Title: An Automated, Multi-Criteria, Weighted Overlay Approach to Helicopter Landing Zones

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Topic Category: Analysis and Geoprocessing or Defense and Intelligence

Abstract: Helicopter landing zone (HLZ) suitability analysis uses GIS to identify safe landing locations for military operations, medical evacuations, and logistical planning. This paper describes the development and methodologies of an ArcGIS script tool using Python that automates the HLZ analysis process. The script is pre-loaded with common helicopter types and their corresponding HLZ criteria based on day or night conditions to include the maximum ceiling, acceptable slope, and minimum surface area. Also taken into account are suitable land cover and soil classification values, and distances from vertical obstructions and roads. Values are reclassified to represent highly, moderately, and barely suitable ranges. These results were combined with a weighted overlay based on the operational environment (urban, forest, barren/grassland, etc). The weights are determined using the Analytic Hierarchy Process (AHP) and a pairwise comparison of criteria. The final HLZ sites include an overall suitability assessment so the user can rank-order the results.

I) Introduction:

Military and civilian geospatial and imagery analysts conduct helicopter landing zone (HLZ) studies on a routine basis. HLZ studies help determine safe landing locations for helicopters in the event of offensive and defensive military operations (Figure 1). They are also integral to logistics planning in remote or inaccessible areas, and for medical evacuation planning. In the event of natural disasters, helicopters may be the only way for first responders to provide aid to the affected population.

Figure 1: An Mi-17 Landing in Afghanistan (Wikipedia, 2013)

Depending on an analyst's skill set and knowledge, an HLZ study can be as simple as looking at imagery and identifying open areas. More advanced analysts combine raster and vector data to determine suitable locations based on slope, land cover, open area, and other variables. From my own firsthand observations, many organizations have developed individual standard procedures and there is rarely consistency in procedures or criteria between organizations. Because HLZ studies are a fairly common geospatial product, these procedures should be standardized and preferably automated to increase accuracy and reliability.

Fortunately, it is relatively easy to find examples of how to conduct helicopter landing zone analysis. Defense-related information technology companies such as Northrop Grumman have built geoprocessing tools to automate HLZ site selection and sell these services to customers (Renner and others, 2009). Figure 2 shows a typical solution using the intersection of vegetation, slope, and surface area.

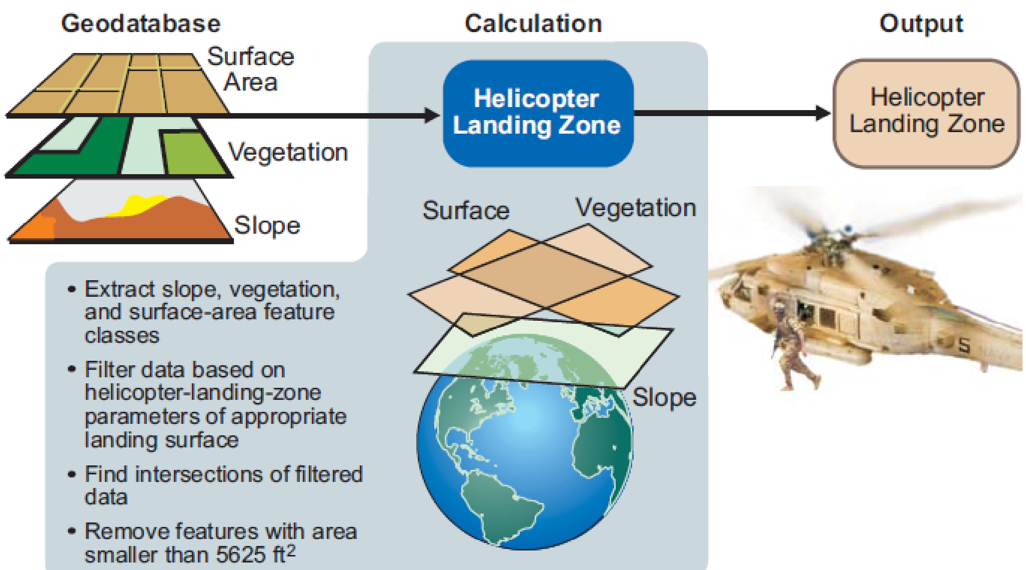

Figure 2: Helicopter Landing Zone Model (Renner and others, 2009)

Carlton & Berry (2011) provide a particularly-detailed contemporary GIS analysis for helicopter landing zones. Their analysis is similar to Renner and others (2009), but factors in the surrounding canopy height as additional criteria (Figure 3).

