ArcGIS Spatial Analyst – Suitability Modeling

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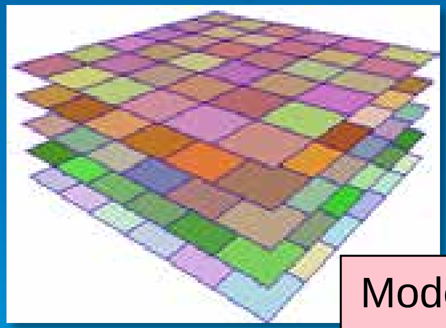
Technical Workshop

Suitability modeling

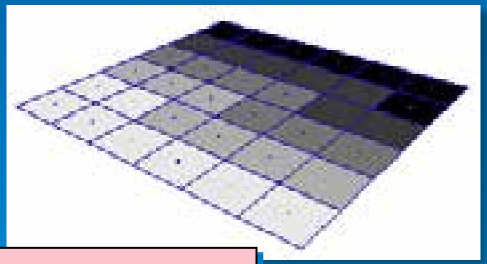
- **Where to site a new housing development?**
- **Which sites are better for deer habitat?**
- **Where is economic growth most likely to occur?**
- **Where is the population at the greatest risk if a chemical spill were to happen?**

Reality

GIS layers



Suitability for store



Model criteria:
- Zoned commercial
- Near target population
- Away from competition

What we know

- The best locations can be determined from the features at each location
- You can identify the features that define the best locations
- You can quantify the relative preference of the features relative to one another
- You know what is not important to the phenomenon
- The attributes and numbers associated with the data vary in type and meaning

The presentation outline

- Background
- How to create a suitability model and the associated issues
- Demonstration
- Look deeper into the transformation values and weights
- Demonstration
- Fuzzy logic

Manipulation of raster data - Background

- Locational perspective of the world
- Defines a portion of the landscape’s attributes
- Worm’s eye view
- To return a value for each cell you must know
  - What is your value
  - What function to apply
  - What cell locations to include in the calculations
    - Within a grid
    - Between grids

Discrete and continuous phenomena

- Discrete phenomena
  - Landuse
  - Ownership
  - Political boundaries
- Continuous phenomena
  - Elevation
  - Distance
  - Density
  - Suitability

Discrete

0	1	1	2
No Data	1	1	1
No Data	1	2	2
1	1	2	2

Vegetation

0 = Barren
1 = Forest
2 = Water

Continuous

1.12	1.75	1.81	2.03
0.26	1.63	1.87	1.98
0.00	0.91	0.73	1.42
0.00	0.18	No Data	No Data

Rainfall (inches)

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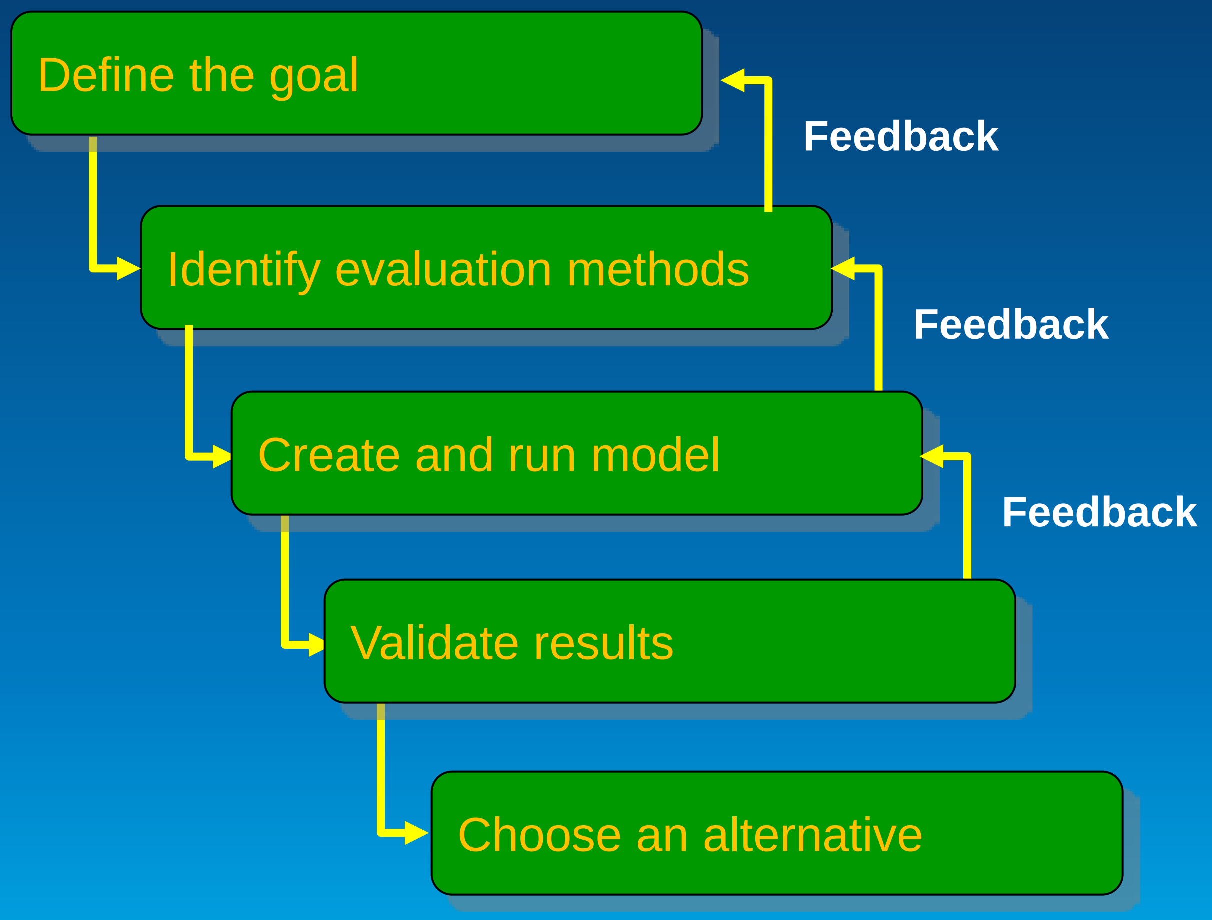
General suitability modeling methodology



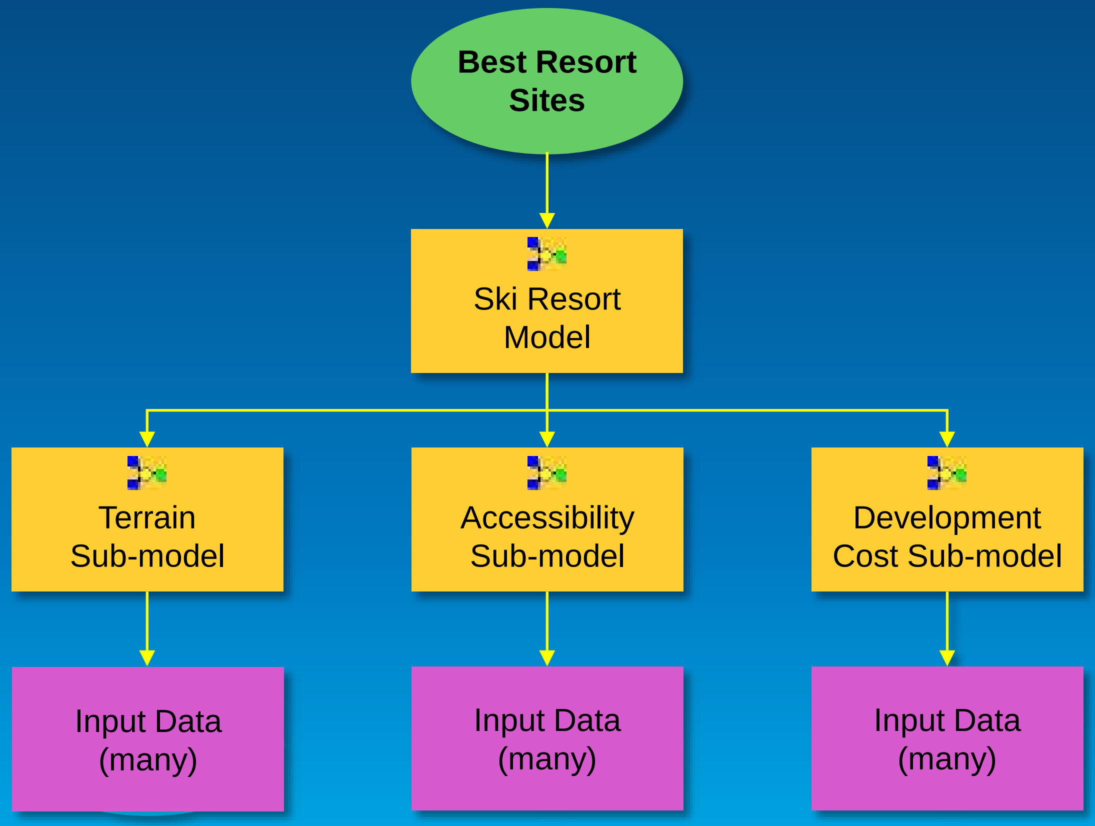
Problem definition

- Most important and most time consuming – glossed over
- Measurable
- The gap between desired and existing states

- Define the problem
  - “Locate a ski resort”
- Establish the over arching goal of the problem
  - Make money
- Identify issues
  - Stakeholders
  - Legal constraints

Models and sub-models

- **Break down problem into sub models**
  - **Helps clarify relationships, simplifies problem**



Identify evaluation methods

- How will you know if the model is successful?
- Criteria should relate back to the overall goals of the model
- May need to generalize measures
  - “On average near the water”
- Determine how to quantify
  - “Drive time to the city”

ModelBuilder

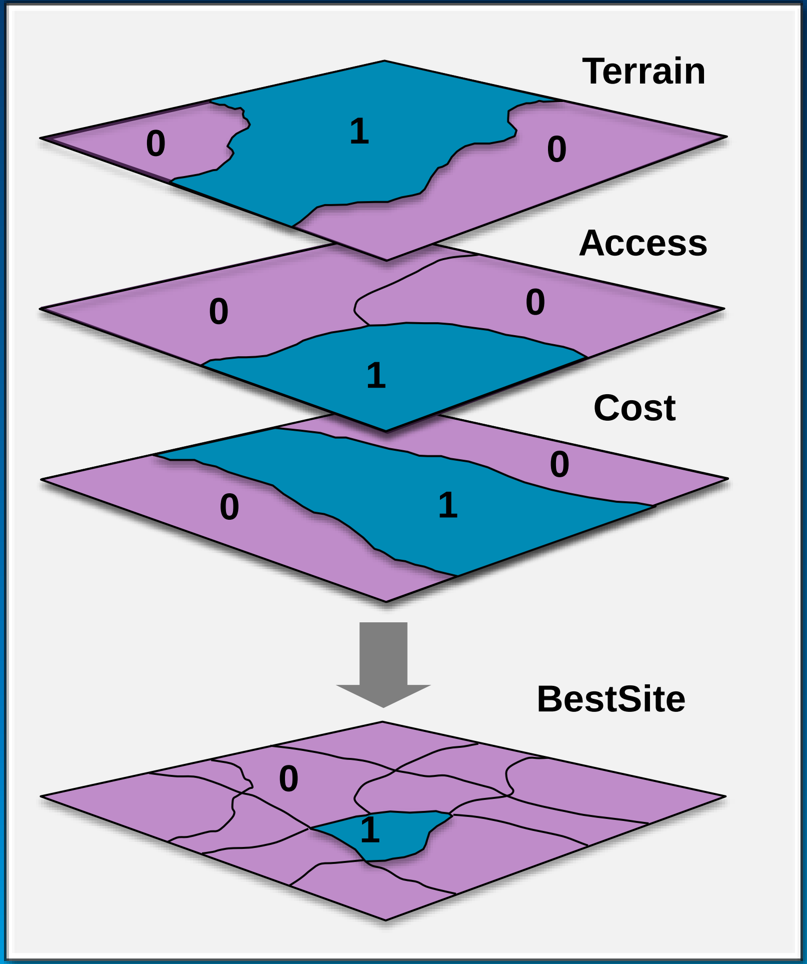
- **ArcGIS graphical model building capabilities**

