Spatial Analyst – Finding the Best Locations Using Suitability Modeling

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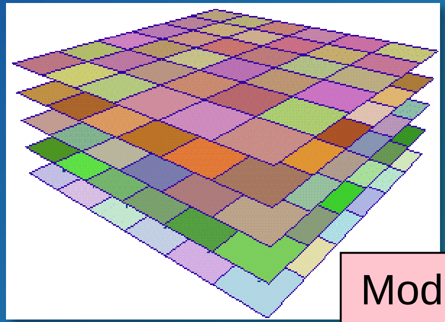
Suitability modeling

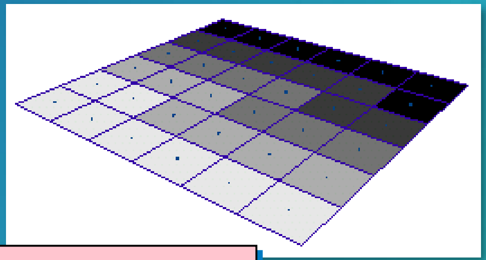
- **Where to site a new housing development?**
- **Which sites are better for deer habitat?**
- **Where is economic growth most likely to occur?**
- **Where is the population at the greatest risk if a chemical spill were to happen?**

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

- Overview for creating a suitability model
- Defining criteria and transforming to common scale - Demonstration
- Weighting and combining the criteria - Demonstration
- Locating the phenomenon – Demonstration
- Case studies and fuzzy logic - Demonstration

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

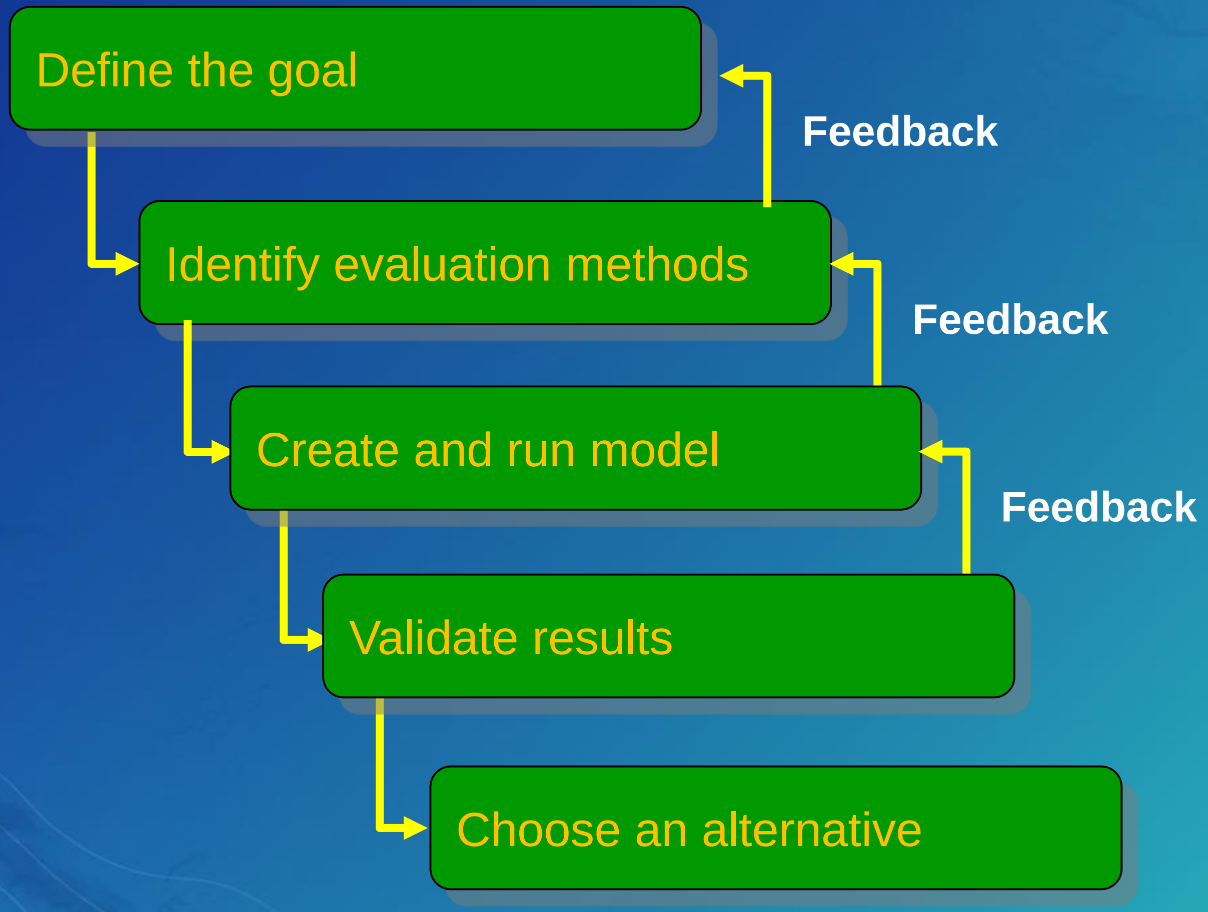
0 = Barren
1 = Forest
2 = Water

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)

General suitability modeling methodology



Define goal

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

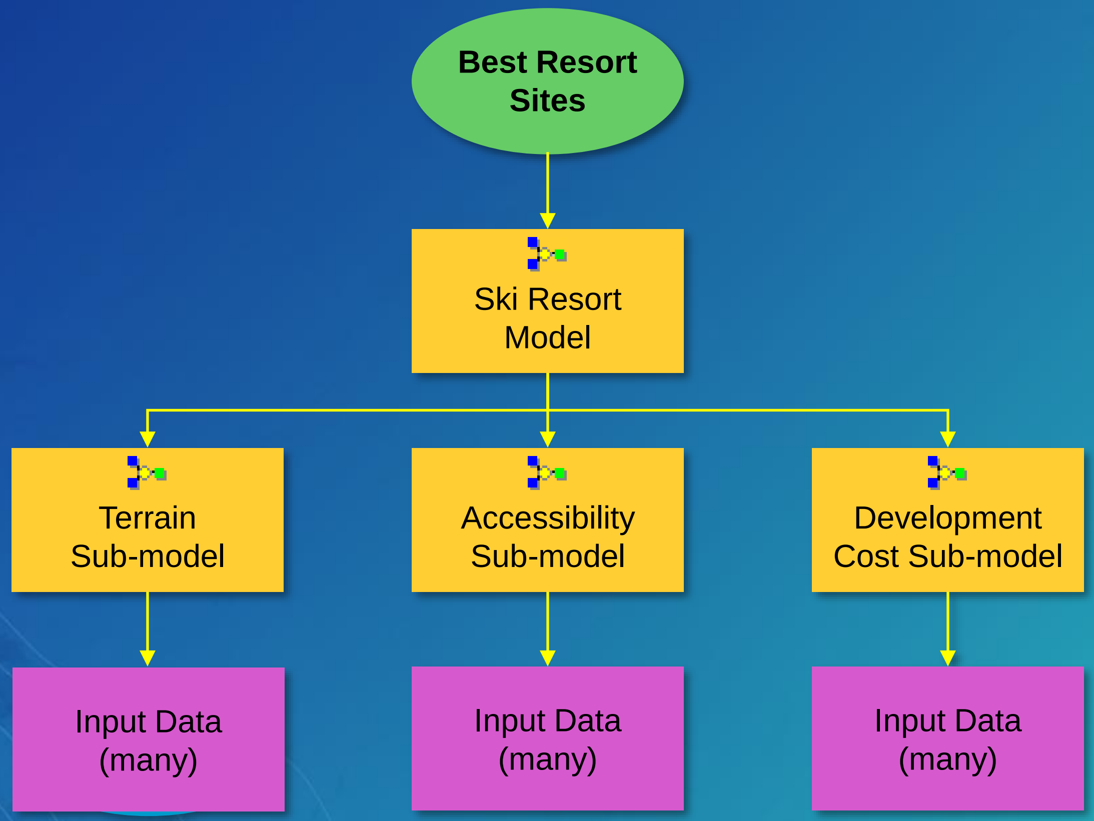
- Define the problem
  - “Locate a ski resort”
- Establish the over arching goal of the problem
  - Make money
- Identify issues
  - Stakeholders
  - Legal constraints

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”
  - Minimize cost; Maximize the visual quality
- Determine how to quantify
  - “Drive time to the city”
  - Reduce the lung disease – amount of carbon dioxide
- The more the better; the less the better

