Geologic Risk and Underground Construction

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The earth is finite, and
natural resources have a limit.

By 2050 at the current rate of growth and with everyone at the U.S. standard of living, we would need 8 earths worth of resources.

Finite Resources

Current rate of placement – 1 Ton of concrete per person per year world-wide

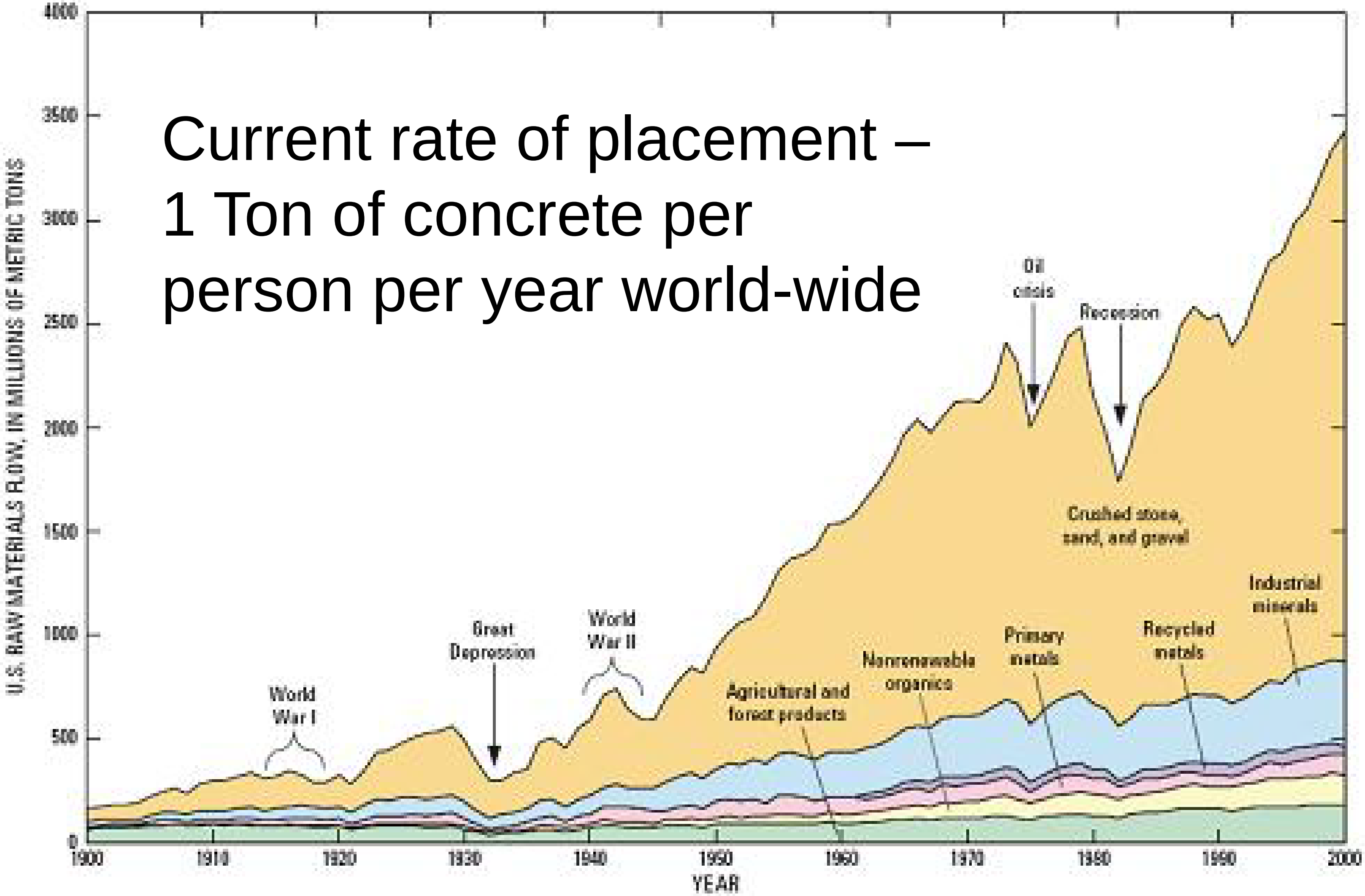
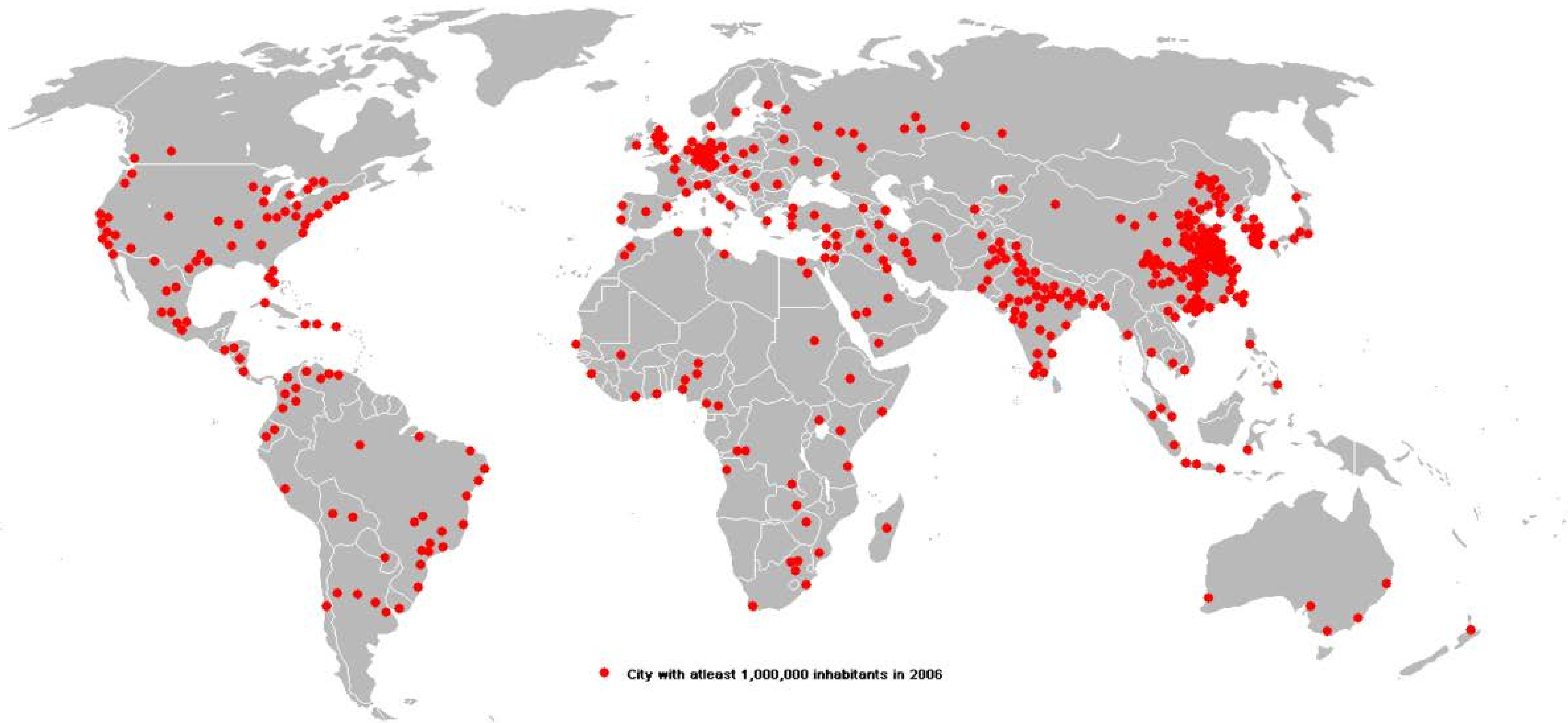


