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Enabling Delta Life

Global Quick Scan of the Vulnerability of Groundwater systems to Tsunamis*

**or other flooding events*

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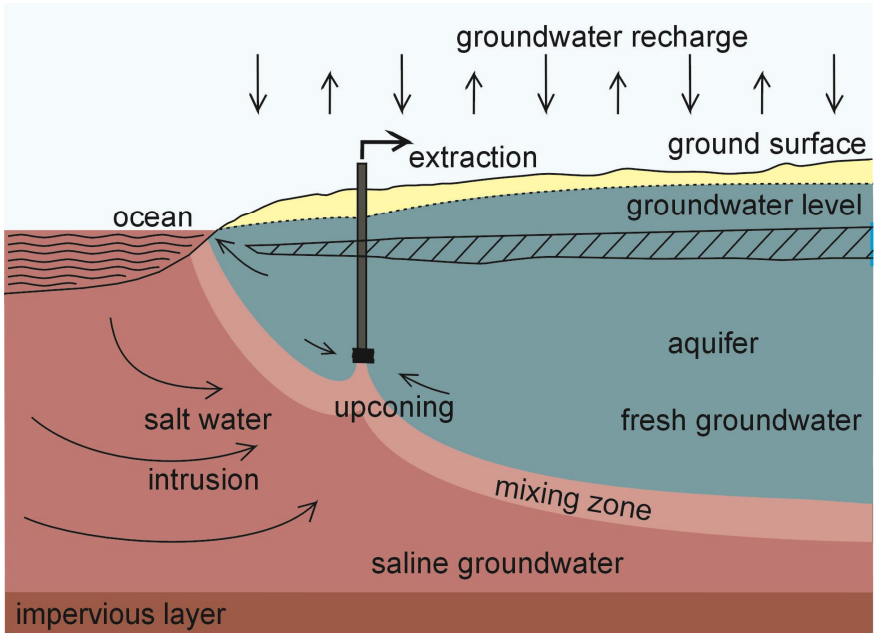
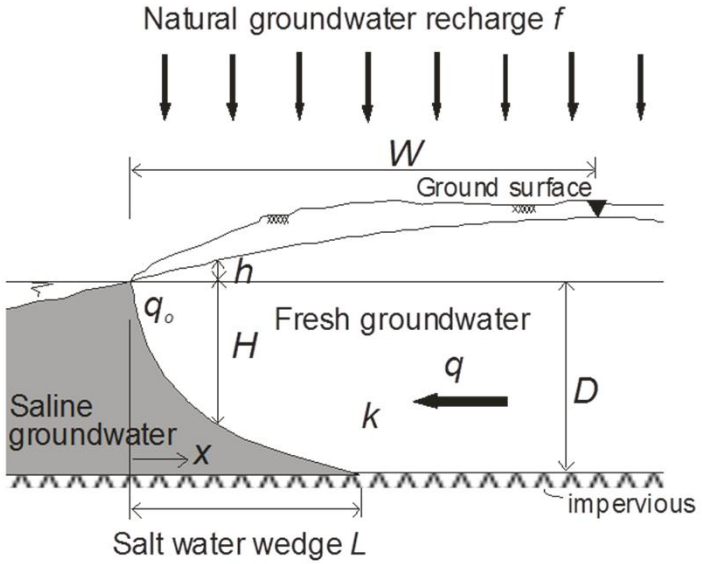
2 WAGENINGEN UR

3 Universiteit Utrecht

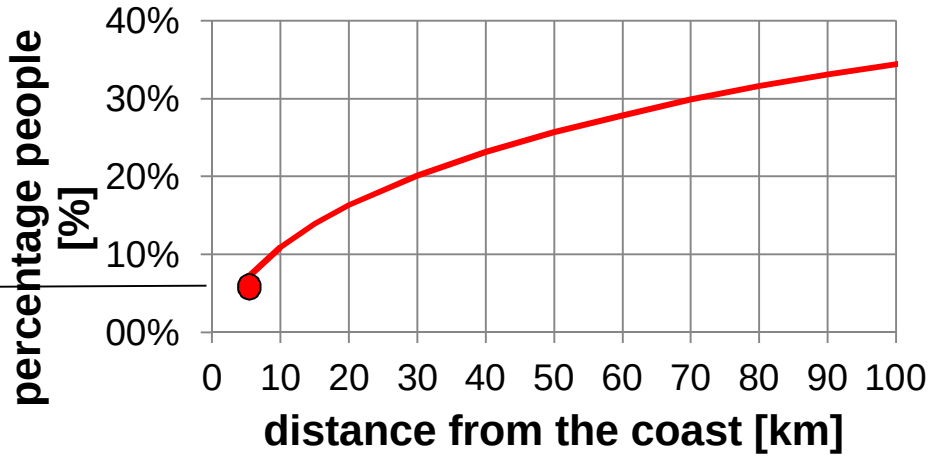
1. *Sense of Urgency*
2. *Approach*
   - *-vulnerability Tsunami index map*
   - *-modelling salt groundwater*
3. *Preliminary results*

Groundwater in the coastal zone





500 million people in the first 5km from the coastline



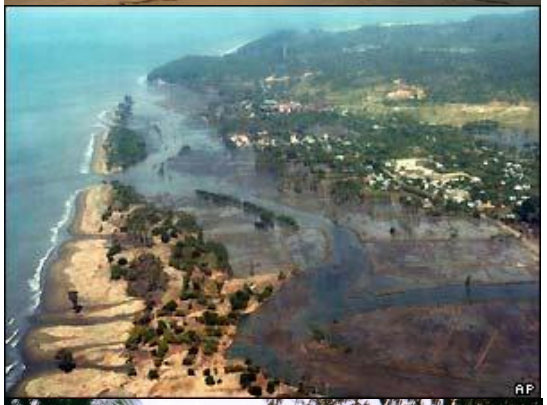
Sense of Urgency

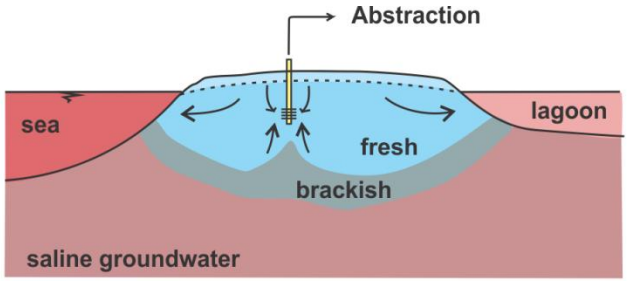
Every year, about 2 million people worldwide die from diarrhea, caused by bad drinking water quality

Groundwater is an important source of drinking water in underdeveloped countries, due to its high quality and relatively easy-to-access quantity (now 30% and increasing)

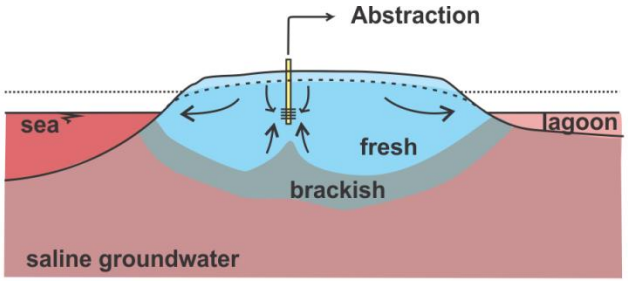
What will happen when a disaster like a tsunami hits a coastal area?

Salinization of fresh groundwater by tsunami inundations might lead to a temporal stop of groundwater extractions in affected areas

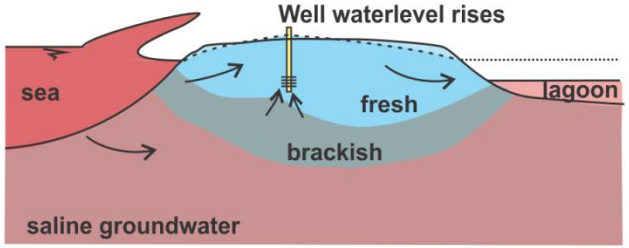




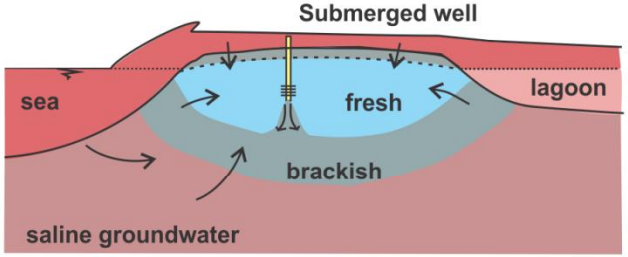
1. Before Tsunami



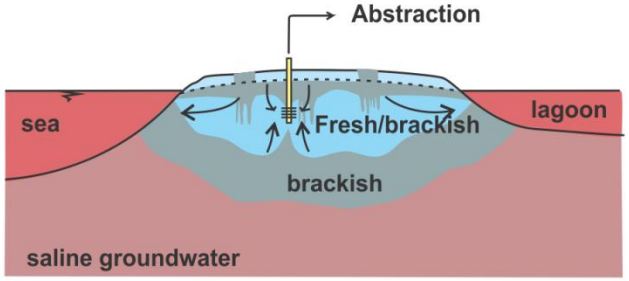
2. Just before Tsunami:
Lowering of sea- and lagoonwater level



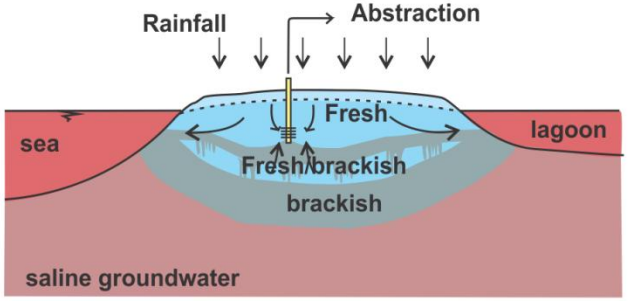
3. Just before Tsunami:
Subsurface pressure wave precedes surface wave



