Suitability Modeling

Suitability Modeling Outline

- Criteria and model development
  - Boolean overlay
  - Process models
  - Index overlay – MCA (Eastman et al. 1995)
  - Fuzzy logic
- Exercise A
- Weighting methods
  - Point or rating
  - Ranking
  - Pairwise comparison
- Exercise B

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GIS use

- An information database
  - Coordinating and accessing geographic data
- As an analytical tool
  - Specifying logical and mathematical relationships among map layers
- As a decision support tool
  - For deciding how to act upon the analyses produced

(Eastman, et al. 1995) 3

As a decision support tool

- Can help us make decisions about multiple and conflicting objectives
- Borrows from the decision science or operations research literature
- Raster based and vector information processing

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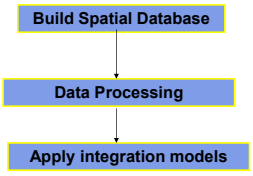
Steps of map integration

- Step 1
- Step 2
- Step 3



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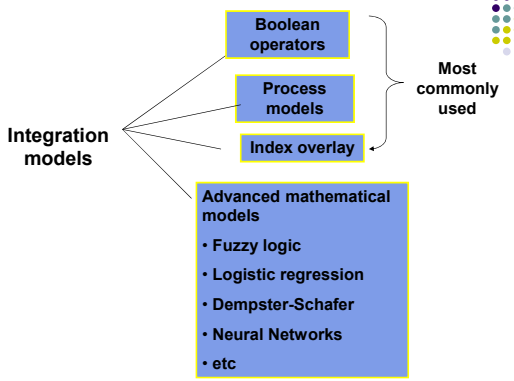

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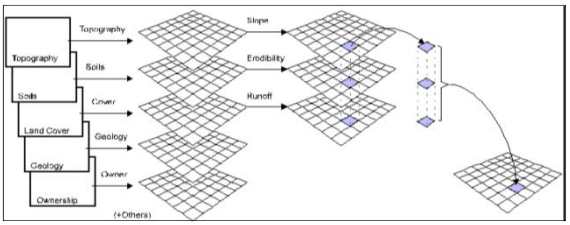
Integration is based on a grid model



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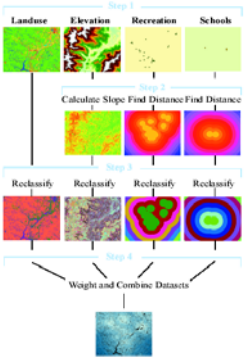
All the steps can be documented



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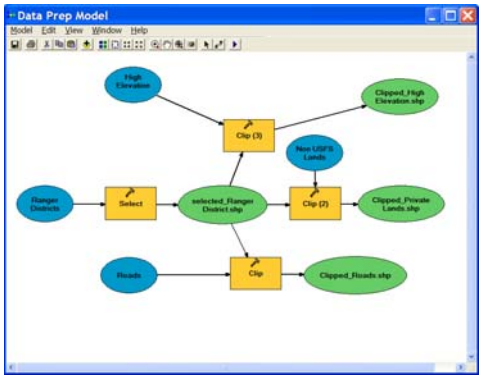

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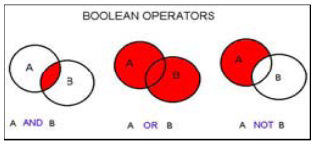
Boolean Operators



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Raster cell values

- Cell values represent geographic features
- Types of cell values:

0	1	0
0	1	0
0	0	1

Binary (0,1)
Presence/absence

Vector data converted to raster

32	32	nodata
12	14	nodata
12	14	11

Integers
Coded values or whole numbers
Land use, elevation

32.23	40.09	36.67
41.09	37.56	38.95
40.56	33.47	39.88

Floating point
Values with decimal places
Slope, aspect

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The Raster Calculator

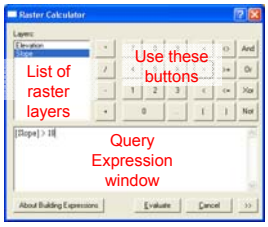
- Use with Analysis mask, analysis extent to "clip" rasters
- Use to base new raster on existing raster
  - Convert m to ft

