic greenhouse gas emissions scenario (RCP8.5): Compared to the 1986-2005 average, the expected average sea level rise along the Slovenian coast by the end of the century (2100) is **0.84 m**.
- S9** pessimistic greenhouse gas emissions scenario (RCP8.5): Compared to the average for the period 1986-2005, the expected maximum sea level rise along the Slovenian coast by the end of the century (year 2100) is **1.10 m**.
- S10** pessimistic greenhouse gas emissions scenario (RCP8.5): Compared to the 1986-2005 average, the expected average sea level rise according to Kopp (2017) by the end of the century (2100) is **1.46 m**.

# SEA LEVEL HEIGHTS FOR DIFFERENT RETURN PERIODS IN MSL RISE CALCULATION SCENARIOS

Povratna  
doba  
poplave  
morja

Višine gladine morja v državnem višinskem KS [m] za različne povratne dobe  
pri računskih scenarijih dviga [cm] SGM

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
[leta]	0	5	10	20	30	40	61	84	110	146
1	1,11	1,16	1,21	1,31	1,41	1,51	1,72	1,95	2,21	2,57
2	1,19	1,24	1,29	1,39	1,49	1,59	1,80	2,03	2,29	2,65
5	1,34	1,39	1,44	1,54	1,64	1,74	1,95	2,18	2,44	2,80
10	1,46	1,51	1,56	1,66	1,76	1,86	2,07	2,30	2,56	2,92
20	1,56	1,61	1,66	1,76	1,86	1,96	2,17	2,40	2,66	3,02
25	1,59	1,64	1,69	1,79	1,89	1,99	2,20	2,43	2,69	3,05
50	1,69	1,74	1,79	1,89	1,99	2,09	2,30	2,53	2,79	3,15
100	1,79	1,84	1,89	1,99	2,09	2,19	2,40	2,63	2,89	3,25
500	1,99	2,04	2,09	2,19	2,29	2,39	2,60	2,83	3,09	3,45
1.000	2,10	2,15	2,20	2,30	2,40	2,50	2,71	2,94	3,20	3,56

# CHANGES IN SEA FLOOD RETURN PERIODS, TAKING INTO ACCOUNT MSL RISE SCENARIOS

Višina gladine morja na vodomerni letvi v Kopru	Višina gladine morja v državnem višinskem KS	Povratna doba poplave morja [leta] ob različnih scenarijih dviga [cm] SGM									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
[m]	[m]	0	5	10	20	30	40	61	84	110	146
3,20	1,11	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
3,28	1,19	2	1,2	<1	<1	<1	<1	<1	<1	<1	<1
3,43	1,34	5	3,3	2,4	1,2	<1	<1	<1	<1	<1	<1
3,55	1,46	10	7,6	5,4	2,7	1,4	<1	<1	<1	<1	<1
3,65	1,56	20	15,3	10,8	5,4	2,7	1,4	<1	<1	<1	<1
3,68	1,59	25	18,8	13,3	6,7	3,3	1,7	<1	<1	<1	<1
3,78	1,69	50	37,6	26,6	13,3	6,7	3,3	<1	<1	<1	<1
3,88	1,79	100	75,2	53,2	26,6	13,3	6,7	1,6	<1	<1	<1
4,08	1,99	500	300,3	212,4	106,3	53,2	26,6	6,2	1,3	<1	<1
4,19	2,10	1.000	643,4	455,0	227,6	113,9	57,0	13,3	2,7	<1	<1



# DEFINITION OF CHARACTERISTIC WAVES OF THE SEA – IMPACT OF WAVES

## Phenomena related to sea level at a given return period:

1. **Average sea level MSL** baseline taking into account the growth trend according to the assumed scenarios
2. **Astronomical tides** tidal fluctuations do not exceed **1.4 m** and no changes in the regime are expected
3. **Meteorological sea level rise** wind surge during prolonged winds – around **0.8 m** in the Gulf of Trieste (W, E)
4. **Inverse barometric effect** compensation for air pressure change  $\sim 1 \text{ cm/hPa}$ ,
5. **Seiche** result of the sea's own oscillation – around **0.4 m** in the Gulf of Trieste,
6. **Subinertial surface fluctuations** rotational movement of the sea due to wind, etc., which can reach up to **0.1m**

## Wind-related phenomena:

7. **Wind waves** maximum waves do not exceed **4.8 m** (SE), a 5% increase is expected due to climate change
8. **Shallow water and wave breaking** transformation and breaking of waves along the coast
9. **Wave deflection and scattering** occurrence of coastal currents and wave concentration on convex or wave scattering on concave parts of the coast
10. **Water stagnation (set-up) and wave reach (run-up)**



