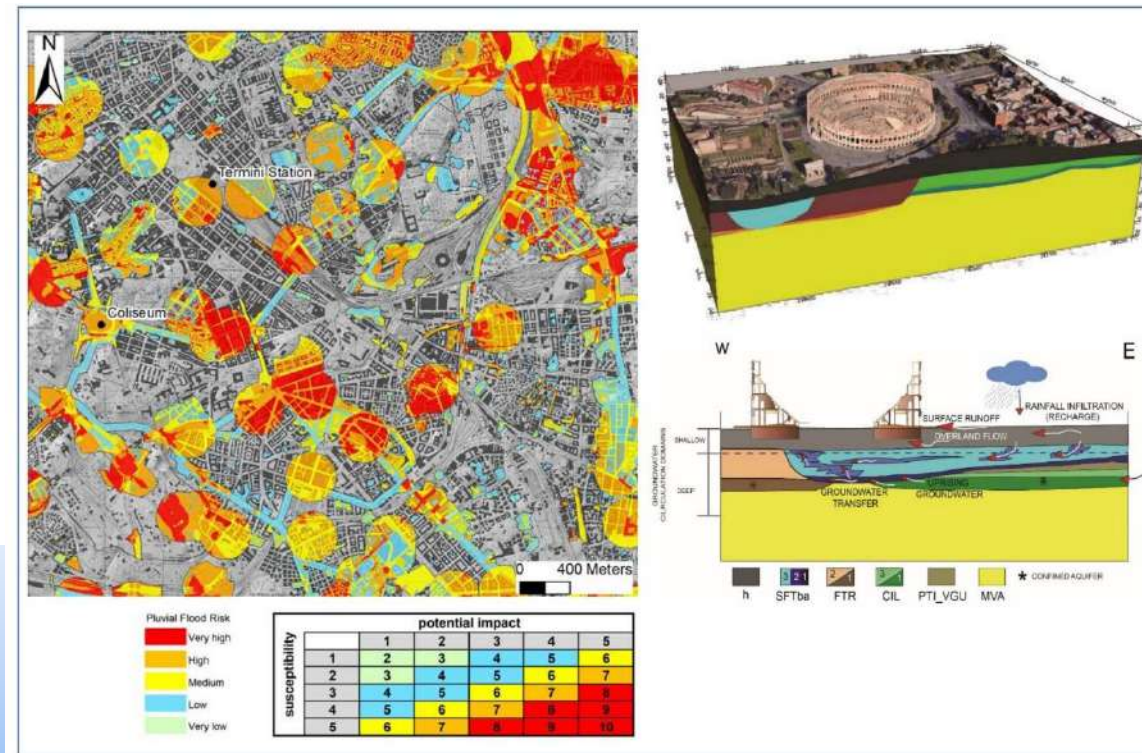


# Metodi di studio per la comprensione delle pericolosità geologiche nei centri storici urbani: casi di studio nella città di Roma

CNR, Istituto di Geologia Ambientale e Geoingegneria (CNR-IGAG), Roma, Italy.



**Cristina Di Salvo**  
[cristina.disalvo@igag.cnr.it](mailto:cristina.disalvo@igag.cnr.it)

# Studi e ricerche di tipo applicativo nel campo dei rischi idrogeologici e dell'idrogeologia condotte da IGAG dal 2011

## **Collaborazioni**

Soprintendenza Speciale per il Colosseo, il Museo Nazionale Romano e l'Area archeologica di Roma (oggi Parco Archeologico del Colosseo)

Dipartimento di Protezione Civile

Mibact

Protezione Civile di Roma Capitale

ISPRA

Roma Capitale

Università Sapienza

## **Are di Studio investigate**

Area dell'Anfiteatro Flavio

Altri studi a scala municipale

Colle Palatino

Colle Quirinale

# Studi e ricerche di tipo applicativo nel campo dei rischi idrogeologici e dell'idrogeologia condotte da IGAG dal 2011

## Collaborazioni

**Soprintendenza Speciale per il Colosseo, il Museo Nazionale Romano e l'Area archeologica di Roma (oggi Parco Archeologico del Colosseo)**

**Dipartimento di Protezione Civile**

Mibact

Protezione Civile di Roma Capitale

ISPRA

Roma Capitale

Università Sapienza

## Are di Studio investigate

**Area dell'Anfiteatro Flavio**

**Altri studi a scala municipale**

Colle Palatino

Colle Quirinale

- **Un modello geologico 3D come base per lo sviluppo di uno schema idrogeologico concettuale nell'area del Colosseo (Roma)**
- **Sviluppo di procedure per la mappatura a scala municipale del rischio da pluvial flood**

# Un modello geologico 3D come base per lo sviluppo di uno schema idrogeologico concettuale nell'area del Colosseo (Roma)

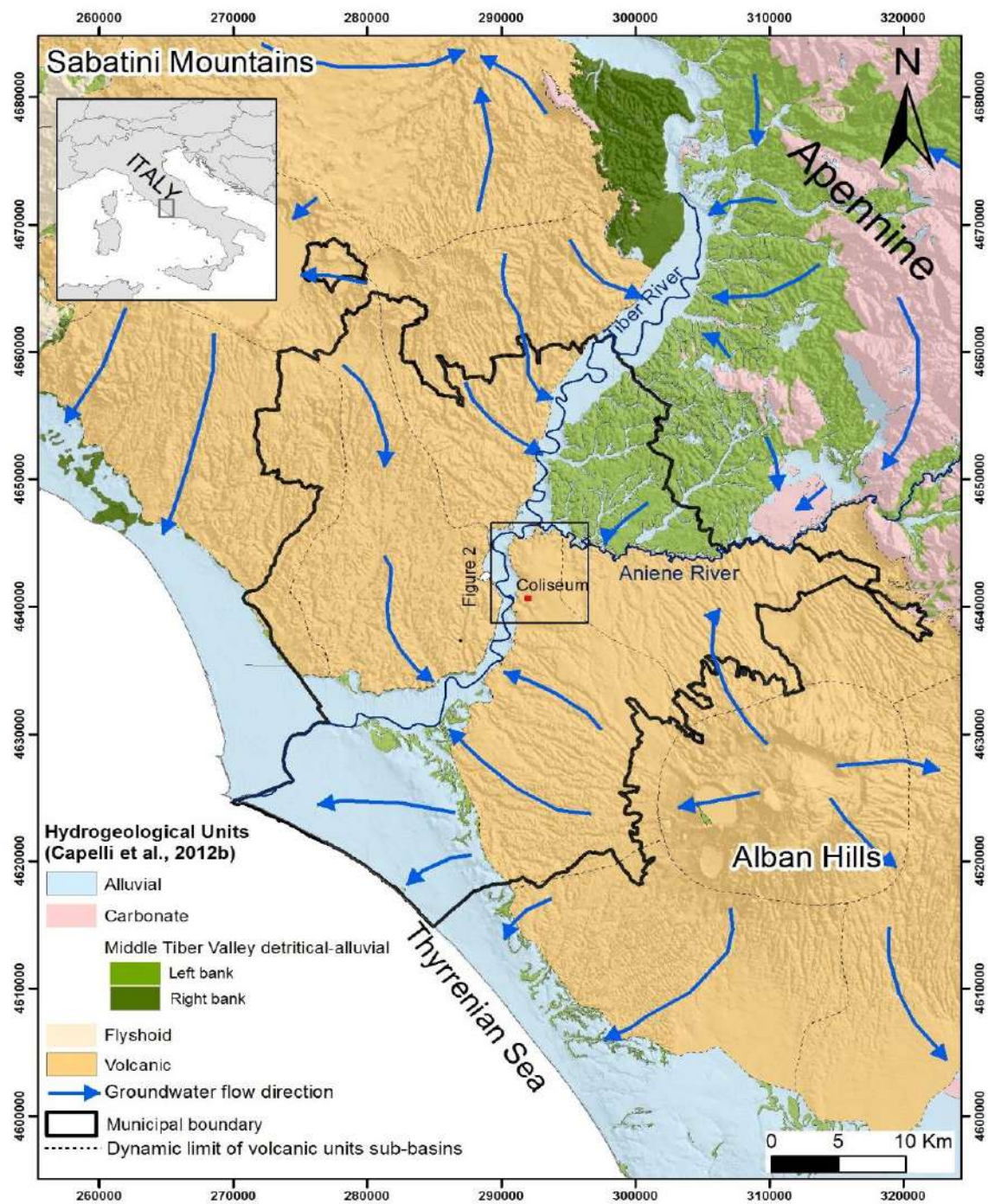
*Cristina Di Salvo, Marco Mancini, Massimiliano Moscatelli, Francesco Stigliano, Maurizio Simionato, Gian Paolo Cavinato*



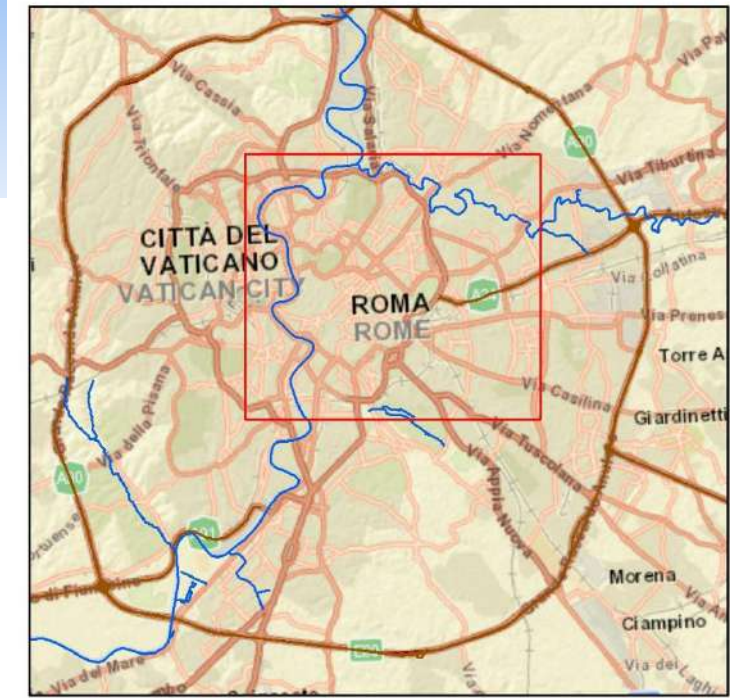
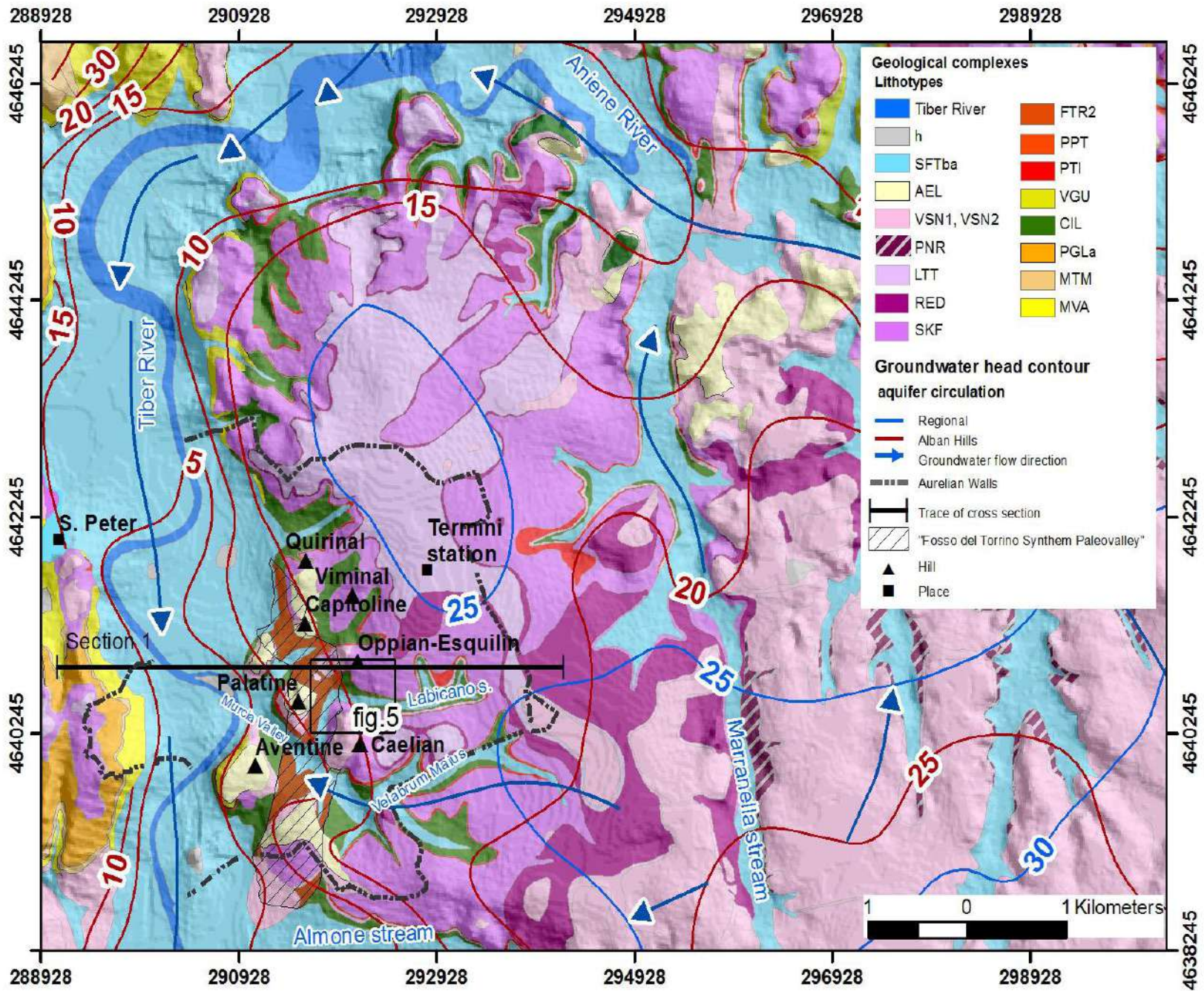
Gaspar Van Wittel, Veduta del Colosseo



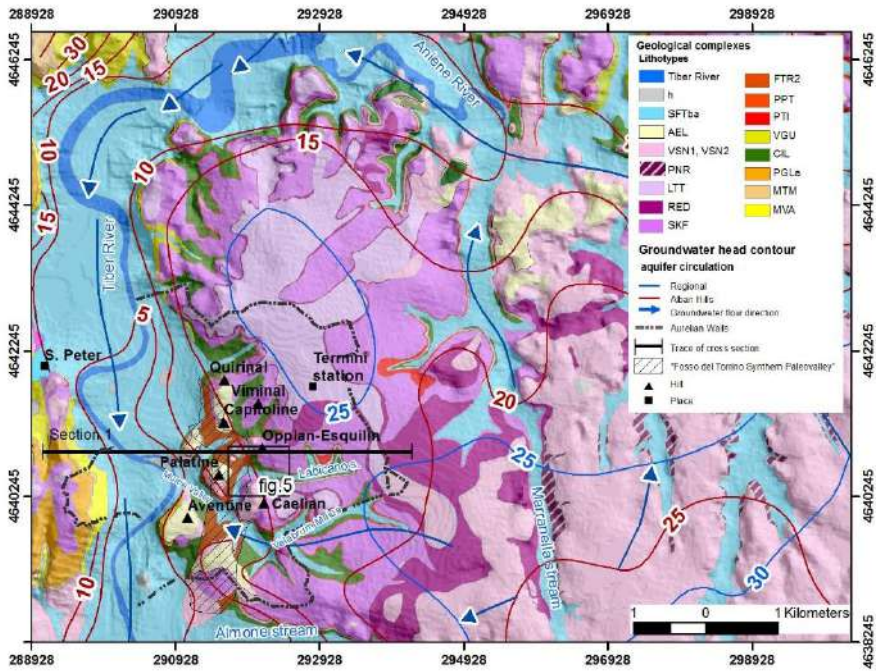
**Allagamento degli ipogei del colosseo durante il nubifragio del 20 Ottobre 2011**



Schema idrogeologico regionale e unità idrogeologiche (after Capelli et al., 2012)



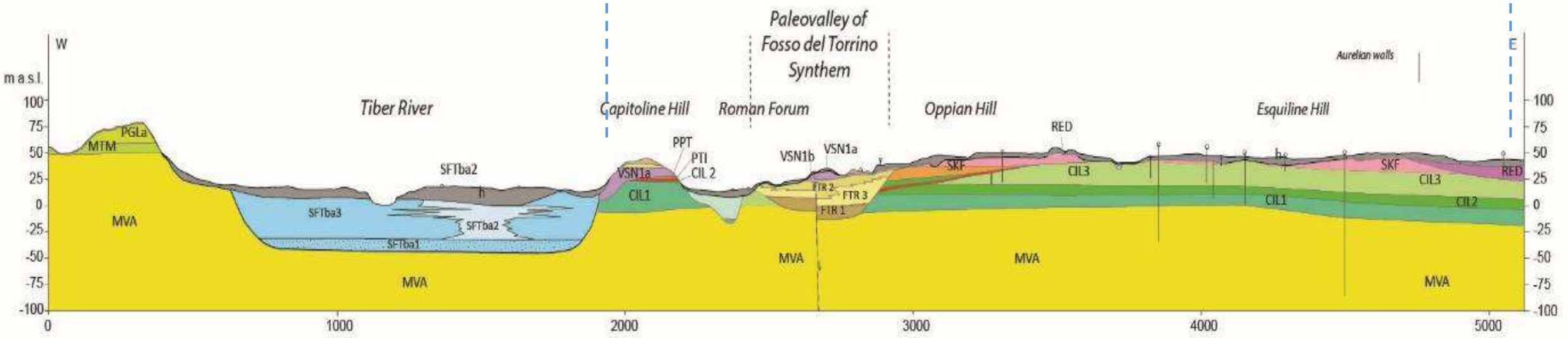




- h - Anthropogenic deposit**  
Late Holocene - Historical age
- SFTba - Alluvial deposit**  
Silty-clayey deposits, with organic clays, sands and gravels.  
SFTba 1 - gravel, SFTba 2 - sands, SFTba 3 - organic clay.  
Upper Pleistocene p.p. - Holocene
- AT**  
**Terraced Alluvial Units AT - Aurelia (AEL) and Vitinia (VTN) Formations**  
Clayey-silty fluvial deposits associated with sands, diatomites and reworked volcanic deposits.  
Middle Pleistocene
- VSN2**  
**Villa Senni Formation: Pozzolanelle member**  
Gray-brown welded scoriaceous ashes (pozzolans), from the Colli Albani volcanic district.  
Middle Pleistocene
- VSN1a**  
**Villa Senni Formation: Tufo Lionato member**  
Massive, generally lithoid brown-red tuff, from the Colli Albani volcanic district.  
a- massive lithoid tuff; b- pozzolan tuff.  
Middle Pleistocene
- VSN1b**
- LTT**  
**Tufi stratificati varicolori di La Storta**  
Alternations of layered tuffs, from the Monti Sabatini volcanic district.  
Middle Pleistocene
- FTR - "Fosso del Torrino" Formation**  
Silt, sandy silt and minor amount of sand and gravel, usually sand-coloured.  
1 - Gravel; 2 - sand; 3 - silty-clayey.  
Middle Pleistocene p.p.
- CIL - "Santa Cecilia" Formation**  
Gravel, sand and clay, usually gray coloured, in sub-horizontal layers.  
CIL 1 - Gravel; CIL 2 - sand and silt; CIL 3 - clay and silt.  
Middle Pleistocene p.p.