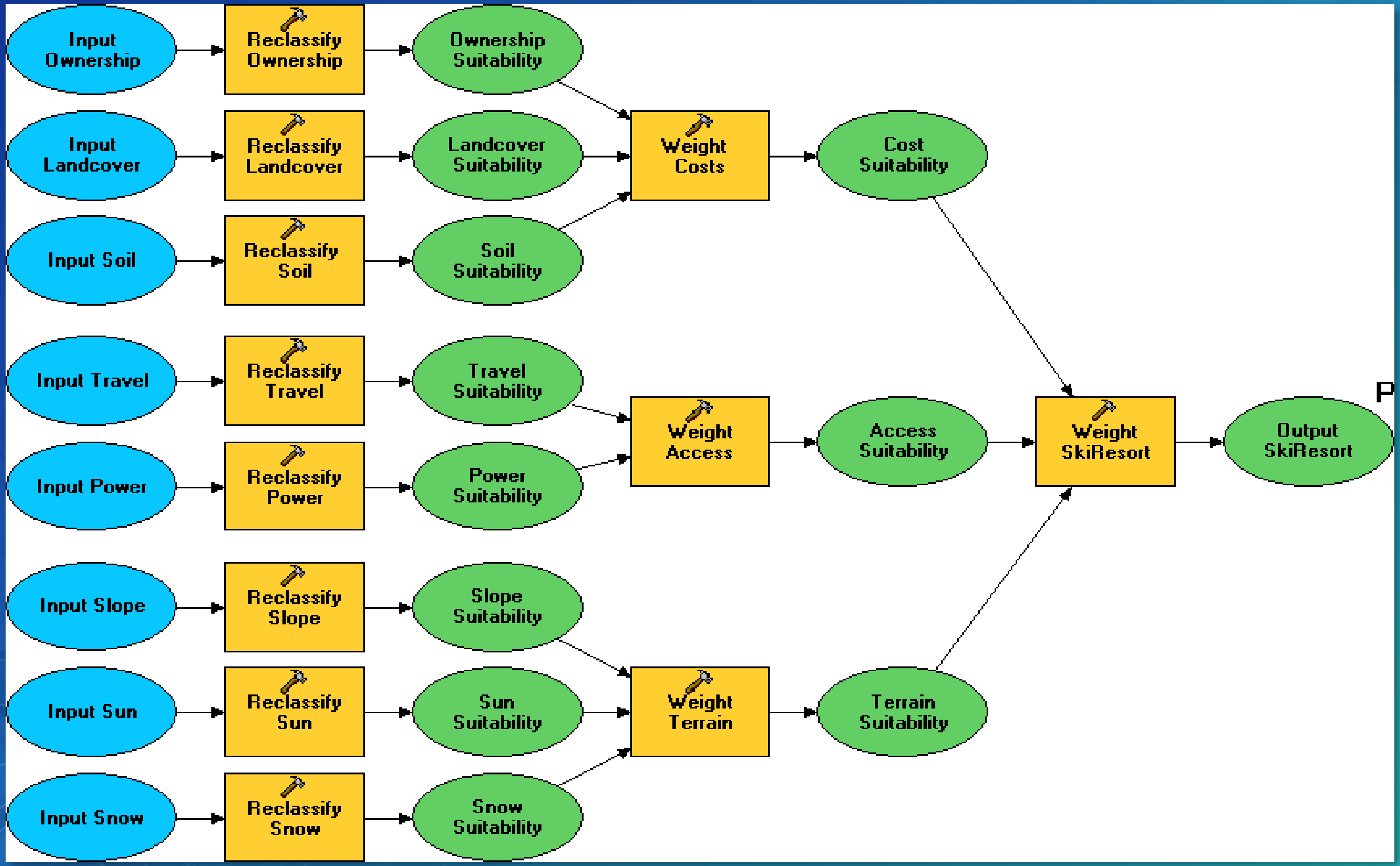
Models and sub-models

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



ModelBuilder

- **ArcGIS graphical model building capabilities**

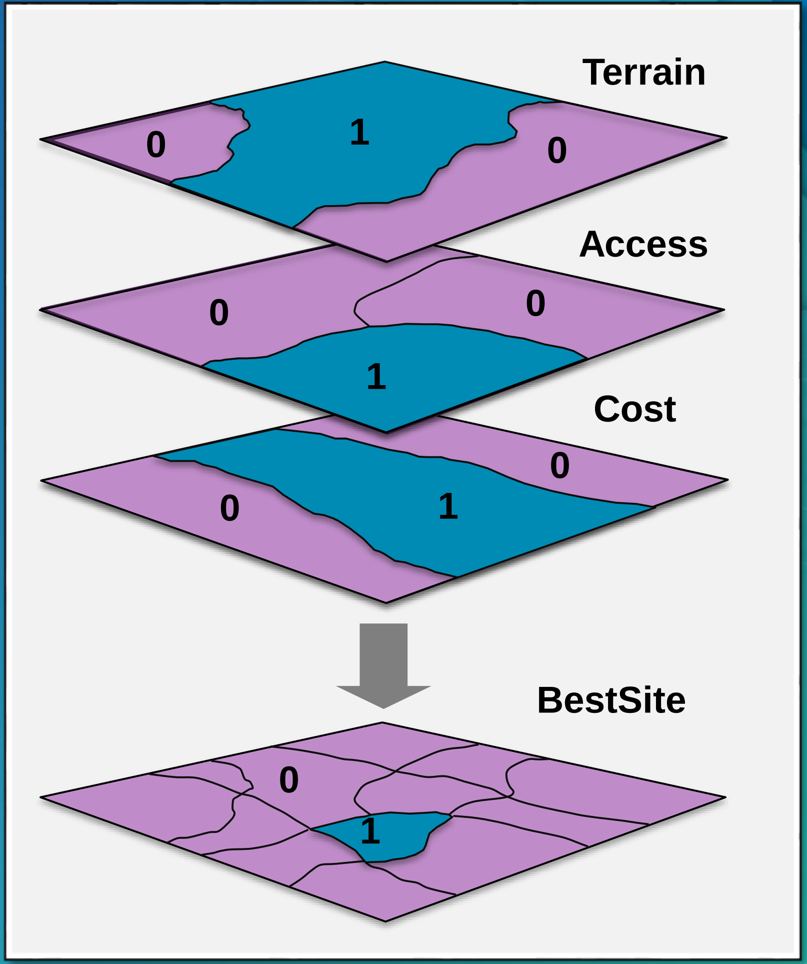


Types of suitability models - Binary

- 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

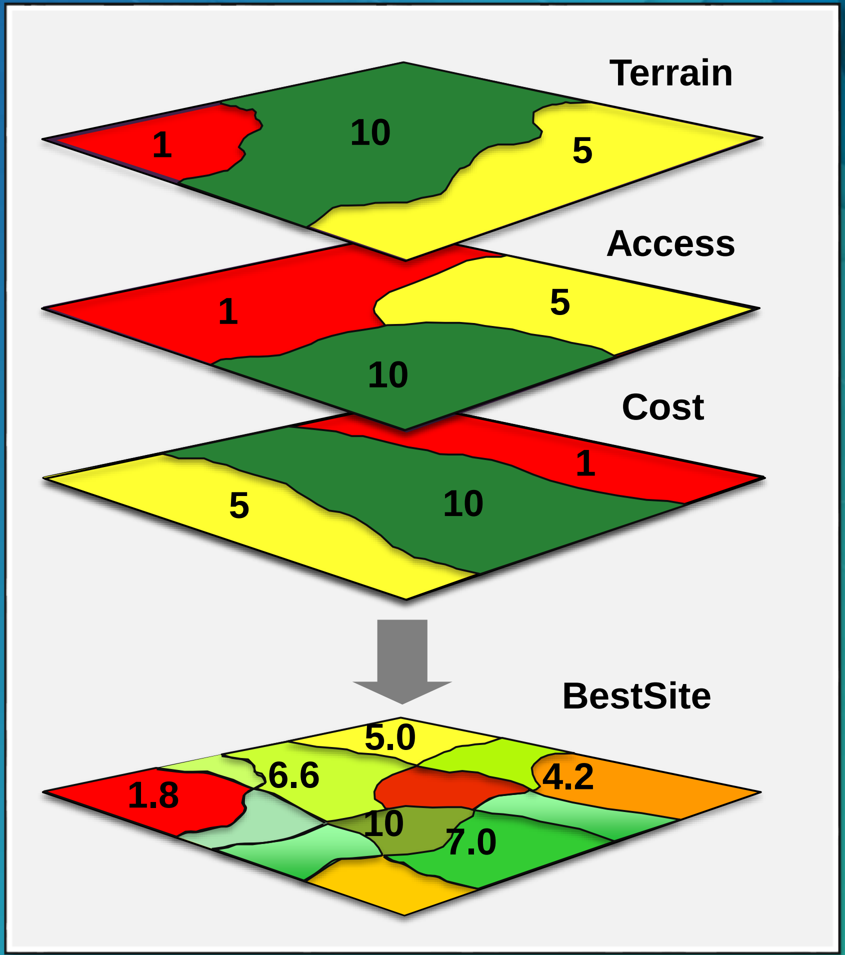


Types of suitability models - Weighted

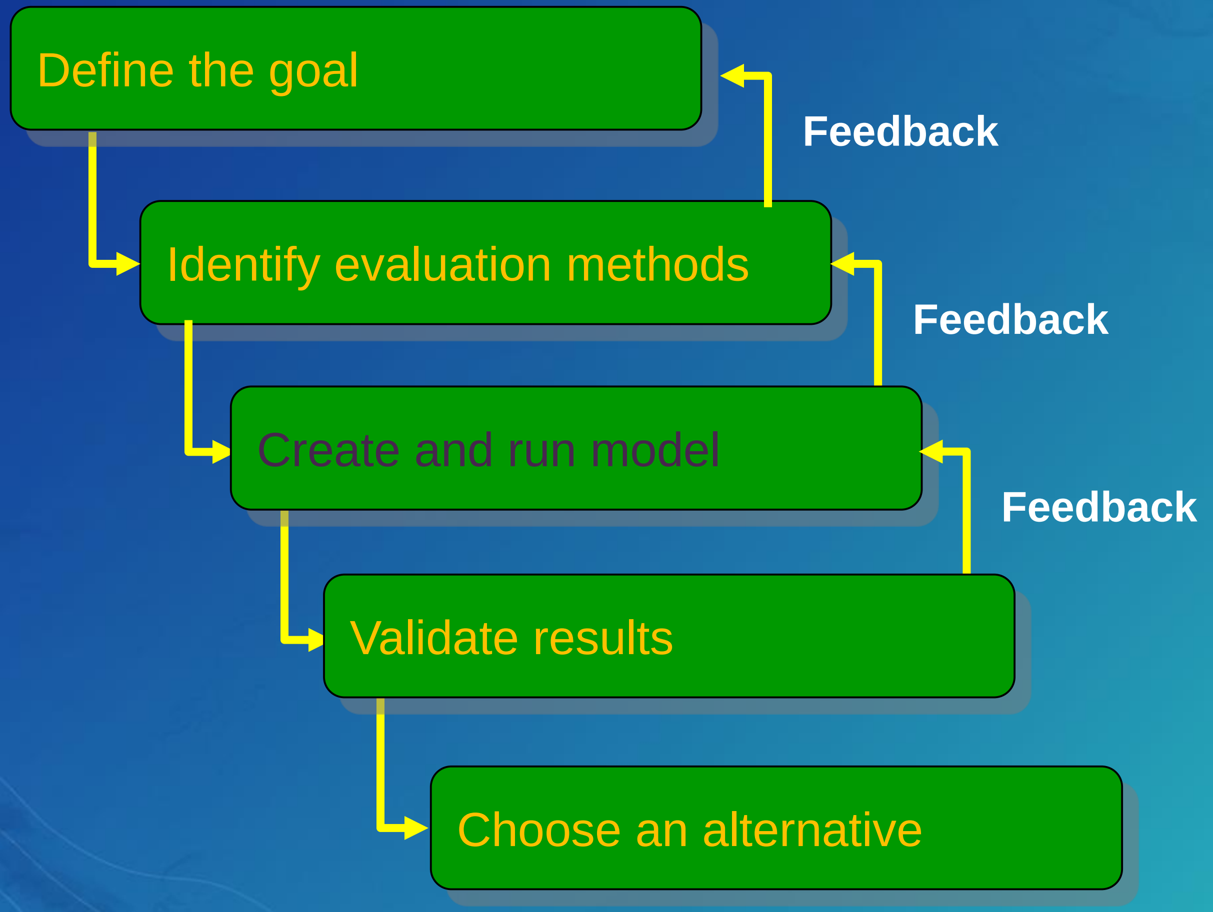
- Use for more complex problems
- Classify layers into suitability 1–9
  - Weight and add together:

```
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

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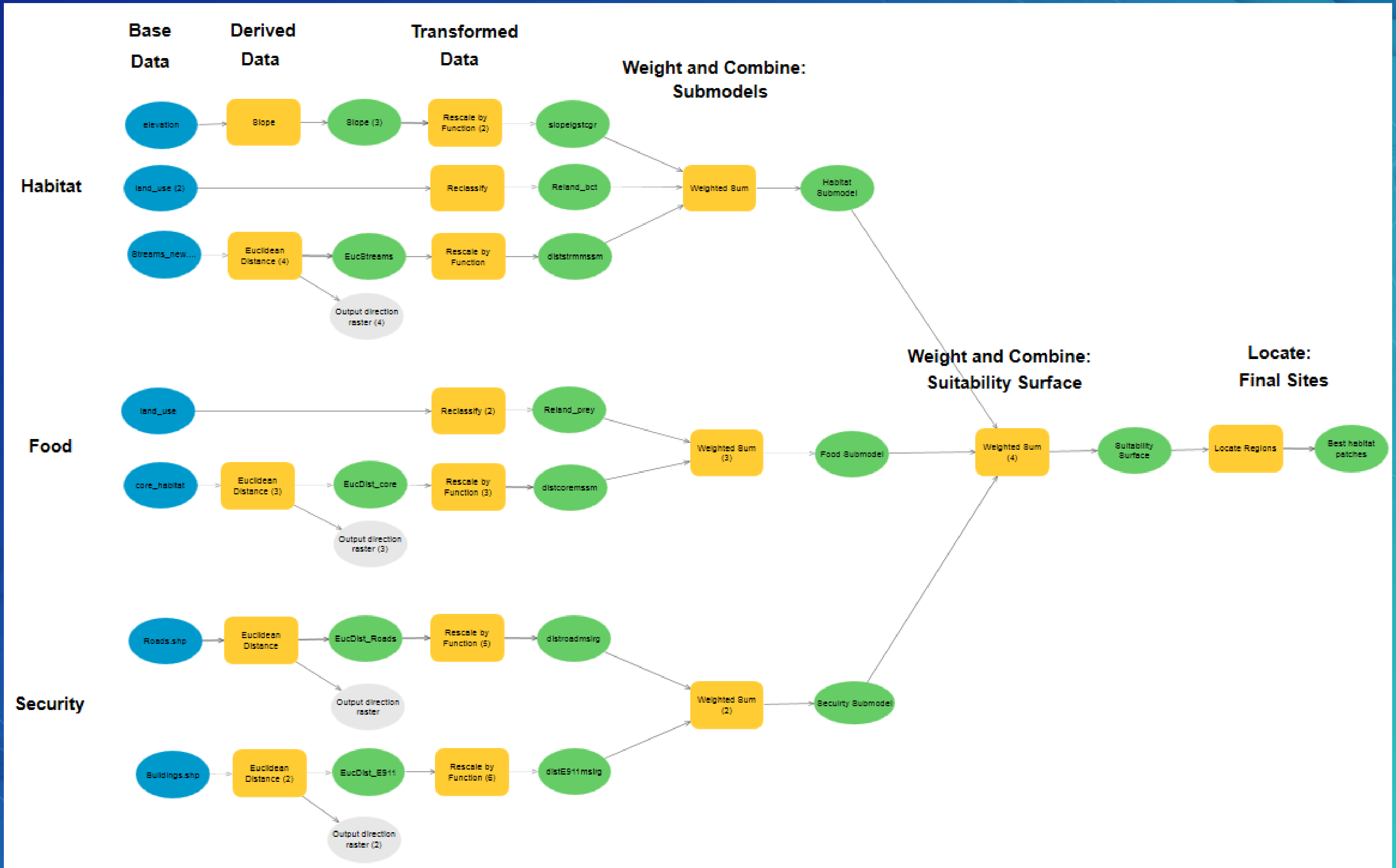
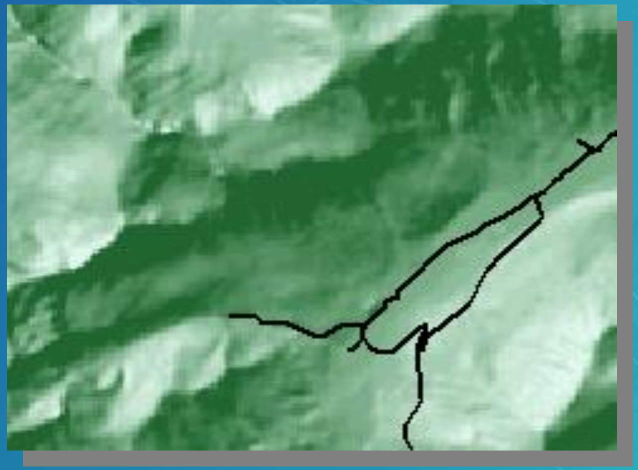


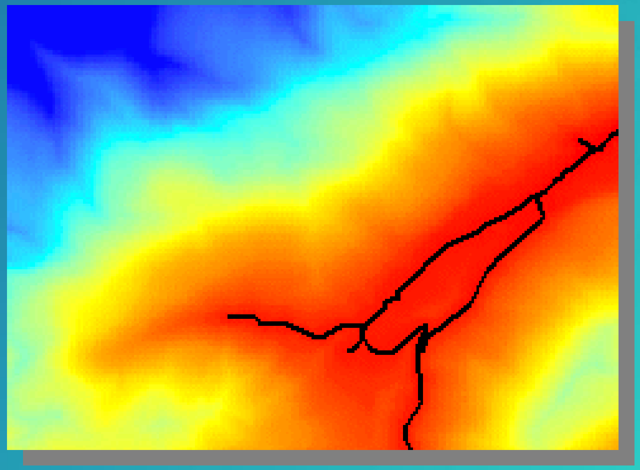
Determining significant layers – Base and deriving data

- 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

Base and deriving data

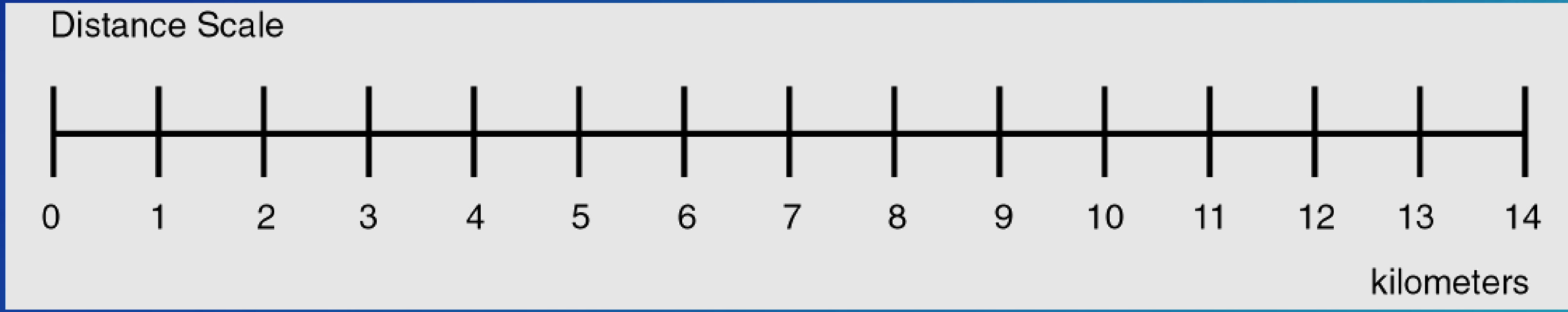
- Base data may not be useful for measuring all criteria
  - Need to measure access, not road location
- May be easy:
  - ArcGIS Spatial Analyst tools
  - Distance to roads
- May be harder:
  - Require another model
  - Travel time to roads



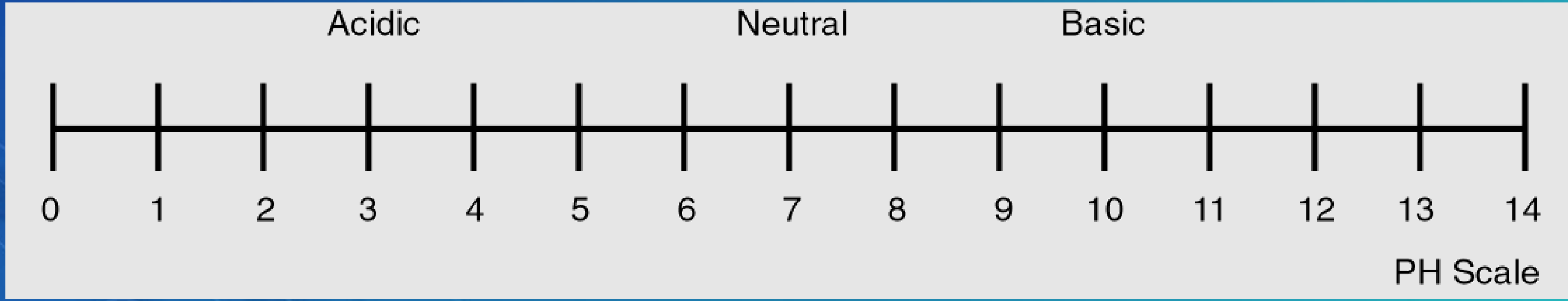


Why transform values?

Ratio:



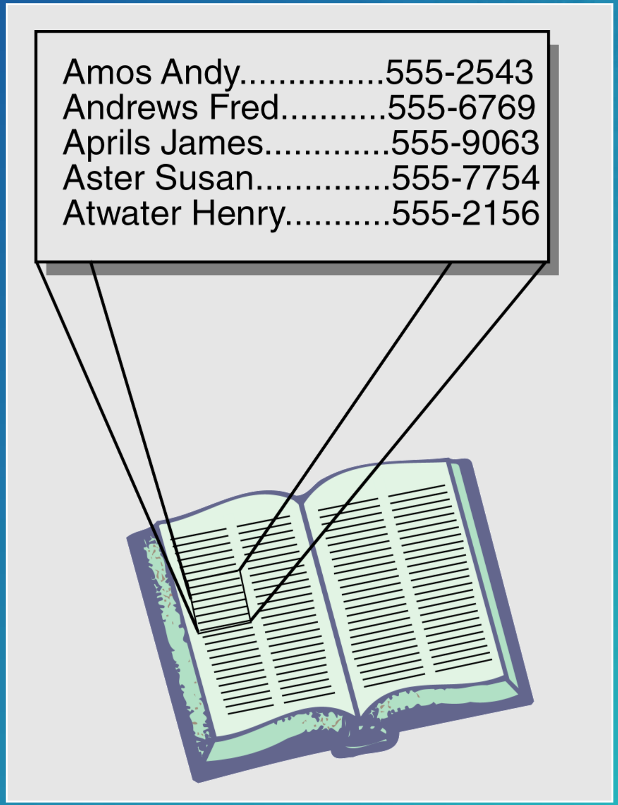
Interval:



Why transform values?

Ordinal:

Nominal:



Transform values – Define a scale of suitability

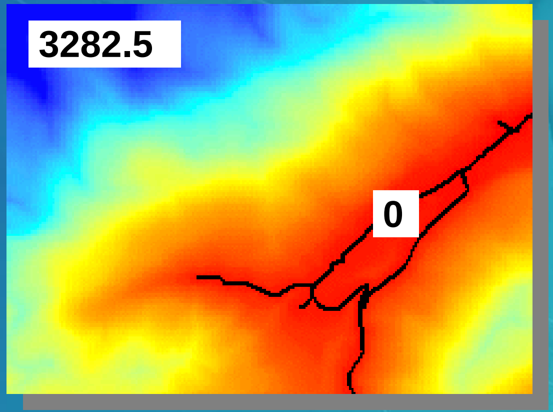
- Define a scale for suitability
  - Many possible; typically 1 to 9 (worst to best)
  - Reclassify layer values into relative suitability
  - Use the same scale for all layers in the model

Accessibility sub model

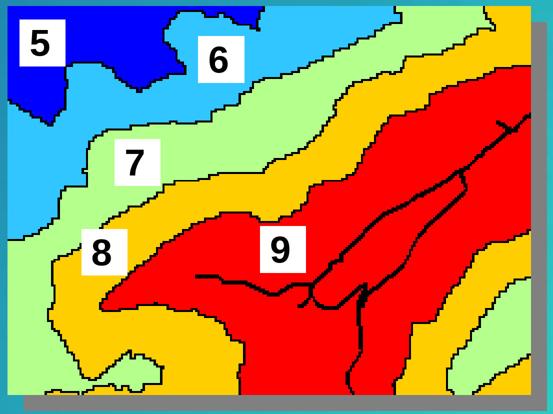
Travel time suitability	
Best	9 – 0 minutes to off ramp
	8
	7
	6
	5 – 15 minutes to off ramp
	4
	3
	2
Worst	1 – 45 minutes to off ramp

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



Distance to roads

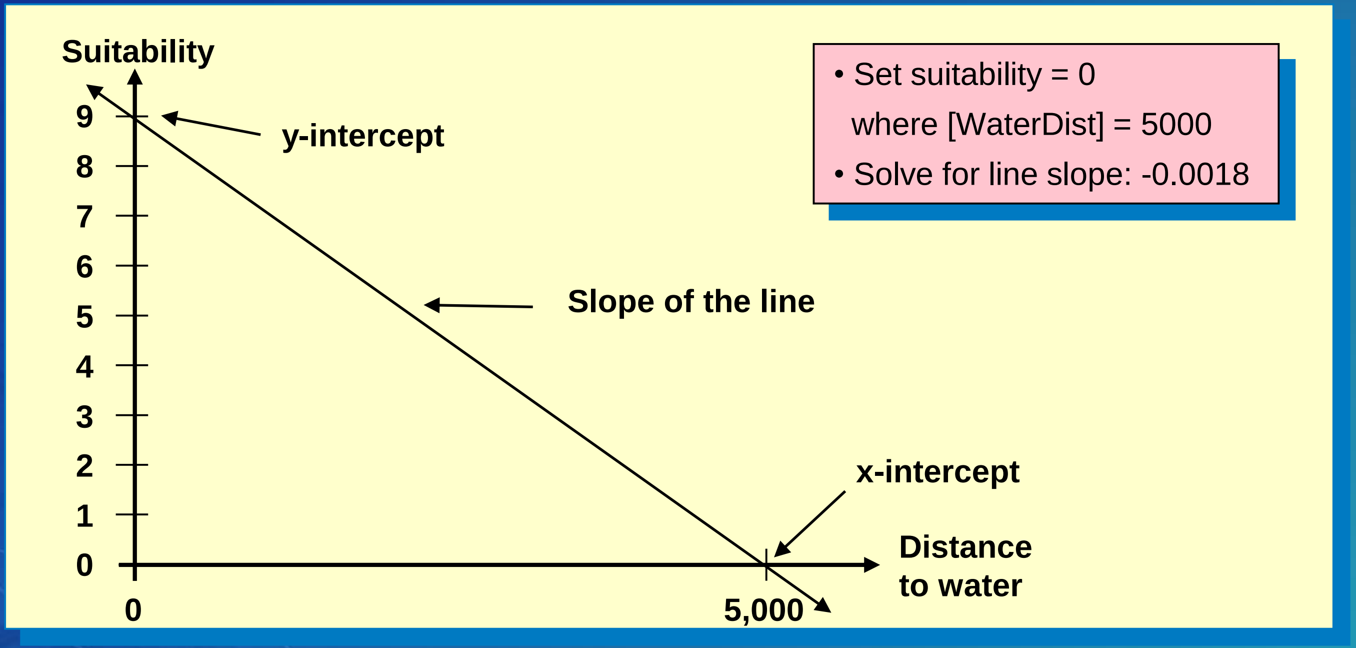


Suitability for Ski Resort

Within and between layers

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:

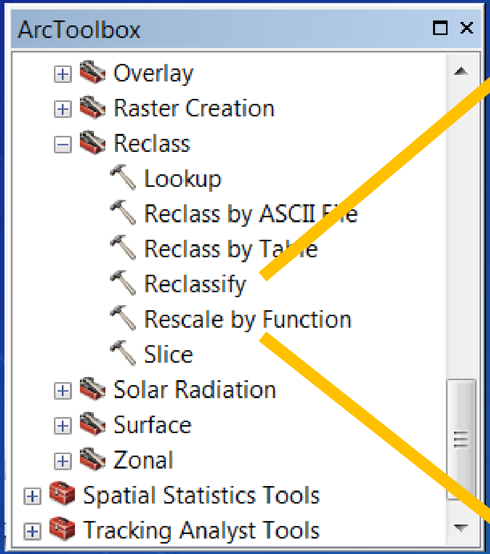
```
WaterSuit = 9 + ( -0.0018 * WaterDist)
```

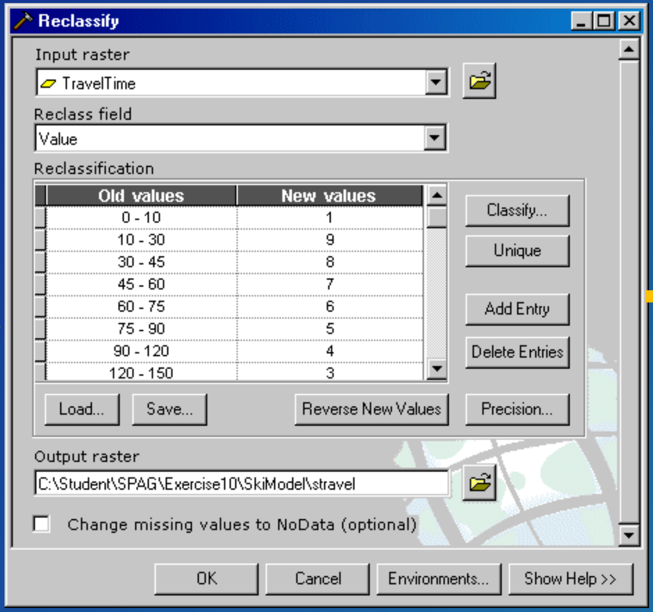
Reclassify versus Rescale by Function

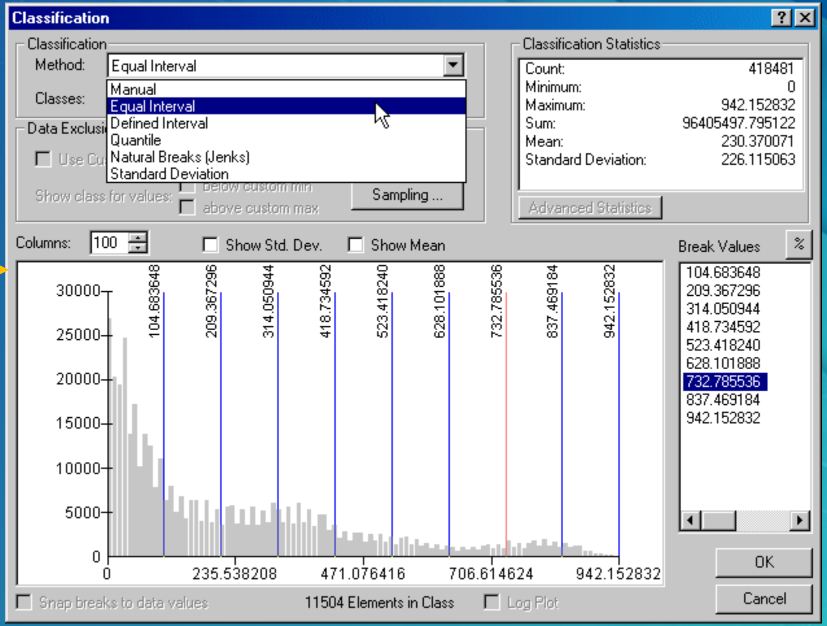
- Reclassify
  - Categorical input
  - Discrete output
  - One to one (or range) mapping

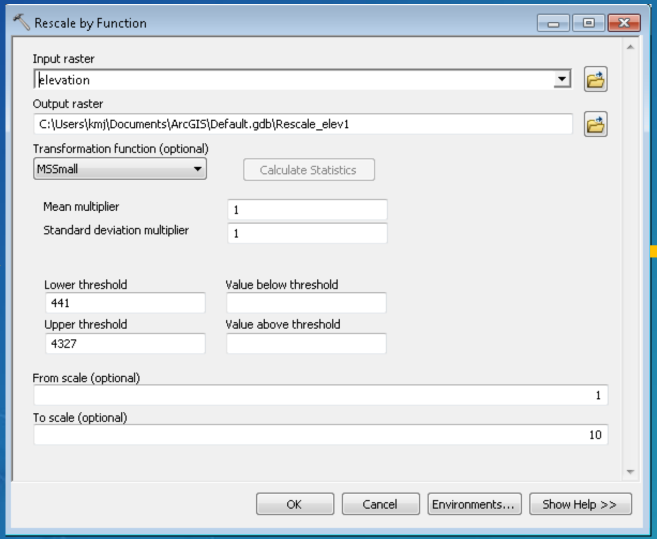
- Rescale by Function
  - Continuous input
  - Continuous output
  - Linear and non linear functions

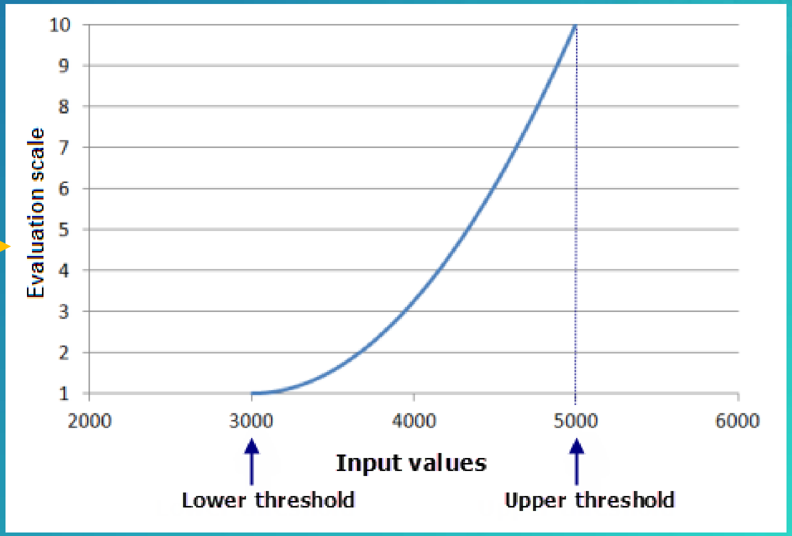
Tools to transform your values – convert to suitability







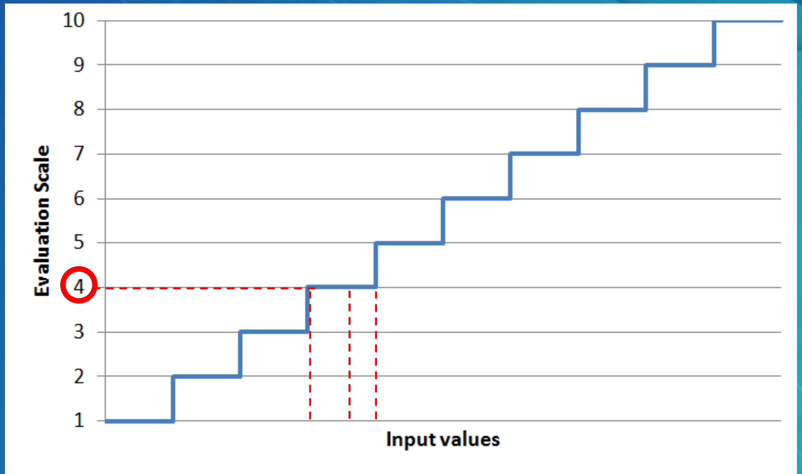




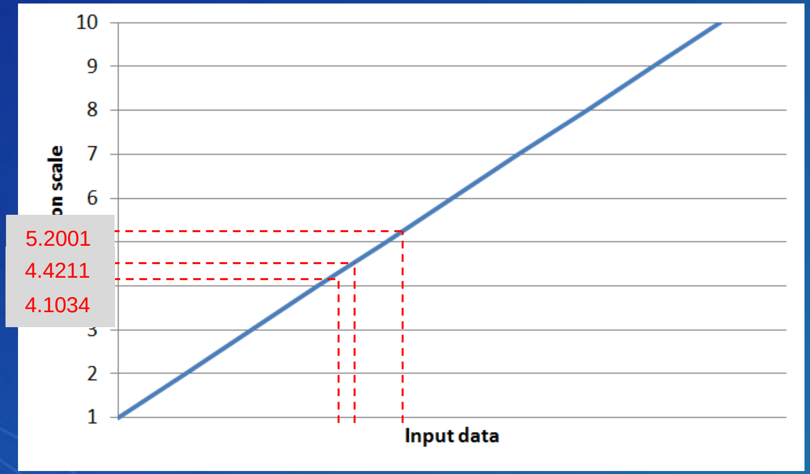
Reclassify versus Rescale by Function

Reclassify

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