# DEFINITION OF CHARACTERISTIC FLOOD EVENTS – IMPACT OF WAVES



Piran – Pirano 1964



Piran – Pirano 1964

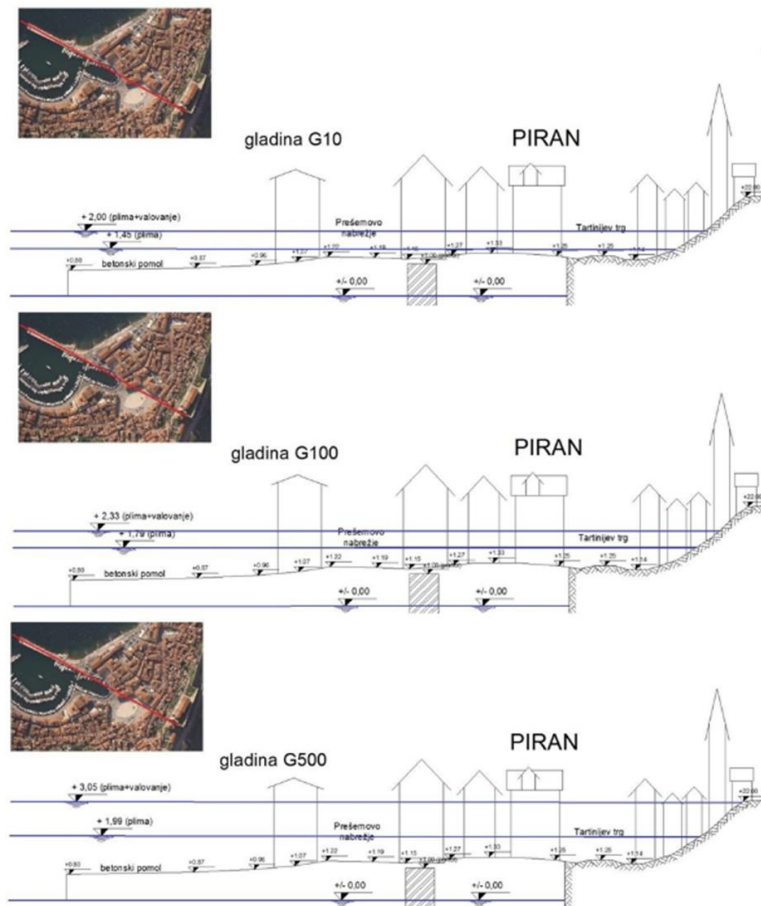


Piran – Pirano



Piran – Pirano 1966

# MAXIMUM SEA LEVELS, TAKING INTO ACCOUNT TIDES AND WAVES, FOR THE URBAN AREA OF PIRAN



Povratna doba [leta]	Višina plime [m]	Amplituda valovanja [m]	Maksimalna vrednost val+plima [m]	Povratna doba [leta]
10	1,46	0,54	2,00	500
100	1,79	0,54	2,33	~5.000
500	1,99	1,06	3,05	~500.000

