7th EUREGEO
EUropean Congress on REgional GEOscientific Cartography and Information Systems

EUREGEO 2012, Bologna 12-15 June 2012

Session 7 – Urban Geology

Index of Susceptibility to Settlement of the Tiber River Alluvial Valley in Rome, Italy

Massimiliano Moscatelli, Alessandro Pagliaroli, Fabrizio Marconi, Giuseppe Raspa, Marco Mancini, Francesco Stigliano, Cristina Di Salvo, Gian Paolo Cavinato, Angelo Corazza

Consiglio Nazionale delle Ricerche
Istituto di Geologia Ambientale e Geoingegneria

Settlements of alluvial deposits in Rome

Settlements
related to consolidation
of recent alluvial deposits
of the Tiber River and
tributaries

Statement of the problem

1. **Settlement** is defined as the vertical component of displacement of the laying of a foundation. In general, the **absolute settlement** indicates the absolute failure in respect to a cornerstone, while **differential settlement** indicates the difference of the absolute failure of two points of the laying of a foundation.

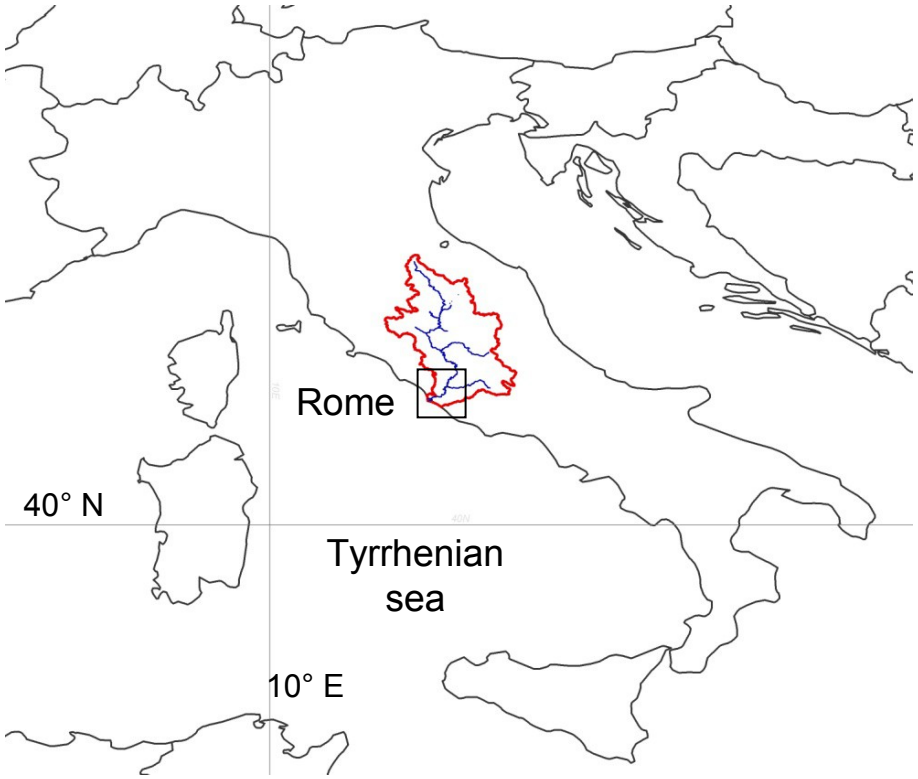
2. The susceptibility to instability caused by settlement is directly dependent on the nature of the foundation soils: the greater the thickness H of the compressible soils, the greater the amount of expected settlement.

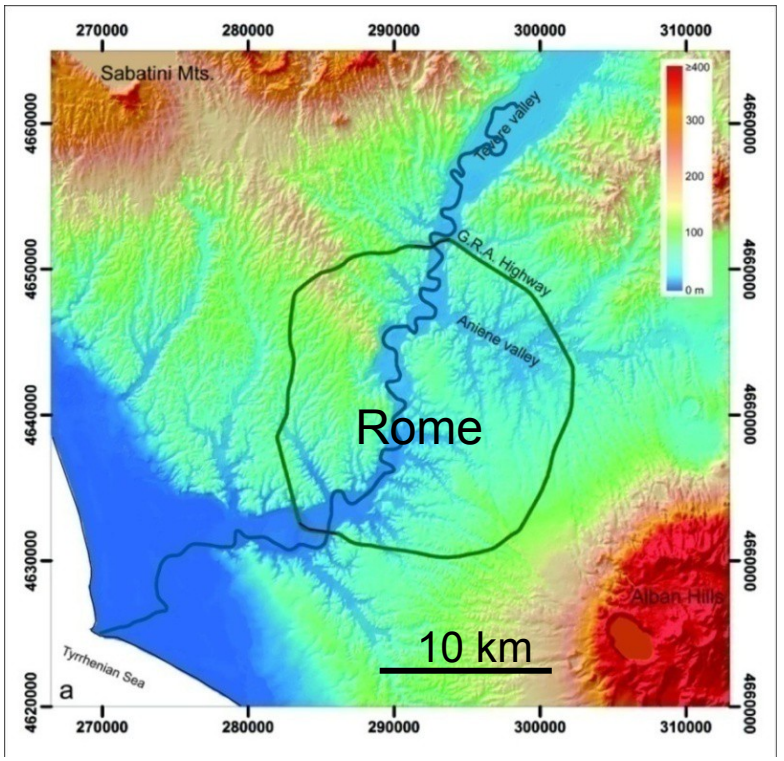
3. Compressible soils are typical of floodplains.

4. An **index of susceptibility to settlement** can be defined for floodplain areas, which takes into account the thickness of the compressible soils (H), their physical and mechanical properties (e_0, Cc, Cs) and the variation of the stress state.

5. This index provides a **quantitative indication of the expected settlement** at a point, but can also be used to **map the susceptibility** to settlement.

Geographic setting and general data





Tiber River's data:

From the entire basin:

lenght: 405 km;

catchment area: 17.375 km^2

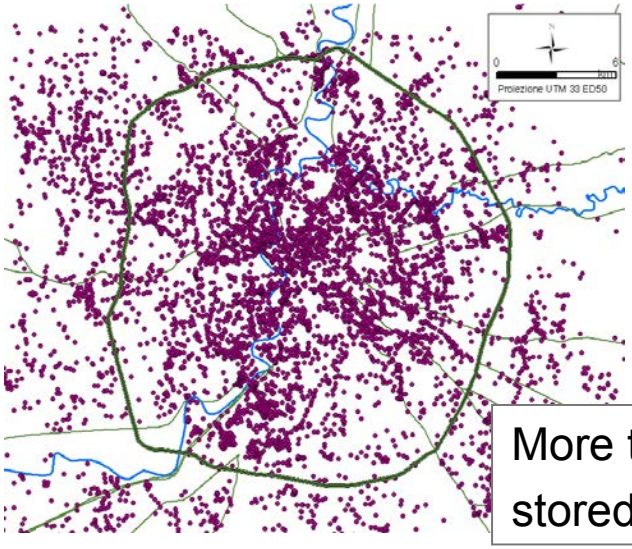
From the urban area of Rome:

area: 620 km^2 ; *lenght*: 52 km;

valley slope: 0.03° (urban area), 0.02° (delta plain);

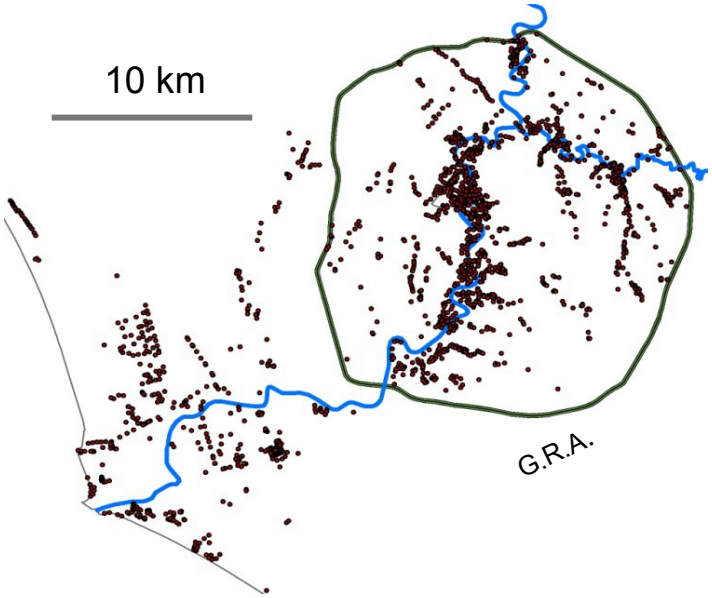
sinuosity: 1.57 (urban area), 1.27 (delta plain)

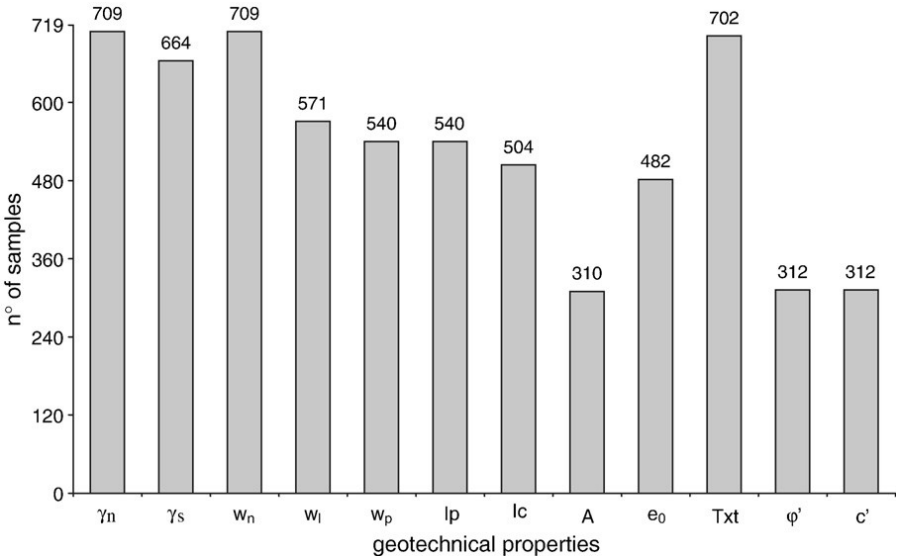
Dataset



Provenance of data:
Laboratorio di Idrogeologia di Roma TRE
Comune di Roma
APAT – Legge n. 464/1984
ANAS S.p.A.
ITALFERR Gruppo Ferrovie dello Stato
Geoplanning – Servizi per il territorio
S.G.S. Studio Geotecnico Strutturale
S.I.G. Studio Indagini Geotecniche
IGES s.n.c.

