GEOTECHNICS AND RISK MANAGEMENT

Sergio Mora

Caraballeda, Venezuela, Dec. 1999

DESPITE...

- The constantly multiplying technical assessments about:
  - Hazards: Seismic, volcanic, landslides, drought, El Niño, Climate Change...
  - Vulnerability: Social, physical, environmental...
  - Damage mitigation: Infrastructural, economic...
- Increasing efficiency in “post-disaster” operatives

Unfortunately, it must be realized that:

- Vulnerability increases; losses become larger and more frequent
- Poverty: Closes and exacerbates the vicious circle of disasters
- Chronic disorder : Infrastructure, productive activities, natural resources exploitation, urbanism –sometimes “planned”-...

Society faces a paradox:

- Creates situations and factors that aggravate the effect of natural processes (vulnerability)
- Tries to mitigate the consequences by means of technology, at very high cost, sometimes … too late
- Takes refuge under the indulgence of being a victim of Nature...

IN VIEW OF SUCH POOR RESULTS, IT IS FAIR TO ASK:

¿Why historical memory is so short and deficient in countries, constantly affected by disasters ? **?**

It is necessary to admit that the engineering and scientific community has failed, at least partially...

FAILURE FACTORS:

- **Poor quality in transmitting information**
- **Lack of political congruent political strategies**
- **Unskilled and ineffective use of our (good) arguments**
- **There is neither learning of lessons nor taking advantage of experiences**
- ***Syndrome: "…we are better now because we have things we did not have in the past…"***
- ***Instead of asking the real question: ... ¿Are we where we should be...?***

DISASTER RISK MANAGEMENT

Current situation

- Countries advance slowly in developing preventive capacities
- Reducing vulnerability is not a priority yet
- Strategies are still subordinated to emergency management; divorced from environmental management and interdisciplinary work
- The impact of natural processes becomes more intense, because of anthropic factors
- Lack or excess in application of standards-codes for design and construction
- Accepted risk levels are too low

- **DRM institutional situation:**
  - Operative weakness, low management capacity; leadership and authority limitations; high staff turnover
  - Chronic lack of resources
  - Obsolete plans and improvisation are the more used tools

- Institutions receive a lot of responsibilities but scarce resources
- Knowledge belongs to individuals, not to institutions
- Centralism; “starring”

It is worth saying that ...

- Decisions about the level of accepted risk are not always accompanied by objective engineering judgment, but sometimes instead by subjective determinations of financial and political criteria
- It is therefore appropriate to ask whether "accepted" risk can also be considered as "*acceptable*" ...
- It happens that those who decide are not always present to face responsibility for the consequences appearing after a disaster
- Those consequences usually fall upon the shoulders of the population, most of the time ill-informed about the levels of risk and the ways it materializes

Armero, Colombia, 1987

"…this will never happen to us…"

Catholic priest of Armero, Colombia, 1987

<u>Risk</u> ⇐ combination of factors

<u>Risk determinants</u>

Hazard: Peril, destructive potential,
solicitation,
demand

active external factors

Failure → consequence of failure

[probability of failure]

Vulnerability: Susceptibility,
resistance,
capacity

passive-induced internal factors

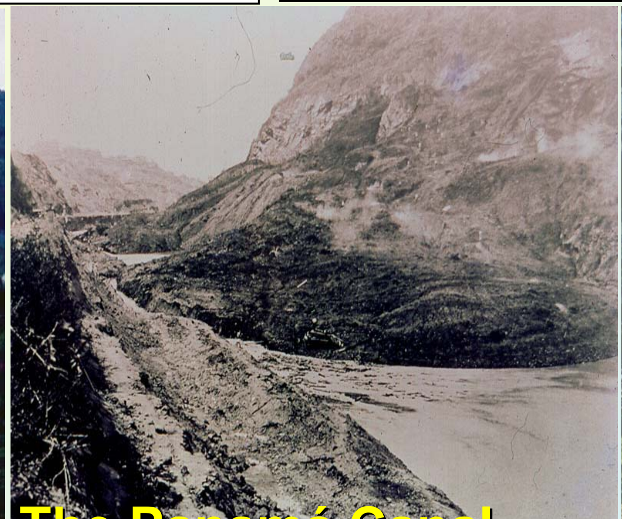
Every action engenders a reaction... *(Isaac Newton)*

Guaire river, Caracas, Venezuela, 2005

Safety, risk, standards… from a geotechnical viewpoint

- There have been innumerable publications attempting to describe the mechanical behavior of soils, rocks, water, and their influence on engineering decision-making

- In the 1950's Brinch Hansen started to apply a probabilistic approach to the analysis of <u>decisions</u> in trying to reduce the empiricism of codes and standards (i.e. factors of weighting)



The Panamá Canal

¿How to effectively face the effects of hazards? ¡By means of adequate engineering!

Sometimes with extraordinary success...

...sometimes without it...

Amiens Cathedral, France, built in 1264, H=42m; resisted several earthquakes

Cathedral of the Carmelites, Lisbon, Portugal, destroyed by the 1755 earthquake

Risk and Geotechnics

- Geotechnical Engineers and Geologists take decisions daily involving risks
- We are usually deeply conservative (uncertainties, liabilities, vanity)
- Prescriptions from standards and codes should lead to the reduction of risk to levels "acceptable" to the society…
- Do they?... Aren't they just "accepted" because an expert said something?
- Aren't we too attached to standards and codes?...Is this distracting us from searching better options?
- Risk analysis is still seen as a cost, not as an investment.

- Difficulties we do not always recognize, quickly enough:
  - –Operational risk
    - Analysis and conception of the project
    - Quantification
  - –Fundamental: Consider the unavoidable interdisciplinary character of our job
    - The physical analysis of soils, rocks and water is not enough!!!
    - Integration of other professions is more than needed (e.g. Chemistry, Botany, Biology, Hydrology, Meteorology, Climatology, Cartography, Geography, GIS, Geotechnical, Civil and Structural Engineering, Social, Political and Economic Sciences, etc.).

Difficulties with the assessment

- Professionals in "traditional" Geotechnics indiscriminately attribute to *risk*, any challenge where they feel not quite proficient enough, but are avert to convoking multidisciplinary approaches
- Extreme simplification and misuse of the concept of "risk"
- The consequence is a delay and/or an overdose of caution in the application of risk analysis to the solution of geotechnical and environmental problems
- <u>ATTN</u>: From now on, geotechnical-environmental hazards will be perceived as very significant

Risk

- Composed at least of:
  - Uncertainty
  - Consequences and conflicting objectives

- Quantification
  - Probability of an undesirable event
  - Consequences:
    - Economic
    - Environmental
    - Social

Economic consequences

(W. Hachich, 2006)

Ecovias - Estabilização Definitiva e Avaliação do Dano Ambiental no Escorregamento de 500.000 m3 de Solo e Rocha, ocorrido no Km 42 da Rod. Anchieta em dezembro de 1999.

Environmental consequences

Ecovias - Estabilização Definitiva e Avaliação do Dano Ambiental no Escorregamento de 500.000 m3 de Solo e Rocha, ocorrido no Km 42 da Rod. Anchieta em dezembro de 1999.

Social consequences

(W. Hachich, 2006)

The consequences of not taking action

Britador, Campos do Jordão, SP, Jan/2000; 500mm/1 week; 450 houses destroyed; after Hachich, 2006 (photo DIGEO/IPT)

Rua Jacinto Rabelo, Alto da Serra, Petrópolis – RJ, Dec/2001; photo PMP

Perpétuo, Teresópolis – RJ, 21/12/2002; photo: Secretaria Municipal de Defesa Civil

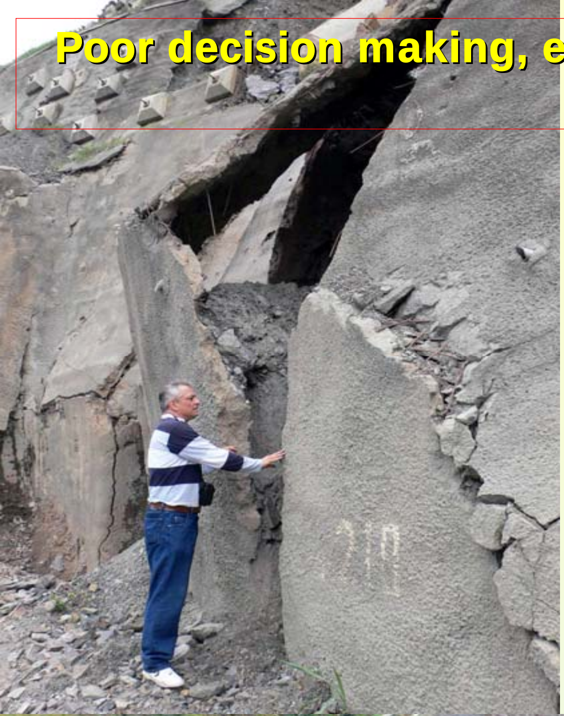
Morro do Tiro, Teresópolis - RJ, 21/12/2002.; photo: Secretaria Municipal de Defesa Civil

The consequences of taking the wrong decisions

Cotapata-Santa Bárbara road, Bolivia, 2006

Cotapata-Santa Bárbara road, Bolivia, 2007

Poor decision making, exacerbated by a poor approach to risk management, leads to poor engineering



Cotapata-Santa Bárbara road, Bolivia, 2007

UNFORESEEN…?

