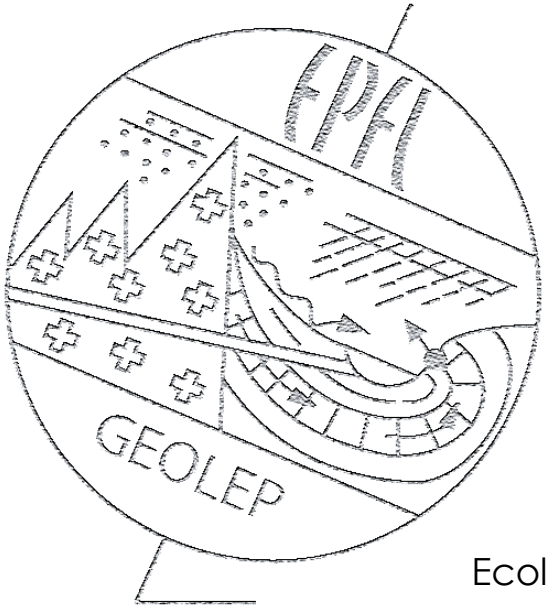
Coupling 3D GIS-based modelling and field methods to evaluate landslide hazard predisposition



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Introduction

- 6% of the Swiss territory affected by landslides
- Occurrences and potential damages always increasing

⇨ Necessity to have objective and easy to update hazard maps

Predisposition factors

Intrinsic factors:

- Resisting forces
  - Cohesion
  - Friction (depends on γ, α, φ)

γ, c, φ

- For rock material: =f(geotype, grade, D, GSI)
- For loose material: =f(granulometry, plasticity)

$$\varphi' = sin^{-1}\left[\frac{6am_b(s + m_b\sigma'_{3n})^{a-1}}{2(1+a)(2+a) + 6am_b(s + m_b\sigma'_{3n})^{a-1}}\right]$$

$$c' = \frac{\sigma_{ci}[(1+2a)s + (1-a)m_b\sigma'_{3n}](s + m_b\sigma'_{3n})^{a-1}}{(1+a)(2+a)\sqrt{1 + [6am_b(s + m_b\sigma'_{3n})^{a-1}]/[(1+a)(2+a)]}}$$

Hoek et al., 2002. Hoek-Brown failure criterion - 2002 Edition. In *NARMS-TAC Conference*. Toronto, 2002

Predisposition factors

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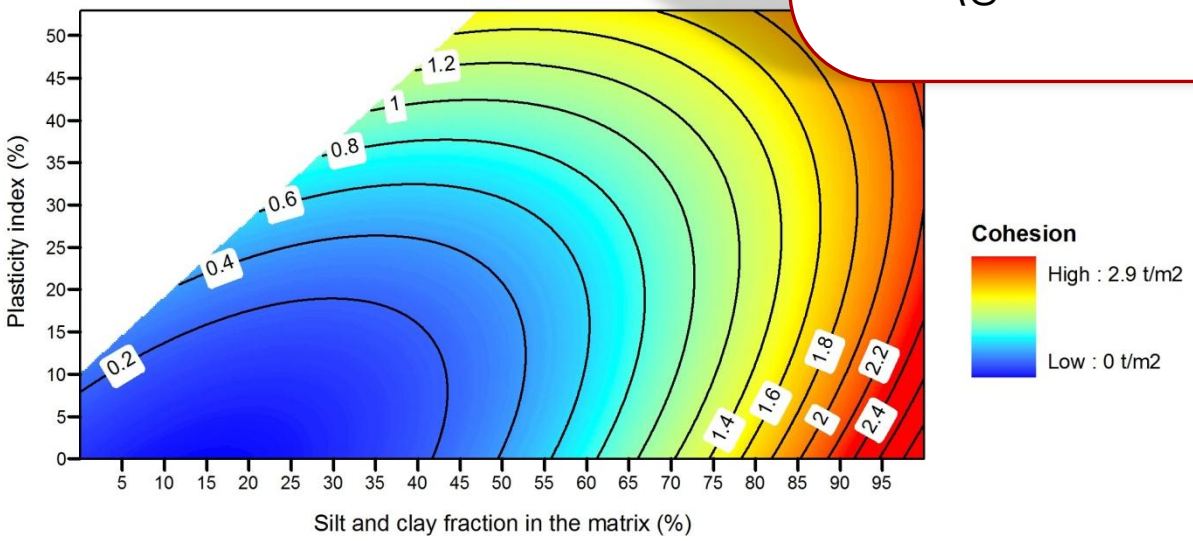
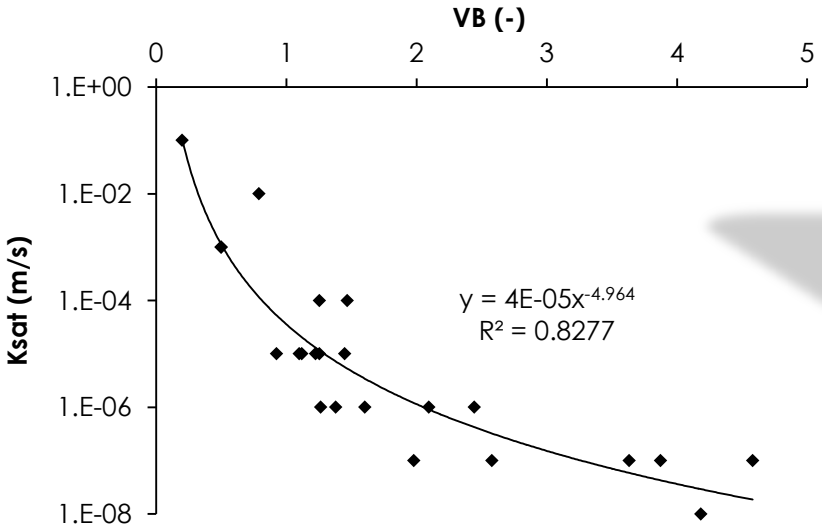


Predisposition factors

Intrinsic factors:

- Driving forces
  - Gravity (depends on γ, α)
  - Percolation (depends on *i*)



i= grad h

- Measured piezometric level (boreholes, springs, etc)
- Spatial distribution of K

Predisposition factors

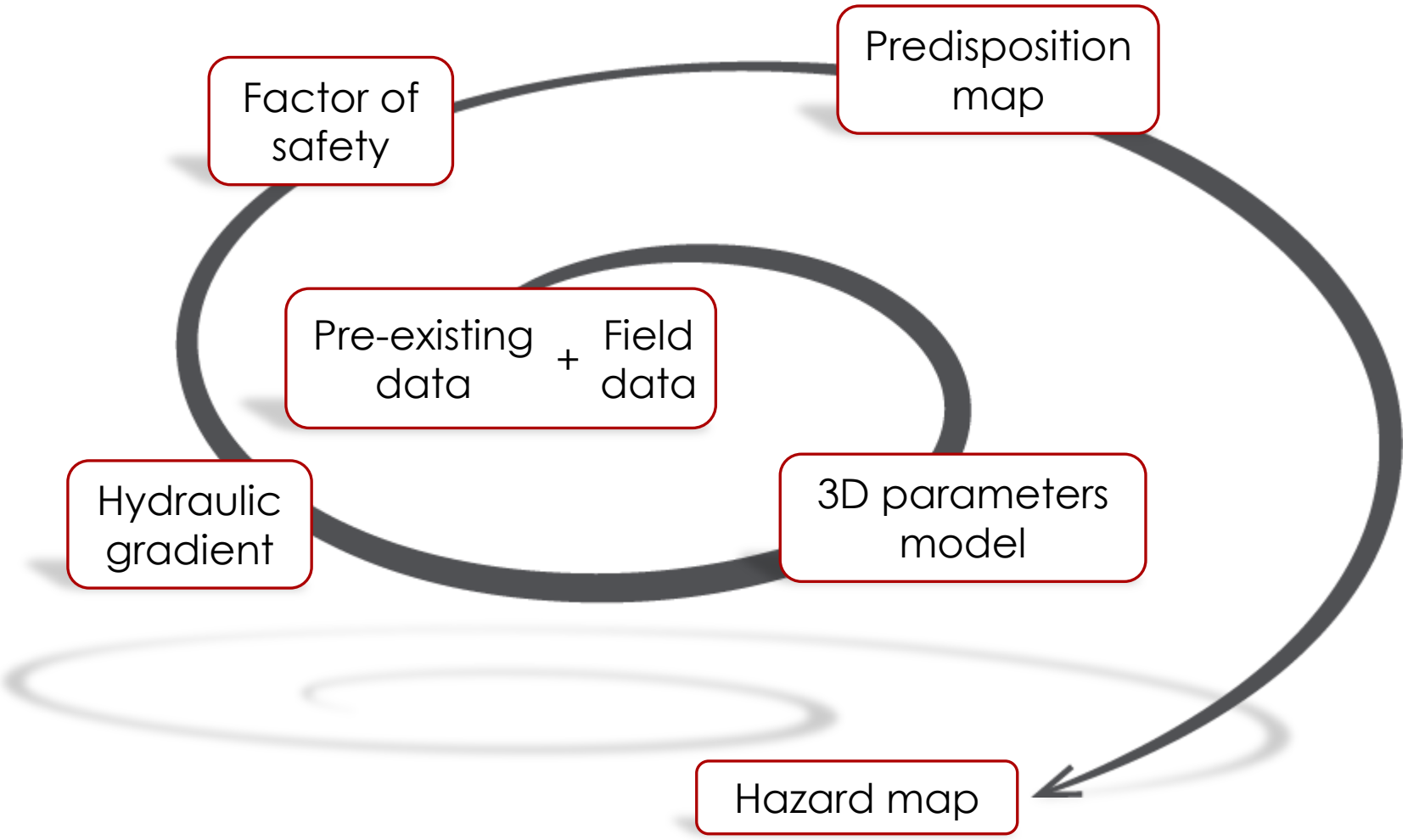
Extrinsic factors:

- Vegetation
- Anthropic impact
- Permafrost melting

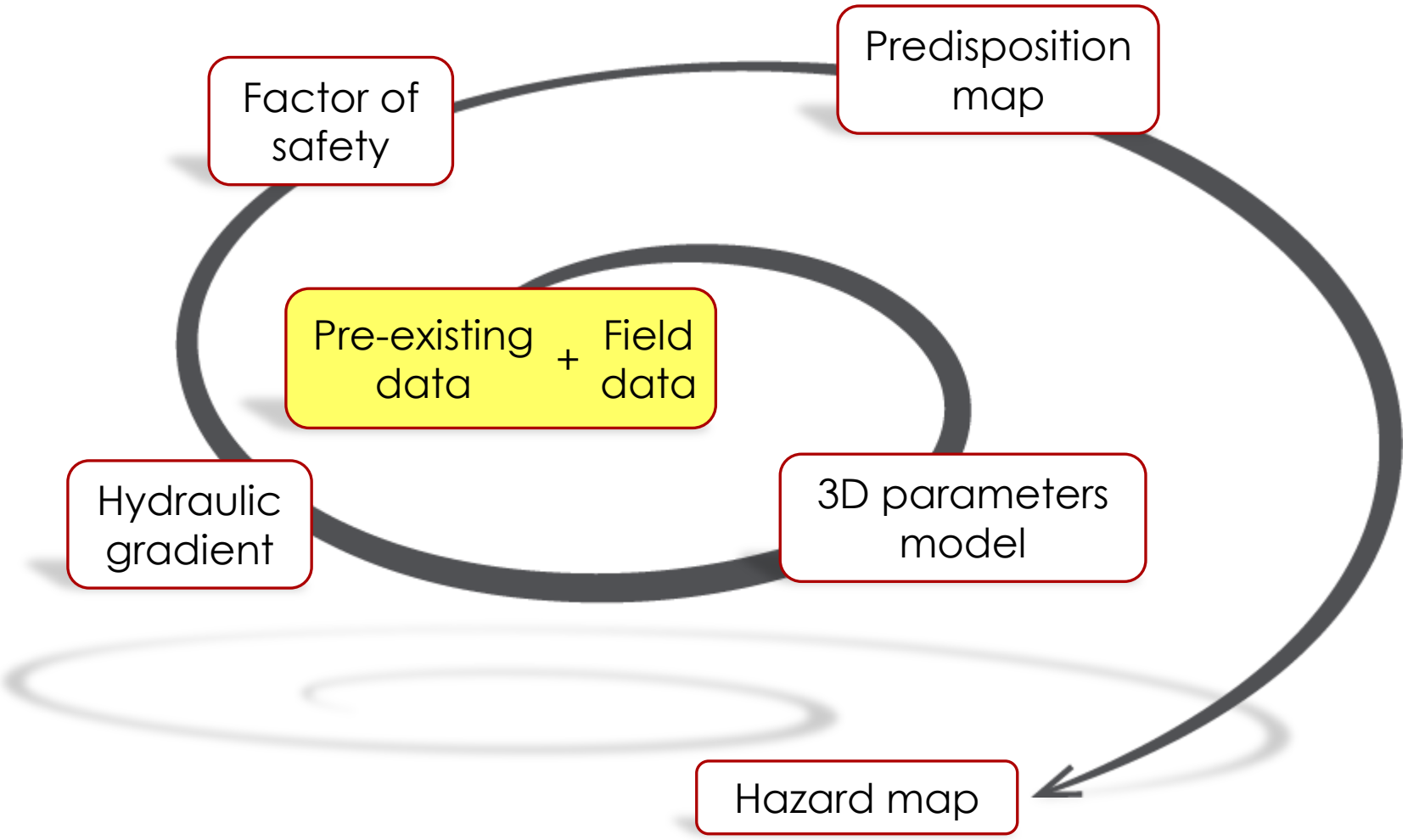
Depending on:

- Location (altitude, aspect)
- Susceptibility of the formation =f(granulometry, plasticity)