Types of suitability models - Binary

- Use for simple problems - query
- Classify layers as good (1) or bad (0) and combine:

```
BestSite = Terrain & Access & Cost
```

- Advantages: Easy
- Disadvantages:
  - No “next-best” sites
  - All layers have same importance
  - All good values have same importance

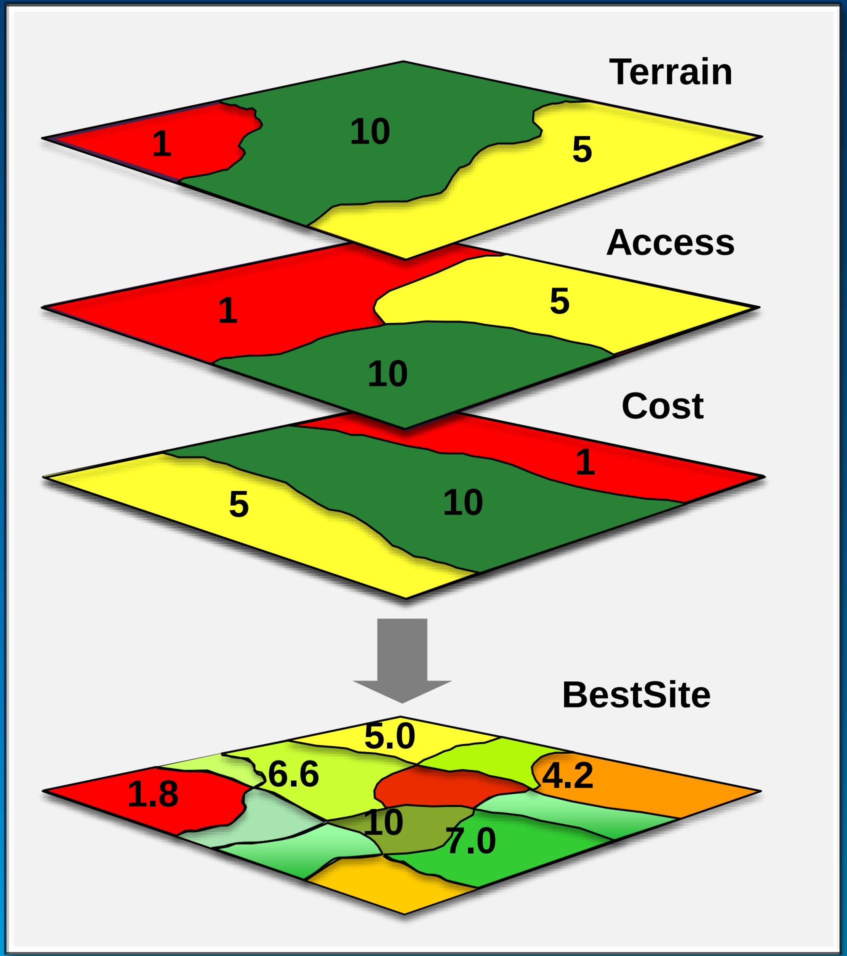


Types of suitability models - Weighted

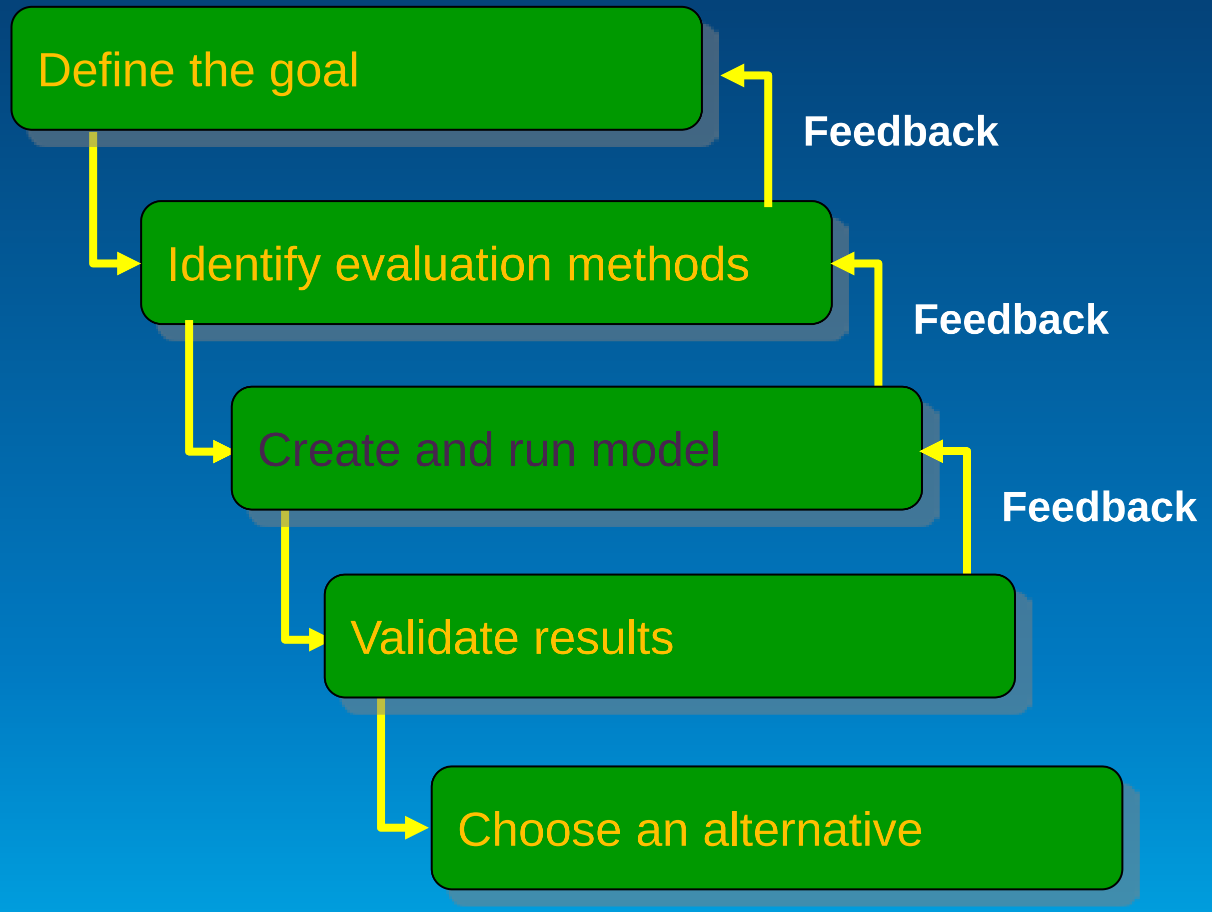
- Use for more complex problems
- Classify layers into suitability 1–9
  - Weight and add together:

```
BestSite = (Terrain * 0.5) +
    (Access * 0.3) + (Cost * 0.2)
```

- Advantages:
  - All values have relative importance
  - All layers have relative importance
  - Suitability values on common scale
- Disadvantages:
  - Preference assessment is more difficult



General suitability modeling methodology



The suitability modeling model steps

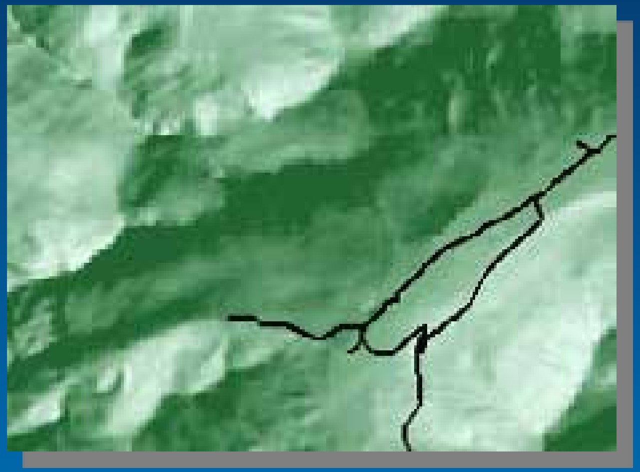
- **Determine significant** layers for each sub model from the phenomenon's perspective
  - May need to derive data
- **Transform values** within a layer onto a relative scale
- **Weight** the importance of each layer and each sub model relative to one another
- **Combine** layers and sub models together
- **Locate** the best areas meeting your goals

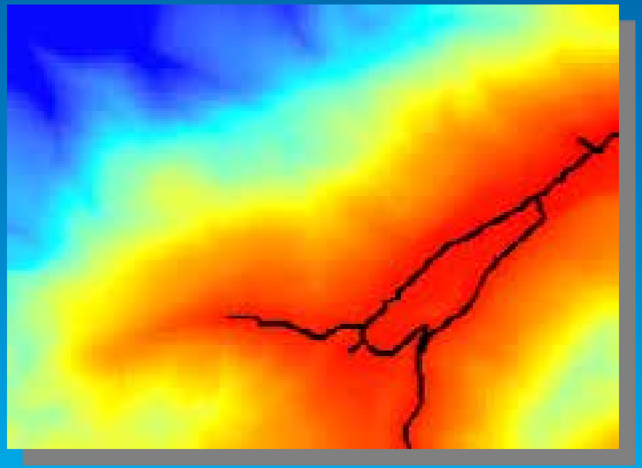
Determining significant layers

- The phenomena you are modeling must be understood
- What influences the phenomena must be identified
- How the significant layers influence the phenomena must be determined
- Irrelevant information must be eliminated
- Simplify the model
  - Complex enough to capture the essence and address the question

Transform values – Place various criteria on common scale

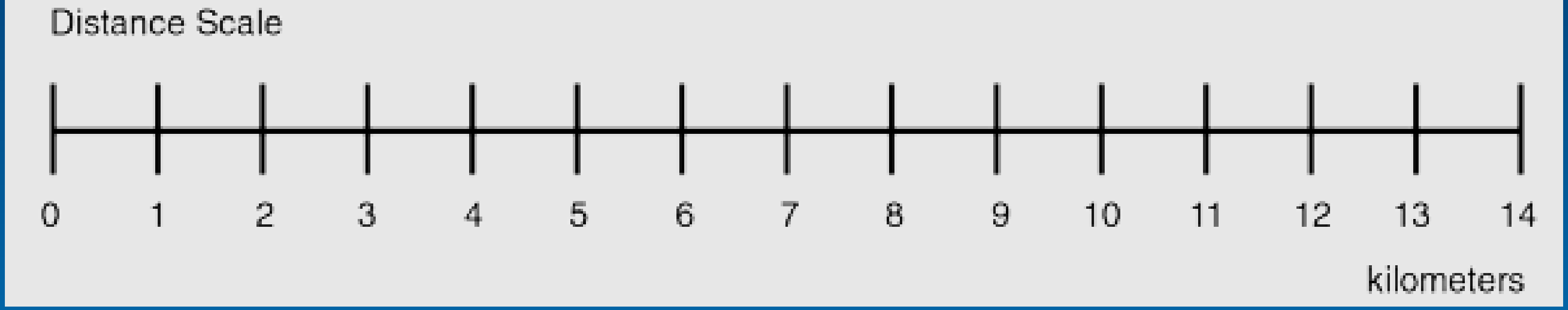
- **Base data may not be useful for measuring all criteria**
  - **Need to measure access, not road location**
- **May be easy:**
  - **ArcGIS Spatial Analyst tools**
  - **Distance to roads**
- **May be harder:**
  - **Require another model**
  - **Travel time to roads**



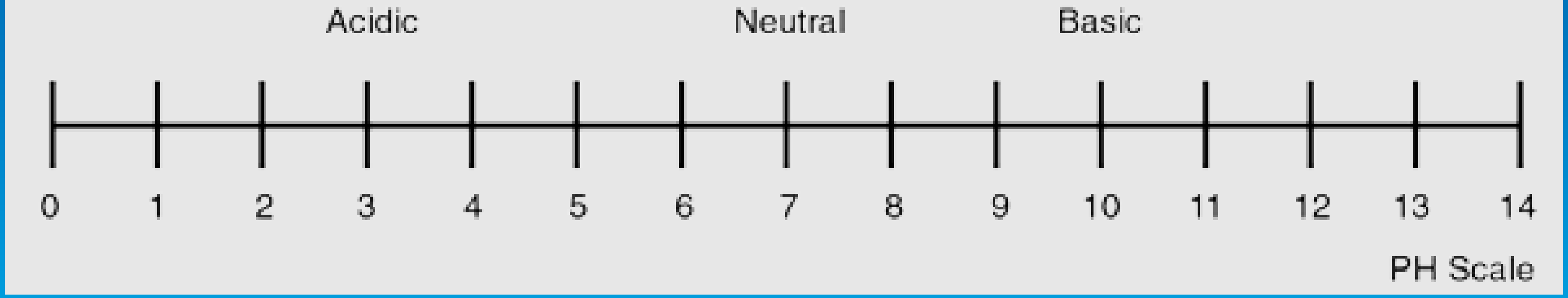


Why transform values?