4. During Tsunami: Flooding of island,
mixing of water due to sudden pressure changes



5. After Tsunami
Freshwater mixed with brackish water

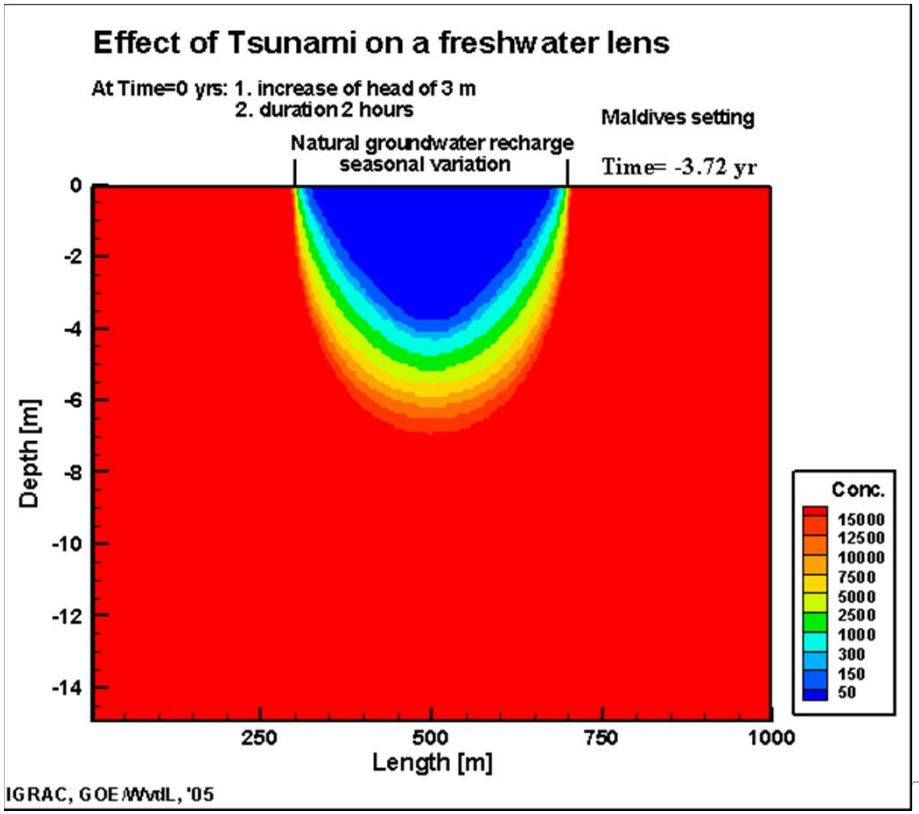


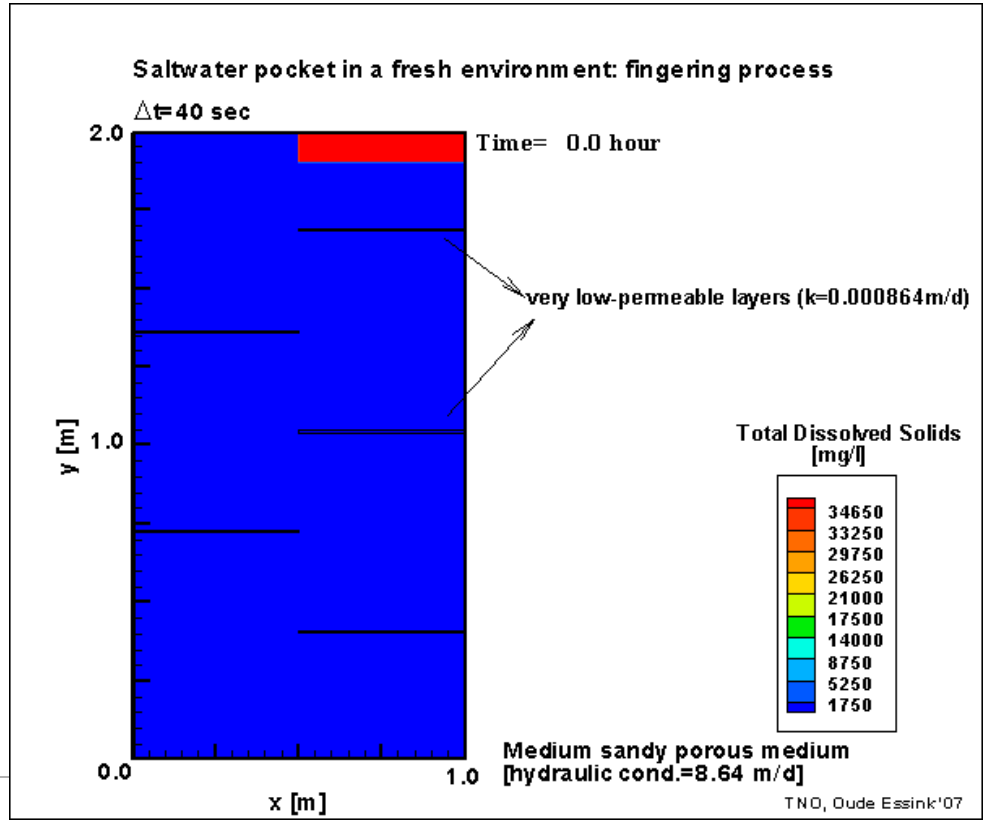
6. After Tsunami
Recharge by rainfall replaces brackish water

Salinisation processes of fresh groundwater reserves

Impression of relevant salinisation processes in coastal aquifers:

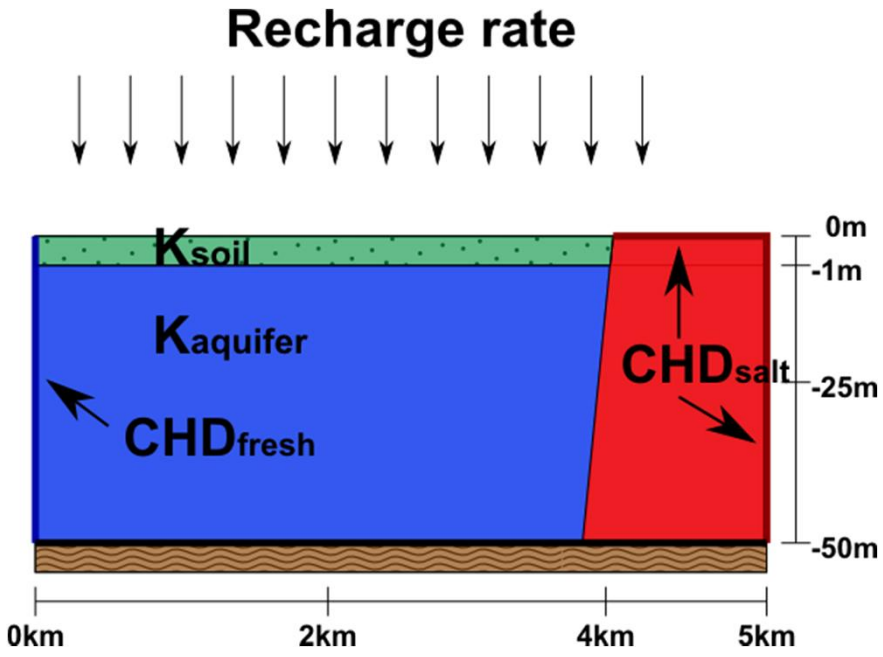
- Contamination freshwater lens after sea water flooding
- Saline fingering processes in the subsoil

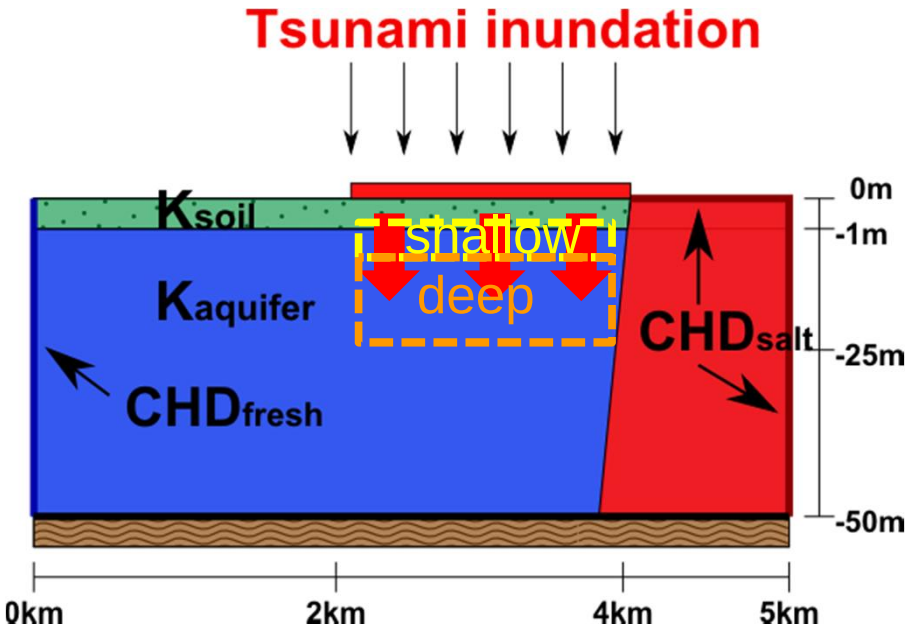




Concept 2D modelling variable-density groundwater flow and coupled salt transport

Normal system





- Focus on coastal *deep* and *shallow* fresh groundwater resources
- How long does it takes before the groundwater system is fresh again, available for groundwater extractions?