- RED**  
**Pozzolane Rosse**  
Massive and chaotic, red to purple to dark gray, semi-lithoid pozzolans, from the Colli Albani volcanic district.  
Middle Pleistocene
  - SKF**  
**Tufi stratificati varicolori di Sacrofano**  
Alternation of layered tuffs, from the Monti Sabatini volcanic district.  
Pleistocene medio p.p.
  - PPT**  
**Prima Porta Unit**  
Layered semi-lithoid ashy tuff, from the Monti Sabatini volcanic district.  
Middle Pleistocene
  - PTI**  
**Palatino Unit**  
Massive lithoid grey-green tuffs, from the Colli Albani volcanic district.  
This is a marker unit locally embedded within the Vale Giulia Formation.  
Middle Pleistocene
  - PGLa**  
**PGLa - Ponte Galeria Fm (PGLa member)**  
Yellow or gray fine sands, locally silty sands.  
Middle-Lower Pleistocene
  - MTM**  
**Monte Mario Fm.**  
Yellow brown silty.  
Lower Pleistocene p.p.
  - MVA**  
**MVA - "Monte Vaticano" Formation**  
Clay and marly clay, consistent, with sandy layers interbedded (10 cm thickness).  
Lower Pliocene p.p. - Upper Pliocene p.p.
- Hypotesized direct fault**
- Borehole**

### Santa Cecilia Formation deposit





*Tiber River*

*Capitoline*

*Velabrum*

*Forum*

*Oppian*

**Colosseum**

*Palatine*

*Aventine*

*Circus Maximum*

*Labicana Valley*

*Caelian*

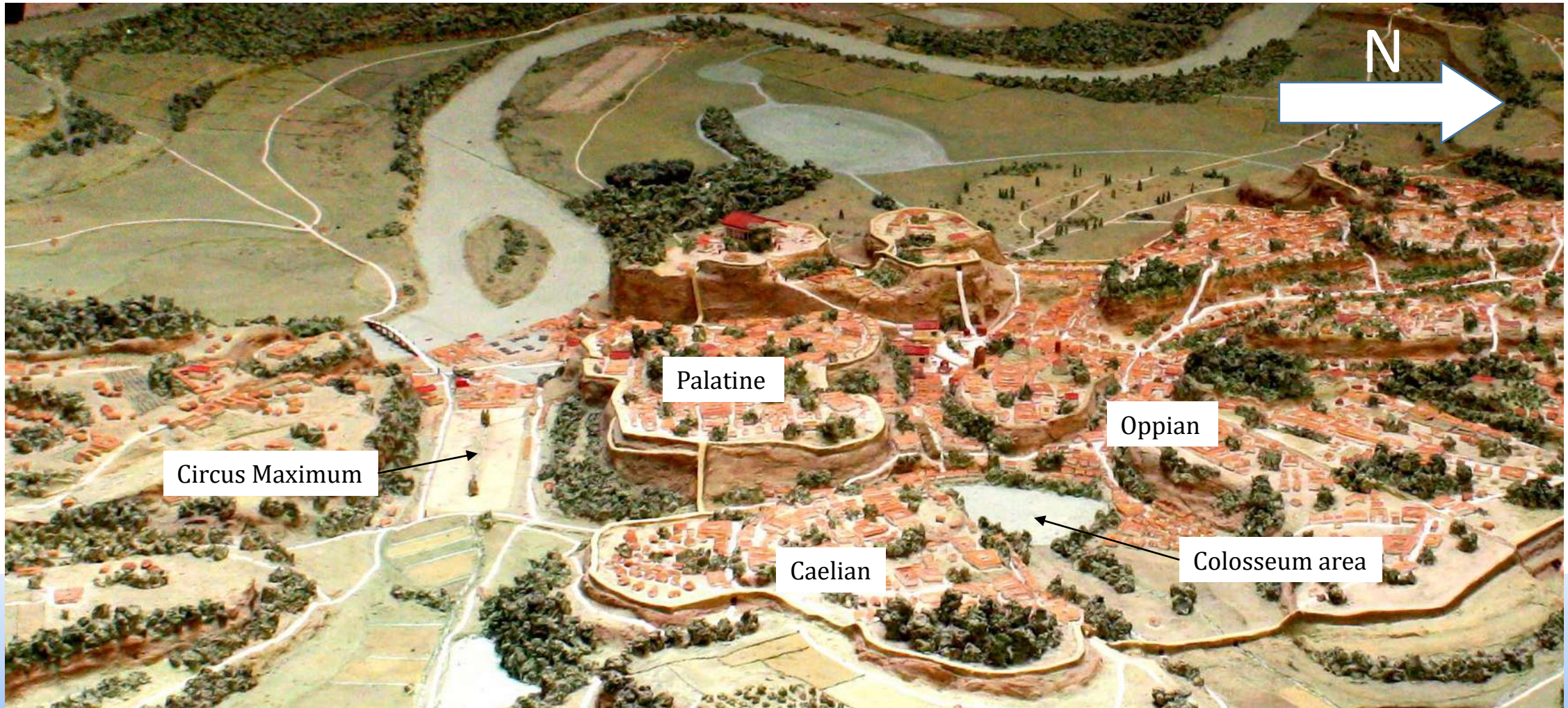
*Murcia Valley*

1 km

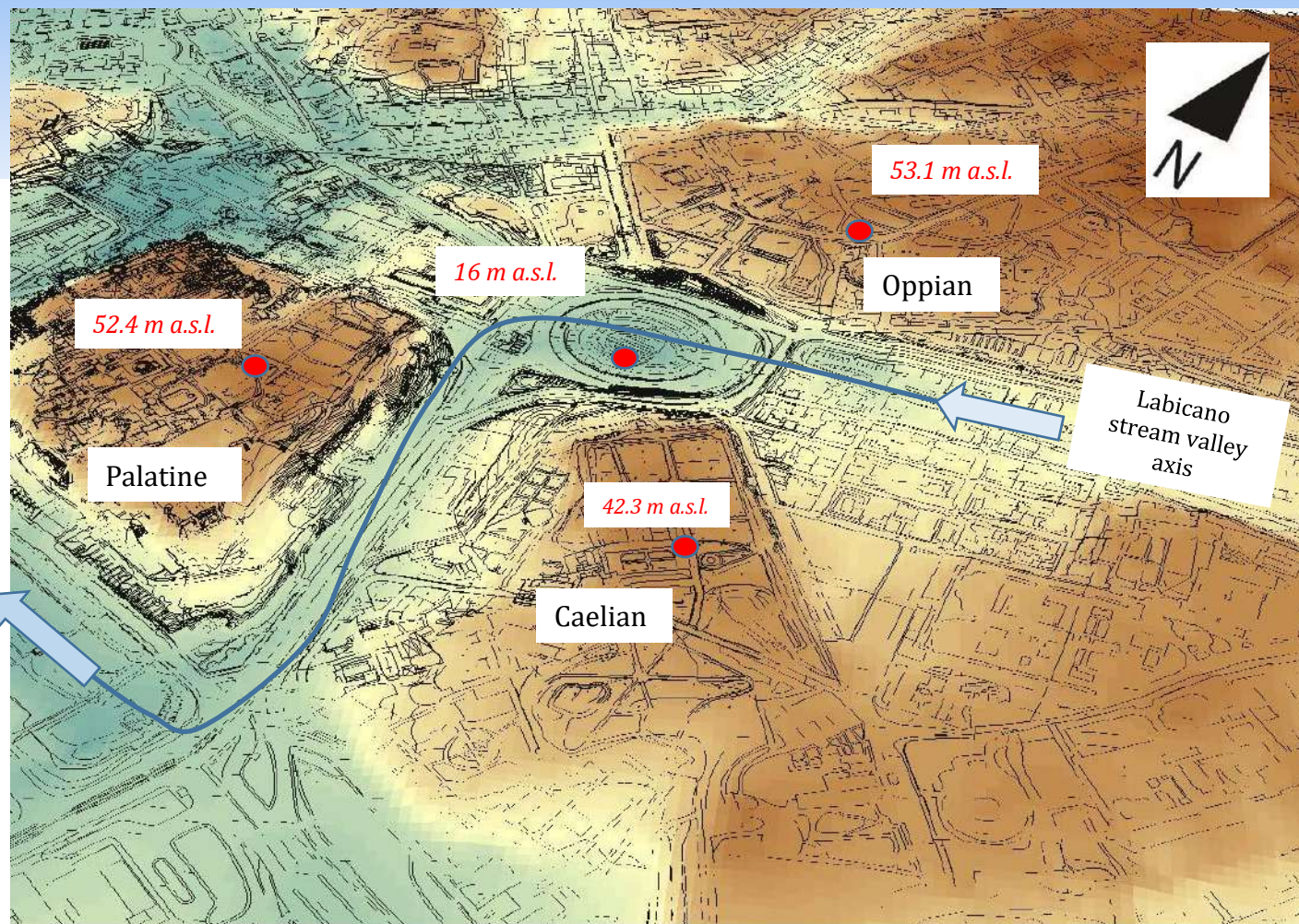
*Imagine from Google Earth*

# Museo della Civiltà romana

## modello di Roma arcaica (from VIII century b.c.)




# Colosseum



DTM.tif

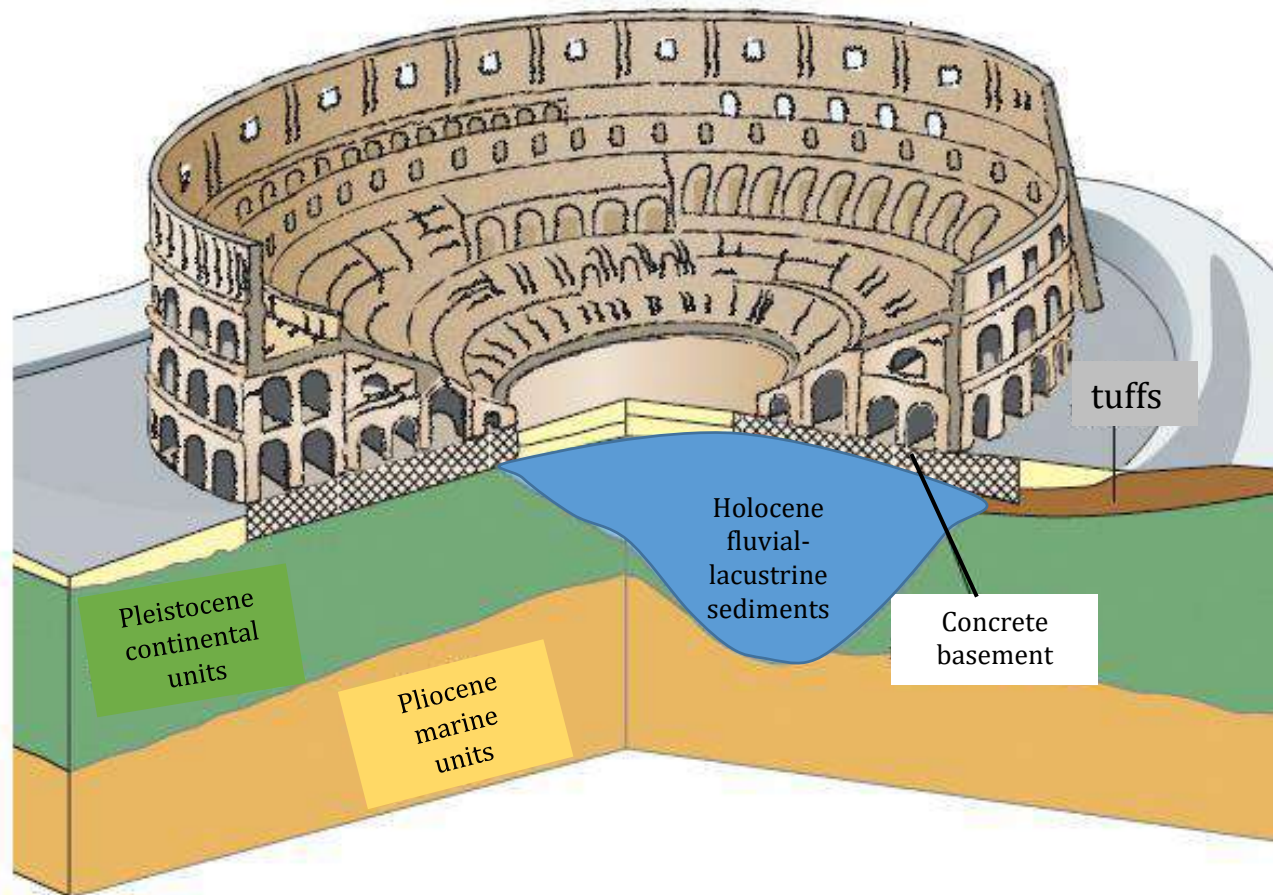
Value

High : 55

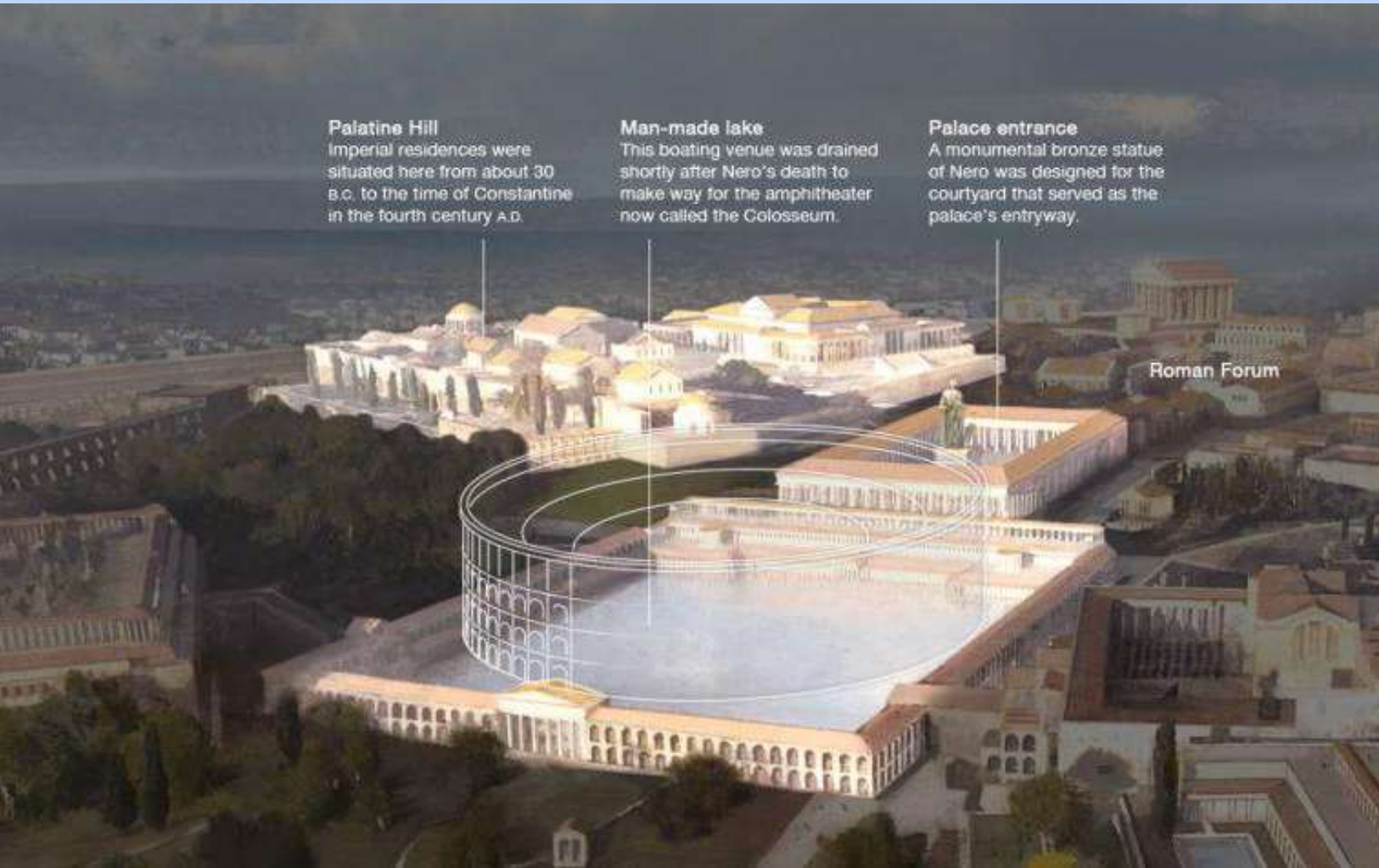


Low : 13

# Colosseum



*Block-diagram showing the geological setting of the area of the Colosseum; view from SW (after Funicello et al., 1995)*



**Palatine Hill**  
Imperial residences were situated here from about 30 B.C. to the time of Constantine in the fourth century A.D.

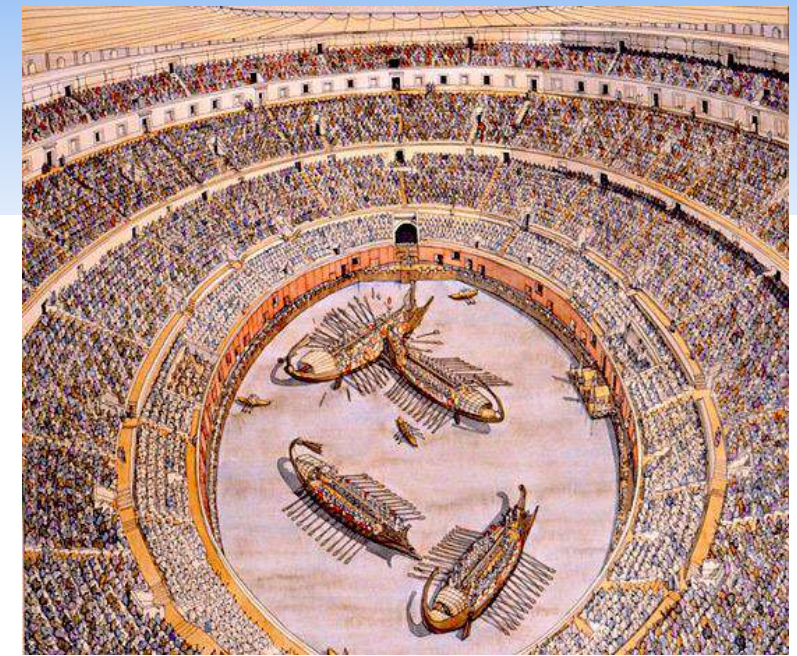
**Man-made lake**  
This boating venue was drained shortly after Nero's death to make way for the amphitheater now called the Colosseum.

**Palace entrance**  
A monumental bronze statue of Nero was designed for the courtyard that served as the palace's entryway.