Figure 4. U.S. flow of raw materials by weight, 1900–98. The use of raw materials dramatically increased in the United States throughout the 20th century (modified from Matos and Wagner, 1998, fig. 3).

As of 2017, there were 47 megacities (>10 million) in existence. China alone has 15 megacities. The United States has two megacities - New York City and Los Angeles.



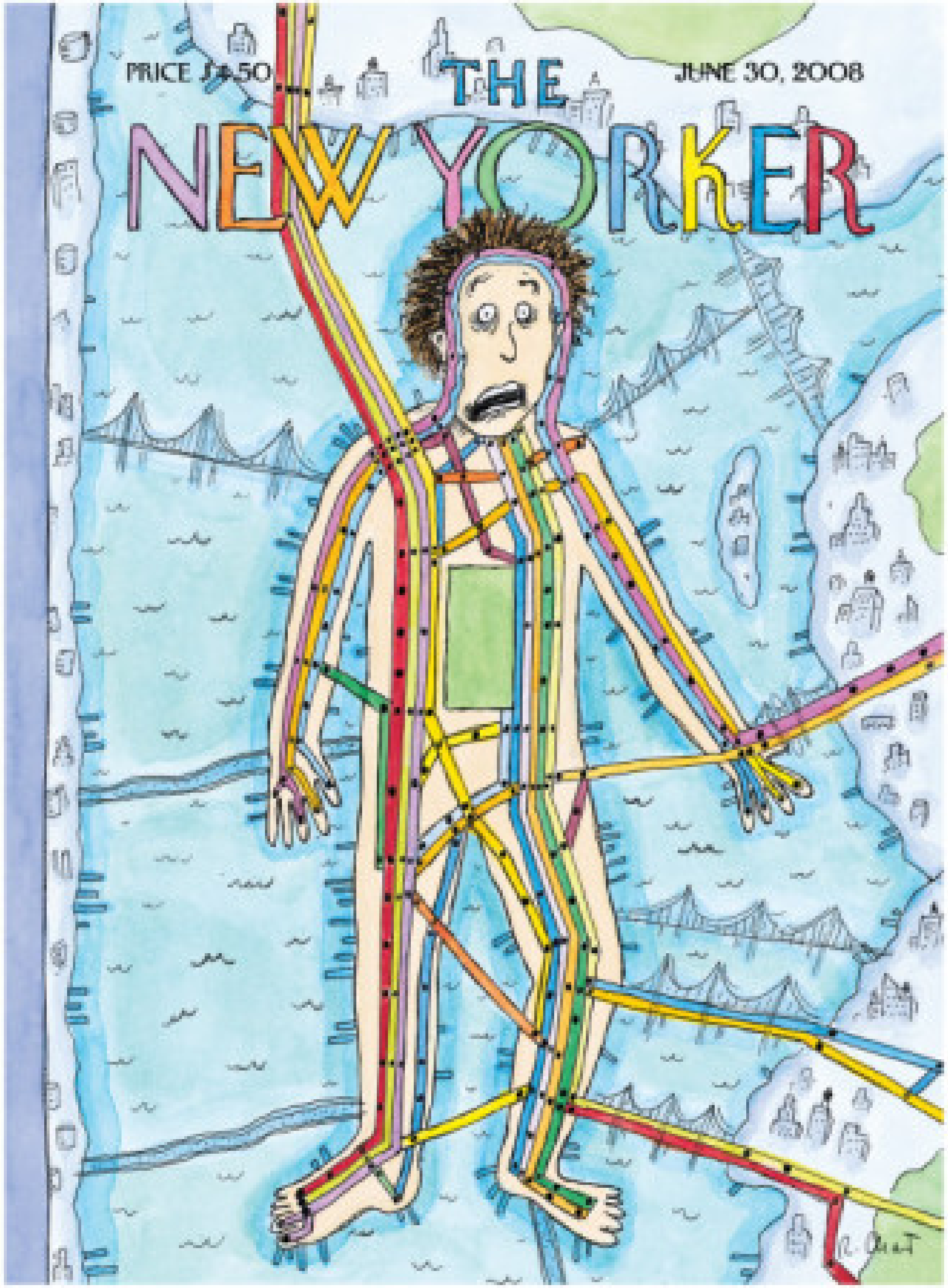
Shangaï 1990-2010

How will our cities grow?

Global expectation is for Compact Cities – growing up and down.

The Importance of Infrastructure

- Megacity and demographic growth demand investment in critical mega-infrastructure systems, many of which are underground.
  - Rehabilitation/repurposing of existing systems
  - Extensions of existing systems
  - New systems in developing countries that have diverse multicultural/societal issues
  - Systems that serve an aging population
- Location and access to infrastructure become issues of equity that are culture-dependent.
- Resource crises will become more acute, with foci on water and energy both of which involve the underground.



Our future urban lives will increasingly rely on the underground. We need geologic perspectives to best provide for the cities of the future.

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UG Cost Increases over past Decades

Cost increases are often driven by increased risks:

Risk = Probability x Consequences (or Impact)

- And we need to gather information that will make sustainable design and life-cycle engineering. What is the value of underground space?
- We need strong and wise owners who are long-term and integrating stewards on behalf of the public.
- We need to develop innovations that will reduce costs. What problems drive risk and cost increases, and where is the will to pay?

Communicate the value of infrastructure

We need to identify and communicate the value of infrastructure and the subsurface.

- The U.S. infrastructure may be valued at between $50 and $80 Trillion, perhaps more.
- This is equivalent to $250k to $300k for each US citizen as his/her birthright.
- The nation's infrastructure is a pre-investment upon which the economic engine runs, the quality of life is assured, and career potential of each individual is leveraged.

How can Costs and Risks be Reduced?

- Risk avoidance
- New technologies and methods
- Better subsurface characterization
- Better management of water
- Decisions and designs based on sustainability
- Risk awareness, assessment and management
- Engineering forensics
- Risk communication and willingness to accept and share risk

Risk Avoidance: New York City

Spatial Chaos in the USA

Consider underground zoning

We need spatial thinking, integrated planning for above and below ground

1916/1917 Beekman Street Subway, NYC

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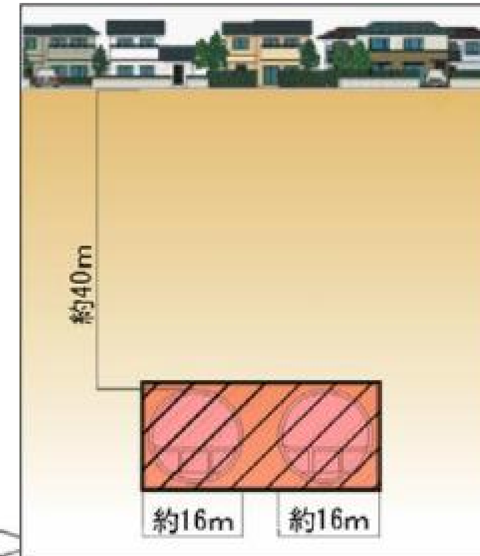
Integrated Urban Planning – Above and Below Ground

Japan experience

- 2001 Deep Underground Utilization Law: land ownership rights in populated areas (e.g., Tokyo, Osaka) only extend to 40 meters below ground, or 10 m below a deep foundation.
- In the case of public use, no compensation to the land owner is required.
- 1st projects using the law: Underground water mains in Kobe, and the Tokyo Gaikan Expressway.