More than 8000
stored boreholes

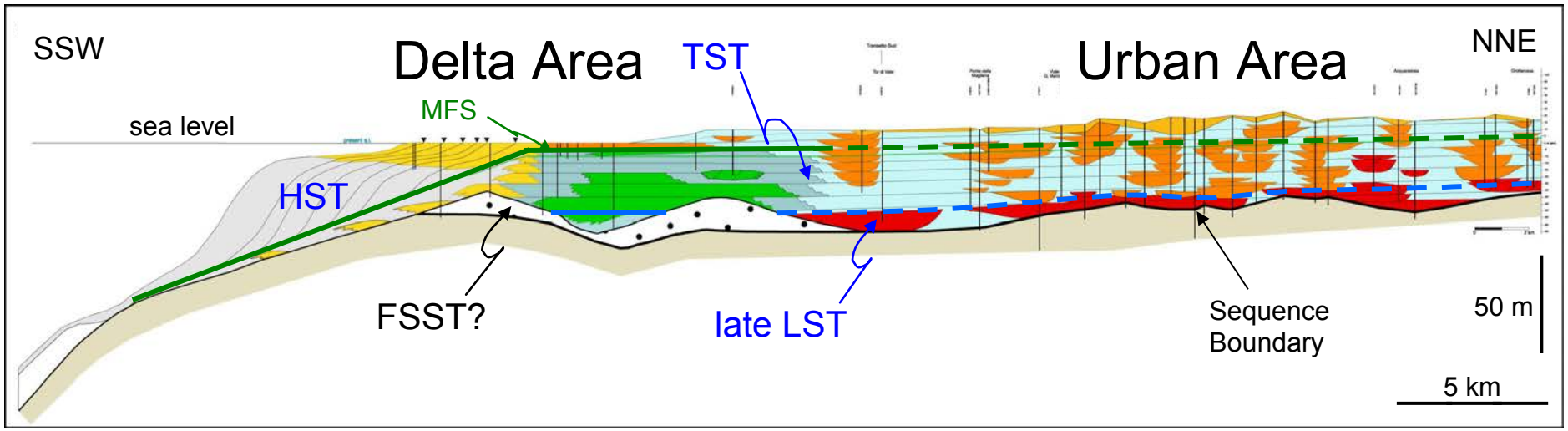




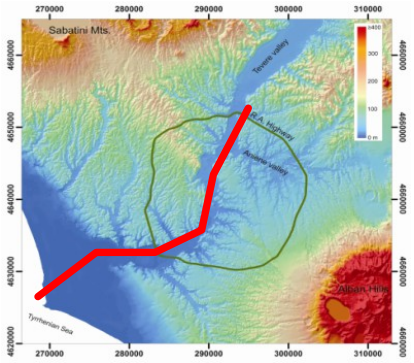
More than 2000 boreholes
cross the recent alluvial deposits.
Approx. 700 wells provided
with laboratory tests.