Roman Forum

### Stagnum Neronis

<https://www.capitolivm.it/meraviglie-di-roma/domus-aurea-la-residenza-dorata-nerone/>



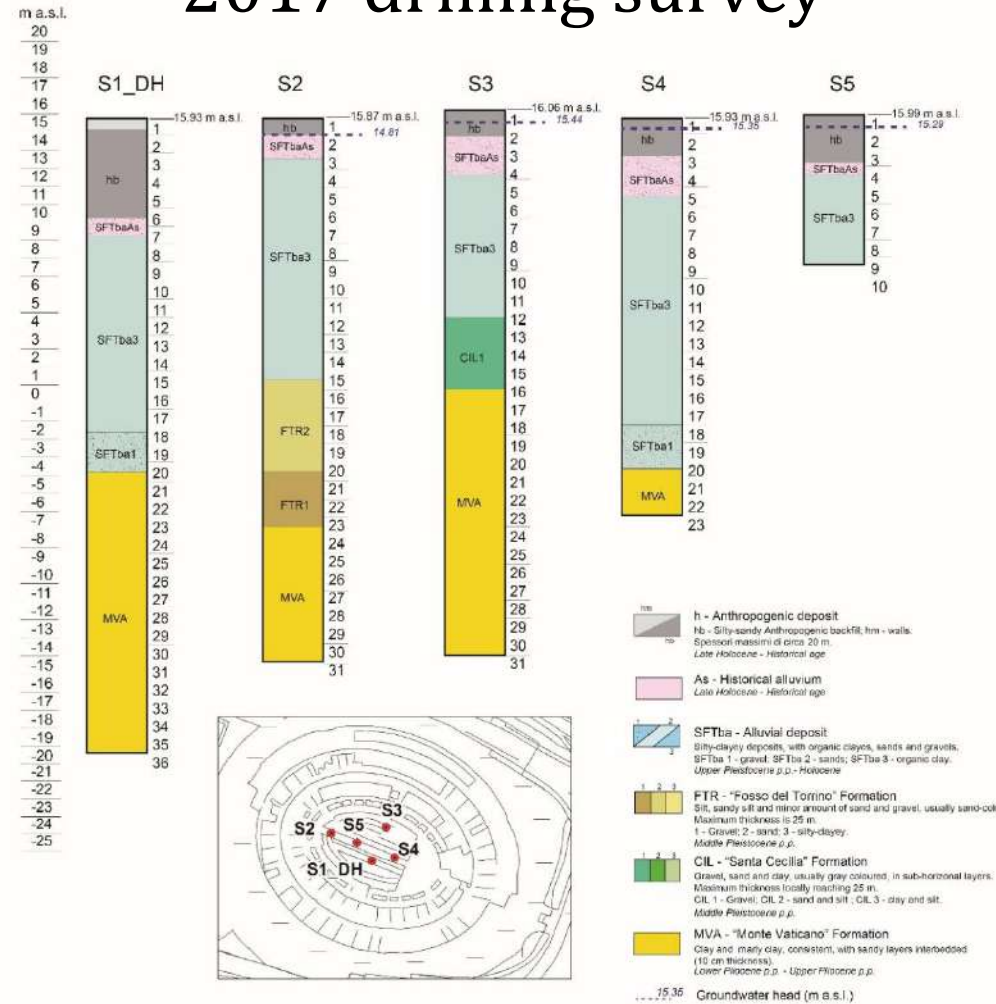
Representation of Naumachiae



Hypogea floor with remains of impermeable cover

Non marine Synthems <sup>(1)</sup> and 3 <sup>rd</sup> order marine Sequence <sup>(2)</sup>	Formation <sup>(1)</sup>	Lithotypes	Hydrostratigraphic complex
Tiber River Synthem (MIS 5-1)	Anthropogenic layer (Holocene)  Alluvial deposit (Tiber River depositional system, Upper Pleistocene-Holocene)	hm: dominant masonry  hb: dominant infill  SFTba 1: gravels SFTba 2: sands SFTba 3: silts and clay	h  SFTba 1 SFTba 2 SFTba 3
Quartaccio Synthem (MIS 10-9)	Aurelia Fm.  Villa Senni Fm.- Pozzolanelle  Villa Senni Fm.- Tufo Lionato (355 ± 2 ka <sup>(3)</sup> )	AEL: sandy-silty  VSN2: poorly cemented, welded coarse scoriaceous ashes VSN1 a: lithoid tuff  VSN1 b: poorly cemented, welded coarse scoriaceous ashes	VTA-Q
Fosso del Torrino Synthem (MIS 12-11)	Pozzolane nere Fm. (407 ± 4 ka <sup>(3)</sup> ) + LTT La Storta Fm. (416 ± 6 ka <sup>(3)</sup> )  Pozzolane Rosse Fm. (457 ± 4 ka <sup>(3)</sup> )  Fosso del Torrino Fm.	PNR: Black massive and chaotic pyroclastic unit LTT: Ashy and scoriaceous pyroclastic deposit RED: massive semicoherent deposit with up to 24 cm diameter FTR 1: sandy gravels FTR 2: silty sands and sandy silts FTR 3: clayey silts and silty clays	VTA-S  FTR 1 FTR 2 FTR 3
Villa Glori Synthem (MIS 14-13)	Tufi stratificati varicolori di Sacrofano Fm. (488 ± 2 ka <sup>(3)</sup> ) Prima Porta Unit (518 ± 5 ka <sup>(3)</sup> ) Palatino Unit (520 ± 8 ka <sup>(3)</sup> ) Valle Giulia Fm.	SKF: pyroclastic deposit with interbedded volcano-sedimentary PTI: lithoid tuff PPT: lithoid tuff VGU 1: gravels  VGU 2: silty sands, sandy silts and clays	PTI-VGU
Flaminia Synthem (MIS 16-15)	Santa Cecilia Fm.	CIL 1: gravels CIL 2: interbedded silty sands and sandy silts CIL 3: Clayey silt	CIL 1 CIL 2 CIL 3
Vatican Sequence	Monte Vaticano Fm. (Lower - Upper Pliocene)	MVA	MVA

# 2017 drilling survey



Stratigraphic scheme reporting formal lithostratigraphic, synthetic and sequence stratigraphic units, from (1) Funciello and Giordano (2008) and (2) Milli (1997), broken down into component lithotypes, from Mancini et al., 2014 (mod). Radiometric age dates (3) are from Karner et al (2001) and reference within. MIS indicate Marine Isotope Stage of the Quaternary Period (see Wright 2000 for further details). In the last column on the right-hand side hydrogeological complexes, into which lithotypes were grouped for the purpose of this work. Related hydrogeological parameters and comparison with literature hydrostratigraphic frames are in table 2.



## *2017 Drilling survey in the Colosseum*

*Soprintendenza Speciale per il Colosseo e l'area Archeologica centrale di Roma - «Grandi Progetti Beni Culturali», Arena Colosseo – Lotto I, Indagini conoscitive, scavi archeologici e interventi di consolidamento delle strutture della parte ipogea.*





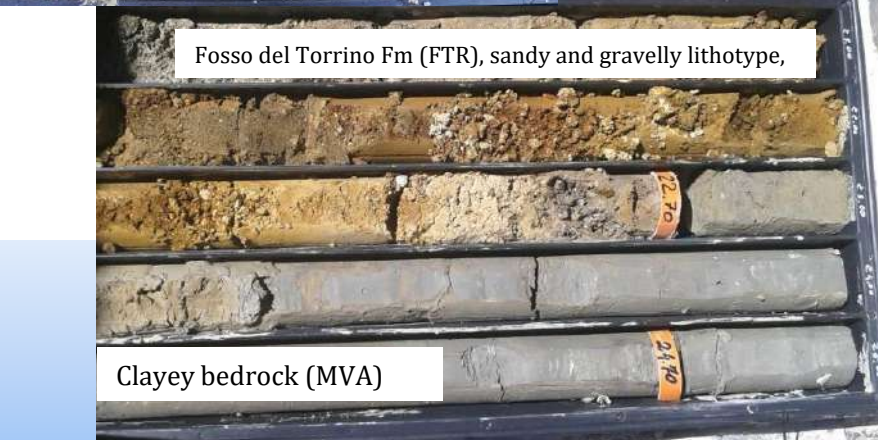
Anthropic Backfill



Holocene alluvium, SFTba



Santa Cecilia Fm (CIL), gravelly lithotype

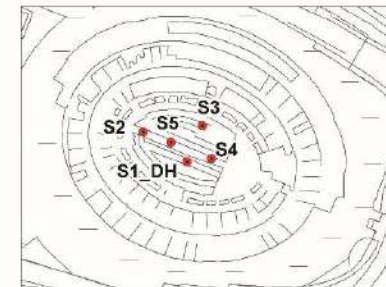
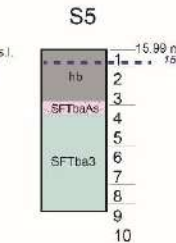
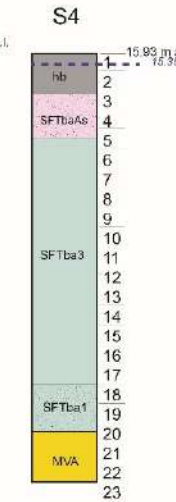
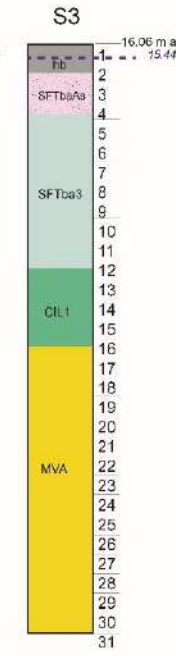
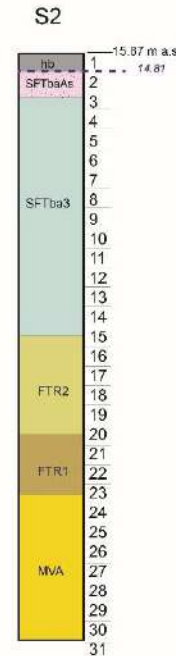
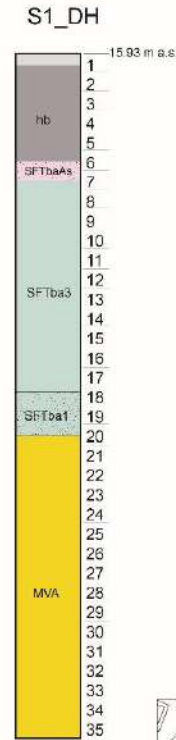
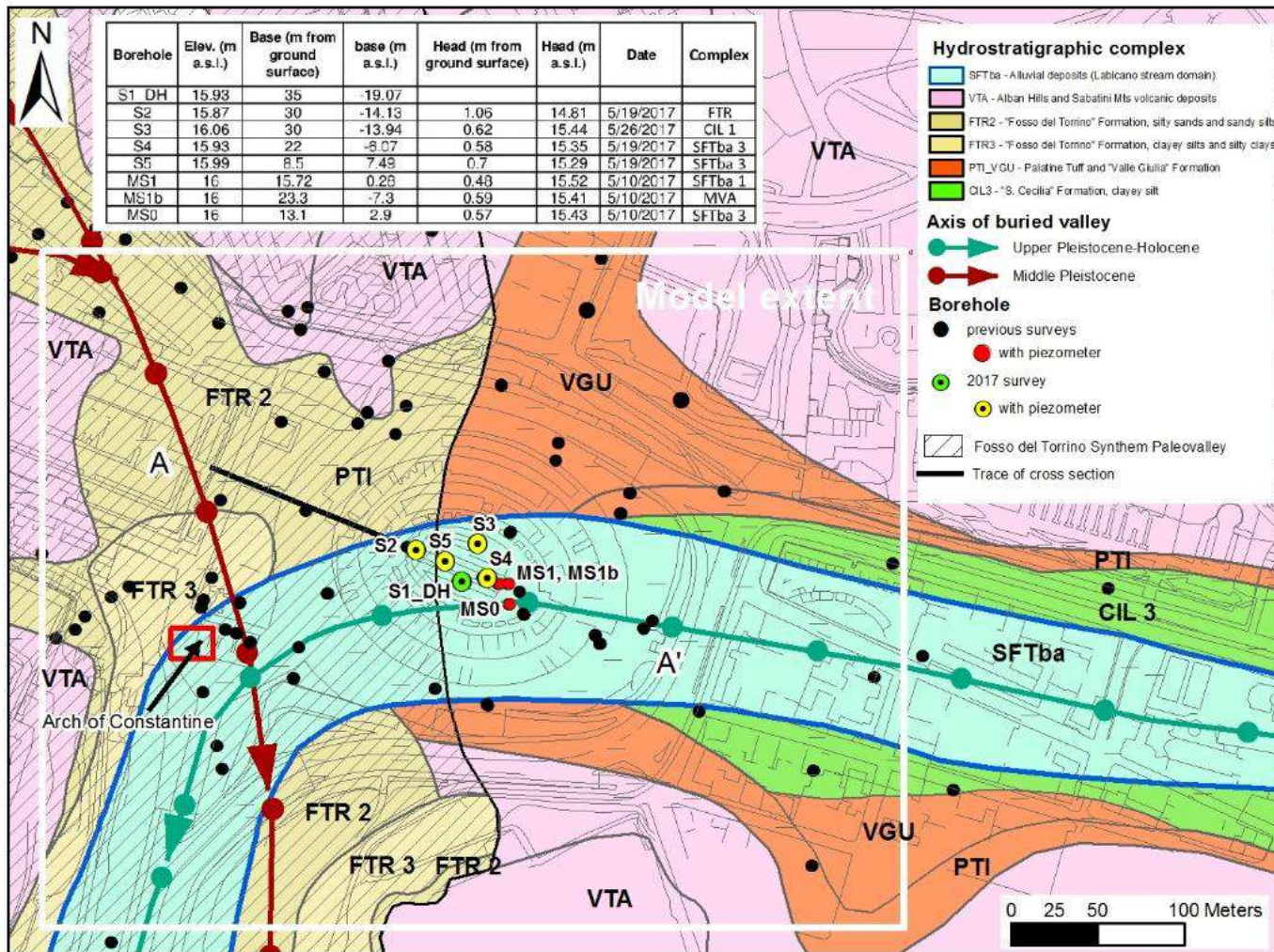


Fosso del Torrino Fm (FTR), sandy and gravelly lithotype,

Hydrostratigraphic frame (current work)	Hydrogeological Unit	Hydrogeological complex				k (m/d)		Hydrogeological condition in the study area	
		Capelli et al., 2008	Di Salvo et al., 2012	La Vigna et al., 2016	Mancini et al., 2014				
h	-	Anthropic backfill c.	Anthropic backfill - Complex 5	Anthropogenic deposit c.	-	-	Uppermost aquifer; variable transmissivity depending upon local thickness, granulometry and texture		
SFTba3	Alluvial	Alluvium deposits c.	Recent alluvium - Complex 4	Alluvial deposit c.	0.00003-0.5		aquiclude		
SFTba2					0.032-43.2		mostly unconfined perched aquifers		
SFTba1					0.003-6.5		confined aquifer, buried at the bottom of alluvial valleys		
VTA	Volcanic	Complexes owing to the Alban Hills Hydrogeological Unit		Volcanic units	Heterogeneous clastic deposit c., "Tufo Lionato" c., High permeability Alban Volcanic deposit.		0.025 - 5.7 <sup>(1)</sup>	Multilayer aquifer	
PTI_VGU		Pisolitic tuff and Sabatini Volcanic complexes	Valle Giulia Formation Complex	Volcanic units	Coeval alluvial deposits	Low permeability volcanic deposits of Alban Hills; Sabatini volcanic c.	Valle Giulia Formation Complex	0.02-2.6	0.002-0.02
FTR3	Middle Tiber Valley detritical-alluvial	Fluvial-marshy complex of Santa Cecilia Fm c.	Ponte Galeria Unit-Complex 2	Santa Cecilia Fm. c. (sandy silty portion)	0.000397		aquiclude		
FTR2					0.14		confined/unconfined aquifer		
FTR1					0.292		confined aquifer		
CIL3					0.0001-0.01		aquiclude		
CIL2					0.02-2		confined/unconfined aquifer		
CIL1					0.0001-0.01		regional basal aquiclude		
MVA	-	Monte Vaticano clay c.	Mone Vaticano Unit - Complex 1	Sandy-clayey basal c.	0.0001-0.01		regional basal aquiclude		

(1) due to the scarce extension of AEL Fm. in the study area, k values are those of Volcanic Units

Hydrostratigraphic frame used in this work; comparison with previous works and hydrogeological parameters.

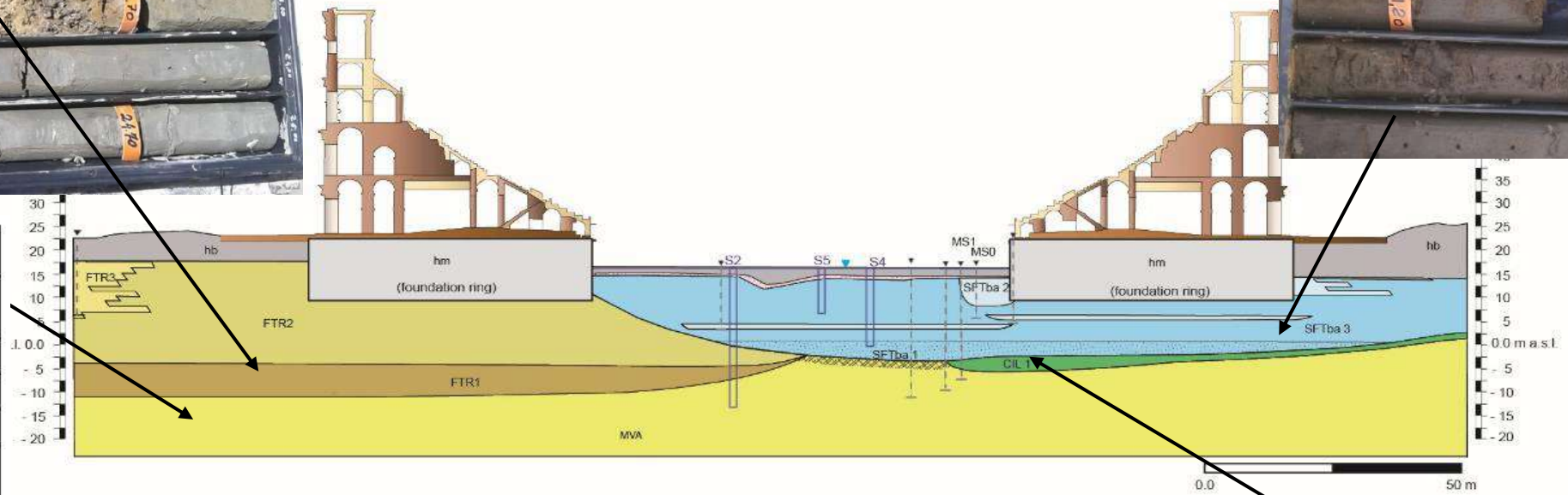


- h - Anthropogenic deposit
- hb - Silty-sandy Anthropogenic backfill; hm - walls; spessore massimo di circa 20 m; Late Holocene - Historical age
- As - Historical alluvium; Late Holocene - Historical age
- SFTba - Alluvial deposit; Silty-clayey deposits, with organic clays, sands and gravels; SFTba 1 - gravel; SFTba 2 - sands; SFTba 3 - organic clay; Upper Pleistocene p.p. - Holocene
- FTR - "Fosso del Torino" Formation; Silty, sandy silt and minor amount of sand and gravel, usually sand-coloured; Maximum thickness is 25 m; 1 - Gravel; 2 - sand; 3 - silt/clayey; Middle Pleistocene p.p.
- CIL - "Santa Cecilia" Formation; Gravel, sand and clay, usually grey coloured, in sub-horizontal layers; Maximum thickness locally reaching 25 m; CIL 1 - Gravel; CIL 2 - sand and silt; CIL 3 - clay and silt; Middle Pleistocene p.p.
- MVA - "Monte Vaticano" Formation; Clay and misty clay, consistent with sandy layers interbedded 1/6 cm thickness; Lower Pleistocene p.p. - Upper Pleistocene p.p.
- ... 15.96 Groundwater head (m a.s.l.)

Fosso del Torrino Fm (FTR), sandy and gravelly lithotype,

Clayey bedrock (MVA)

Holocene alluvium, SFTba



Hydrostratigraphic complex	k (m/d)
h	-
SFTba 1	0.003-6.5
SFTba 2	0.032-43.2
SFTba 3	0.00003-0.5
VTA-Q	0.025 - 5.7
VTA-S	
FTR 1	0.292
FTR 2	0.14
FTR 3	0.000397
VTA-P	0.02-2.6
VGU	0.002-0.02
CIL 1	0.02-2
CIL 2	0.0001-0.01
CIL 3	
MVA	0.0001-0.01

- hm - Anthropogenic deposit
- hb - Silty-sandy Anthropogenic backfill; hm - walls. Spessori massimi di circa 20 m. Late Holocene - Historical age
- As - Historical alluvium. Late Holocene - Historical age
- SFTba - Alluvial deposit. Silty-clayey deposits, with organic clays, sands and gravels. SFTba 1 - gravel; SFTba 2 - sands; SFTba 3 - organic clay. Upper Pleistocene p.p. - Holocene
- Alteration zone
- S1 - Groundwater head (m a.s.l.)

