Methods and models in land evaluation

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Topics

1. Land evaluation concepts (with in-class exercises)

2. Models in land evaluation

3. Current land evaluation research

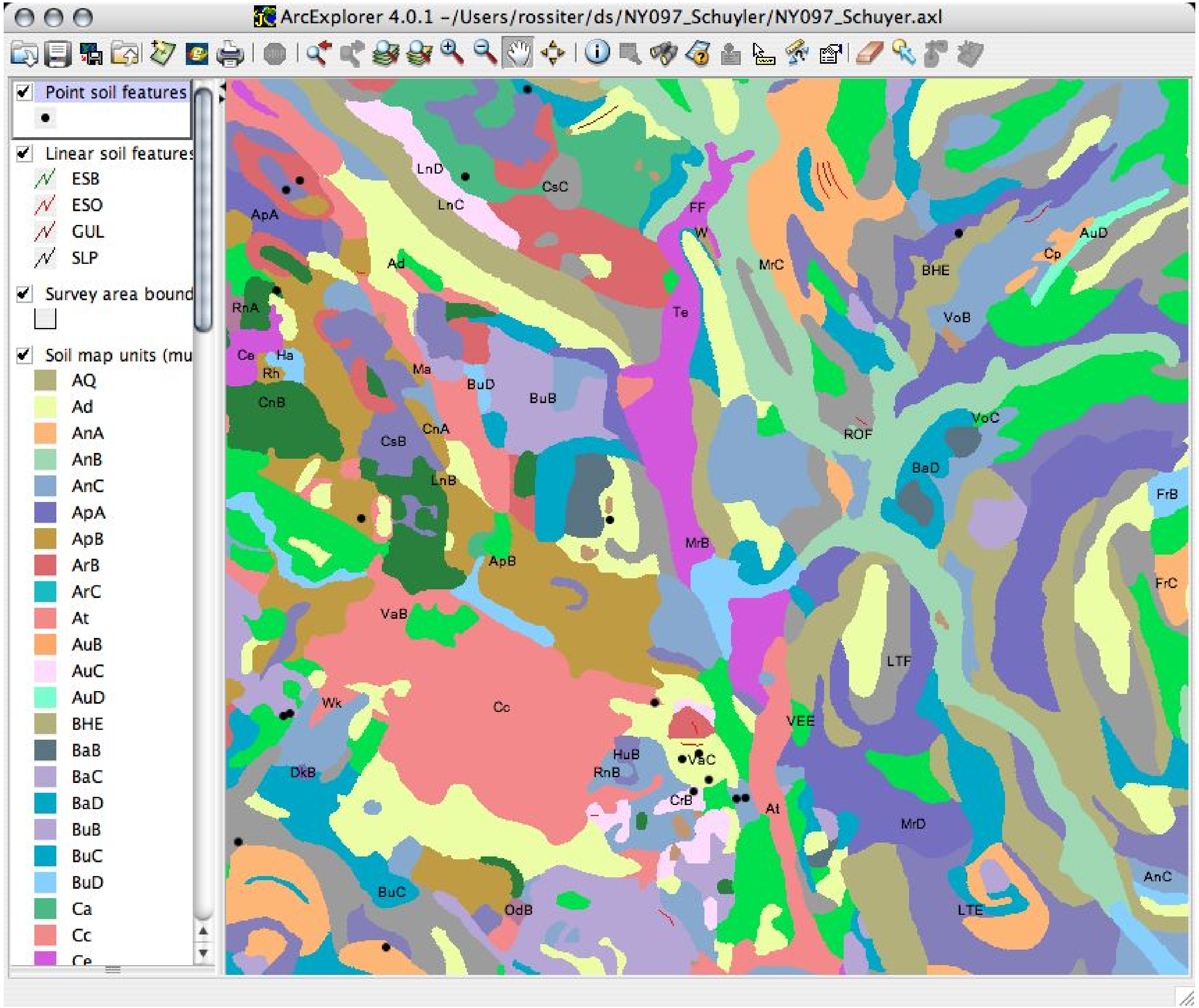
4. Difficulties, towards solutions (new directions)

Part 1 – Concepts

Paradigm:

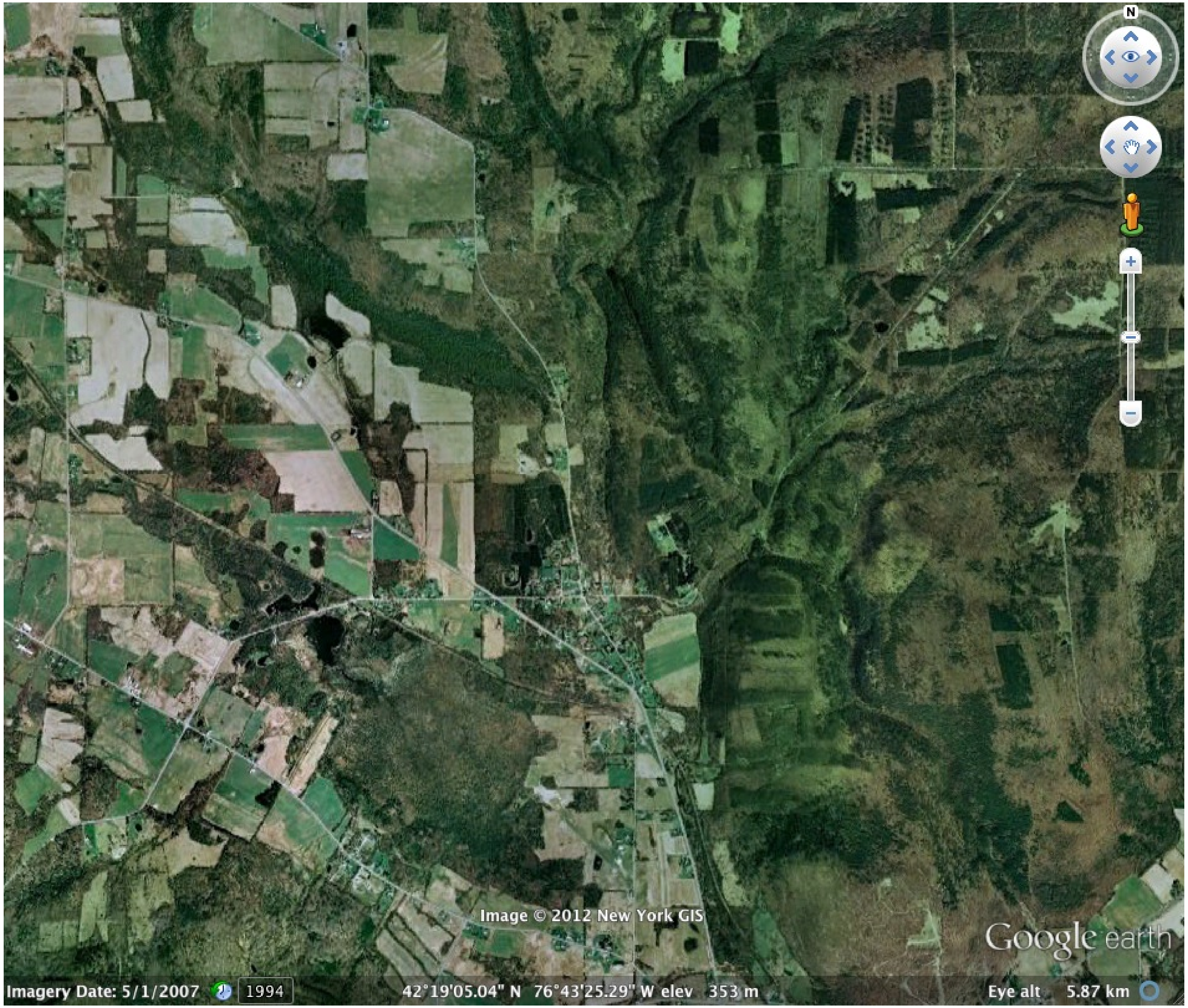
- Land **provides** a resource
- Land use is **affected by** the resource
  - areas **differ** in their characteristics, potentials and performance
  - opportunities, constraints
- Land use **affects** the resource
  - sustainability, degradation, improvement . . .
- Idea: **match** land use and land resource