February 1951	
Prec. (mm)	Pr. Acum. (mm)
3.6	3.6
1.0	4.6
0.0	4.6
0.0	4.6
1.0	5.6
0.0	5.6
0.0	5.6
0.0	5.6
1.0	6.6
10.9	17.5
0.0	17.5
0.9	18.4
0.0	18.4
0.0	18.4
71.8	90.2
153.4	243.6
17.1	260.7
2.2	262.9
18.3	281.2
1.0	282.2

Date	December 1999	
Day	Prec. (mm)	Pr. Acum. (mm)
1	6.0	6.0
2	**77.3**	83.3
3	**121.2**	204.5
4	**11.8**	**216.3**
5	0.0	216.3
6	1.1	217.4
7	5.0	222.4
8	8.1	230.5
9	10.4	240.9
10	0.0	240.9
11	23.2	264.1
12	21.8	285.9
13	7.1	**293.0**
14	**120.0**	413.0
15	**380.7**	793.7
16	**410.4**	**1,204.1**
17	2.9	1,207.0
18	0.0	1,207.0
19		
20		

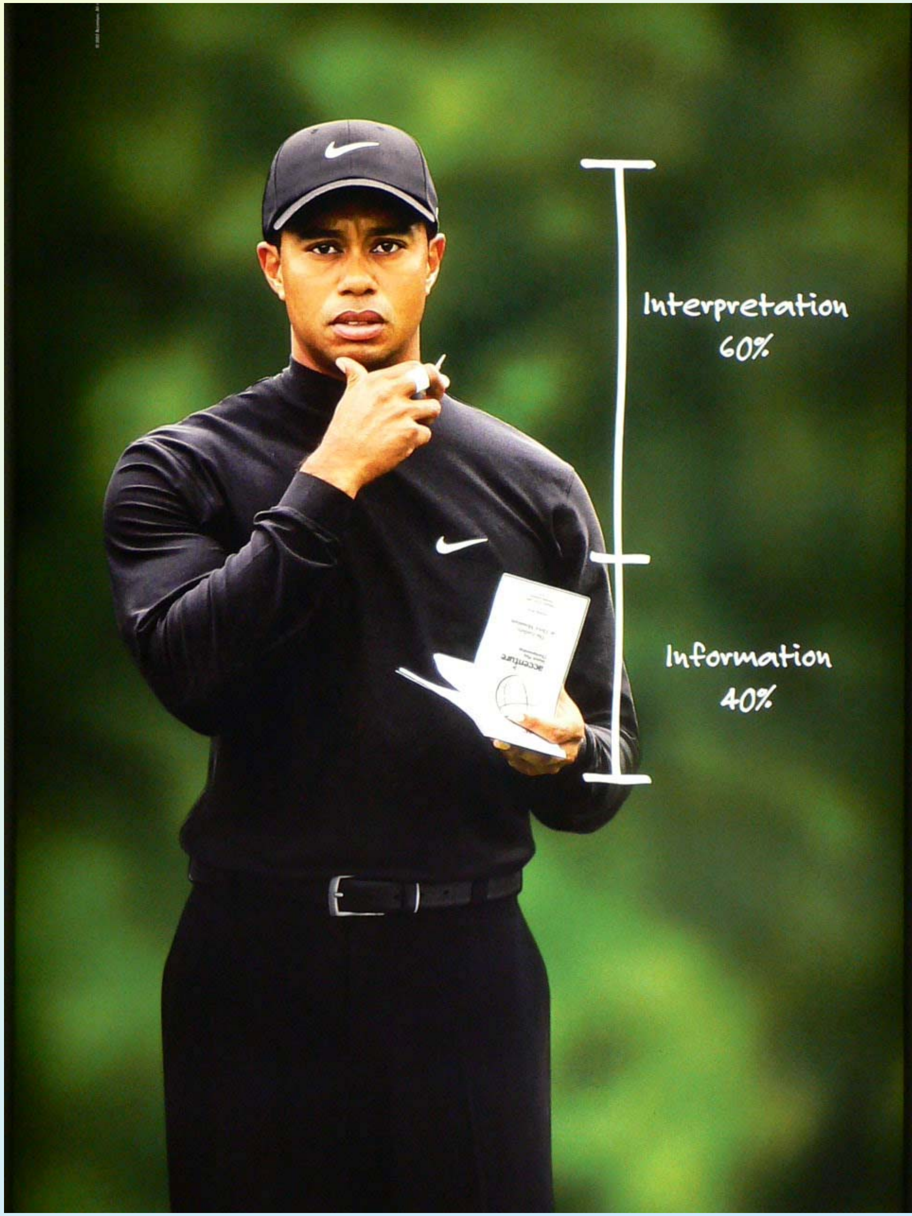
El Guapo dam, Venezuela; Dec-1999

An example of a decision based on a benefit/cost analysis… but of what kind…?

La Florida, La Paz, Bolivia, 2004

Antidote 1: Observational method (Terzaghi)

- A project starts with a hypothesis, based upon available information
- Laboratory, field data, calculations and analysis are performed, more or less influencing the orientation of the project
- Further data, calculations and interpretations furnish more options, which could generate confirmations or diversions from the original hypothesis



- Uncertainty must always be identified in any project
  - During the data and information acquisition and processing
  - During the execution of the project (i.e. “re-design as you build”)
- Always make a contingency-tolerant project

Antidote 2: Risk management

- It is not necessary to eliminate all the uncertainties, but to reduce them to “acceptable” levels
- Define what it is to investigate “sufficiently”

- The level of investment in field reconnaissance, testing, laboratory analysis, calculations and interpretation are dependant on the “<u>accepted</u>” level
  - It is important to verify whether this level is also “<u>acceptable</u>”, according to the perception of risk
  - Afterwards, it is a matter of “risk management”

Risk management

- Formal Analysis +
- Accumulated experience +
- “Good” engineering judgment

- Prescriptions, recommendations, codes, standards.