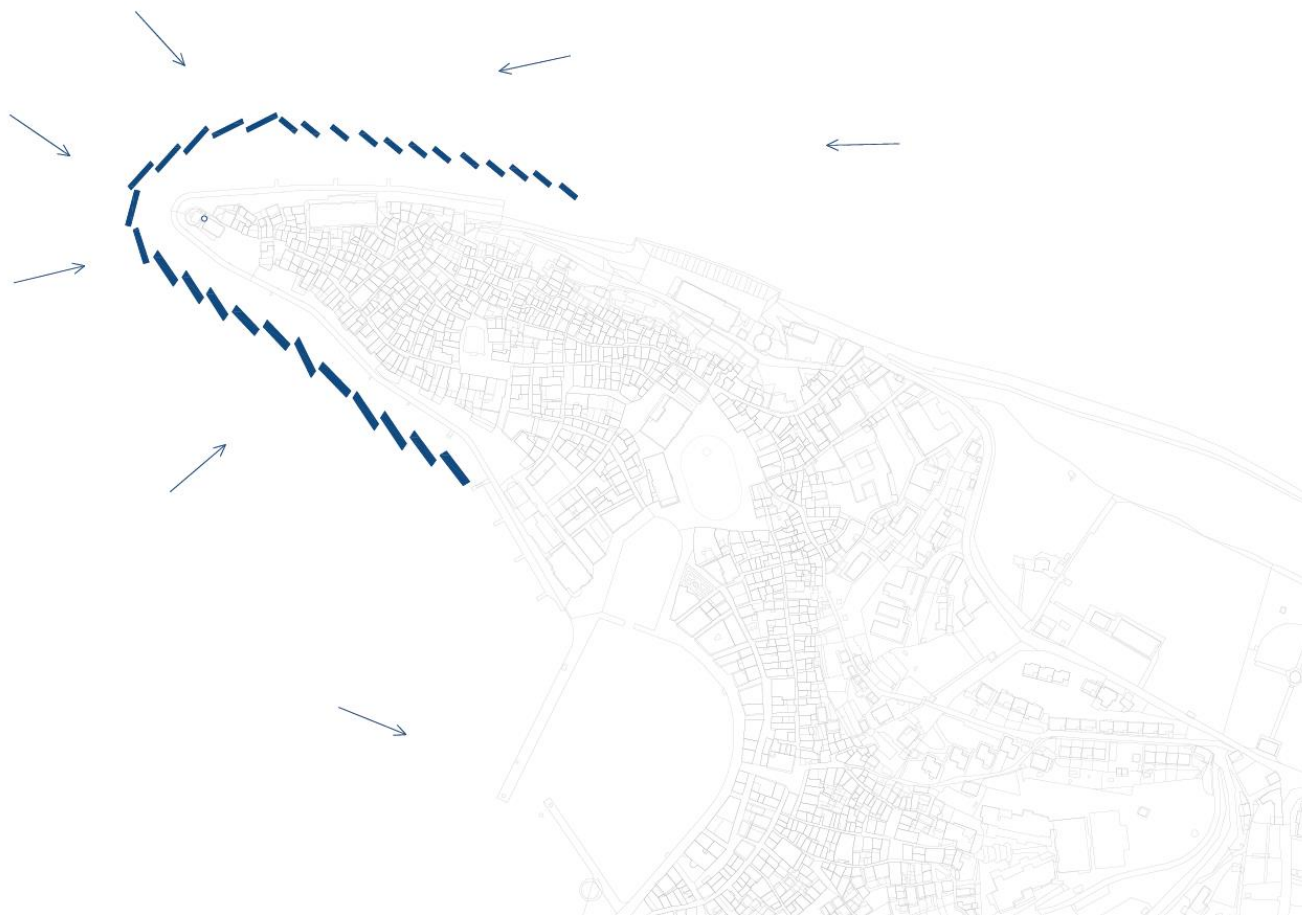


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# PRESENTATION OF A SET OF MEASURES FOR WAVE TRANSFORMATIONS IN THE URBAN AREA OF PIRAN





## UPGRADING THE METHODOLOGY FOR DETERMINING THE FDI ON BUILDINGS OF CULTURAL HERITAGE – FVI INDEX

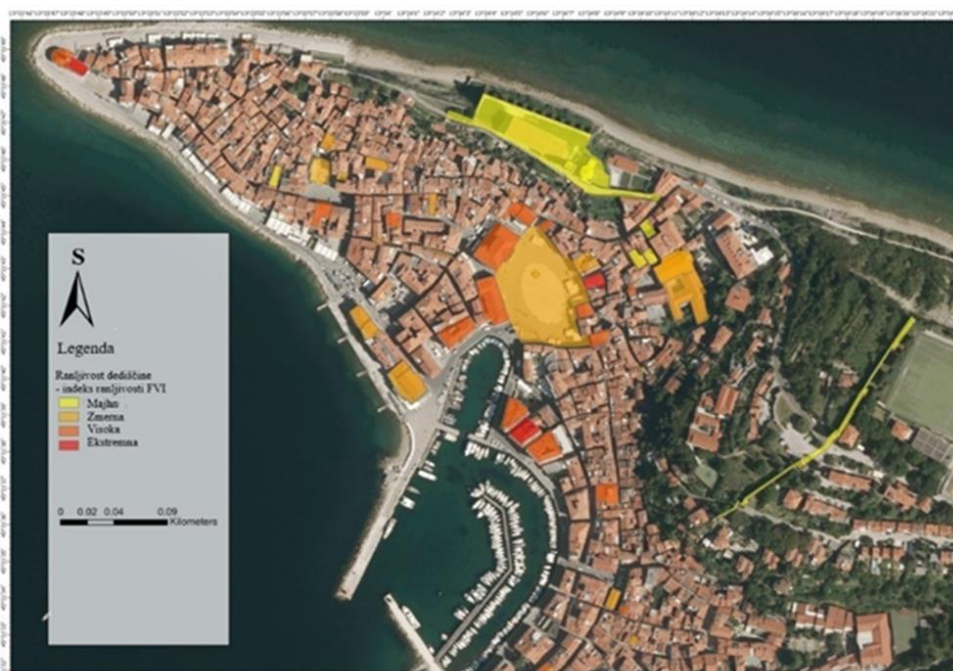
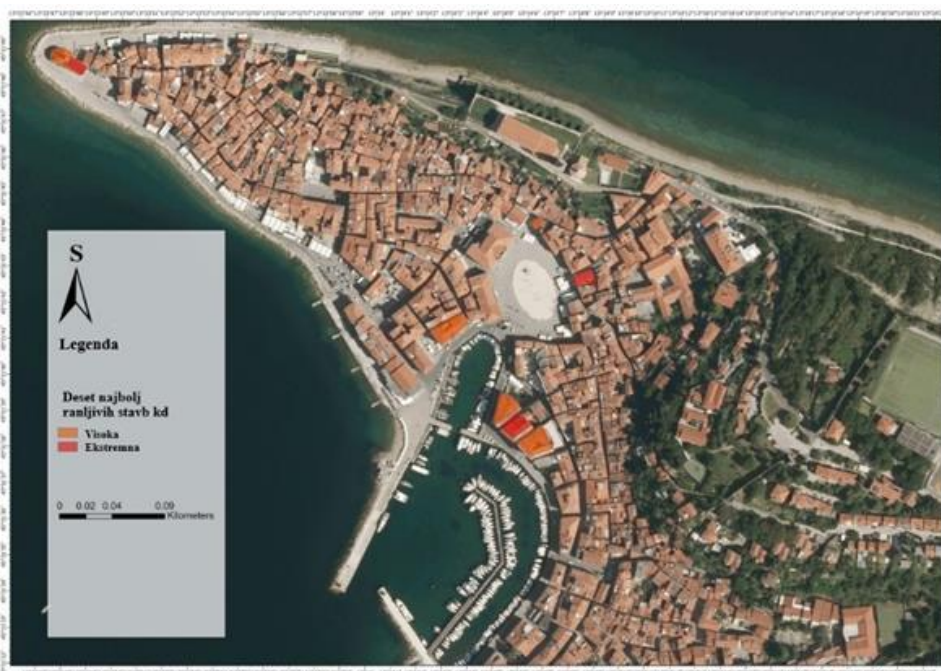
- **FVI – the flood vulnerability index** is defined as:  $FVI = \text{exposure} * \text{vulnerability}$
- The following **vulnerability parameters** were selected for the area of Piran in the analysis:
  - (1) **heritage status** (exceptional or general), (2) **number of floors** (1, 2, 3 or 4 and more), (3) **material** (flysch, masonry sandstone, exposed bricks or limestone and other vulnerable materials), (4) **presence of wall decorations**, (5) presence of stone or limestone **facade base**, (6) **condition** (well preserved, slightly damaged or damaged), (7) **recent renovation** (if any), and (8) **age** (up to the 15th century or from the 16th to the 20th century)
- And **exposure parameters** based on their location: (1) elevated area not exposed to the sea; (2) low-lying area not exposed to the sea; and (3) low-lying area exposed to the sea