Methodology



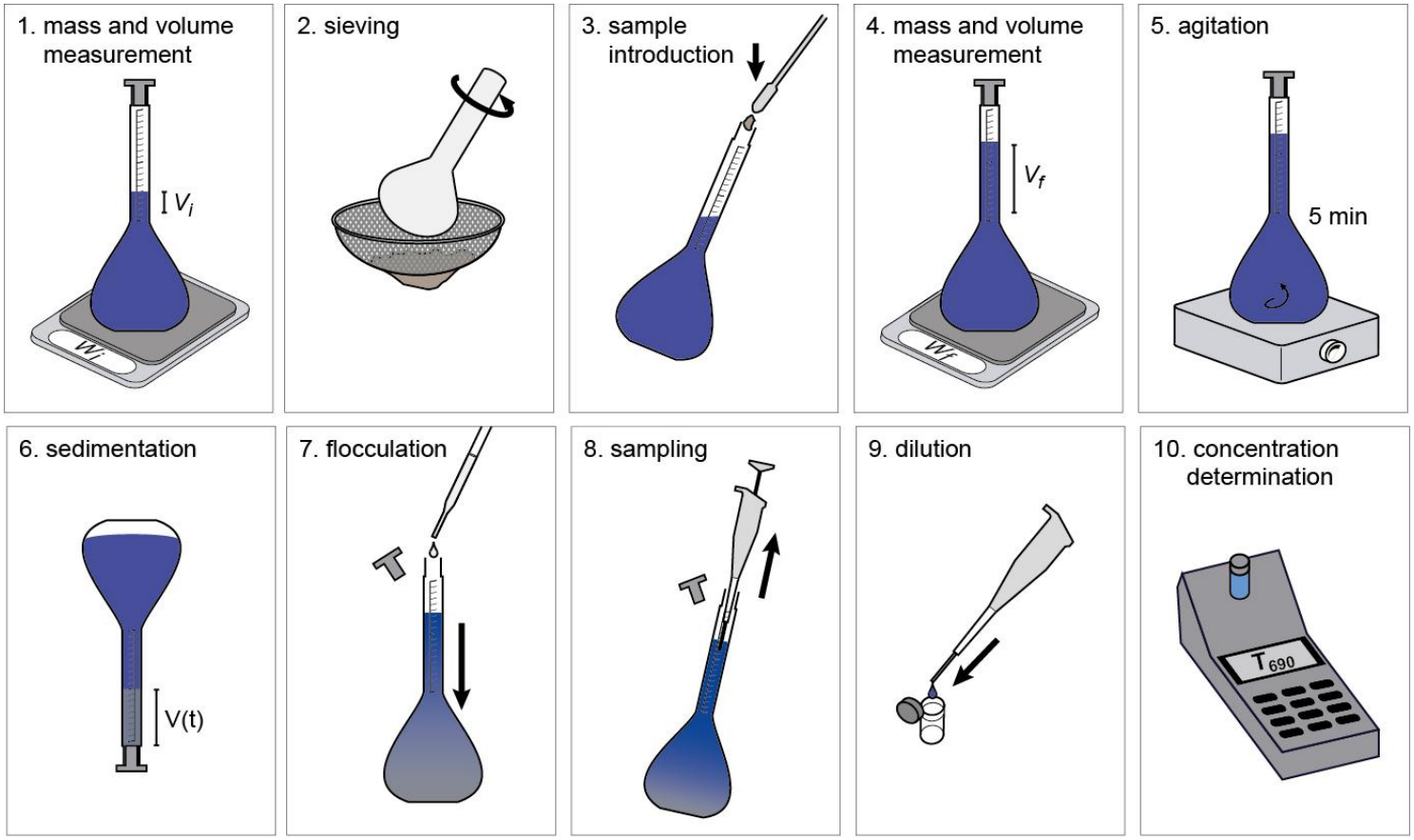
Methodology



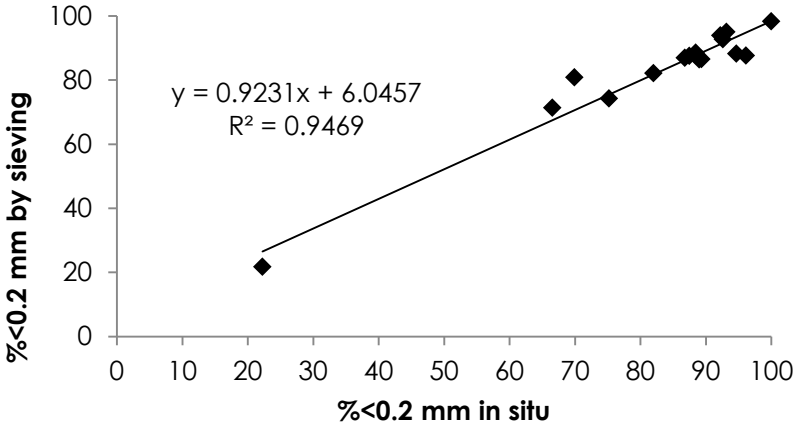
Field mapping

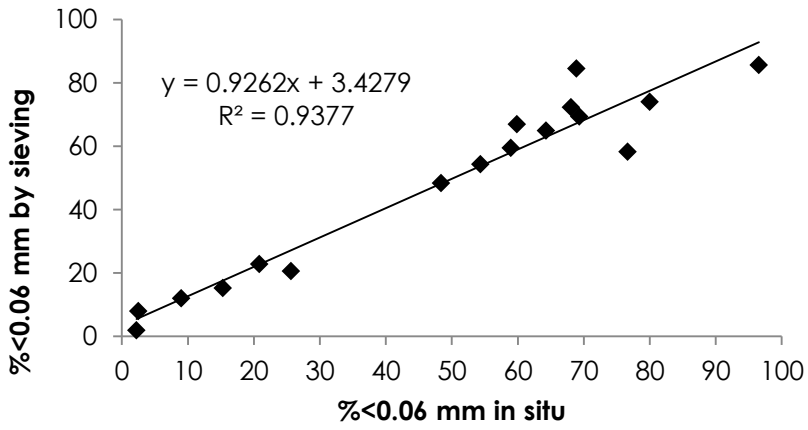
- Phenomena
- Geology
  - Discontinuities
  - Formations
  - Fracturation, grade and GSI
  - Granulometry and plasticity
- Hydrology
  - Springs and wet areas
  - Supposed associated aquifer
- Vegetation
- Structures