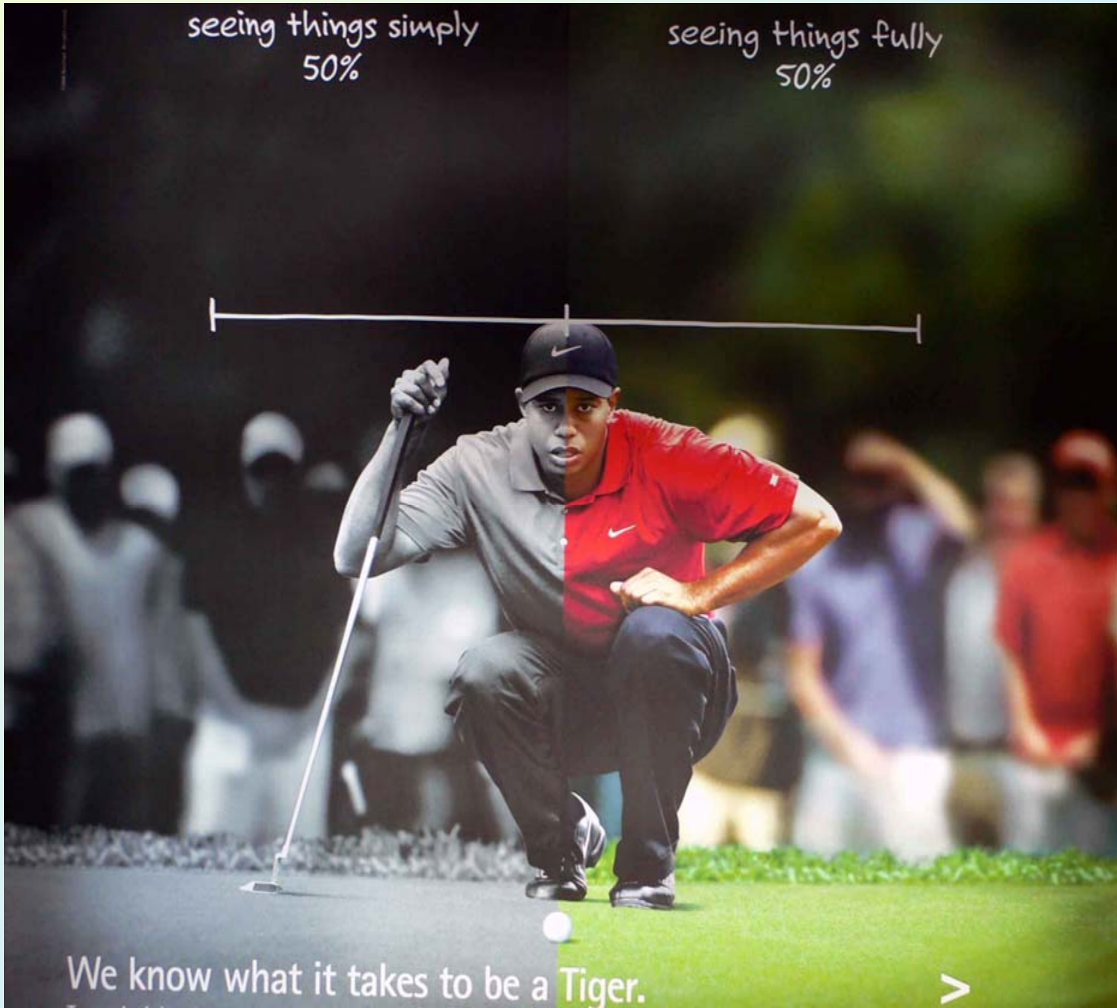
Risk: Formal analysis

- Uncertainty Consequences
  - Uncertainty:
    - In relation to the natural conditions
    - In relation to the methods of investigation, their suitability and interpretation
  - Consequences
    - Economic
    - Social
    - Environmental

Investigation methodologies

- "***Good ones***"
  - Designed to meet the objectives and achieve the desired outcomes
  - Well executed
  - Analysis appropriate to level of information
  - Help to reduce uncertainties
  - Can have significant costs

- "***Bad ones***"
  - Inadequate; not well scoped or prescribed
  - May be poorly executed
  - May result from over-empirism
  - Can also have significant costs



Why is it important to quantify risk?

- For taking balanced-better decisions, based upon adequate criteria
  - Case by case
- For avoiding taking unnecesary risks
- But... Watch what you are basing your calculations on...

Reliability of a system

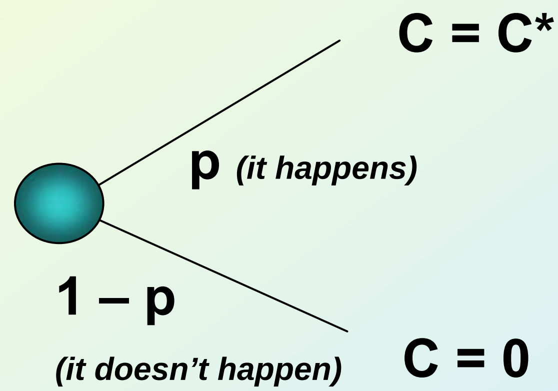
- Probability of failure in a system, based on the probability of failure of its components
- Analysis using:
  - Failure tree
  - Event tree
  - “Diffused logics”
  - Other “less formal-rigid” techniques (HAZOP, FMOP, "checklist", etc.)

Acceptability of mitigation measures

- How do we define acceptable measures?
- How much to invest?
- What is the level of risk “accepted” <u>by</u> and “acceptable” <u>to</u> your client ?
- Will they want more than what is stated in standards and codes?
- Then, proceed with the analysis of decisions with multiple objectives and attributes
  - Economic
  - Environmental
  - Social
  - Political

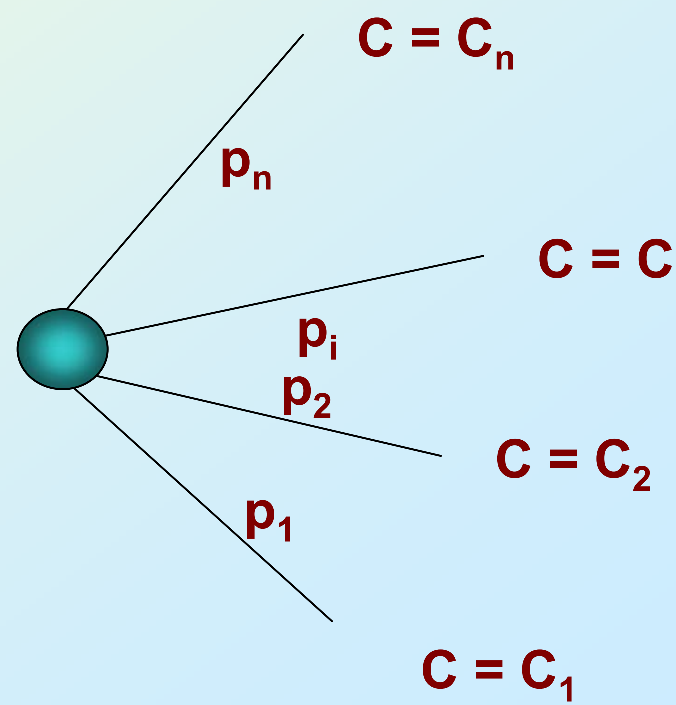
Risk = Uncertainty □ Consequences

$$\text{Risk} = E[C] = p \cdot C^*$$



Risk = Foreseen consequences

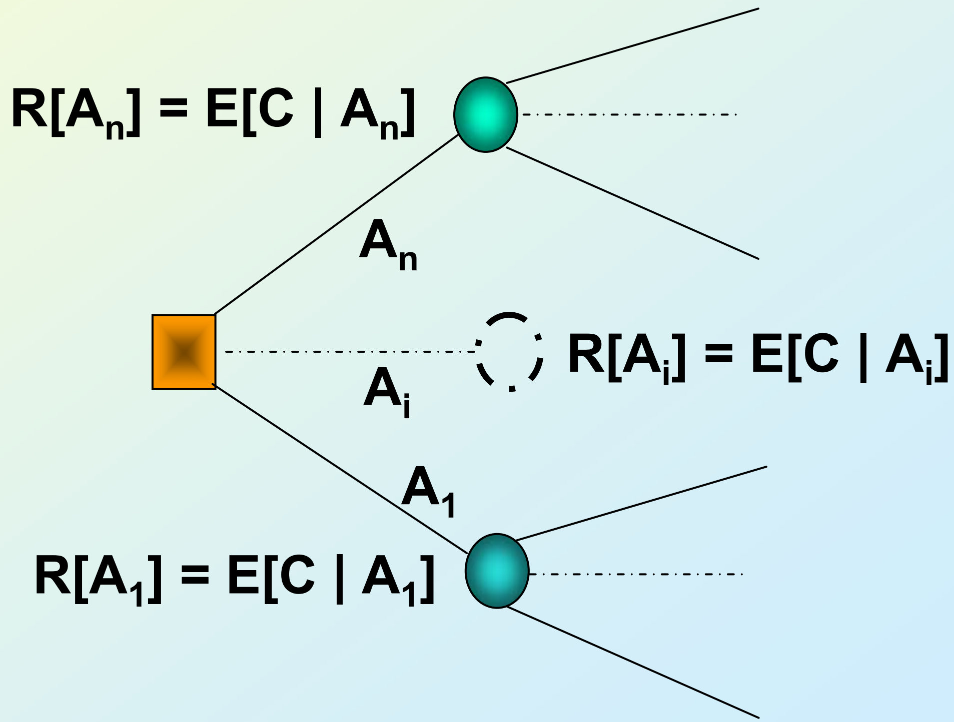
$$\text{Risk} = E[C] = \sum_{i=1}^{n} p_i \cdot C_i$$