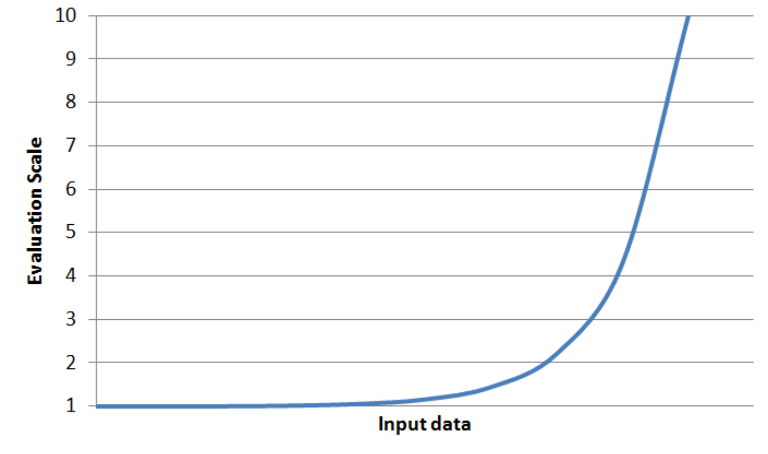
If input is continuous - stair step effect caused by the discrete classes



Rescale by Function

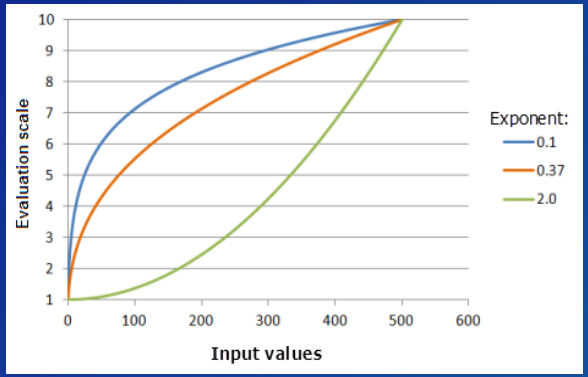
For continuous input and output

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

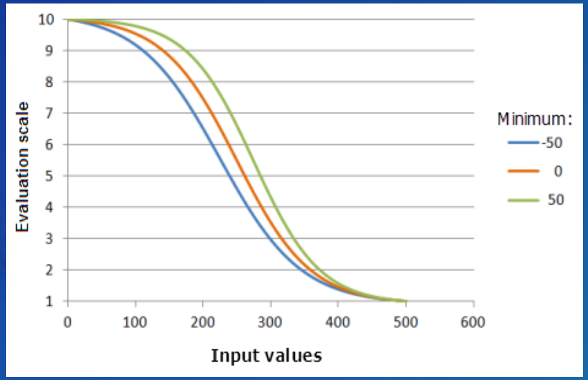


Nonlinear functions

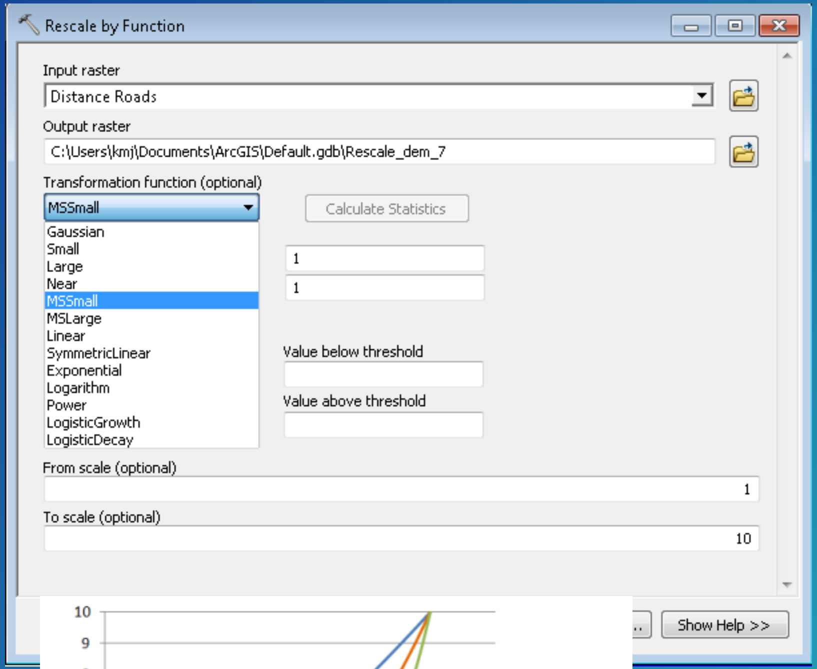
Rescale by Function: the functions

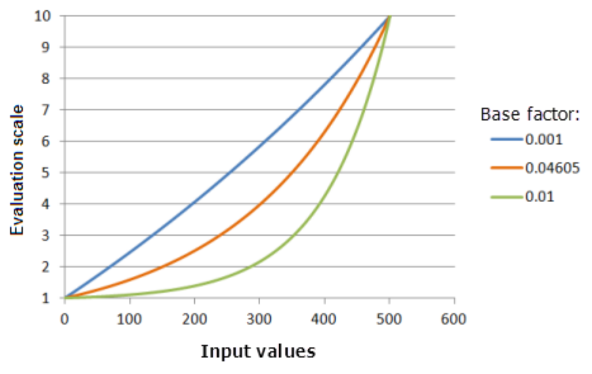


Power

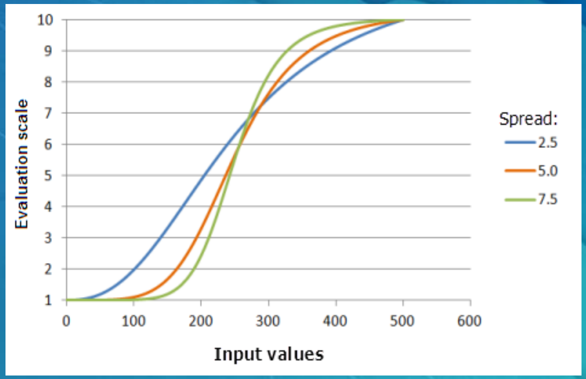


Logistic decay

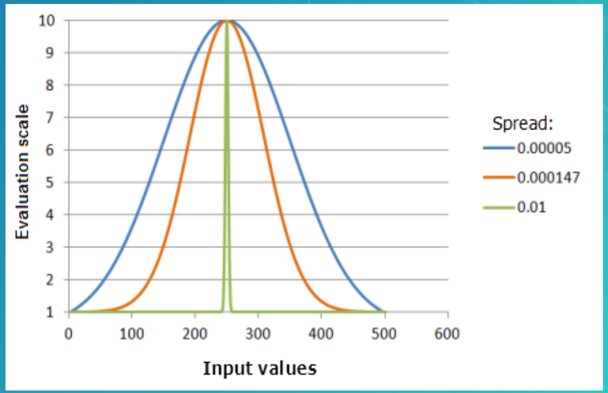




Exponential



Large

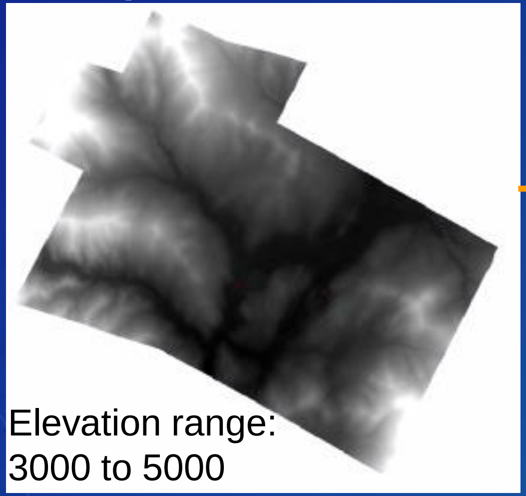


Gaussian

The function can be further refined by the function parameters

Anatomy of applying a function

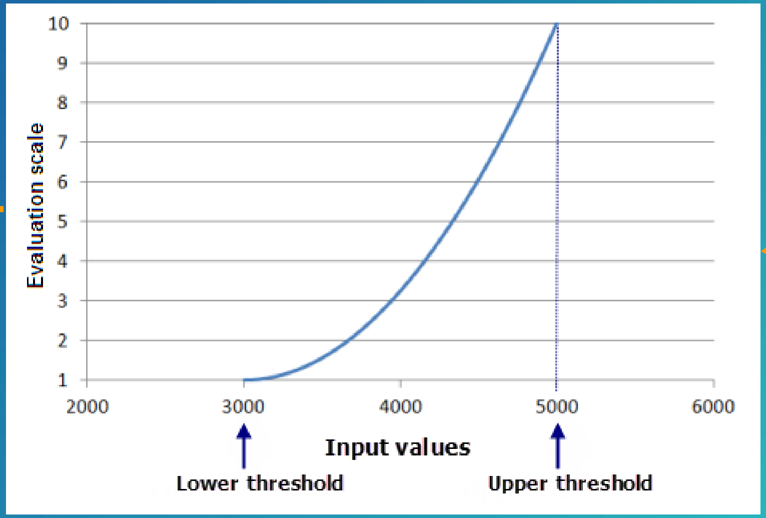
Input data



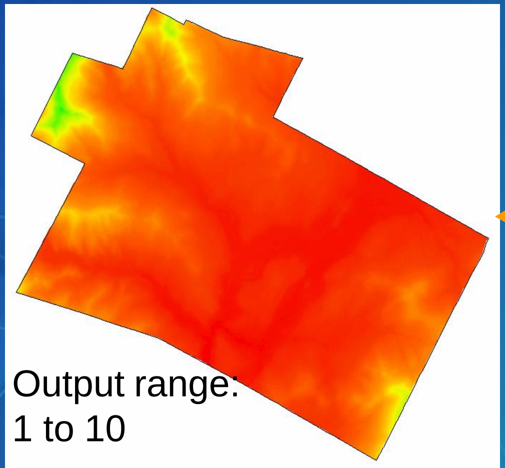
Apply the rescale function to the input values creating function values – f(x)

Exponential function

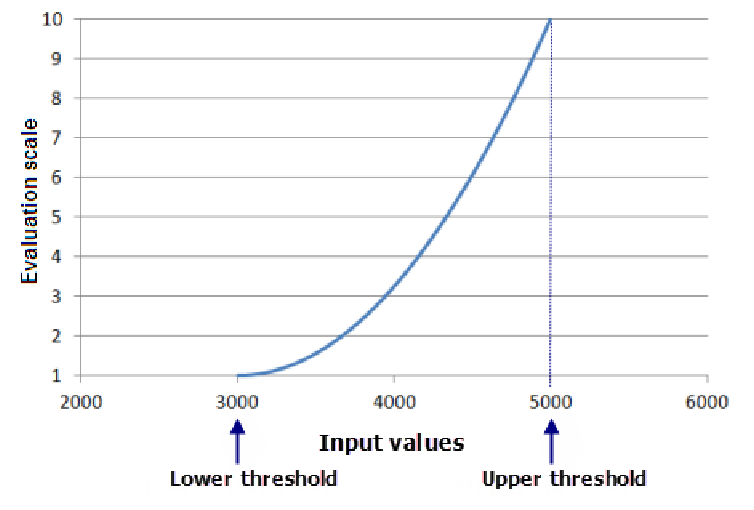
The function range is mapped to the evaluation scale (e.g., 1 to 10 suitability)



Output data

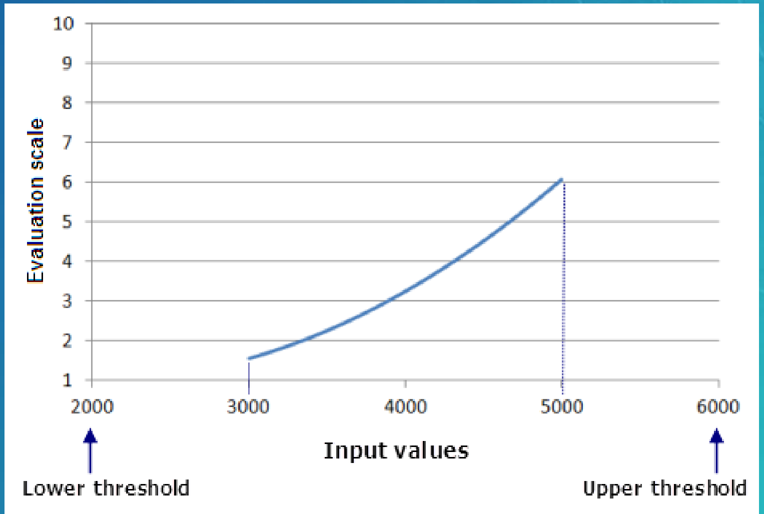


Rescale by Function – Data dependent

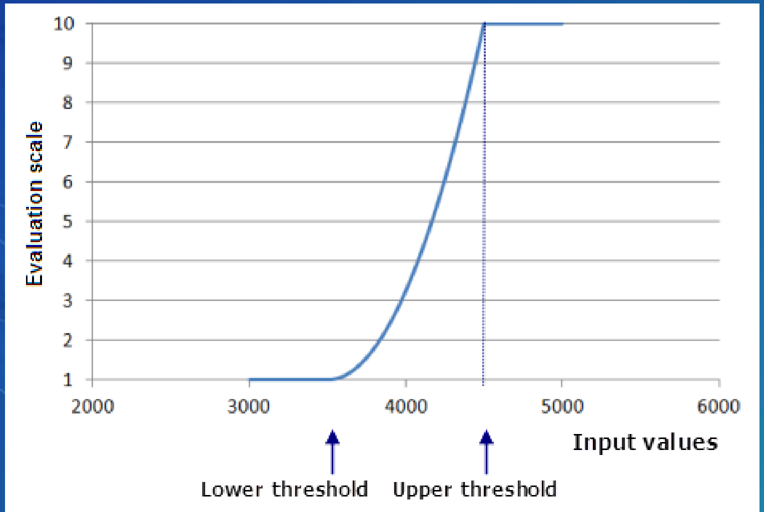


Suitability of deer within the study area:
Data dependent scenario

Input range in study area: 3000 to 5000

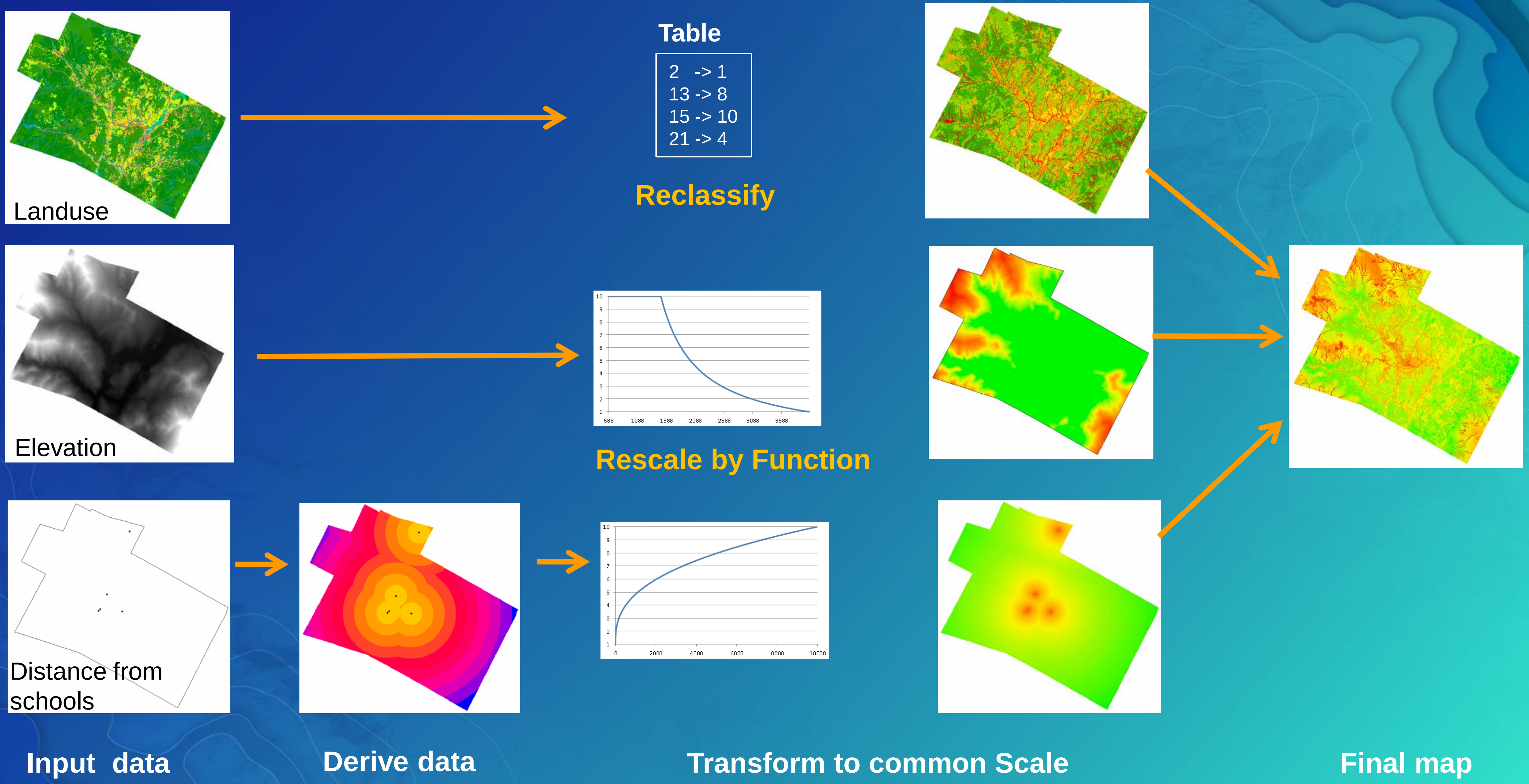


Suitability of deer relative to population:
Data independent scenario



Suitability of deer within the study area that reach a threshold

Suitability workflow



Demo

Deriving base data and transforming data

- Reclassify
- Rescale by Function

Additional thoughts from multicriteria decision making

- GIS and Multicriteria Decision Analysis (J. Malczewski)
- Operation Research (linear programming)
- Decision support
- Provide you with alternative approaches
  - Problem you are addressing
  - Available data
  - Understanding of the phenomenon
- Make you think about how to transform the values and weight within and between the criteria

Transform values

- Direct scaling (as you have seen)

- Value/utility functions (Rescale by Function)

- Linear transformation
  - Divide each value by the maximum value
  - Scale 0 – 1 (relative order of magnitude maintained)
  - Apply to each layer

- Others:
  - Fuzzy sets

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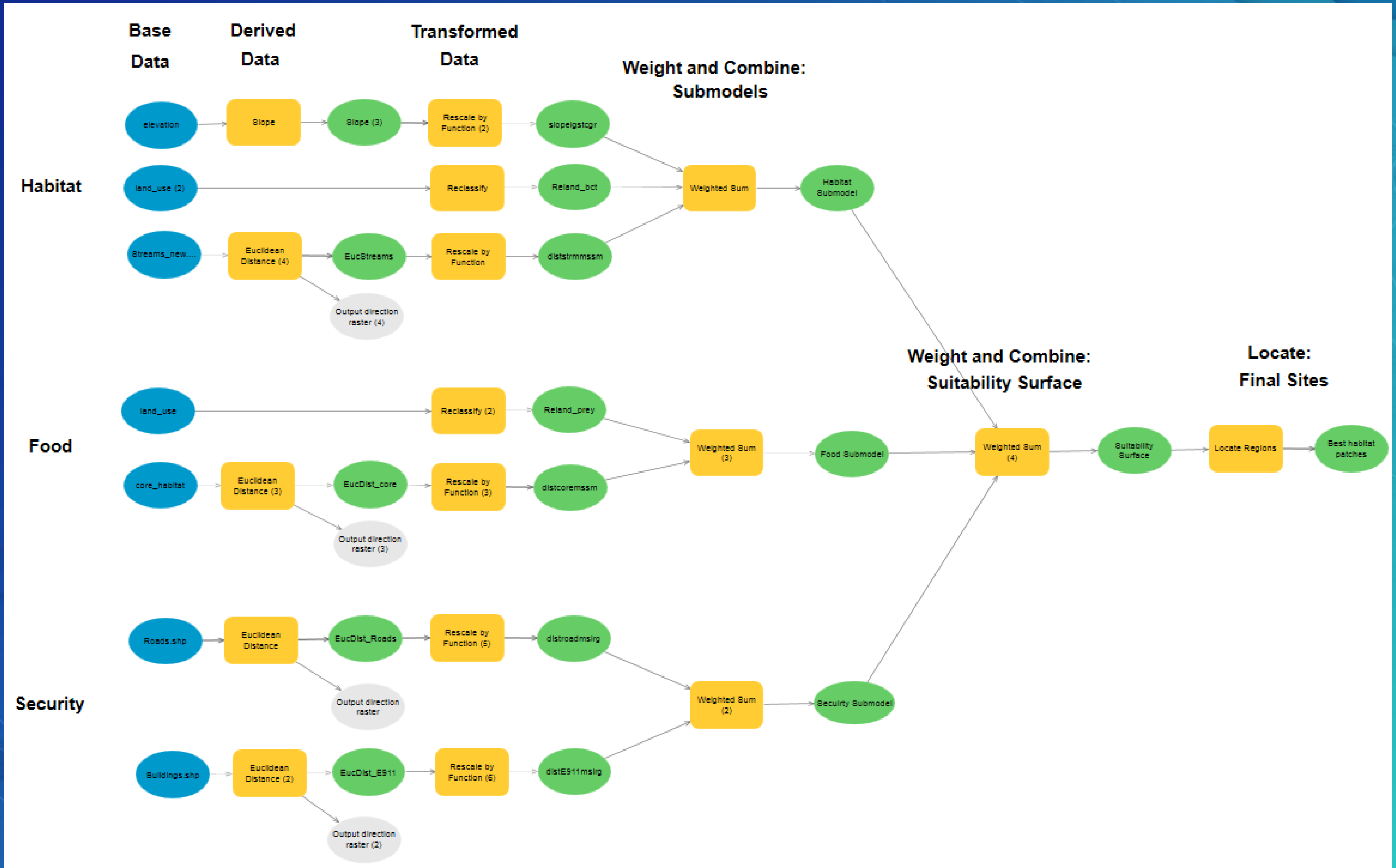
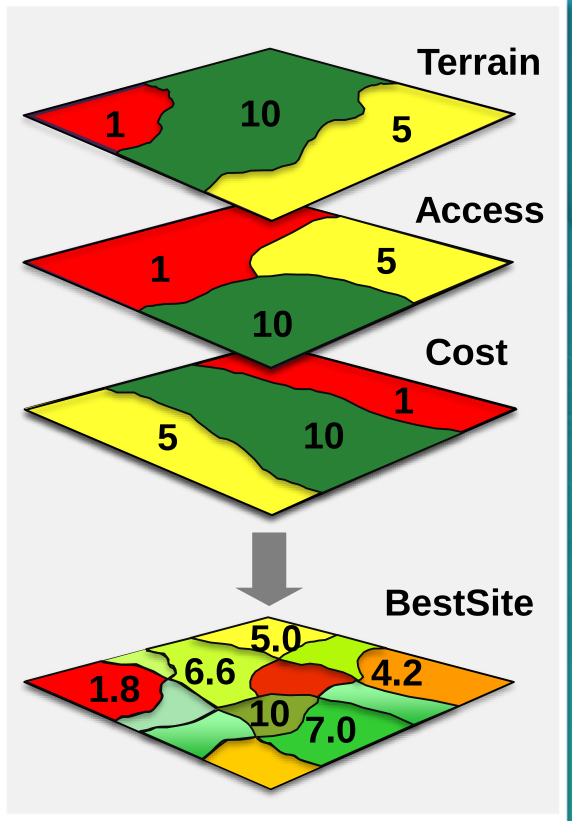
The suitability modeling model steps



Weight and combine the layers

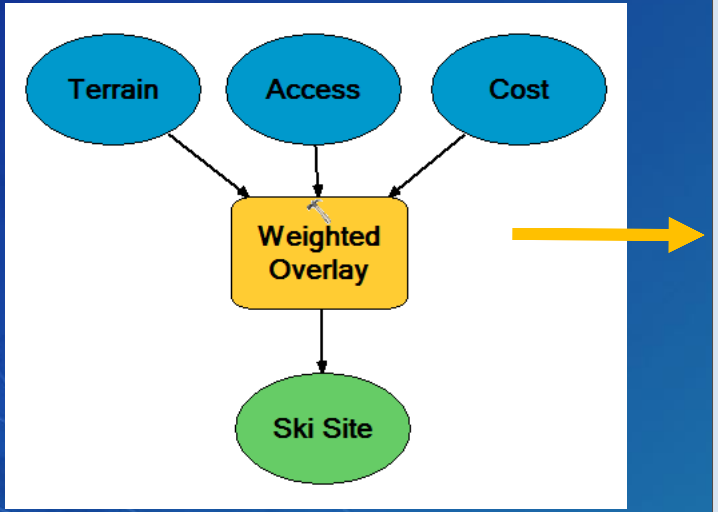
- Certain criteria may be more significant than others and must be weighted appropriately before combining
  - Terrain and access may be more significant to the ski area than cost
- Use Weighted Overly, Weighted Sum, or Map Algebra

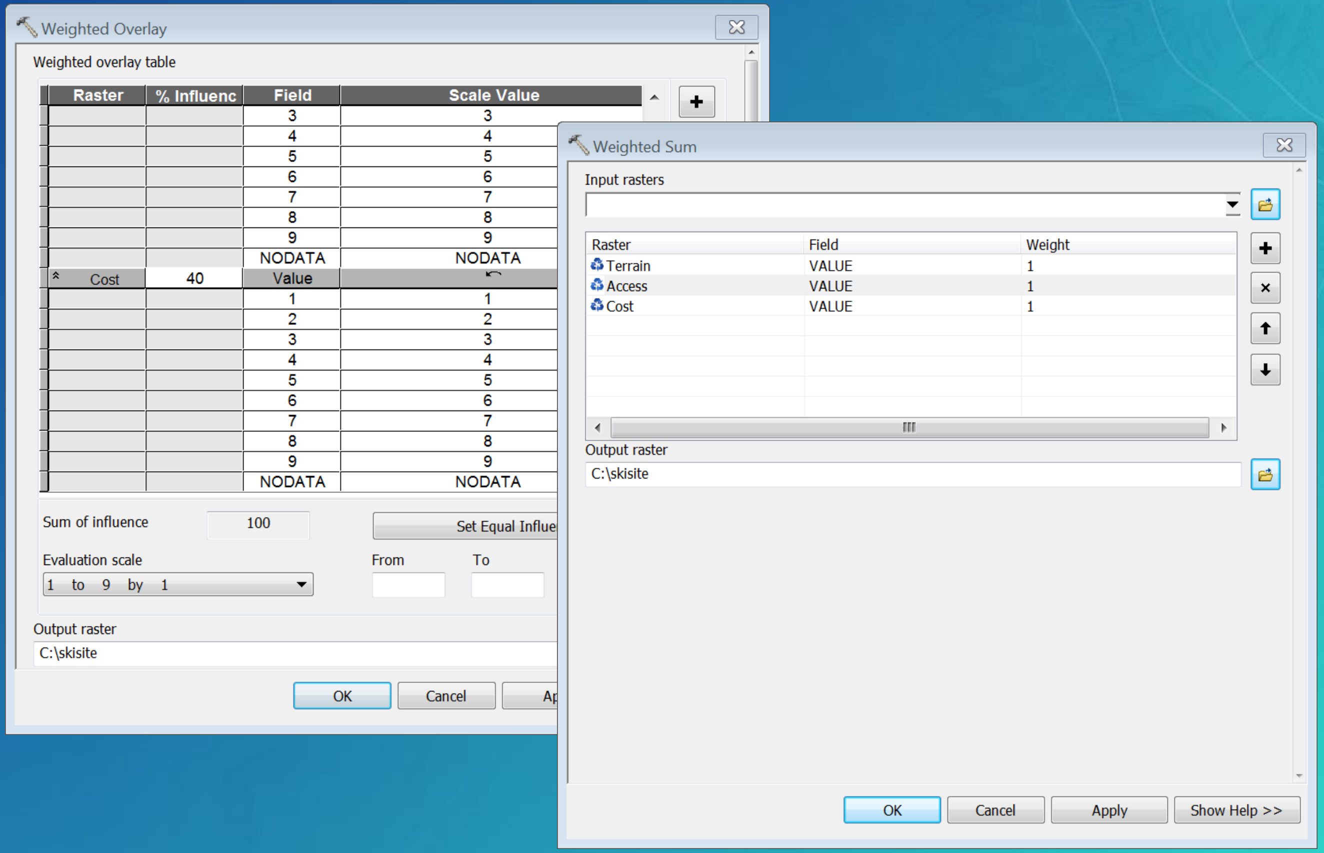