# UPGRADING THE METHODOLOGY FOR DETERMINING THE ED ON BUILDINGS OF CULTURAL HERITAGE – FVI INDEX

The 10 most vulnerable cultural heritage buildings in Piran according to the FVI

Flood vulnerability index classes for cultural heritage buildings in Piran





## EXPECTED DAMAGE ESTIMATION - SPECIFIC CHARACTERISTICS OF SEA FLOODS

- **Corrosiveness of salt water:** salt water damages infrastructure more quickly, especially metal elements (bridges, vehicles, machinery) and concrete, which increases restoration costs
- **Long-term soil degradation:** salt water can contaminate agricultural land and destroy the fertile soil layer, making recovery from flooding more difficult and reducing agricultural productivity.
- **Intrusion into groundwater:** salt water can contaminate drinking water sources, which can cause long-term problems with drinking water supply.
- **Presence of wave erosion processes:** strong waves and seawater can accelerate the erosion of coastal areas, increasing the risk of landslides and long-term land loss.
- **more difficult cleaning and remediation:** after saltwater flooding, removing debris and drying buildings is more difficult because salt remains in walls, wooden structures, and materials, causing further damage
- Default value - **+15%** compared to inland water flooding

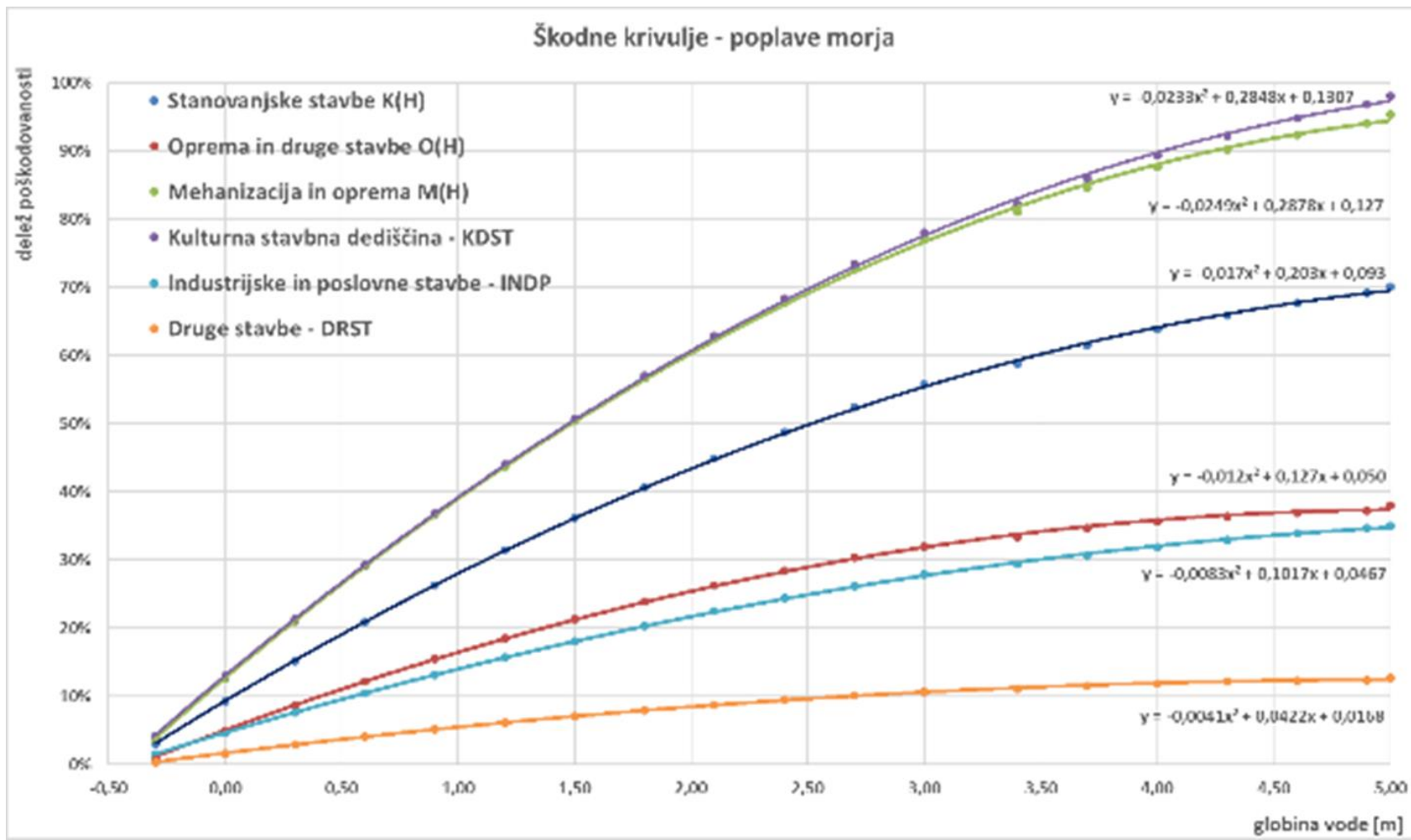


## EXPECTED DAMAGE ESTIMATION

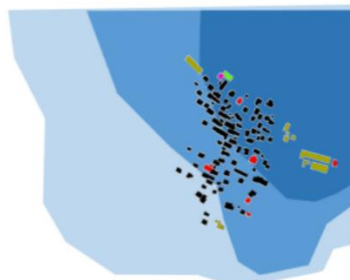
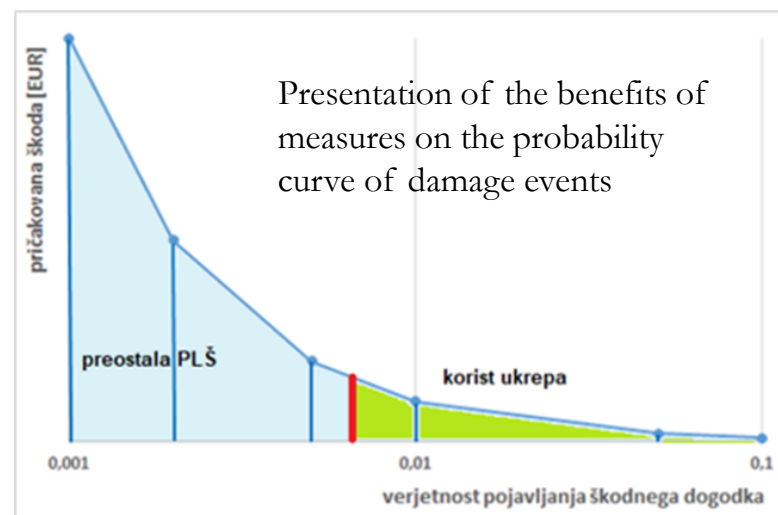
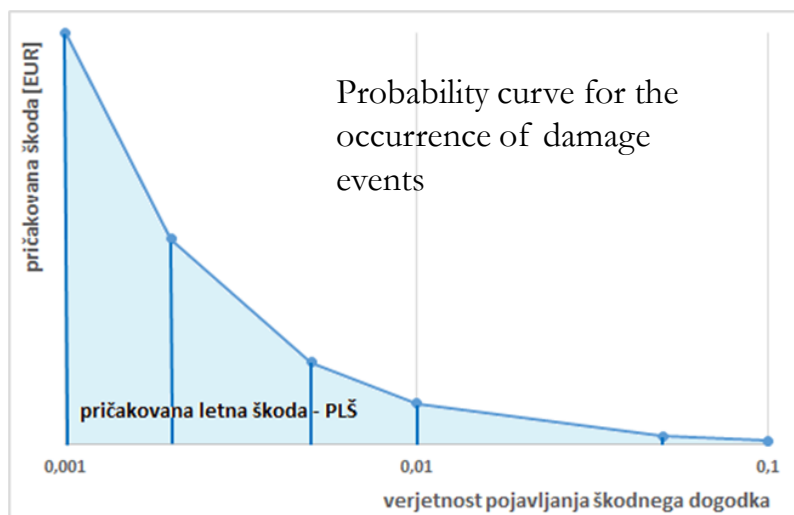
- The dimension** indicates the extent, number, or size of endangered persons in a selected area during a specific period
  - area of flooded entities within the reach of sea floods
  - length of the flooded entity within the reach of sea floods
  - the number of people at risk located within the reach of sea flooding
  - the average number of people at risk located within the reach of sea flooding
- Exposure** is the probability of the presence of people at risk in a selected area during a specific period.
- Vulnerability** is the structural damage to people at risk in a selected area when a dangerous event of a certain intensity occurs
- Magnitude** of a flood event is expressed by the depth of water in the area where people at risk are located in the sea flood zone
- The value** is the indexed prices from the basic KR PAN application from 2019 – the starting construction price is **EUR 1,680** for buildings and **EUR 2,352** for cultural heritage buildings



# DAMAGE CURVE



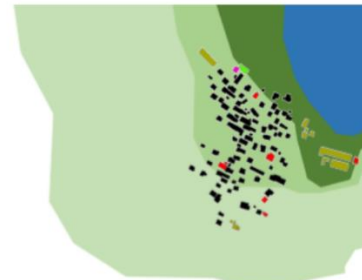
## EXPECTED ANNUAL DAMAGE CURVE



Before measure.