Decision: Minimize risk

Decision criteria: Choice of the best possible action A_j that will make:

$$R[A_j] = \min \; E[C \mid A_i]$$



Pseudo-quantitative matrix

Probability →	Low	Moderate	High
Consequence ↓			
Low	1	2	3
Moderate	2	3	4
High	3	4	5

Quasi-quantitative matrix A (“R_A”)

Probability →	$< 10^{-4}$	10^{-4} a 10^{-2}	$> 10^{-2}$
Consequence ↓			
< 1	1	2	3
1 to 1000	2	3	4
> 1000	3	4	5

Quasi-quantitative matrix B (“R_B”)

Probability →	$< 10^{-4}$	10^{-4} to 10^{-2}	$> 10^{-2}$
Consequence ↓			
< 1	1	2	3
1 to 1000	2	4	6
> 1000	3	6	9

Comparing risks

Hypothetical situation	p	C	E[C]	“R_A”	“R_B”
1	0,005	500	2,5	2	3
2	0,001	1500	1,5	3	2
3	0,02	5	0,1	1	1

Slopes

Uniform risk criterion

$p_{NW} \cdot C_{NW} = p_{SW} \cdot C_{SW} = p_{NE} \cdot C_{NE}$

- Slopes: $F_{NW} = 1.45$ $F_{SW} = 1.35$ $F_{NE} = 1.49$

- Slope 1 NW:
  - p_{NW} = Probability of landslide at slope NW
  - C_{NW} = Consequence of landslide at slope NW
- Slope 2 SW:
  - p_{SW} ...
  - C_{SW} ...
- Slope 3 NE:
  - p_{NE} ...
  - C_{NE} ...

Estimating consequences

- Consequences depend on:
  - Volume of sliding mass
    - The volume defined by the most critical surface of failure
  - Land use in, around and at the foot of the landslide
    - Estimating quasi quantitatively the impact of each of the possible ruptures
  - Possibility of ex-ante intervention (i.e. having an early warning system; evacuation, protection, mitigation, etc.)
- Best estimate
  - $C_{NW} = 1$
  - $C_{SW} = 7$
  - $C_{NE} = 10$

Hypothetical situation	FS	C_i	E[C]	"R_A"	"R_C"
1	1.45	1	1.45	3	1
2	1.35	7	9,45	2	2
3	1.49	10	14.9	1	3

<u>WARNING</u>: Slopes with the largest critical surface of failure and/or largest volumes, do not necessarily yield the highest risk

Efficiency of mitigation measures

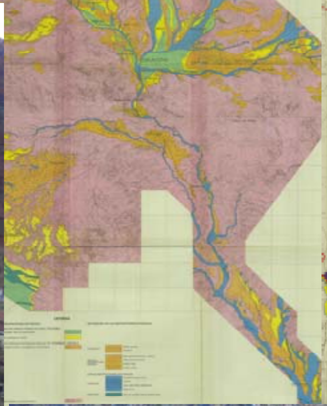
Option	1	2
Benefit	$C_0 - E[C \mid A_1]$	$C_0 - E[C \mid A_2]$
Cost	V_1	V_2
Cost/Benefit	$V_1 / (C_0 – E[C \mid A_1])$	$V_2 / (C_0 – E[C \mid A_2])$

<u>Risk scenarios</u>: methods for the representation of risk… are we finally learning to make them useful, accessible, credible and reliable…?

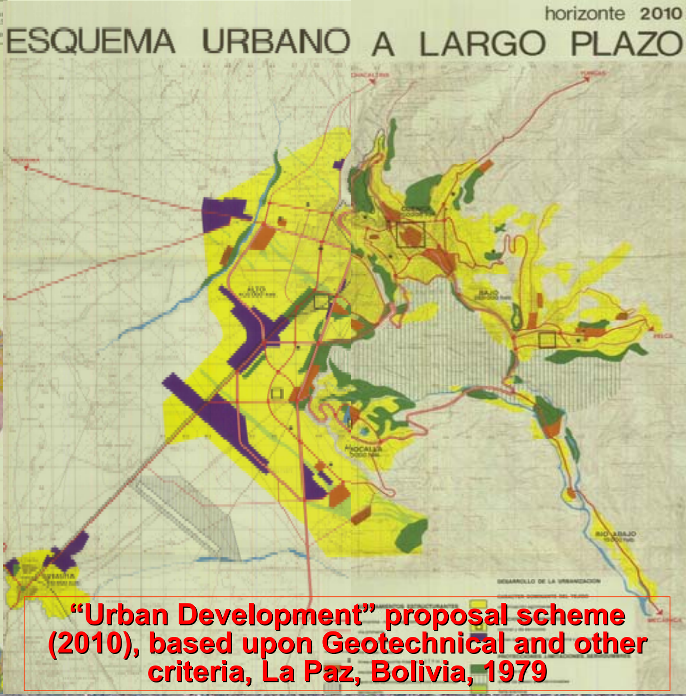
<u>RISK “MAPS”</u>

- **Cartographic expression of the probability of losses in a specific territory**
- **Graphically indicate factors in different scales to facilitate their comprehension**
- **Require or are based on different types of parameters expressing geomorphic, geotechnical and/or hydro-meteorological conditions of the territory.**

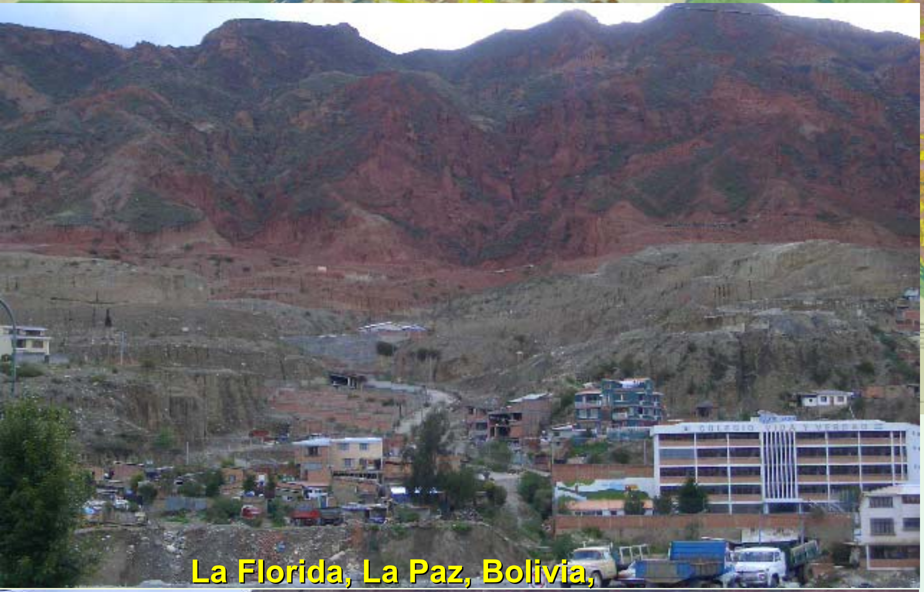
- **But…**
- **Commonly built as hazard maps**
- **Coverage, dimensions, time and static designs, are most of the time irrelevant for decision making processes**
- **Typically very attractive in their presentation but incomprehensible for most of the non-expert users**
- **Many times they just say what we want them to say.**

