Principles of Land Resources Evaluation

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Outline

- **Motivation**
- **FAO Framework**
  - principles, definitions
- **Land Use Requirements**
  - for the FAO Framework
- **Modelling for Land Evaluation**
- **New directions**

Motivation

- **Land provides a resource**
- **Land use is *affected by* the resource**
  - opportunities, constraints
- **Land use *affects* the resource**
  - sustainability, degradation, improvement
- **Objective is to *match*:**
  - *land use* with the *land resource*

FAO Framework for Land Evaluation

- **3 levels**
  - Framework, Guidelines, Evaluations
- **Framework 1976**
- **Guidelines 1980's**
  - rainfed & irrigated agriculture
  - forestry
  - steeplands, extensive grazing

FAO Framework - principles - 1

- **Evaluate *land areas* for a set of *specific uses*, each with their own requirements**
- ***Suitability* is defined by objective criteria**
  - productive
  - environmental
  - social
  - economic
- **Land uses must be *sustainable***

FAO Framework - principles - 2

- **Various *relevant* and *feasible* options are compared**
  - decision-makers then decide among the options
- **Evaluations take into account the *context* of the area concerned**
  - physical, economic, social, political

Definitions

- Land
- Land Use Type (LUT)
- Land Evaluation Unit (LEU)
- Land Use System (LUS)

Land

- **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**, . . .

Land (continued)

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

- **A geographic concept**
  - each land area is uniquely located in space and is defined by that location

Land Use Type (LUT)

- **A specific manner of occupying and using the land...**
  - with specified management methods...
  - ...in a defined technical and socio-economic setting.
- **It may involve any number of activities and products, as long as they form part of one system of management.**
- **Also called *Land Utilization Type***

Determinants of a LUT

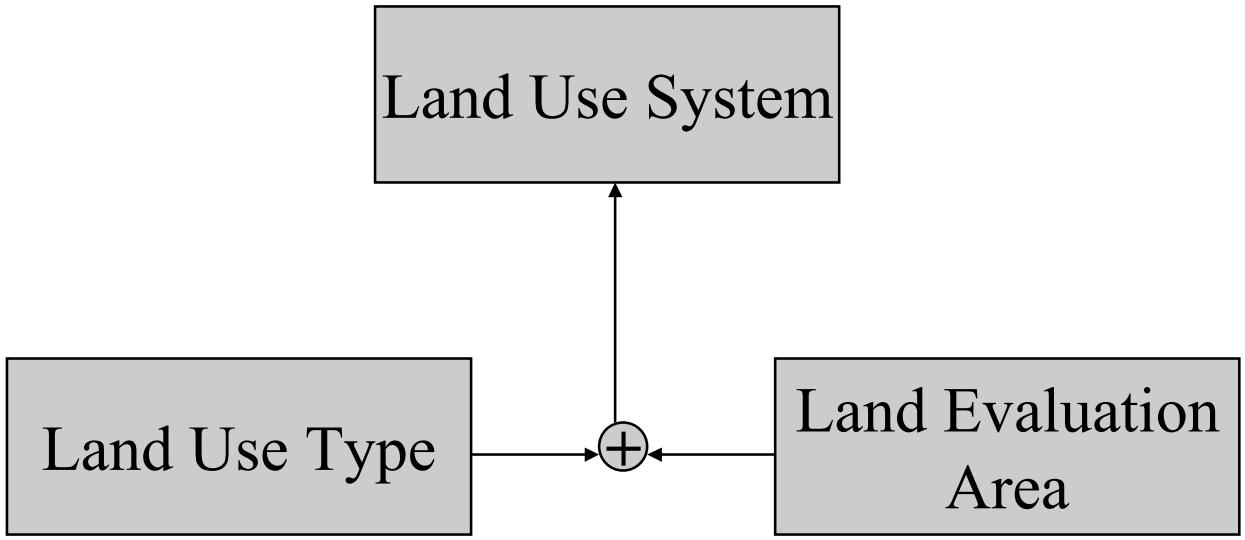
- **All aspects of the use that might be affected by the land resource**
  - product(s); market(s)
  - technology: land preparation, harvest...
  - inputs: water, fertilizers, agro-chemicals...
  - source of power (esp. for tillage)
  - management techniques (e.g. type of irrigation, method for scheduling...)