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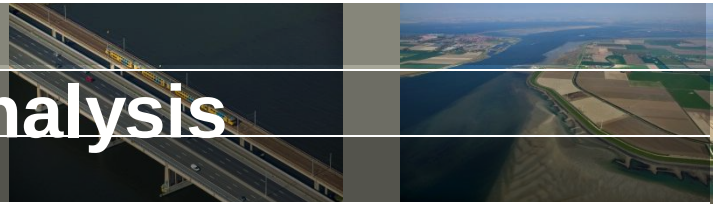
Using global datasets in the analysis



- **SRTM – DEM of the world**
  - Used to create:
    - *Slope*
    - *Distance to coast*
- **Resampling**
  - Different resolution of other original datasets (e.g. population density)

Name	Type	Resolution
SRTM	raster	90 m
Population density	raster	≈ 4.6 km
Land use	raster	300 m
Soil map	raster	≈ 1 km
Precipitation	raster	≈ 1 km
Tsunami occurrence	point shape file	-
Bathymetry	raster	≈ 1 km
GDP	raster	≈ 1 km

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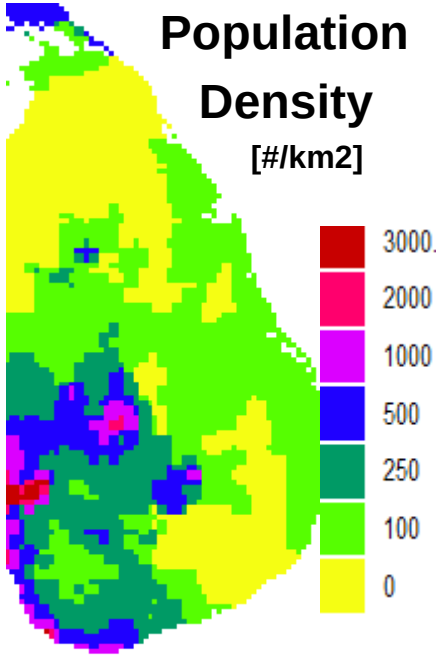
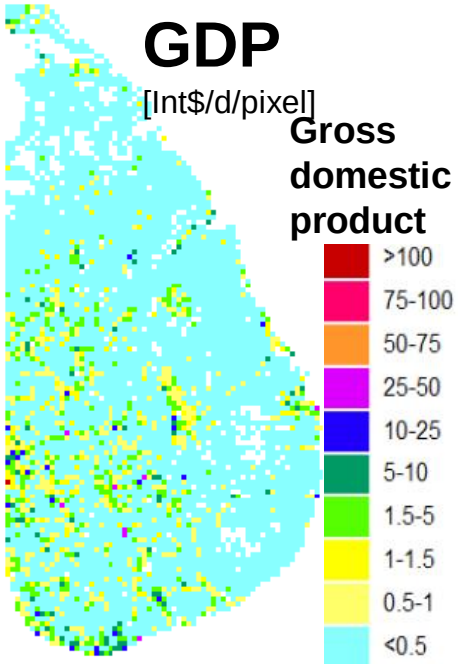
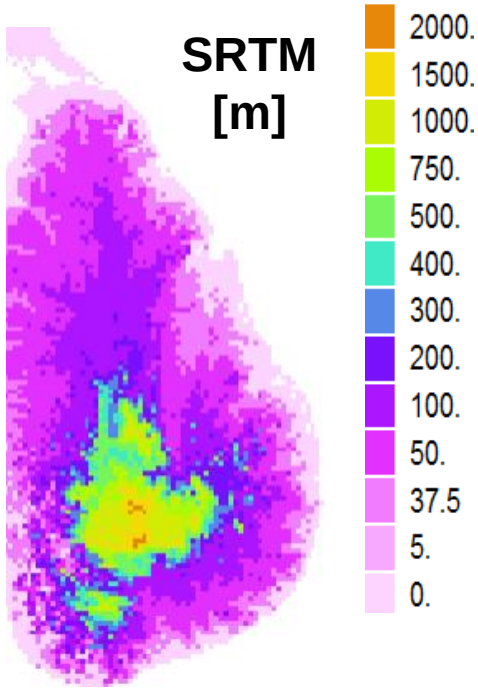
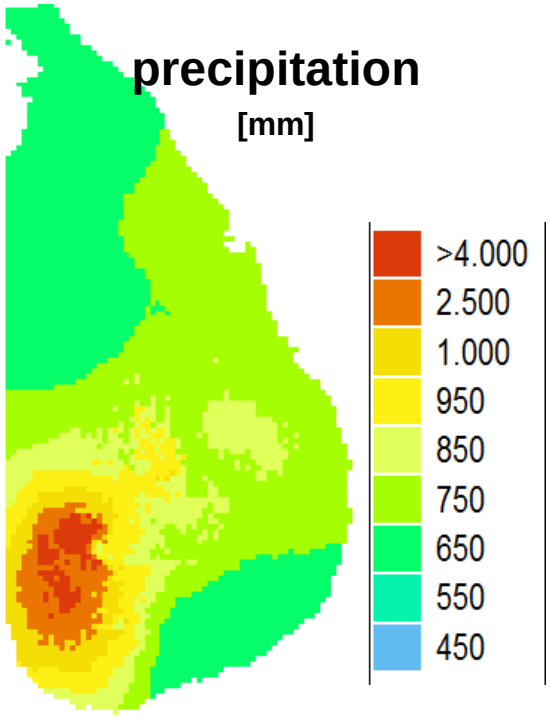
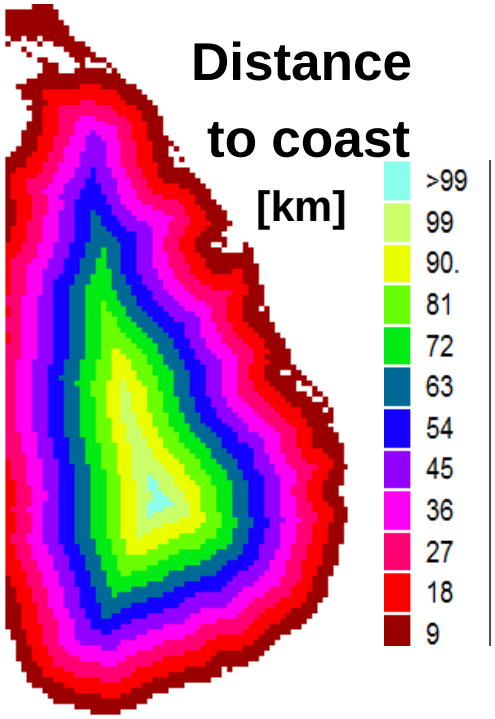
Tile:
_53_11
Jaffna
Kilinochchi
Vavuniya
Kuchchaveli
Hamillewa
Trincomale
Anuradhapura
Megaswewa
Batticalo
Sri Lanka
Negombo
Kandy
Gampaha
Nuwara
Eliya
Malabe
Moratuwa
Yala National
Park
Galle
Tangalla
Matara

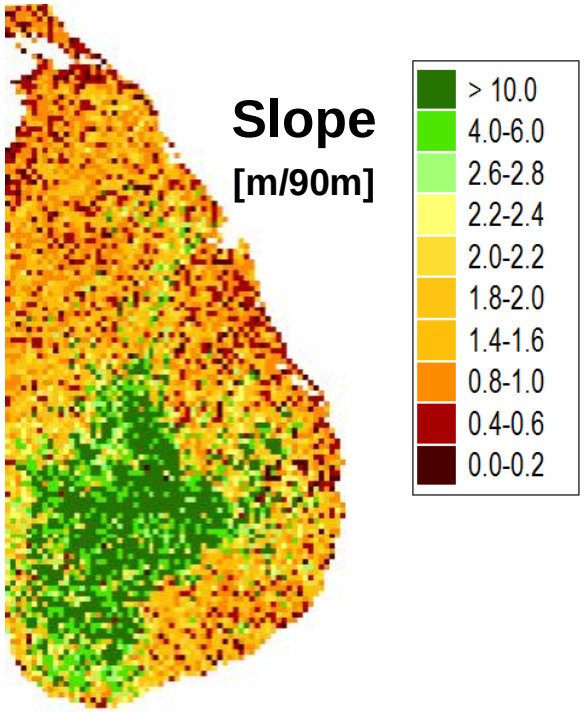

Population
Density
[#/km2]
3000.
2000
1000
500
250
100
0

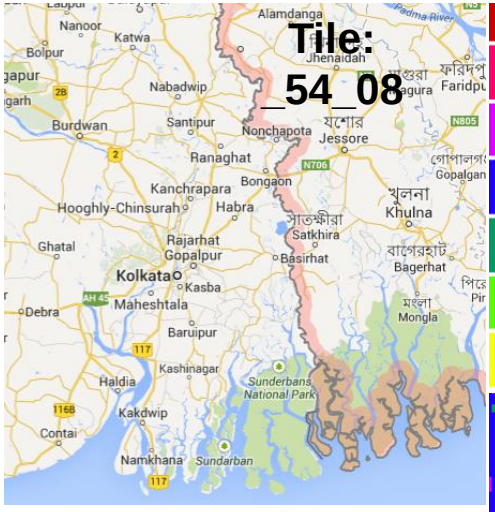

GDP
[Int$/d/pixel]
Gross
domestic
product
>100
75-100
50-75
25-50
10-25
5-10
1.5-5
1-1.5
0.5-1
<0.5

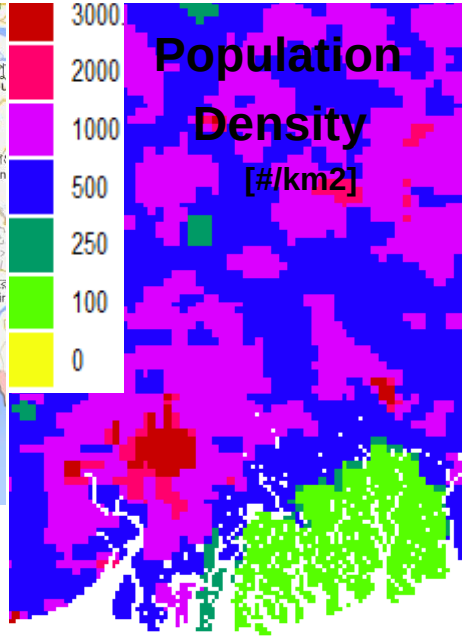

SRTM
[m]
2000.
1500.
1000.
750.
500.
400.
300.
200.
100.
50.
37.5
5.
0.

