EXPERIENCE FEEDBACK ABOUT THE USE OF GEOSTATISTICS FOR CONTAMINATED SITE CHARACTERIZATION (RECORD NETWORK)

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Context and objectives

• Context
  – Framework: characterization of potentially contaminated sites
  – Geostatistics: one of the relevant solutions that helps in meeting various objectives: sampling optimization, contamination mapping, assessment of contaminated volumes, uncertainty quantification!
  – However: added value and conditions for a successful application still difficult to assess...

• Objectives of the project
  – Using different elements of analysis, draw up a report about the use of geostatistics for characterizing contaminated sites, in France & abroad;
  – Assess the current use of geostatistics: benefits, potential barriers to its application, remaining issues;
  – Provide recommendations to ensure success and improve operational integration during site remediation.
A few words about geostatistics

• Geostatistics in general
  – Probabilistic methods developed in the 50’s for mining resource estimation
  – 70’s: applications in Oil & Gas and hydrogeology
  – General idea: describe the spatial continuity of the target variable in order to:
    o predict it at unsampled locations (mapping),
    o estimate the related uncertainty.

• For contaminated site characterization:
  – First applications on real cases in the 80’s
  – Several PhD theses dedicated to both chemical / radiological pollution
  – Main applications:
    o Sampling optimization,
    o Mapping (better understanding of the pollution),
    o Assessment of soil compatibility with future land use,
    o Computation of contaminated volumes + uncertainties,
    o Orientation of excavation/remediation of soils/materials.
Elements of analysis

• State of the art of main geostatistical concepts and answers to issues encountered in the context of contaminated sites.
  – Integration of results from former R&D projects (ADEME projects Outrage and Reparage, reports of the working group GeoSiPol)
  – Broader and more critical point of view!

• Analysis of the complementarity between geostatistics and the acquisition of geophysical or in situ measurements,

• International literature review,

• Analysis of the regulatory context in different countries,

• Survey among actors involved in site characterization,

• Illustrative case studies,

• Existing software and training offer, on-going research themes.
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Elements of analysis: regulatory context

- Geostatistics mentioned in methodological guides and directives from various countries.

- Examples:

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Date</th>
<th>Geostatistics mentioned for…</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Since 1989</td>
<td>Pollution mapping (block kriging)</td>
</tr>
<tr>
<td>Quebec</td>
<td>Since 2008</td>
<td>Sampling optimization</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Since 2003</td>
<td>Data interpretation</td>
</tr>
<tr>
<td>France</td>
<td>Since 2007</td>
<td>Data interpretation + optimization of mesh pattern for systematic sampling</td>
</tr>
<tr>
<td>Wallonia</td>
<td>2012</td>
<td>Backfill characterization + delineation of hot spots</td>
</tr>
</tbody>
</table>
Elements of analysis: survey among actors

- **Aim of the questionnaire:**
  - Get a *feedback on the perception* of the application of geostatistics in order to understand:
    - the use of geostatistics (expertise, subcontracting, confrontation as authority),
    - the perceived usefulness of the approach,
    - recommendations and perspectives that would optimize its efficiency.
  
- **Target:** more than 100 people involved in the management of contaminated sites + NICOLE network and Common Forum members.

- **27 answers received,** mostly from France, Switzerland and Belgium but also Ireland, Quebec and Brazil.

- **Questionnaires included “case study sheets”** to have some examples of real projects integrating a geostatistical approach.
Elements of analysis: case studies

• Four “case study sheets” illustrating the context (site, pollution type), the expected objectives, the chosen approach, the results and a critical analysis.

• Among others, it is interesting to mention:
  – A case study on a CEA site illustrating the added value of geostatistics to improve the understanding of a deep radiological contamination and its delineation, allowing starting the remediation with confidence.
  – The opportunity to successfully validate the prediction of contaminated volumes on a former oil deposit with actual remediation data.
Results: present use of geostatistics

• Pros:
  – Geostatistics applied during the last 15 years on a significant number of sites corresponding to various activities, sizes and issues.
  – Geostatistics:
    o generally applied by people having a good level in the subject,
    o led for most of them to a total or partial success.
  – Actors faced to such studies mention the interest of the geostatistics to:
    o visualize the pollution in 2 or 3 dimensions,
    o assess the volumes of soil to be remediated,
    o quantify the uncertainties and financial risks,
    o optimize new sampling campaigns given the already collected information.
  – Cost / benefit ratio of a geostatistical modeling considered as positive by a majority of the survey participants.
Results: present use of geostatistics

• Cons potentially leading to disappointment in some cases:
  – **Mismatch** between the context (site, data) and the expected results of the geostatistical modeling
    (lack of data, poorly distributed, of poor quality, very heterogeneous pollution...)
  – **Communication problems** between the numerous stakeholders (site owner, consulting firm in charge of the characterization, geostatistician, site remediation company, authority)
    → Person in charge of the geostatistical study usually not considered as being a key partner in the project.
  – Communication regarding uncertainties is especially a difficult subject:
    → For example, with empirical or deterministic methods, **the lack of uncertainty quantification should not be interpreted as an absence of uncertainty**!
    → Conversely, uncertainty quantification by geostatistical methods should not be seen as an imperfection of the method!
Results: present use of geostatistics