Land Evaluation Unit (LEU)

- **A specific area of land about which predictions will be made**
- **Topology**
  - May be a *single* delineation (polygon or grid cell)
    - can evaluate *spatial aspects* in this case
  - May be a *set* of delineations (polygons) sharing the same characteristics (a 'map unit')

Land Use System (LUS)

- **A specific *Land Utilization Type* practised on a specific *Land Evaluation Unit***



More Definitions

- Land Characteristic (LC)
- Land Quality (LQ)
- Land Use Requirement (LUR)

Land Characteristic (LC)

- **A *simple* attribute of a Land Evaluation Unit**
- **Can be *measured or estimated* in *routine* field, office laboratory work**
- **May be used to define one or more Land Qualities**
- **Examples**
  - site slope gradient
  - soil particle-size distribution with depth

Land Quality (LQ) - 1

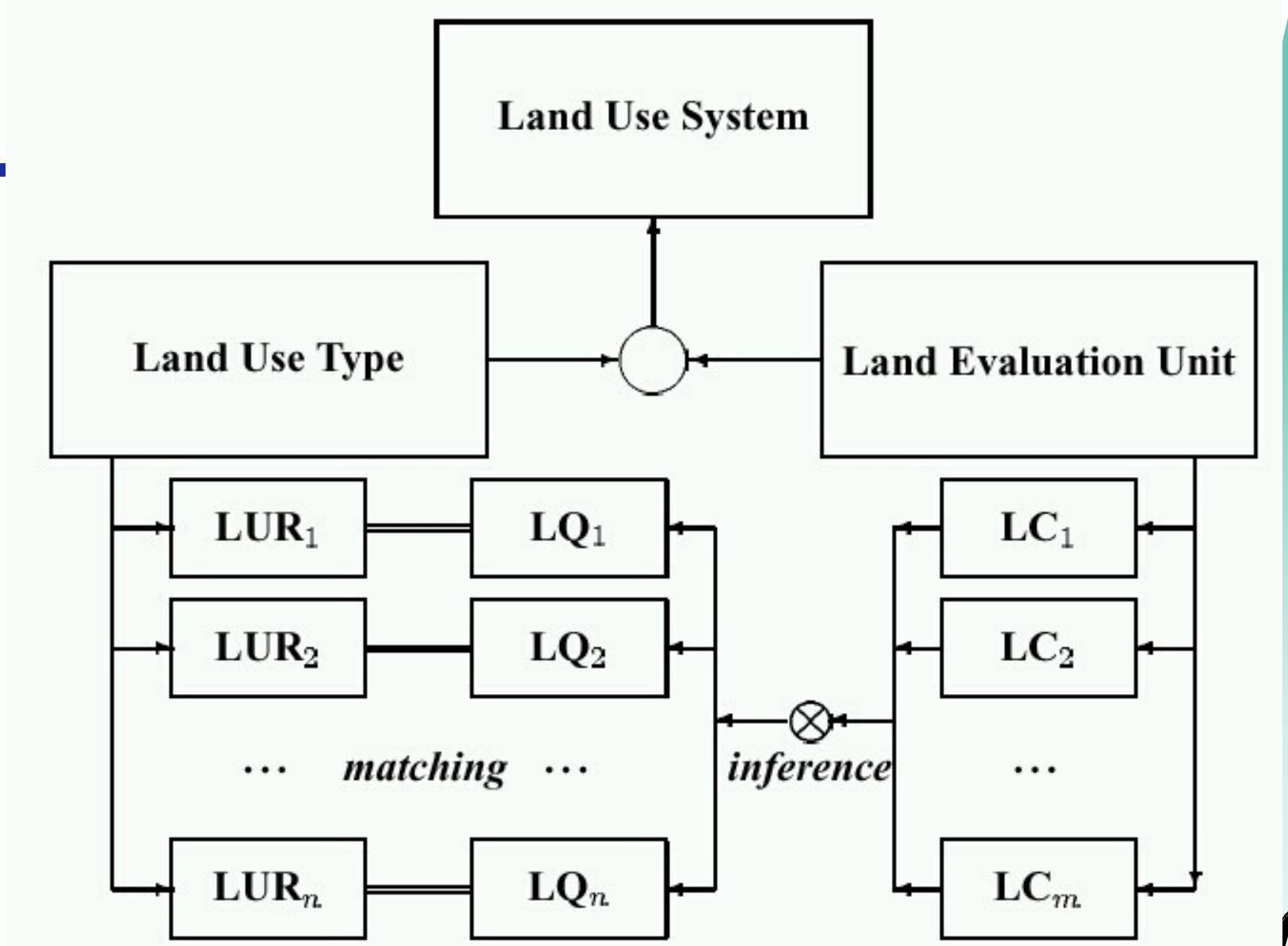
- **A *complex* attribute of land...**
- **... which acts in a manner (more or less) *distinct* from the actions of other land qualities in its influence on the suitability of the land use system.**
- **Follows the time sequence of the land use**
- **Examples**
  - erosion hazard
  - moisture supply