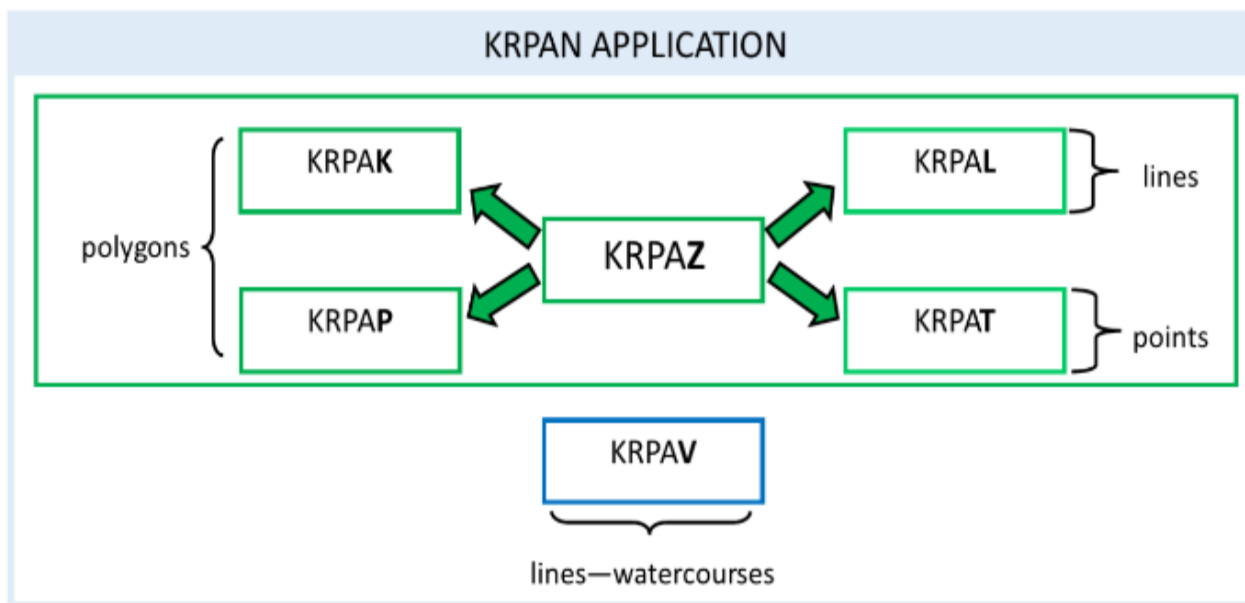


After measure.



Difference = Benefit.