Different soils . . .



source: STATSGO

. . . different land uses



source: Google Earth

Why formalize?

- Since before history humans have known about differential land suitability!

- Under **unchanging** or **slowly-changing** conditions humans can easily adapt by **trial-and-error**

- Even major changes can happen by adaptation / experimentation

  - e.g., introduction of New World crops to Europe (but this took about 200 yr to become widespread)

- Modern times: changes must be more **rapid**; penalties for failed experiments are greater (?)

Viewpoints

1. **Known land area**, what use?

   - depends on strategic objectives
   - e.g., raise yields, enhance income, integrate into cash economy, diversify/reduce risk, reduce degradation . . .

2. **Known use**, what area?

   - e.g., new technology, new crop, new use for crop . . .

Examples: known land area

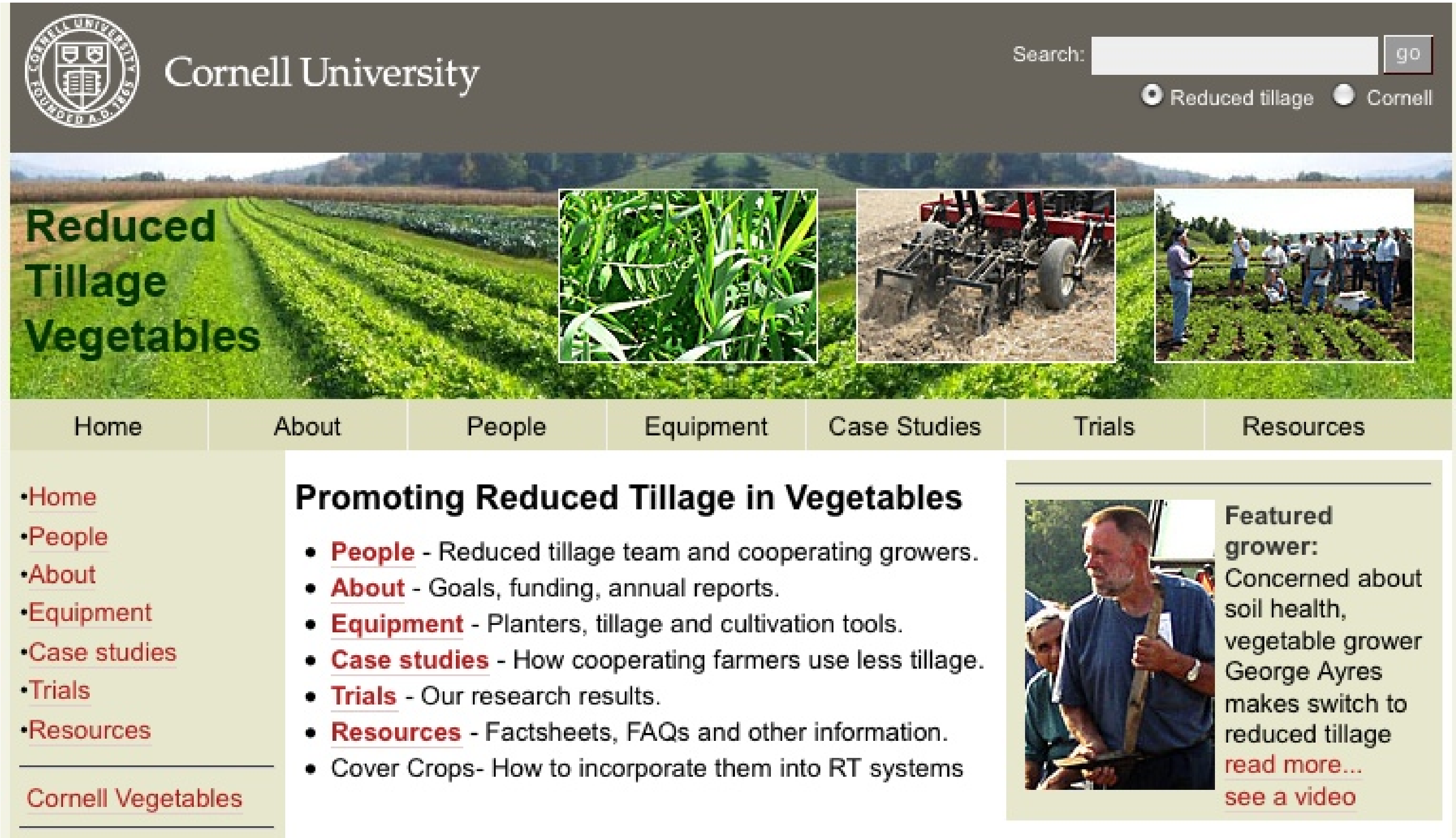
- single farm/field
- catchment upstream of new reservoir
  - land use must be controlled to prevent sedimentation
- identified rural development area
  - target for living standards / carrying capacity
- transmigration/resettlement with defined area

Land characteristics radically changed, what are suitable uses / management for resettlement? (Mt. Merapi, Yogjakarta, Java)

Examples: known use

- “green revolution” technologies
  - where are different “packages” applicable?
- transmigration/resettlement with known agricultural systems
- new production systems
  - conservation tillage, early planting, split fertilizer application . . .
  - these are successful/profitable on some soils, not on others
  - these are feasible within some production systems, not within others
- crops used for biomass vs. grain or fodder
  - accumulate starch/sugars, not protein

Example: New technology for existing systems



Source: `http://www.vegetables.cornell.edu/reducedtillage/index.htm`

System is not applicable (or must be adapted) in some soils.