Land Quality (LQ) - 2

- **The ability of the land to fulfil a specific LUR of a specific LUT**
- **The `supply' side of the land use - land area matching procedure.**
- ***Can not be measured or estimated* in *routine* survey, so...**
- **... must be *inferred* from a set of *diagnostic* LCs**
- **Example**
  - erosion hazard from rainfall intensity, topsoil silt & fine sand content, topsoil structure, slope gradient, ...

Land Use Requirement

- A condition of the land necessary for successful and sustained implementation of a specific *Land Utilization Type*.
- The ‘demand’ side of the land use - land area matching procedure.
- Matches with a single “Land Quality”
- The *land use* requires ... the *land* supplies


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

More Definitions

- Land Evaluation
- Suitability
- Sustainability

Land Evaluation

- **“The prediction of land performance over time under specific uses”**
- **Key words:**
  - “prediction”
  - “performance”
  - “specific uses”
  - “over time”

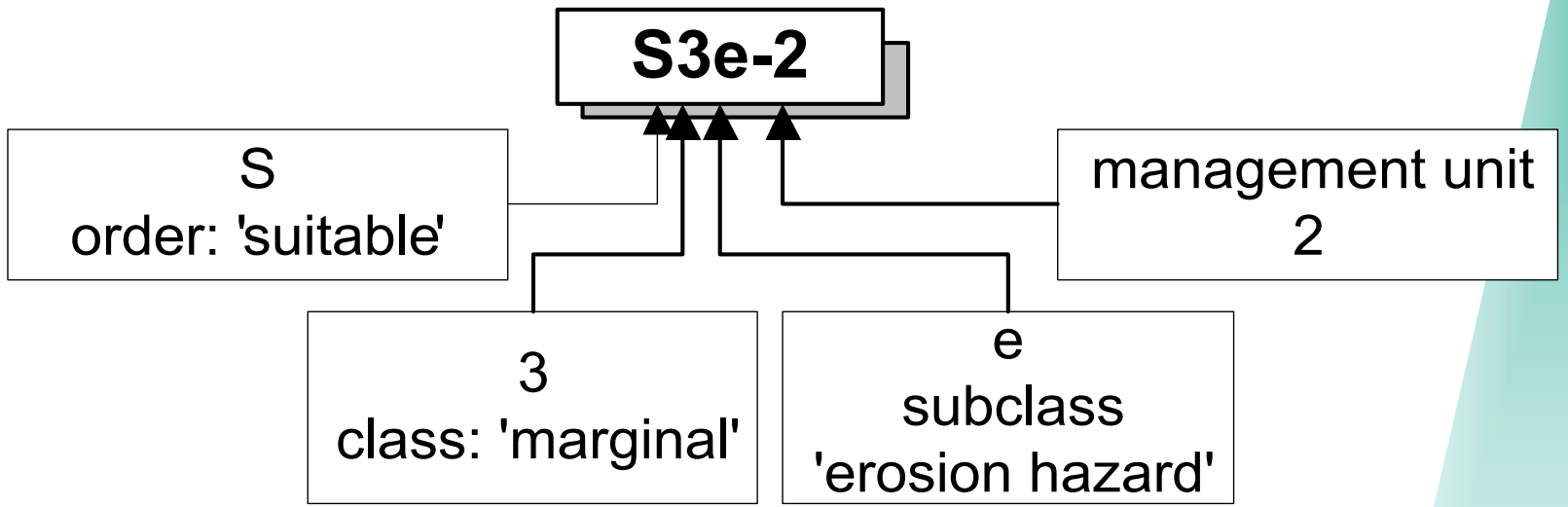
Suitability

- **The ‘fitness’ of a given *Land Use System***
- **i.e., the degree of its success if implemented**
- **Scales of measurement**
  - classes (1 = best, ..., *n* = worst)
  - continuous index (e.g. 0 to 100)
  - yield or other output, on a continuous scale
  - economic metric
    - cost / benefit ratio, net present value, internal rate of return, gross margin...