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New Technologies and Methods

- Industry/owners partner with universities to develop new technologies and methods including new ways to cut rock (e.g., laser, microwave)
- Incentivize application of new technologies
- Proactively implement ground improvement
- Design for sustainability and maintainability
- Safety innovations
- Integrated geophysics and remote sensing for spatial and temporal variations
- Rethink materials/methods (e.g., concrete, blasting)

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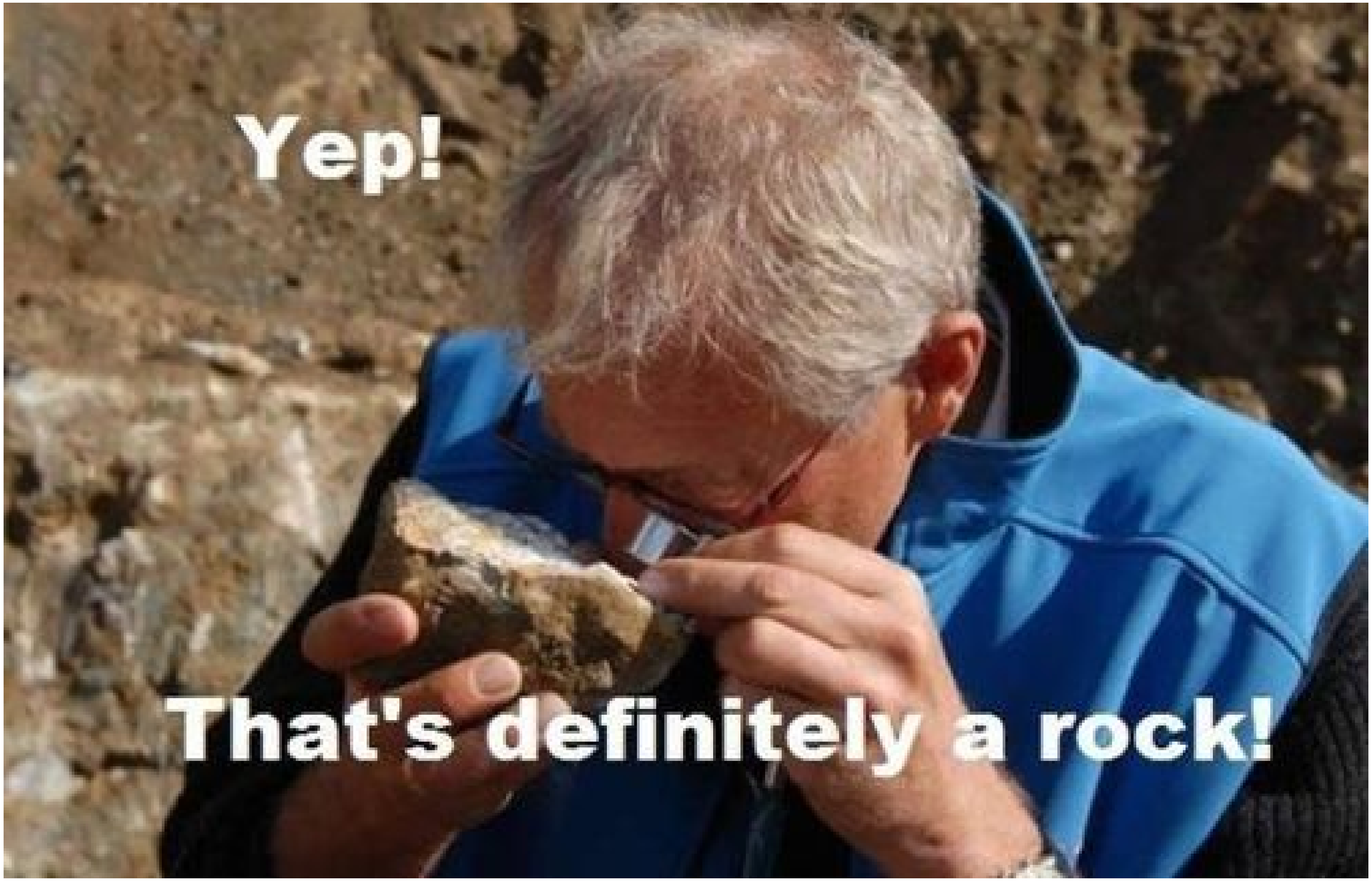
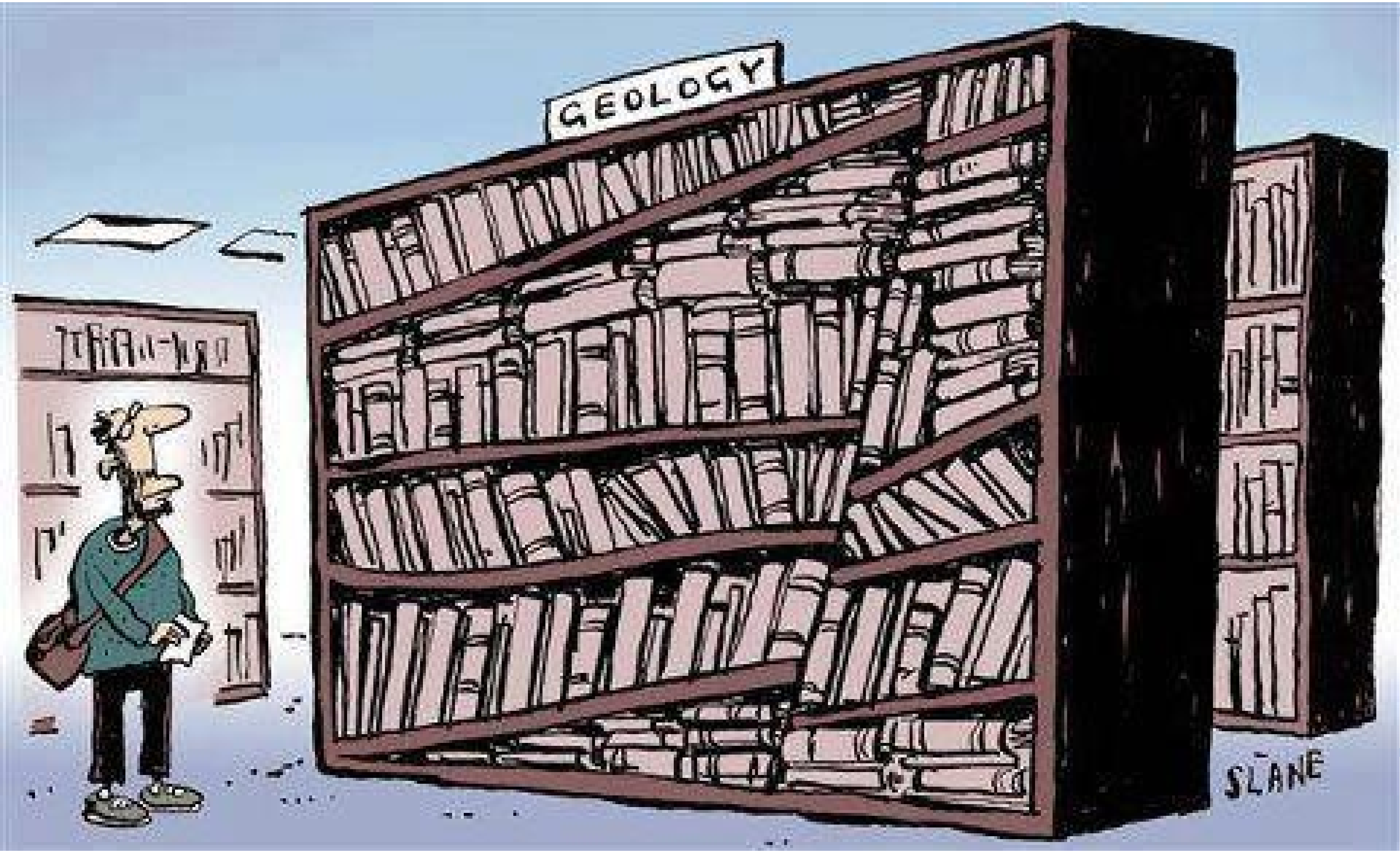
Better Subsurface Characterization