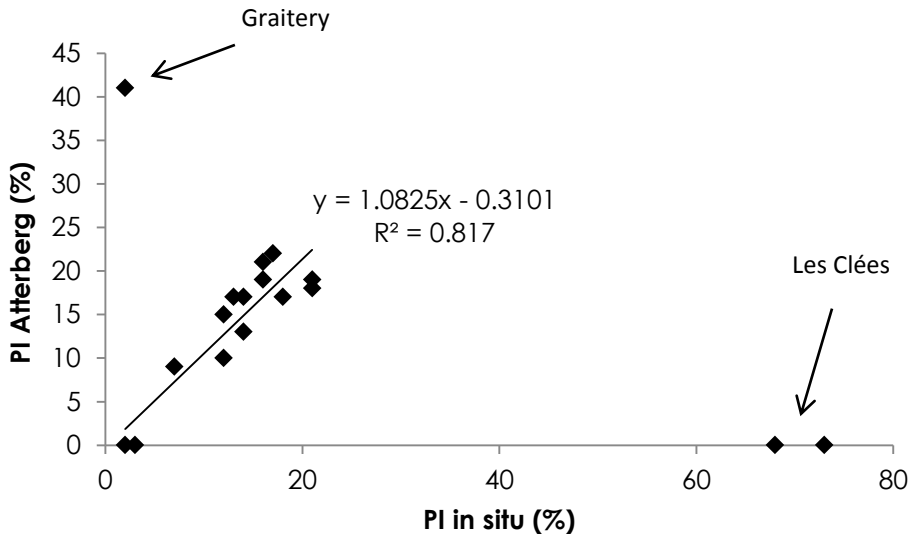
Loose material characterization



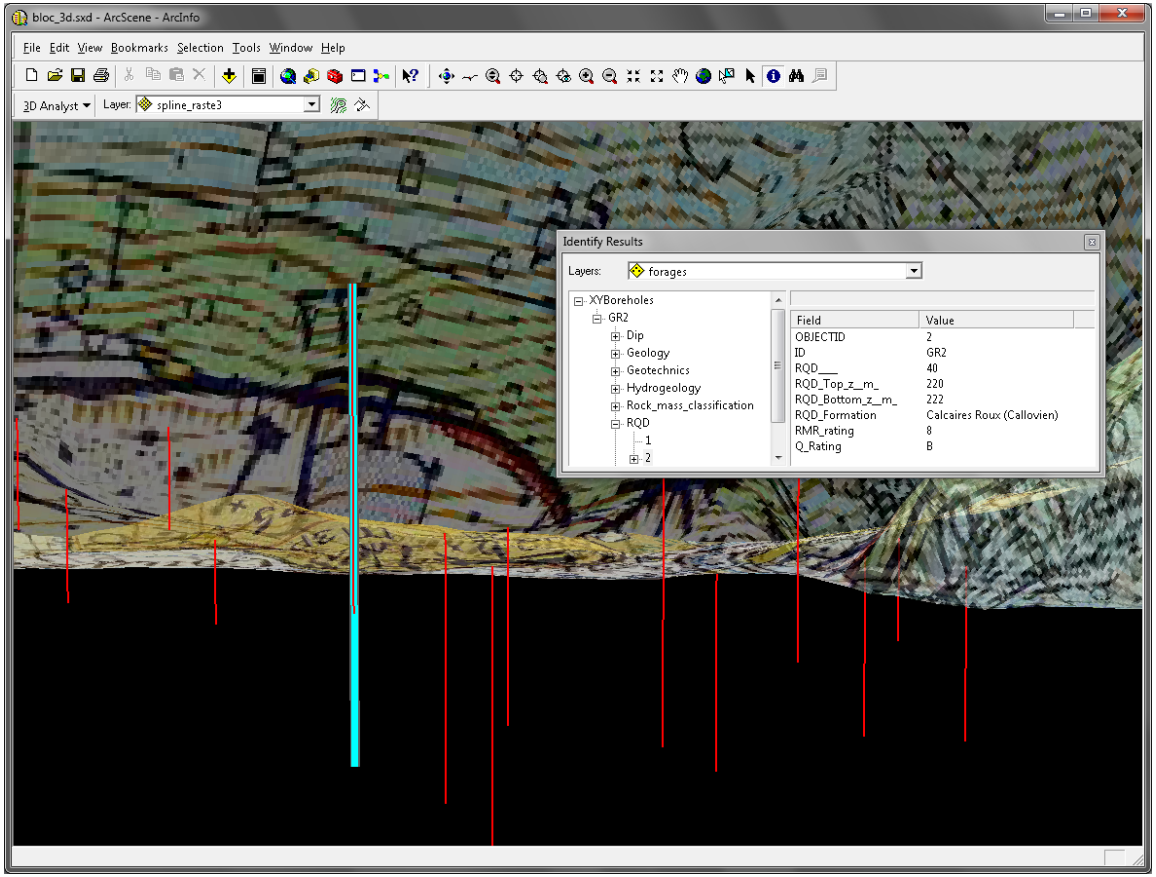
Loose material characterization





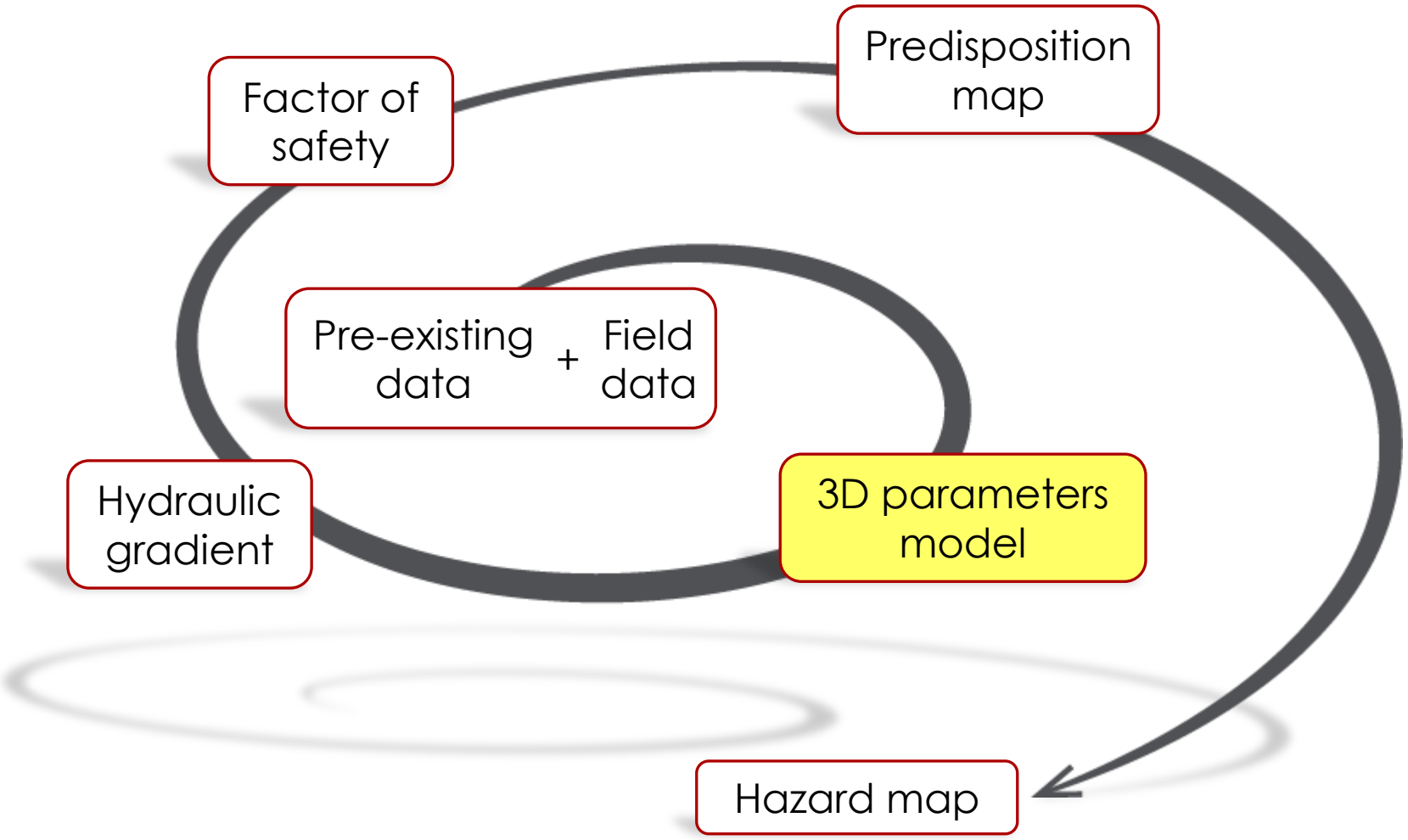


Integration of pre-existing data

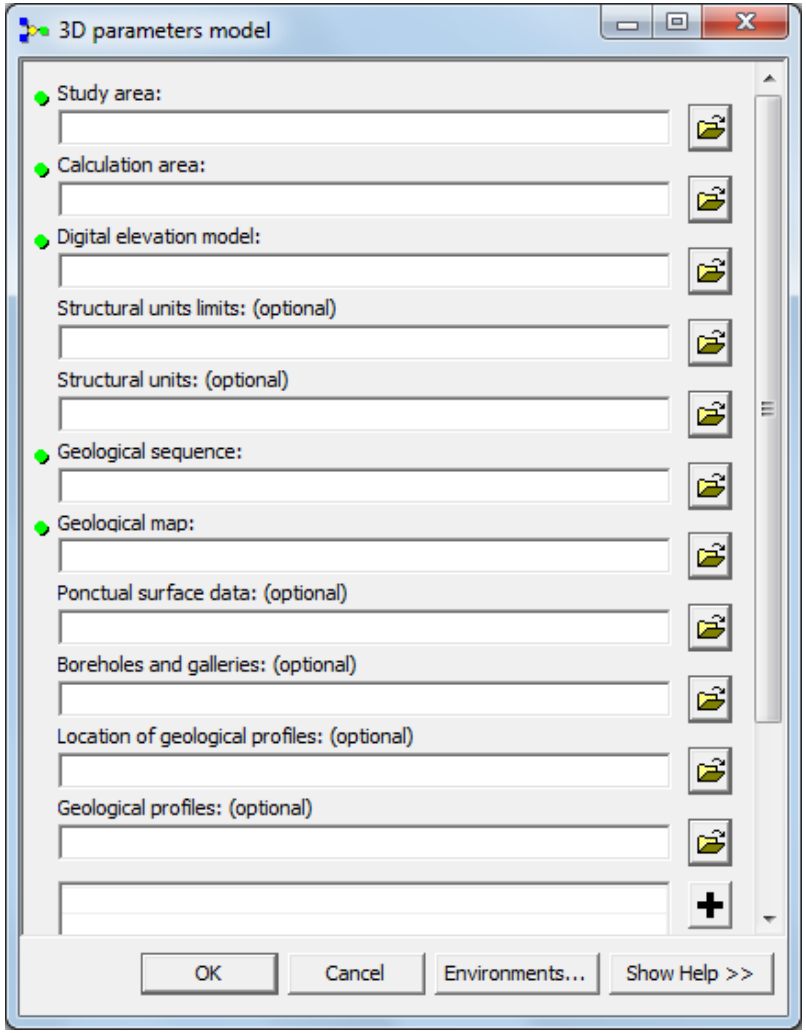


Collecting data from previous projects → Integrating them in a geodatabase

Methodology

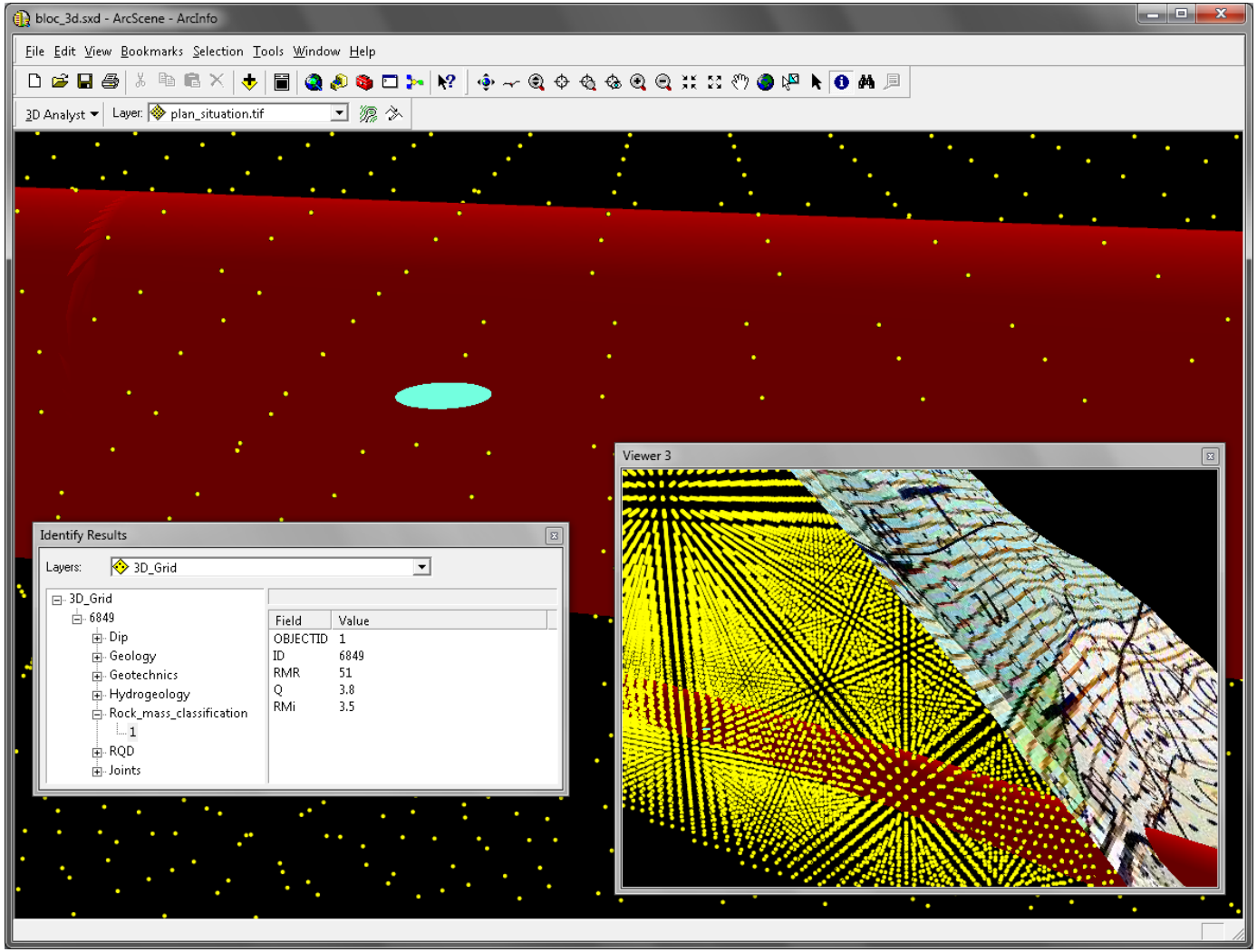


3D parameters model

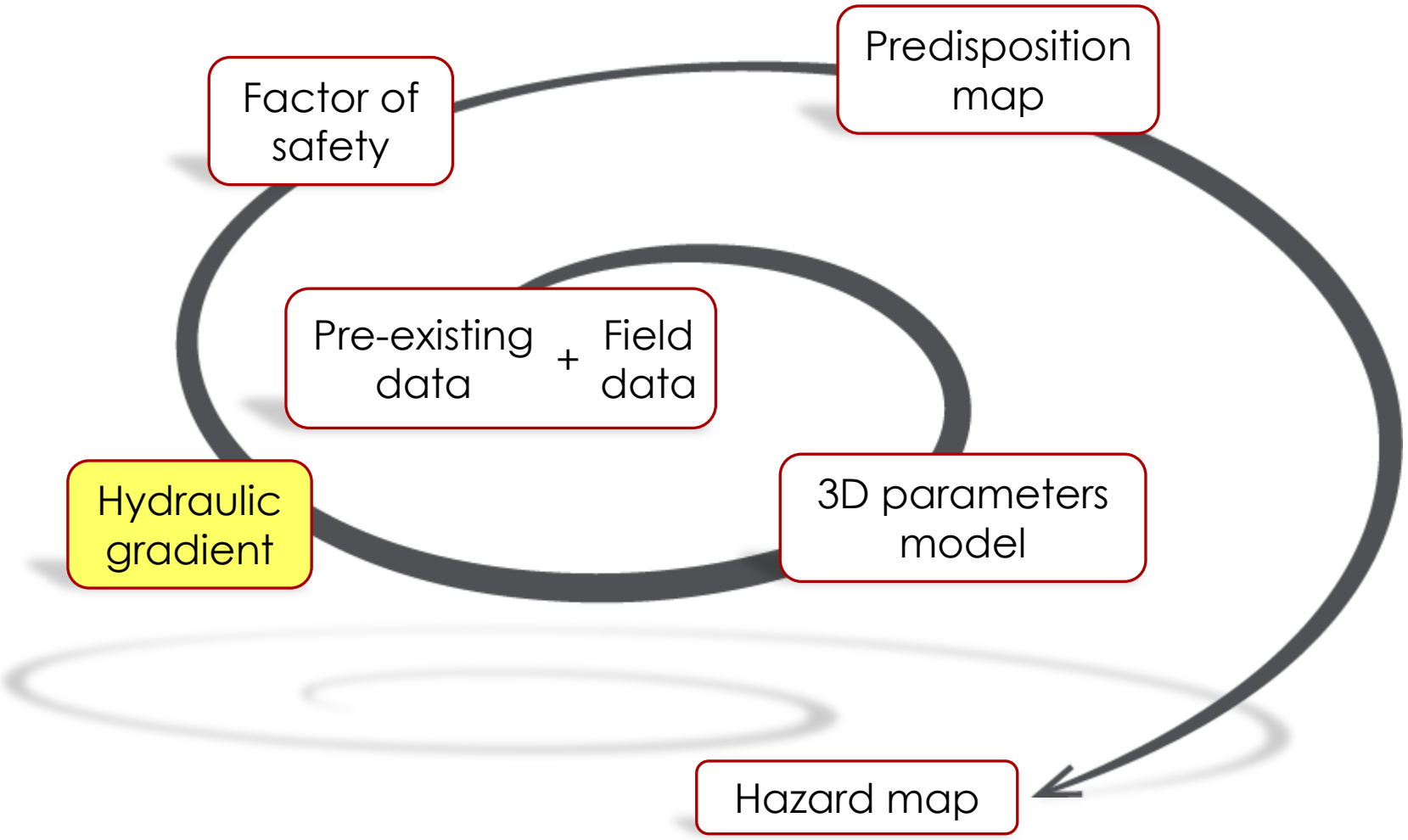


- Determination of the 3D limits of the structural units
- Kriging of the dips and strikes in each structural units
- Modelling the rock formations with respect to field observation, boreholes information, profiles and dip and strike interpolation
- Modelling the loose formations with respect to field observation, boreholes information, profiles and modelled rock formations
- Kriging of the parameters inside of each polygone or using the database