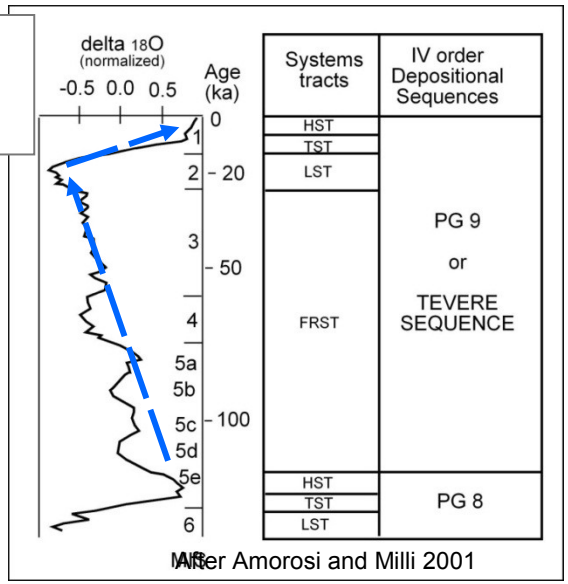
GEOLOGICAL SETTING

Tiber River stratigraphy (Tevere Sequence) and facies associations

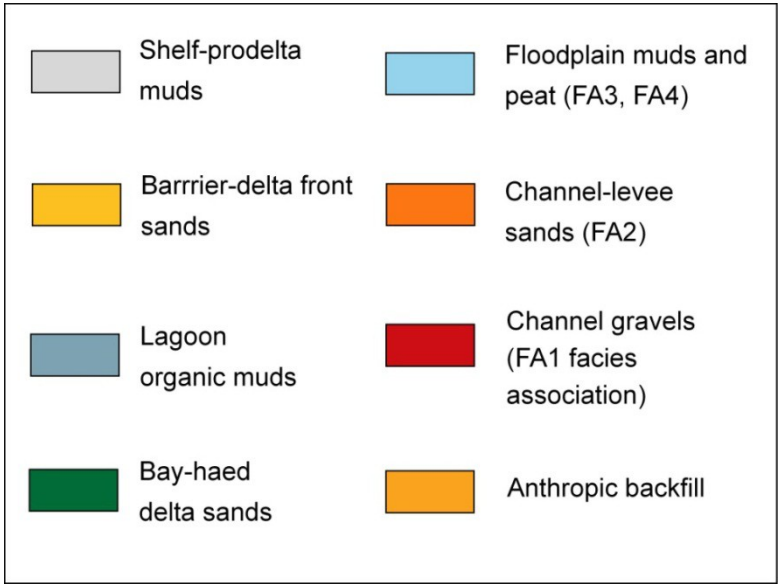


More than 60 m
of alluvial deposits

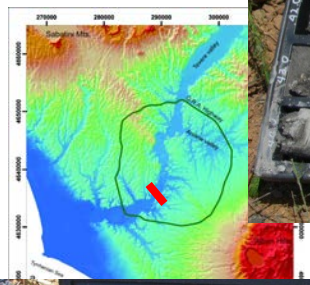


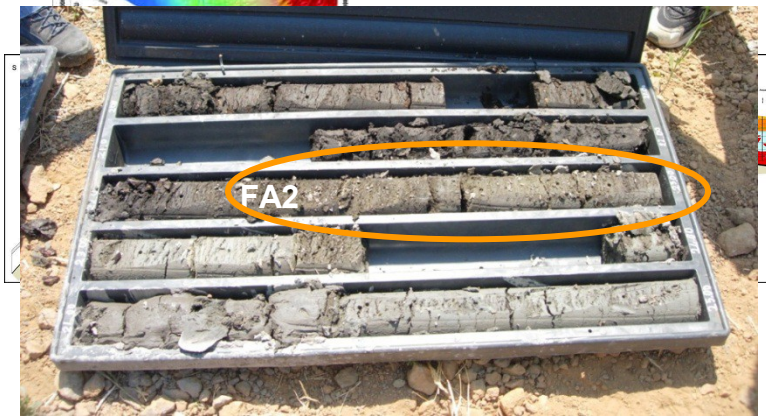


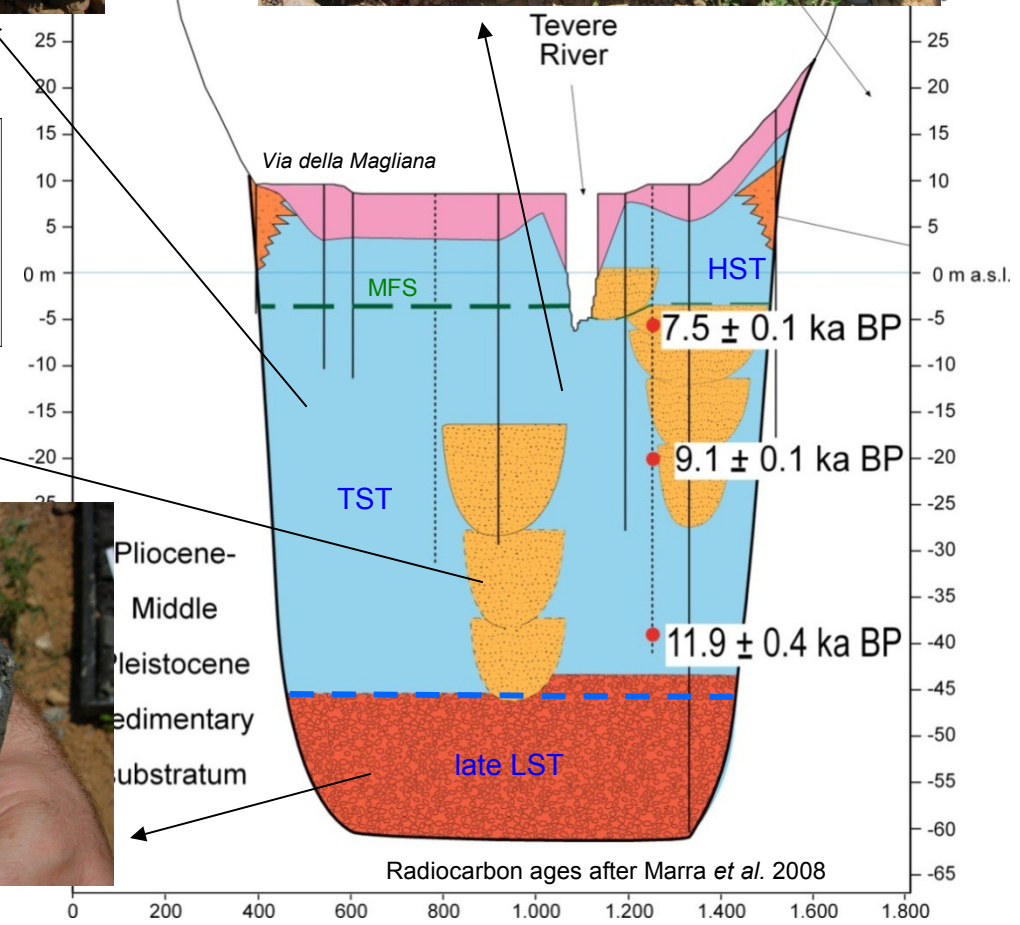
After Amorosi and Milli 2001



Archite… …s mai…







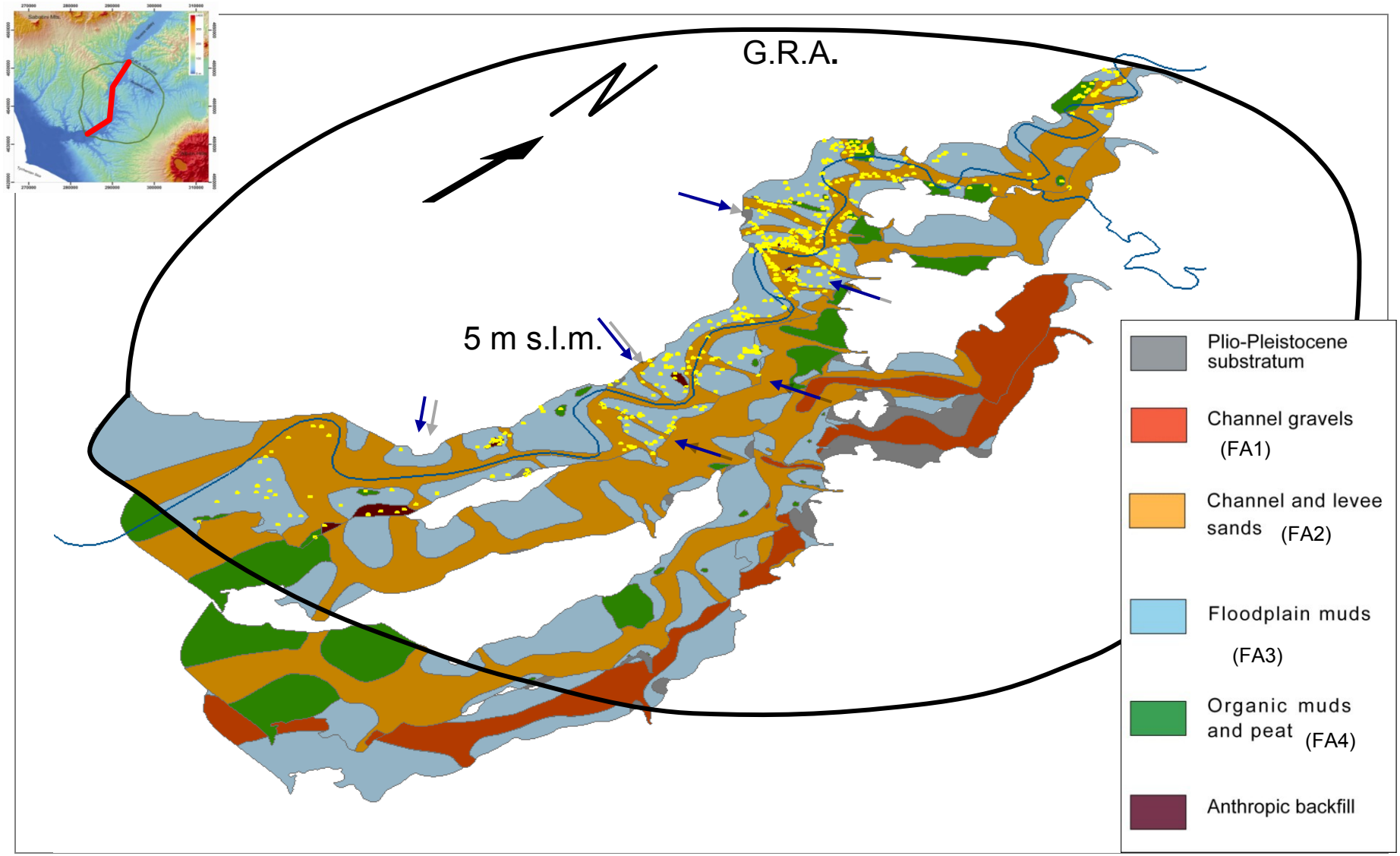
Floodplain muds … peat (FA3, FA4)

Channel-levee sands (FA2)

Channel gravels (FA1)

Pliocene-Middle …leistocene …edimentary …ubstratum

Distribution of the Tiber's fluvial facies assemblages



From the geological setting to the Indexing and Mapping of the Susceptibility to Settlement

Facies assemblages are grouped into **3 main lithotypes**, each characterized by geothecnical parametres (averaged values)

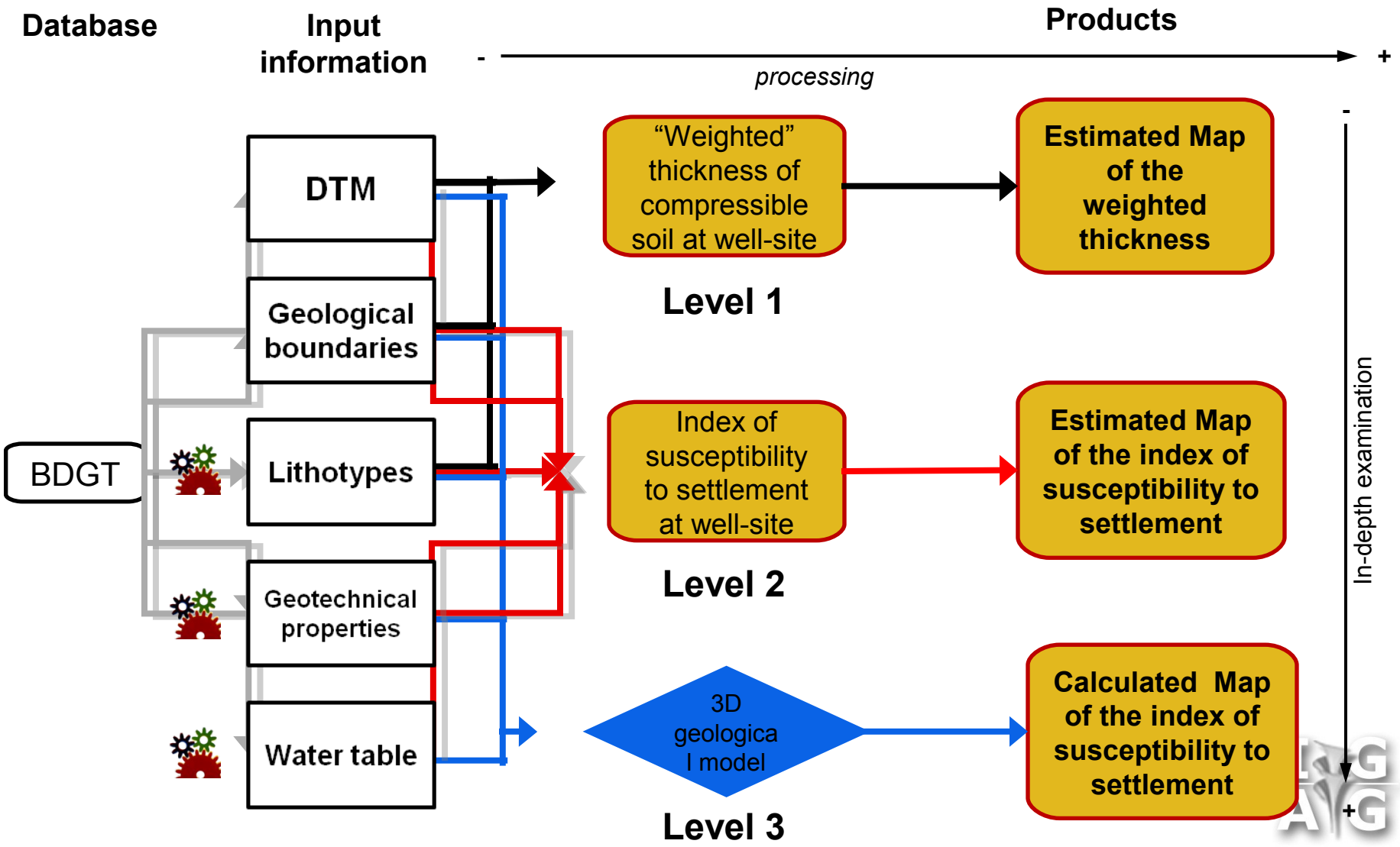
LITHOTYPE 3
Pelitic and organic deposits of floodplain