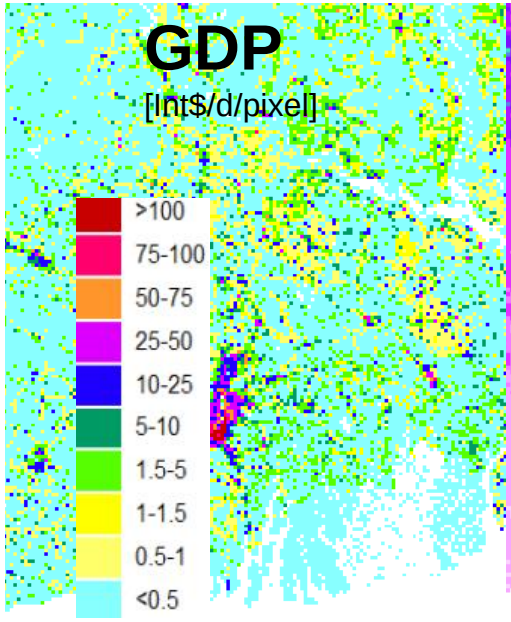

precipitation
[mm]
>4.000
2.500
1.000
950
850
750
650
550
450

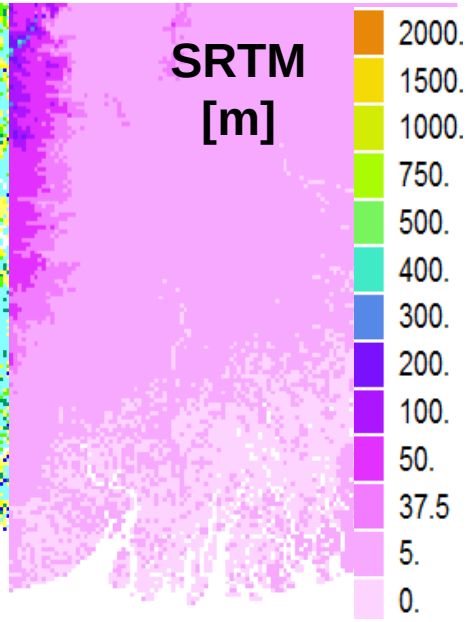

Distance
to coast
[km]
>99
99
90.
81
72
63
54
45
36
27
18
9


Slope
[m/90m]
> 10.0
4.0-6.0
2.6-2.8
2.2-2.4
2.0-2.2
1.8-2.0
1.4-1.6
0.8-1.0
0.4-0.6
0.0-0.2

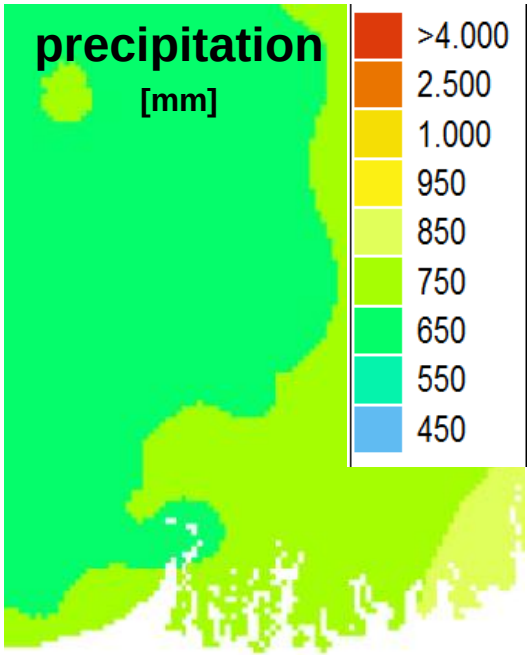


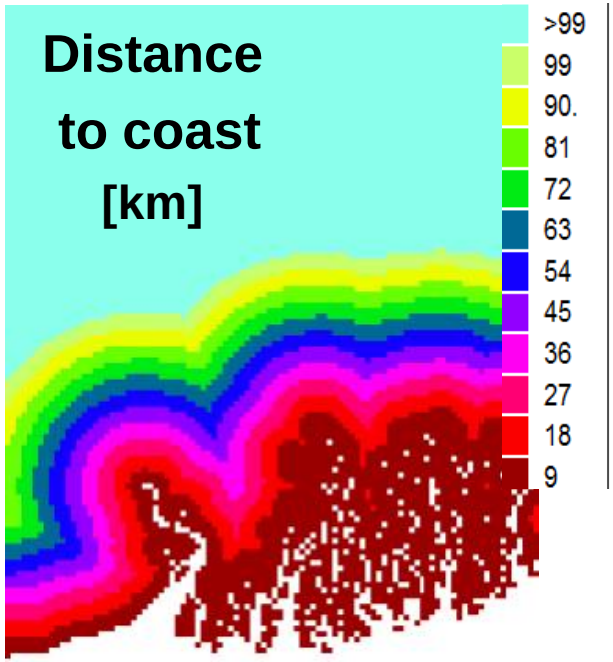




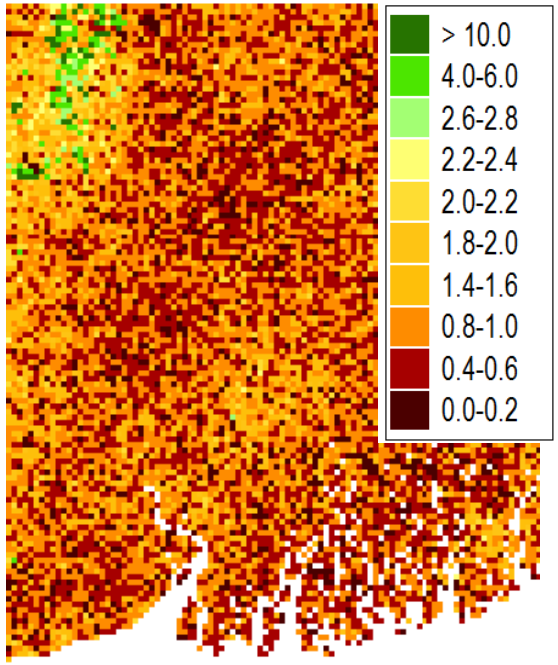


Bangladesh





Slope [m/90m]



Methodology Vulnerability Tsunami Index

- **Combine topography, tsunami risk and socio-economic factors (poverty)**
- **Topographical vulnerability index: *Elevation, Slope, Distance to coast***
- **Determine simple equation and ranges of values**
  - **Literature review (e.g. regional studies Indonesia)**
  - **Tsunami inundation extents and affected areas in history**

$Elevation \quad ID_{elev}$

$Slope \quad ID_{slope}$

$Distance\ to\ coast \quad ID_{dist}$

$$vulnerability\ index = 4 * ID_{elev} + ID_{dist} + ID_{slope}$$

Final index	Variable ID values and ranges					
Variable / ID	1	2	3	4	5	30
Topographical elevation (m above sea level)	min - 8	8 - 16	16 - 24	24 - 32	32 - 40	> 40
Topographical slope (°)	0 - 1	1 - 2	2 - 3	3 - 4	4 -5	> 5
Distance to coast (pixels)	0 - 7	7 - 15	15 - 25	25 - 40	40 - 55	> 55
Distance to coast (m)	0 - 540	540 - 1350	1350 - 2250	2250 - 3600	3600 - 4950	> 4950

Vulnerability level	Sum of IDs	Vuln. ID
Very high	6 - 9	1
High	10 - 14	2
Medium	15 - 19	3
Low	20 - 24	4
Very low	25 - 29	5
None	> 30	6