Better Subsurface Characterization



Better Subsurface Characterization

- Continuing Geologic Issues
  - Shallow cover, varying depth to rock
  - Settlement, subsidence
  - Weathered rock and rock mass (incl. karst)
  - Structure, incl. shears/faults
  - Time dependency and progressive deterioration in geologic materials
  - Abrasiveness and stickiness
  - Aggregate reactions and concrete durability
  - Stresses and redistribution

Rock Mass Issues

- Scale effects
- Rock mass ratings
  - Uninformed and inconsistent use
  - Limited validation of empirical correlations
- Excavation shapes and dimensions
- Validation of computational models
- In situ stress state – geologic framework vs point measurements
- Spatial variability of rock mass structure

Subsurface Characterization: Non-contact Methods

- Many geophysical techniques are misused and underused.
- Need integrated application of a variety of geophysics and remote sensing (including LiDAR) methods to permit detection and time-dependent assessment of underground materials.
- Need to understand spatial and temporal variations that affect performance of existing facilities for sustainable design and operations.

Our conventional site investigations should be **confirmatory** rather than exploratory.

The Civil Industry should be partnering with Mining and Geology

- Geologic perspective on risk.
- Potential for real spatial understanding of rock mass and water inflow and pressures variability.
- Better understanding of time effects – possibility of developing sustainability performance information.
- Low FS, high slopes, tall caves, deep shafts - possibility to observe and learn from failures.
- Environmental issues in common, including issues of mine closure.