- FTR - "Fosso del Torrino" Formation. Silt, sandy silt and minor amount of sand and gravel, usually sand-coloured. Maximum thickness is 25 m. 1 - Gravel; 2 - sand; 3 - silty-clayey. Middle Pleistocene p.p.
- CIL - "Santa Cecilia" Formation. Gravel, sand and clay, usually gray coloured, in sub-h. Maximum thickness locally reaching 25 m. CIL 1 - Gravel; CIL 2 - sand and silt; CIL 3 - clay and s. Middle Pleistocene p.p.
- MVA - "Monte Vaticano" Formation. Clay and marly clay, consistent, with sandy layers inter. (10 cm thickness). Lower Pliocene p.p. - Upper Pliocene p.p.
- Borehole drilled during previous surveys (solid and dashed lines)



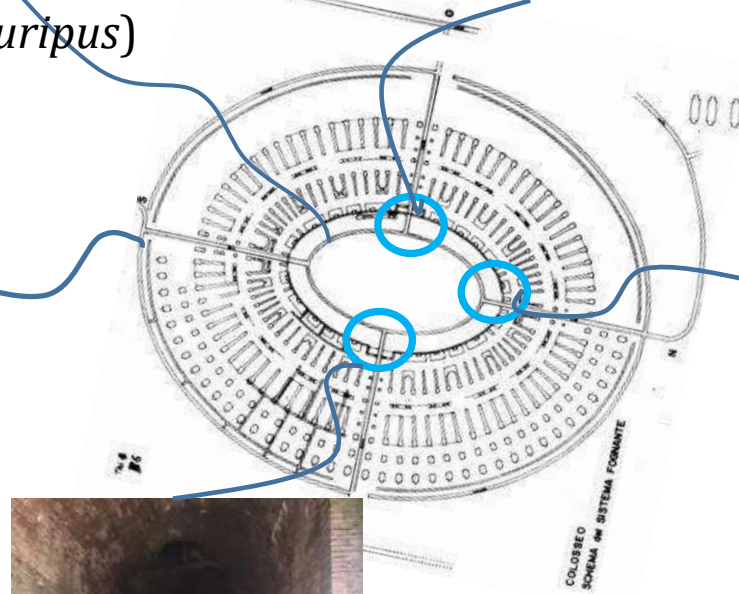
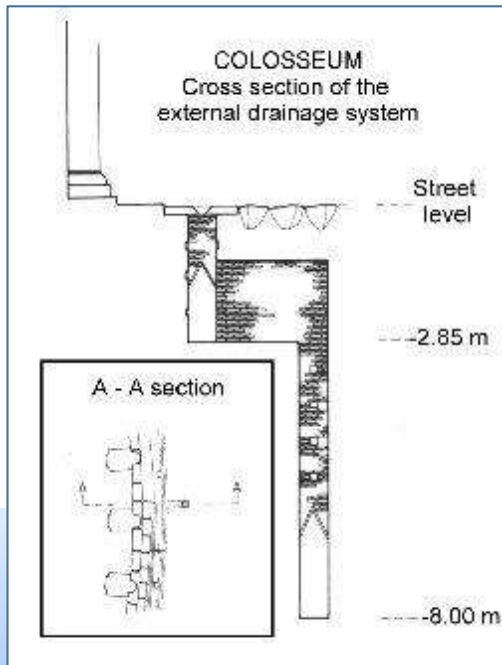
Borehole (2017 survey)

Gallery from Esquiline-Oppian hill side



*Il sistema di drenaggio artificiale,  
ad oggi parzialmente inesplorato*

Internal drainage system (*euripus*)



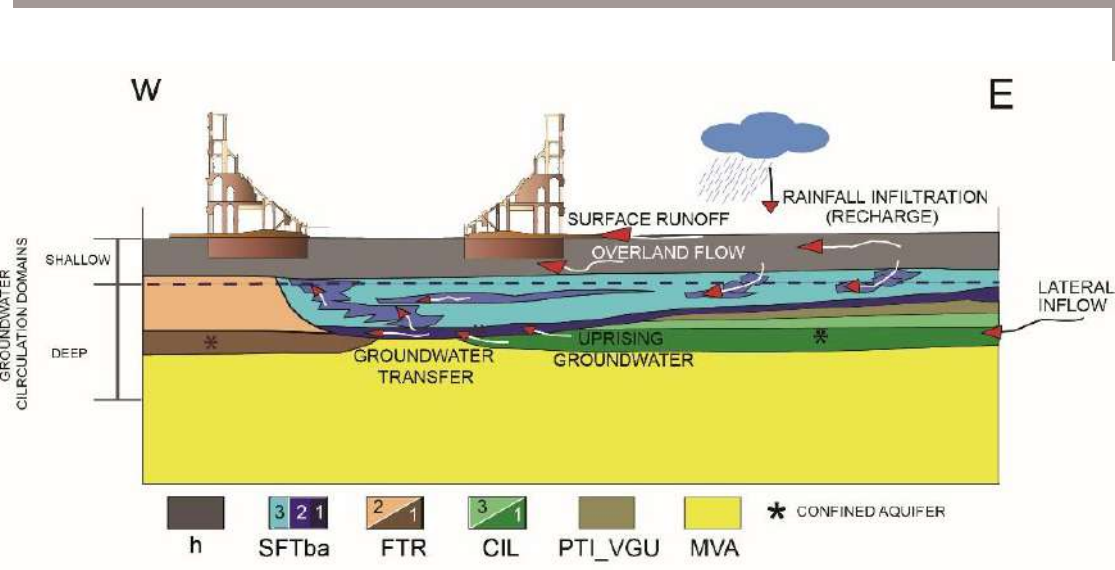
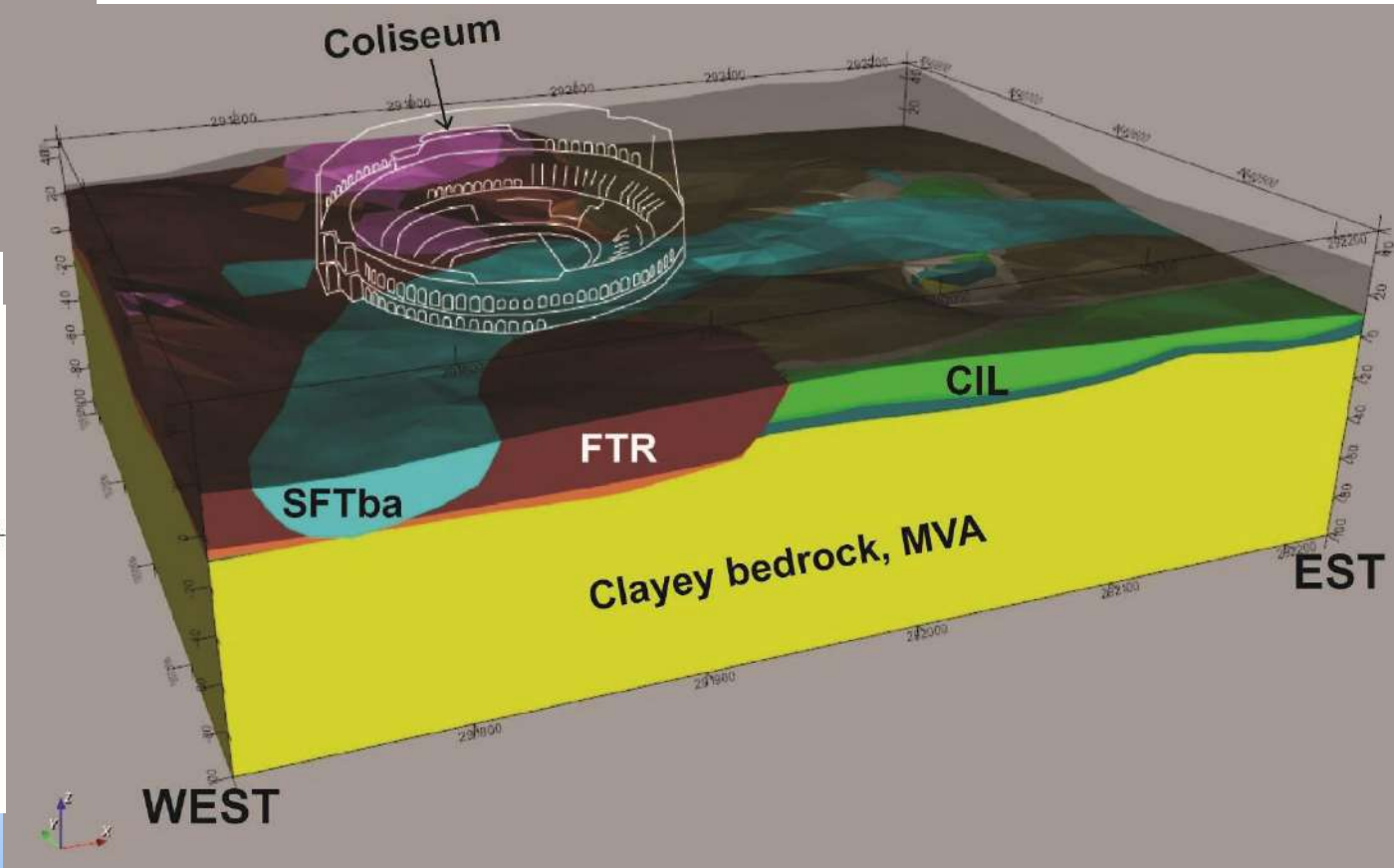
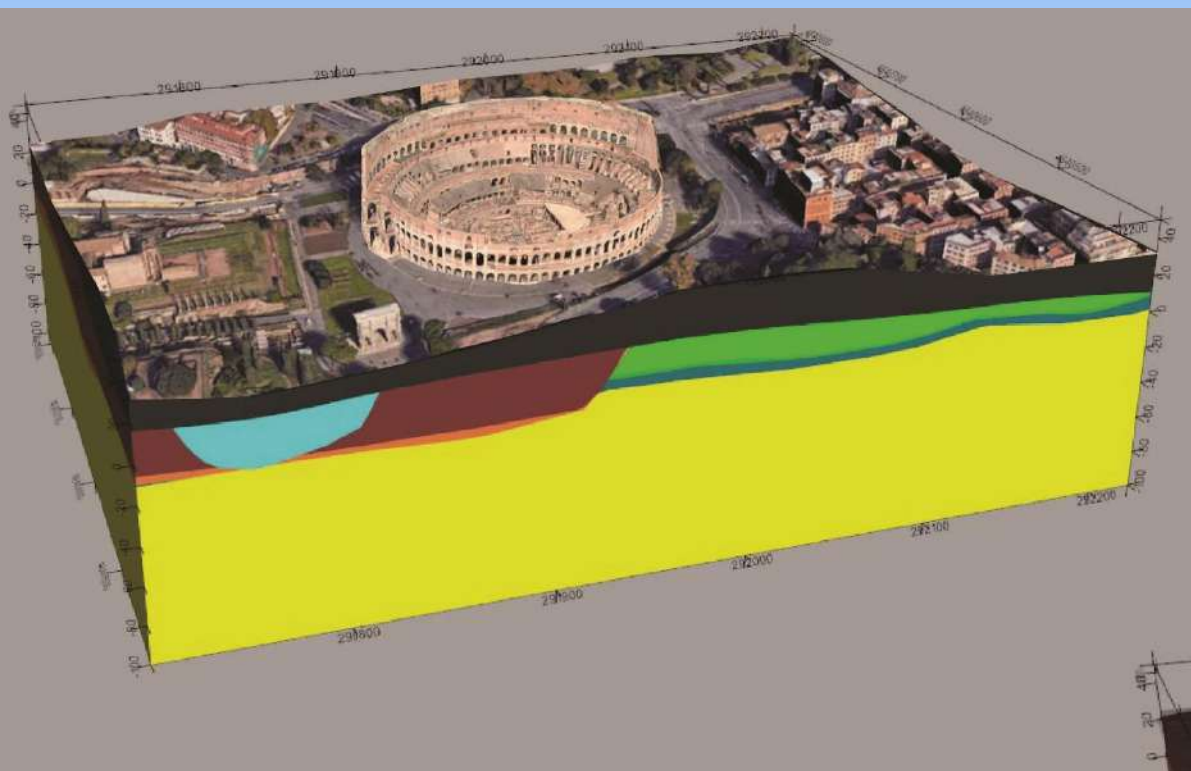
Inflow of channelized Labicano Stream

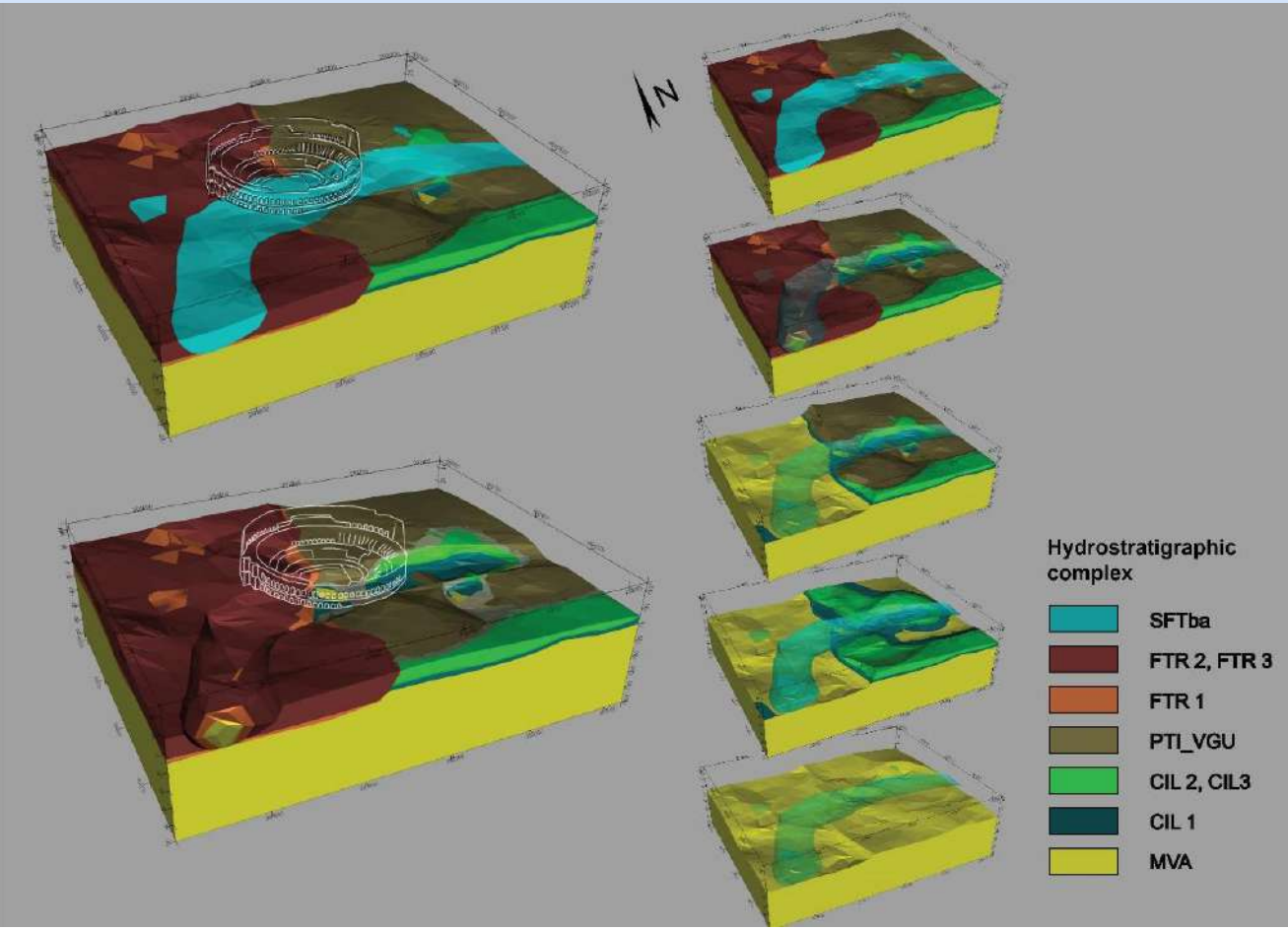
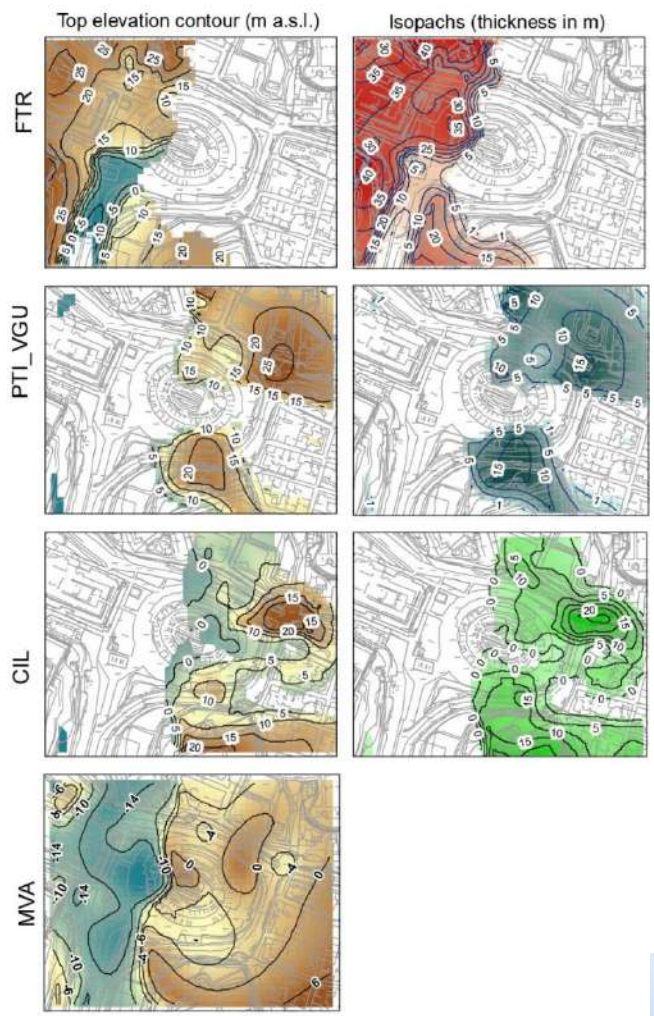
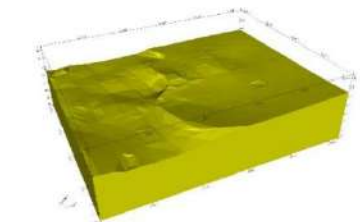
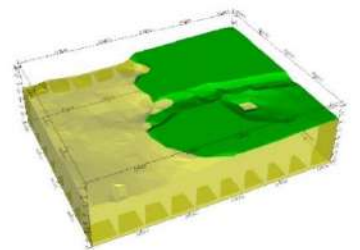
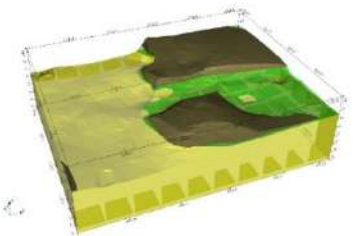
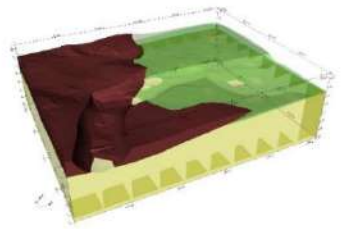


Gallery from Caelium hill side

Dimensioni modello:  
518 x 408.5m  
Area totale: 0.211 km<sup>2</sup>




Software: Geomodeller ® v 4.0 (Intrepid Geophysics)