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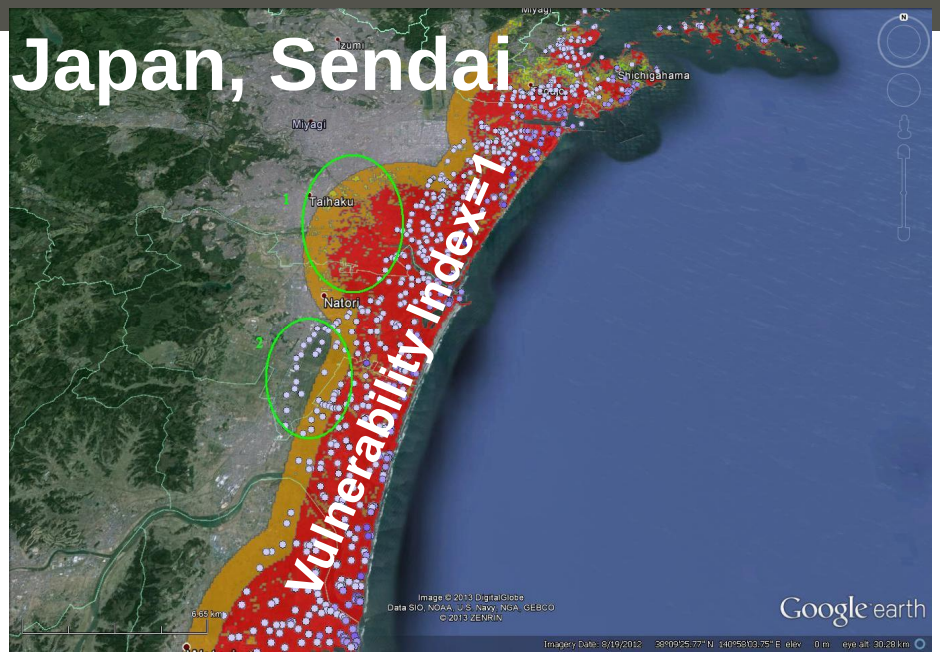
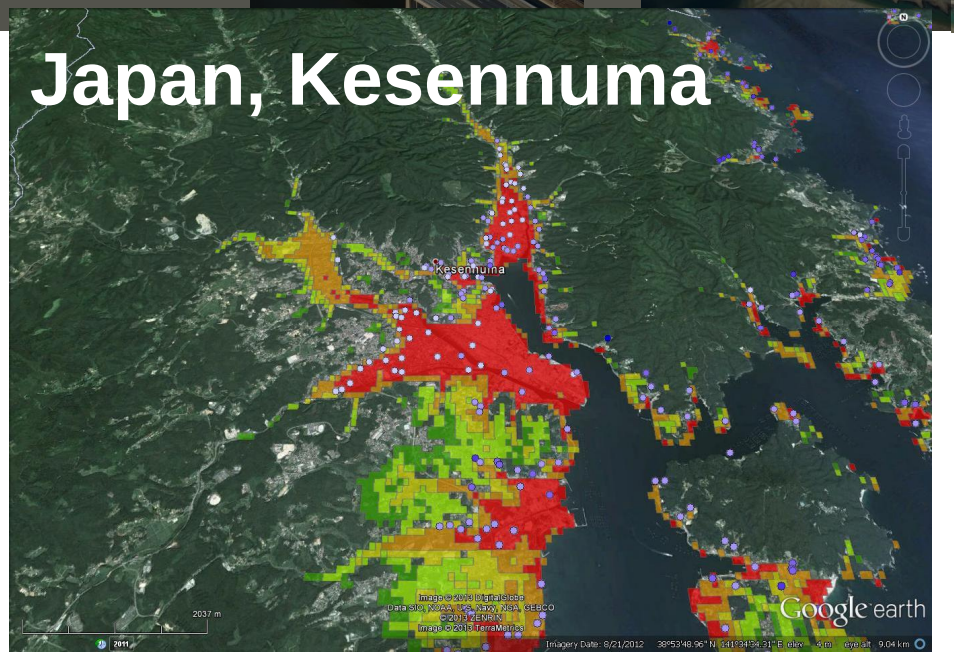
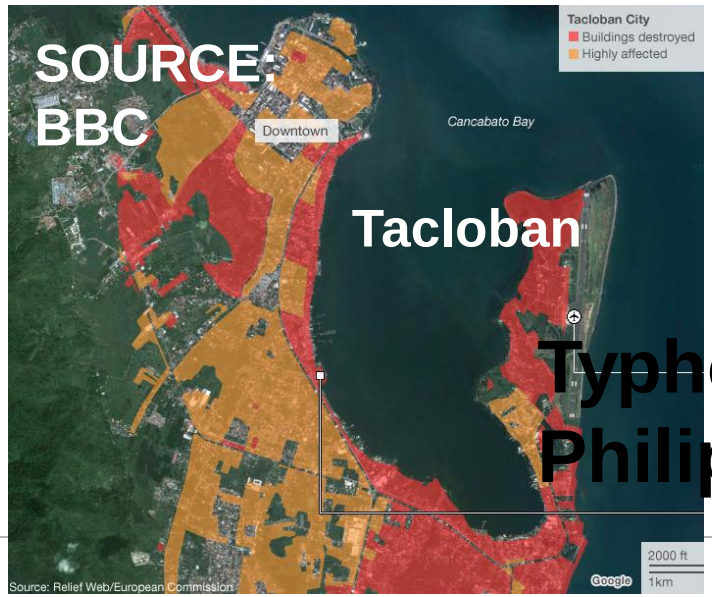
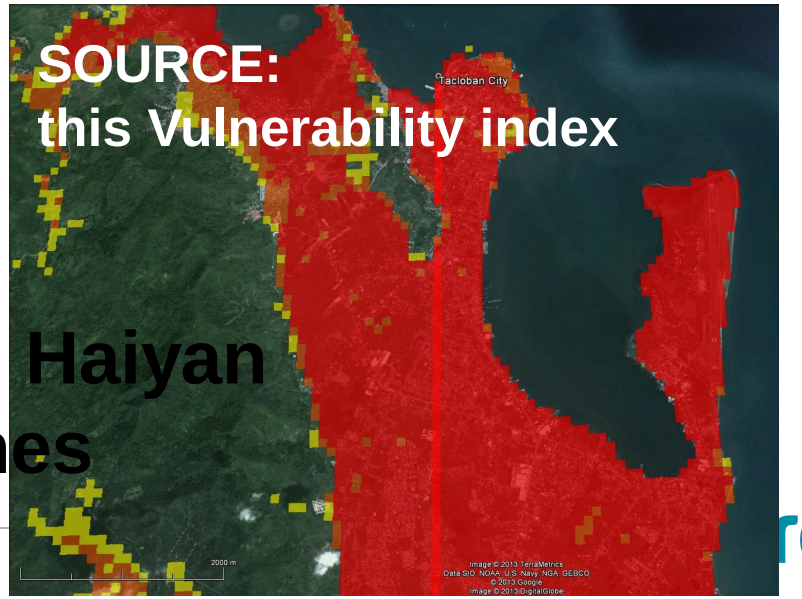
Vulnerability Tsunami index example







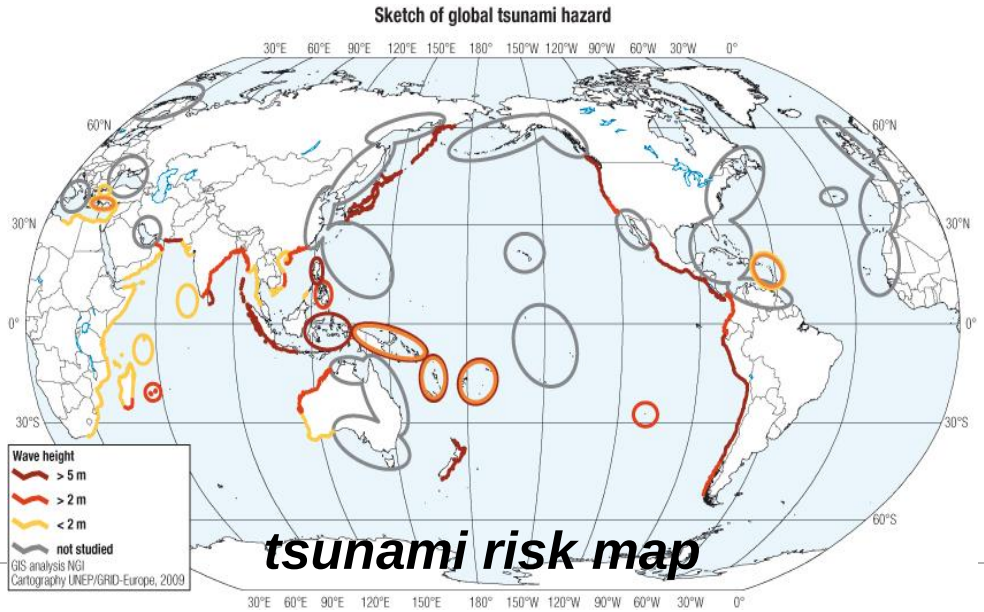


Typhoon Haiyan
Philippines

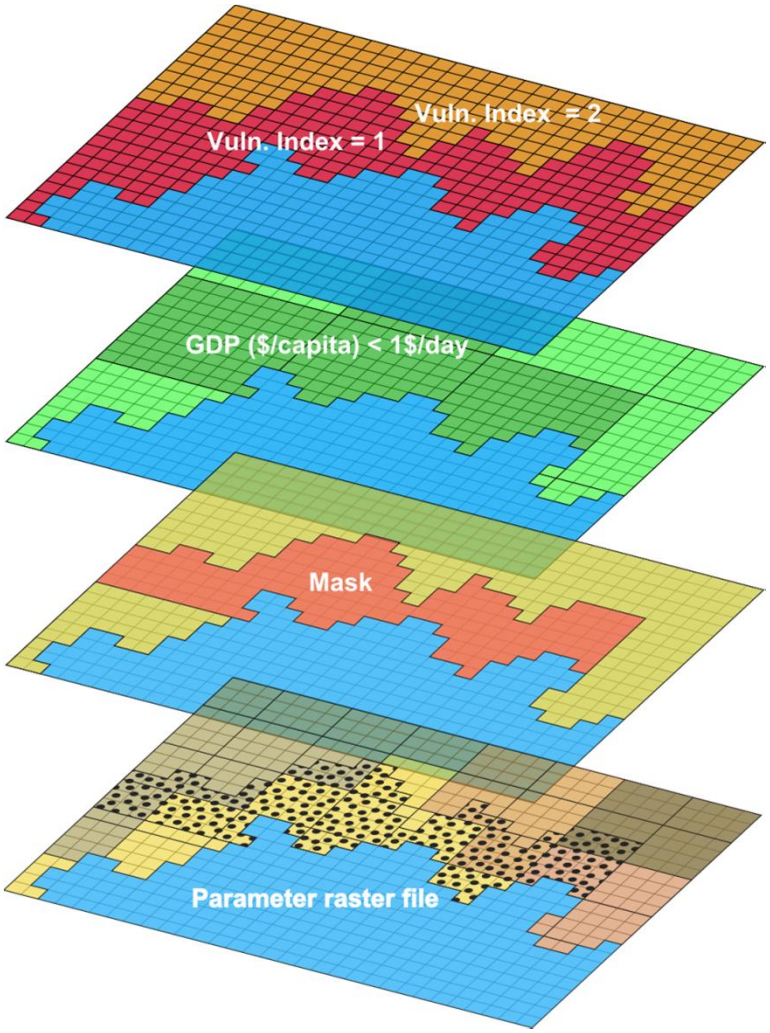
Socio-economic factor and parameter values statistics