Ratio:

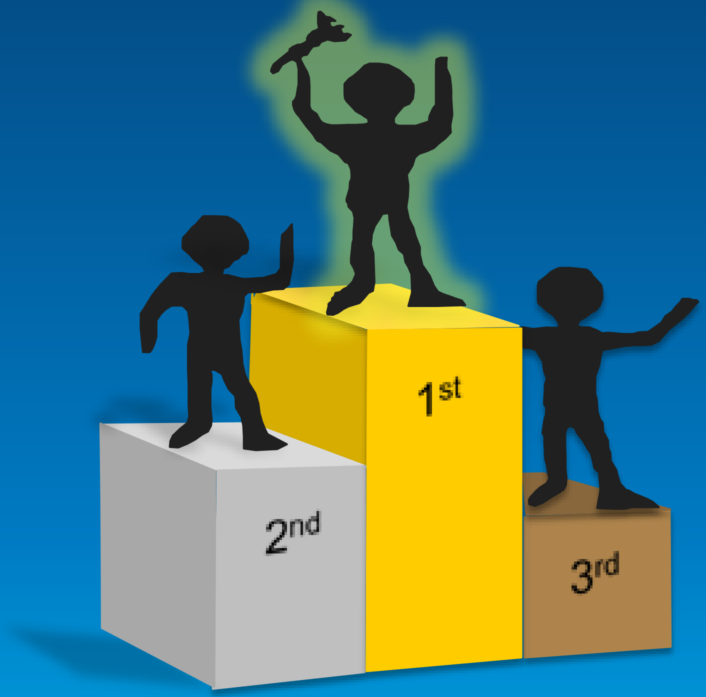


Interval:

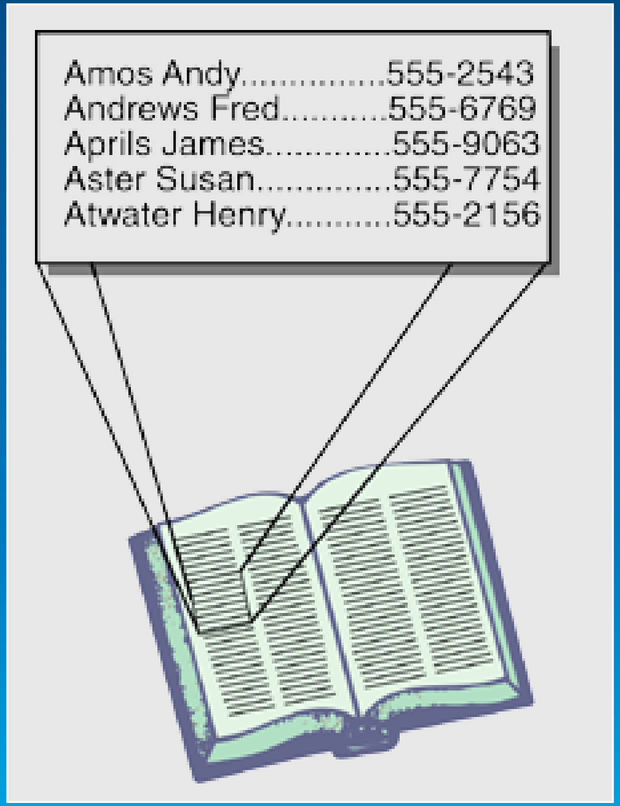


Why transform values?

Ordinal:

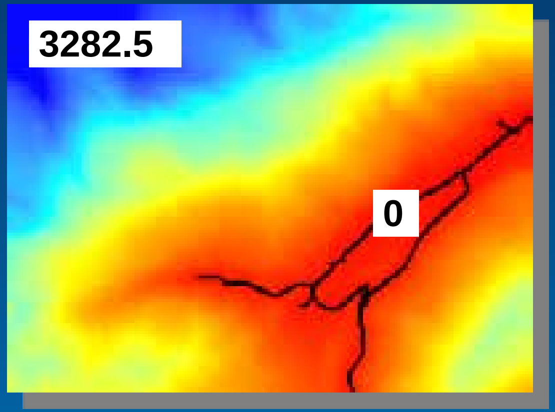


Nominal:



Transform values - Define a scale of suitability

- Define a scale for suitability
  - Many possible; typically 1 to 9 (worst to best)
  - Reclassify layer values into relative suitability
  - Use the same scale for all layers in the model



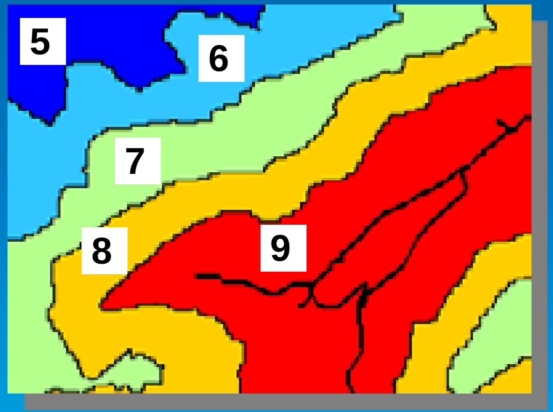
Distance to roads

Accessibility sub model

	Travel time suitability
Best	9 – 0 minutes to off ramp
	8
	7
	6
	5 – 15 minutes to off ramp
	4
	3
	2
Worst	1 – 45 minutes to off ramp

Development sub model

	Soil grading suitability
Best	9 – Recent alluvium; easy
	8
	7
	6
	5 – Landslide; moderate
	4
	3
	2
Worst	1 – Exposed bedrock; hard

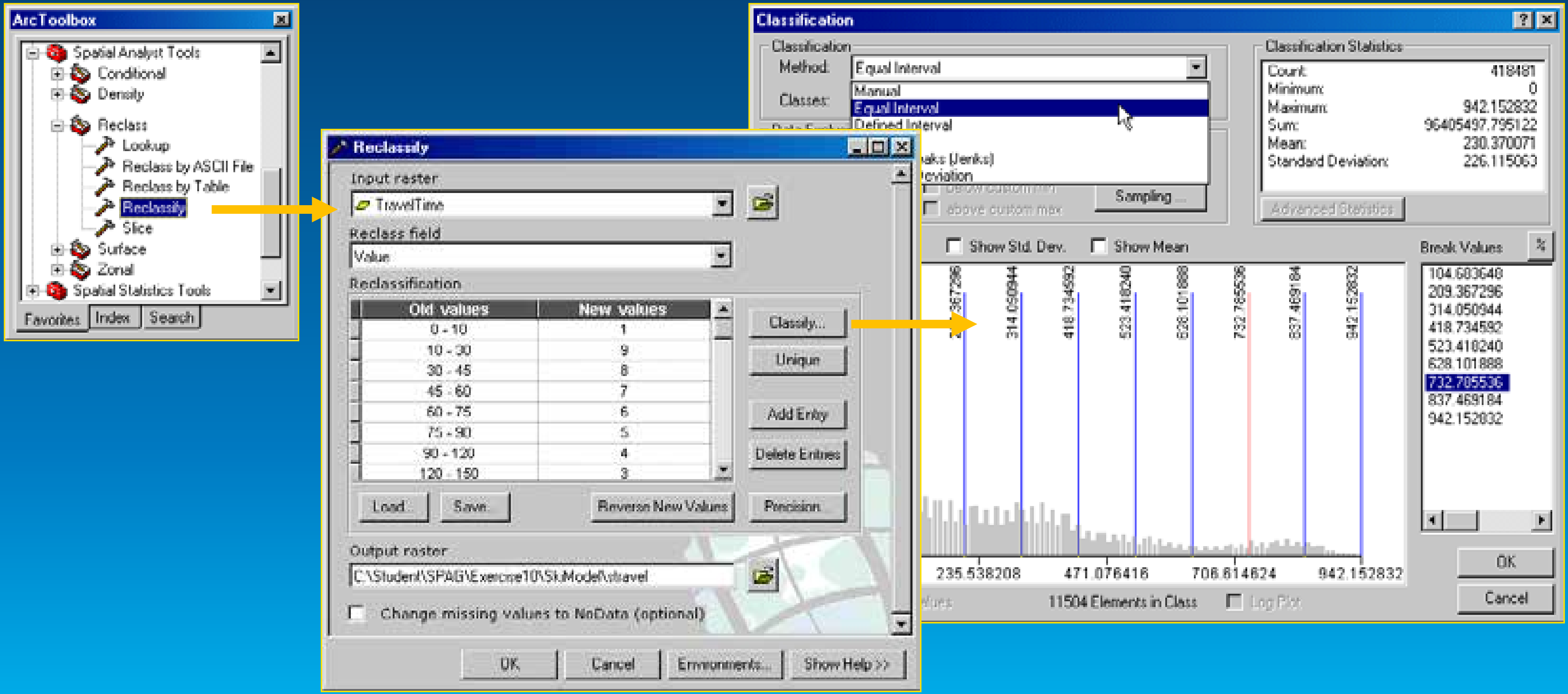


Suitability for Ski Resort

Within and between layers

The Reclassify tool

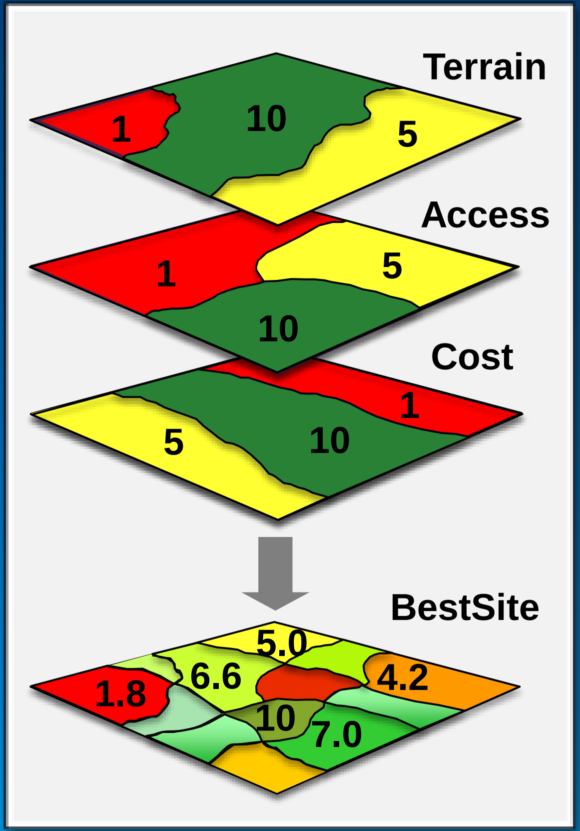
- **May use to convert measures into suitability**



Weight and combine the layers

- Certain criteria may be more significant than others and must be weighted appropriately before combining
  - Terrain and access may be more significant to the ski area than cost

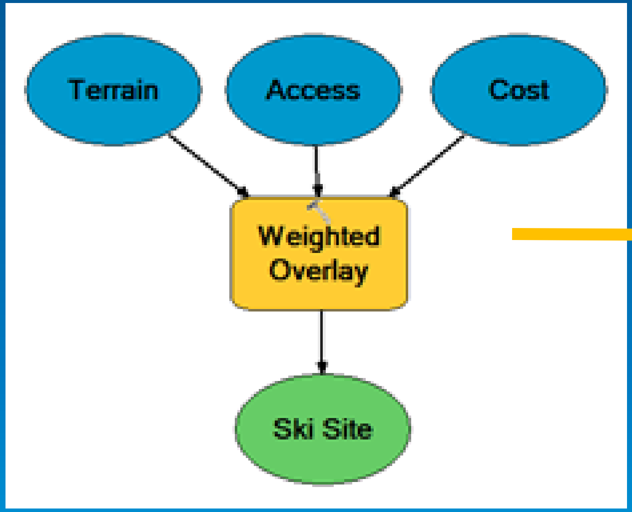
- Use Weighted Overly, Weighted Sum tool, or Map Algebra