Land evaluation

Broad definition: The **prediction** of land performance over time under **specific uses**

Note:

- No such thing as “good” or “bad” land in general, only with respect to a **specified use**
- “This land is highly suitable for maize” – meaningless statement
  - production system, crop cycle, variety, use, market . . .
- **prediction** “is dangerous, especially about the future” – Niels Bohr

Land evaluation vs. land-use planning

- **Land evaluation** provides **objective** and (semi-)quantitative information on the probable success of proposed land uses

- **Land use planners**

  1. **solicit** this information (set boundary conditions, terms of reference)
  2. **use** this information in their multi-criteria, politico-social decision-making

FAO. (1993). *Guidelines for land-use planning*. FAO development series. Rome, Italy

'Cui bono?' (Who benefits?)

1. Land and associated resources (esp. water) are increasingly scarce
   (a) population and wealth pressure
   (b) growth-oriented economy / life style

2. Competition for resources
   - Any change in land use benefits some group, very often at the expense of another or of the general good (e.g., loss of ecological services)
   - Example: new large commercial farms in Africa, so-called "land grabbing"

Activist view: `http://farmlandgrab.org/`; `http://www.grain.org/e/4626` "Brazilian megaproject in Mozambique set to displace millions of peasants"

Balanced view: `http://www.fao.org/docrep/011/ak241e/ak241e00.htm` "Land grab or development opportunity – Agricultural investment and international land deals in Africa", IIED/FAO/IFAD, London/Rome. ISBN: 978-1-84369-741-1

Land evaluation is always political

1. The knowledge of which land uses will perform well on which land areas
   - knowledge is power
   - local populations vs. “metropolis”
2. Who hires the land evaluator? Who sets the terms of reference?

Land evaluation vs. land valuation

- land **valuation**: assign a monetary value to each land area for taxation, land taking, land exchange
  - typically from land market, current production, or production of dominant crop in typical technology; not a prediction
    - e.g., German “bonitas” system
    - can use land evaluation for a dominant land use type as a basis
    - land evaluation unit is either a field or farm

- land **evaluation**: predict performance of various land uses on a specific land area
  - land evaluation unit can be field, farm, soil map unit, landscape unit . . .

Exercise (1)

Describe a setting where land evaluation may be needed:

- Social or environmental problem
- Possibilities for land use change
- *Cui bono*?

History

- Soil survey interpretations (1899 ff.): best practices **per soil type**
- Land Capability Classification for conservation farm planning (USDA SCS, 1930's)
  - widely used (abused) for other purposes
  - ranks land in general terms, not for specific use systems
  - implied context
- Irrigation Suitability Classification (USBR, 1950's)
- **FAO Framework for Land Evaluation** (1976)
- Land-use systems modelling, GIS (1990's)

FAO Framework for Land Evaluation

- International consultation early 1970's
- Attempted to consolidate previous practice worldwide
- A general approach to land evaluation projects
- Framework 1976
- Guidelines for application in different land uses 1980's

FAO Framework principles

- Evaluate land areas for a **set** of **specific uses**
  - each use has its own **requirements**
- Various relevant and feasible options are **compared**
  - including “no change” option
  - decision-makers then decide among the options
- Evaluations are in **context**: physical, economic, social, political
- Suitability is defined by **objective criteria**
  - productivity, environmental benefits, ecosystem services, economic, social
- Land uses must be **“sustainable”** (undefined / undefinable?)
  - in practice, use quantifiable indicators

FAO definition: Land

FAO Framework: “An **area** of the earth’s surface . . .

. . . including all reasonably **stable**, or predictably cyclic, attributes of the biosphere **vertically above and below** this area . . .

. . . including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, . . .

. . . and the results of **past and present human activity** . . .

. . . to the extent that these attributes **exert a significant influence on present and future uses** of the land by humans.”

FAO definition: Land Use (Utilization) Type

A **specific** manner of occupying and using the land:

- with specified **management**;
- in a defined technical and socio-economic **setting** (context).

A LUT may include any number of activities and products, as long as they form part of one system of management on one parcel of land.

Determinants of a LUT

All aspects of the use that might be affected by the land resource

- product(s); market(s)
- technology: land preparation, harvest
- inputs: water, fertilizers, agro-chemicals
- source of power (esp. for tillage)
- management techniques (e.g., type of irrigation, method for scheduling)

Much more than a botanical species!

Paten village, Magelang Regency, Yogjakarta, Indonesia

Exercise (2)

Describe a LUT:

- relevance to the land evaluation
- major determinants

More FAO definitions

LEU Land Evaluation Unit: an area evaluated as a unit (no subdivision)

LUS Land Use System: A LUT carried out on a LEU

LC Land Characteristic: directly measurable attribute of the land

LUR Land Use Requirement: something necessary (demand) for the success of a LUS

LQ Land Quality: same, seen from the viewpoint of what the LEU supplies

Land Use Requirements

(LUR)

Definition: A **general condition** of the land necessary for successful and sustained implementation of a specific LUT

- The **demand** side of the LUT – LEU matching procedure: the LUT **requires**
- Matches with a single **Land Quality** (LQ)
- The land use requires, the land supplies
- The LUR can be (partially) met by **inputs** – this depends on the definition of the LUS
  - compare LUT {with/without/with different levels} of inputs

Land Quality

(LQ)