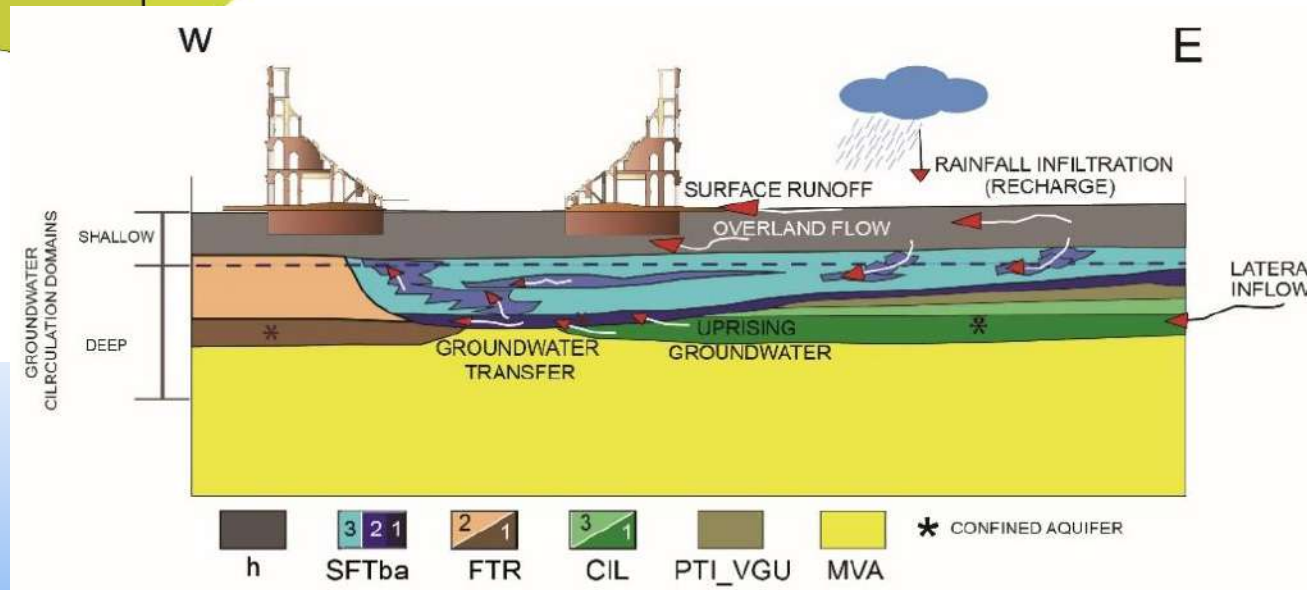
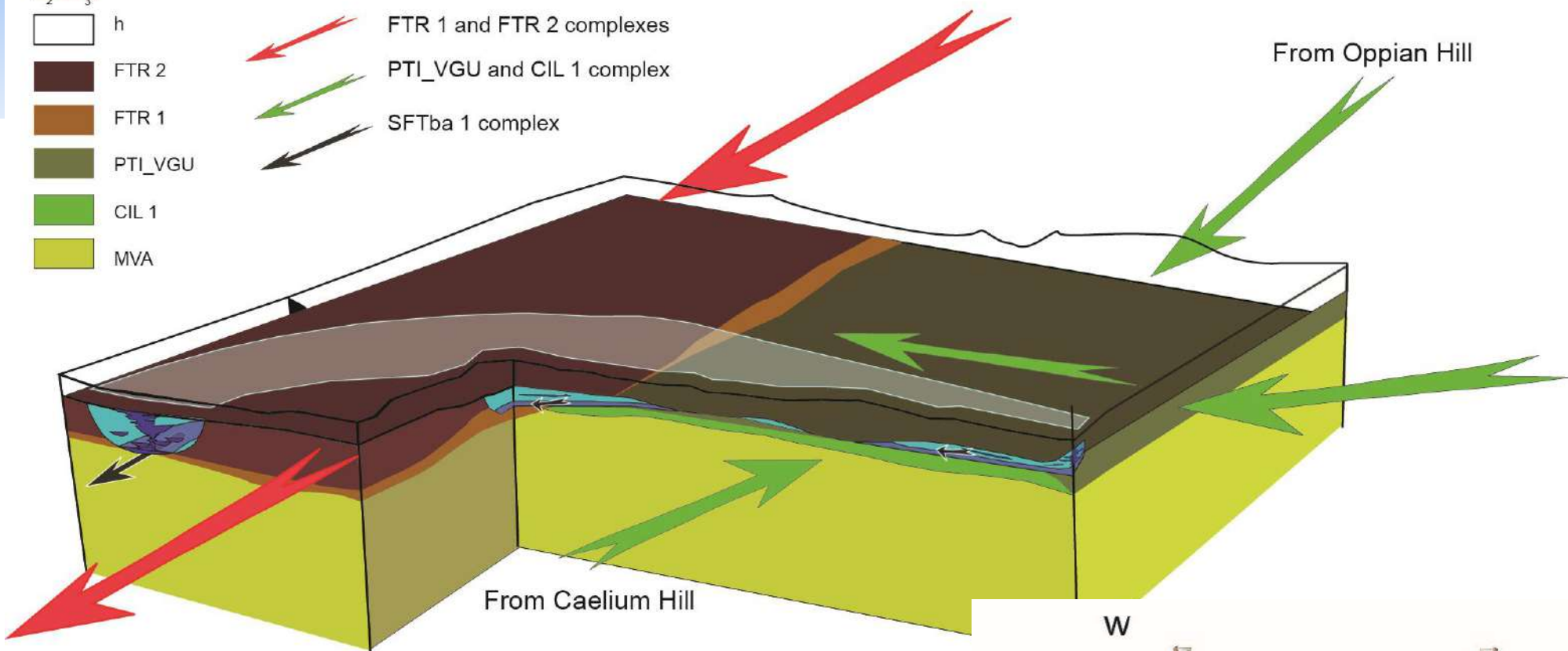


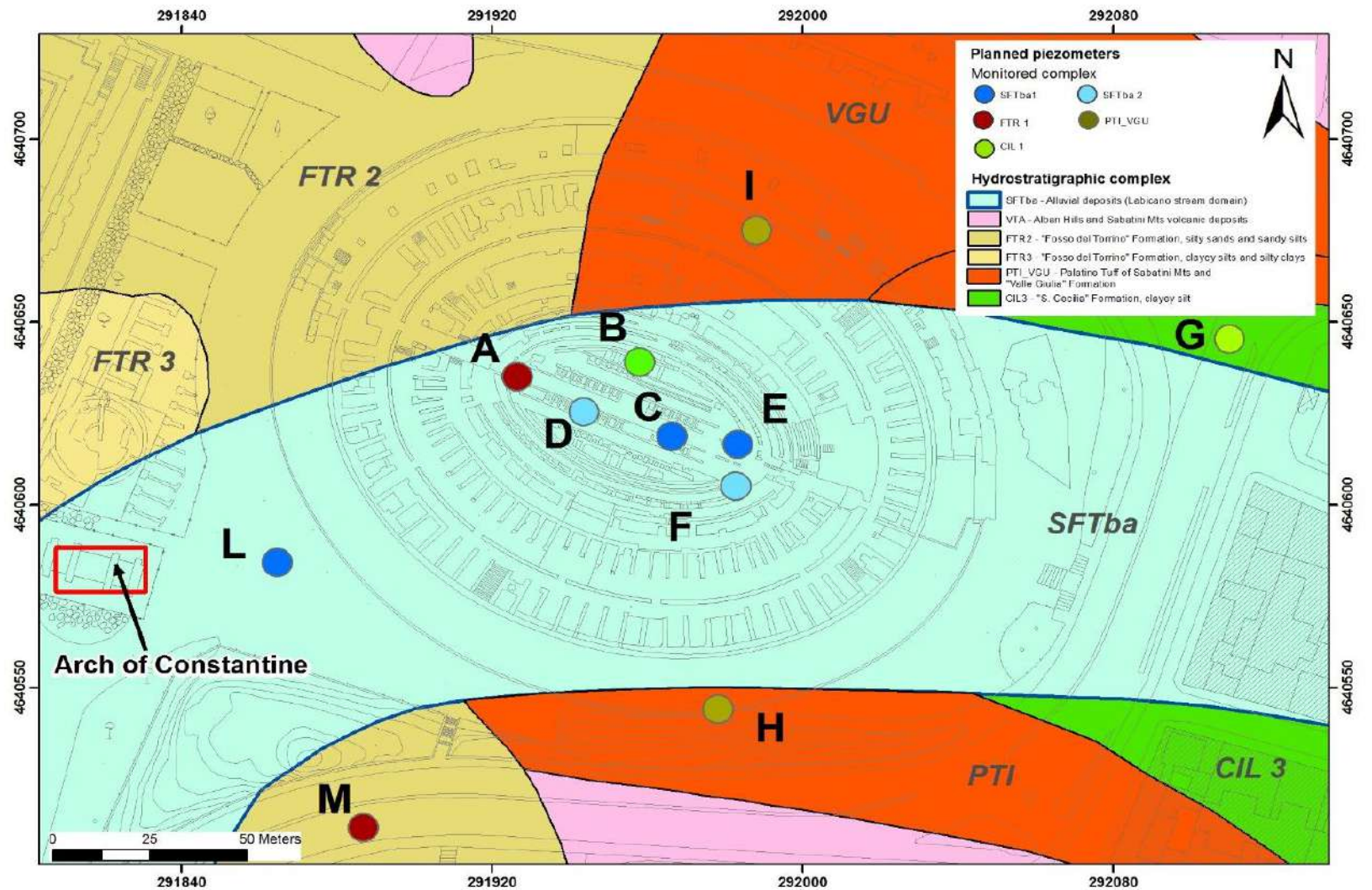


# Deep groundwater circulation domains

-  SFTba
-  h
-  FTR 2
-  FTR 1
-  PTI\_VGU
-  CIL 1
-  MVA

-  FTR 1 and FTR 2 complexes
-  PTI\_VGU and CIL 1 complex
-  SFTba 1 complex



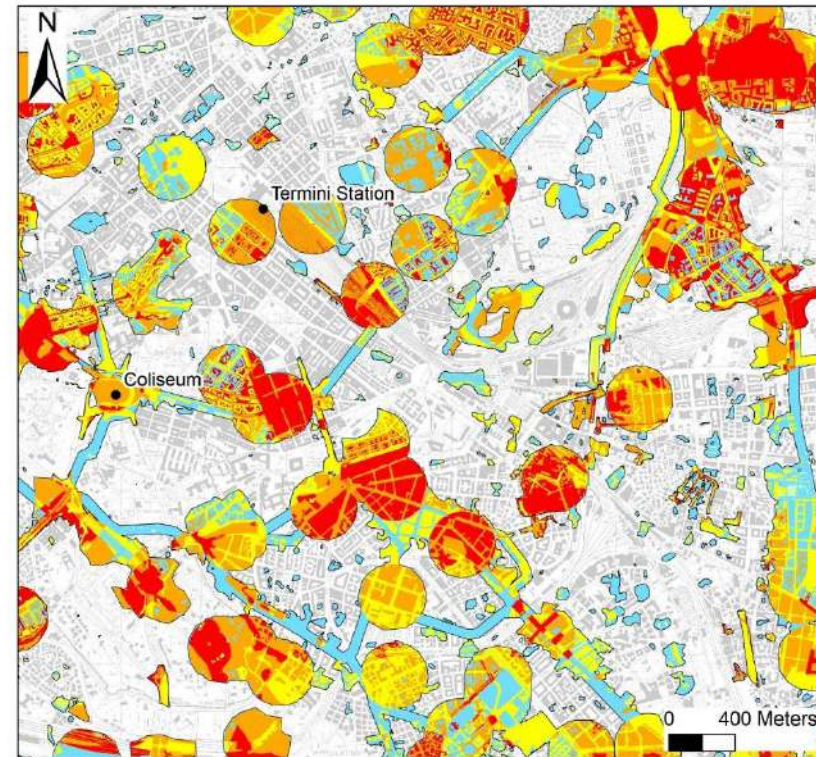


Suggerimento per l'installazione di una rete di monitoraggio piezometrico



# Sviluppo di procedure per la mappatura a scala municipale del rischio da pluvial flood

*Cristina Di Salvo, Francesco Pennica, Giancarlo Ciotoli, Gian Paolo Cavinato*



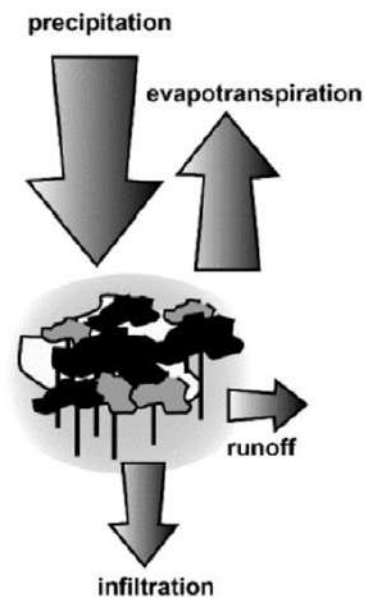
Pluvial Flood Risk

- Very high
- High
- Medium
- Low
- Very low

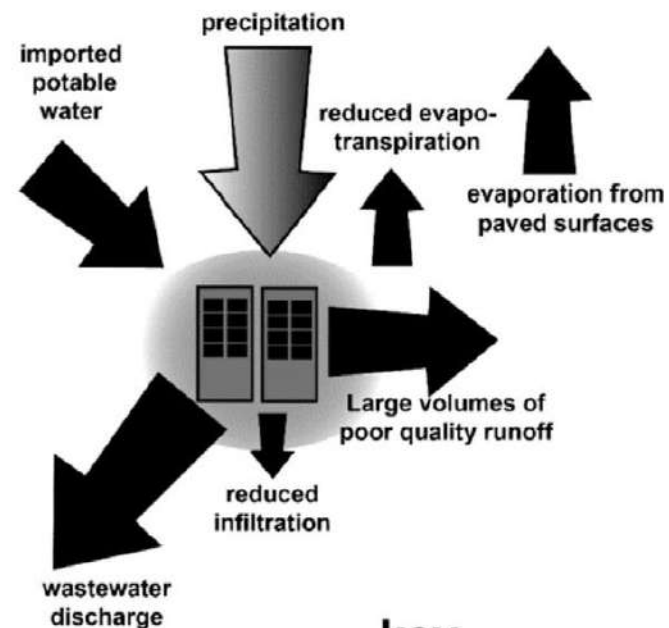
		potential impact				
		1	2	3	4	5
susceptibility	1	2	3	4	5	6
	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10

storm event (starting date)	n. observed floodings	max mm/1h	max mm/3h	max mm/24h	max mm/72h
05/24/2001	36	60.8	70.6	72.6	85.8
09/15/2001	5	36.2	37.2	37.6	37.8
08/10/2002	9	56.8	111.4	160.6	160.8
08/28/2002	7	43.8	60.8	109.2	293.2
11/01/2002	41	70.2	128.4	224	224.2
11/18/2002	11	43.2	106.4	67.4	68.8
11/26/2003	10	24	33.6	53.6	73
02/19/2004	2	80.4	80.4	107.6	107.6
07/26/2004	1	43.4	87.8	82.8	105
09/09/2005	19	57.4	91.4	96.8	97
09/22/2005	20	52.6	86	86.4	89.8
10/20/2005	8	44	59.4	83.4	104.4
09/25/2006	23	33	50.6	99.2	99.2
05/21/2008	49	21.2	41.6	97.4	134
10/17/2008	18	80.4	134.4	89.2	89.2
10/28/2008	130	72.4	151.2	155	160
11/04/2008	3	28.6	32.8	79.2	79.2
11/13/2008	30	65	93.4	98.6	104.2
12/11/2008	85	36.8	57.4	101.2	183.4
06/21/2009	21	36	37.6	47.4	53.5
07/02/2009	5	40.6	40.8	41	41
11/28/2010	11	23.8	28.4	72.2	75
03/16/2011	10	13.6	23.6	66.6	87.2
07/27/2011	14	84	95.2	109.4	114
12/12/2011	76	45	84.2	91.6	91.6
06/16/2014	118	98.4	112.6	129.8	181.8

### natural water balance



### urban water balance



### key



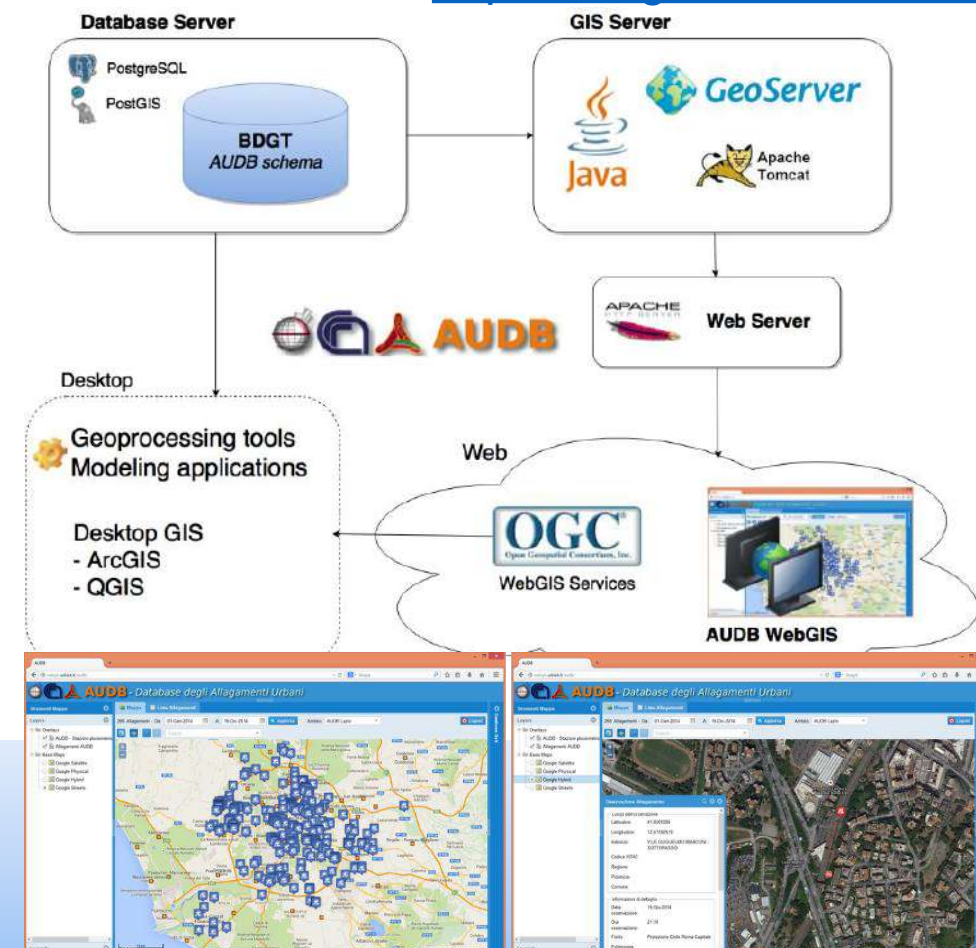
# Obiettivi del lavoro

- Testare una catena di strumenti GIS per la mappatura della **suscettibilità** da pluvial flood a scala municipale
- Derivare **scenari di impatto** compatibili con i dati a disposizione sul danneggiamento osservato
- Integrare suscettibilità e impatto potenziale per derivare una mappa preliminare di **rischio** da pluvial flood a scala municipale



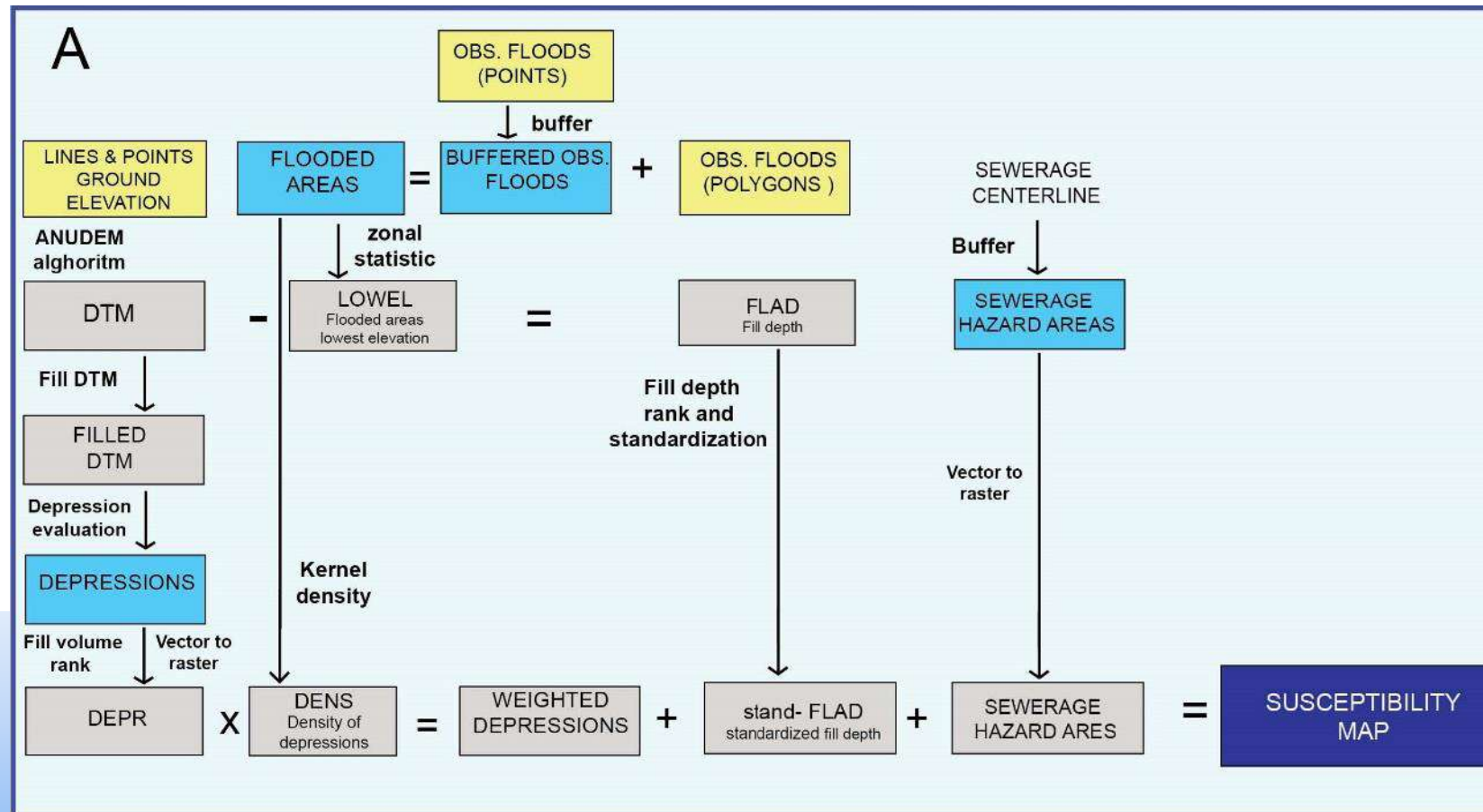
- **Linee e punti quotati** dalla cartografia regionale della Regione Lazio (scala 1:5000)
- Shape poligonale con **impronta degli edifici** e destinazione d'uso (Regione Lazio)
- Perimetro **aree a rischio alluvione** (Autorità di Bacino del Tevere, 2006; 2013)
- Shape lineare della **rete stradale e metropolitana** (Geoportale nazionale)
- **Numero di impiegati** nelle attività commerciali (ISTAT, 2015)
- **Popolazione residente** suddivisa per zone (ISTAT, 2015)
- Shape puntuale delle **caditoie** (Comune di Roma, Ufficio di Protezione Civile, 2008)
- Shapefile lineare dei principali **segmenti di fognatura** (digitalizzazione di immagini raster provenienti dal web)
- Shape poligonale (30 poligoni) degli **allagamenti osservati tra il 2004 e il 2007** (Comune di Roma, Protezione Civile)
- Shape puntuale (1430 punti) relativi **agli allagamenti osservati tra il 2001 e il 2014** (Vigili del Fuoco, Polizia Municipale, Comune di Roma, dati raccolti online)