"Geotechnical" and "Contructability" maps, La Paz, Bolivia, 1979



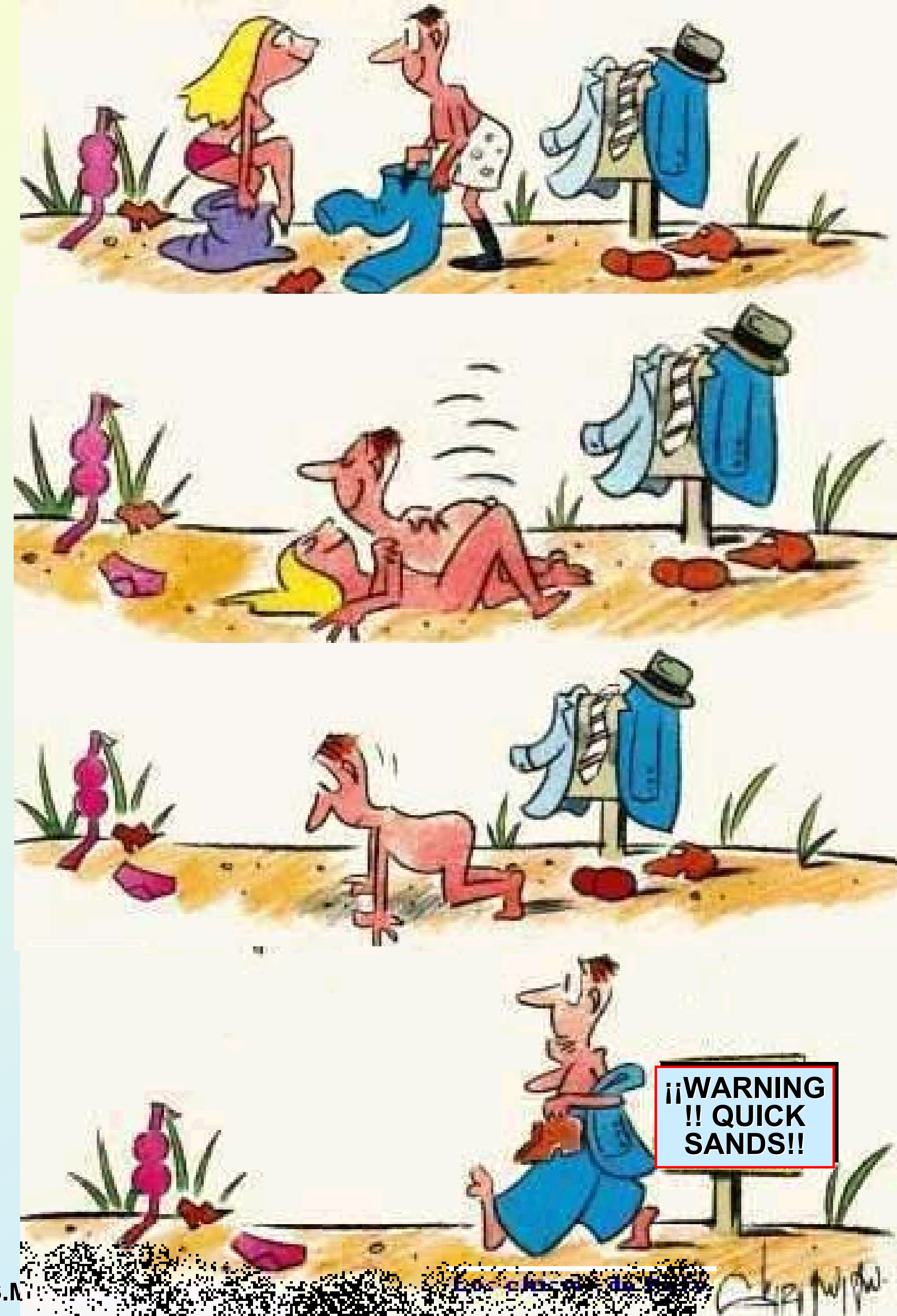
"Urban Development" proposal scheme (2010), based upon Geotechnical and other criteria, La Paz, Bolivia, 1979