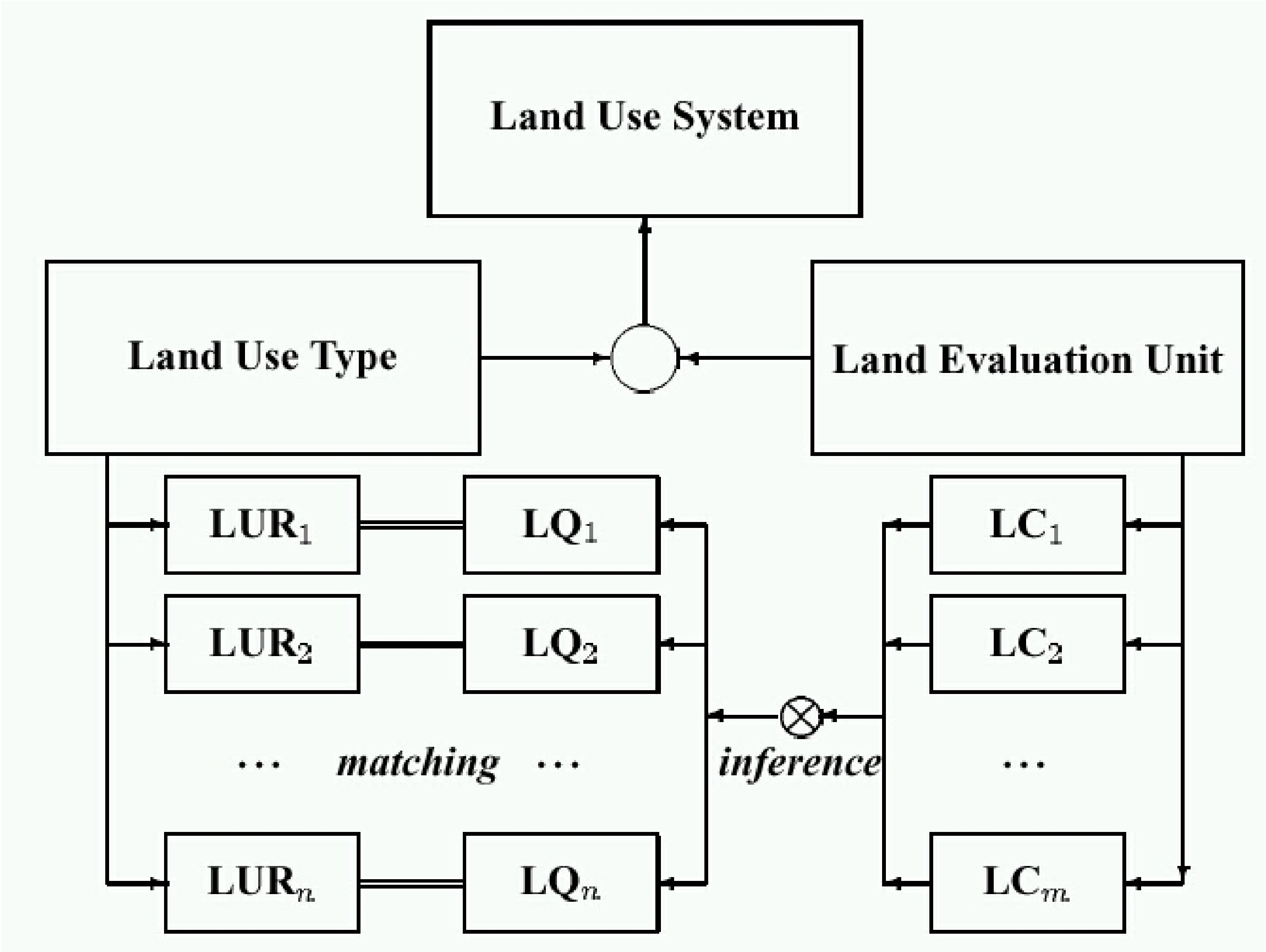
- *Sorry for the confusion with "soil quality" (inherent 'goodness' of soil – another lecture)*

- The **supply** side of the LUT – LEU matching procedure: the LEU has a certain **quality**

- Can (partially) compensate for a lower quality with **inputs** – this depends on the definition of the LUS
  - compare LQ within LUT {with/without/with different levels} of inputs

- More abstract than an LC

- Distinction between LQ and LC is somewhat fuzzy; usually an LC can be measured directly but a LQ must be inferred by some model



Land Use System
Land Use Type
Land Evaluation Unit
LUR1
LUR2
LURn
LQ1
LQ2
LQn
LC1
LC2
LCm
... matching ...
inference
...

Groups of LUR/LQ

A	Agro-ecological
A.1	Sufficiency of ecological factors for production
A.2	Constraints to production
B	Management
C	Spatial
D	Land improvement
E	Conservation & environment
E.1	On-site (sustainability)
E.2	Off-site (environmental issues)
F	Social & political
G	Management and economic constraints
H	Whole-area

Group A: agro-ecological (1 of 2)

Agro-climate	
A1.1	growing period
A1.2	radiation
A1.3	temperature
A1.4	moisture
A1.5	oxygen
A1.7	air humidity
Agro-climate at specific points in the cycle	
A2.1	establishment conditions
A2.2	rooting conditions
A2.3	maturity conditions
Soil conditions	
A3.1	nutrient sufficiency
A3.1.1	nutrient supply
A3.1.2	nutrient retention
A3.2	salinity
A3.3	sodicity
A3.4	soil toxicities, including direct effects of pH

Group A: 2 of 2

Agro-environment	
A4.1	diseases, pests, weeds
Natural hazards	
A5.1	flood hazard
A5.2	physiographic hazards - landslide
A5.3	climatic hazards
A5.3.1	fire
A5.3.2	frosts
A5.3.3	wind
Animal production	
A6.1	drinking water quantity and quality
A6.2	minerals

Group B: Management

B1		water management
	B1.1	water availability for irrigation
	B1.2	water quality (short-term)
	B1.3	water application for irrigation
	B1.4	drainage
B2		tillage
B3		pre-harvest management
B4		harvest management
B5		post-harvest management
B6		storage and processing
B7		mechanization

Group C: Spatial

C1		transportation costs
C2		adjacency to other uses
C3		distance from other uses
	C3.1	proximity (closer is better)
	C3.2	separation (further is better)
	C3.3	ideal distance
C4		accessibility to the production unit
C5		access within the production unit
C6		shape and size of the parcel

Group D: Land improvement

D1	clearing
D2	land shaping
D3	flood protection
D4	drainage
D5	leveling (topography)
D6	physical, chemical & organic amendments
D7	leaching
D8	recuperation period
D9	irrigation works (construction)

Group E: Conservation & environment

On-site (sustainability)	
E1	prevention of salinity and sodicity
E2	long-term water quality and control
E3	erosion hazard
E4	land degradation hazard
E5	vegetation degradation hazard
Off-site (environmental issues)	
E6	streamflow response
E7	preservation of species (biodiversity)
E8	environmental risks

Group F: Social & political

F1	political entity
F2	land tenure
F3	farmer attitudes
F4	labour availability

Group G: Management and economic constraints

G1	seasonality (opportunity)

Group H: Whole-area

H1	sufficient total area for development (e.g., to invest in a processing plant)
H2	presence of contrasting land areas (e.g., winter and summer pasture)

Selection of LUR

The simplest model that successfully predicts performance is best; how to limit the LUR to the smallest sufficient set?