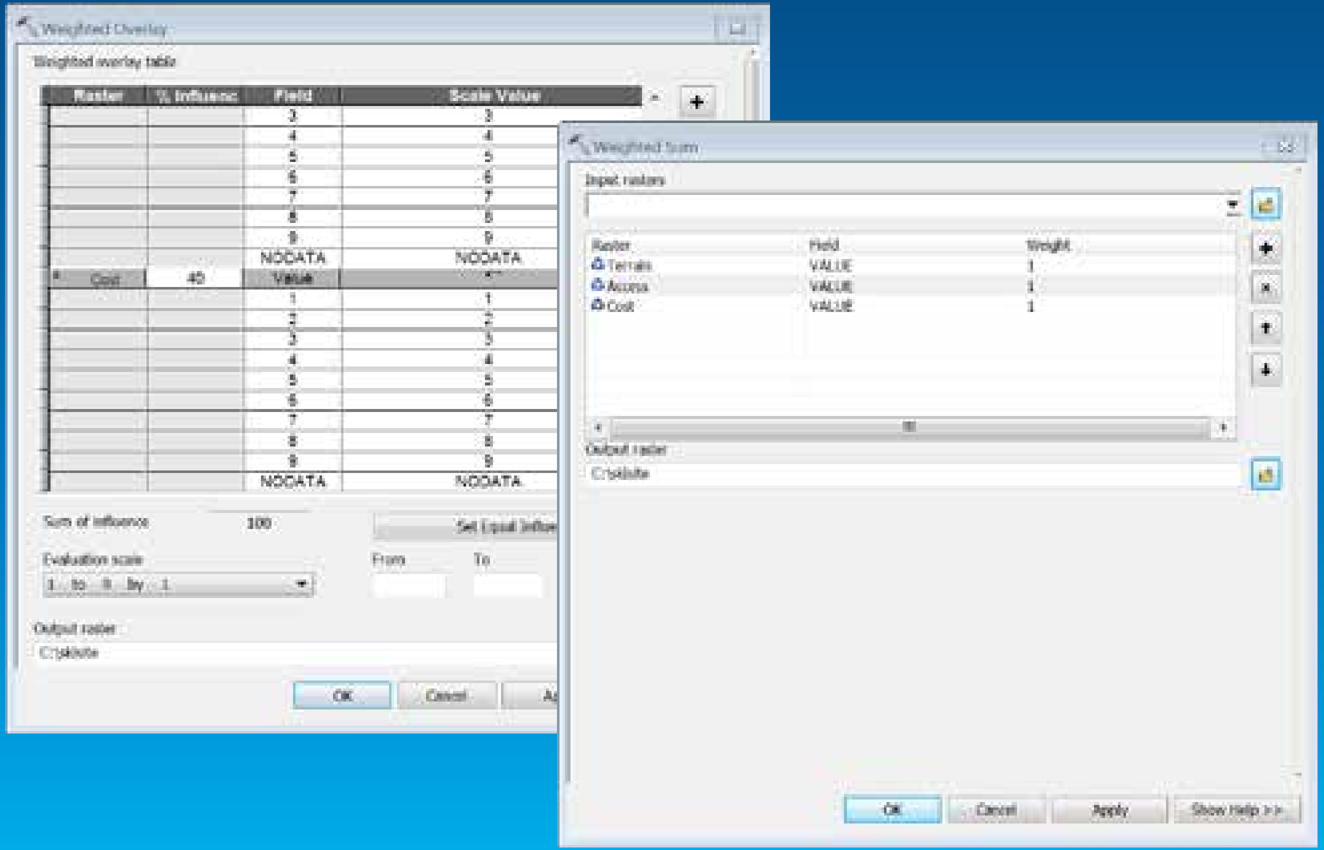



```
SkiSite = (Terrain * 0.5) + (Access * 0.3) + (Cost * 0.2)
```

The Weighted Overlay tool

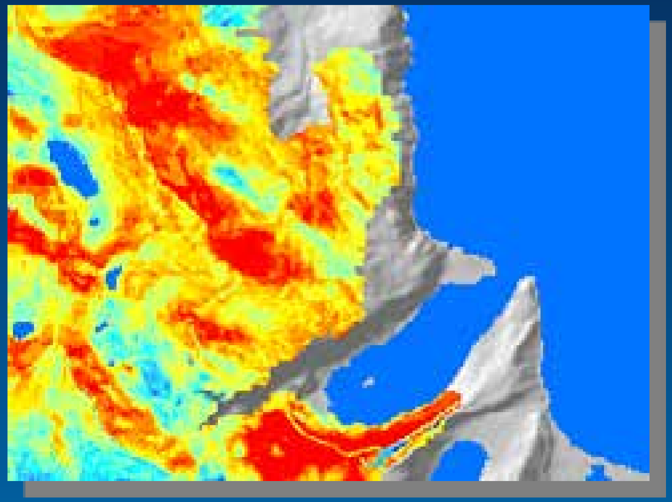
- **Weights and combines multiple inputs**
  - **Individual criteria (layers)**
  - **Sub models**

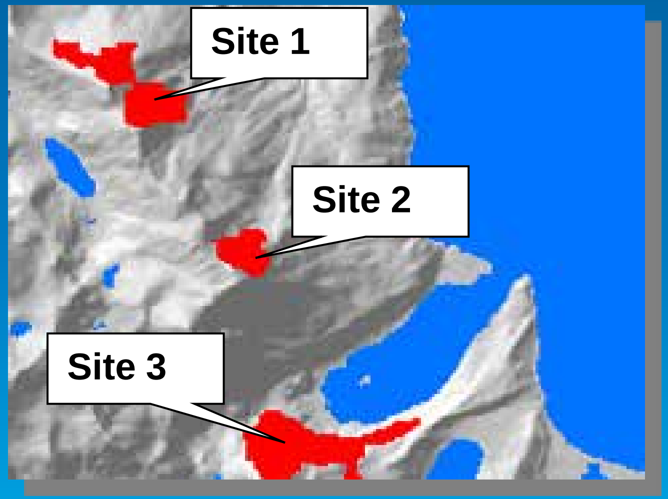




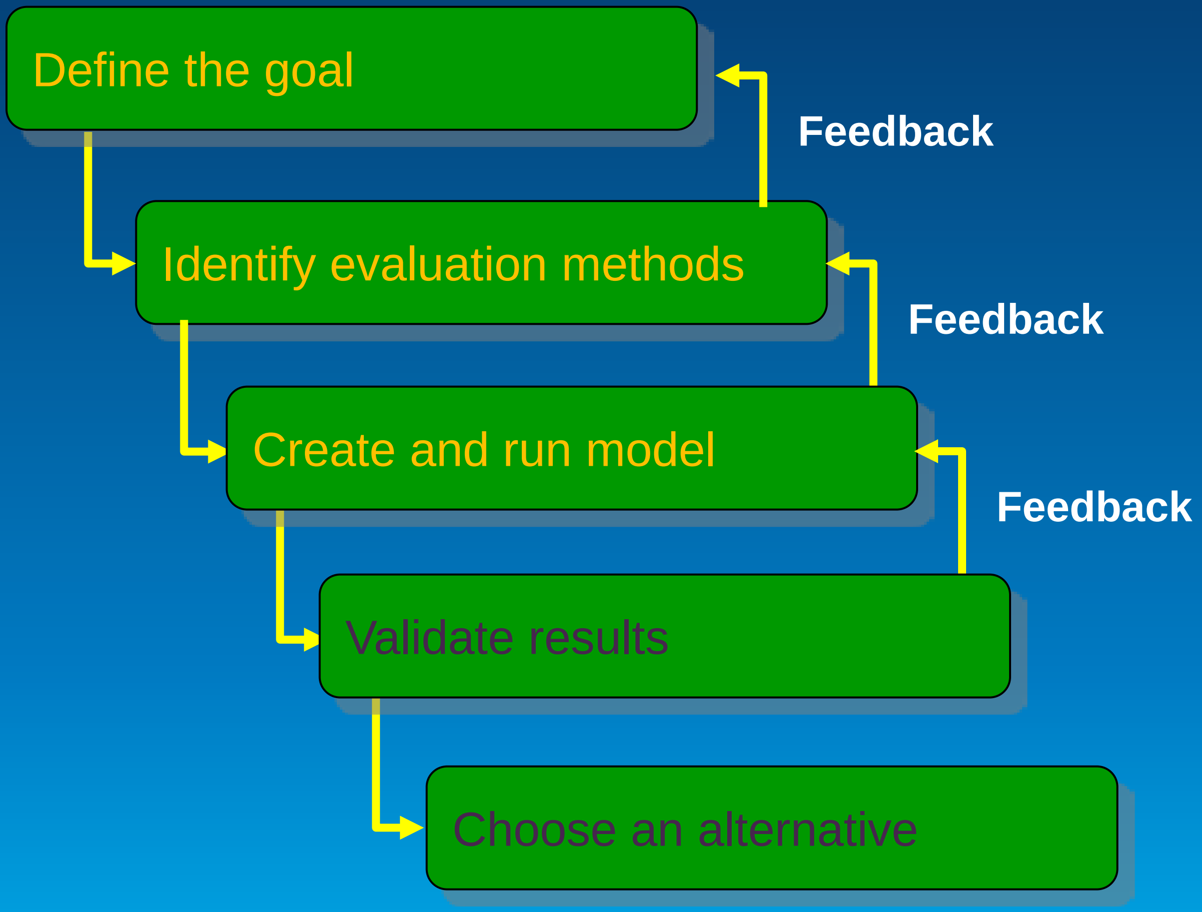
Locate

- Model returns a suitability “surface”
  - Ranks the relative importance of each site to one another relative to the phenomenon
- Create candidate sites
  - Select cells with highest scores
  - Define regions with unique IDS (Region Group)
  - Eliminate regions that are too small
- Choose between the candidates





General suitability modeling methodology



Validation

- Ground truth – visit the site in person
- Use local knowledge and expert experience
- Alter values and weights
- Perform sensitivity and error analysis

Limitations of a suitability model

- Results in a surface indicating which sites are more preferred by the phenomenon than others
- Does not give absolute values (can the animal live there or not; ordinal not interval values)
- Heavily dependent on the transformed values within a criterion and the weights between criteria