- **Focus on poor areas (1$/day per capita)**
  - Combining the pop. density and GDP datasets
- **Parameter statistics for chosen areas**
  - Soil types
  - Precipitation
  - Population density

Input to model (total # simulations : 96)



tsunami risk map



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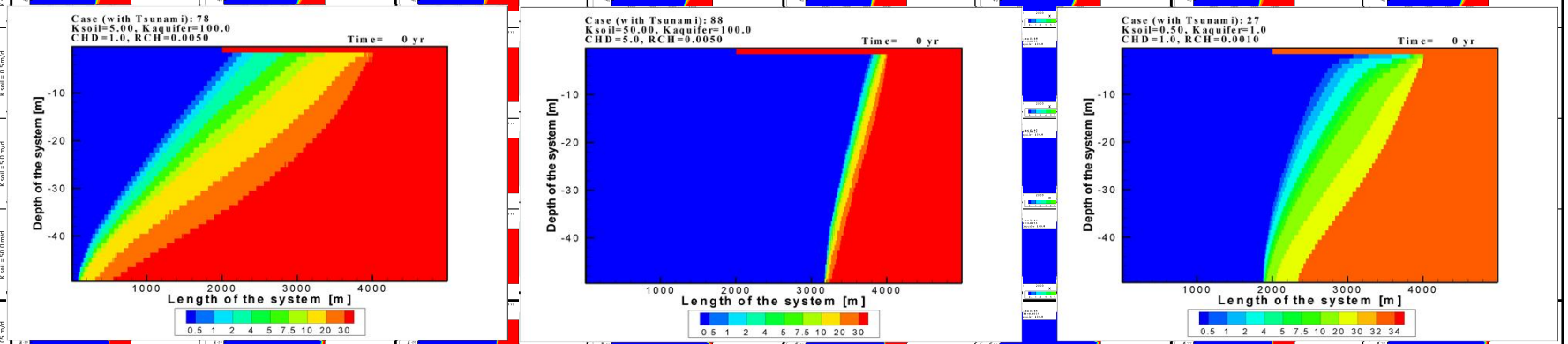
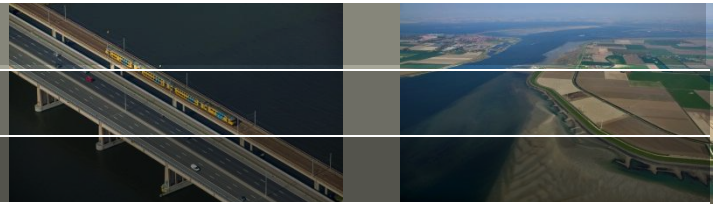
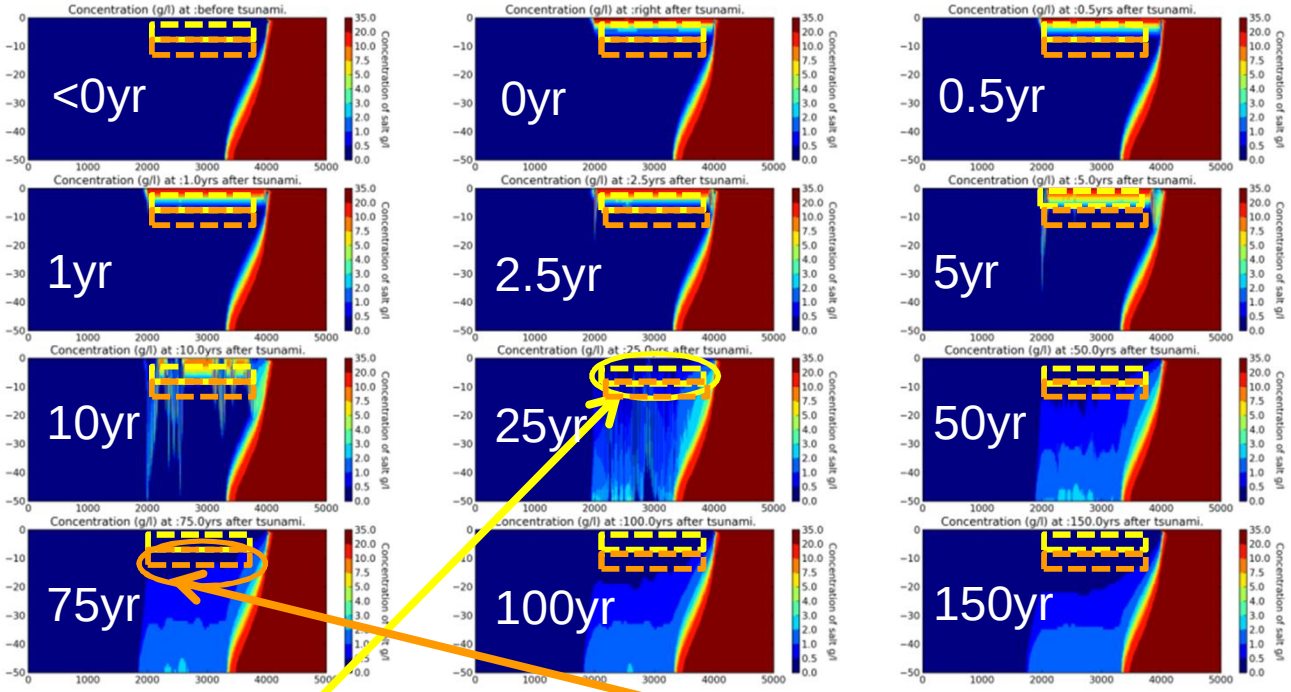
Variable parameters	Value			
	A	B	C	D
Recharge (fresh) (m/d)	0.0001	0.001	0.0025	0.005
CHD fresh (m)	1.0	5.0	15.0	-
K soil (m/d)	0.005	0.05	5.0	50.0
K aquifer (m/d)	1.0	100.0	-	-