LITHOTYPE 2
Fine silty sand-bar and levee

LITHOTYPE1
Coarse sand and gravel; bar and channel axis

Lithotype	n	■ (kN/m^3)	e_0	OCR	C_c	C_r
1	-	20.0	-	-	-	-
2	51	19.0	-	-	-	-
3 - NC	149	18.7	0.838	1	0.295	0.071
3 - OC	30	19.2	0.771	3.5	0.272	0.052

Index of susceptibility to settlement (3 levels)



Level 1 - “Weighted” thickness

Weighted thickness of compressible soil

$$I_{\delta,s} = \sum_{i=1}^{n} H_{0,i} * \frac{\Delta\sigma'_{v,i}}{q}$$

q = 100 kPa uniform load (square base, 25x25 m)

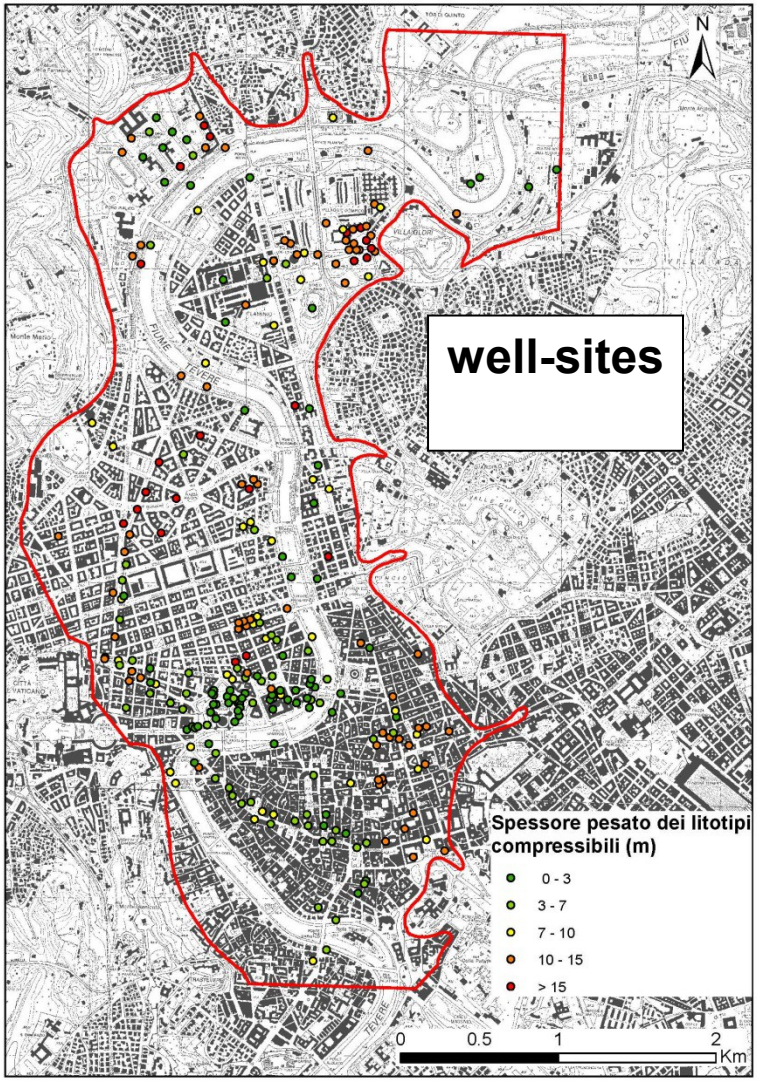
n: number of beds within the significant thickness of soil (generally twice the width of the foundation).

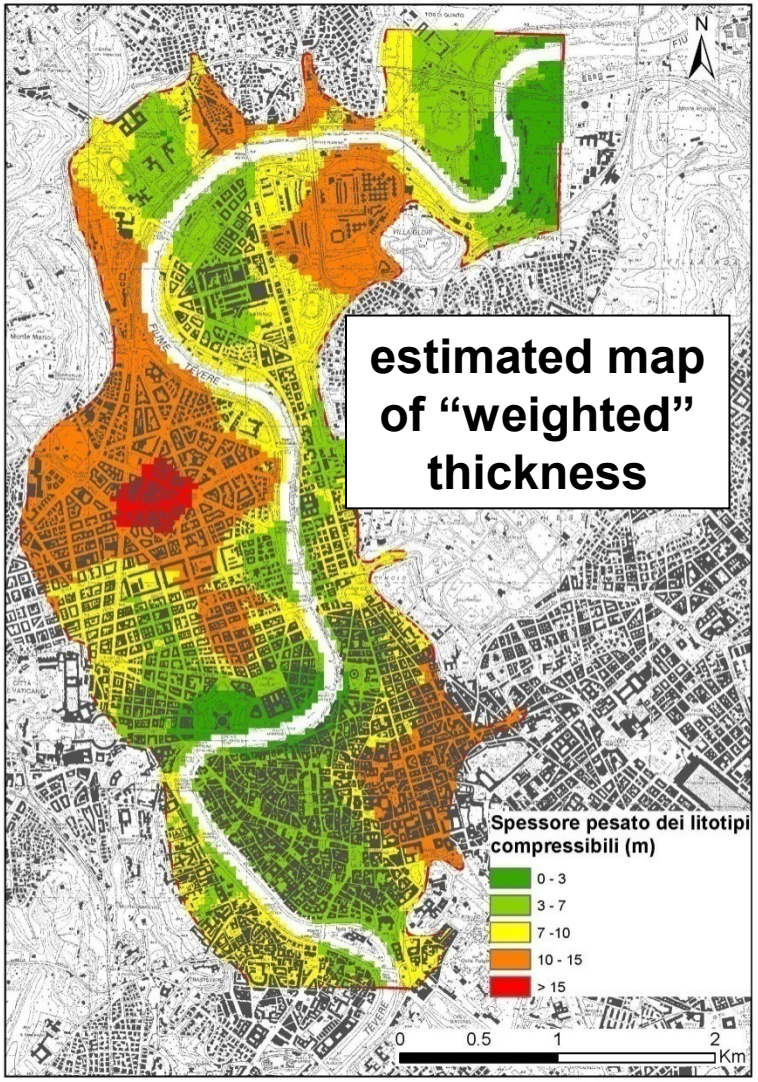
$H_{0,i}$: initial thickness of the sub-layer i within the significant thickness of soil (discretization: 10 cm).

$\Delta\sigma'_{v,i}$: vertical stress increment in the sub-layer I, variable with depth according to linear elastic theory.

The layers are weighted more as they are placed close to ground level, where the increase of the stress state due to the application of the load is bigger. In this sense, then the index of level 1 represents a kind of measure of the "weighted" thickness of the compressible lithotypes (L3). The "weighted" thickness is calculated at the well-site if the boreholes have a significant minimum length (related to the significant thickness).

Level 1 - “Weighted” thickness





Level 2 - Index of susceptibility to settlement I□

Index of susceptibility to settlement

$$I_\delta = \sum_{i=1}^{n} \frac{H_{0,i}}{1+e_{0,i}} * C_i * \log \frac{\sigma'_{v0,i} + \Delta\sigma'_{v,i}}{\sigma'_{v0,i}}$$

n: number of beds within the significant thickness of soil (maximum depth: 50 m from ground level).

$H_{0,i}$: initial thickness of the sub-layer i within the significant thickness of soil (discretization: 10 cm).

$e_{O,i}$: initial void ratio of soil in sub-layer i.

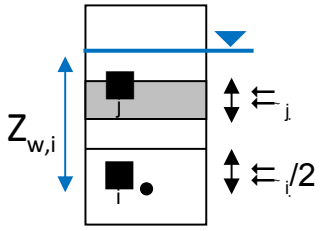
C_i: Compressibility Index for soil in sub-layer i (Cc or Cr).

?$_{v0,i}$: Initial Vertical Effective Stress in the midpoint of sub-layer i.

⇆∇$_{v,i}$: vertical stress increment in the sub-layer I, variable with depth according to linear elastic theory.

Effective stress ?$_{v0,i}$

$$\sigma'_{v0,i} = \left(\sum_{j=1}^{i-1} \gamma_j H_{0,j}\right) + \gamma_i \frac{H_{0,i}}{2} - \gamma_w z_{w,i}$$

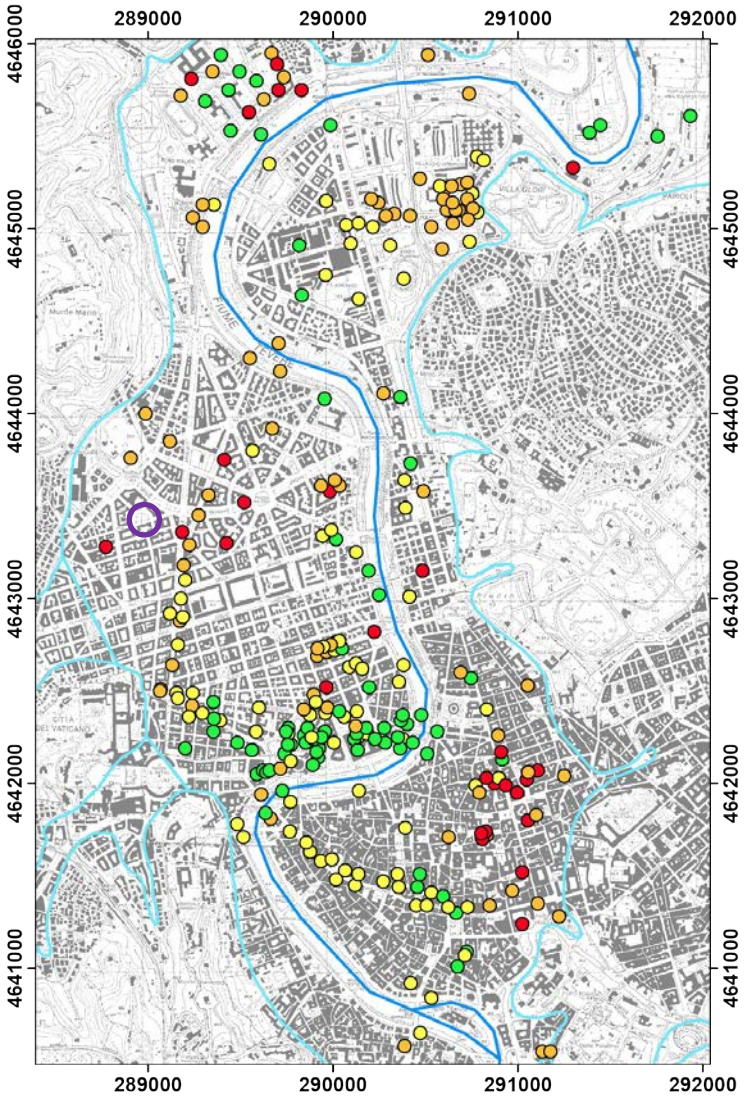


■$_j$, ■$_i$ total unit weight of soil in sub-layers j and i.