Sustainability

- "The ability of a land use system to continue indefinitely at an acceptable level of performance, so long as its context does not change"
- Measurable ('performance') but only over time
- Indicators can be used to monitor ('early warning')

FAO suitability *order*, *class*, *subclass*, and *unit*



Orders: S, N

Classes: S1, S2, S3...; N1, N2

FAO method

- **Steps:**
  - Define relevant *LUTs*
  - Select *LURs* for each LUT
  - Select *Diagnostic LC* for each LUR's corresponding LQ
  - Define *diagnostic procedures*
  - Evaluate severity levels of *LQ* from *Diagnostic LC*, to obtain *single factor ratings*
  - Combine *factor ratings* to obtain *overall suitability* for the LUT

Land Use Requirements

- For the FAO method

Groups of Land Use Requirements

- **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**
- **F Social & political**
- **G Management constraints**
- **H Whole-area**

In Red: require spatial analysis

A - Agro-ecological LUR - 1

- **Agro-climate (general)**
  - 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

In Red: soil information especially relevant

A - Agro-ecological LUR - 2

- **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
- **Agro-environment**
  - A4.1 diseases, pests, weeds

A - Agro-ecological LUR - 3

- **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

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**

C - Spatial

- **C1 transport 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**

D - Land Improvement

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

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 (environ-mental issues)**
  - E6 streamflow response
  - E7 preservation of species (biodiversity)
  - E8 environmental risks

F - Social & Political

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

G - Management constraints

- **G1 seasonality (opportunity)**

H - Whole-area

- **constraints over the entire Land Evaluation Area or Land Planning Area**
  - maximum, minimum production
  - maximum, minimum area

Selection of LURs

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

Evaluation of Land Qualities

- **Expert judgement**
  - Matching Tables
  - Decision Trees
- **Computation**
  - Empirical-statistical models
  - Dynamic models

Example of Matching Table

Diagnostic LC's

Land Characteristic	Severity Level of the Land Quality			
	s1 (optimum)	***s2 (moderate)***	***s3/n1 (marginal)***	***n2 (impossible)***
texture/structure, class	C-60s, SiCS, Co, SiCL, CL, Si, SiI, SC,L, SCL, SL	C+60v , C+60s, C-60v, LfS, LS	Cm, SiCm, LcS, fS, S	cS
coarse fragments, volume %	<15	<35	<55	>55
soil depth, cm	>50	>20	>10	<10
$CaCO_3$, %	<25	<35	<50	>50
Ca_2SO_4, %	<6	<10	<20	>20