## UPGRADE OF THE KRPAK APPLICATION





## AREA OF APPLICABILITY





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## FLOOD HAZARD MAPS

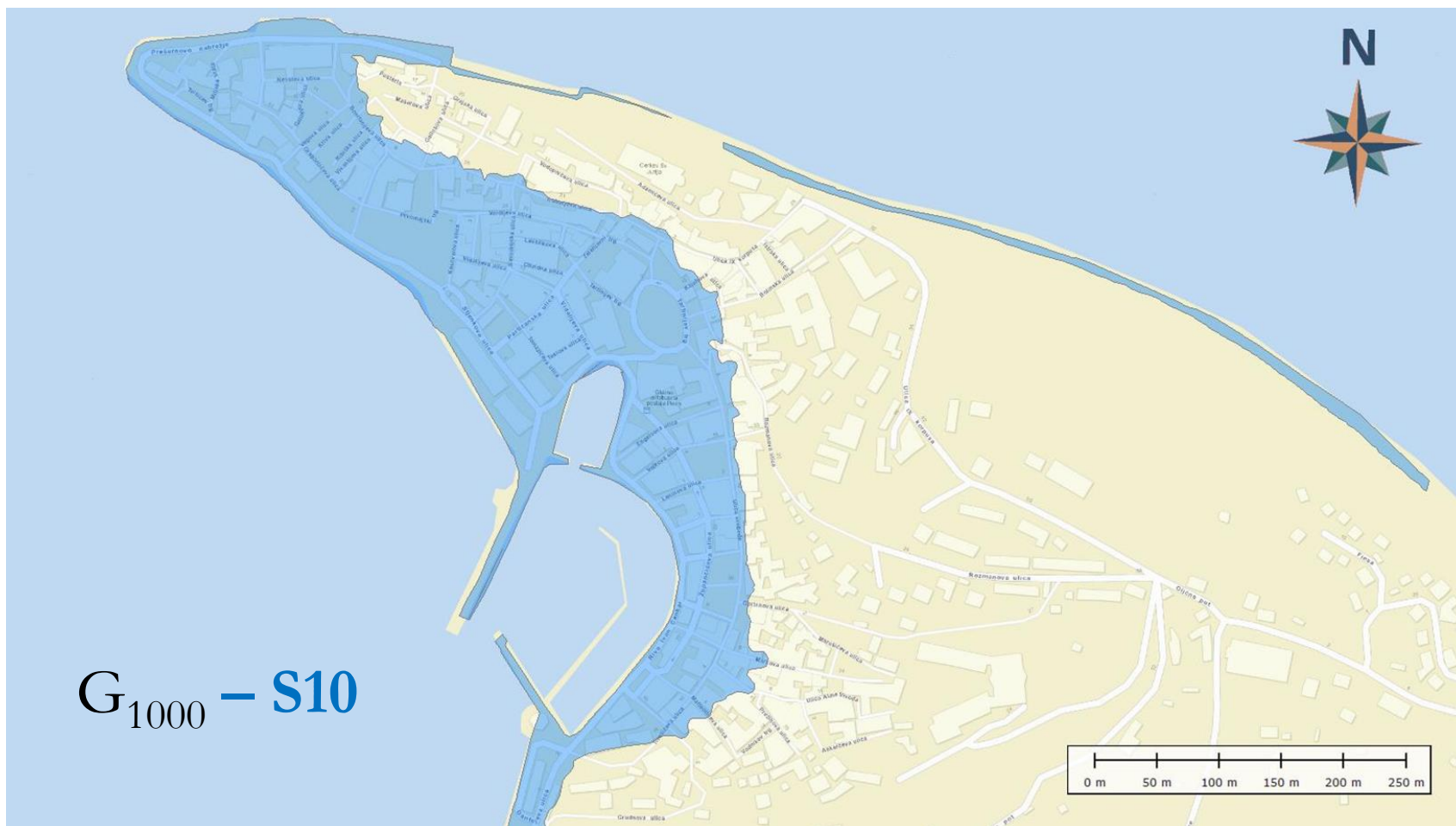
$G_{1000} - S10$



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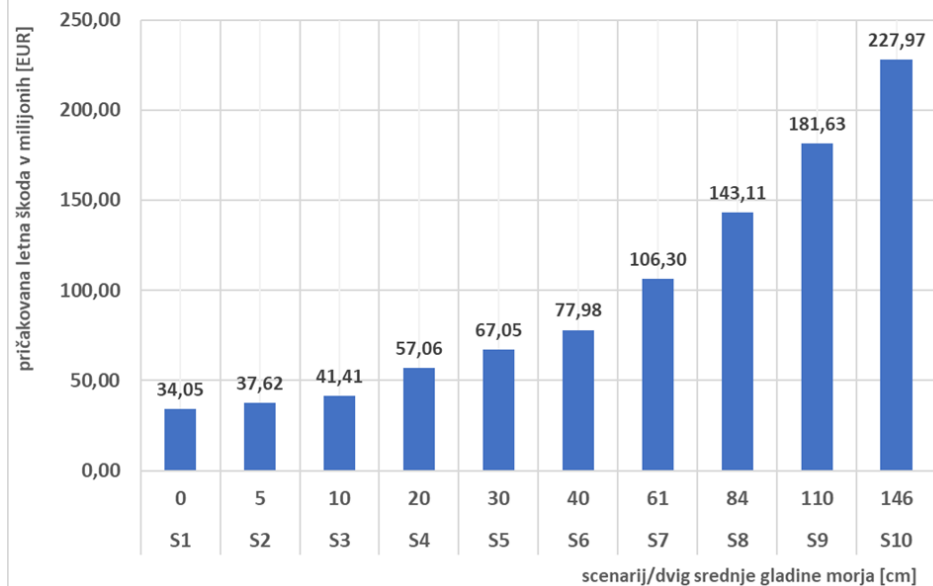
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## FLOOD HAZARD MAPS