Underground Construction and Tunnel Engineering: Industry Focused Research

…from very applied to blue sky

Cross passage support

Ground vision

uct.mines.edu

ground
under

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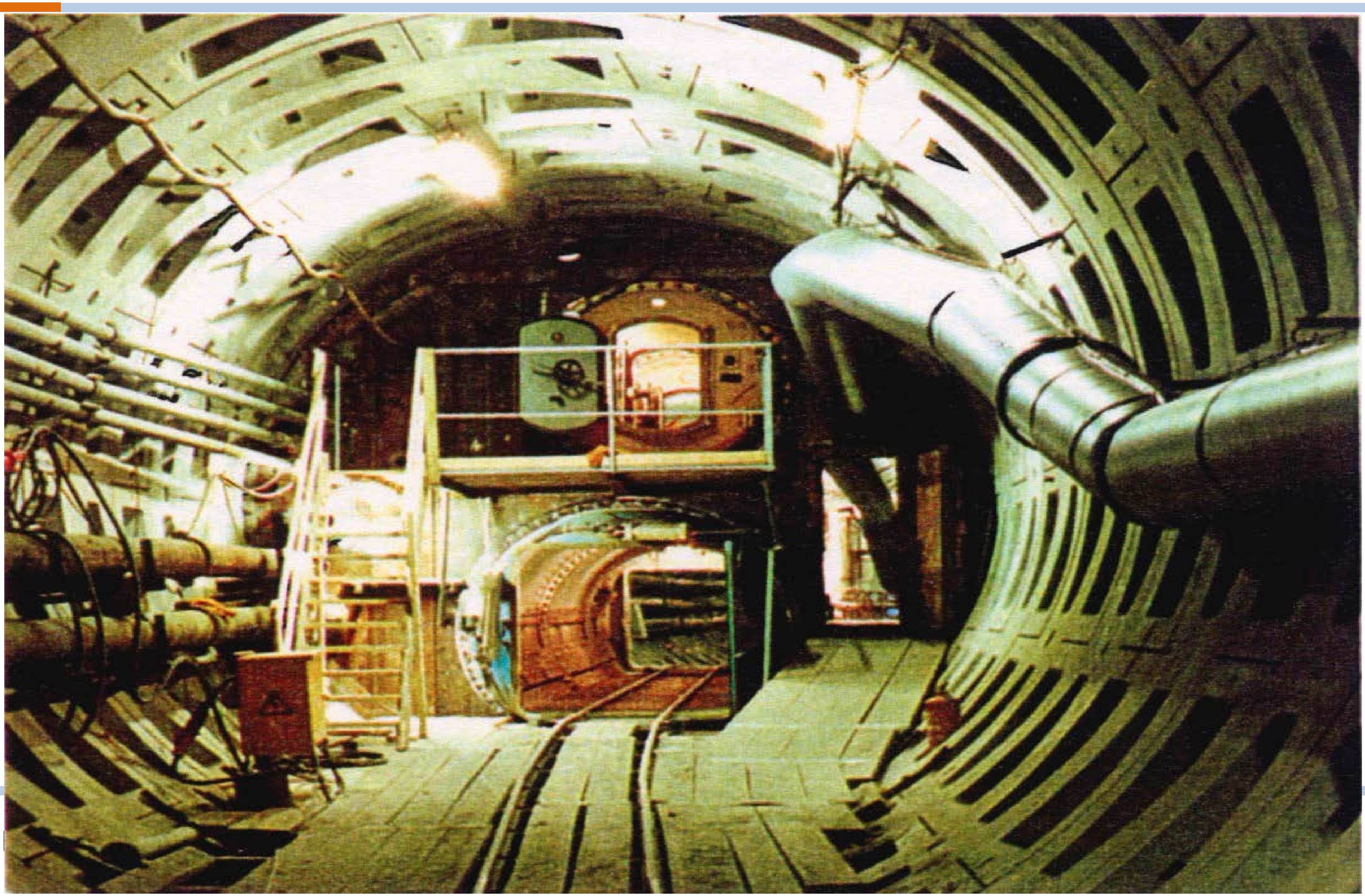
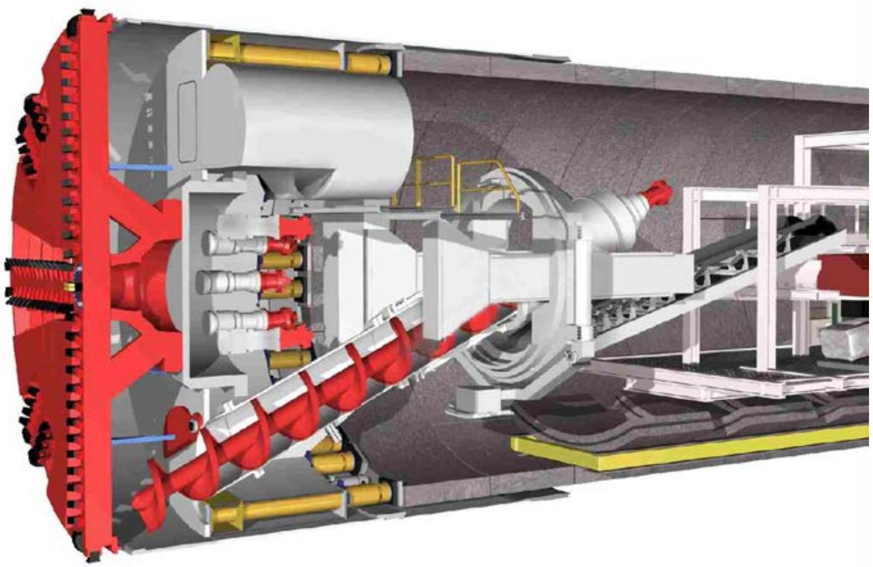
Compressed Air
Worker and Materials Air Lock