The presentation outline

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- Fuzzy logic

Demo 1: Suitability Model

Transform values

Weight

Combine

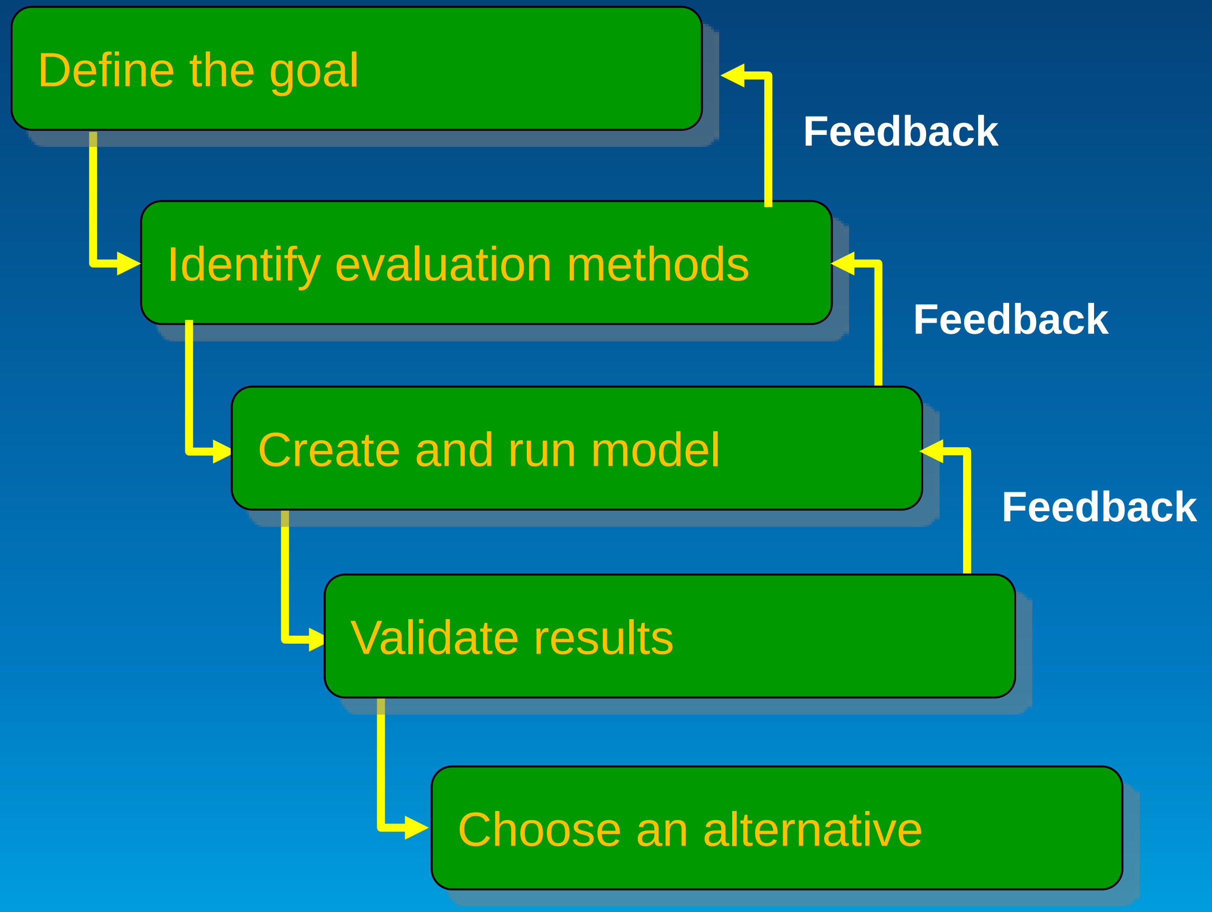
The story is not over

- How the values are transformed within criterion and weighted between criteria have not been critically examined
- Do the transformed values accurately capture the phenomenon?
- The transformation of the values was done by expert opinion – are there other approaches?
- Continuous criterion were reclassified by equal interval
- Assumes more of the good features the better
- What happens when there are many criteria?

Multicriteria decision making

- GIS and Multicriteria Decision Analysis (J. Malczewski)
- Operation Research (linear programming)
- Decision support
- We are not trying to identify the best method
  - Problem you are addressing
  - Available data
  - Understanding of the phenomenon
- Provide you with alternative approaches
- Make you think about how to transform the values and weight within and between the criteria

General suitability modeling methodology



Identify evaluation methods

- Objectives and criteria
  - Build on slopes less than 2 percent
- Many times take on the form:
  - Minimize cost; Maximize the visual quality
- The more the better; the less the better
- Proxy criteria
  - Reduce the lung disease – amount of carbon dioxide
- How to determine influence of the attributes
  - Literature, studies, Survey opinions
  - Conflicts?

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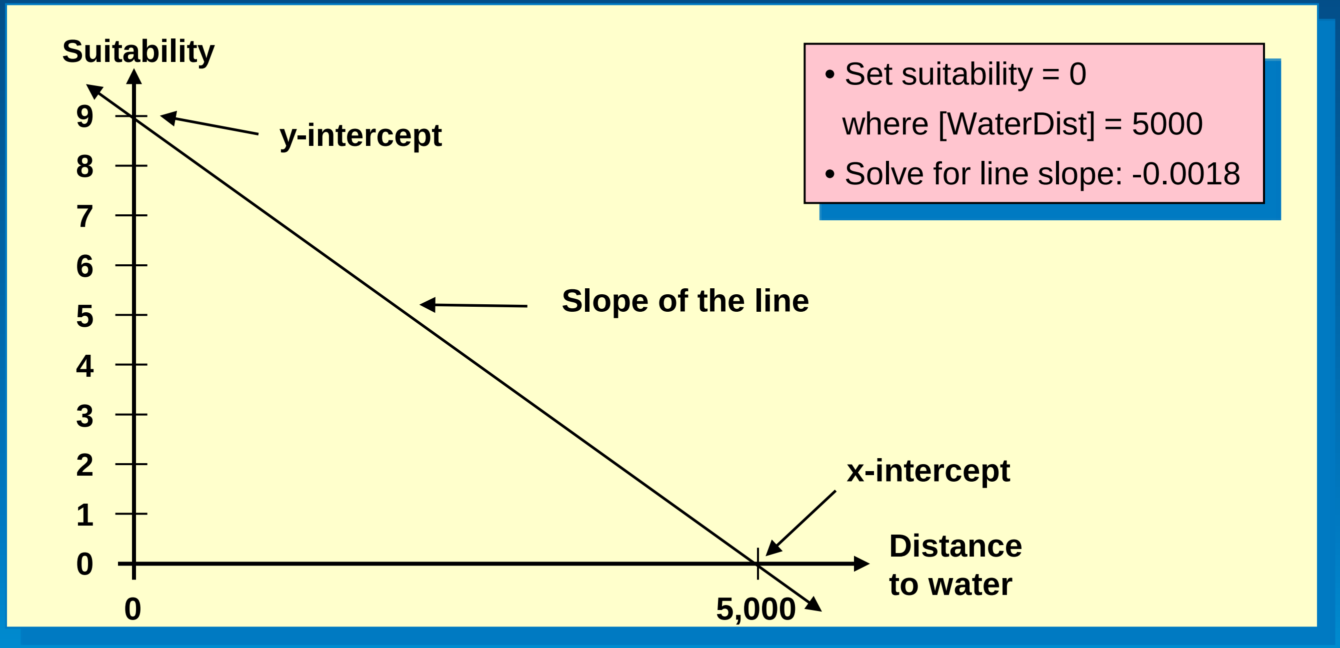
Transform values

- Evaluation criteria
- Direct scaling (as you have seen)
- Linear transformation
  - Divide each value by the maximum value
  - Scale 0 – 1 (relative order of magnitude maintained)
  - Apply to each layer
- Value/utility functions
- Others:
  - Fuzzy sets

Transform values: Value/Utility functions

- **Transform values with equations – ratio data**
  - **Mathematical relationship between data and suitability**

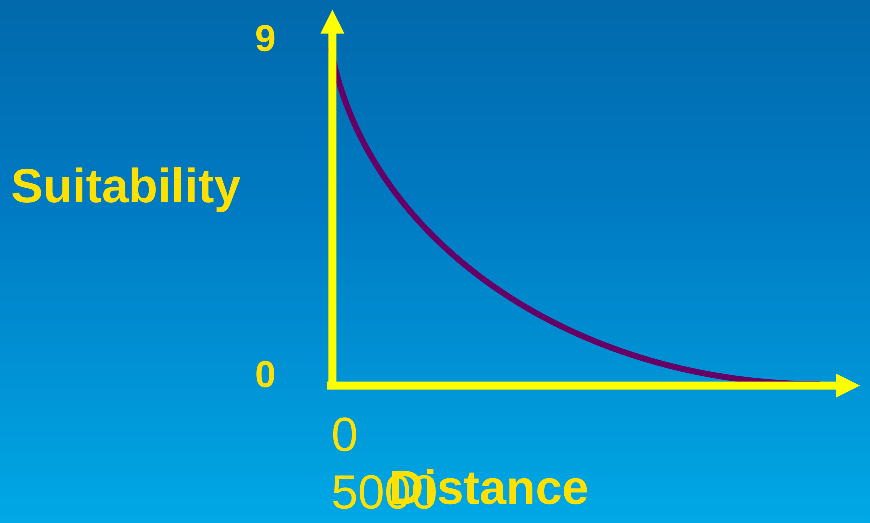


Implement with Rescale by Function or Map Algebra:

```
WaterSuit = 9 + ( -0.0018 * WaterDist)
```

Transform values: Value/Utility functions

- Not a linear decay in preference
- The intervals for the attribute are not equal
- The preference scaling is not equal
- Output evaluation values are continuous



Reclassify versus Rescale by Function

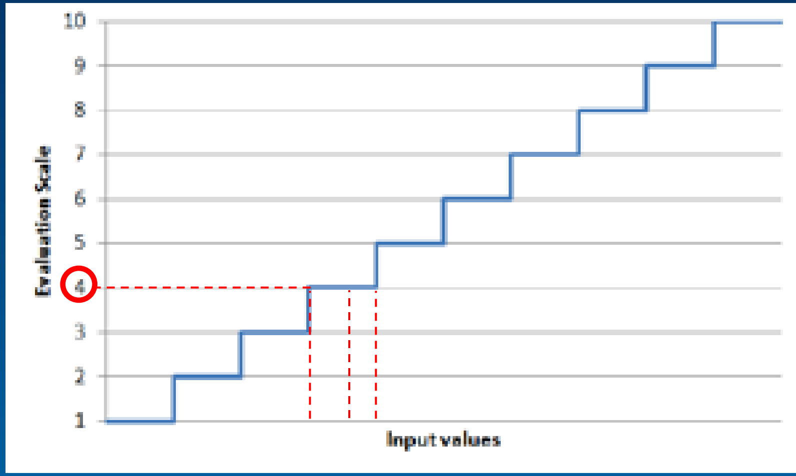
- Reclassify
  - Categorical input
  - Discrete output
  - One to one (or range) mapping

- Rescale by Function
  - Continuous input
  - Continuous output
  - Linear and non linear functions

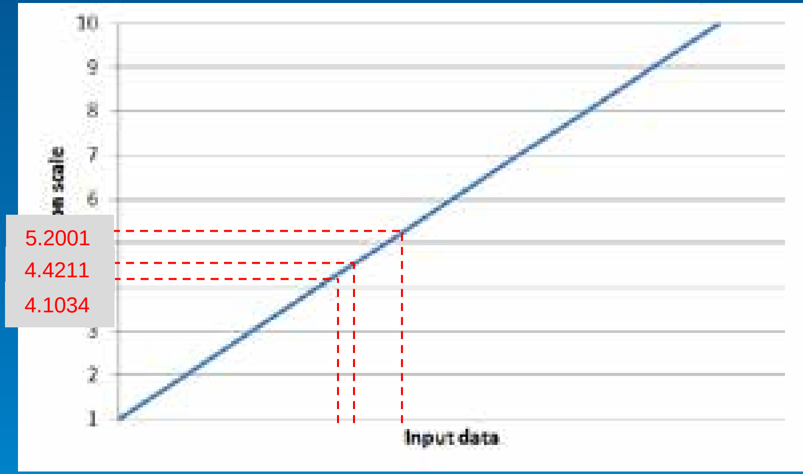
Reclassify versus Rescale by Function

Reclassify

For discrete input and output (or input has continuous known class breaks)



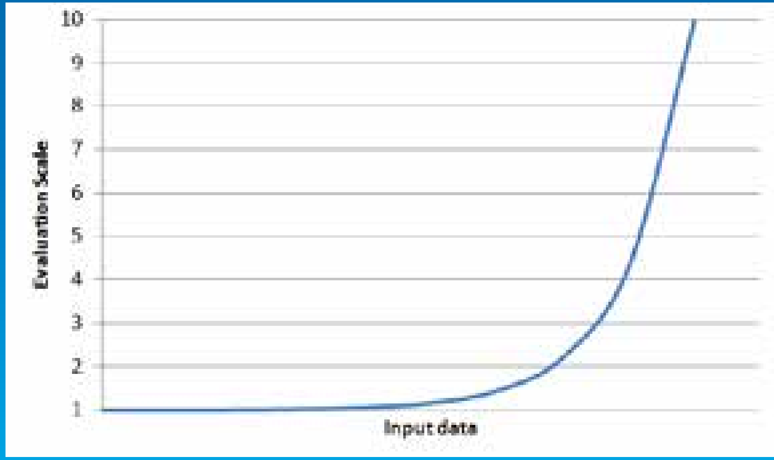
If input is continuous - stair step effect caused by the discrete classes