- Important for use, i.e., have an **effect** on LUT success
- Existence of **critical values** in study area
  - Some sub-optimum, varying over the area
  - otherwise, variables become constants
- **Data** to evaluate are available
  - diagnostic Land Characteristics
- **Knowledge** on how to evaluate is available
  - selection of diagnostic Land Characteristics
  - models

Economic land evaluation

- LQ: can link lower levels to economic loss:
  - **lower** yields
  - **delayed** yields
  - **higher costs** to obtain the optimum yield

- LUT: compute financial value as:
  - gross margin (does not take into account time value of money)
  - Net Present Values (NPV) – requires the specification of a **discount rate**
  - Benefit/Cost ratio (B/CR) – from the NPV over the life of the project

- NPV, BC/R apply to multi-year LUT
  - e.g., fruit plantations, irrigation projects

Exercise (3)

1. List relevant LUR for the chosen LUT

2. How does a sub-optimal level of the corresponding LQ affect suitability?

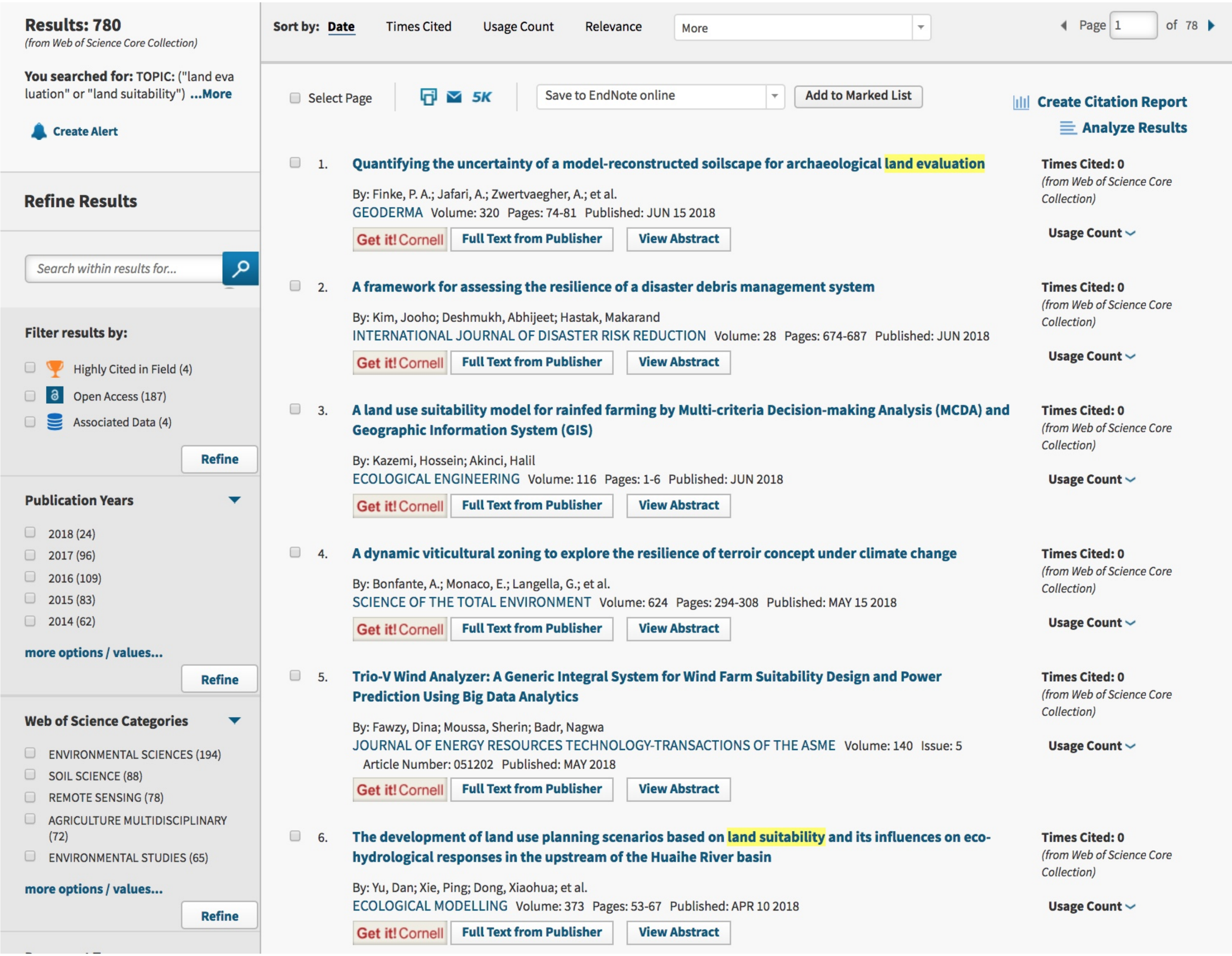
    - fewer benefits (e.g., lower yield)?
    - higher costs? (e.g., more labour or inputs)?
    - off-site damages?

3. List possible LC to evaluate the LQ

Part 2 – Land evaluation research

- narrowly defined: terms “land evaluation” or “land suitability” in the **title**
- broadly defined: terms also in the **keywords or abstract**

Newest land evaluation research (Web of Science search) 20-May-2018



Most cited land evaluation research 2008–2018 (Title)

1. **Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation**
   By: Zorner, Robert J.; Trabucco, Antonio; Bossio, Deborah A.; et al.
   AGRICULTURE ECOSYSTEMS & ENVIRONMENT Volume: 126 Issue: 1-2 Pages: 67-80 Published: JUN 2008
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 201 *(from Web of Science Core Collection)*
   Usage Count

2. **Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation**
   By: Chen, Y.; Yu, J.; Khan, S.
   ENVIRONMENTAL MODELLING & SOFTWARE Volume: 25 Issue: 12 Pages: 1582-1591 Published: DEC 2010
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 148 *(from Web of Science Core Collection)*
   Highly Cited Paper
   Usage Count

3. **Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi**
   By: Thapa, Rajesh Bahadur; Murayama, Yuji
   LAND USE POLICY Volume: 25 Issue: 2 Pages: 225-239 Published: APR 2008
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 74 *(from Web of Science Core Collection)*
   Usage Count