```
SkiSite = (Terrain * 0.5) + (Access * 0.3) + (Cost * 0.2)
```

The Weighted Overlay and Weighted Sum tools

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





Demo

Weight and combine

- Weighted Overlay
- Weighted Sum

Additional thoughts - Weight

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

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: 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

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

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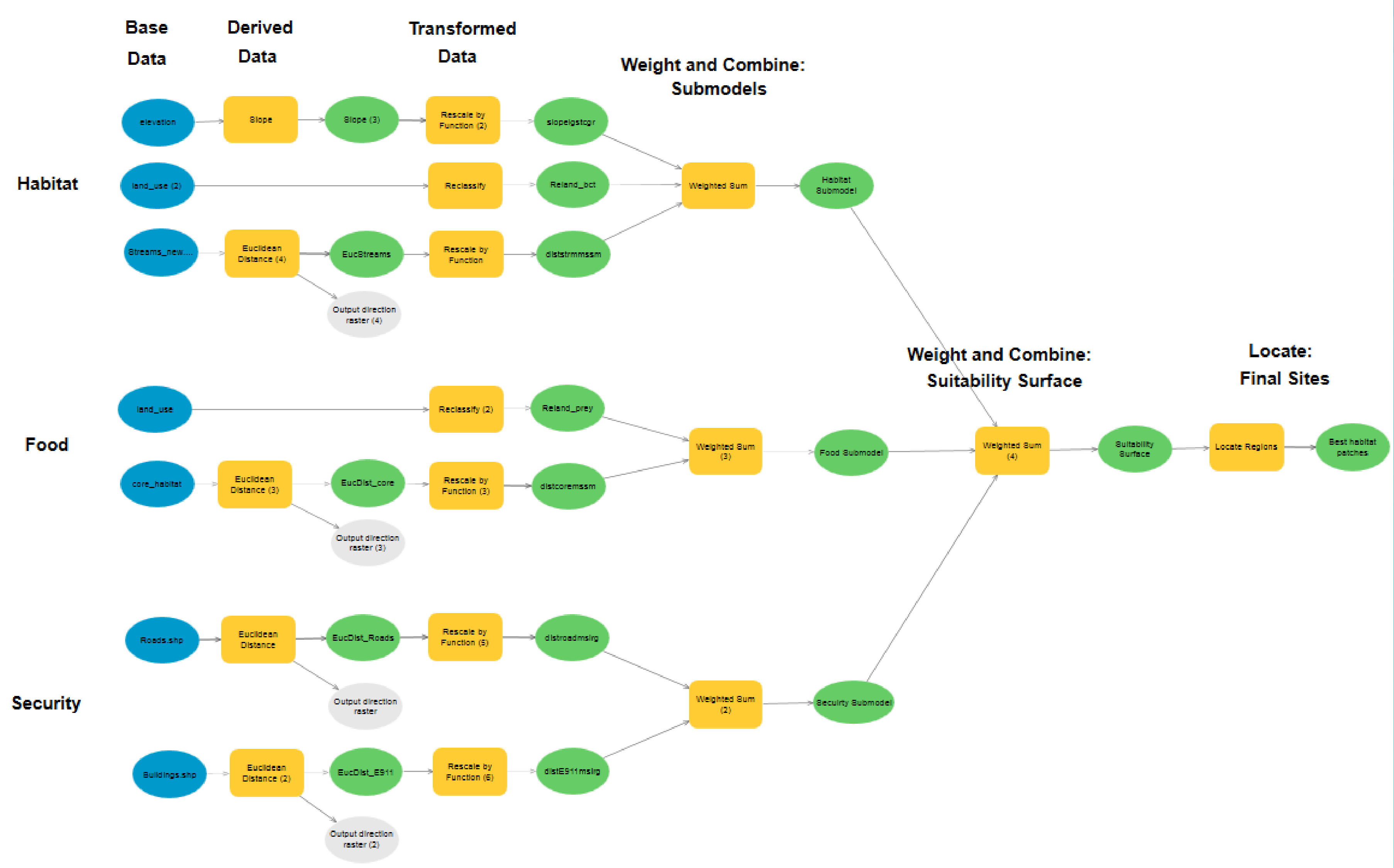
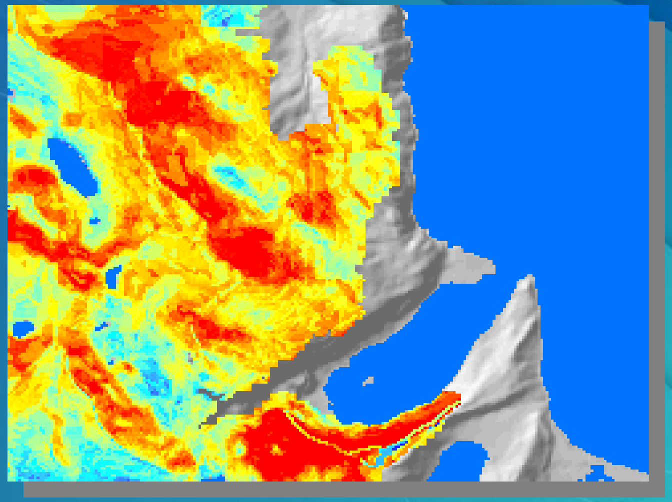
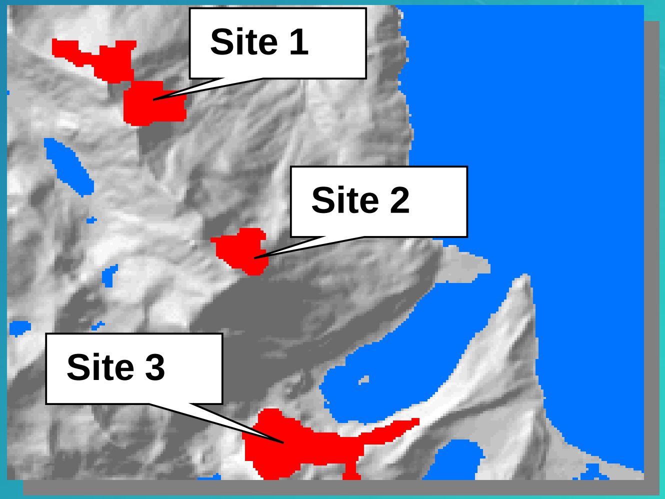


Locate

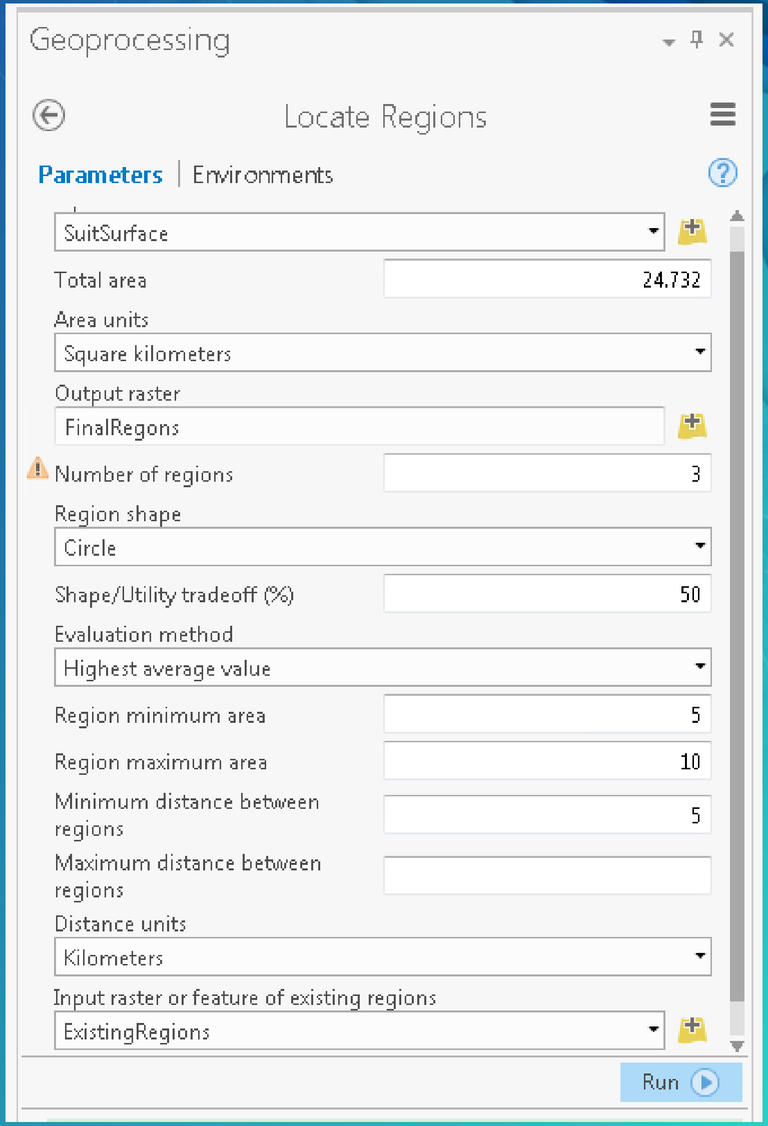
- **Model returns a suitability "surface"**
  - Ranks the relative importance of each site to one another relative to the phenomenon
- **Create candidate sites**
  - Select cells with highest scores
  - Define regions with unique IDS (Region Group)
  - Eliminate regions that are too small
- **Choose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





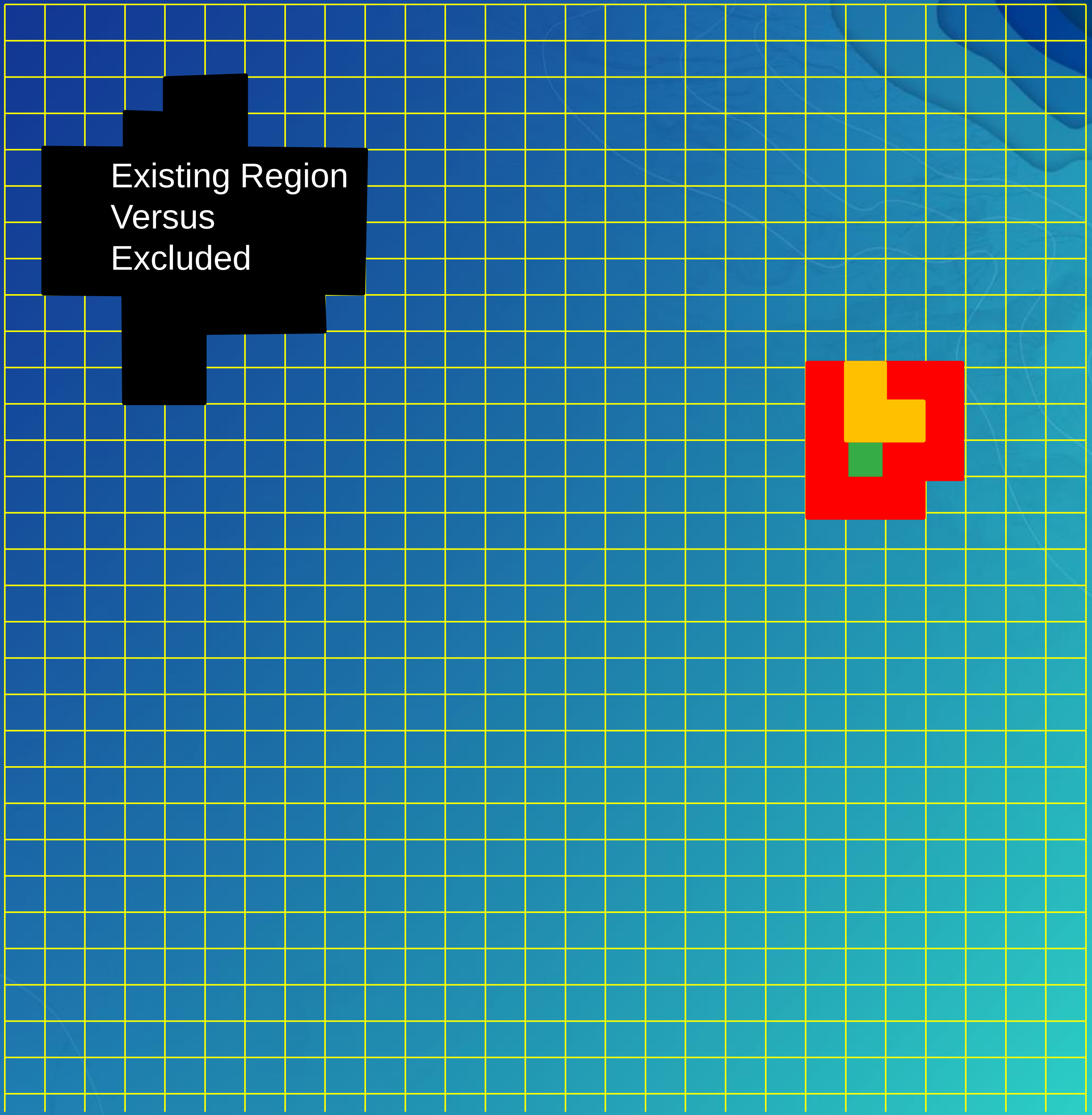
Locate Regions

- Requirements for the phenomenon to function
- Region characteristics
  - Size (500 contiguous acres)
  - Shape (compact as possible)
  - Number of regions
    - Minimum and maximum region sizes
- Inter spatial relationships
  - Minimum distance between patches
  - Maximum distance between patches
- Evaluation methods
- Optimum configuration
  - Combinatorial evaluation



How Locate Regions works

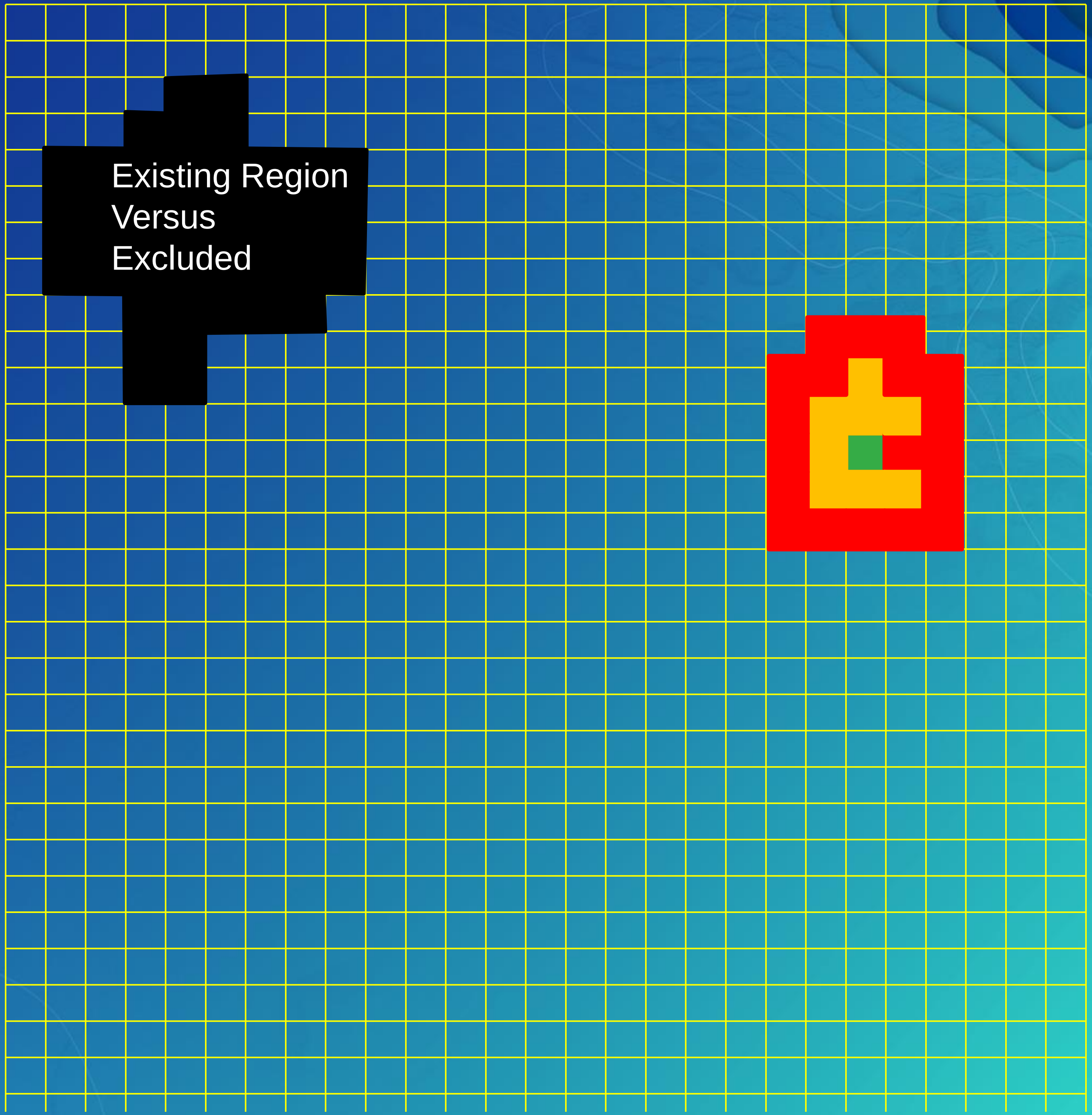
Candidate Regions PRG



Cell allocation is based on the shape/utility tradeoff

How Locate Regions works

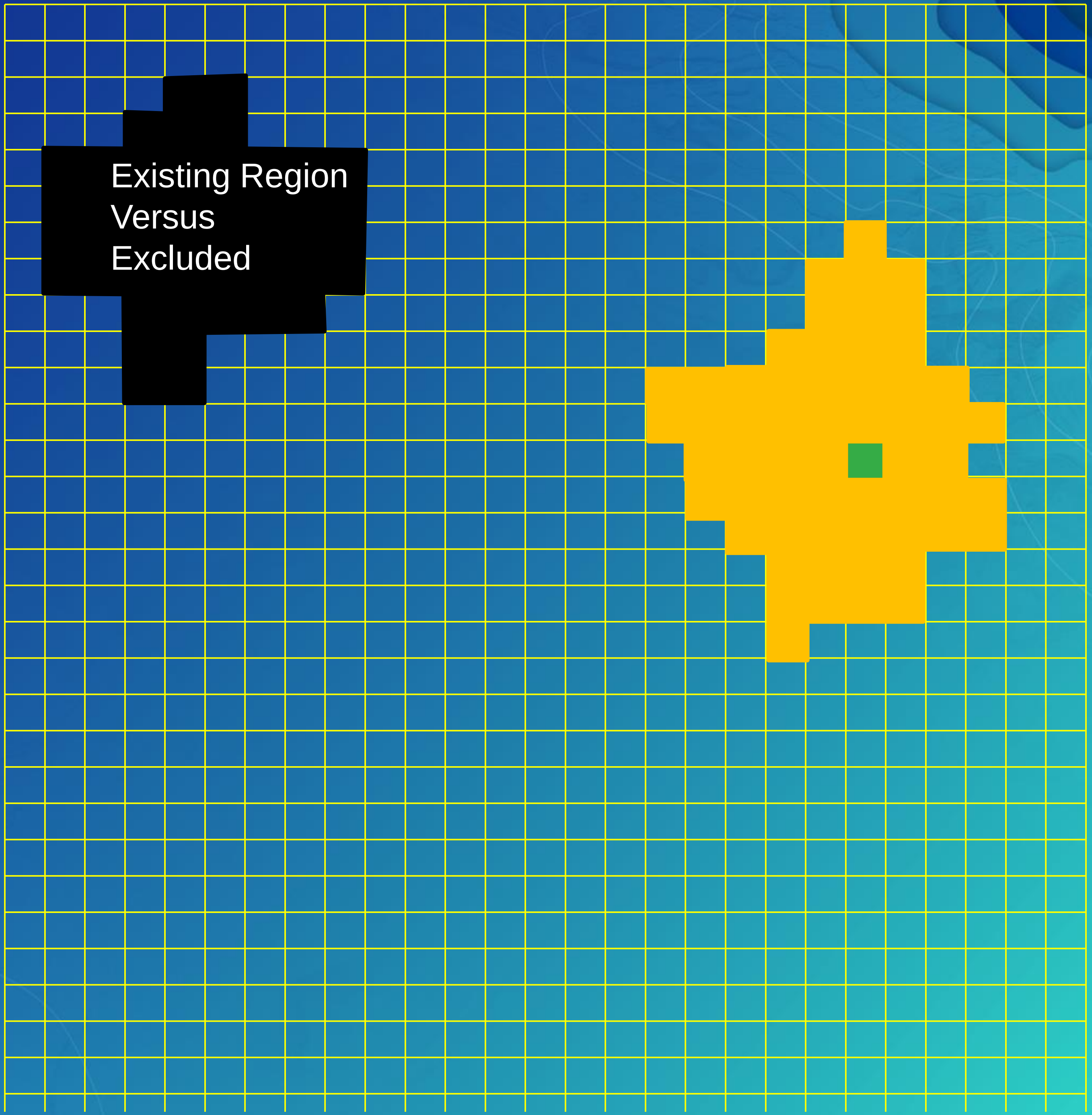
Candidate Regions PRG



Tradeoff:
shape/utility

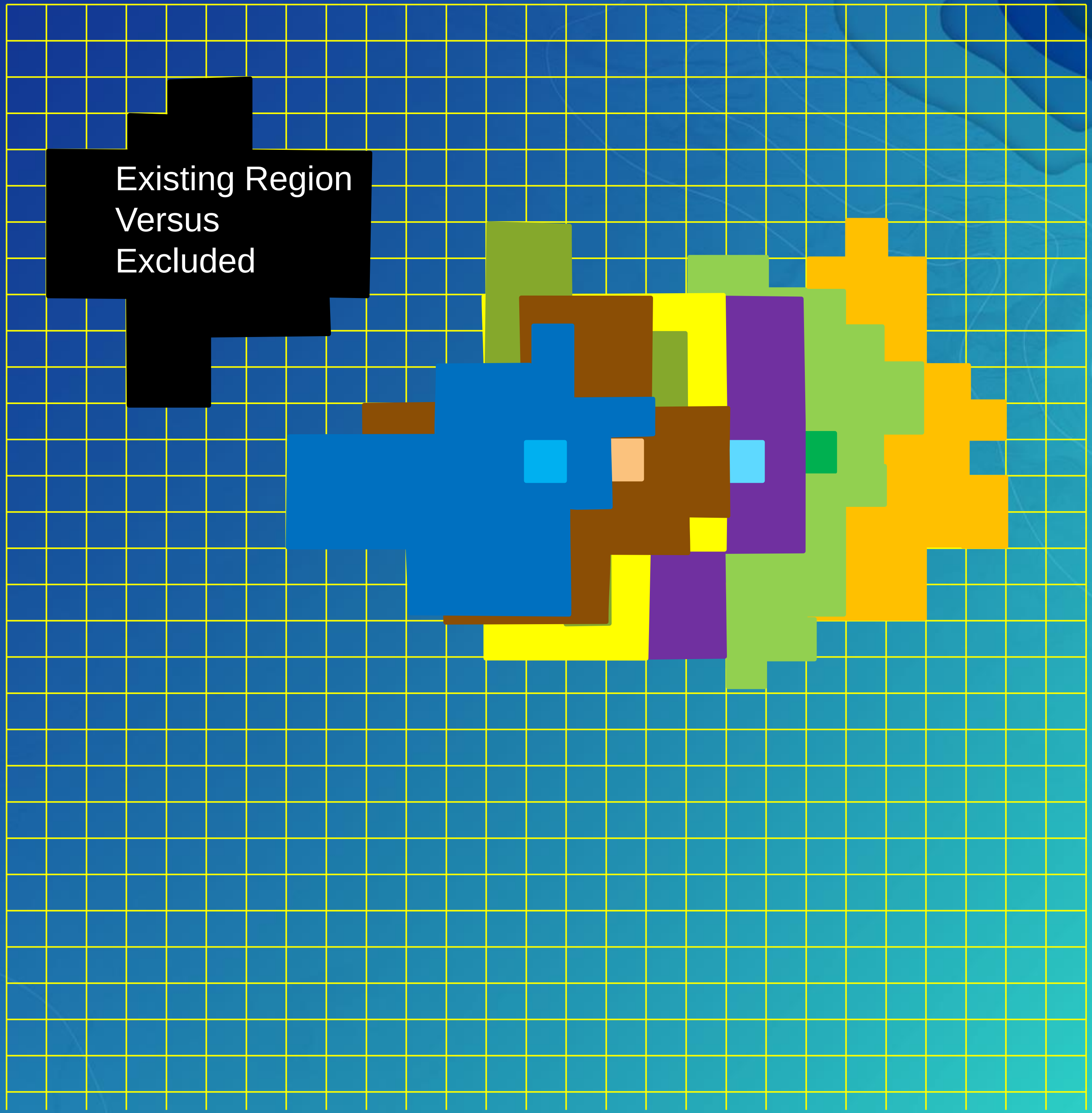
How Locate Regions works

Candidate Regions PRG



How Locate Regions works

Candidate Regions PRG



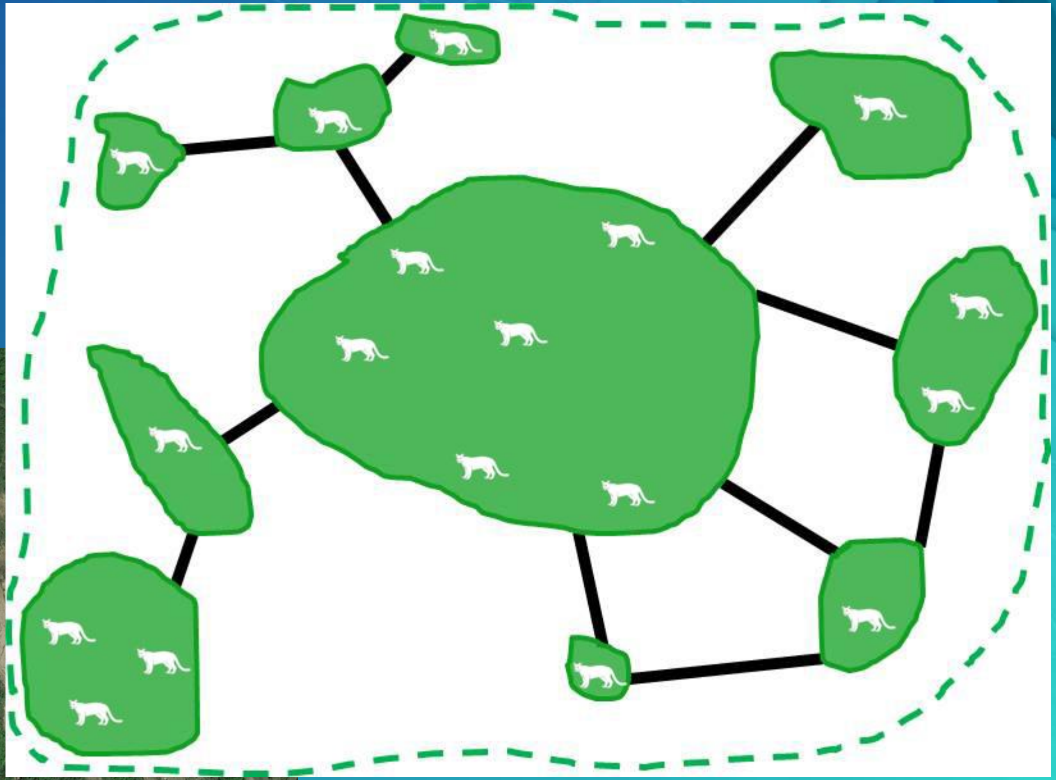
Select the “best” region(s)

- Evaluation criteria
  - Highest average value
  - Highest sum
  - Highest median value
  - Highest single value
  - Lowest single value
  - Largest core area
  - Greatest edge
  - Highest cumulative of core
- While honoring spatial constraints
- Combinatorial approach

Why do patches need to be connected?

- Fragmentation

Metapopulation