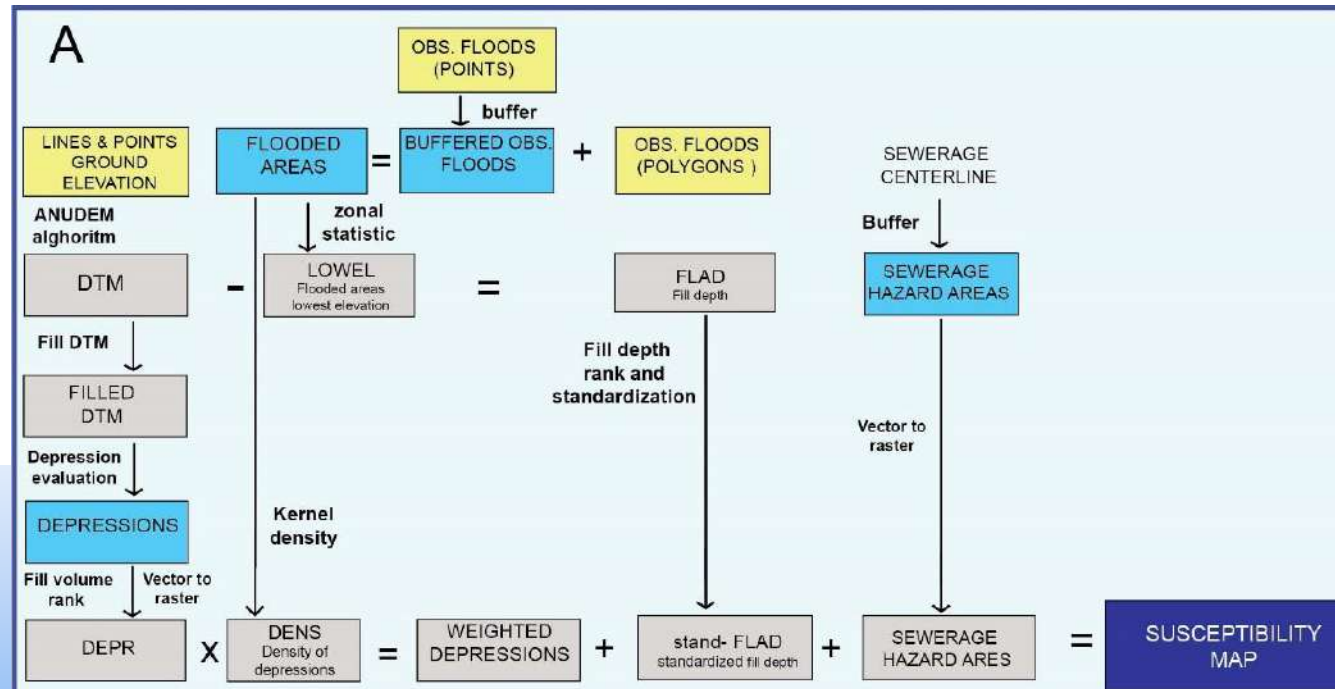
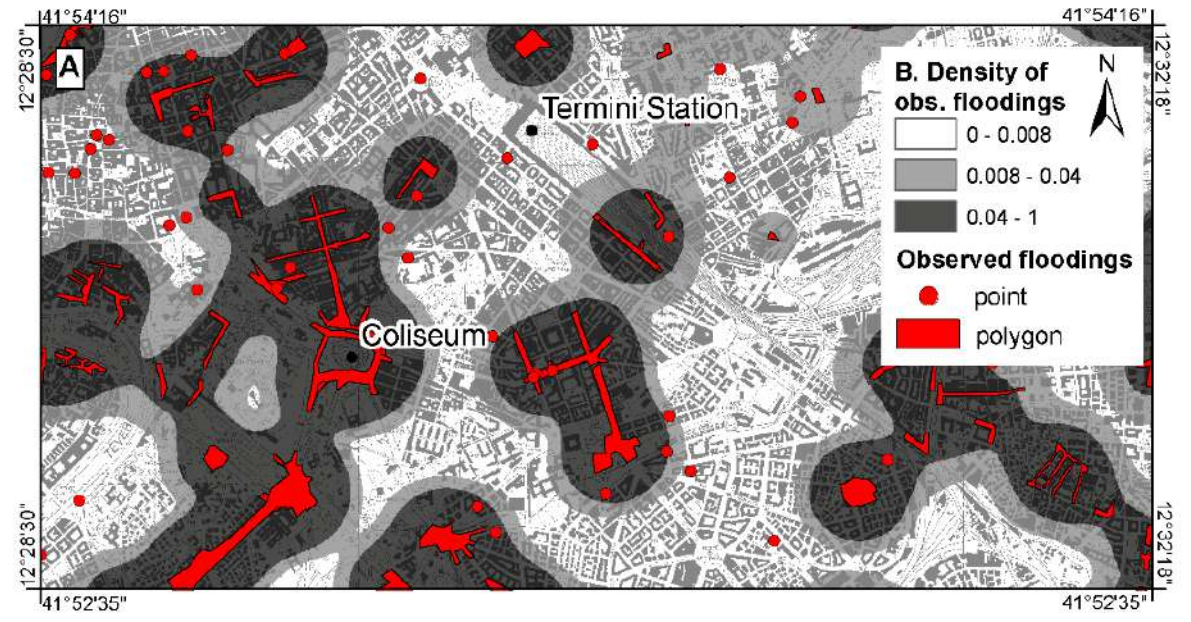
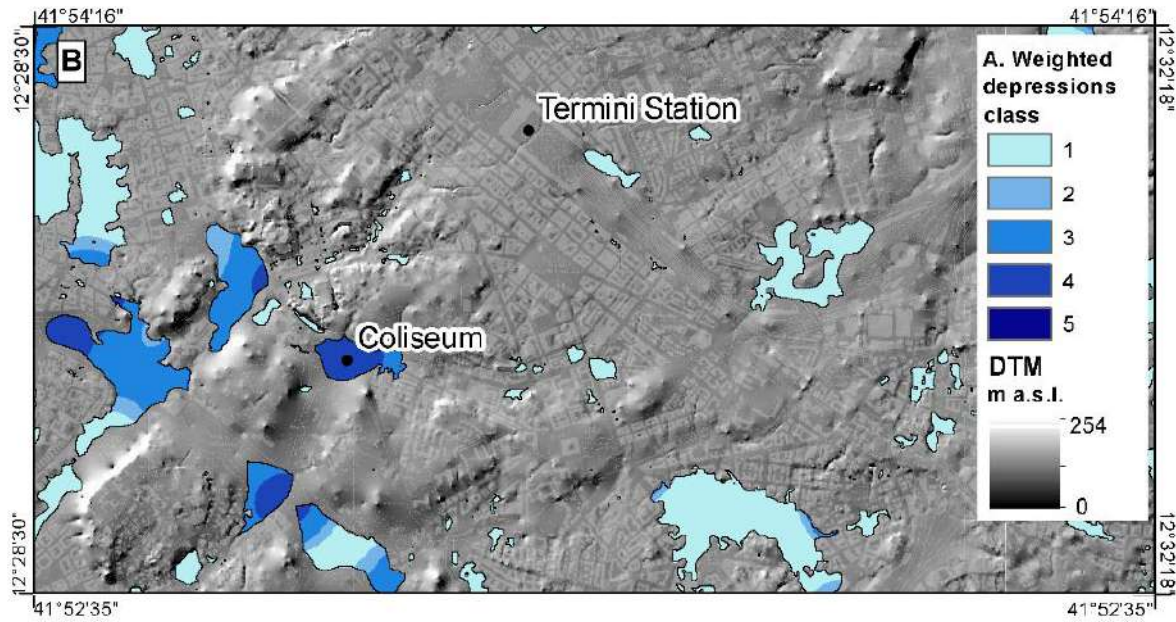
<http://webgis.urbisit.it/audb>

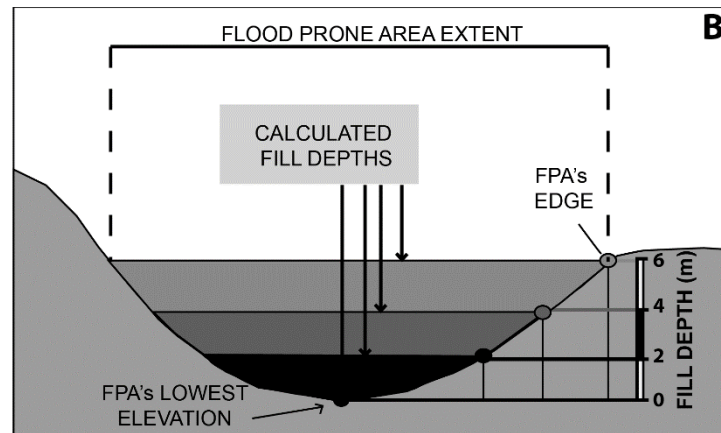
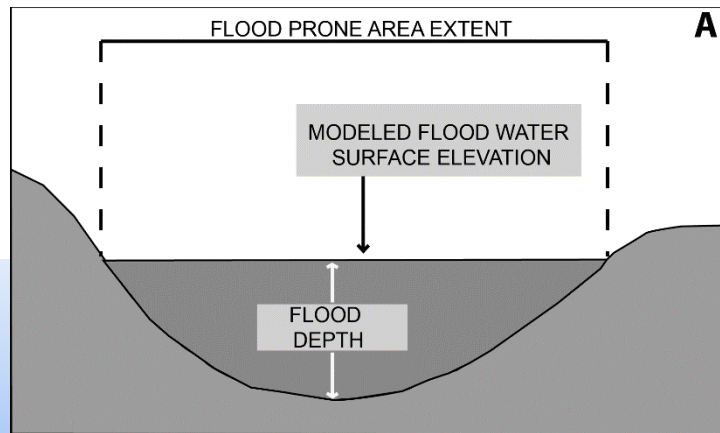
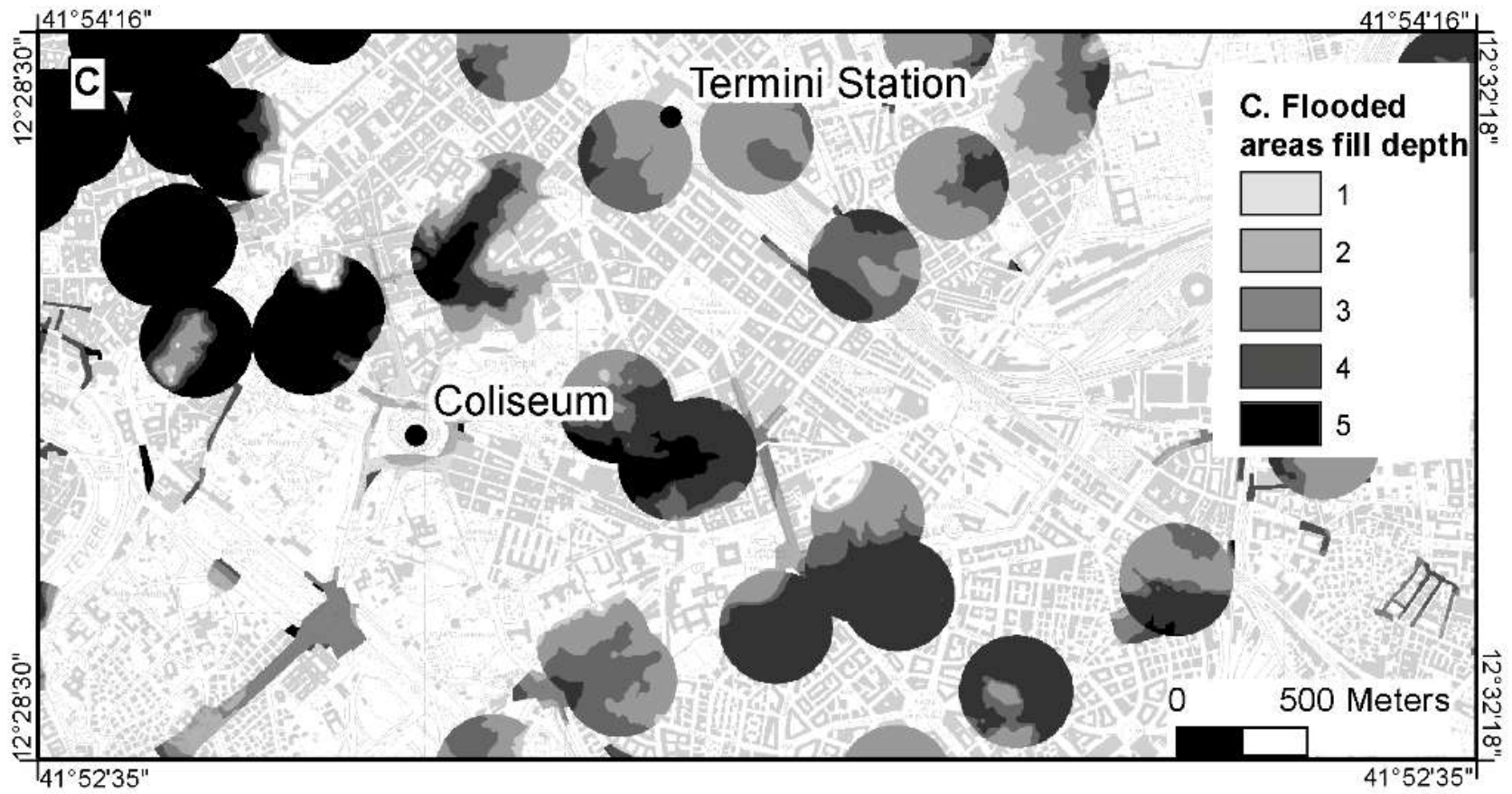


# Analisi di suscettibilità

Suscettibilità: definita come la probabilità di un allagamento di avvenire, in risposta alla morfologia del substrato e alla probabilità di densità spaziale degli allagamenti storici.

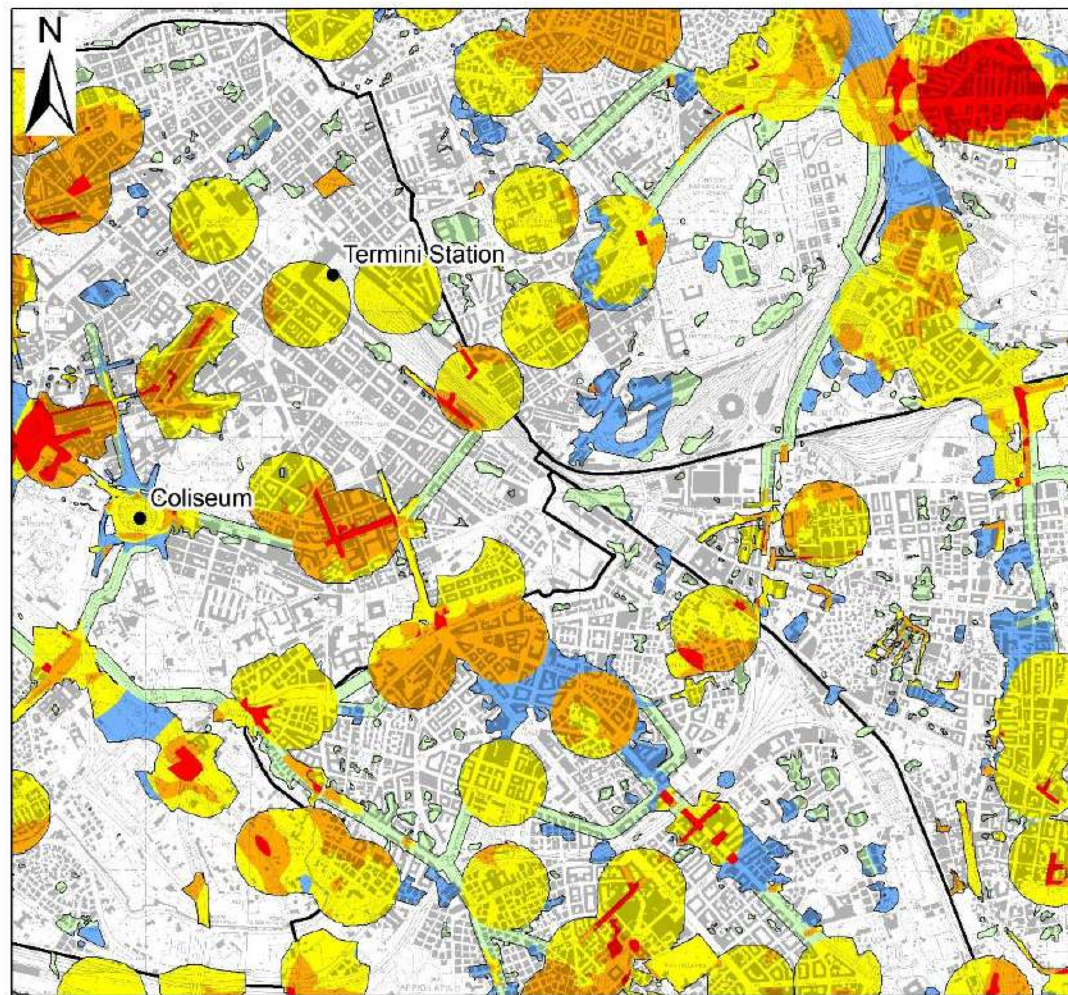
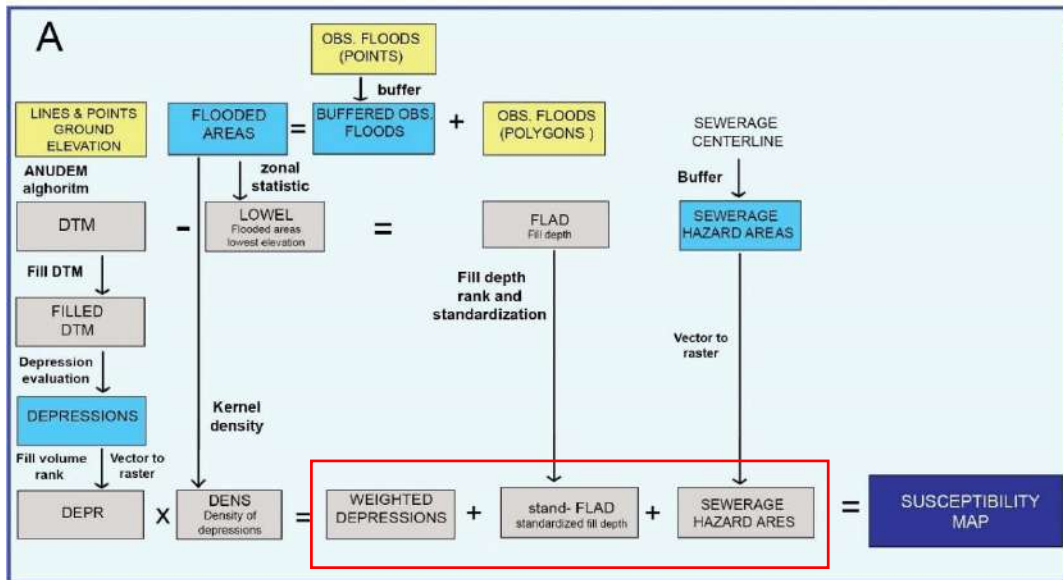