Can also be used to find cells meeting query expressions:

•[Slope] > 10%

•([Elevation] > 500) and ([Elevation] < 1000)

•Note raster layer names in square brackets [like this]



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NODATA cells

- Special cell value
- Used to indicate:
  - No value at location
  - No data at location (missing)
  - Data outside study boundary
- NODATA is not zero!
- Can affect calculations in Spatial Analyst

2	2	nodata
3	4	nodata
3	4	1

*

20	10	0
10	0	10
10	10	0

=

40	20	nodata
30	0	nodata
30	40	0

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Practice #1 - Transform

ND	9.10	0
1.34	6.76	4.93
4.00	0	ND

int[ingrid] =

ND	9	0
1	6	4
4	0	ND

3	8	0
3	ND	7
4	5	0

[ingrid] >= 5 =

0	1	0
0	ND	1
0	1	0

3	2	0
1	4	7
ND	0	0

[ingrid] >1 &
[ingrid] <= 6 =

1	1	0
0	1	0
ND	0	0

ND = no data

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Practice #2 - Overlay

ND	8	0
1	2	7
4	0	ND

and

3	1	0
1	0	2
2	0	ND

=

ND	1	0
1	0	1
1	0	ND

ND = no data

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Practice #2 – Overlay ANSWERS

ND	8	0
1	2	7
4	0	ND

and

3	1	0
1	0	2
2	0	ND

=

ND	1	0
1	0	1
1	0	ND

ND = no data

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Limitations with boolean operators

- In a binary map only 2 situations are possible,
  - each location is either satisfactory or not.

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Notes

- Integration by Boolean operators is a <u>very extreme</u> form of decision making.
  - For example if logical AND (the intersection operator), is applied to combine the criteria a location must meet every criterion for it to be included in the final decision set.
- If even a single criterion fails to be met, the location will be excluded in the final binary result map.
- “Risk adverse”, “Conservative”

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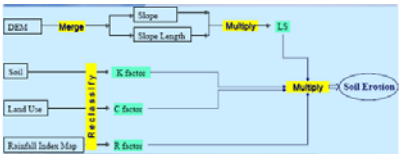
Process Models



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Example 1 of a process model

Model for snow melt in densely forested areas

MELT = (0.19T + .17D)

Where M is the melt rate in cm/day

T is temperature in Celsius

D is dewpoint temperature

We could clearly produce a snow melt rate map (M).
To do so would require multiplying the temperature raster by 0.19, the dewpoint raster by 0.17 and adding the two results.

* *Dunne, T., and Leopold, L.B., (1978) Water in Environmental Planning, (W.H. Freeman and Co.: San Francisco)*

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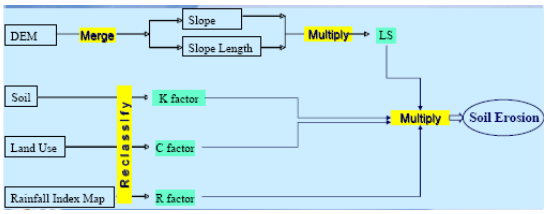
Example 2 of process model



By preparing the data as recommended and integrating them in a GIS, simulation or predictive map(s) representing the phenomena can be generated. Such methodologies and processes are usually recommended by researchers.

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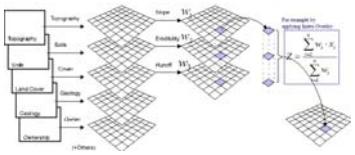
Index overlay



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Multiple criteria in decision making

- Usually several criteria will need to be evaluated all together in order to meet a specific objective.

$$Z = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

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Suitability models

- An interpretation of data with respect to its suitability for an activity
- Typically used to locate something (no definable units to compare)
- Results in a numeric measure of suitability
- Used when the problem is complex or important
- Suitability scores can be subjective or quantitative

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Compared to boolean overlay…

- Index Overlay model has more flexibility and ability for priority indication on spatial units of factormaps (ranking).
- Index overlay method is a simple and commonly used method for GIS layer integration to generate suitability, potential , risk maps,…etc.