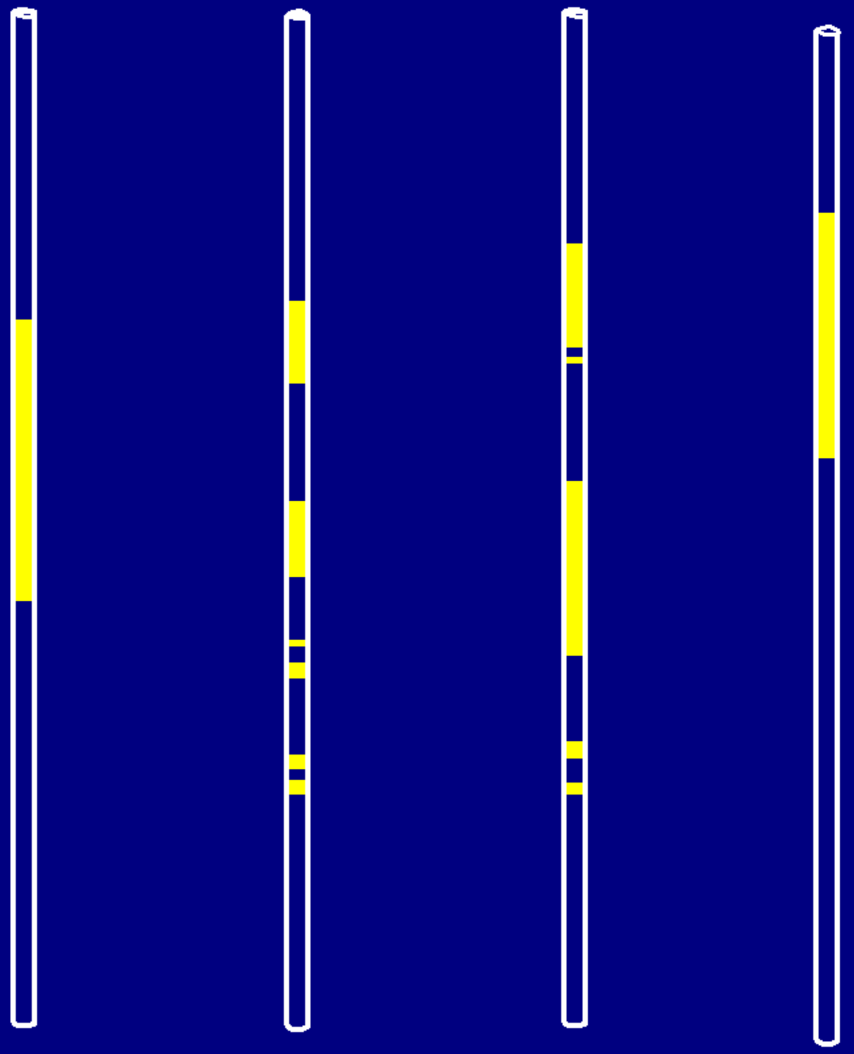

La Florida, La Paz, Bolivia, 2003-2006

La Paz-El Alto, Bolivia, 2006

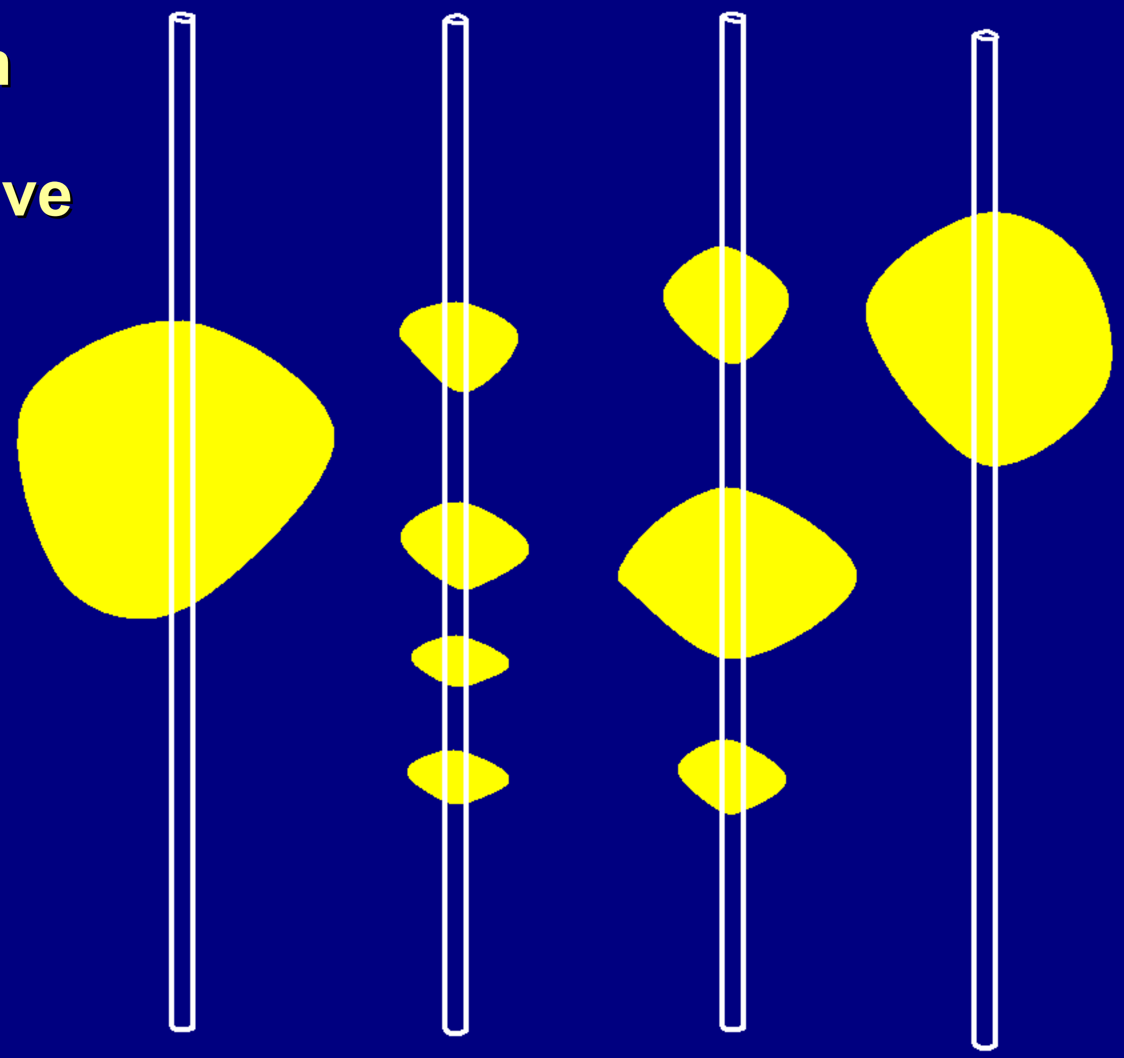

They say this is a landslide hazard area
So, they say?


¡¡WARNING !! QUICK SANDS!!

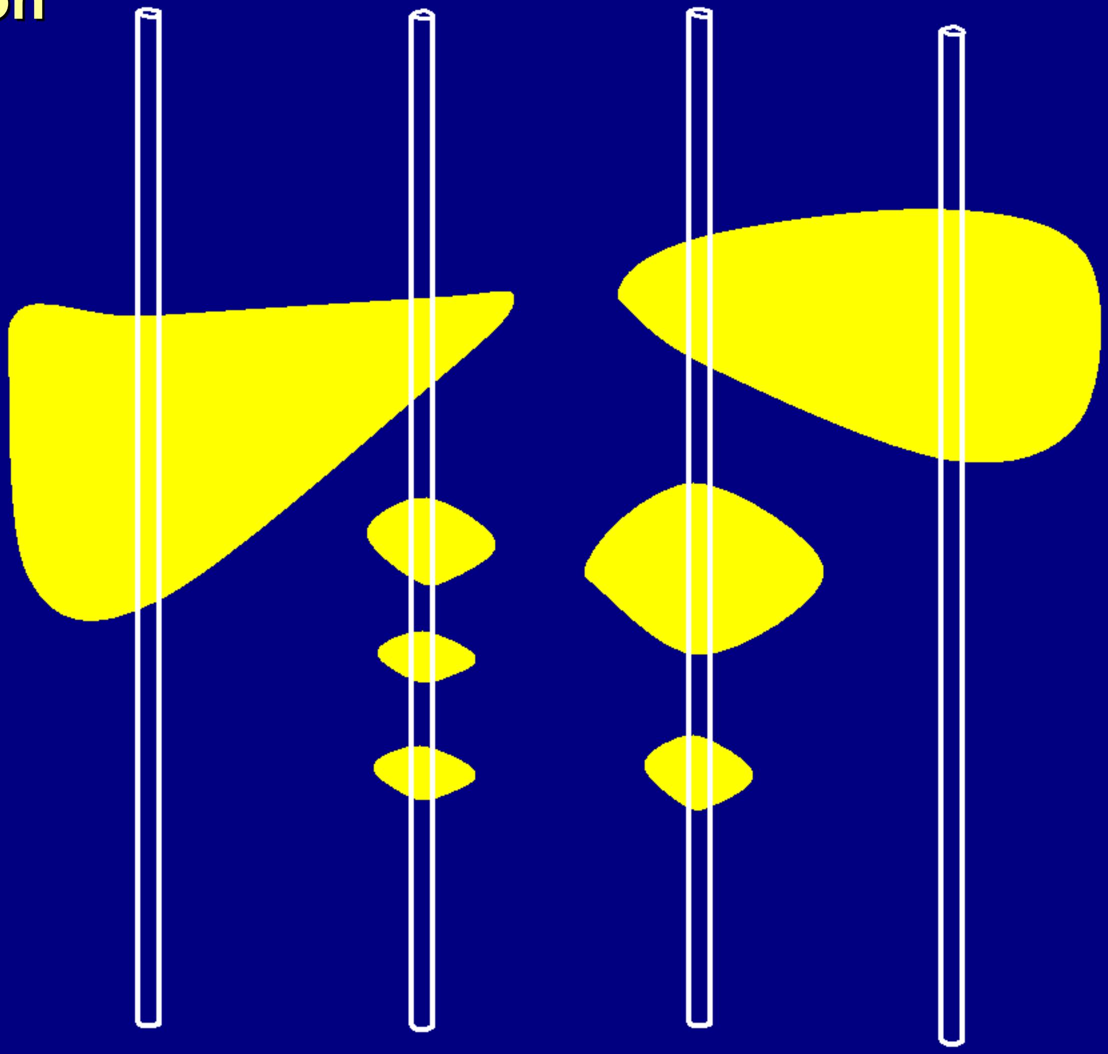
Let's consider a group of drill holes and some layers of sand



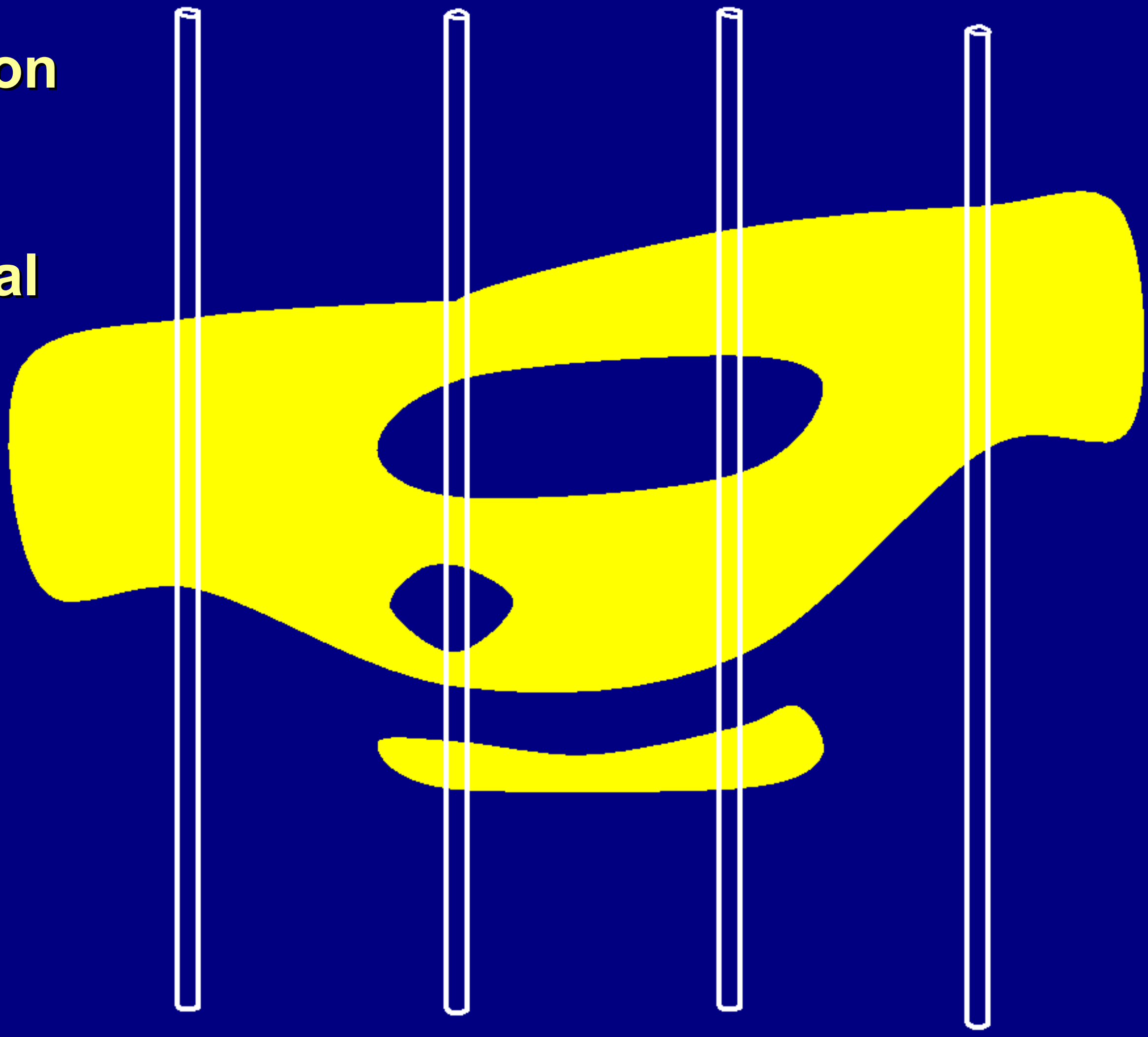
This might be the correlation made by a conservative geologist