Rescale by Function

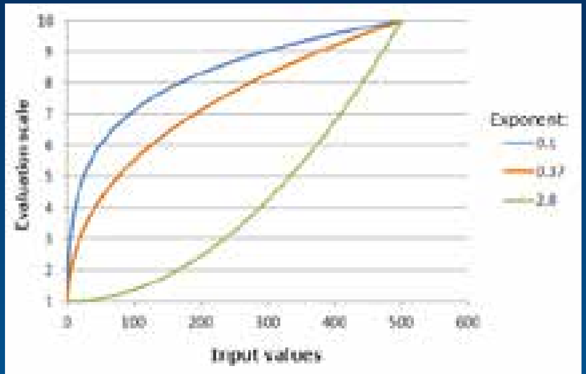
For continuous input and output

Suitability continuously changes with each unit of change of the input data

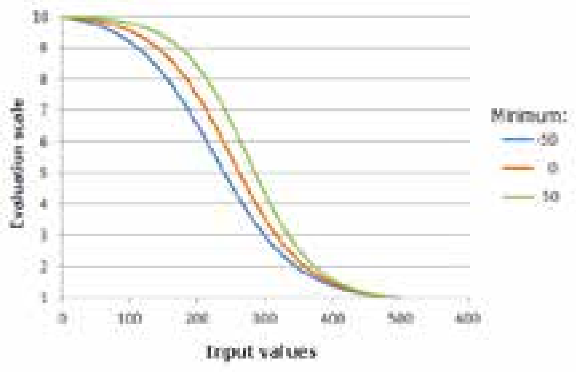


Nonlinear functions

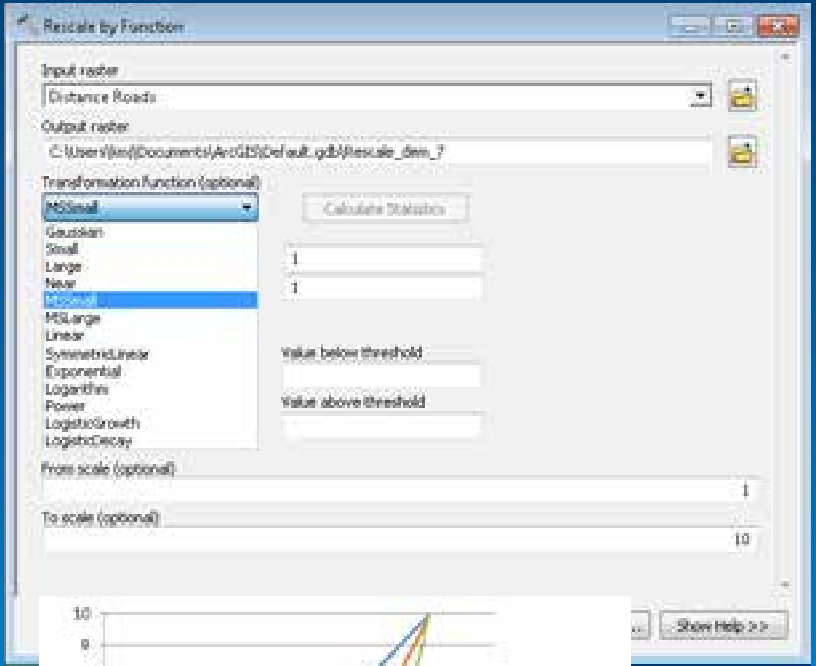
Rescale by Function: the functions

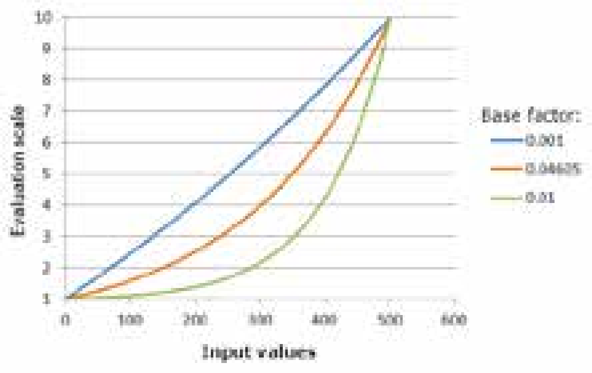


Power

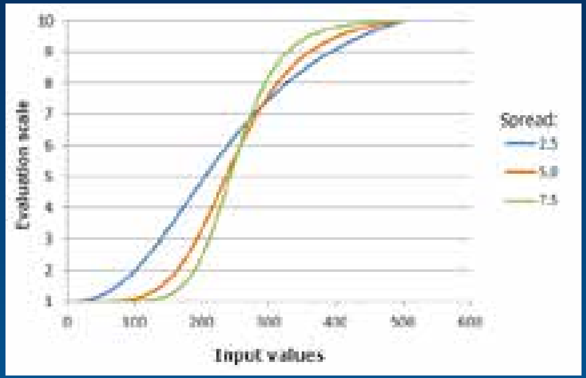


Logistic decay

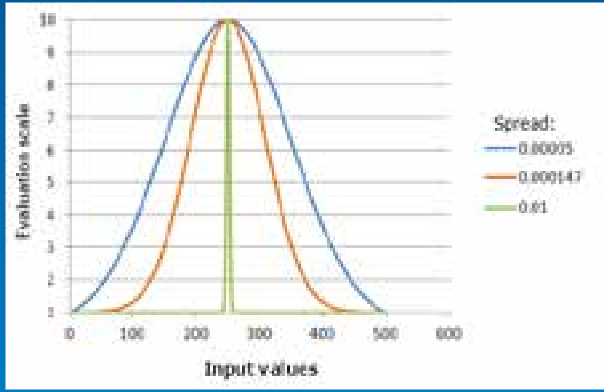




Exponential



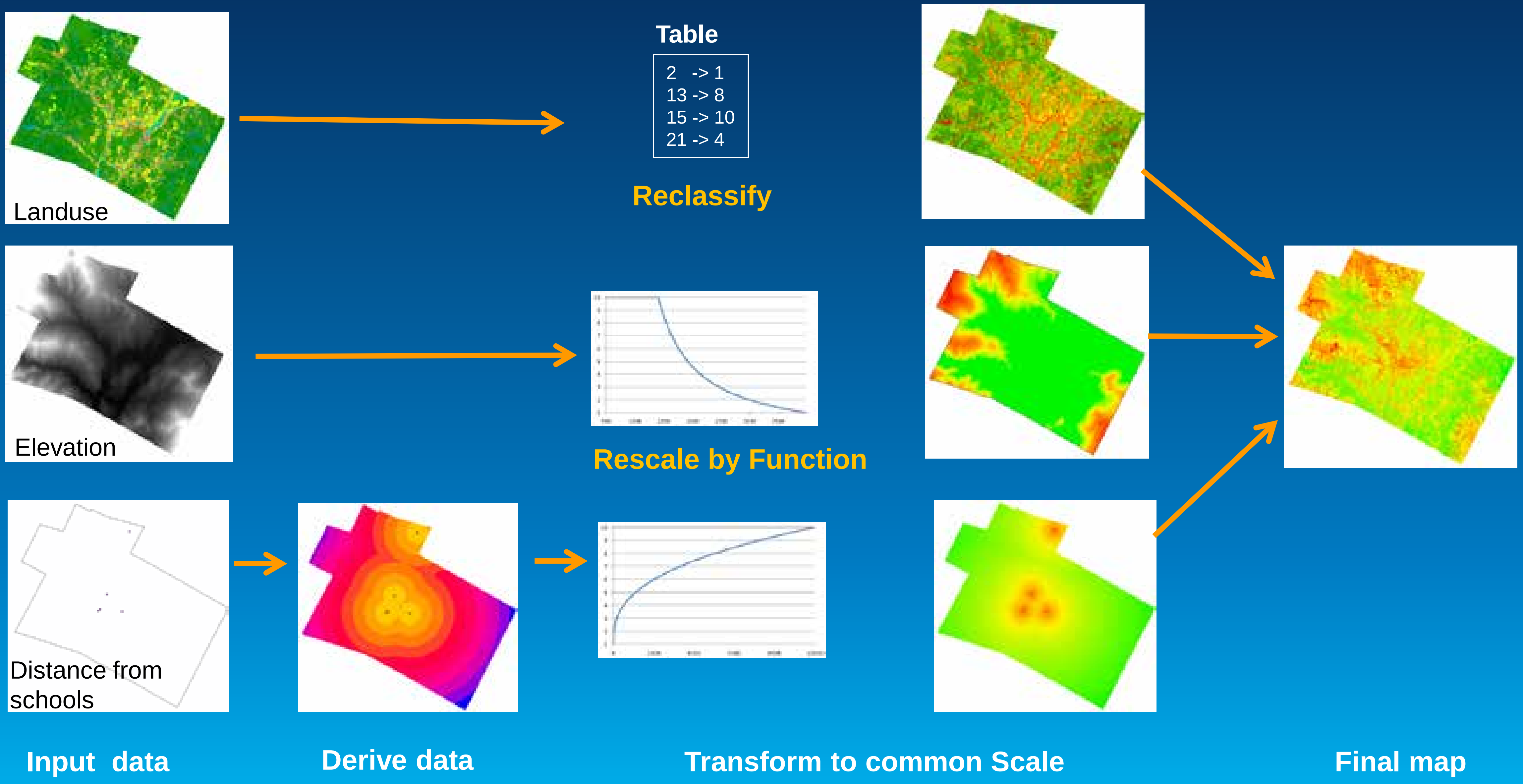
Large



Gaussian

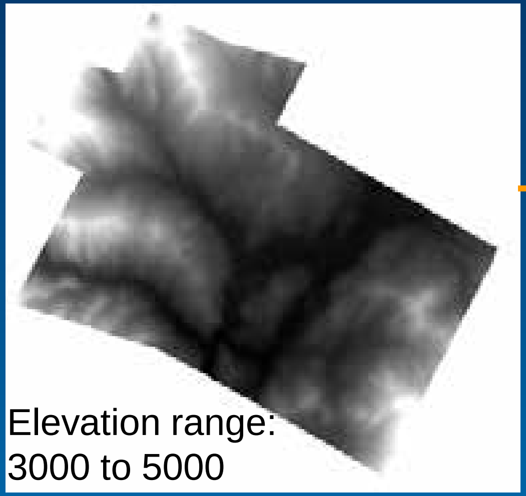
The function can be further refined by the function parameters

Suitability workflow



Anatomy of applying a function

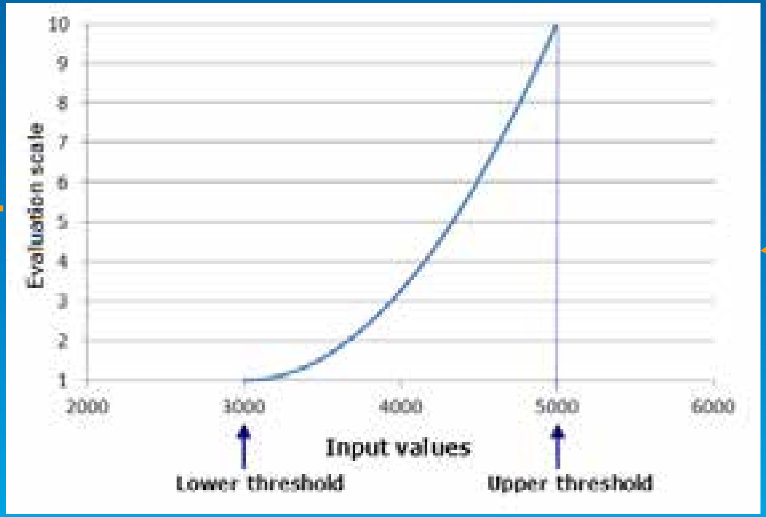
Input data



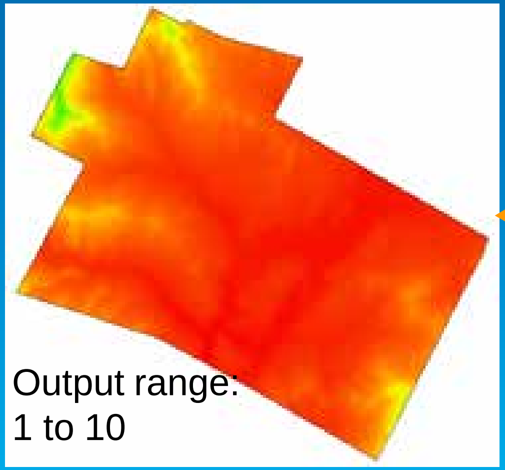
Apply the rescale function to the input values creating function values – f(x)