4. **A GIS-integrated fuzzy rule-based inference system for land suitability evaluation in agricultural watersheds**
   By: Reshmidevi, T. V.; Eldho, T. I.; Jana, R.
   AGRICULTURAL SYSTEMS Volume: 101 Issue: 1-2 Pages: 101-109 Published: JUN 2009
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 60 *(from Web of Science Core Collection)*
   Usage Count

5. **Wind farm land suitability indexing using multi-criteria analysis**
   By: Al-Yahyai, Sultan; Charabi, Yassine; Gastli, Adel; et al.
   RENEWABLE ENERGY Volume: 44 Pages: 80-87 Published: AUG 2012
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 55 *(from Web of Science Core Collection)*
   Usage Count

6. **Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico**
   By: Buenrostro Delgado, Otoniel; Mendoza, Manuel; Lopez Granados, Erna; et al.
   WASTE MANAGEMENT Volume: 28 Issue: 7 Pages: 1137-1146 Published: 2008
   Times Cited: 48 *(from Web of Science Core Collection)*

Most cited land evaluation research 2008–2018 (Title)

1. **The prehistoric and preindustrial deforestation of Europe**
   By: Kaplan, Jed O.; Krumhardt, Kristen M.; Zimmermann, Niklaus
   QUATERNARY SCIENCE REVIEWS Volume: 28 Issue: 27-28 Pages: 3016-3034 Published: DEC 2009
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 310 *(from Web of Science Core Collection)*
   Highly Cited Paper
   Usage Count

2. **Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation**
   By: Zorner, Robert J.; Trabucco, Antonio; Bossio, Deborah A.; et al.
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   Times Cited: 148 *(from Web of Science Core Collection)*
   Highly Cited Paper
   Usage Count

4. **Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation**
   By: Geneletti, Davide; van Duren, Iris
   LANDSCAPE AND URBAN PLANNING Volume: 85 Issue: 2 Pages: 97-110 Published: APR 10 2008
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 94 *(from Web of Science Core Collection)*
   Usage Count

5. **Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj)**
   By: Moeinaddini, Mazaher; Khorasani, Nematollah; Danehkar, Afshin; et al.
   WASTE MANAGEMENT Volume: 30 Issue: 5 Pages: 912-920 Published: MAY 2010
   Get it! Cornell | Full Text from Publisher | View Abstract
   Times Cited: 89 *(from Web of Science Core Collection)*
   Usage Count

6. **Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi**
   Times Cited: 74 *(from Web of Science Core Collection)*

Part 3 – Models in land evaluation

- Models: **simplified** representations of systems, capturing their essential behaviour
  - **process-based**: represent presumed processes mathematically
  - **empirical**: establish predictive statistical relations
  - In practice the line is blurry: empirical are motivated by presumed processes, process-based have many empirical calibrations

  Rossiter, D. G. (2003). *Biophysical models in land evaluation*. Encyclopedia of Life Support Systems (EOLSS), Article 1.5.27. Oxford: EOLSS Publishers. Retrieved from `http://www.itc.nl/personal/rossiter/Docs/EOLSS_1527_Preprint.pdf`

- Land evaluation: simulate land use systems or components

Classification of Models

On three axes:

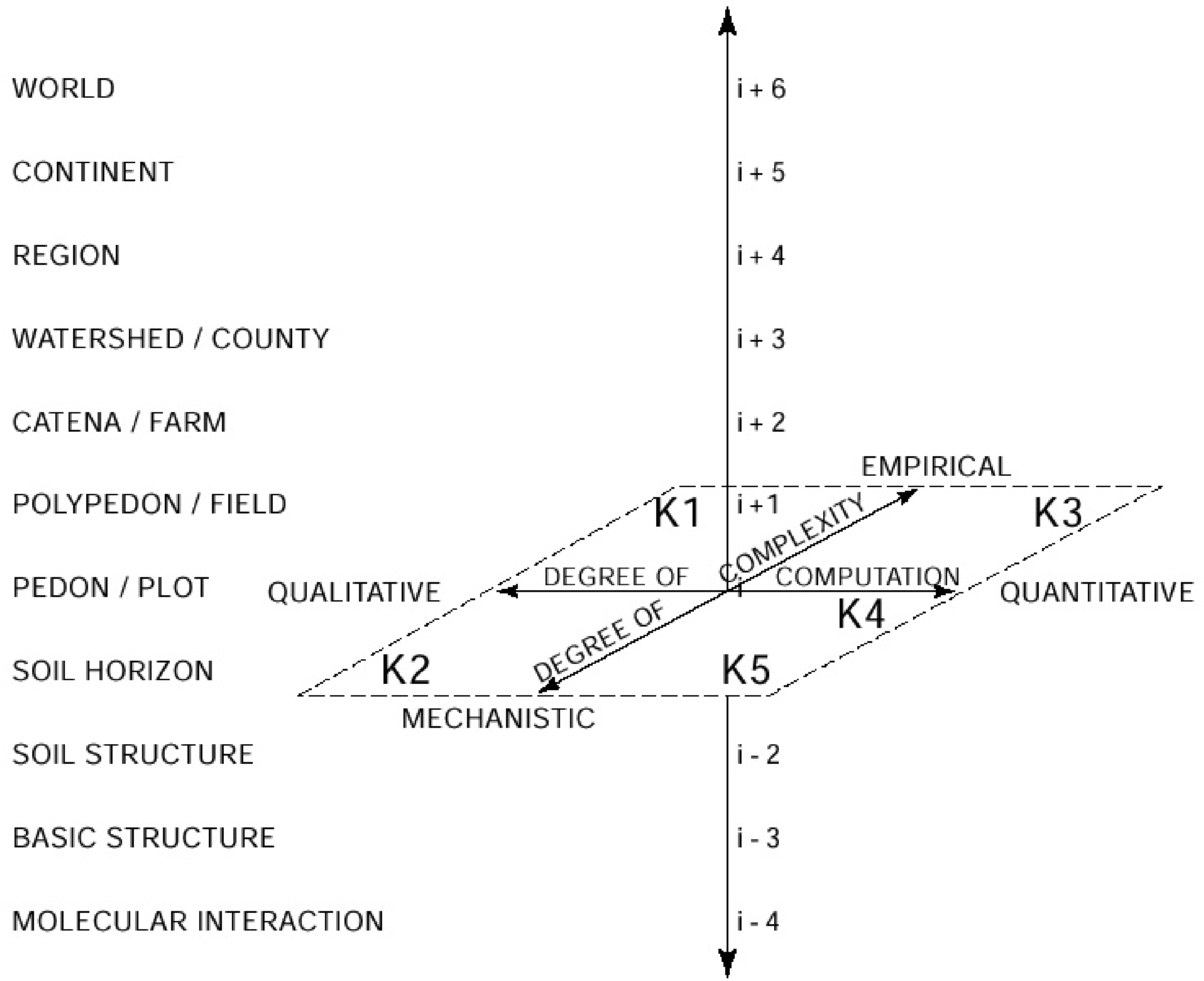
1. **Scale** of process

2. degree of **computation**

3. degree of **complexity**

Most models "jump" in this space; i.e., have parts at different scales and with different computation and complexity.