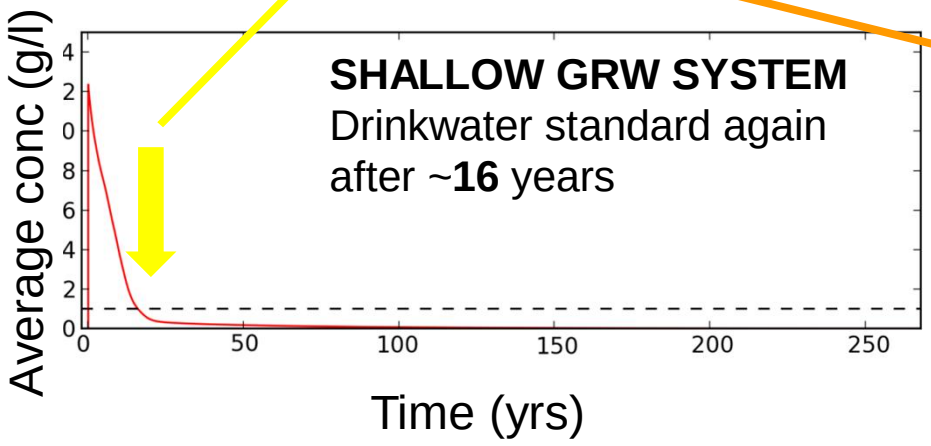


Results of one case

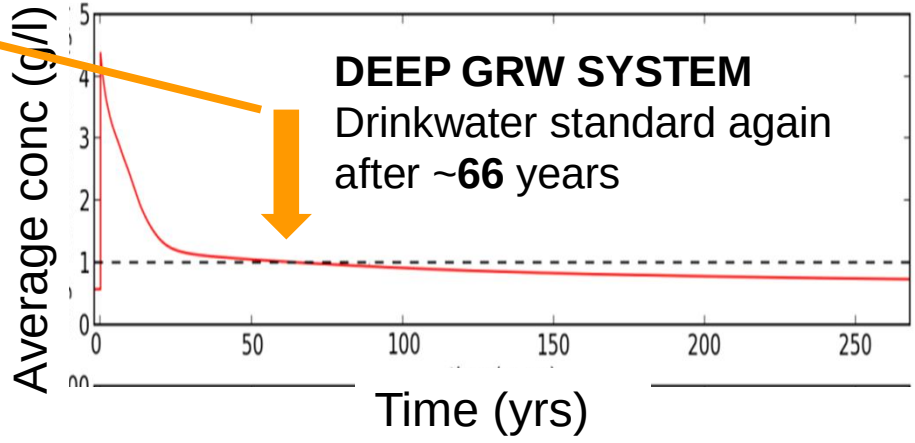




Salt water fingers intrude the groundwater system the coming tens of years



SHALLOW GRW SYSTEM
Drinkwater standard again after ~**16** years

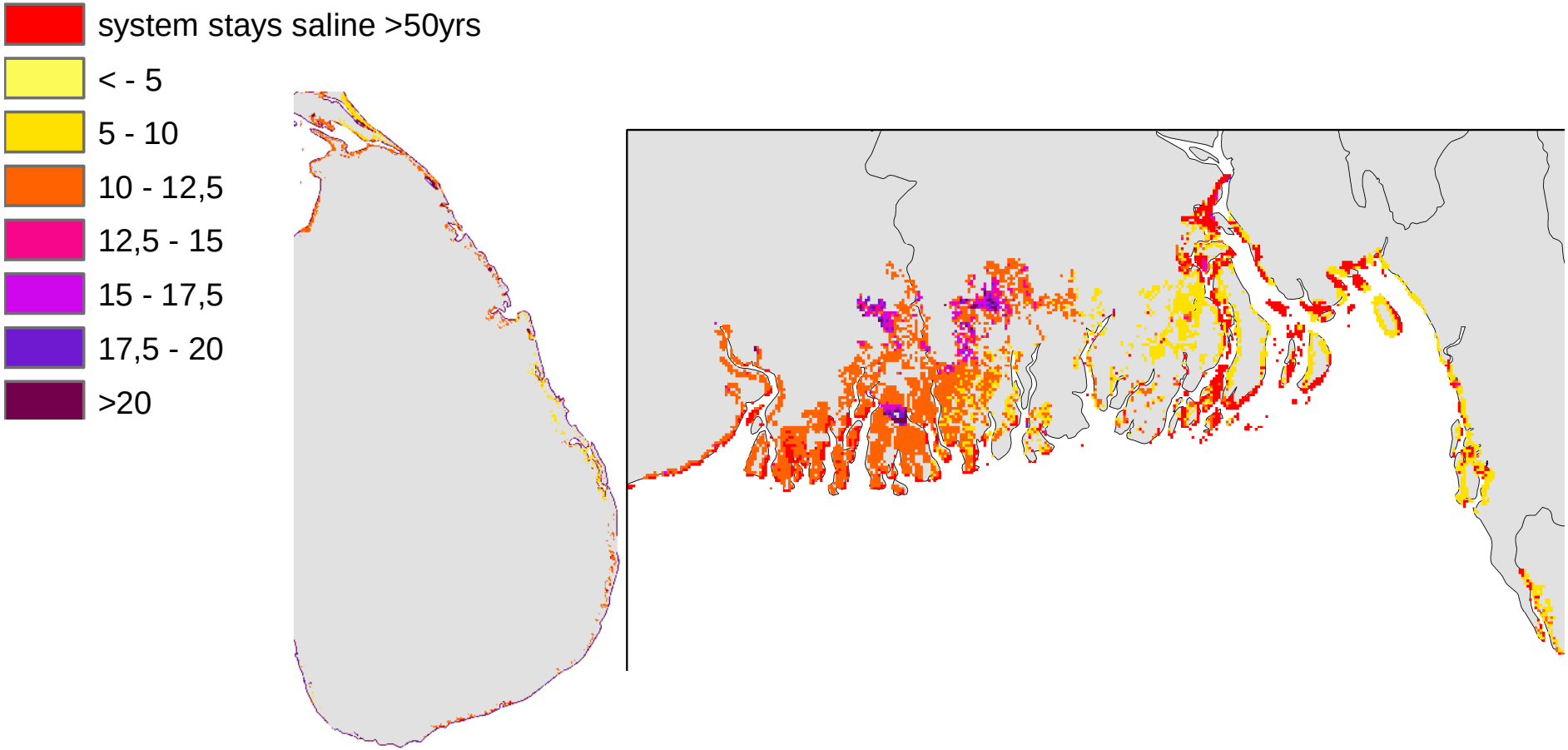


DEEP GRW SYSTEM
Drinkwater standard again after ~**66** years

Back to the Map!

- Shallow groundwater system
- GDP<1 US$/day/capita

Legend Time (yrs) before the shallow coastal groundwater system is fresh enough again for drinking water extraction



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Concluding

On approach

- Assessing vulnerability index on global scale is possible with free accessible datasets and tools
- Methodology is tested in some regional studies and shows good fit with tsunami run-up measurements

On fresh water resources:

- After a tsunami, groundwater in the coastal zone may stay salty and not drinkable for many years

We want to:

- test approach in one specific regional area, with detailed information

We need:

- global dataset on geology

Next steps are:

- upscale to other flooding events (e.g. storm surges)
- Climate Change, Sea Level Rise, Global Change (groundwater extractions)
- 3D approach for the top 25 deltas worldwide, including land subsidence

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Result:

- Global coastal groundwater salinisation assessment under tsunami* conditions
- Tsunami vulnerability index map, from coastal groundwater perspective

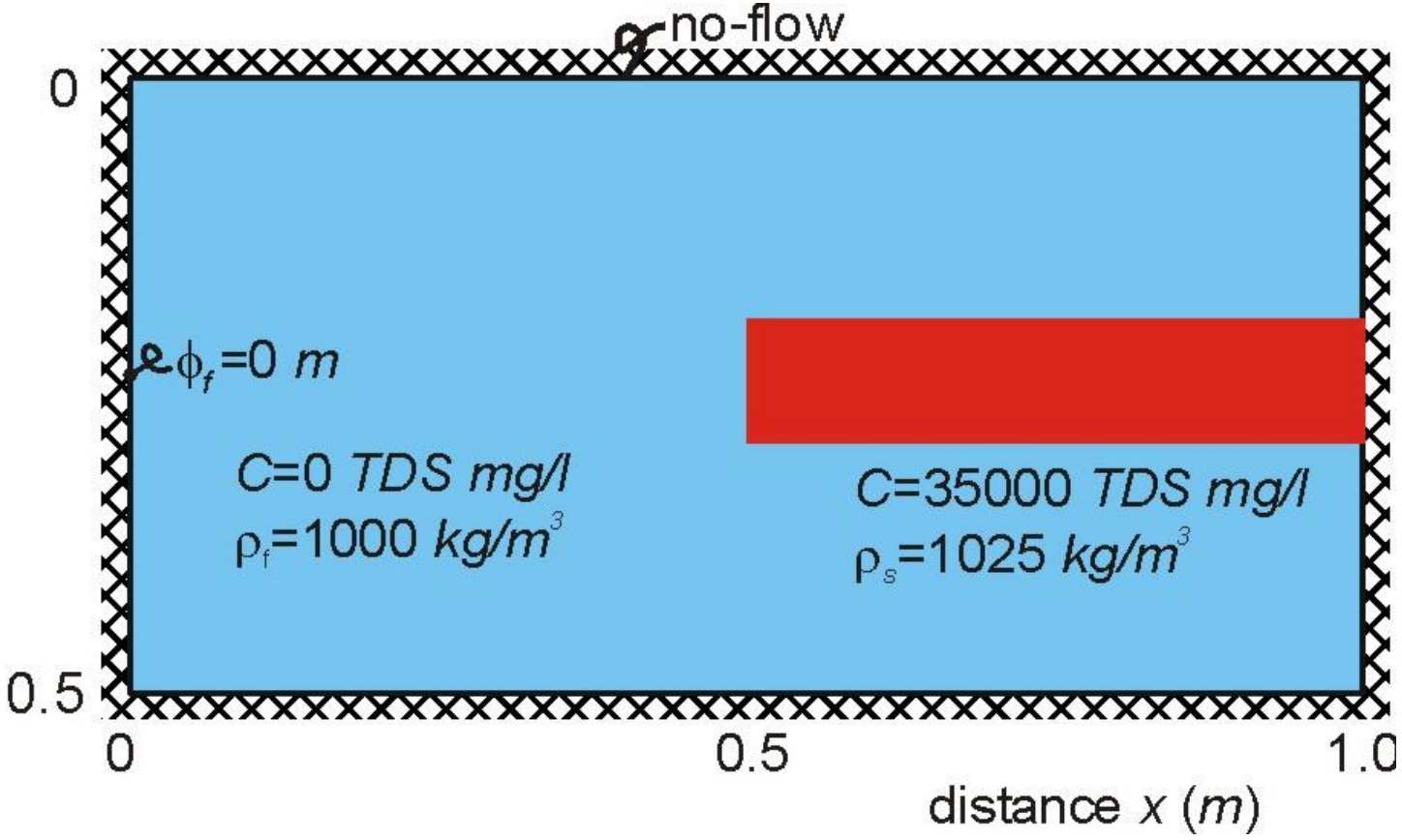
**and other flooding events*

Questions?