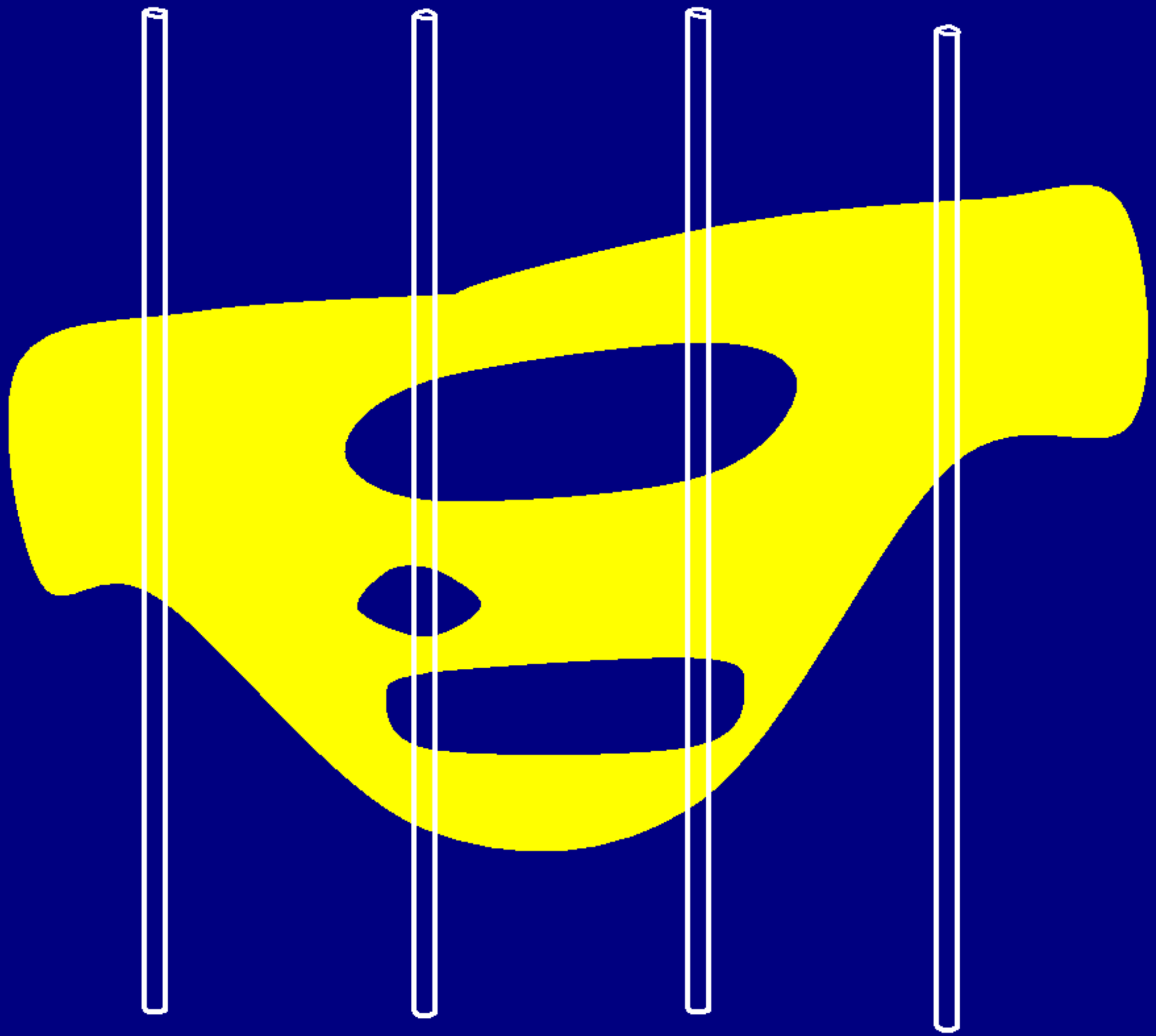
This might be the correlation made by a conservative engineering geologist



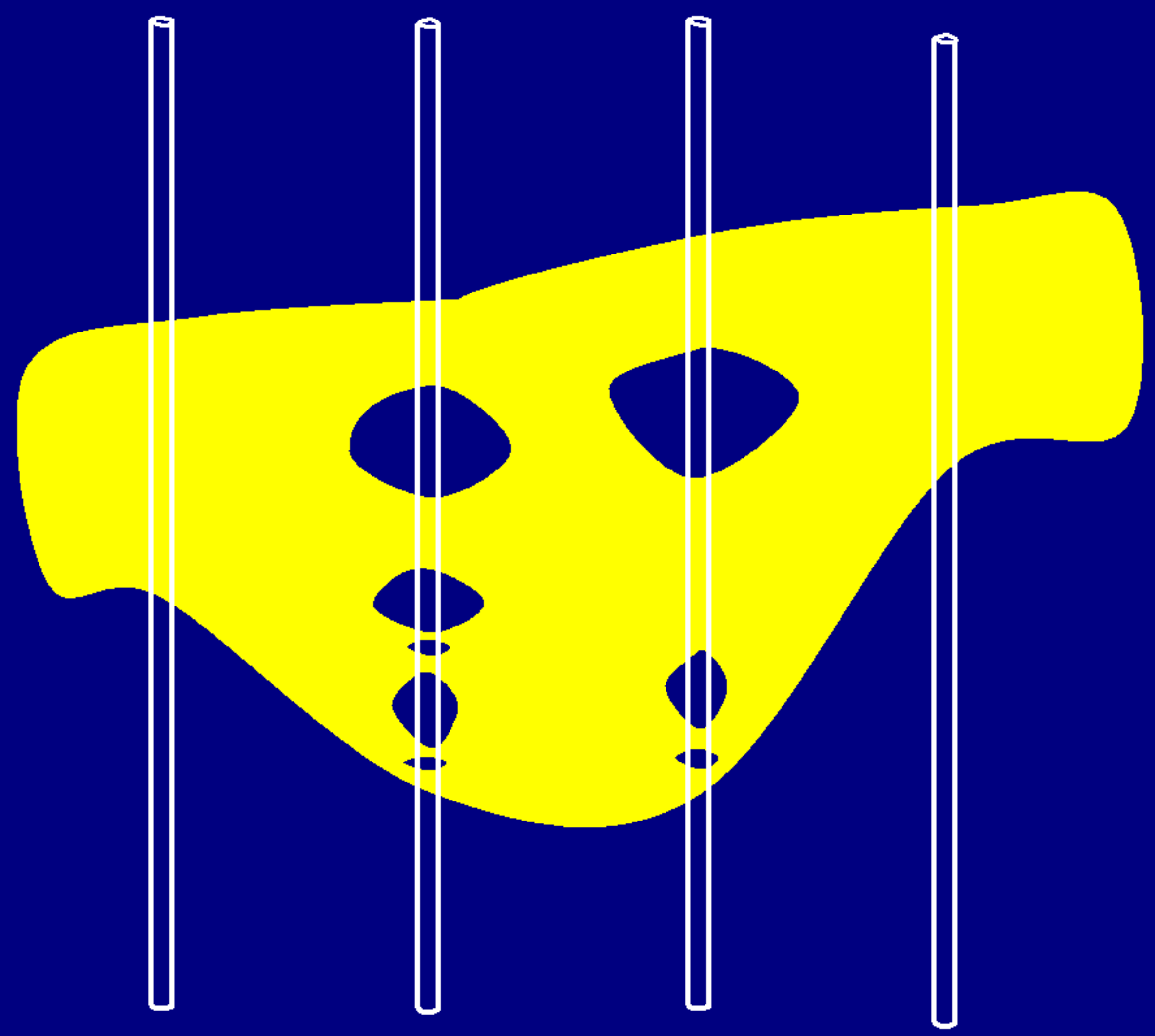
This might be the interpretation of an optimistic geotechnical engineer