Hoosbeek, M. R., & Bryant, R. B. (1992). *Towards the quantitative modeling of pedogenesis - a review*. Geoderma, 55, 183-210.



adapted from Bouma, J. (1997). *The role of quantitative approaches in soil science when interacting with stakeholders*. Geoderma, 78, 1-12.

Some types of model knowledge

K1 user expertise (empirical, qualitative)

- often at more general scales; difficult to extrapolate

K2 expert knowledge (mechanistic, qualitative)

K3 generalized holistic models (empirical, quantitative)

K4 complex holistic models (semi-mechanistic, quantitative)

K5 complex models of system components (mechanistic, quantitative)

- often at more detailed scales

Bouma, J., & Droogers, P. (1999). *Comparing different methods for estimating the soil moisture supply capacity of a soil series subjected to different types of management*. Geoderma, 92(3-4), 185-197.

Examples of models in land evaluation

K1 extensionist's knowledge

K2 FAO Framework implemented/extended in ALES

Rossiter, D. G. (1990). *ALES: A framework for land evaluation using a microcomputer*. Soil Use & Management, 6(1), 7-20.

K3 multivariate regressions of yield etc. on environmental factors

Olson, K. R., et al. (2001). *Equations for predicting grain crop yields of Illinois soils using soil properties*. Soil Survey Horizons, 42, 52-64.

K4 WOFOST, APSIM, DSSAT . . . agrosystem simulation models

K5 LEACHM (pesticide / nitrate transformations in soils)

Hutson, J. L. (2003). *LEACHM: Leaching Estimation and Chemistry Model*. A process-based model of water and solute movement, transformation, plant uptake and chemical reactions in the unsaturated zone. Version 4. Ithaca: New York State College of Agriculture and Life Sciences

Part 4 – Difficulties & new directions

There is still activity in land evaluation . . .

. . . but what is its quality?

. . . is it relevant?

. . . is it used?

Difficulties

1. **Complicated reality** → prediction is difficult

2. Inappropriate / oversimplified **evaluations**

3. Inappropriate **models**

4. Lack of **information**
   - on land resource
   - on **response** of land resource to uses

5. Poor relation with **stakeholders**

Difficulty: Complicated reality

- Success/failure of a land use system depends on many inter-related factors

- Notable failure:Tanganyika Groundnut Scheme (late 1940's)

  Wood, A. (1950). *The groundnut affair*. London: The Bodley Head.

  - short time-series of rainfall records (drier than anticipated)
  - topsoils too clayey for nut development/harvesting
  - no reliable irrigation or drinking water
  - inadequate equipment for land clearing:
  - no experienced managers or workers; undeveloped labour market

Difficulty: Oversimplified evaluations

- evaluations often required by projects as an output, not in response to specific demand

- so, evaluators take the easy way out:
  - using botanical species as a LUT
  - blind application of Sys tables or similar
    Sys, C., Van Ranst, E., Debaveye, J., & Beernaert, F. (1993). *Land evaluation, Part 3: Crop requirements*. Brussels: General Administration for Development Cooperation.
  - not considering locally-important factors, especially management methods

Difficulty: improper application of models

Refer to previous section on modelling

- not the output that the client needs
- wrong scale
- poor description of process
- model not locally calibrated

Lack of information on land resources

- Many areas of the world with coarse or unreliable information on **soils**
  - "legacy" data: difficult to interpret / incorporate in GIS
    Dent, D. L., & Ahmed, F. B. (1995). *Resurrection of soil surveys: a case study of the acid sulphate soils of The Gambia. I. Data validation, taxonomic and mapping units*. Soil Use and Management, 11(2), 69-76. DOI: 10.1111/j.1475-2743.1997.tb00557.x
  - SoilGrids (ISRIC) https://soilgrids.org/
  - GlobalSoilMap.net project http://www.globalsoilmap.net/

- Sparse distribution, short/unreliable time series of weather, stream flow records etc.

- However, some excellent fine-resolution data sources
  - **DEM** → terrain characterization
  - satellite imagery
  - compiled global datasets
    http://worldgrids.org/doku.php?id=source_data

Difficulty: poor relation with stakeholders

Land evaluation is aimed at providing reliable information on land use options to various interested parties (**"stakeholders"**).

If the results do not meet their needs, the effort is wasted or (worse) mis-directed.

Problems with current practice

- top-down, bureaucratic, **technocratic**
- **supply-driven** (organizational / donors require)
  - "have model, will travel"
- based on evaluator expertise, not user needs
  - lots of time wasted on **unrealistic options**