# Mappa di suscettibilità



## Legend

Municipal boundary

### Susceptibility to pluvial flood

- 1- Very low
- 2 - Low
- 3 - Medium
- 4 - High
- 5 - Very high

0 400 Meters



## *Elementi considerati nell'analisi dell'impatto potenziale*

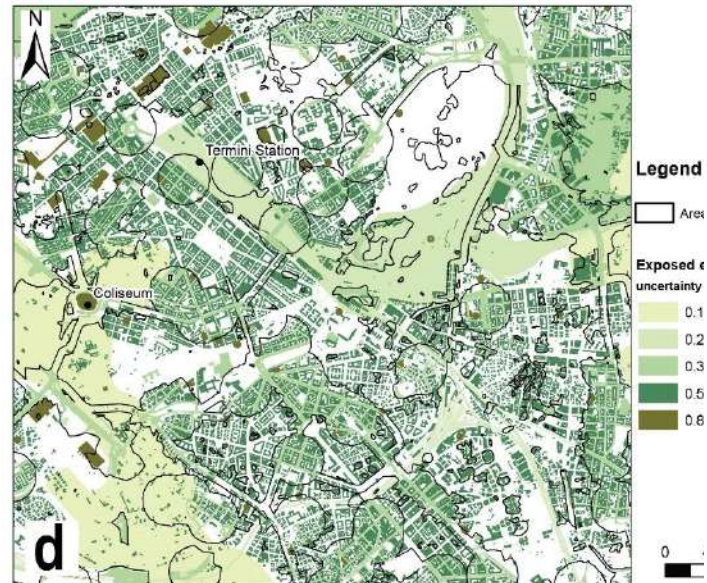
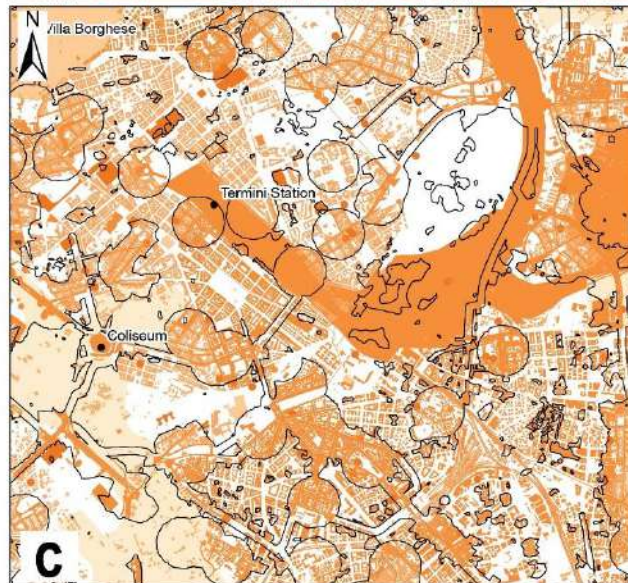
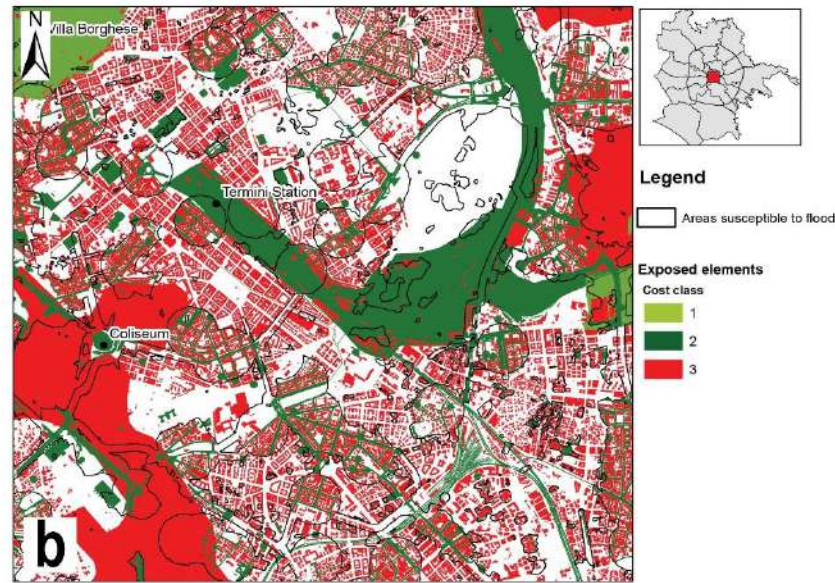
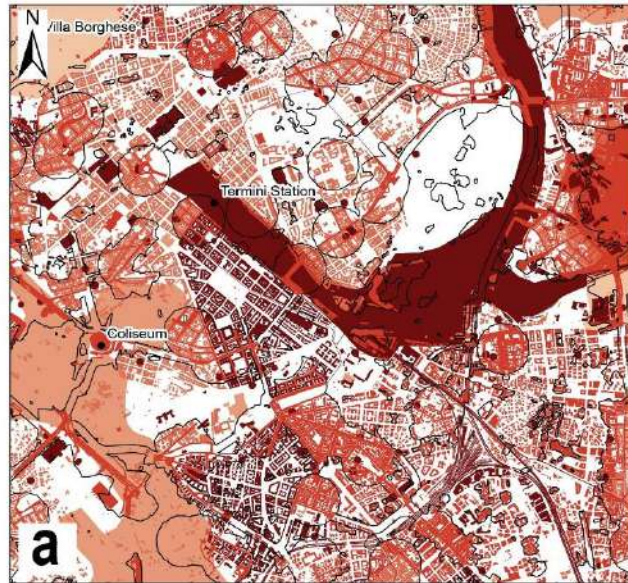
1. **Edifici** (e.g., residenziali, uffici pubblici, scuole, ospedali, infrastrutture strategiche, attività ricreative e religiose);
2. **Attività commerciali** (e.g., inclusi impianti sportive e colture agricole);
3. **Reti di trasporti e servizi e altri elementi urbani critici** (e.g., strade, sottopassi, metropolitane);
4. **Elementi ad alto potenziale inquinante**(e.g., impianti industriali, depuratori, discariche);
5. **Siti di interesse culturale, archeologico, ambientale;**

Classe di danno potenziale	Criterio per la stima qualitativa delle caratteristiche degli elementi a rischio
5	Pericolo per perdita di vite umane; aree in cui le acque di allagamento possono mobilizzare sostanze tossiche; interruzione delle vie di accesso da e verso el aree allagate; interruzione di servizi; interruzione della mobilità urbana; interruzione di servizi di trasporto pubblico
4	Potenziale pericolo per l'incolumità delle persone; danno a beni culturali e archeologici; potenziale disfunzione delle linee di trasporto pubblico e traffico veicolare
3	Danno potenziale limitato per l'incolumità delle persone; locale interruzione di traffico
2	Numero di persone limitato e altamente variabile di persone e/o beni esposti
1	Assenza di persone ed elementi esposti

# Dati disponibili per il calcolo delle categorie di costo

A	Categories of reported cost	SCENARIO 1 (20 October 2011)		SCENARIO 2 (16-19 June 2014)	
		cost (euros)	cost %	cost (euros)	cost %
	Urgent intervention on urban structures and other emergency management costs	280'000	2.78	12'000'000	4.90
	Cost of damage recovery in public buildings and infrastructures (railways, roads), comprising economic entrance loss for interruption of transports; costs of damage recovery for water and energy delivery network	2'800'000	27.78	222'146'000	90.73
	Private losses (commercial and residential buildings)	7'000'000	69.44	7'000'000	2.86
	Public gardens and parks	not reported		3'710'000	1.52
	<b>Total estimated economic loss (euro)</b>	<b>10'080'000</b>	<b>100</b>	<b>244'856'000</b>	<b>100</b>
B	Damage cost class (scenario 1)		Damage cost class (scenario 2)		
	1. Public gardens and parks		1. Public gardens and parks		
	2. Damage cost for public buildings and transport infrastructures		2. Private losses (commercial activities and residential buildings)		
	3. Private losses (commercial activities and residential buildings)		3. Damage cost for public buildings and transport infrastructures		

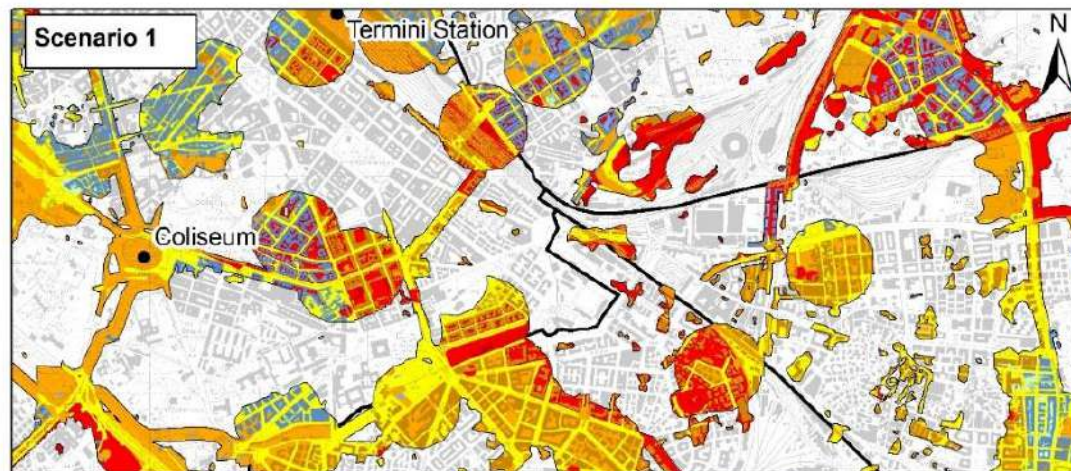
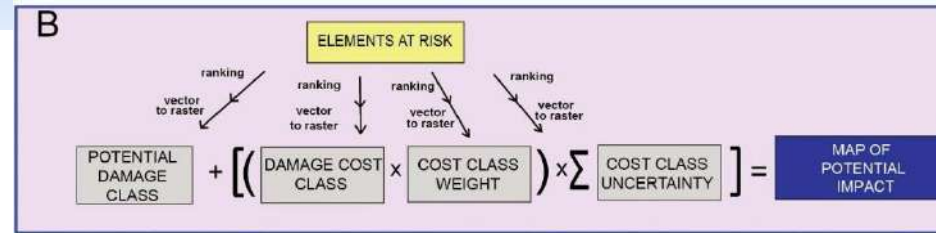
# Incertezza sulla stima del costo di danneggiamento



**Table 4**  
Uncertainty sources and corresponding uncertainty value.

Uncertainty source	Value
Type of element	0.5
Structural vulnerability	0.4
Conservation status	0.4
N. of consumer, end-user, passengers	0.3
Environmental relevance	0.2
Changes in land use	0.1

classe di danno potenziale + [(classe di costo di danneggiamento\*peso della classe di costo)\* $\sum$ incertezza]



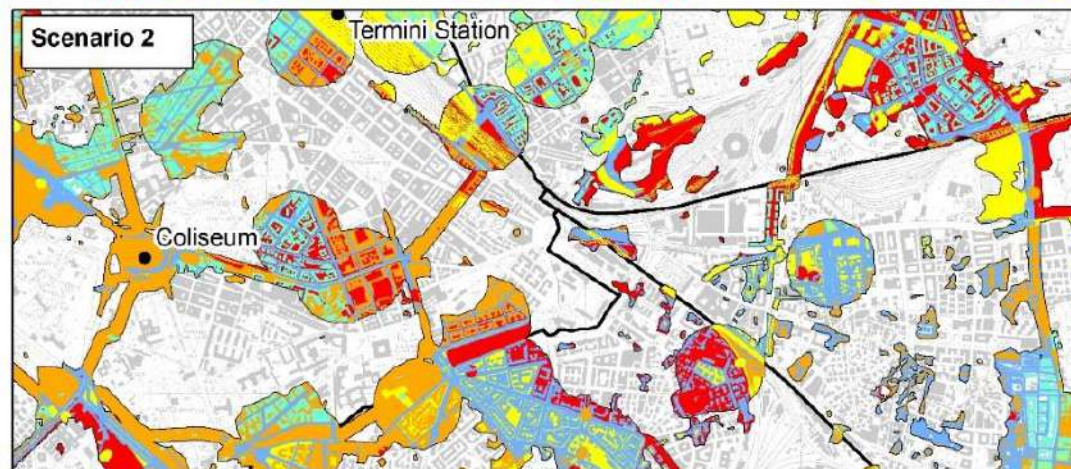
**Legend**

- Municipal boundary
- Area susceptible to flood

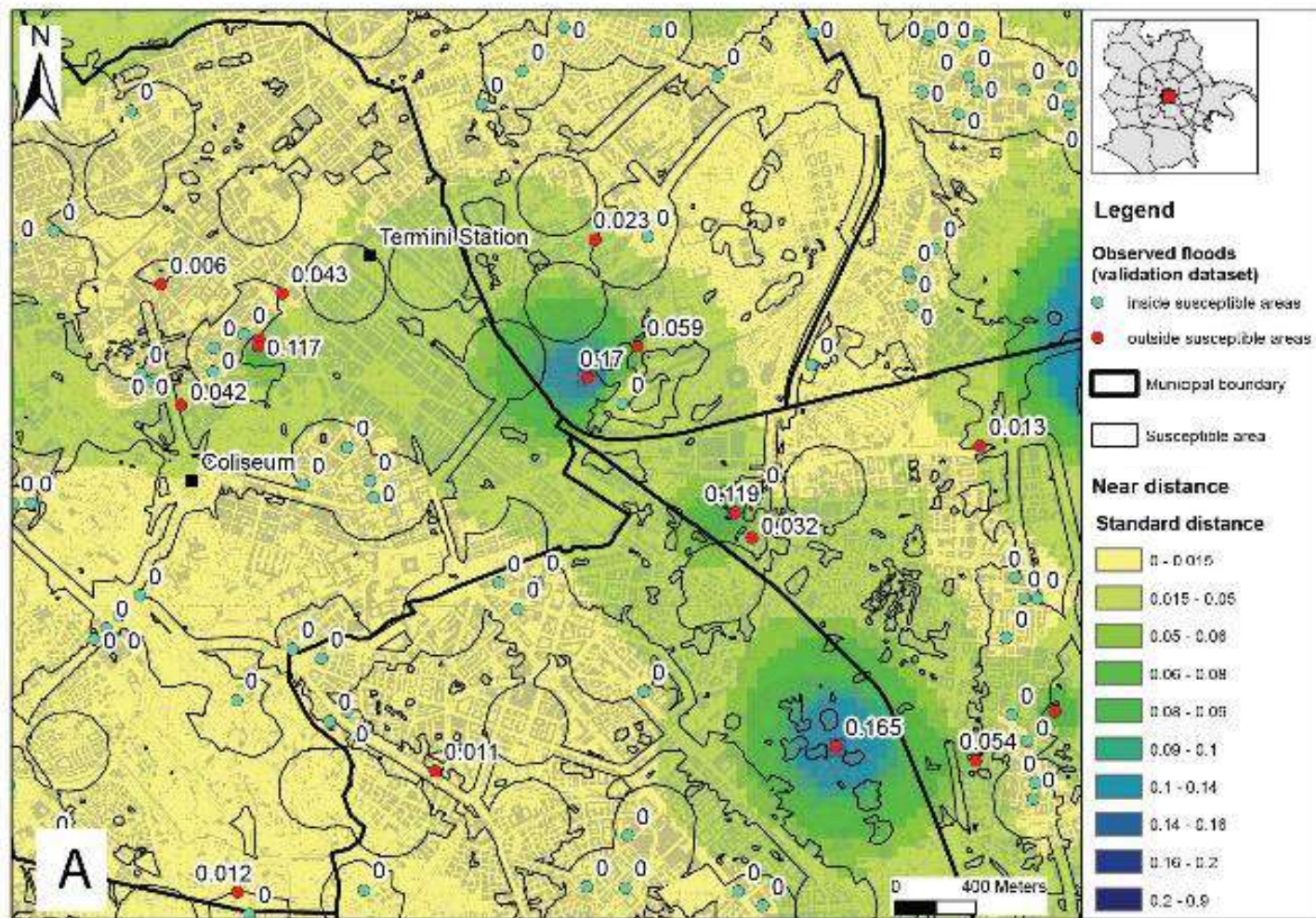
**Potential impact**

- 1- Very low
- 2 - Low
- 3 - Medium
- 4 - High
- 5 - Very high

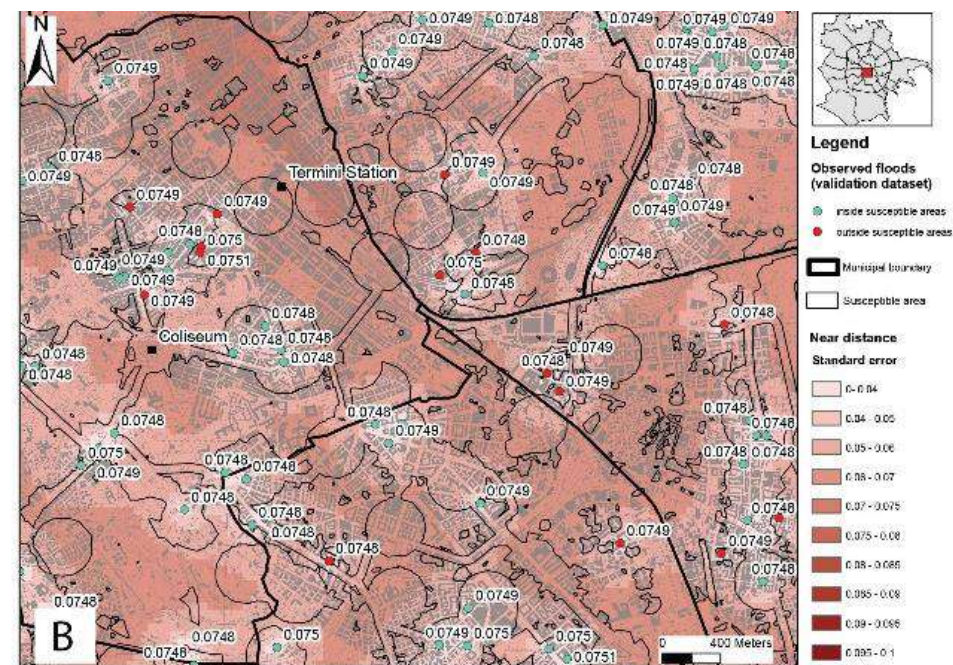
0 400 Meters



# Validazione dell'analisi di suscettibilità



Number of points	Minimum distance (m)	Maximum distance (m)	Sum (m)	Mean (m)	Standard deviation (m)
513	0 m	284.71 m	6890	13.4	32.45