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Building suitability models, steps

1. Define the problem or goal
2. Decide on evaluation criteria
3. Normalize and create utility scales
4. Define weights for criteria
5. Calculate a ranking model result
6. Evaluate result

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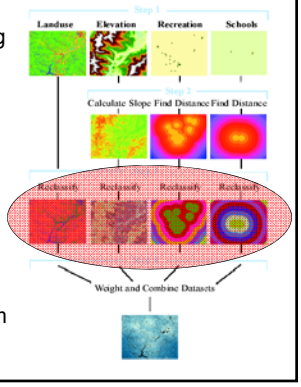
Options for reclassifying

- Reclassification (converting continuous variables to ordinal scale)
- If all factors are numerical and normally distributed, calculating normal zscore
- Reclassification to fuzzy membership values
- Applying "normalizing" calculations such as:

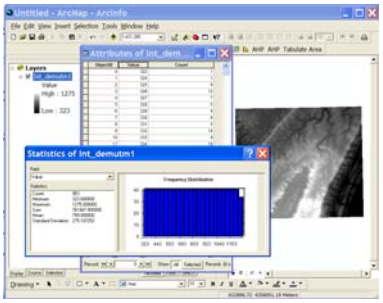
using minimum and maximum



Using minimum and maximum to rescale

$$x_i = \frac{(R_i - R_{\min})}{(R_{\max} - R_{\min})} * \text{standardized_range}$$

where R = raw score



Fuzzy logic

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Premise

- We rarely have perfect information
- We rarely have error free data
- Leads to uncertainty in decision making rules

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Uncertainty in using GIS for suitability modeling

- Which parameters, attributes or thresholds should we use in our index overlays?
- What is a gentle slope?
  - If less than 5% is gentle, what about 5.001% slope? Is it not gentle?
  - No distinct or sharp boundaries – it is fuzzy!

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Fuzziness

- Refers to vagueness and uncertainty, in particular to the vagueness related to human language and thinking
  - " the set of tall people"
  - "all people living close to my home"
  - "all areas that are suitable for corn"
- Provides a way to obtain conclusions from vague, ambiguous or imprecise information. It imitates the human reasoning process of working with non precise data.

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Crisp sets versus fuzzy sets

Crisp sets
Characteristic function

X_A: X -> {0,1}

where

$$X_A(X) = \begin{cases} 1 \text{ iff } X \in A \\ 0 \text{ iff } X \notin A \end{cases}$$

Fuzzy sets
Membership function

UA: X -> [0, 1]

where

$U_A(X)$ is the membership value of x in A

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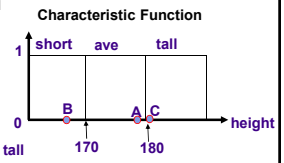
Example of crisp sets versus fuzzy sets

- Height of three adults: A is 178cm, B is 166cm, and C is 181cm

Crisp set	
short	under 170cm
average	170 to 180cm
tall	over 180cm



	short	ave	tall
A	0	1	0
B	1	0	0
C	0	0	1

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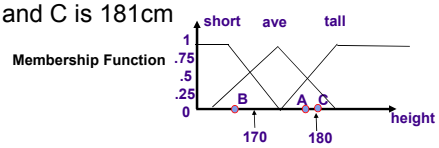
Example of crisp sets versus fuzzy sets

- Height of same three adults: A is 178cm, B is 166cm, and C is 181cm



	short	ave	tall
A	0	.4	.6
B	.8	.2	0
C	0	.3	.7

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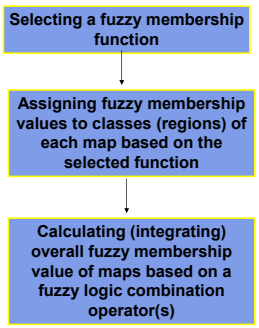
Steps of map integration with fuzzy logic



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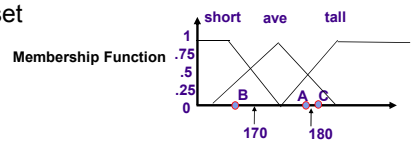
Choice of membership function