LUT: rainfed sorghum, low technology

LQ: Rooting conditions

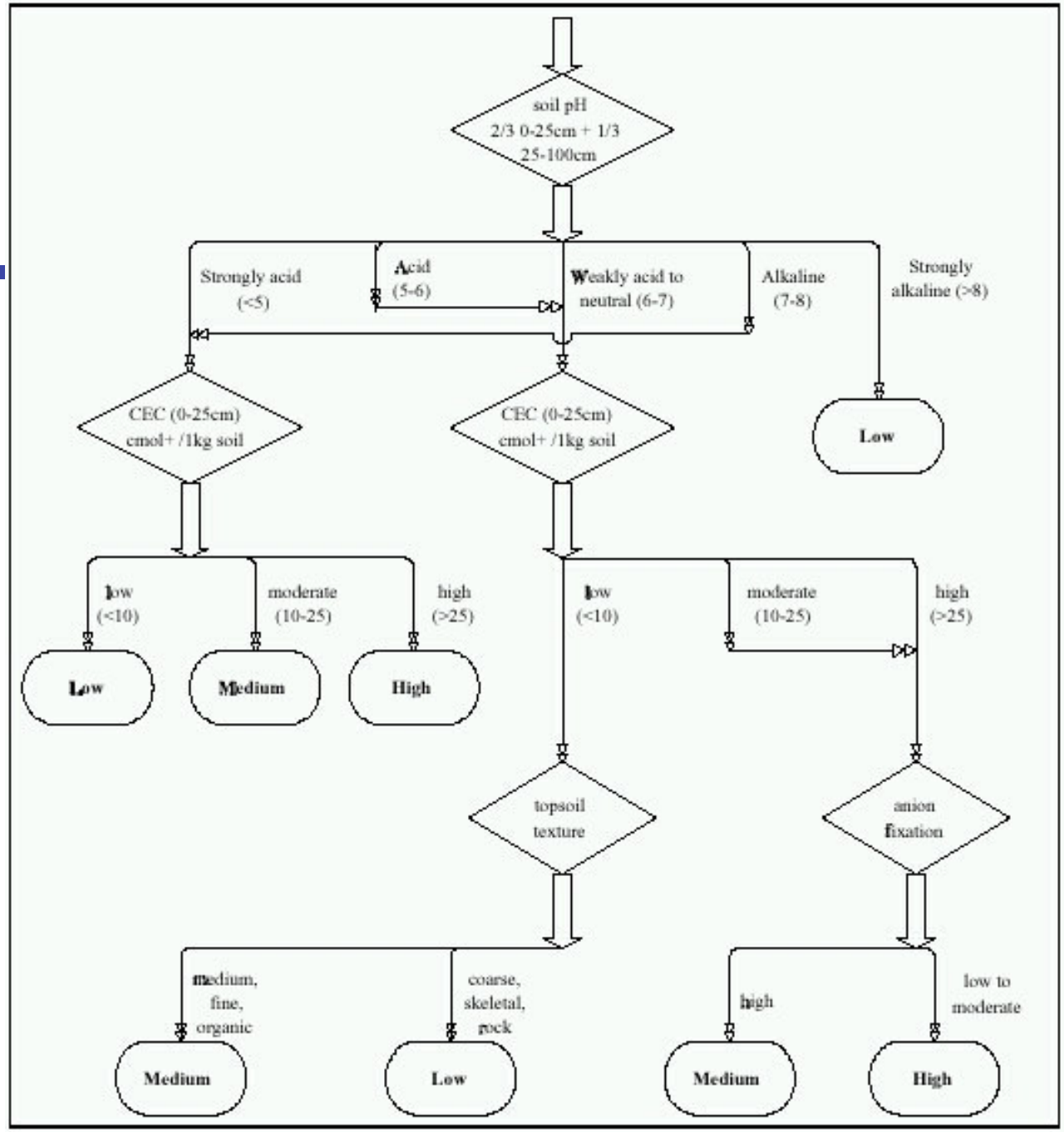
ITC

Use of matching table

texture/structure, class	LfS
coarse fragments, volume %	20
soil depth, cm	100
$CaCO_3$, %	45
Ca_2SO_4, %	5

Most limiting

	Severity Level of the Land Quality			
Land Characteristic	***s1***	***s2***	***s3/n1***	***n2***
texture/structure, class	C-60s, SiCS, Co, SiCL, CL, Si, SiI, SC,L, SCL, SL	C+60v , C+60s, C-60v, **LfS**, LS	Cm, SiCm, LcS, fS, S	cS
coarse fragments, volume %	<15	**20** <35	<55	>55
soil depth, cm	**100** >50	>20	>10	<10
$CaCO_3$, %	<25	<35	**45** <50	>50
Ca_2SO_4, %	**5** <6	<10	<20	>20


soil pH
2/3 0-25cm + 1/3
25-100cm
Strongly acid
(<5)
Acid
(5-6)
Weakly acid to
neutral (6-7)
Alkaline
(7-8)
Strongly
alkaline (>8)
CEC (0-25cm)
cmol+ /1kg soil
CEC (0-25cm)
cmol+ /1kg soil
Low
low
(<10)
moderate
(10-25)
high
(>25)
low
(<10)
moderate
(10-25)
high
(>25)
Low
Medium
High
topsoil
texture
anion
fixation
medium,
fine,
organic
coarse,
skeletal,
rock
high
low to
moderate
Medium
Low
Medium
High

Combining Land Qualities

- **Compute severity levels separately**
- **Combine with:**
  - Maximum limitation (most limiting)
  - Decision tree (allows compensation)
  - Arithmetic combination

Models

- A representation of reality
- Simulation of real processes
- Can ‘compute’ and thus make predictions

Classification of models

- **Degree of computation**
  - qualitative to quantitative
- **Descriptive complexity**
  - empirical to mechanistic
- **Level in the organizational hierarchy**
  - molecular to continental

(from Hoosbeek & Bryant, *Geoderma*, 55:183–210, 1992)

Levels of Knowledge

- K1 user expertise
- K2 expert knowledge
- K3 generalized holistic models
- K4 complex holistic models
- K5 complex models of system components