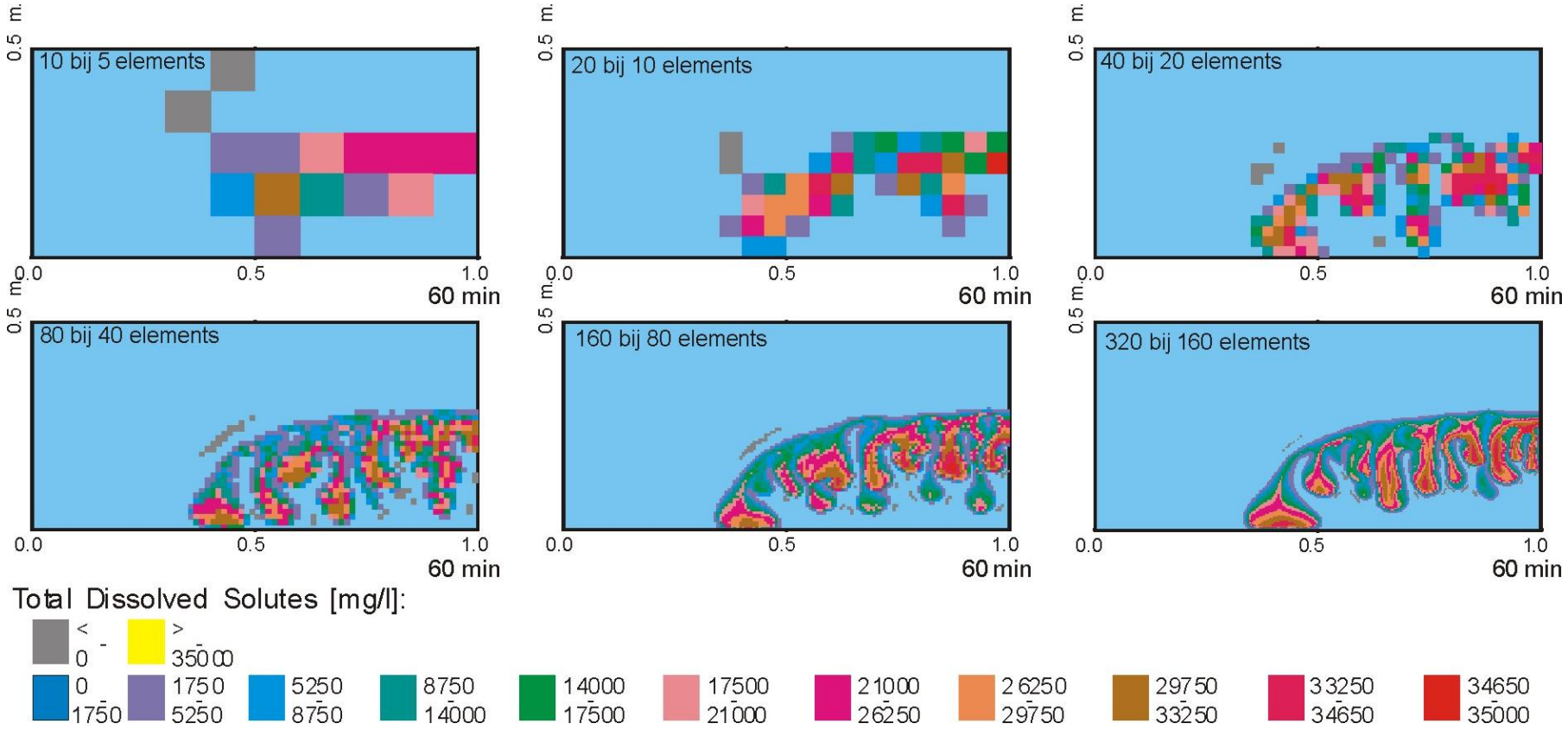
Universiteit Utrecht

Effect model cell size on physical process of fingering

EXAMPLE

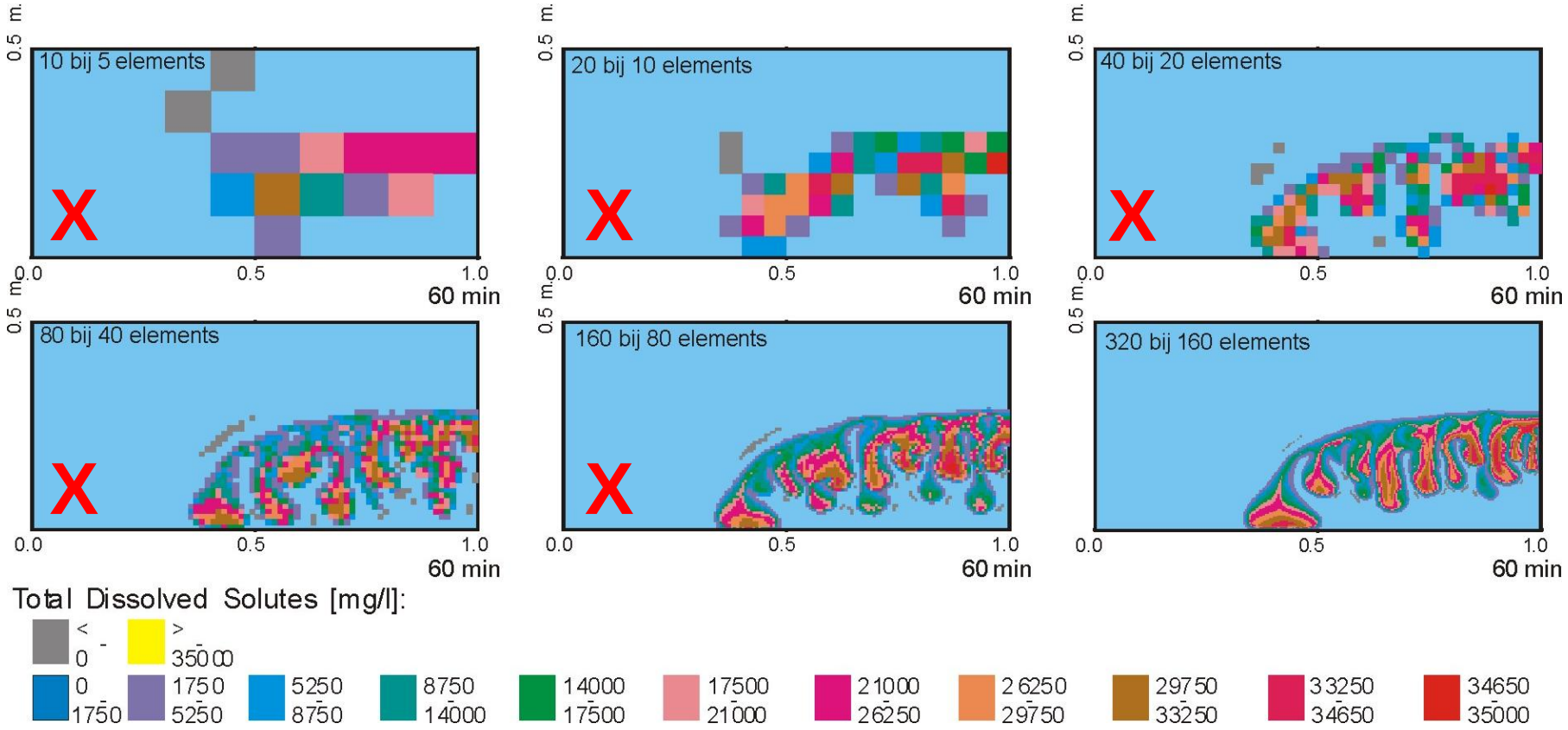


Effect of model cell size on physical process



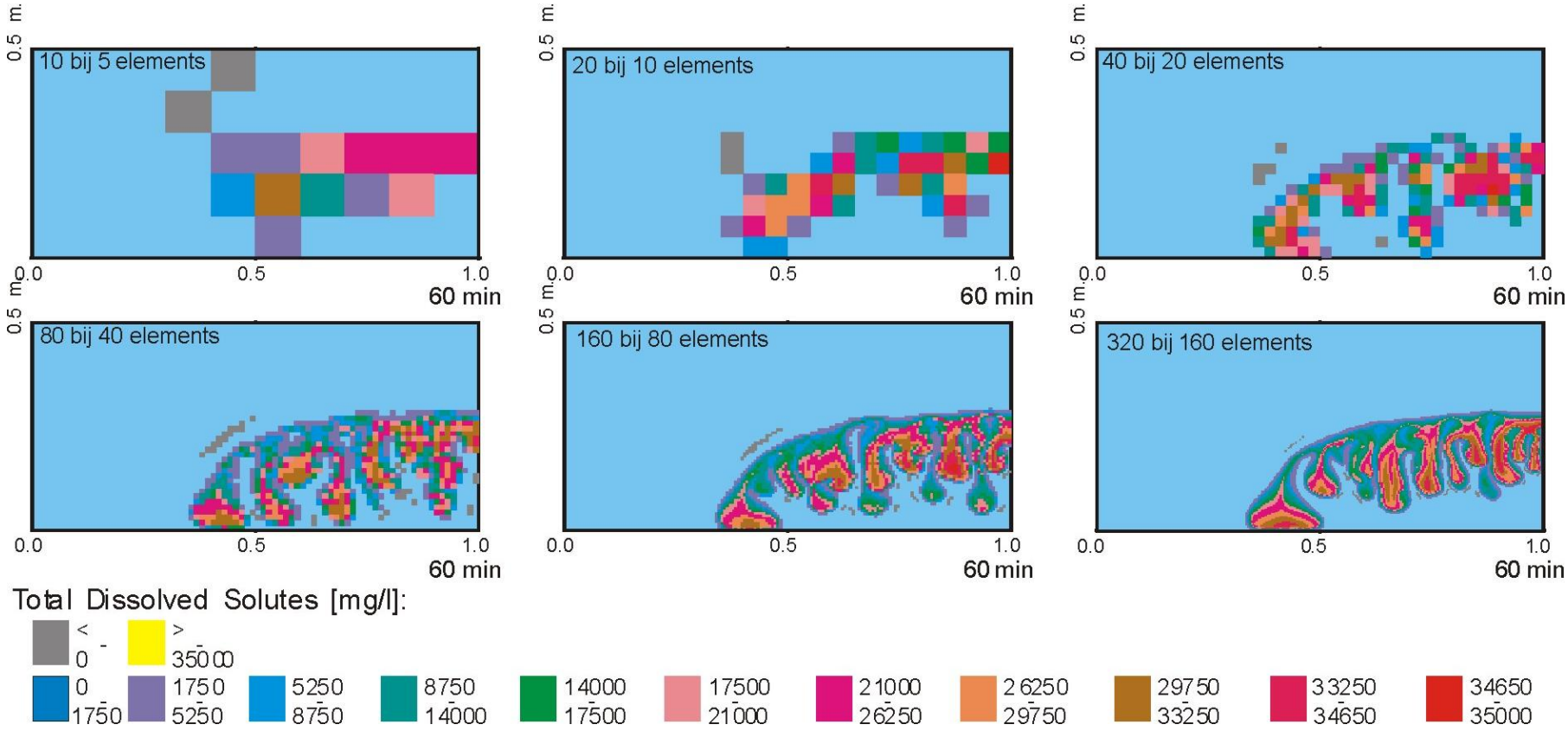
Model size cell has a **large** effect on modelling result!

Effect of size model cell on physical process



X= LOUSY models for predicting exact number of salt water fingers

Effect of size model cell on physical process



All models are GOOD for predicting moment of touching bottom (60min)!