- The grade of membership should be 1 at the center of the set
- The membership function should “fall off” in an appropriate way from the center through the boundary
- The point with membership grade .5 (crossover point) is at the boundary of the crisp set



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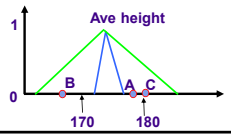
Choice of membership function

- The membership function depends on the application
- EX: moderate elevation may be defined much differently in West Virginia versus moderate elevation in Colorado
- There are linear and sinusoidal membership functions, I will focus on linear in the example which follows



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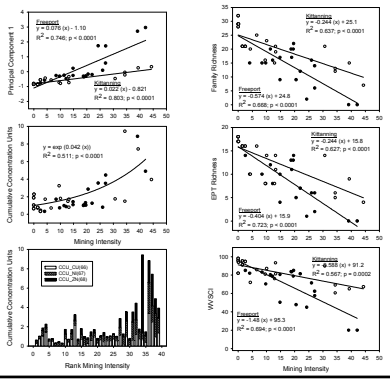
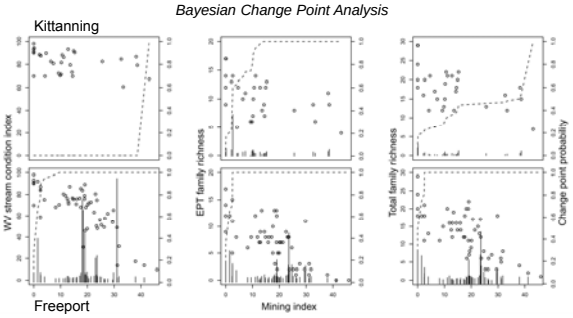
Petty, J. T., Fulton, J. B., Merovich, G. T, Jr., Strager, M. P., Stiles, J., and Ziemkiewicz, P. F. 2010. Landscape indicators and thresholds of ecological impairment in an intensively mined Appalachian watershed. *Journal of the North American Benthological Society.*



Mining Thresholds - Northern Coalfields

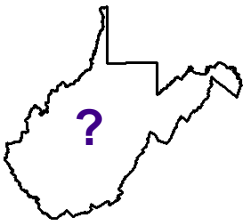
Bayesian Change Point Analysis



5% mining – consistent loss of HQ conditions (coldwater relevance)
20% mining – consistent change to "impaired" conditions.
30% mining – total carnage

Example

- We want to find an ideal location for building a ski resort based on the following criteria:
  - Steeply sloped terrain
  - North facing hillside
  - Higher elevation
  - Near water



Fuzzy concepts

- An average slope of the terrain should be 30 to 50 percent (to have green, blue, black terrain)
- Aspect if favorable when the terrain is oriented toward the North
- Elevation is preferred from 600 meters and up
- It is favorable to have access to water within 800 meters

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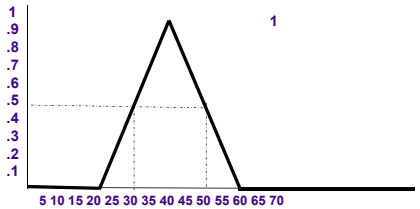
Slope membership function

"Slope is favorable between 30 and 50 percent"

Bad slope =	0	20 < x or x > 60
	(x – 20) / 20	20 <= x < 40
	(60 - x) / 60	40 < x <= 60
	1	40



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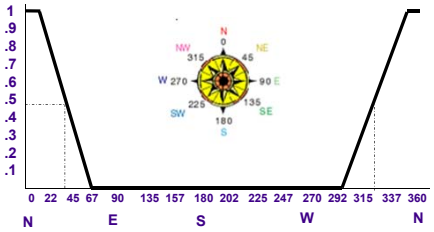
Aspect membership function

"Aspect is favorable when the terrain is oriented towards north ie (0 to 22, 337 to 360 degrees aspect)

Favorable Aspect =	1	x <= 22 or x >= 337
	(67 – x) / 67	22 < x <= 67
	(x – 292) / 45	292 < x < 337
	0	67 < x < 292