Exponential function

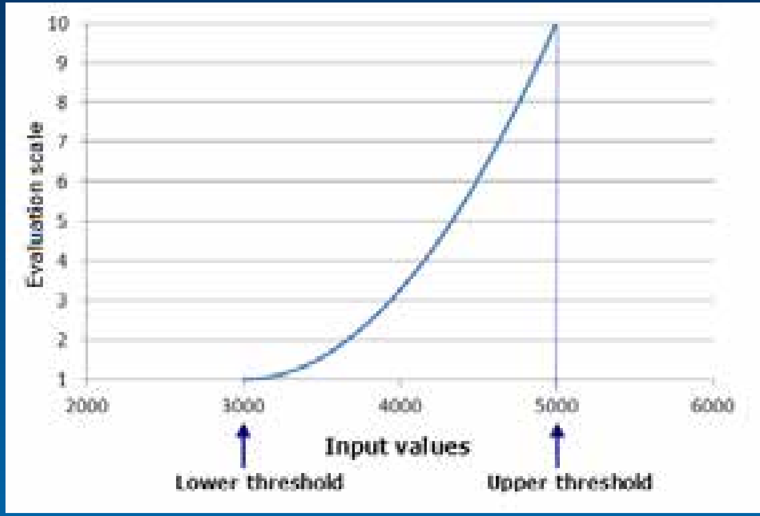
The function range is mapped to the evaluation scale (e.g., 1 to 10 suitability)



Output data

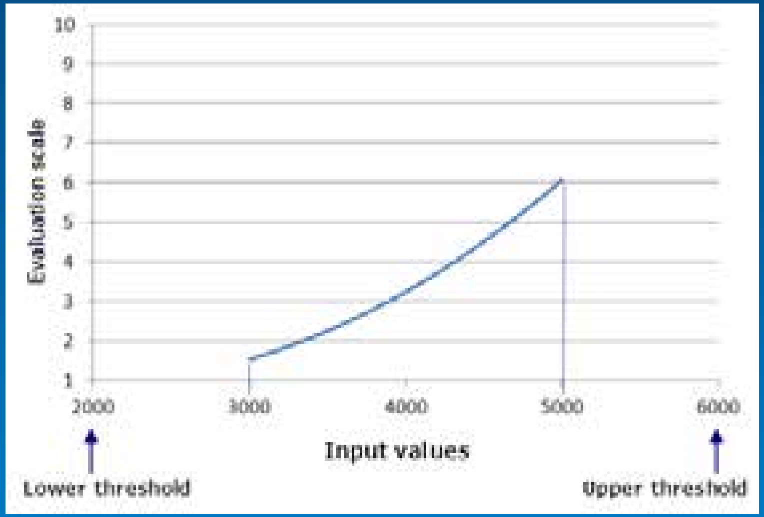


Rescale by Function – Data dependence

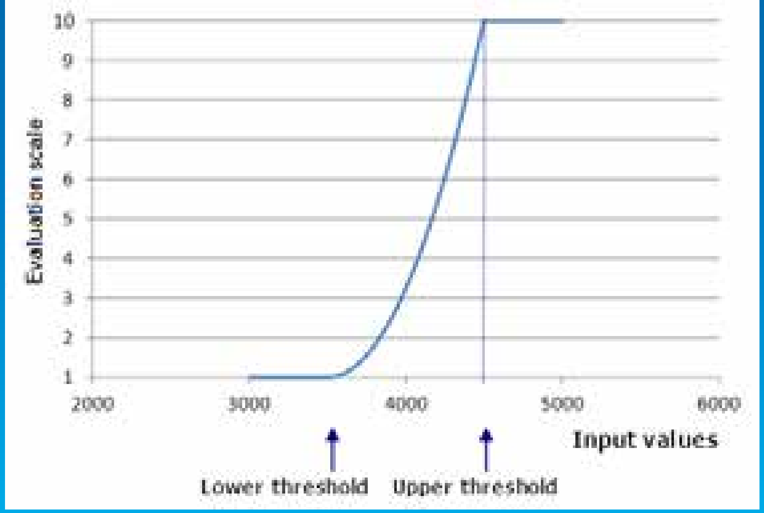


Suitability of deer within the study area:
Data dependent scenario

Input range in study area: 3000 to 5000



Suitability of deer relative to population:
Data independent scenario



Suitability of deer within the study area that reach a threshold

The suitability modeling model steps

- Determine significant layers for each sub model from the phenomenon’s perspective
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Decision alternatives and constraints

- Constraints
  - Reduces the number of alternatives
  - Feasible and non feasible alternatives

- Types of Constraints
  - Non compensatory
    - No trade offs - in or out (legal, cost, biological)
  - Compensatory
    - Examines the trade offs between attributes
      - Pumping water – (height versus distance relative a cost)

- Decision Space
  - Dominated and non-dominated alternatives

Weight

- Ranking Method
  - Rank order of decision maker (1 most, 2, second…)
- Rating Method
  - Decision maker estimates weights on a predetermined scale
  - Point allocation approach (similar to demonstration)
  - Ratio estimation procedure (Easton)
    - Arbitrarily assign the most important, other assigned proportionately lower weights
- Pairwise
- Trade-off analysis

Weight: Pairwise

- Analytical hierarchy process (AHP) (Saaty)
- Three steps
  - Generate comparison matrix
  - Compute criterion weights
    - Sum columns; divide by column sum; average rows
  - Estimate consistency ratio (math formulas)
- Pairwise comparison
  - Rate1: Equal importance – 9: Extreme importance

Criteria	Terrain	Access	Cost
Terrain	1	3	6
Access	1/3	1	8
Cost	1/6	1/8	1

Weight: Trade-off

- Direct assessment of trade offs the decision maker is willing to make (Hobbs and others)
- Compares two alternatives with respect to two criteria defining preference or if indifferent
- Compare other combinations

Site 1		Site 2		
Slope	Aspect	Slope	Aspect	Preference
1	10	10	1	1
2	10	10	1	1
4	10	10	1	Indifferent
6	10	10	1	2
8	10	10	1	2
10	10	10	1	2

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Combine

- Decision rules
- Simple Additive Weighting (SAW) method
- Value/utility functions (Keeney and Raiffa)
- Group value/utility functions
- Ideal point method
- Others:
  - Concordance method
  - Probabilistic additive weighting
  - Goal programming
  - Interactive programming
  - Compromise programming
  - Data Envelopment Analysis

Combine: SAW

- What we did earlier
- Assumptions:
  - Linearity
  - Additive
    - No interaction between attributes
- Ad hoc
- Lose individual attribute relationships
- All methods make some trade offs

Combine: Group Value

- Method for combining the preferences of different interest groups
- General steps:
  - Group/individual create a suitability map
  - Individuals provide weights of influence of the other groups
  - Use linear algebra to solve for the weights for each individual's output
  - Combine the outputs
- Better for value/utility functions

Combine: Ideal Point

- Alternatives are based on separation from the ideal point
- General steps
  - Create weighted suitability surface for each attribute
  - Determine the maximum value
  - Determine the minimum value
  - Calculate the relative closeness to the ideal point

$$C_{i+} = \frac{s_{j-}}{s_{i+} + s_{i-}}$$

  - Rank alternatives

- Good when the attributes have dependencies

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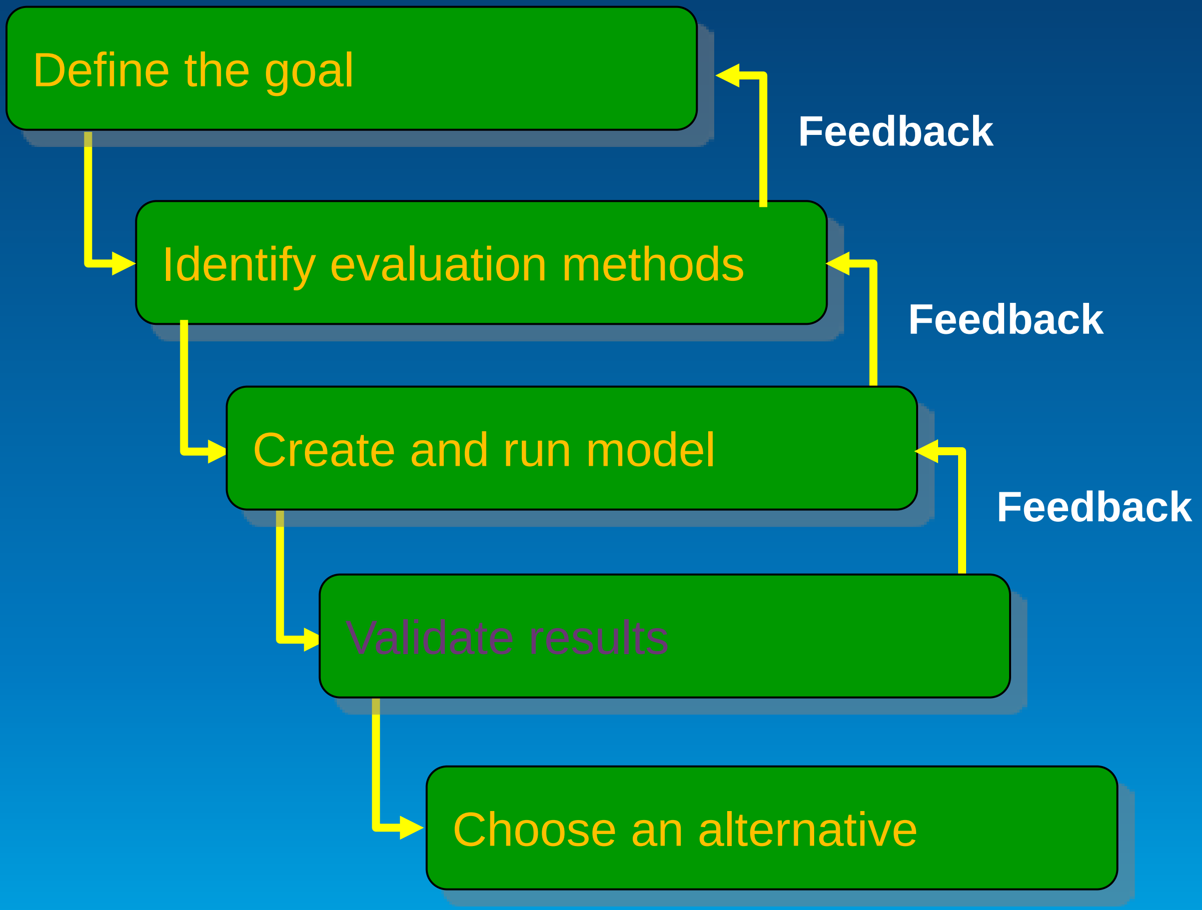
- Determine significant layers for each sub model from the phenomenon’s perspective
  - May need to derive data
- Transform values within a layer onto a relative scale
- Weight the importance of each layer and each sub model relative to one another
- Combine layers and sub models together
- Locate the best areas meeting your goals

General suitability modeling methodology

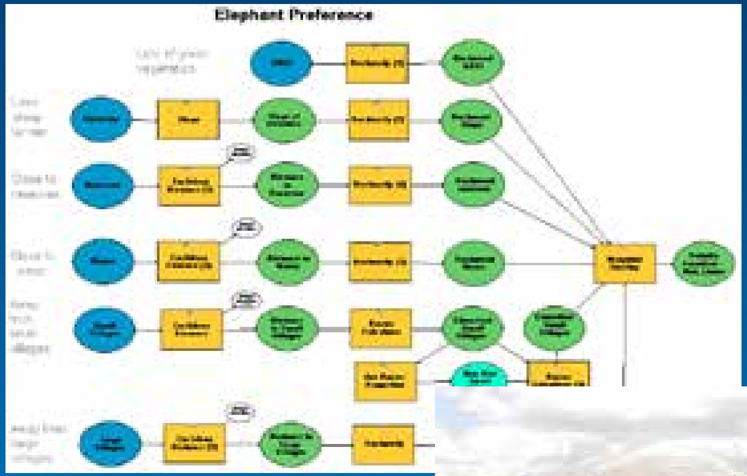


Validate results: Sensitivity analysis (and error analysis)

- Systematically change one parameter slightly
- See how it affects the output
- Error
  - Input data
  - Parameters
  - Address by calculations or through simulations