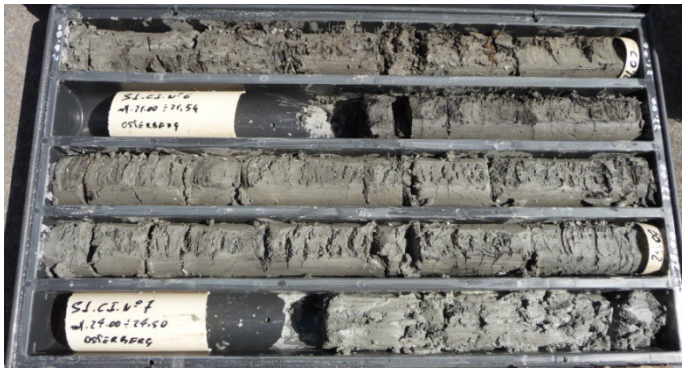
■$_w$: unit weight of water.

$Z_{w,i}$: depth of midpoint of sub-layer i from water table.

Level 2 - Index of susceptibility to settlement I$_\delta$

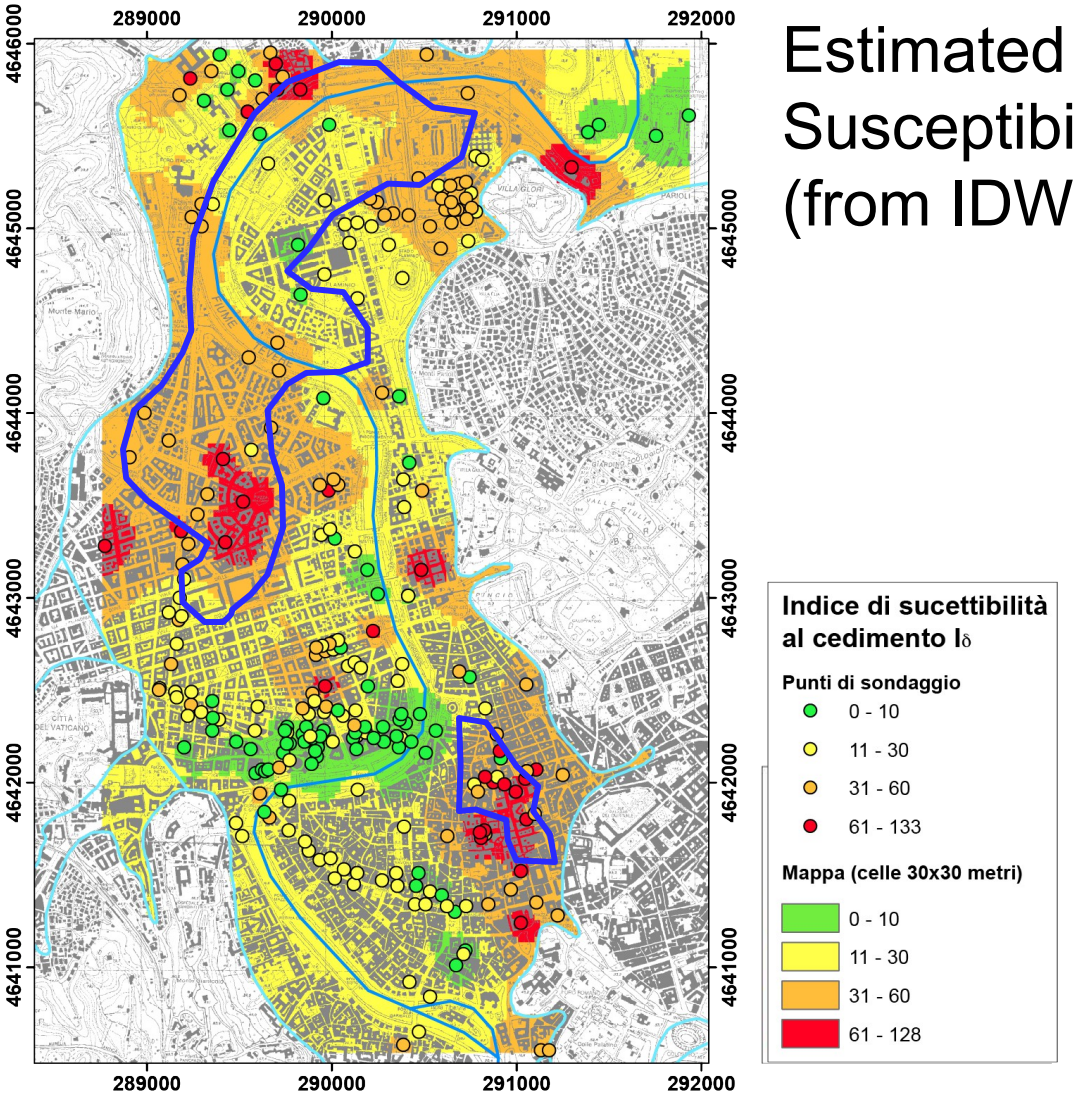


Index of susceptibility to settlement at well-site



Organic clay

Level 2 - Index of susceptibility to settlement I$_\delta$



Estimated map of the Index of Susceptibility to Settlement (from IDW data interpolation)

source: http://webgis.irea.cnr.it

Level 3 - Index of susceptibility to settlement I

Geological model
Plurigaussian

Geotechnical model
Statistical analysis

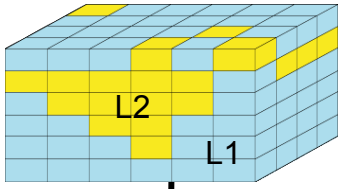
Hydrogeological model
Flow equation

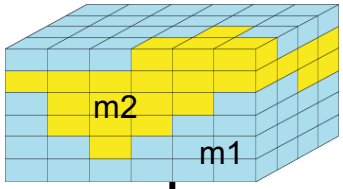
Index of susceptibility
Theory of consolidation