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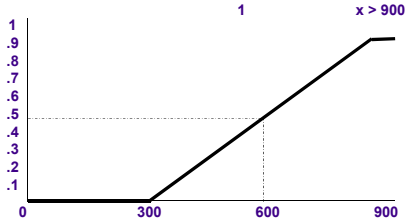
Elevation membership function

"Elevation is favorable over 600m"

0	x < 300
(x - 300) / 600	300 <= x <= 900
1	x > 900



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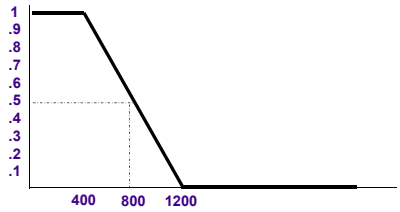
Water membership function

"It is favorable to have access to water within 800 meters"

Preferred distance = 1	x < 400
(1200 - x) / 800	400 <= x <= 1200
0	x > 1200



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Calculation within ArcGis spatial analyst

For elevation example, use the con function which is an if than else statement

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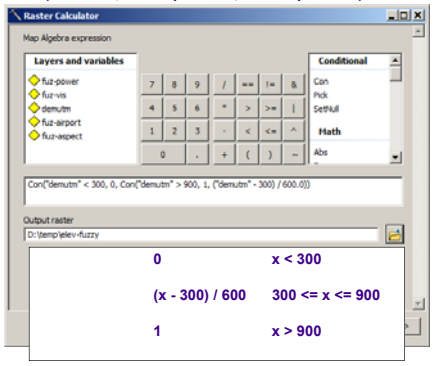
Calculation

Con(condition, true expression, false expression)



0	x < 300
(x - 300) / 600	300 <= x <= 900
1	x > 900

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NOTE: Con function is case and space sensitive!!!

Results in a suitability map

- Areas more suitable have a higher modeled grid value result
- Weights can easily be changed to test the spatial sensitivity of preferences

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Comparison of boolean (map overlay), suitability modeling (index overlay) and fuzzy logic model

- Map overlay = method has most errors due to boolean operator
- Suitability model = most subjective due to utility scales and weight allocation method, however weights don't have to be incorporated

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Cont'

- Fuzzy number method = least subjective and often the best method due to the ability to incorporate scale, accuracy errors in a "gentler" comparison method
- Overall you must determine what is most important to you in the study and choose a method that fits time, money, expertise

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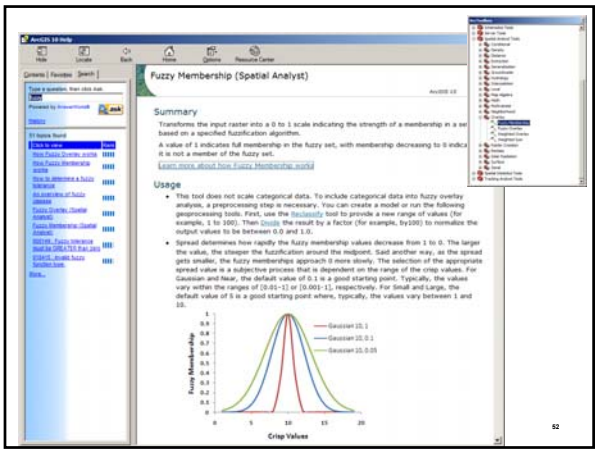

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Fuzzy logic summary

+ Flexibility of assigning fuzzy memberships
+ Choice of combination operators
+ Mimic decision by expert

- Problem of missing data
- Confusion between fuzzy membership and uncertainty

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Preference Weighting for Suitability Studies

Outline

- Weighting techniques
  - Point allocation
  - Ranking methods
  - Pairwise comparison
- Class exercise
- Lab: Criteria weighting for suitability models and spatial sensitivity

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Building suitability models, steps

1. Define the problem or goal
2. Decide on evaluation criteria
3. Normalize and create utility scales
4. Define weights for criteria
5. Calculate a ranking model result
6. Evaluate result