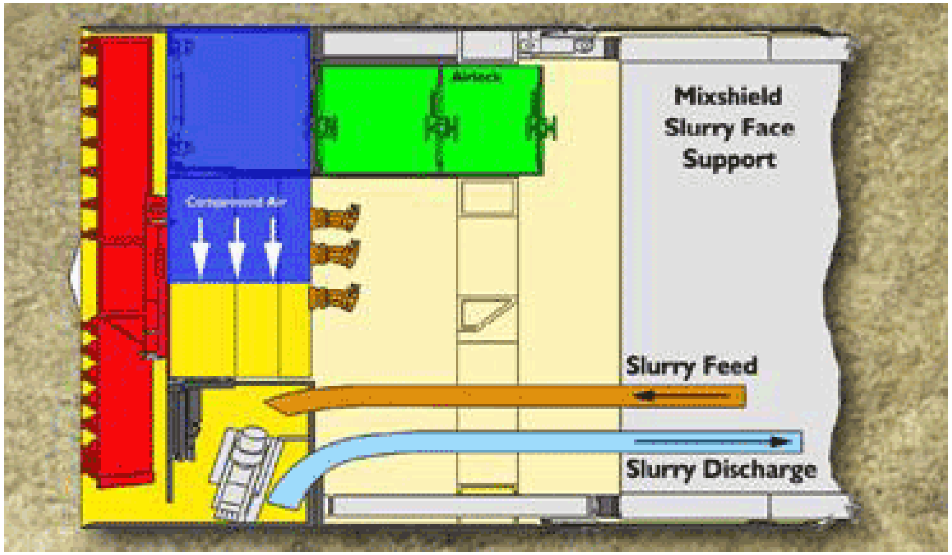


Soft Ground Tunneling



Earth Pressure Balance Mining (EPBMs) Machines

Slurry Mining Machines



Better Management of Water

- Resource conservation
- Environmental impacts (bio-geo-chemical)
- Construction impacts (safety, equipment)
- Performance of installed support
  - Waterproofing
  - Drained vs undrained
- Operational impacts – water drives long term deterioration in the underground
- Piping - ground loss

Need to consider volume, flow rate, quality, pressure, and changes over time.

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Decisions and Design Based on Sustainability

- Long-term vs first cost and design for reuse:
  - Accepted methods to evaluate sustainability
  - Valuation methods for existing infrastructure
  - Valuation for underground space (beyond resource extraction)
  - Data base development
    - System management and performance
    - Construction and rehabilitation costs and time
  - Environmental impact management
  - Bio-driven deterioration of concrete

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Risk Awareness, Assessment and Management

- Geologic framework
  - Geo-Infrastructure Information Management including cost, time and materials data
  - Analysis of performance and synthesis of lessons learned from past projects based on geology
  - Geologic analysis of soil and rock structural, spatial and temporal variability
- Risk based evaluation of impacts
  - Engineering forensics
  - "Geoproblem event" frequency to characterize risks
  - Risk registries and mitigation planning – need a consensus method of risk analysis

Risk-based evaluation of impacts

- Risk registries and mitigation planning – need a consensus method of risk analysis
- Geologic analysis of “geoproblem event” frequency for stochastic assessment of risks

Geoproblem Events

Collect data to inform statistical probability and consequences of encountering Major Geotechnically-Driven Stoppages in underground excavations

- Spatial frequency, km/event
  - Typical event sources: excavation and equipment, ground control, water.
- Temporal frequency, hrs/event
- Duration distribution
- Quality/performance of contractor

Not everything about a specific project is "one-off".