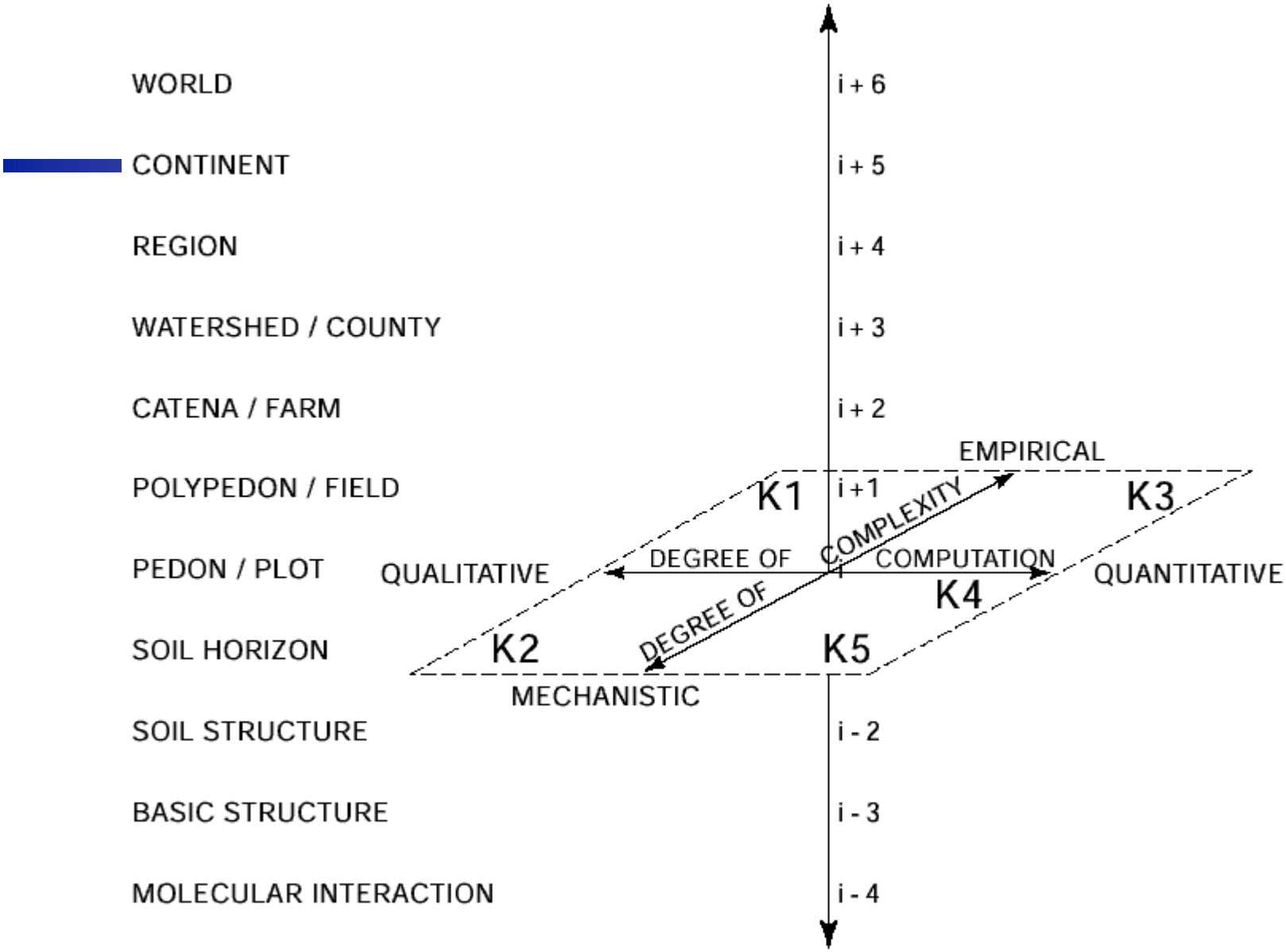
(from Bouma, *Geoderma*, 78:1–12, 1997)

Holistic vs. reductionist evaluation

- **Holistic**
  - evaluate system as a whole
  - interactions are explicitly built into model
- **Reductionist**
  - evaluate system components separately
  - combine these results
  - interactions are ignored or simplified