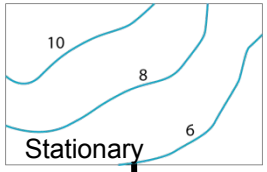
Generative tool
Isatis® and new codes

Generative tool
Average value

Generative tool
MODFLOW 2000

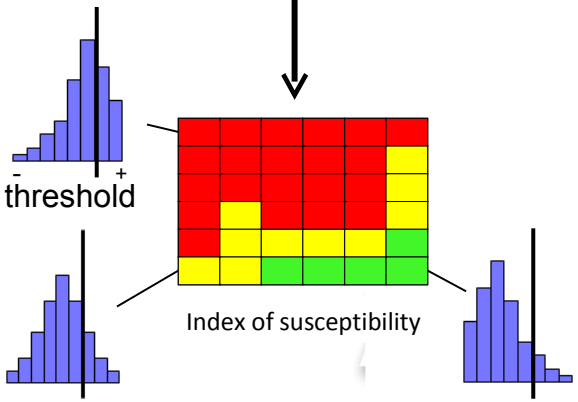


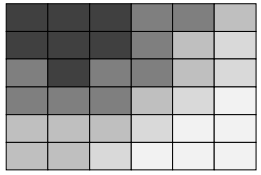




Thickness of compressive soil + Stiffness of compressive soil + Piezometric load

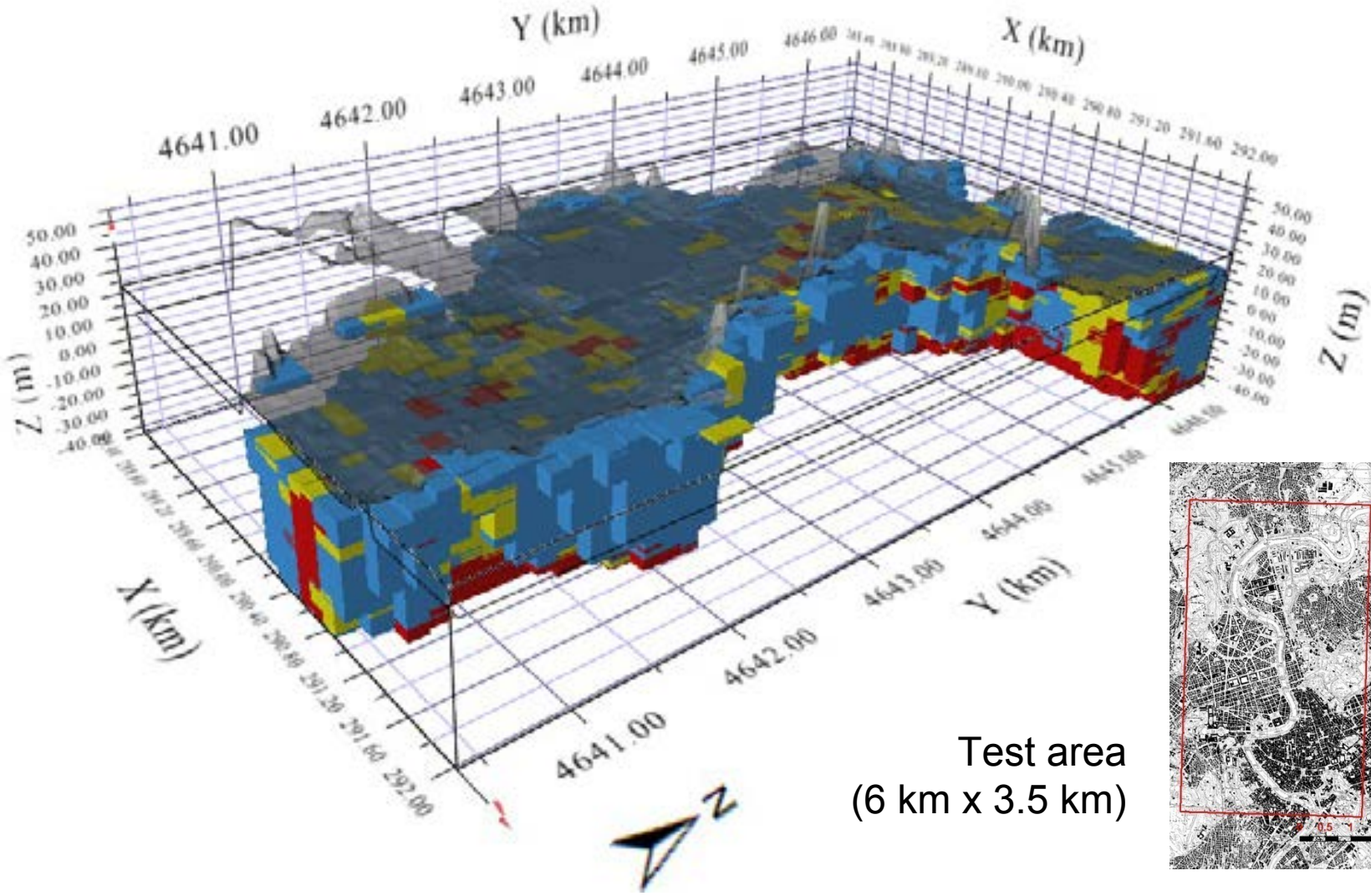
Generative tool
Index formula





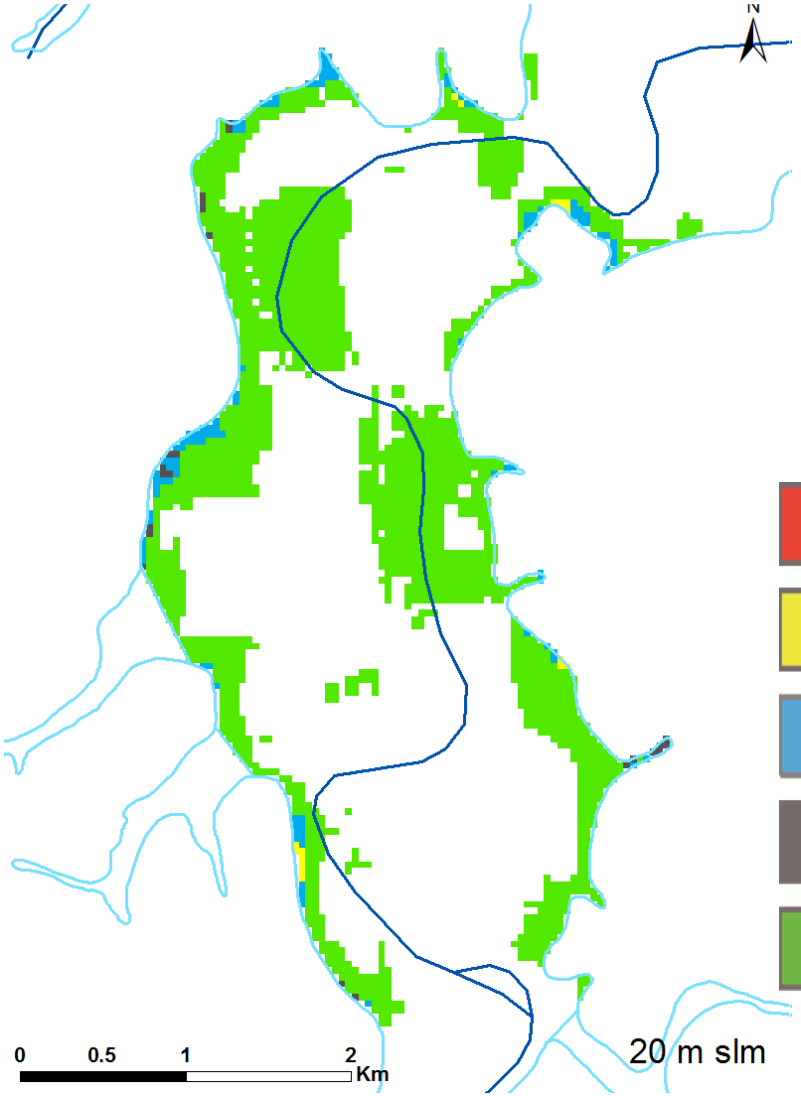
Map of susceptibility to settlement
Probability to exceed the critical threshold

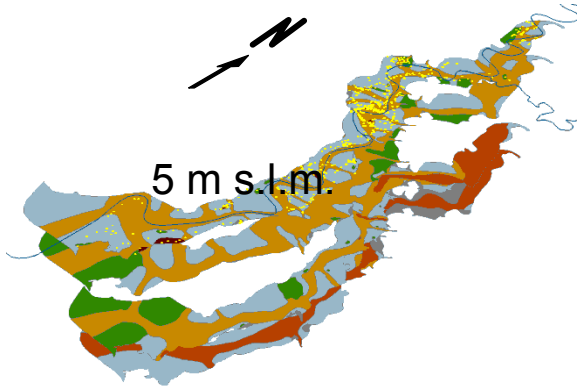
Level 3 - 3D stochastic geological model, based on a Plurigaussian simulation of the spatial distribution of lithotypes



Test area
(6 km x 3.5 km)

3D geological model: running the simulation at different intervals of depth





Lithotype 1 (coarse sands and gravels)

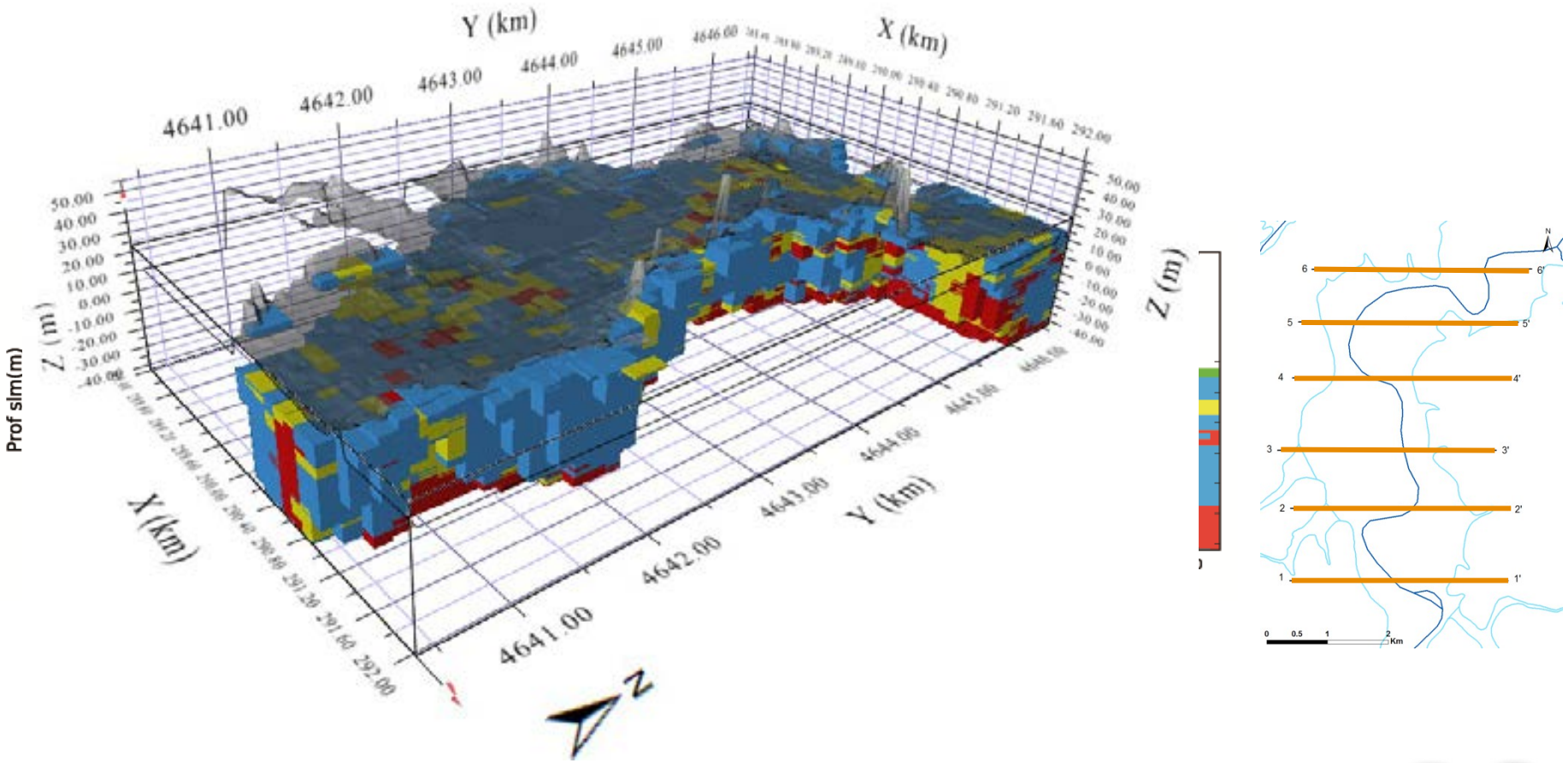
Lithotype 2 (fine sands)