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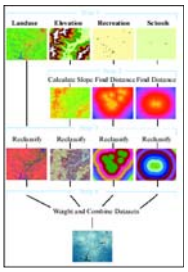
Defining weights for criteria

- Purpose: to express the importance of each criterion relative to other criteria



Int(("fuzzy aspect" * "fuzzy visibility" * "fuzzy power dist" * "fuzzy airport dist" * "fuzzy elev") * 100)

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Weighting methods

- Differ in:
  - Accuracy
  - Ease of use
  - Understanding of decision makers
  - Theoretical foundation

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Weighting

- A value assigned to an evaluation criterion that indicates its importance relative (not absolute) to other criteria under consideration (Malczewski, 1999)
- Weights are normalized to be within a range of 0 to 1

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Methods to create weights for criteria

A. Rating methods
  - Point allocation

B. Ranking methods
  - Rank sum
  - Rank reciprocal
  - Rank exponent

C. Pairwise comparison
  - AHP

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A. Rating methods

- Require the decision maker to estimate weights on the basis of a predetermined scale

ie. 0 to 100

> 0 = the criterion should not be considered
> 100 = the criterion is the only one that should be considered

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Point allocation

- Weights are estimated by the decision maker on a predetermined scale, for example 0 to 100.
- In this approach, the more points a criterion receives, the greater its relative importance.
- The total of all criterion weights must sum to 100. This method is easy to normalize.

		Weight
Criteria that are important for ranking watersheds	Elev change	10
	Wetlands	25
	Roads	5
	Row crops	40
	Mining	20

	Total	100

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Point allocation method

+ unlimited number of judgments
+ very easy to use
+ applicable to GIS applications

- No underlying theoretical foundation
- Not very precise
- Difficult with more than 6 to 8 criteria

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B. Ranking methods

- The easiest method for decision makers because they only need to come up with a straight rank
- Most important criterion= 1, next = 2, next = 3, and so on…..
- Once straight rank is done, the analyst has methods to derive weights

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Rank sum, reciprocal, exponent

Ranking methods to assign weights, after Malczewski (1999)

Criterion	Straight rank
Elev change	4
Mining	2
Roads	5
Wetlands	1
Row crops	3

Straight rank is first step

1 = most important criterion
5 = least important of the five criterion

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Rank sum, reciprocal, exponent

Ranking methods to assign weights, after Malczewski (1999)

		Rank Sum		Rank Reciprocal		Rank Exponent	
		Weight	Normalized	Weight	Normalized	Weight	Normalized
Criterion	Straight rank	$(n-r_j+1)$		$(1/r_j)$		$(n-r_j+1)^p$ $p=2$	
Elev change	4	2	.133	.250	.109	4	.073
Mining	2	4	.267	.500	.219	16	.291
Roads	5	1	.067	.200	.088	1	.018
Wetlands	1	5	.333	1.000	.438	25	.454
Row crops	3	3	.200	.333	.146	9	.164
		15	1.000	2.283	1.000	55	1.000

Straight rank is first step

n = total number of criteria
r_j = the straight rank

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Ranking methods

+ a good first step in working with decision makers toward consensus
+ spreadsheet calculation
+ applicable to GIS applications

- Becomes difficult to straight rank many criteria
- No underlying theoretical foundation
- Not very precise, just approximations

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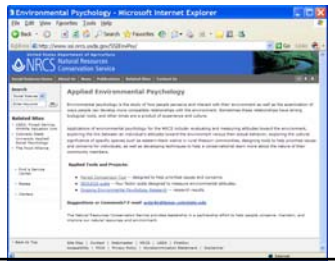
C. Pairwise comparison

- Used by NRCS, USFS, Park Service in land management
- Developed by psychoanalysts



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Background on pairwise comparison

- A well-developed method of ordering attributes or characteristics of a given set of items (Saaty, 1972) – AHP analytical hierarchy process
- Every response the individual makes is reduced to a simple choice between two items.
- The result of these paired choices is a set of items, rank-ordered in terms of which items are chosen more often.