FAO method in this structure

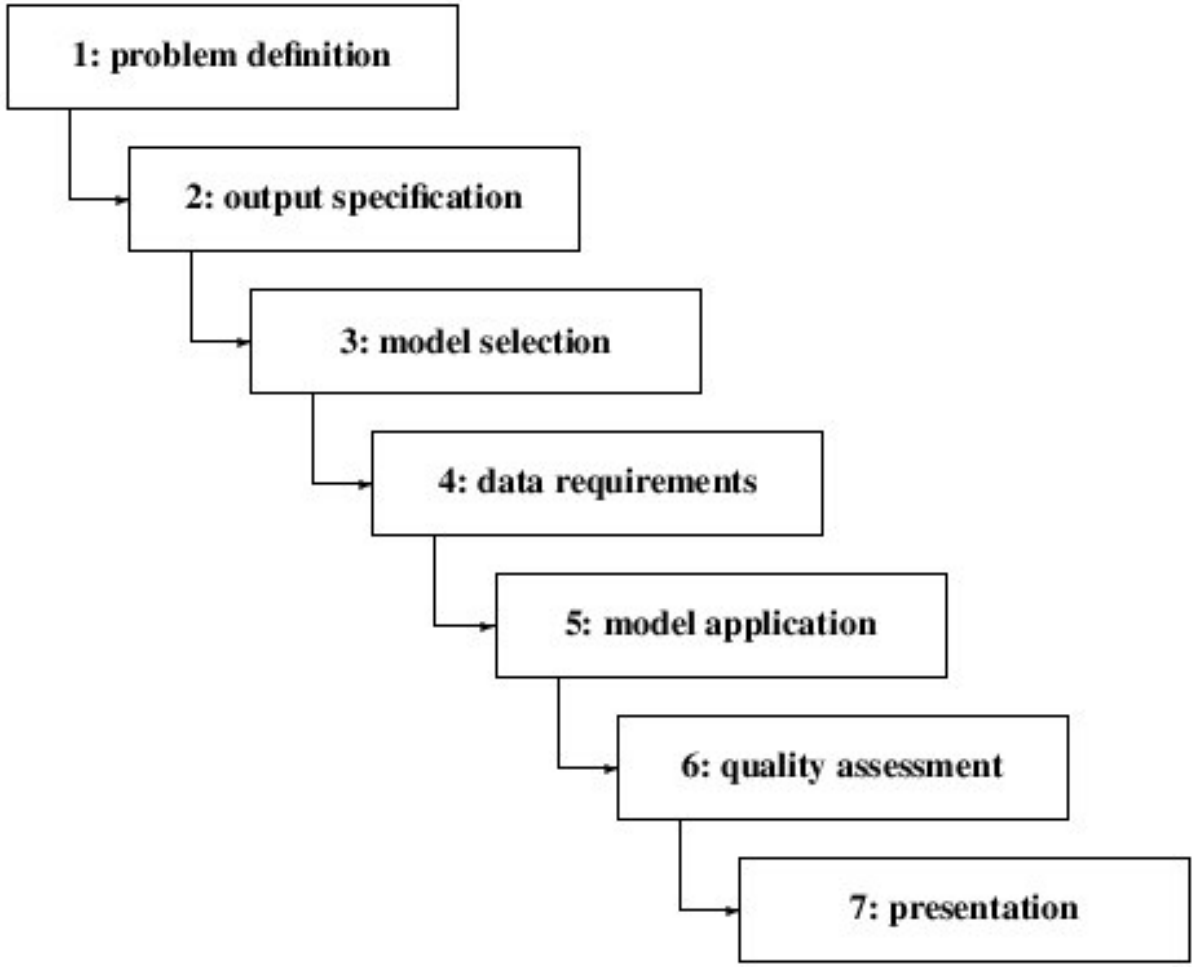
- **Knowledge levels**
  - K2 (expert knowledge), and some simple models of system components
- **Reductionist**


WORLD
CONTINENT
REGION
WATERSHED / COUNTY
CATENA / FARM
POLYPEDON / FIELD
PEDON / PLOT
SOIL HORIZON
SOIL STRUCTURE
BASIC STRUCTURE
MOLECULAR INTERACTION
i + 6
i + 5
i + 4
i + 3
i + 2
i +1
i - 2
i - 3
i - 4
EMPIRICAL
K1
K3
K2
K4
K5
QUALITATIVE
QUANTITATIVE
MECHANISTIC
DEGREE OF COMPLEXITY
DEGREE OF COMPUTATION