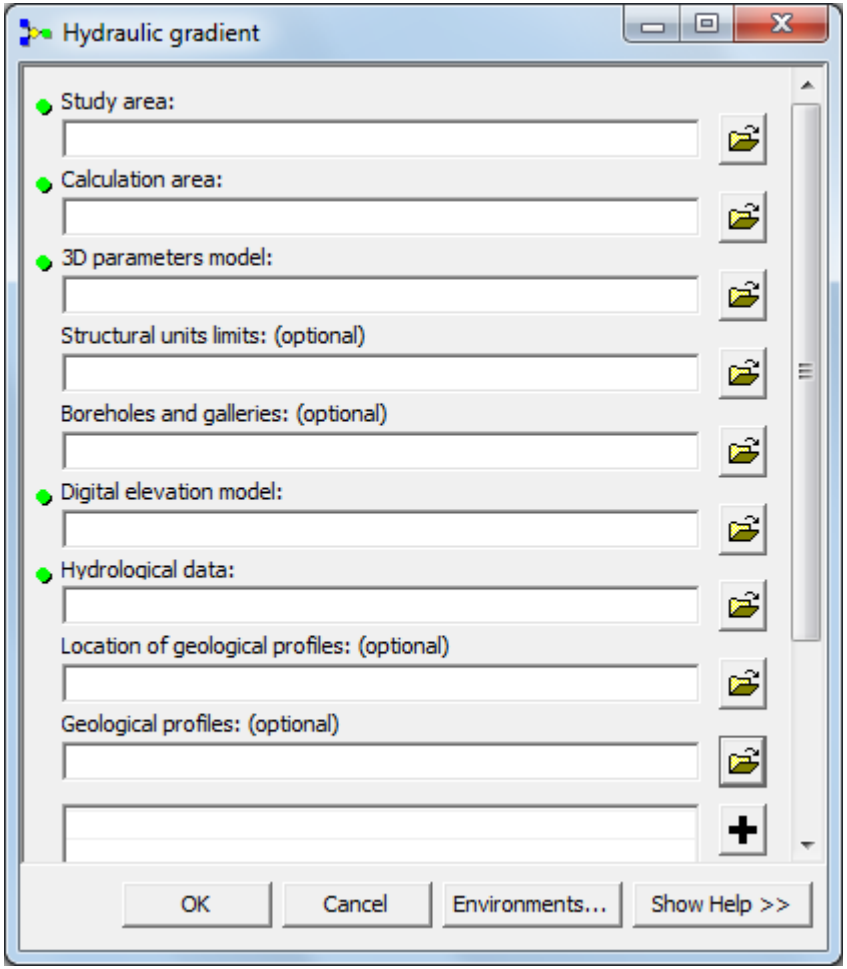
3D parameters model



Methodology

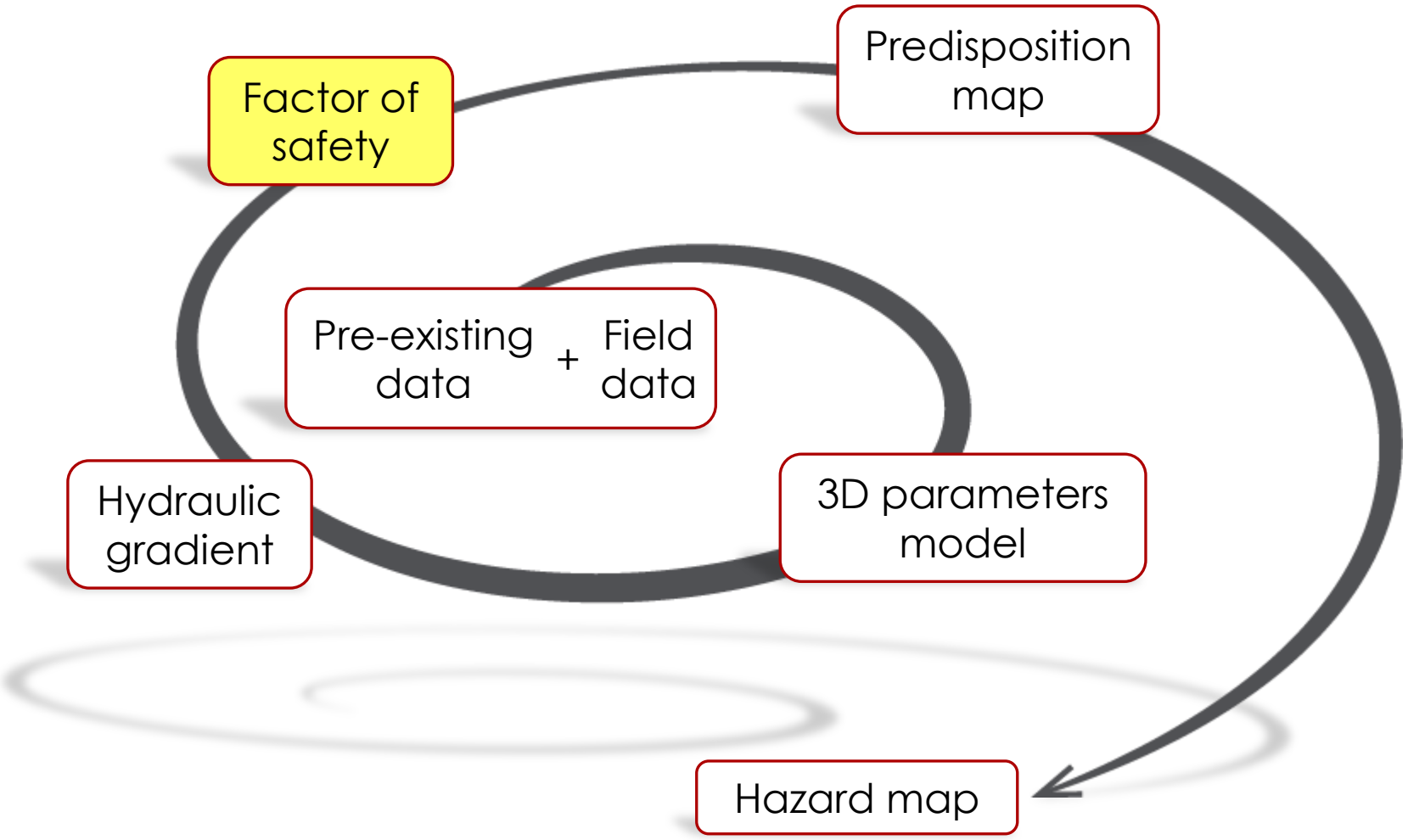


Hydraulic gradient

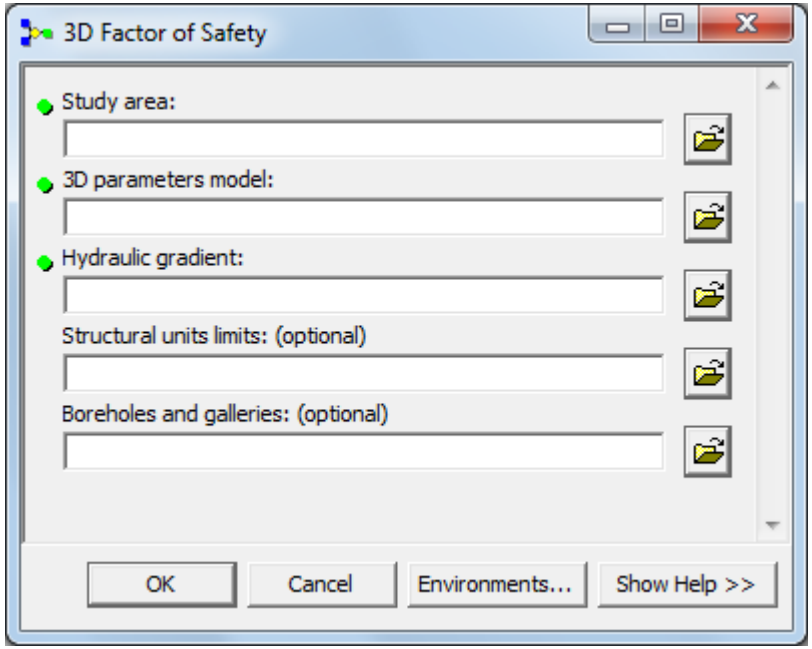


- Connecting each piezometric level, spring or wet area to the corresponding aquifer
- Evaluating the geometry of each aquifer according to the repartition of K in the model
- Interpolating the hydraulic head in each aquifer
- Calculating the hydraulic gradient