Lithotype 3 (organic and inorganic mud)

Pre-Holocene substratum

Anthropogenic backfill

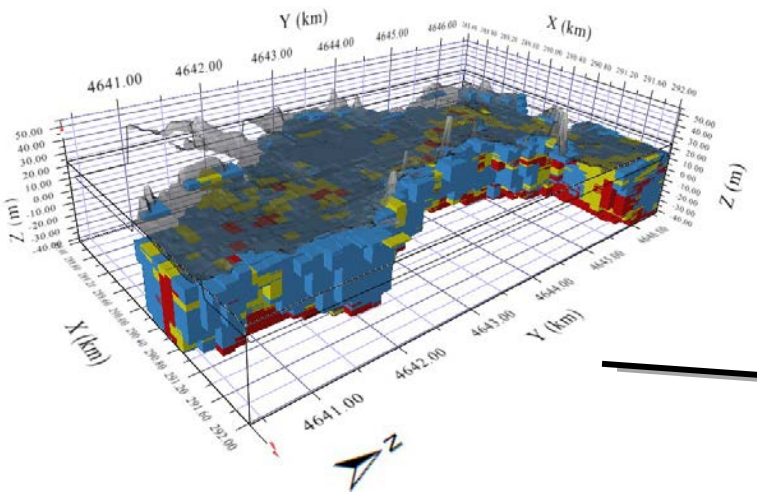
3D geological model: transversal sections



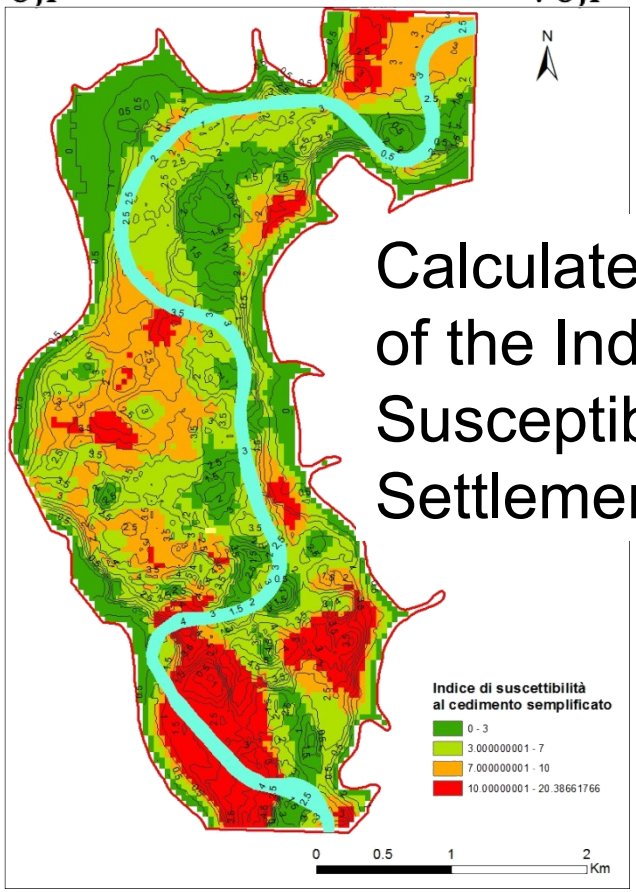
Applying the Index to each cell (40 x 40 x 0.5 m) of the 3D geological model

Index of susceptibility to settlement

$$I_\delta = \sum_{i=1}^{n} \frac{H_{0,i}}{1 + e_{0,i}} * C_i * \log \frac{\sigma'_{v0,i} + \Delta\sigma'_{v,i}}{\sigma'_{v0,i}}$$