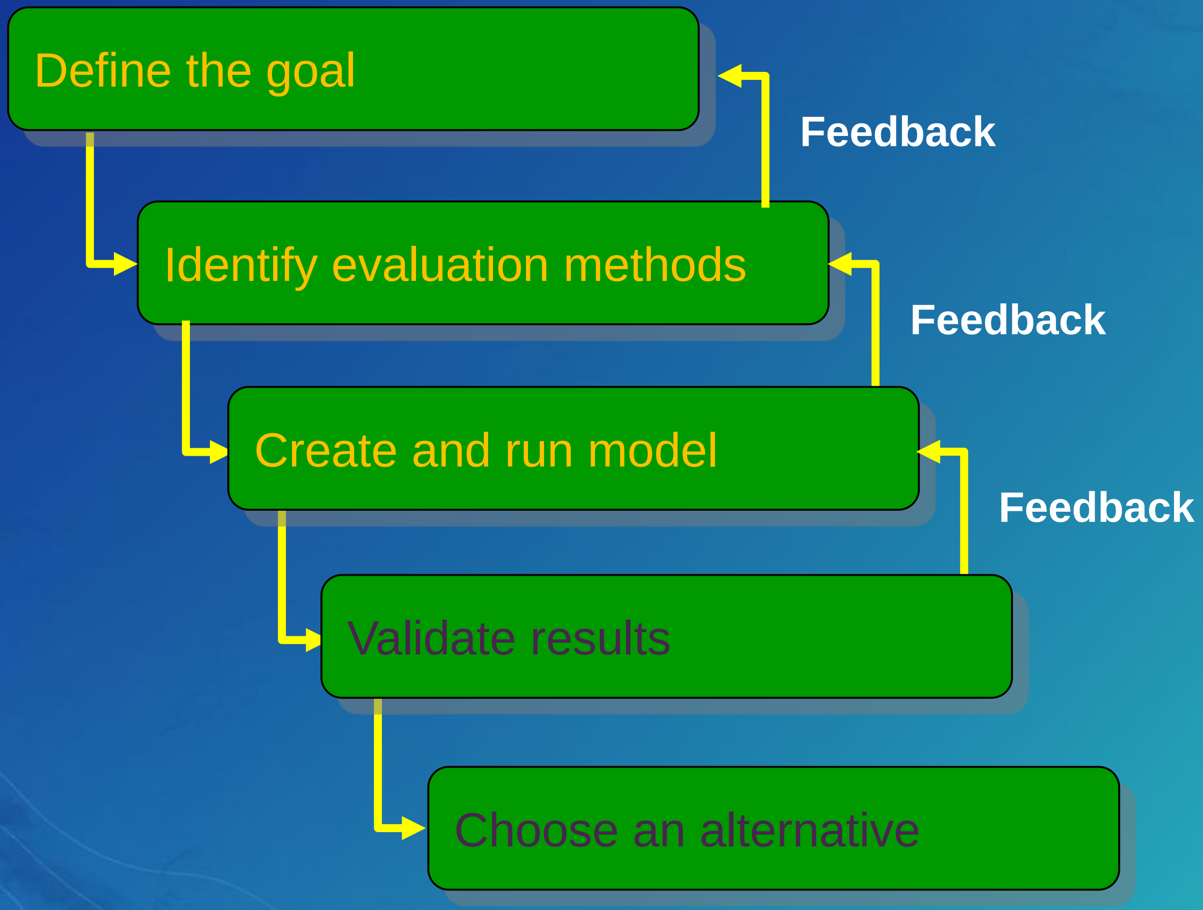
- Logging Roads
- Supply routes for military locations
- Fire fighting routes

Demo

Locating the phenomenon

- Locate Regions
- Cost Connectivity (a sneak peek)

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

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

Limitation 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

- Overview for creating a suitability model
- Defining criteria and transforming to common scale - Demonstration
- Weighting and combining the criteria - Demonstration
- Locating the phenomenon – Demonstration
- Case studies and fuzzy logic - Demonstration

Additional resource

- Two case studies in the Find locations section of the case studies in the online help
- Suitability modeling:

  http://desktop.arcgis.com/en/analytics/case-studies/understanding-the-suitability-modeling-workflow.htm
- Case study and 4 lessons with data (ArcGIS desktop and Pro)
  - Lesson 1: Exploring and deriving data
  - Lesson 2: Transforming data onto a common scale
  - Lesson 3: Weighting and Combining Data
  - Lesson 4: Locating and connecting regions

Additional resource

- Cost distance analysis

  http://desktop.arcgis.com/en/analytics/case-studies/understanding-cost-distance-analysis.htm

- Case study with 4 lessons with data
  - Lesson 1: Creating a cost surface
  - Lesson 2: Creating an optimal connectivity network
  - Lesson 3: Creating a least cost path
  - Lesson 4: Creating a corridor

Demo

Case studies and lessons

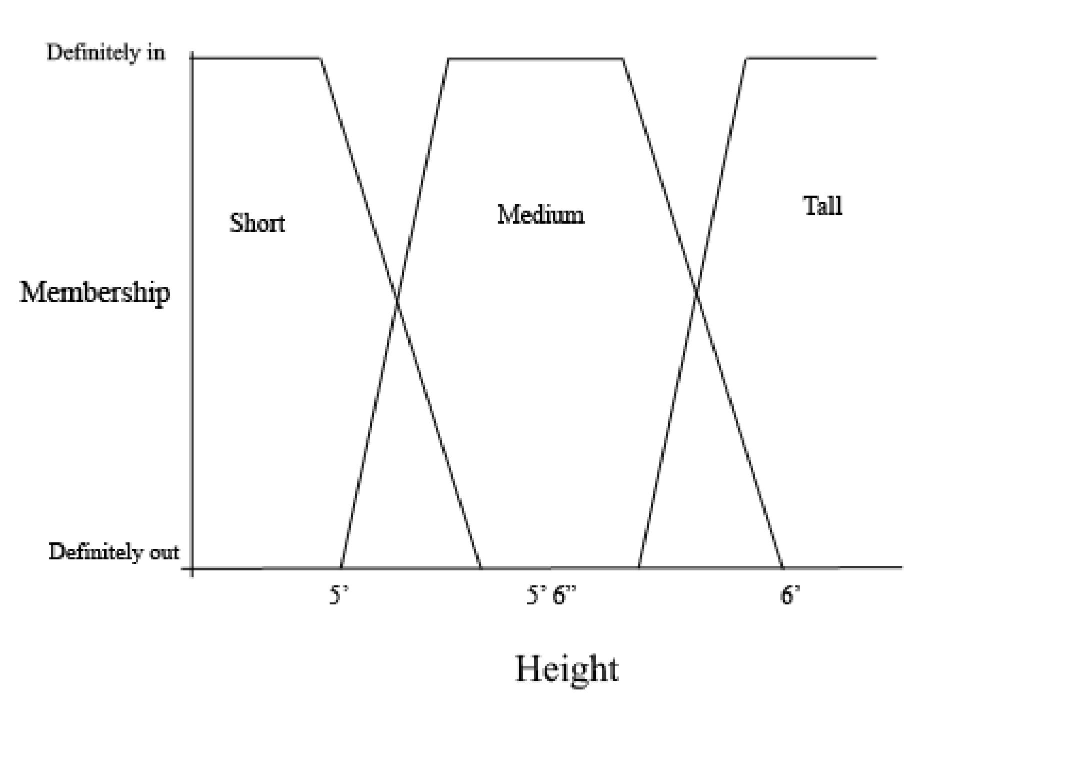
- Suitability modeling
- Cost distance analysis

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

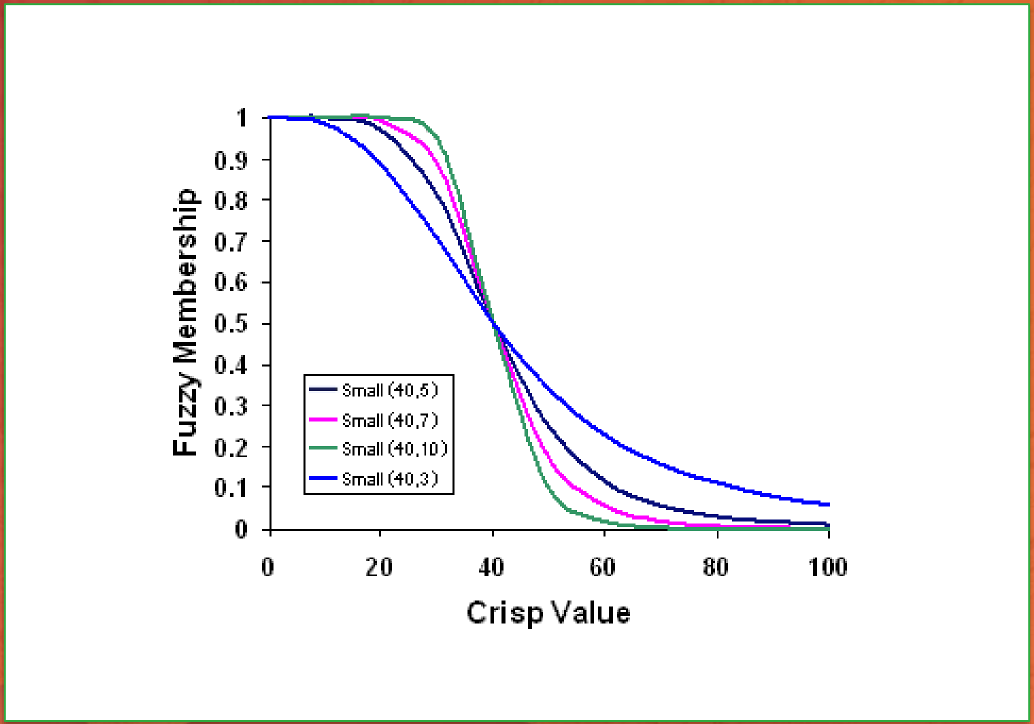


Fuzzy overlay – Transform values

- 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 - 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

Fuzzy Analysis

Fuzzification

Fuzzy Overlay

Summary

- 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
- Locate Regions identifies the best contiguous group of cells that meets the internal and inter- region spatial functional requirements

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

Acknowledgements: The Vermont Center for Geographic Information for the use of their data in this presentation

Other Spatial Analyst sessions

- Spatial Analyst: An Introduction
  - Tues 10:15 – 11:30