Methodology



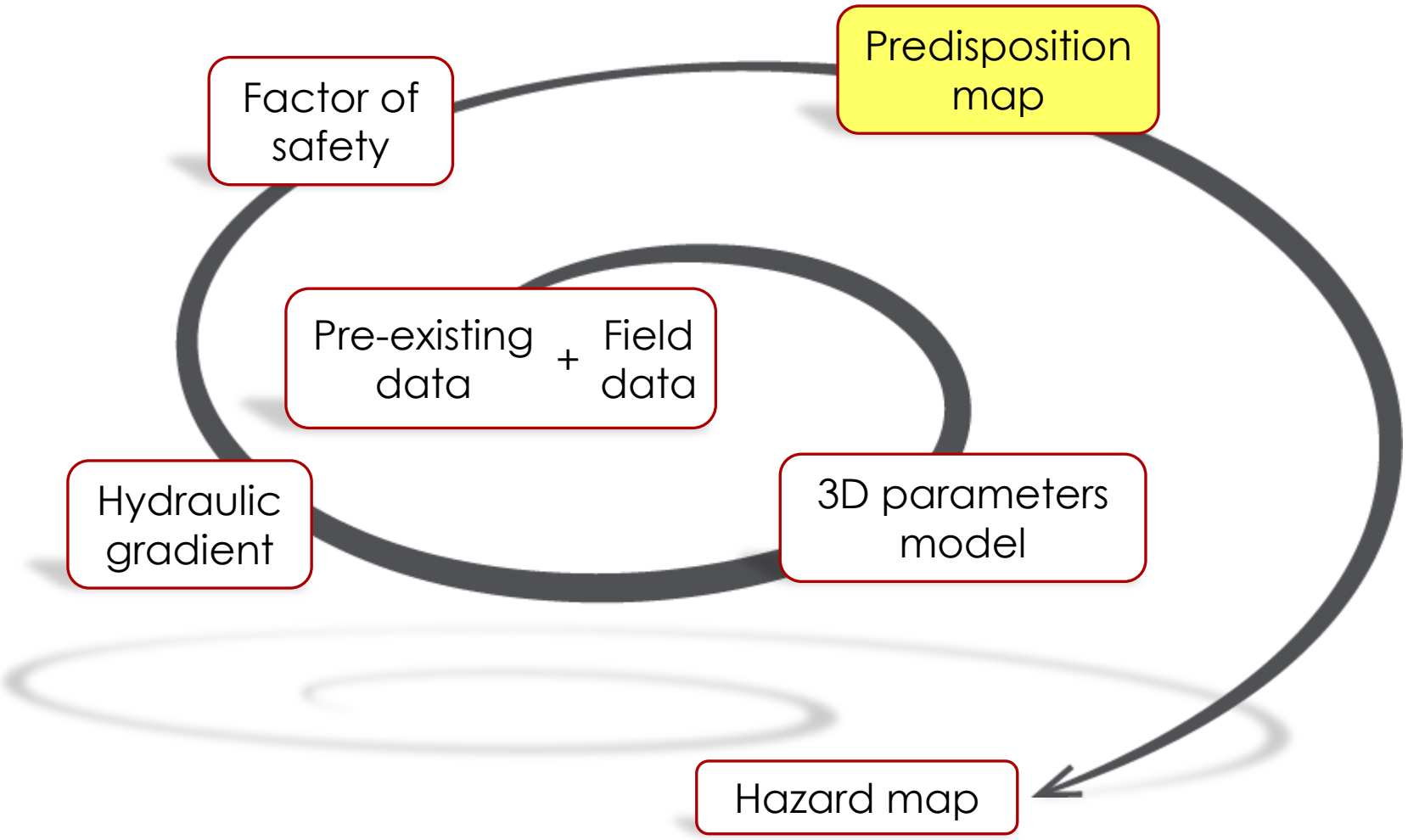
Factor of Safety



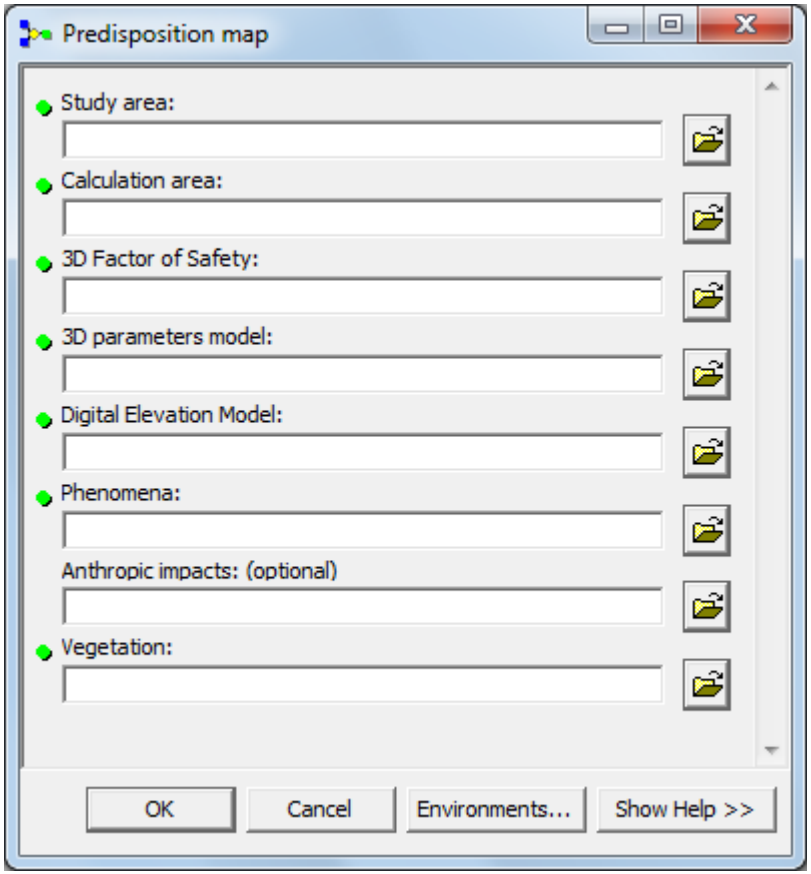
$$FoS = \frac{c + \tan\varphi\,(\gamma \times \cos\alpha)}{(\gamma \times \sin\alpha) + (\gamma_w \times i)}$$

- For each (x,y) couple, calculation of the FoS at each interface between homogeneous geological units
- For each (x,y) couple without calculated FoS < 1, calculation of the FoS at each z step, keeping the lowest value