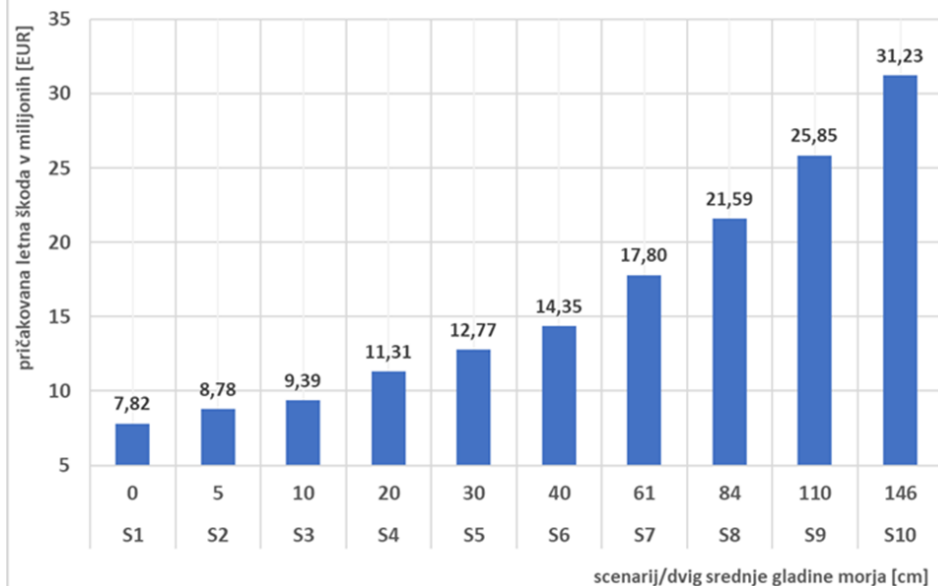


## EAD VALUES

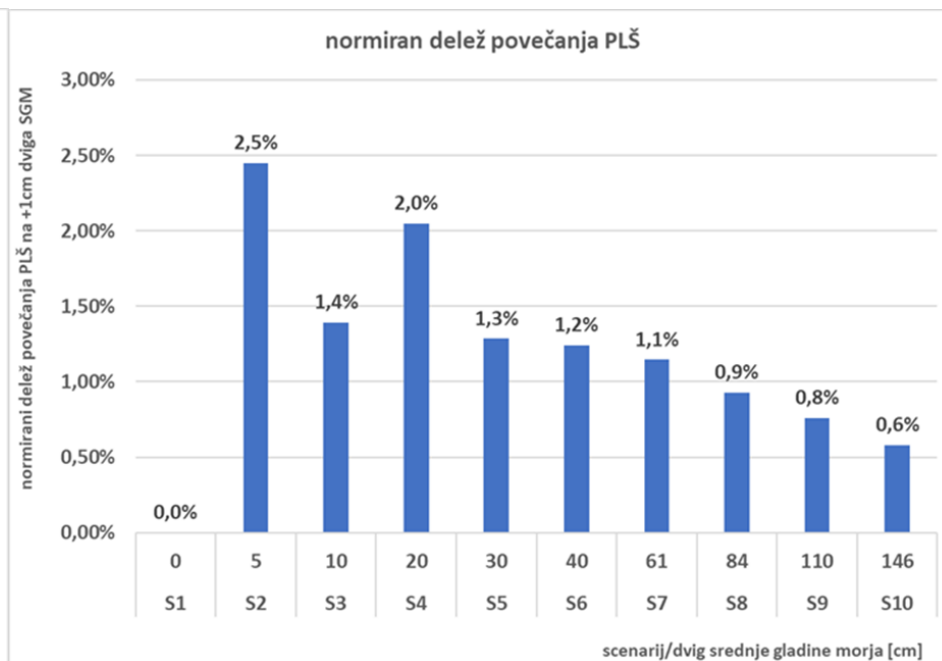
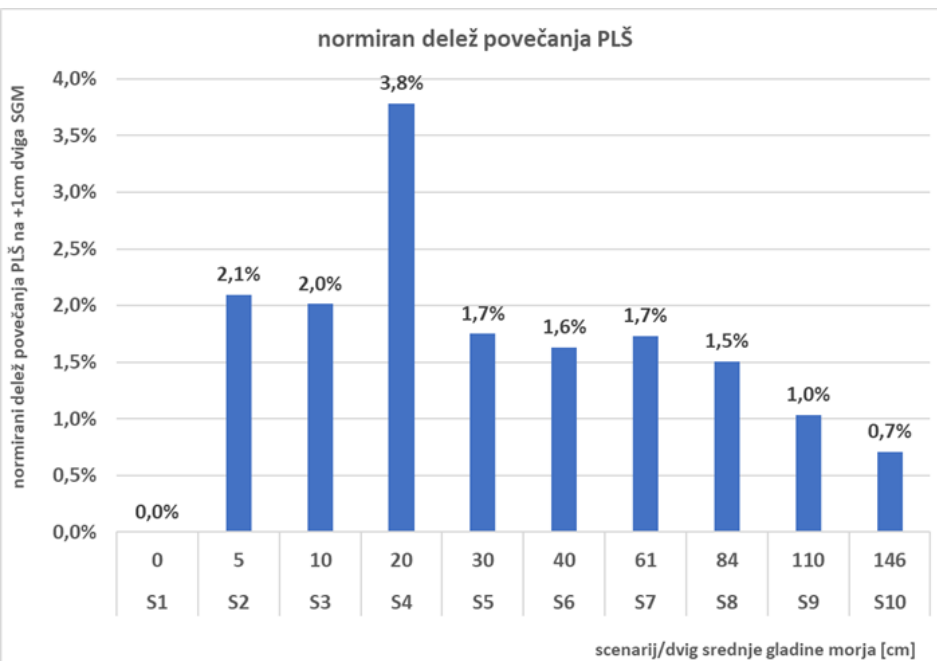
PLŠ za scenarije poplave morja v slovenski Istri



PLŠ za scenarije poplave morja v Piranu



## EAD INCREMENTS





## CONCLUSIONS AND RECOMMENDATIONS

- As a result of the project, the objective of upgrading the methodology for determining EAD — with a focus on cultural heritage buildings— and expanding the applicability of the KR PAN application to assess flood damage from sea floods in Slovenian Istria was fully achieved.
- The upgraded methodology takes into account the specific characteristics of sea floods compared to inland floods, with particular emphasis on the distinctive features of cultural architectural heritage sites.
- For determining reference values of mean sea level (MSL) rise due to climate change, 10 scenarios were analyzed, covering 9 return periods of sea floods (ranging from 2 to 1,000 years).
- When interpreting the results, their validity must be considered under the assumption that a set of wave transformation measures has been implemented in advance, thereby excluding or mitigating the dynamic effects of waves.



## CONCLUSIONS AND RECOMMENDATIONS

- Based on 360 flood maps, flood damage curves and expected annual damage estimates were developed for Slovenian Istria, Piran, and the Sečovlje salt pans. These outputs can be applied to qualitative assessments of damage caused by sea floods at any scale.
- In calculating the expected annual damage, nine characteristic flood events were considered, enabling the construction of more accurate damage curves. The analysis revealed that return periods with lower flood frequencies (up to 10 years) account for the majority of EAD. These events are not adequately captured by the commonly applied return periods (10, 100, and 500 years), which means that the benefits of flood protection measures may be significantly underestimated. It is therefore essential that cost–benefit (C-B) analyses also include scenarios with shorter return periods, as they are crucial for demonstrating the effectiveness of protective measures.
- The upgraded KR PAN application has been adapted for sea floods in the coastal area of Slovenian Istria and is based on cost data from 2025. However, the basic KR PAN application will require urgent updates—both in terms of calculation methodologies and databases—to reflect the current situation.



EU Strategy for the  
Adriatic and Ionian Region  
**EUSAIR**

# TEDEN SREDOZEMSKO OBALNE IN MAKROREGIONALNIH STRATEGIJ

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