  - Wed 10:15 – 11:30
- Finding the Best Locations Using Suitability Modeling
  - Tues 1:30 – 2:45
  - Thurs 8:30 – 9:45
- Identifying the Best Paths with Cost Distance
  - Tues 3:15 – 4:30
  - Wed 1:30 – 2:45
- Suitability Modeling and Cost Distance Analysis Integrated Workflow (Demo Theater)
  - Wed 4:30 – 5:15
- Python: Raster Analysis
  - Tues 8:30 – 9:45
- Getting Started With Map Algebra Using the Raster Calculator and Python (Demo Theater)
  - Thurs 9:30 – 10:15

Other Spatial Analyst sessions

- Modeling Renewable Energy Potential Using ArcGIS (Demo Theater)
  - Tues 1:30 – 2:15
- Creating Watersheds and Stream Networks
  - Wed 10:00 – 10:30
- Hydrologic and Hydraulic Modeling
  - Wed 3:15 – 4:30
  - Thurs 1:30 – 2:45
- GIS Techniques for Floodplain Delineation (Demo Theater)
  - Tues 12:30 – 1:15
- Creating a Hydrologically Conditioned DEM (Demo Theater)
  - Tues 10:30 – 11:15
- Creating Surfaces from Various Data Sources
  - Tues 3:15 – 4:30
  - Thurs 3:15 – 4:30
- Choosing the Best Kriging Model for Your Data (Demo Theater)
  - Wed 11:30 – 12:15

Other Spatial Analyst sessions

- Surface Interpolation in ArcGIS (Demo Theater)
  - Thurs 10:30 – 11:15
- Creating Watersheds and Stream Networks (Demo Theater)
  - Wed 10:00 – 10:30
- Working with Elevation Services (Demo Theater)
  - Tues 10:30 – 11:15
  - Wed 9:30 – 10:15
- Building Python Raster Functions (Demo Theater)
  - Tues 10:30 – 11:15
- Raster Analytics in Image Server: An Introduction
  - Wed 3:15 – 4:30
- Raster Classification with ArcGIS Desktop (Demo Theater)
  - Thurs 9:30 – 10:15
- Raster Function Processing (Demo Theater)
  - Thurs 10:30 – 11:15

Want to learn more?

- Documentation
  - ArcGIS Pro Help
  - Terminology and user interface reference guide
- Related Esri Training and Tutorials
  - Introduction to ArcGIS Pro for GIS Professionals (Instructor Led)
  - Getting Started with ArcGIS Pro (Virtual Campus)
  - Get Started with ArcGIS Pro (Learn ArcGIS)
- Additional Resources
  - ArcGIS Pro Site

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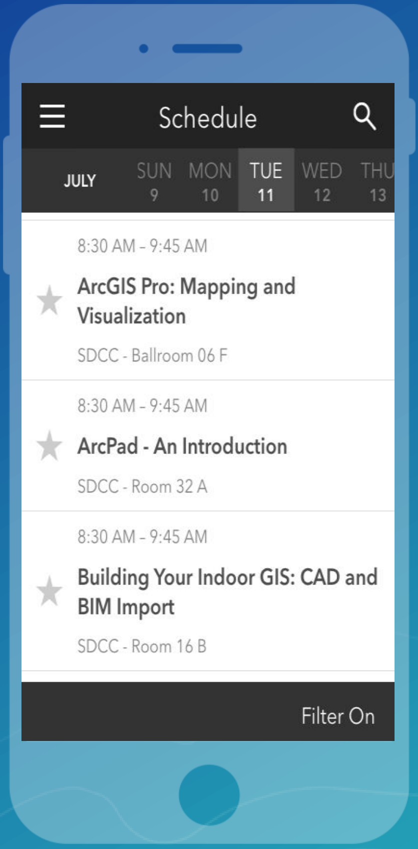
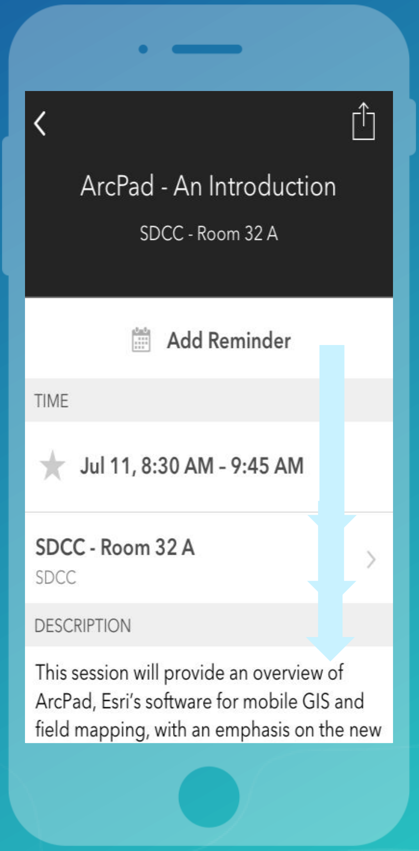
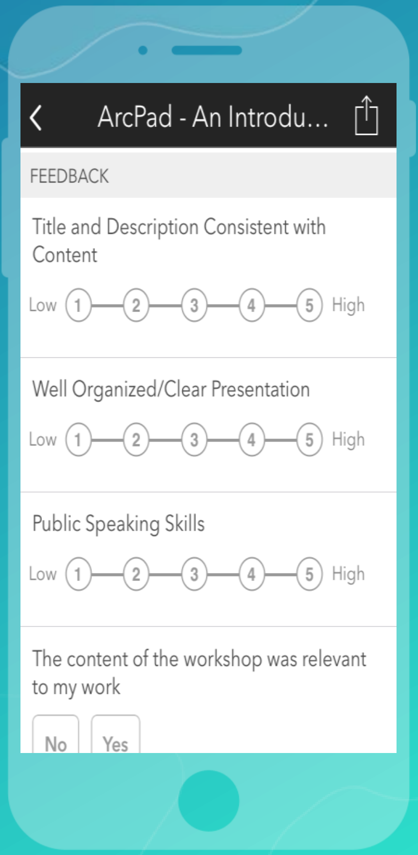
Select the session you attended



Scroll down to find the survey



Complete Answers and Select "Submit"



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