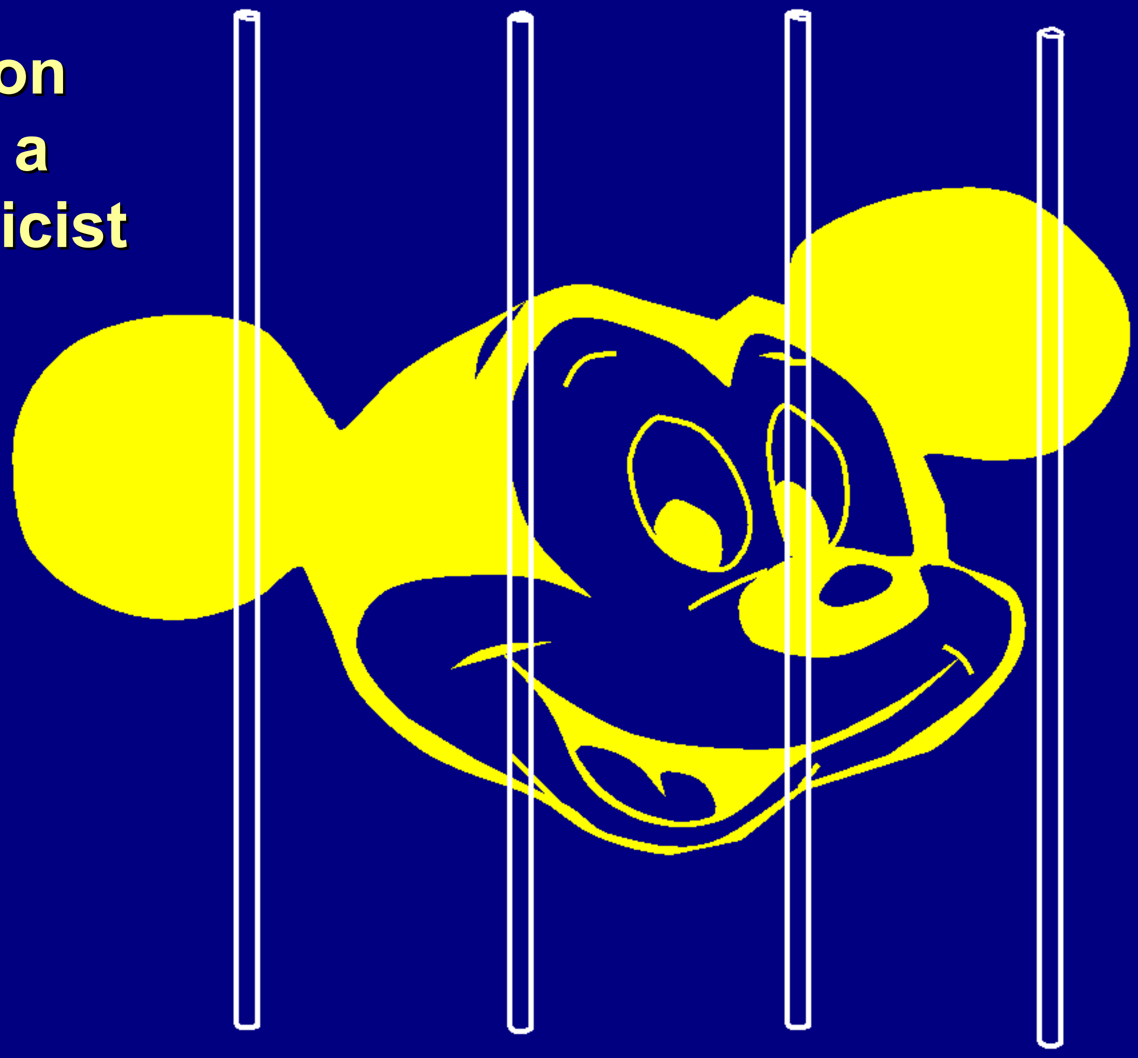
The opinion of a very optimistic mining geologist



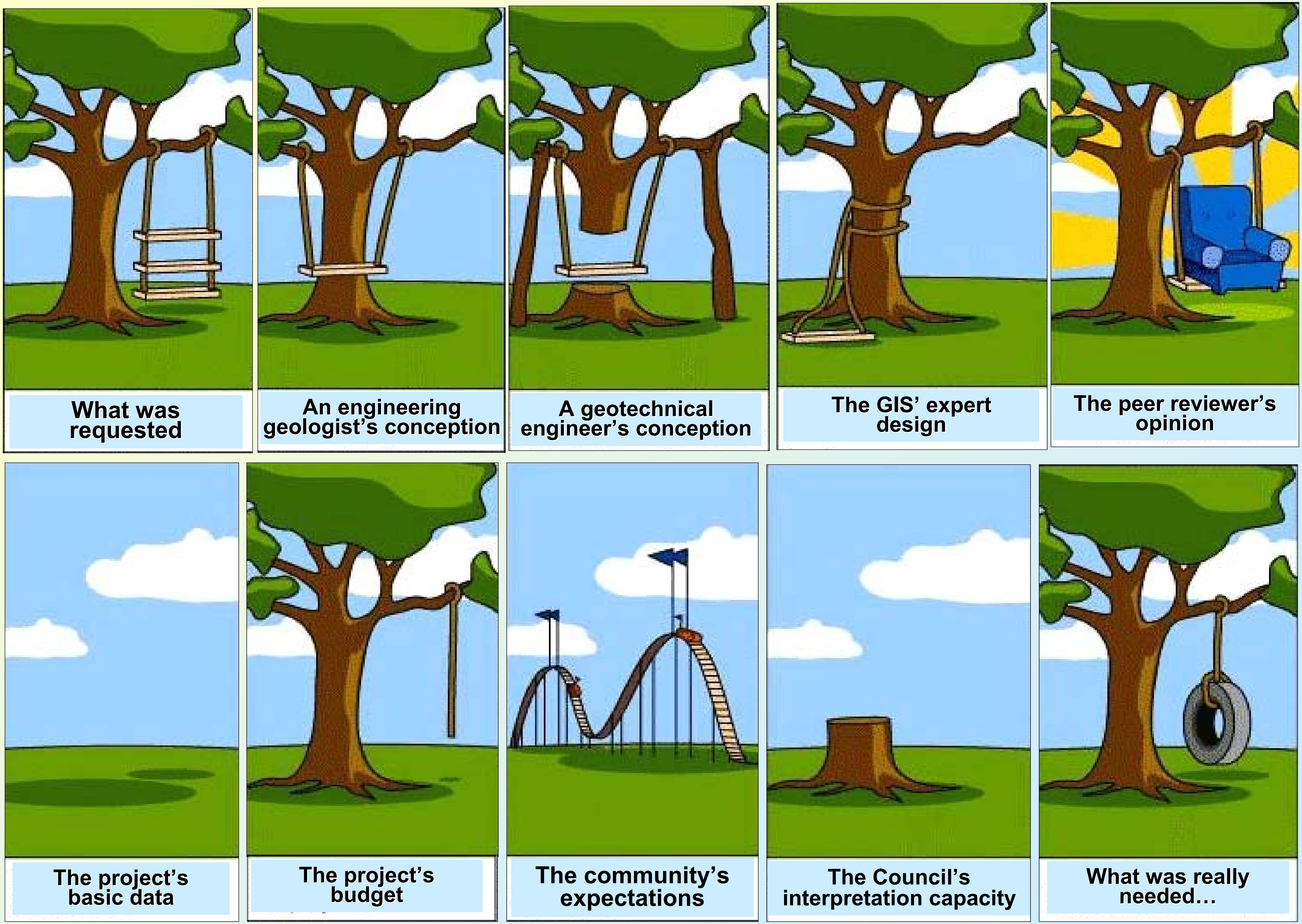
The opinion of a very optimistic hydro-geologist



… and this is the correlation made by a geophysicist



Different points of view about a risk assessment



¡¡¡ MUCHAS GRACIAS !!!

Puerto Varador; Trinidad, Bolivia, 2005

A delicious fried piranha !!!