The presentation outline

- Background
- How to create a suitability model and the associated issues
- Demonstration
- Look deeper into the transformation values and weights
- Demonstration
- Fuzzy logic



Demo 2: Non-linear Suitability Model

Use functions to transform values

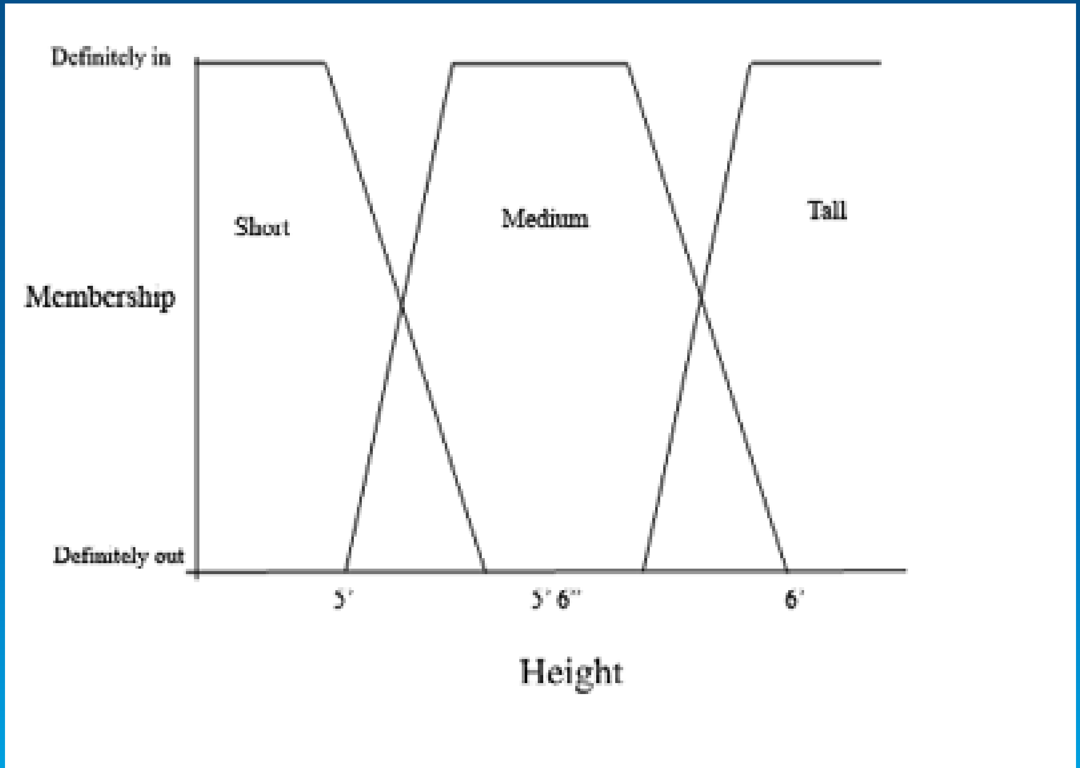
Rescale by Function

The suitability modeling model steps

- **Determine significant** layers for each sub model from the phenomenon's perspective
  - May need to derive data
- **Transform values** within a layer onto a relative scale
- **Weight** the importance of each layer and each sub model relative to one another
- **Combine** layers and sub models together
- **Locate** the best areas meeting your goals

Fuzzy overlay – The problem

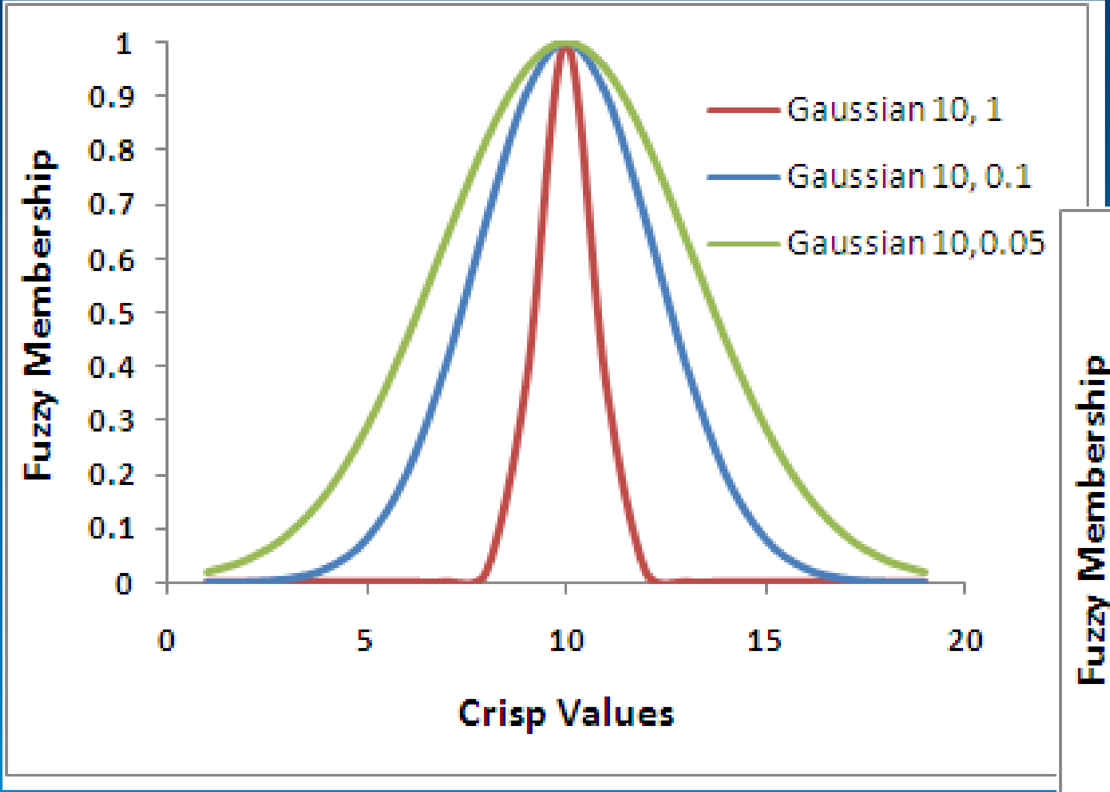
- Inaccuracies in geometry
- Inaccuracies in classification process

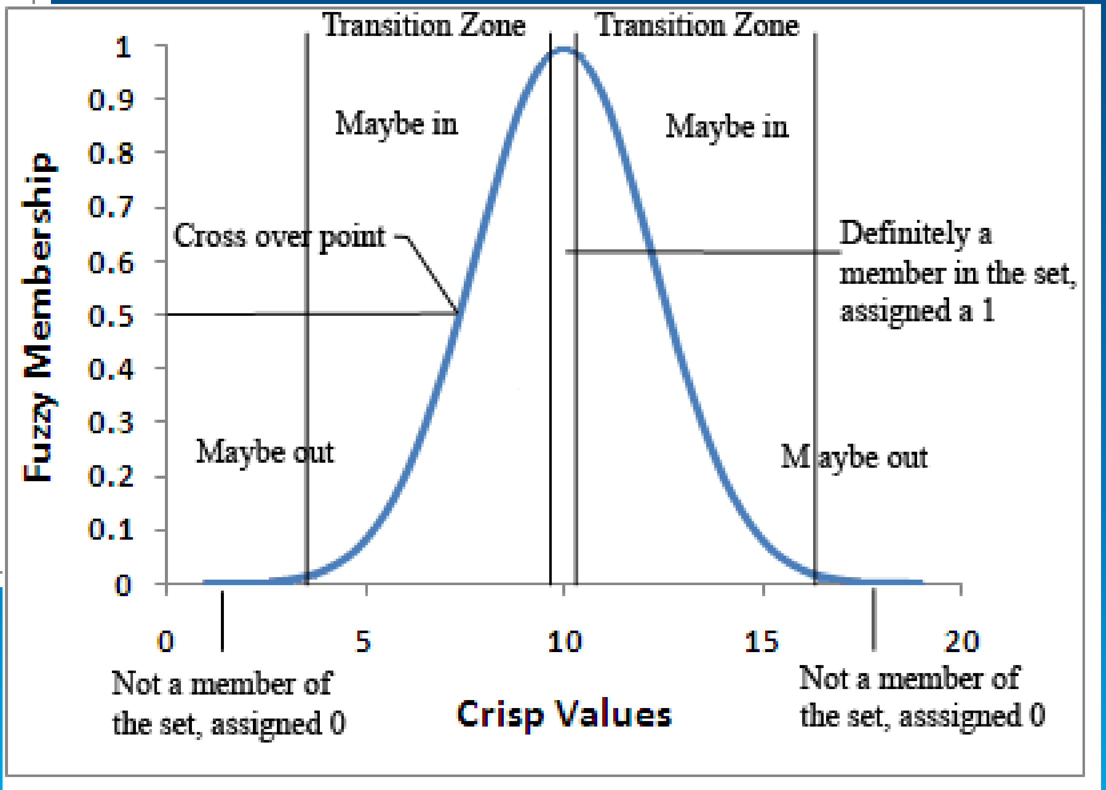


Fuzzy overlay – Transform values

- Predetermined functions are applied to continuous data
- 0 to 1 scale of possibility belonging to the specified set
- Membership functions
  - FuzzyGaussian – normally distributed midpoint
  - FuzzyLarge – membership likely for large numbers
  - FuzzyLinear – increase/decrease linearly
  - FuzzyMSLarge – very large values likely
  - FuzzyMSSmall - very small values likely
  - FuzzyNear- narrow around a midpoint
  - FuzzySmall – membership likely for small numbers

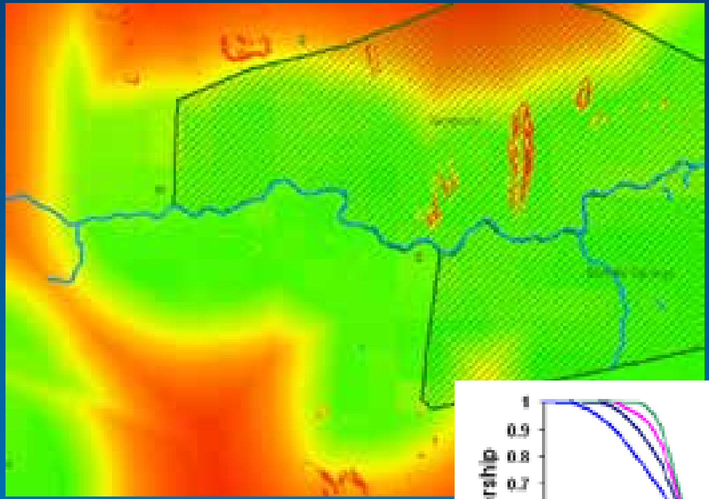
Fuzzy overlay – Transform values

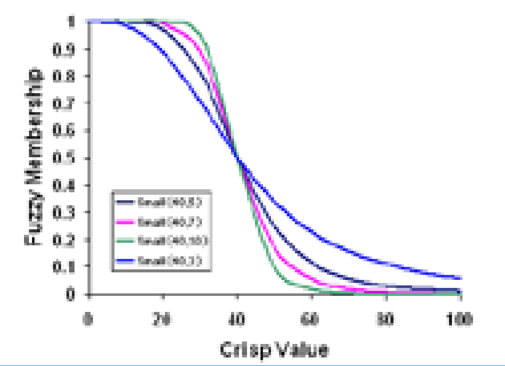




Fuzzy overlay – Combine

- Meaning of the transformed values - possibilities therefore no weighting
- Analysis based on set theory
- Fuzzy analysis
  - And - minimum value
  - Or – maximum value
  - Product – values can be small
  - Sum – not the algebraic sum
  - Gamma – sum and product





Demo 3: Fuzzy Analysis

Fuzzification

Fuzzy Overlay

Summary

- Problems with:
  - Locate - if cells need to be contiguous
  - Allocating one alternative influences the suitability of another
- Can be done in the vector world
- Multiple ways to transform values and define weights
- Multiple ways to combine the criteria
- Your transformation values and weights depend on:
  - the goal
  - the data
  - the understanding of the phenomenon
- How the values are transformed and weights defined can dramatically change the results

Carefully think about how you transform your values within a criterion and weight between the criteria

Thank you…

- **Please fill out the session survey:**

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