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Other notes

- Using the method of paired comparisons can be helpful for ranking items that are too numerous or too similar to mentally rank order.
- This technique is objective, simple, and also ensures that every participant in a workgroup or public meeting has a voice in how things get prioritized.

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Pairwise comparison

Intensity	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

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Pairwise comparison

	Intensity	Definition
Equal	1	Equal importance
Somewhat prefer	2	Equal to moderate importance
	3	Moderate importance
Prefer	4	Moderate to strong importance
	5	Strong importance
	6	Strong to very strong importance
Strongly prefer	7	Very strong importance
	8	Very to extremely strong importance
	9	Extreme importance

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Example of pc sheet

Name_____

For each paired choice below, fill in the circle to indicate which criteria is more important (or equal) for ranking watersheds for pollution potential

criteria	strongly prefer	prefer	somewhat prefer	equal	somewhat prefer	prefer	strongly prefer	criteria
elevation change	O	O	O	O	O	O	O	wetlands
wetlands	O	O	O	O	O	O	O	road length
road length	O	O	O	O	O	O	O	row crops
row crops	O	O	O	O	O	O	O	mining area

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Pairwise comparison limitation

- Number of full pairwise comparisons add up quickly!

N = number of criteria
Comparisons = (N(N – 1)) / 2

For 10 criteria or judgments…..
comparisons = (10(10-1))/2
= 45

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To limit full comparisons…

- Assume transitivity of preference (an abbreviated pairwise test)

If A is preferred to B and
B is preferred to C
then we assume
A is preferred to C

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Ex of abbreviated pc sheet

Name

For each paired choice below, fill in the circle to indicate which of these criteria you feel are more important (or equal) for siting windfarms.

	strongly prefer	prefer	somewhat prefer	equal	somewhat prefer	prefer	strongly prefer	
Degree of visibility	O	O	O	O	O	O	O	Elevation
Elevation	O	O	O	O	O	O	O	Westerly facing slopes
Westerly facing slopes	O	O	O	O	O	O	O	Distance away from airports
Distance away from airports	O	O	O	O	O	O	O	Distance near power

Abbreviated pairwise test does not allow for tests of consistency since it assumes consistency! (ie. if A > B and B > C then A > C)

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Ex of full pc test

For each paired choice below, fill in the circle to indicate which of these criteria you feel are more important (or equal) for siting windfarms.

	strongly prefer	prefer	somewhat prefer	equal	somewhat prefer	prefer	strongly prefer	
Degree of visibility	O	O	O	O	O	O	O	Elevation
Degree of visibility	O	O	O	O	O	O	O	Westerly facing slopes
Degree of visibility	O	O	O	O	O	O	O	Distance away from airports
Degree of visibility	O	O	O	O	O	O	O	Distance near power
Elevation	O	O	O	O	O	O	O	Westerly facing slopes
Elevation	O	O	O	O	O	O	O	Distance away from airports
Elevation	O	O	O	O	O	O	O	Distance near power
Westerly facing slopes	O	O	O	O	O	O	O	Distance away from airports
Westerly facing slopes	O	O	O	O	O	O	O	Distance near power
Distance away from airports	O	O	O	O	O	O	O	Distance near power

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Step 1. create a comparison matrix

For our windfarm suitability model, assume we use three criteria

- visibility (vis)
- elevation (elev)
- aspect (asp)

Criterion	Vis	Elev	Asp
Vis			
Elev			
Asp			

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Step 2.

- Get comparisons using selected intensities

1 = equal preference
3 = prefer
6 = strongly prefer

For finding suitable windfarm locations we find that:
Vis is preferred over elev
Vis is strongly preferred over asp
Elev is preferred over asp

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Step 3.a

- After making the diagonal values = 1, Fill in upper right corner of the matrix

1 = equal preference
3 = prefer
6 = strongly prefer
For finding suitable windfarm locations we find that:
Vis is preferred over elev
Vis is strongly preferred over asp
Elev is preferred over asp