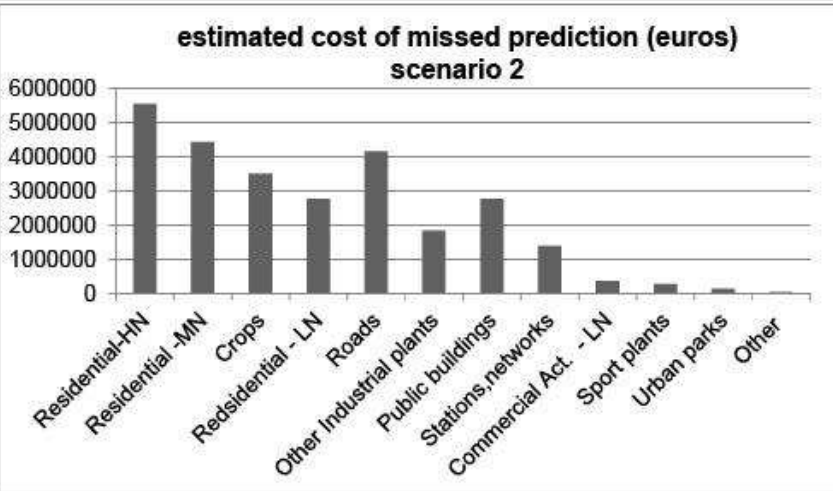
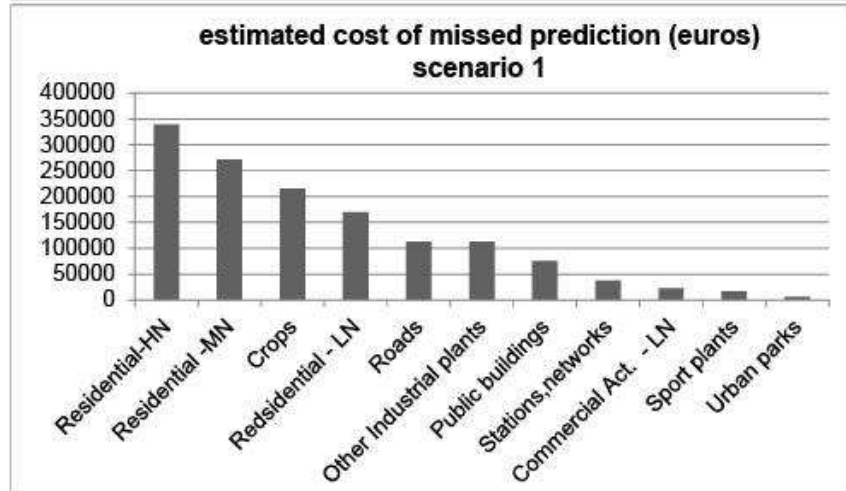


Mean error (m)	Root mean square error (m <sup>2</sup> )	Mean standardized (m)	Root mean square error standardized (m <sup>2</sup> )	Average standard error (m)
-0.00383	0.103	-0.0321	1.5	0.057

Element type	n. failed points	% failed points	damage class	weight	uncertainty	Scenario 1				Scenario 2			
						class cost	Potential Impact class	weighted cost (%)	estimated cost of missed prediction (euros)	class cost	Potential Impact class	weighted cost (%)	estimated cost of missed prediction (euros)
Crops	38	55.07	2	0.1	0.2	3	1	16.52	214783	2	1	11.01	3506054
Residential-HN	6	8.70	5	1	0.8	3	4	26.09	339130	2	4	17.39	5535875
Residential -MN	6	8.70	4	0.8	0.8	3	4	20.87	271304	2	3	13.91	4428700
Residential - LN	6	8.70	3	0.5	0.8	3	2	13.04	169565	2	1	8.70	2767937
Sport plants	3	4.35	2	0.1	0.5	3	1	1.30	16957	2	1	0.87	276794
Roads	3	4.35	4	1	0.5	2	3	8.70	113043	3	3	13.04	4151906
Other Industrial plants	2	2.90	4	1	0.5	3	4	8.70	113043	2	2	5.80	1845292
Urban parks	1	1.45	1	0.3	0.4	1	1	0.43	5652	1	1	0.43	138397
Public buildings	1	1.45	5	2	0.9	2							
Stations and networks	1	1.45	5	1	0.3	2							
Commercial Activities - LN	1	1.45	3	0.4	0.8	3							
Other	1	1.45	1	0.1	0.1	1							
<b>TOTAL</b>	<b>69.00</b>	<b>100.00</b>	<b>39.00</b>	<b>8.30</b>	<b>6.60</b>	<b>29.00</b>							

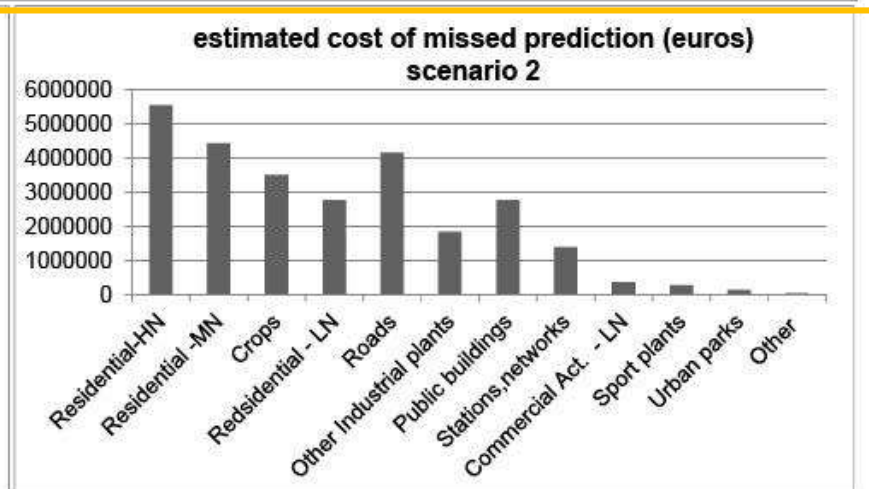
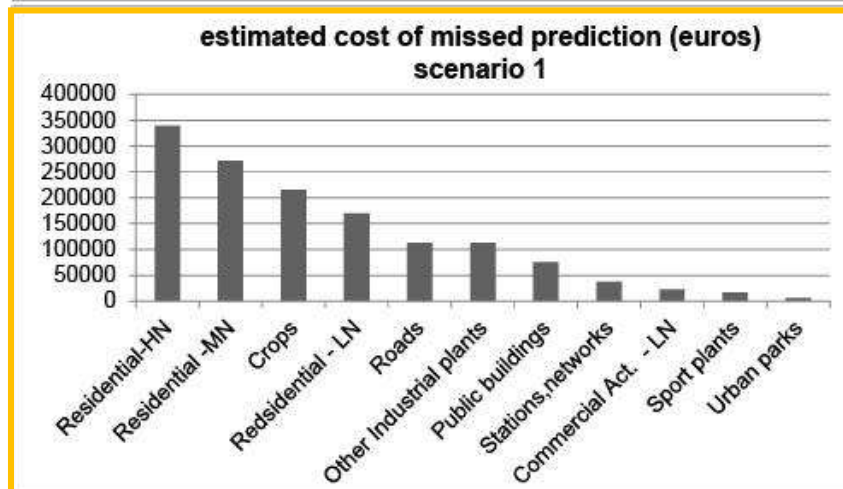
		Potential Impact class				
		1	2	3	4	5
<b>scenario 1</b>	n. of failed prediction points	43	7	3	15	1
	%	62.32	10.14	4.35	21.74	1.45
<b>scenario 2</b>	n. of failed prediction points	50	2	10	6	1
	%	72.46	2.90	14.49	8.70	1.45



Element type	n. failed points	% failed points	damage class	weight	uncertainty	Scenario 1				Scenario 2			
						class cost	Potential Impact class	weighted cost (%)	estimated cost of missed prediction (euros)	class cost	Potential Impact class	weighted cost (%)	estimated cost of missed prediction (euros)
Crops	38	55.07	2	0.1	0.2	3	1	16.52	214783	2	1	11.01	3506054
Residential-HN	6	8.70	5	1	0.8	3	4	26.09	339130	2	4	17.39	5535875
Residential -MN	6	8.70	4	0.8	0.8	3	4	20.87	271304	2	3	13.91	4428700
Redsidential - LN	6	8.70	3	0.5	0.8	3	2	13.04	169565	2	1	8.70	2767937
Sport plants	3	4.35	2	0.1	0.5	3	1	1.30	16957	2	1	0.87	276794
Roads	3	4.35	4	1	0.5	2	3	8.70	113043	3	3	13.04	4151906
Other Industrial plants	2	2.90	4	1	0.5	3	4	8.70	113043	2	2	5.80	1845292
Urban parks	1	1.45	1	0.3	0.4	1	1	0.43	5652	1	1	0.43	138397
Public buildings	1	1.45	5	2	0.9	2							
Stations and networks	1	1.45	5	1	0.3	2							
Commercial Activities - LN	1	1.45	3	0.4	0.8	3							
Other	1	1.45	1	0.1	0.1	1							
<b>TOTAL</b>	<b>69.00</b>	<b>100.00</b>	<b>39.00</b>	<b>8.30</b>	<b>6.60</b>	<b>29.00</b>							

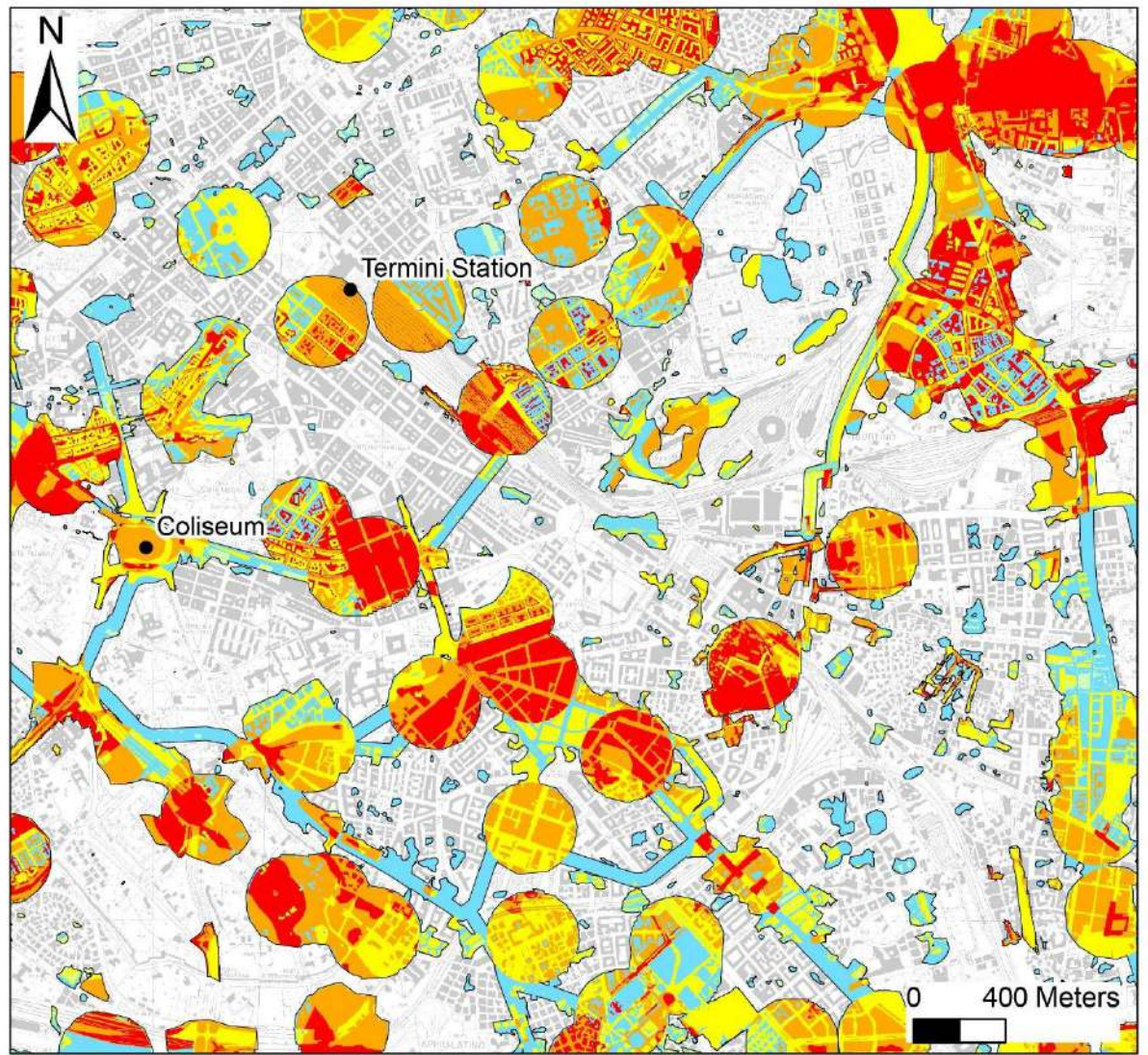
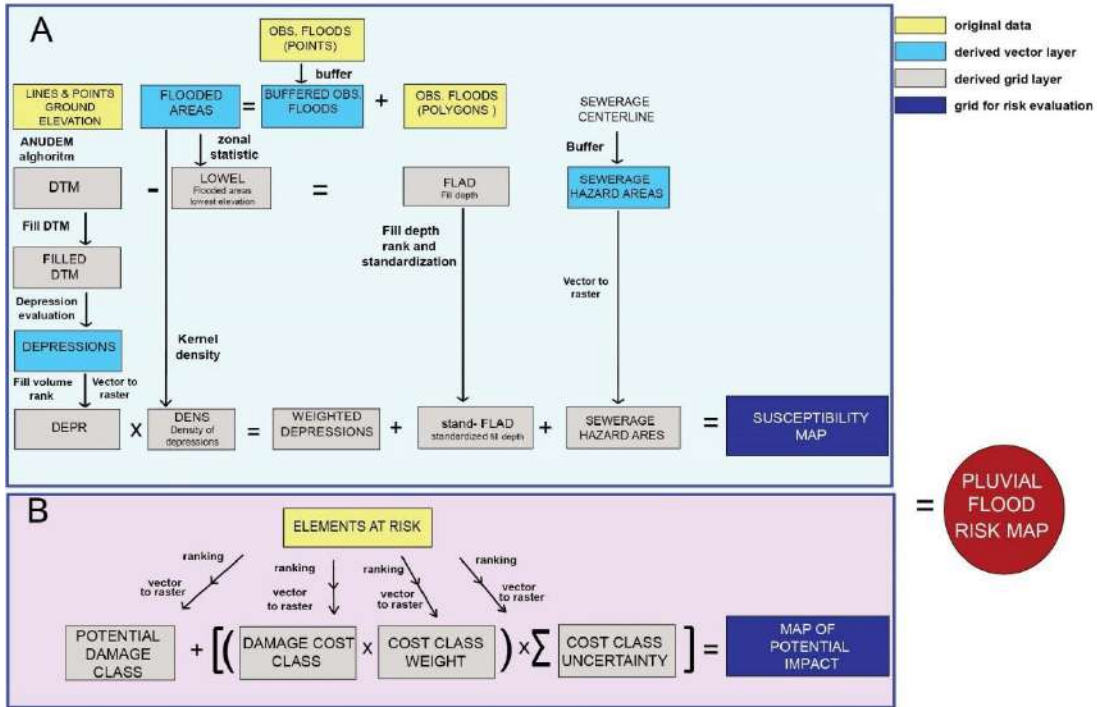
  

		Potential Impact class				
		1	2	3	4	5
<b>scenario 1</b>	n. of failed prediction points	43	7	3	15	1
	%	62.32	10.14	4.35	21.74	1.45
<b>scenario 2</b>	n. of failed prediction points	50	2	10	6	1
	%	72.46	2.90	14.49	8.70	1.45



Ottenuto suddividendo il costo della failed prediction per i due scenari (13% dei costi del danno) nelle percentuali di ogni elemento

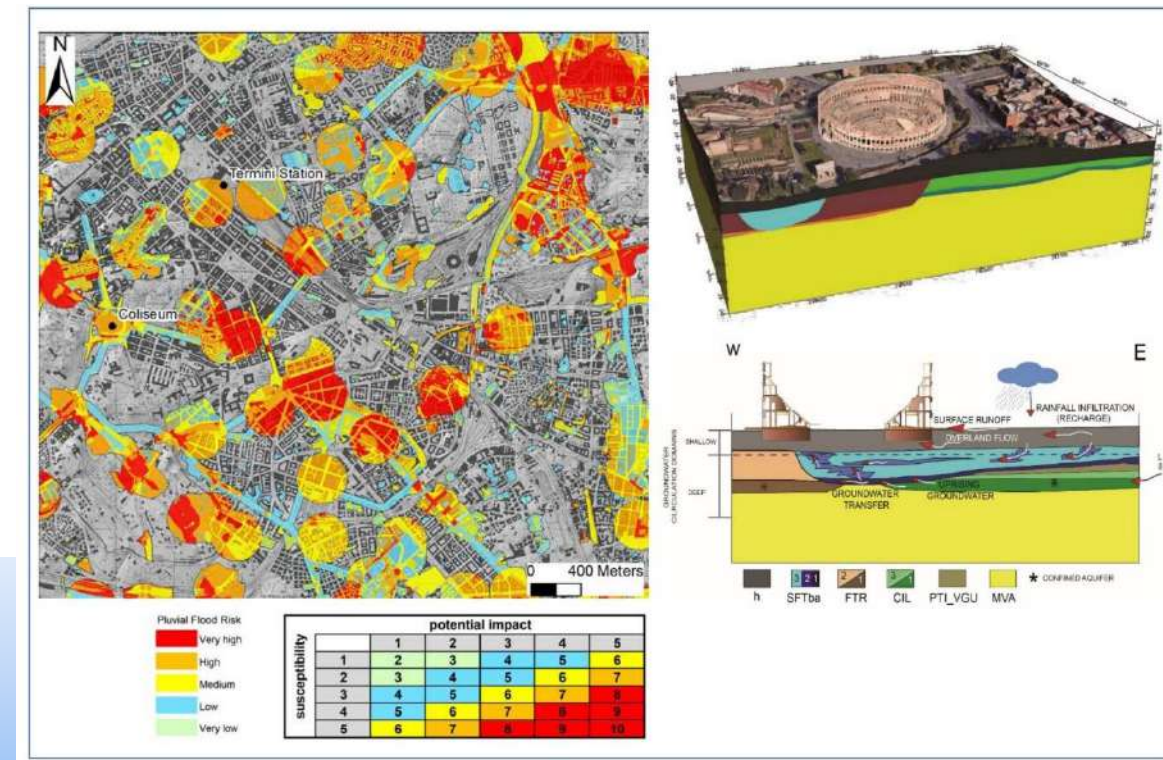




		potential impact				
		1	2	3	4	5
susceptibility	1	2	3	4	5	6
	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10

# Cosa abbiamo imparato da queste esperienze

- Questi casi di studio dimostrano che la corretta conoscenza del substrato geologico e delle modalità di circolazione idrica sotterranea possono fornire un valido supporto alla comprensione dei fenomeni di allagamento da forti piogge, e costituire uno strumento per la pianificazione di schemi di monitoraggio.
- Inoltre, la padronanza dei sistemi GIS consente di applicare tecniche speditive e di basso costo per la classificazione delle aree a rischio, e orientare studi più approfonditi oltre a programmare interventi di mitigazione mirati.





## Bibliografia

- Di Salvo C., Mancini M., Moscatelli M., Stigliano F., Simionato M., Cavinato G. P., 2019, Preserving archaeological heritages from flood hazard: use of 3D geological models as a base for conceptual hydrogeological scheme in the area of the Coliseum (Rome). Flowpath, Milano, 12-14 giugno 2019
- Di Salvo C., Pennica F., Ciotoli G., Cavinato G.P., 2018, a GIS-based procedure for preliminary mapping of pluvial flood risk at metropolitan scale, Environmental modelling and software, Vol 107, pp 64-84, <https://doi.org/10.1016/j.envsoft.2018.05.020>
- Di Salvo C., Ciotoli G., Pennica F., Cavinato G.P., 2017, pluvial flood hazard in the city of Rome (Italy). Journal of Maps, vol 13, issue 2
- Mancini M., Marini M., Moscatelli M., Pagliaroli A., Stigliano F., Di Salvo C., Simionato M., Cavinato G P., Corazza A. A physical stratigraphy model for seismic microzonation of the Central Archaeological Area of Rome (Italy), Bull Earthquake Eng (2014) 12:1339–1363 DOI 10.1007/s10518-014-9584-2