• Several obstacles to a more recurrent use of geostatistics:
  – Additional cost generated by the geostatistical study
    → How to convince a site owner to invest in a methodology that is not discussed in the official methodological guides?
  – Authorities’ position
    → How to convince the client of the benefit of an approach that is not discussed in the official methodological guides, which are also relatively vague about the choice of the remediation mesh, the type of control samples after cleanup, etc.?
  – Software: a lack of software tools tailored to the domain of contaminated sites is pointed out.
  – Training and information:
    o professionals are not enough trained to geostatistics and application software,
    o lack of information of actors involved in the management of contaminated sites.
  – Demonstration cases: despite significant efforts, still not enough case studies available to prove the validity of a geostatistical approach (confidentiality issues, lack of feedback about the remediation...).
Results: lessons learned / recommendations

• Potential improvements to solve these issues and obstacles (1/2):
  – Adapt expected outcomes of the geostatistical modeling to the practical case (site, data):
    → Before the investigations, pay attention to the consistency between the objectives, the nature of the investigations AND the relevance of a geostatistical modeling! Think before...
  – Improve communication between different actors by:
    → Improving the knowledge of the different actors about the geostatistical methodology (concepts, methods, working hypotheses),
    → Involving more closely the geostatistician in the project to ensure he is familiarized with the project practical constraints & expectations.
  – Analyze the cost-benefit of a geostatistical study:
    → Cost of the geostatistical study must be weighted against the benefit (either during cleanup or resulting in a better understanding of pollution and thus better decisions).
    → It is now recognized that a detailed and accurate investigation, although more expensive, leads to savings during remediation.
Results: lessons learned / recommendations

• Potential improvements to solve these issues and obstacles (2/2):
  – Present the geostatistical methodology in official documents including a discussion of its advantages and limitations.
  – Have appropriate software, which offer is increasing, considering various selection criteria.
    (complexity of the studies and their objectives, level of knowledge of geostatistical and programming methods, users’ time available, software support and updates provided by the software vendor)
  – Develop training and awareness programs.
    → The development of short seminars seems to meet the needs of actors who need to be aware of the geostatistical approach without an effective need to apply it personally.
  – Present case studies with contaminated volumes validation
    → Considered as one of the most convincing demonstrations for the added value of geostatistics for contaminated sites.
Results: relevance of a geostatistical study

- How to assess it beforehand?
- Goal:
  - Answer Frequently Asked Questions about the use of geostatistics to characterize contaminated sites.
  - Help to evaluate the benefits of a geostatistical study during the characterization phase, for a given objective.
- Examples:
  - *When should I ask whether geostatistics is relevant in my case?*
  - *Do I have or can I acquire enough data?*
  - *Do I have data of adequate quality?*
  - *Is it possible that my site is completely heterogeneous or too complex?*
  - *How much will cost a geostatistical study and for which benefit? Is it worth the effort?*

<table>
<thead>
<tr>
<th>Objective</th>
<th>Min. nb. of data</th>
<th>Geostatistical approach</th>
<th>Cost Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data QC and summary</td>
<td>~10-15</td>
<td>Basic tools: elementary statistics, histograms, scatter plots, data location maps.</td>
<td>A few hours</td>
</tr>
<tr>
<td>2D/3D mapping of contamination</td>
<td>&gt; 20</td>
<td>Kriging interpolation. Recommendation: when data are in a limited number, be careful about the interpretation of the maps and communicate about the uncertainties.</td>
<td>A few hours, usually integrated in the consulting firms services</td>
</tr>
<tr>
<td>Estimation of contaminated volumes (3D)</td>
<td>&gt;25-30 (&gt;3-4 per borehole)</td>
<td>Estimation of contaminated masses and associated uncertainties, soil classification, sampling optimization to reduce uncertainties</td>
<td>A few days to a few weeks, individual service</td>
</tr>
</tbody>
</table>
Conclusions

• Project goal: make a critical and objective feedback of the use of geostatistics for contaminated site characterization.

• Several analysis angles have been investigated
  State of the art regarding the main geostatistical methods used for site characterization, review of scientific work published in various countries, survey amongst practitioners, regulatory contexts, real case studies.

• Based on this work:
  – Geostatistics appears as a relevant tool to help decision-making in the context of contaminated site characterization.
  – It allows improving the understanding of in place pollution, mapping contamination, estimating incompatible volumes, quantifying related uncertainties and optimizing investigation schemes.

• However...
Recommendations

• Training/Awareness
  – Applying geostatistics requires dedicated knowledge and practice...
  – As a consequence, there is a need of dedicated training for engineers in charge of such projects but also a need of awareness for people facing these projects.

• Communication
  – Communication between the geostatistician, the people in charge of the site characterization, the site owner and the regulatory authority is a key element to ensure the success of geostatistical projects.

• Other points
  – Clarify the conditions to be met for a useful application of geostatistics.
  – Be recognized within official methodological guides and documents in order to ease its relevant recommendation by site owners.
  – Need of demonstration cases illustrating in practice the added value.
R&D perspectives

• Perspectives for R&D themes
  – Experimental integration of indirect information (PID, geophysics).
  – Combination of geostatistical and health risk assessment models.
  – Integration of remediation constraints in the geostatistical model to ensure as far as possible consistency between prediction and remediation conditions.

• Acknowledgments
  – The RECORD network for funding the project and giving the authorization to present this work:
    http://www.record-net.org
Don’t miss the 10\textsuperscript{th} conference on geostatistics for environmental applications!!

The website will be up and running in a few days:

http://www.geoenv2014.org