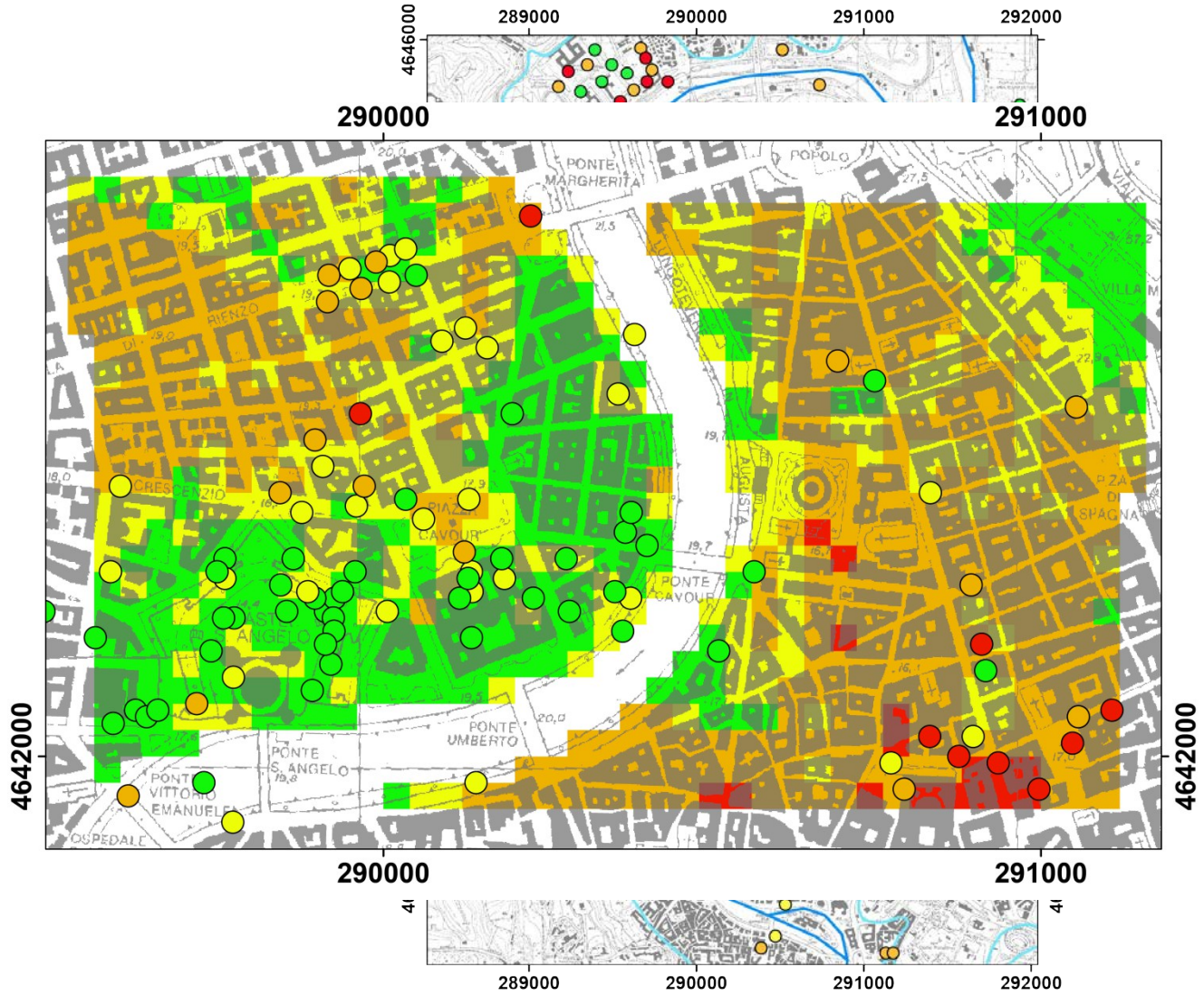


3D stochastic geological model



Calculated map of the Index of Susceptibility to Settlement

Level 3 - Index of susceptibility to settlement I_



Calculated map of the index of susceptibility to settlement

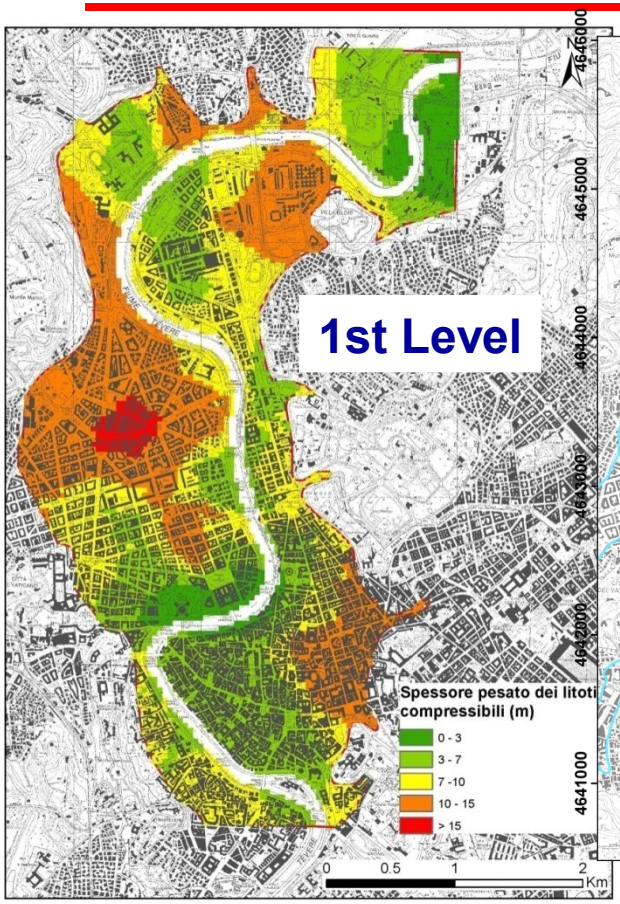
Well-sites

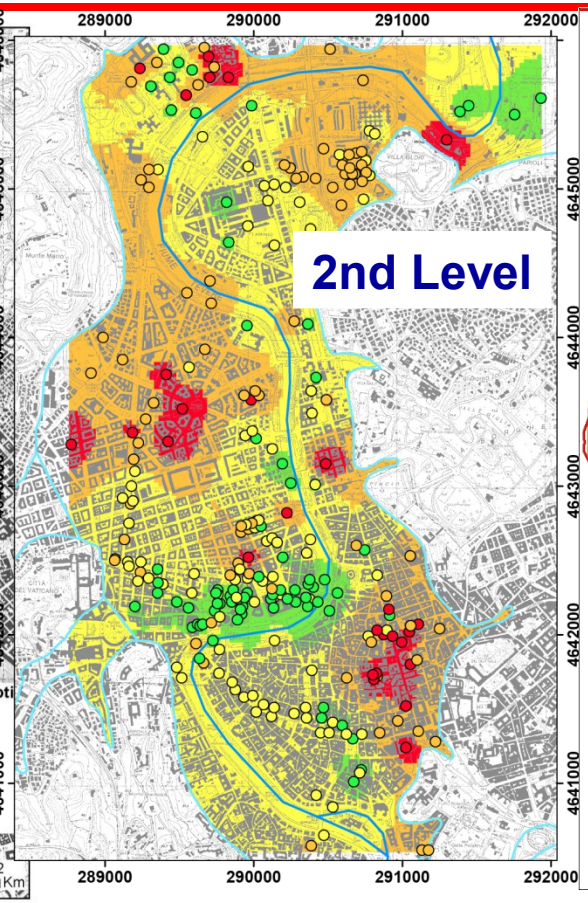
- 0 - 10
- 11 - 30
- 31 - 60
- 61 - 133

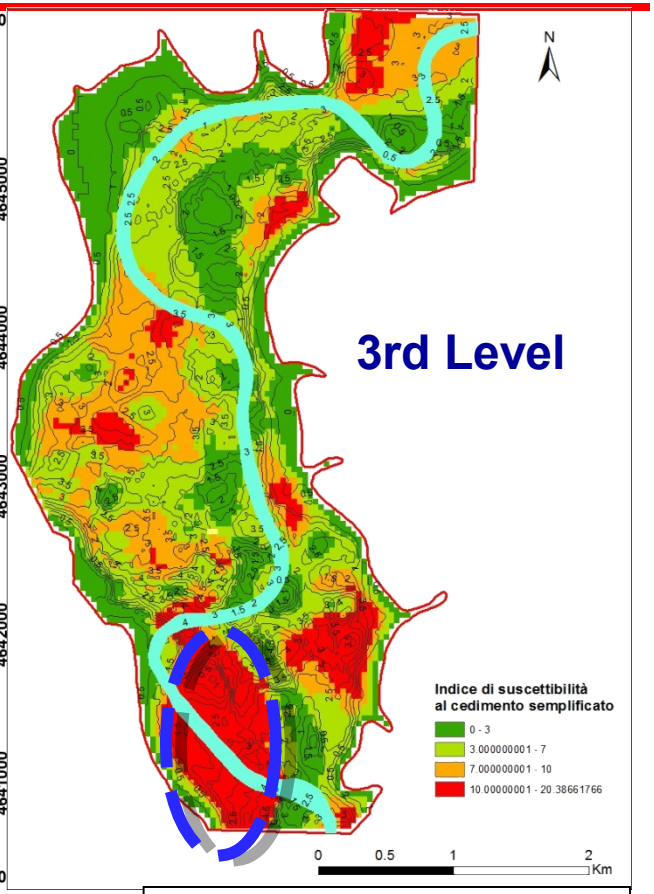
Map (cells 40x40 m)

- 0 - 10
- 11 - 30
- 31 - 60
- 61 - 63

Comparison of maps







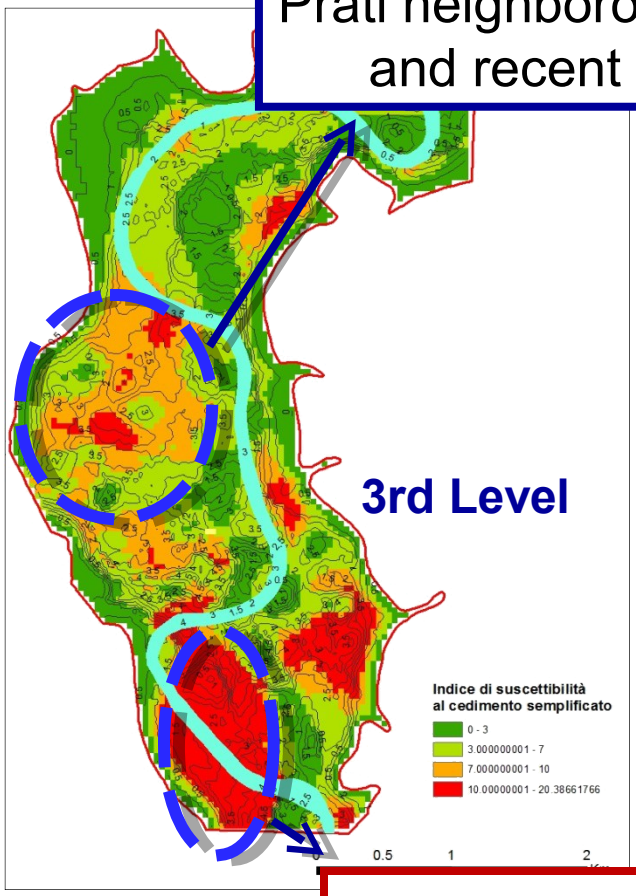
Estimated map of "weighted" thickness

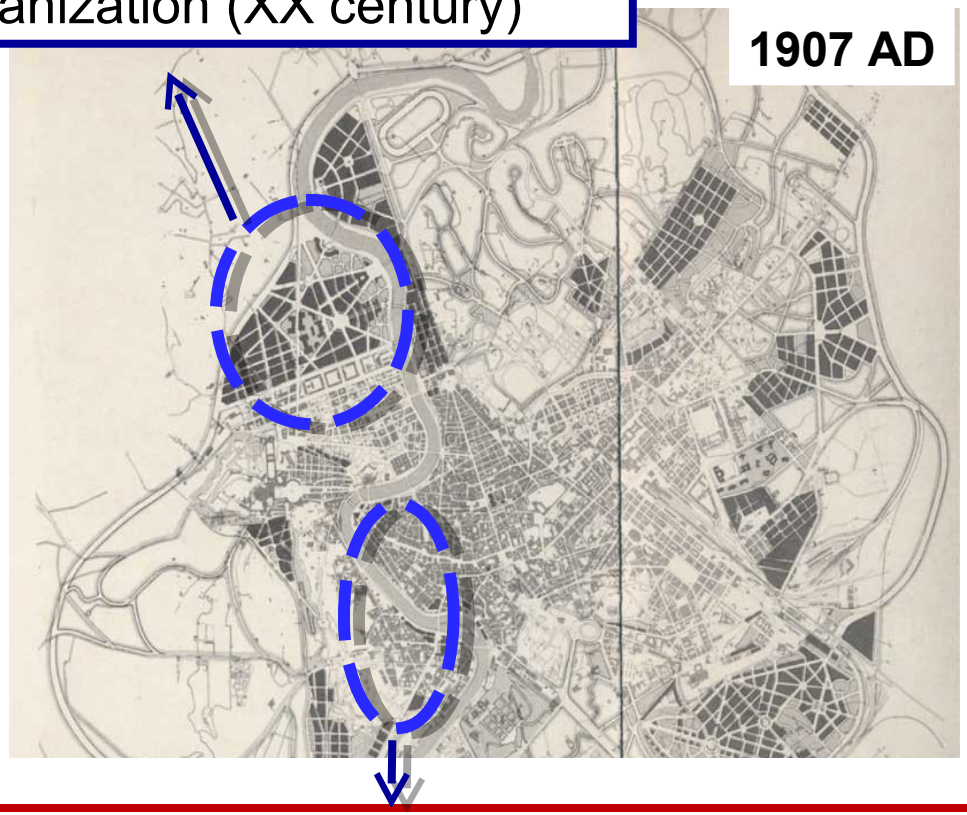
Estimated map of the Index of Susceptibility to Settlement

Calculated map of the index of susceptibility to settlement

Different consolidation

Prati neighborough: compressible lithotypes and recent urbanization (XX century)





Western neighboroughs (Trastevere) of Historical Centre: compressible lithotypes and two millenia long urbanization

Future works

- **Integration of spatial variability** of geotechnical parameters in the model.
- **Integration of time variability** of hydrogeological parameters in the model.
- **Introduction of the time-factor:** variation of settlements in time.
- Development of **procedures for using maps of susceptibility in the interpretation of interferometric monitoring** of urban areas.