Methodology

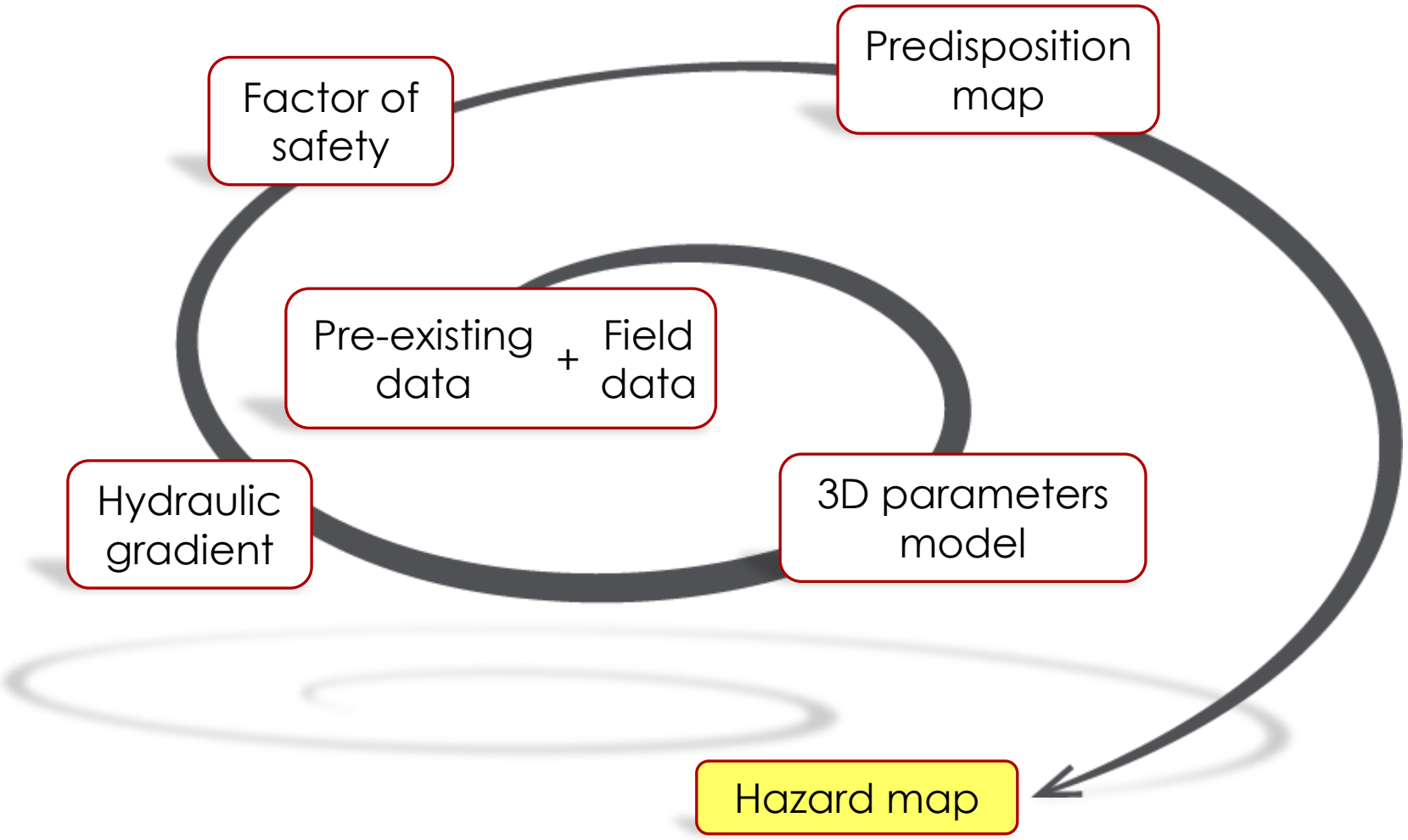


Predisposition map

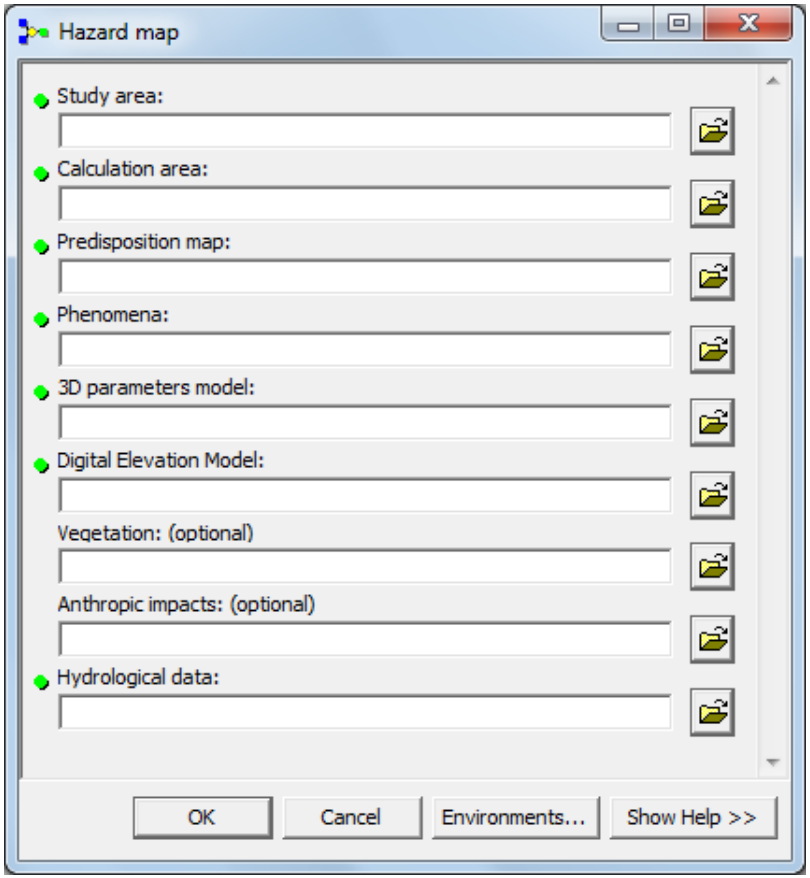


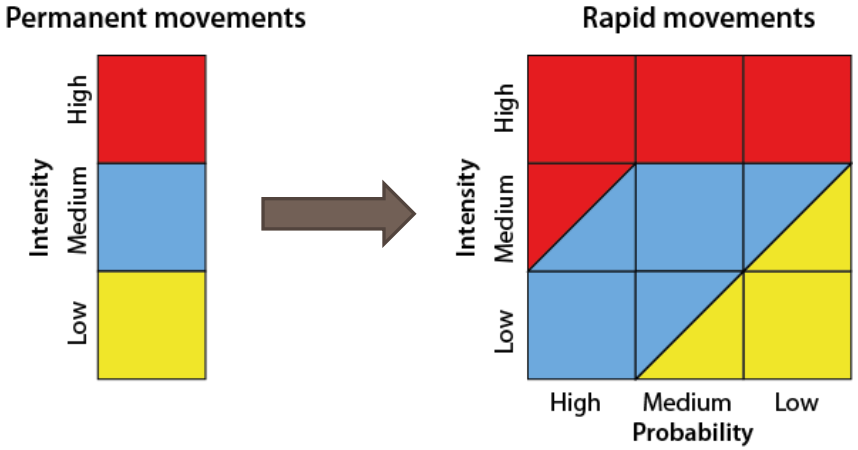
- Applying bayesian probability model to evaluate the weight of frozen soil, vegetation and anthropic infrastructures in the susceptibility to landslides
- Calculating the predisposition map
- Verifying the coherence of the predisposition map with respect to the map of phenomena

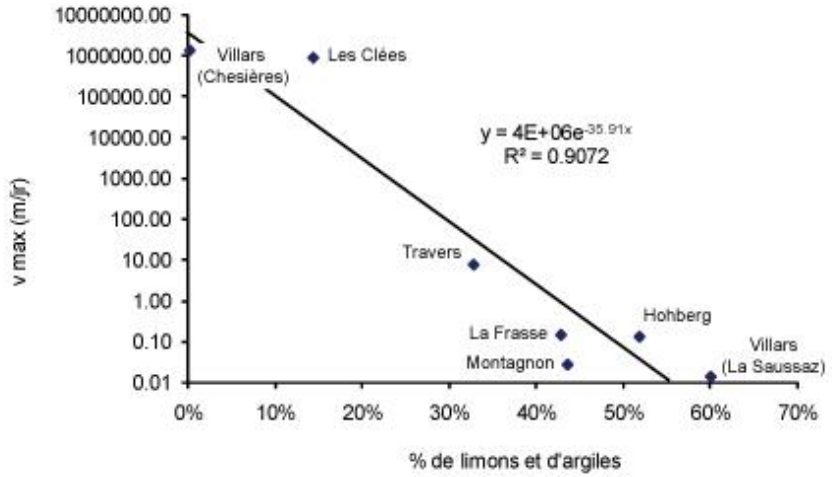
Methodology



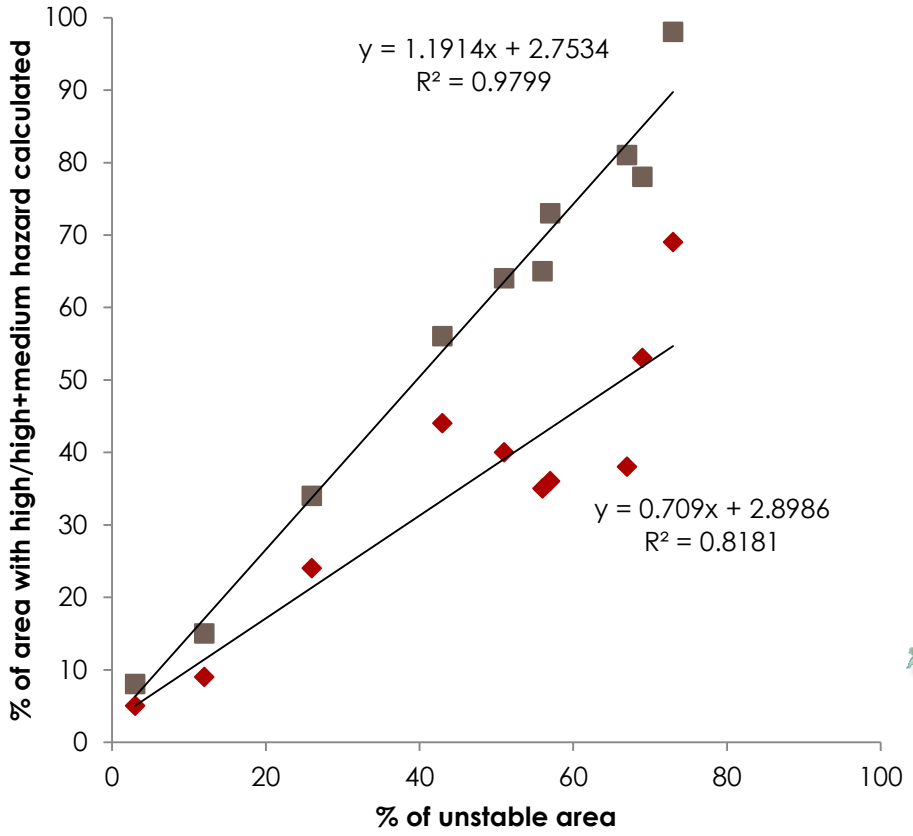
Hazard map

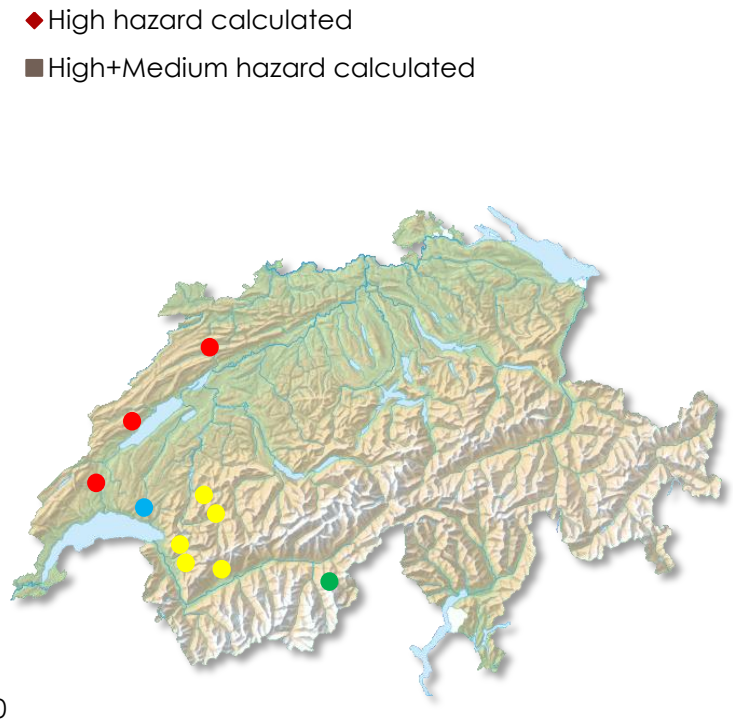

Hazard map
Study area:
Calculation area:
Predisposition map:
Phenomena:
3D parameters model:
Digital Elevation Model:
Vegetation: (optional)
Anthropic impacts: (optional)
Hydrological data:
OK
Cancel
Environments...
Show Help >>


Permanent movements
Rapid movements
Intensity
High
Medium
Low
Probability


v max (m/jr)
% de limons et d'argiles
y = 4E+06e-35.91x
R² = 0.9072
Villars (Chesières)
Les Clées
Travers
La Frasse
Montagnon
Hohberg
Villars (La Saussaz)

Hazard map


y = 1.1914x + 2.7534
R² = 0.9799
y = 0.709x + 2.8986
R² = 0.8181
% of area with high/high+medium hazard calculated
% of unstable area
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100


High hazard calculated
High+Medium hazard calculated

Conclusion

- Methodology applicable at larger scale with simple Quaternary structures (without lenses)
- Data infrastructure allows to change the scale easily
- Data can be easily updated or re-used (high interoperability)
- Toolboxes can be used separately in other domains (natural resources management, tunnel engineering, etc)
- In order to reduce the costs and to provide better results, development of equivalent plugins for GRASS (in progress)

Thank you for your attention!

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