Solutions

- demand-driven land evaluation

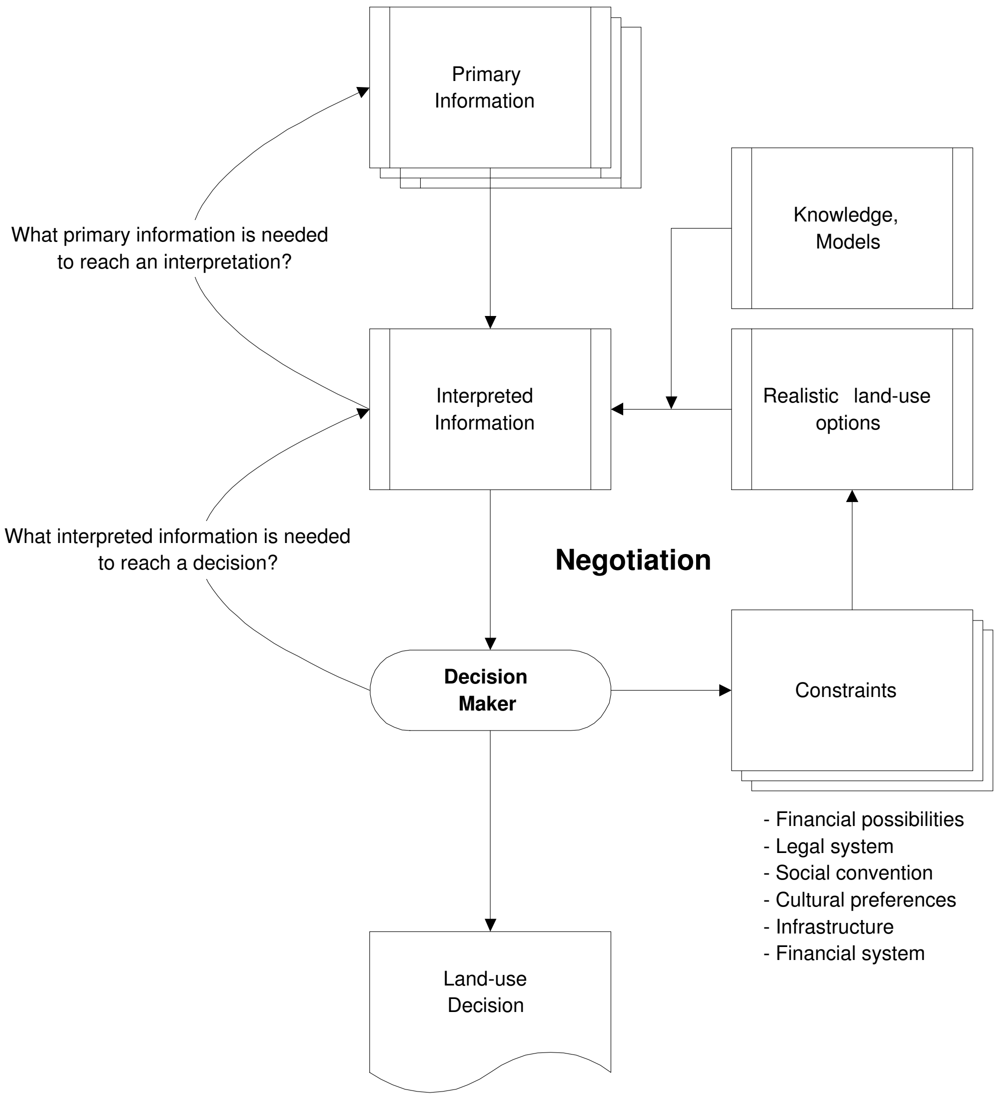
- research chain

- better data sources and models

Demand-driven land evaluation

- fact: most contexts are **highly constrained**
  - except for totalitarian states – even there, grass-roots pressure constrains
  - spectacular failures in large-scale unconstrained schemes, so top-down planners are more cautious
- in settled areas, most options are **adaptations**
  - most land users have little room for maneuver
  - example: zone tillage; frost tillage (NE USA)
- only evaluate for **realistic options**, agreed-on with stakeholders

Demand-driven land use decisions



“Interpreted information” = land evaluation

Research chain

- Bouma, J. (1999). *Land evaluation for landscape units*. In M. E. Sumner (Ed.), *Handbook of soil science* (p. E393-E412). Boca Raton, FL: CRC Press.

- Insight: most land use changes are highly constrained

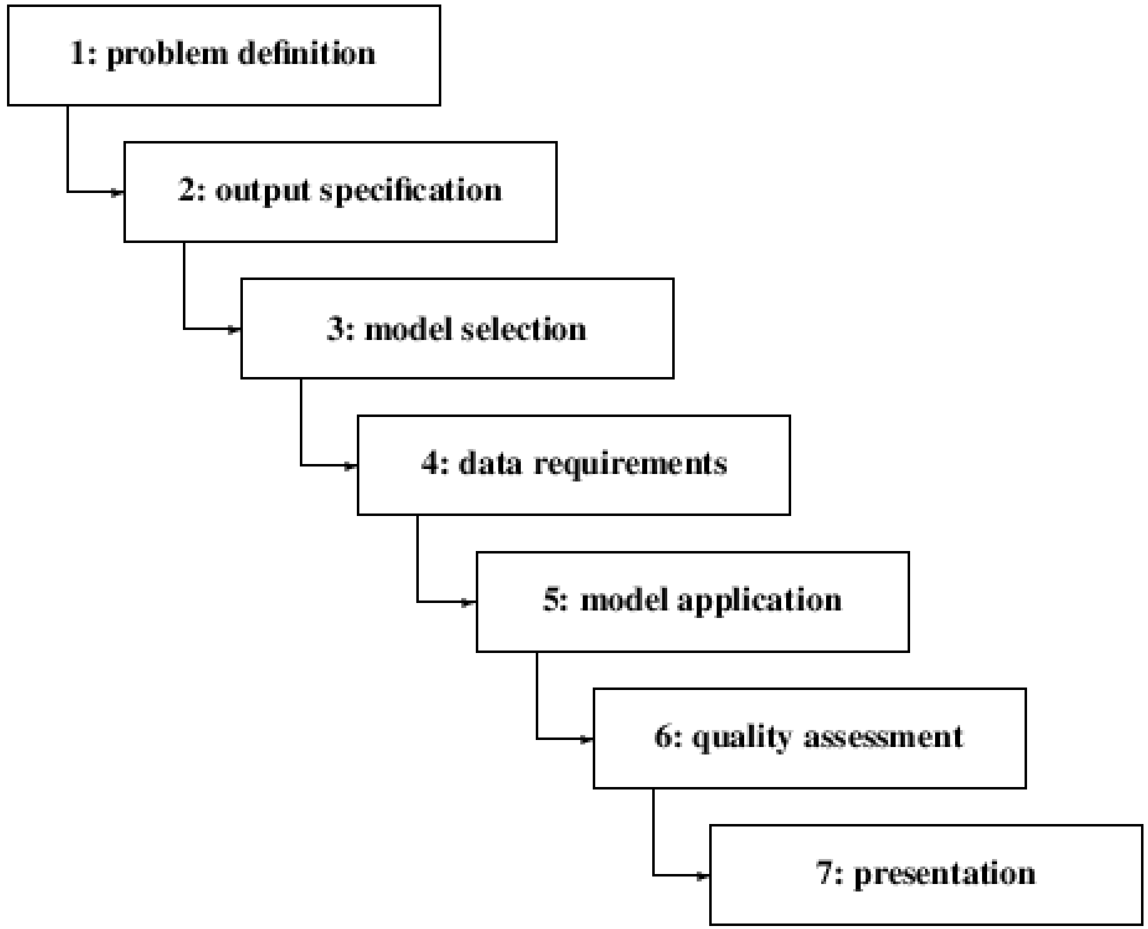
- Insight: most ready-made models only cover part of what is needed

- So: Land evaluation is only carried out on demand, with a clear **problem definition** and agreed **output specification** – what the user needs to make a decision

- So: models are **coupled** *ad hoc* as appropriate to produce the required output

  may require new model components or linking models

Research chain



End