New directions in land evaluation

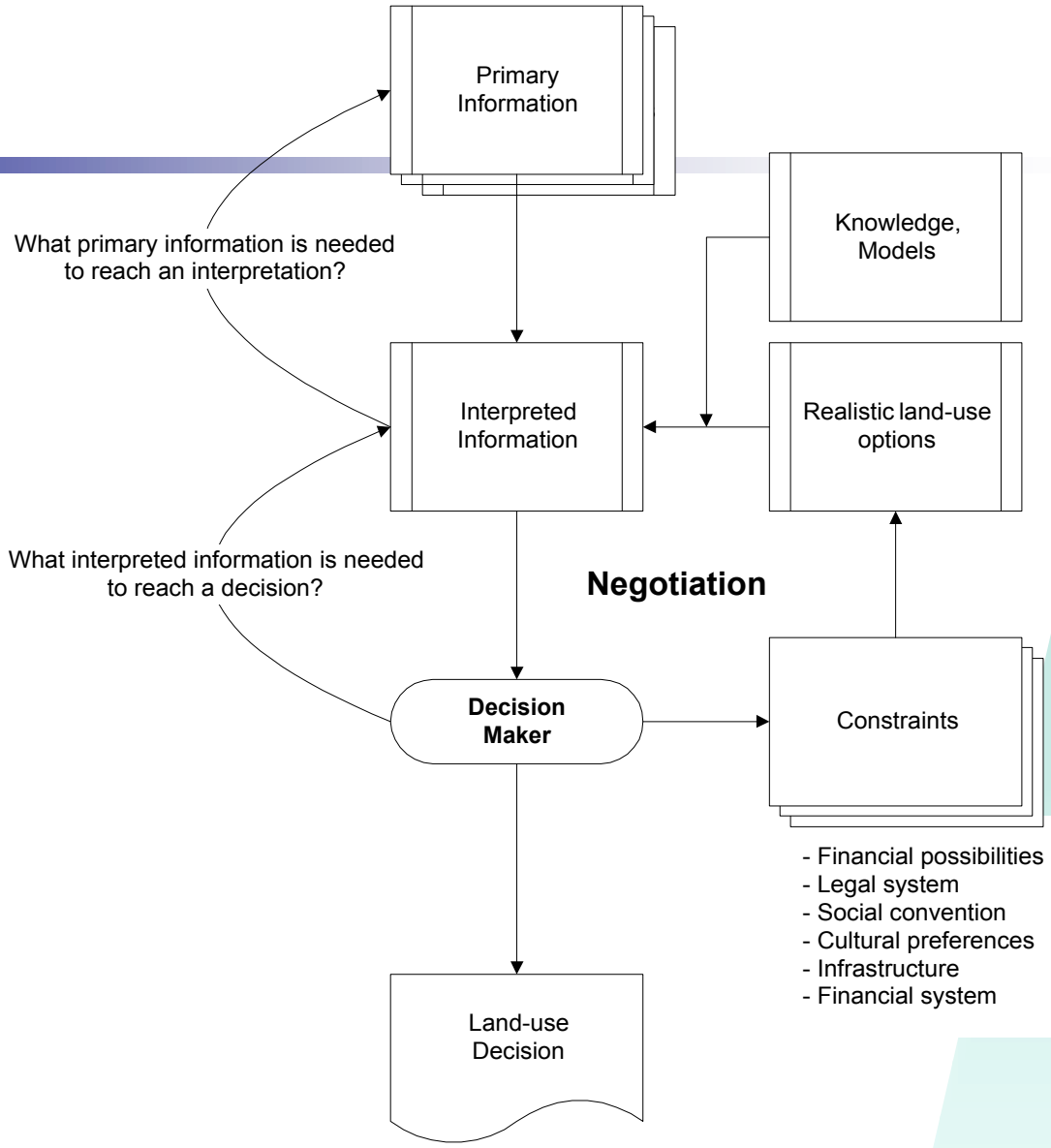
- The research chain
- Demand-driven (client-centred) approach
- Stakeholder involvement
- Seive (stepwise refinement)

The Research Chain



After Bouma (1999), "Land evaluation for landscape units", Handbook of Soil Science, pp.E393-E412

Demand-driven resource inventory & evaluation



Seive (stepwise refinement)

- **Increasingly detailed knowledge as suitable areas are identified**
  - 1 - eliminate completely unsuited areas with expert knowledge (K1 or K2)
  - 2 - calibrate system models (K4 or K5) in promising areas only
  - 3 - use system models to make quantified predictions in these areas