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Engineering Forensics

Learning from past experience (3 collaborating sectors: academe, industry, owners) – in spite of liability issues

- Analysis
  - Test assumptions made for design
  - Evaluate decisions made for construction
  - Influence of operation and management approaches on life cycle performance
- Retrospective assessment of sustainability and life cycle engineering effectiveness

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Risk communication and willingness to accept risk

- Return to era of the strong owner – building and integrating owner staff engineering knowledge and judgment
- Encourage long-term view of responsibilities
- Connect with the public and children – social license

And as we move forward…

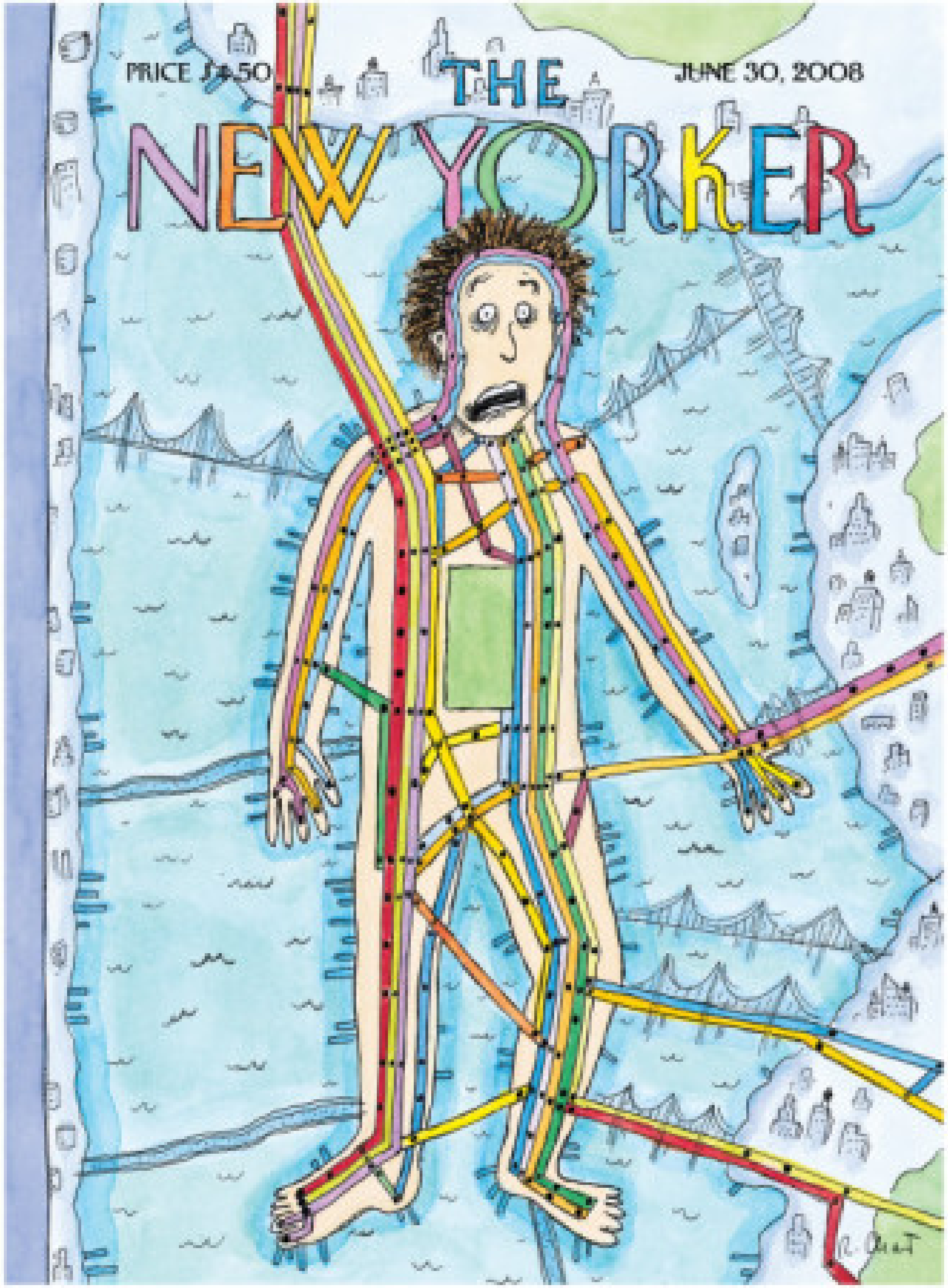
- Urban underground space in the future will be much more than tunnels and stations.
- Prepare for the creative use of urban underground space that our society will demand
  - Shapes/depths
  - Partnering with planners and architects
  - Human occupancy (social acceptance, spatial referencing, emergency response, aging population).
- Develop and adopt new technologies that will decrease costs and increase flexibility and quality of our urban spatial resources.

Summary of Issues for Risk Reduction

- Rethink materials and methods.
- Advance methods for subsurface characterization.
- Extend applications for pre-construction ground improvement methods.
- Improve framework for understanding risk and spatial variability of geologic conditions.
- Improve understanding of assessment and redistribution of in situ stress.
- Focus on validation of computational models.
- Improve understanding of 3-D fracture across scales.

Summary of Issues for Risk Reduction

- Advance excavation methods including drill/blast, lasers and other innovative technologies methods.
- Acquire data to support rational and long-term sustainable design and LCE, including time-dependency.
- Establish a market value of underground space.
- Advance knowledge about how the underground can minimize risks from extreme events.
- Develop new understanding of urban underground design for the public.



Urban Resilience

Underground Infrastructure can be the medicine for our cities in the future.