Criterion	Vis	Elev	Asp
Vis	1	3	6
Elev		1	3
Asp			1

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Step 3.b

- Fill in matrix with reciprocal values

Criterion	Vis	Elev	Asp
Vis	1	3	6
Elev	1/3	1	3
Asp	1/6	1/3	1

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Step 4.a

- Sum columns

Criterion	Vis	Elev	Asp
Vis	1	3	6
Elev	1/3	1	3
Asp	1/6	1/3	1
	1.50	**4.33**	**10.00**

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Step 4.b

- Normalize the matrix

Criterion	Vis	Elev	Asp
Vis	1	3	6
Elev	1/3	1	3
Asp	1/6	1/3	1
	1.50	**4.33**	**10.00**

Criterion	Vis	Elev	Asp
Vis	.666	.692	.600
Elev	.222	.230	.300
Asp	.111	.076	.100

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Step 4.c

- Find the average of the rows, this will be the weights for the criteria

Criterion	Vis	Elev	Asp
Vis	.666	.692	.600
Elev	.222	.230	.300
Asp	.111	.076	.100

(.666+.692+.600) / 3 = 0.653 Visibility
(.222+.230+.300) / 3 = 0.251 Elevation
(.111+.076+.100) / 3 = 0.096 Aspect

Sum to 1

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Step 5.

- Check for consistency in comparisons by first computing a consistency vector

Criterion	Vis	Elev	Asp
Vis	1	3	6
Elev	.333	1	3
Asp	.166	.333	1

Original matrix from 3.b

0.653 Visibility
0.251 Elevation
0.096 Aspect

Weights from 4.c

Vis	(0.653)(1) + (0.251)(3) + (0.096)(6) = 1.982
Elev	(0.653)(.333) + (0.251)(1) + (0.096)(3) = 0.756
Asp	(0.653)(.166) + (0.251)(.333) + (0.096)(1) = 0.2878

Vis	1.982 / 0.653 = 3.035
Elev	0.756 / 0.251 = 3.011
Asp	0.287 / 0.096 = 2.989

New consistency vector

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Step 6.a

- Now that we have the consistency vector, we need to compute two more terms, lambda (λ) and the consistency index (CI)

λ = the average of the consistency vector from step 5.

= (3.305 + 3.011 + 2.989) / 3

= 3.101

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Step 6.b

- Compute the consistency index which provides a measure from consistency

CI = (λ – N) / (N- 1)

N = number of criteria

CI = 3.101 – 3 / 3 -1

= 0.050

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Step 7.

- With the consistency index (CI) we can now use the random index (RI) table to compute the consistency ratio (CR)

CR = CI / RI

= 0.050 / 0.58

= 0.086

Number of criteria	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Saaty (1999) p.186

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Step 8.

- Interpretation of the consistency ration (CR)

If CR < 0.100 then there is consistency in responses

In our example, since the CR is 0.086 which is < 0.100 then we can use the weights from step 4c.!

0.653 Visibility
0.251 Elevation
0.096 Aspect

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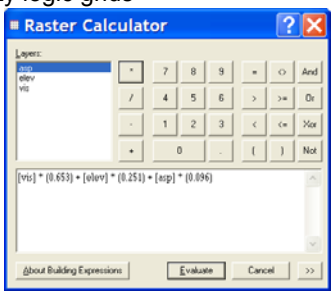
Step 9.

- Integrate into GIS with the index overlay or fuzzy logic grids



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Pairwise comparison

+ good theoretical foundation for further statistical test (Mann-Whitney)
+ easy for decision makers to understand
+ applicable to GIS applications

- Becomes difficult to straight rank many criteria
- Must check for consistency or assume transitivity of preferences
- Time consuming computations
- Path dependency issue

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Summary

Which method to use depends on the trade-offs one is willing to make between

- Ease of use
- Accuracy
- Degree of understanding on the part of the decision maker
- Theoretical foundation
- Availability of computer software

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FYI: Software for weighting

- Criterion Decision Plus
- Expert Choice
- Logical Decisions
- Pairwise comparison program by NRCS
- AHP Arcscripts toolbar for ArcGIS

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Other options for weights

- Use modeled output from logistic regression or principal component analysis
- Past studies or published literature
- Interview experts, survey results
- Habitat suitability indices (HSIs) for wildlife studies

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