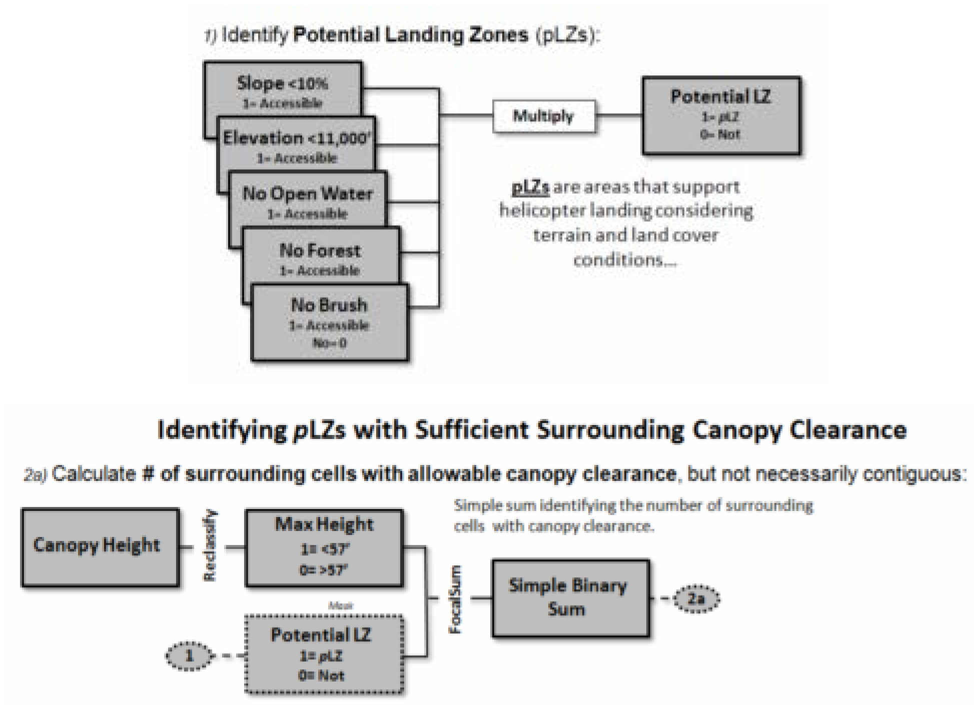

Figure 3: Potential Landing Zones with Slope, Elevation, Vegetation, and Canopy Height (Carlton & Berry, 2011)

Unfortunately, these analysis techniques provide only a go/no-go solution. In other words, they identify landing sites and areas where a helicopter can or cannot land. No analysis is done to assess the degree of suitability of a site or to rank-order potential landing zones so an analyst can pick the most ideal site.

II) Project Objectives and Goals:

For this project, I have refined the typical HLZ analysis process to include multi-criteria weighting so that the final list of potential sites can be rank-ordered based on suitability. I developed an ArcGIS script tool using Python and ArcGIS 10. The script is pre-loaded with common helicopter types and their corresponding HLZ criteria, and typical land cover and soil classification tables for USGS and USDA data products. These values are contained in data dictionaries that can be modified by an experienced user. For example, the HLZ criteria includes the maximum service ceiling (altitude), minimum surface area, minimum width, maximum slope, and minimum vertical obstruction distance. These criteria will vary depending on the type of helicopter and whether the user specifies if the analysis is for day or night conditions. A medium utility helicopter, such as a UH-60 Blackhawk, can land in a much smaller area than a heavy cargo helicopter, such as a CH-47 Chinook, but the Blackhawk's maximum flight ceiling is lower. At night, all helicopters require larger areas due to safety concerns. I have also determined values within the acceptable ranges that represent highly suitable, moderately suitable, and barely suitable ranges for different types of helicopters. The soil and land cover reclassifications should be independent of helicopter type. After providing input data, the script automatically determines the appropriate overlay weights based on the environments (forest, urban, barren/grassland), performs the analysis, and outputs potential HLZ sites in shapefile and Google Earth KML format. These sites will have an overall suitability assessment and be rank-ordered so an analyst can determine which sites are most ideal.

III) Data Sources:

The United States Geological Survey provides a seamless digital elevation model called the National Elevation Dataset (NED). The NED is distributed in North American Datum 1983 with geographic coordinates and is updated in two month cycles. The data is available throughout the United States at a spatial resolution of 1 arc-second (approximately 30 meters), 1/3 arc-seconds (approximately 10 meters), and 1/9 arc-seconds (approximately 3 meters). The files are presented as floating point ArcGrid, GRIDFLOAT or IMG formats in 1 degree by 1 degree tiles (United States Geological Survey, 2012a). The NED is necessary to determine flight ceiling limitations and the slope.

The Federal Aviation Administration provides a Digital Obstacle File for the United States that describes all man-made aviation obstacles which affect aeronautical charting products. It comes in a file with geographic coordinates in the World Geodetic System-1984 datum. Since the coordinate format is degree minute second, it has to be converted into decimal degree format for display in ArcGIS. The obstacle height measurements are given in feet above ground level (AGL) or mean sea level. The DOF is updated every 56 days and includes thousands of features in every state (Federal Aviation Administration, 2013). For example, in Colorado, there are 3,114 obstacles.

The USGS provides National Land Cover Database 2006 and 2001 (NLCD) for the entire United States, which greatly assists with classifying suitable areas. The NLCD is distributed in NAD 83 with an Albers Conical Equal Area projection. LandSat imagery is used to determine the land cover classification. The data has a resolution of 30 meters and is distributed as a GeoTiff through the USGS National Map server which allows the user to download one of 66 pre-packaged regional datasets with land cover classifications (Figure 4) (United States Geological Survey, 2012b).

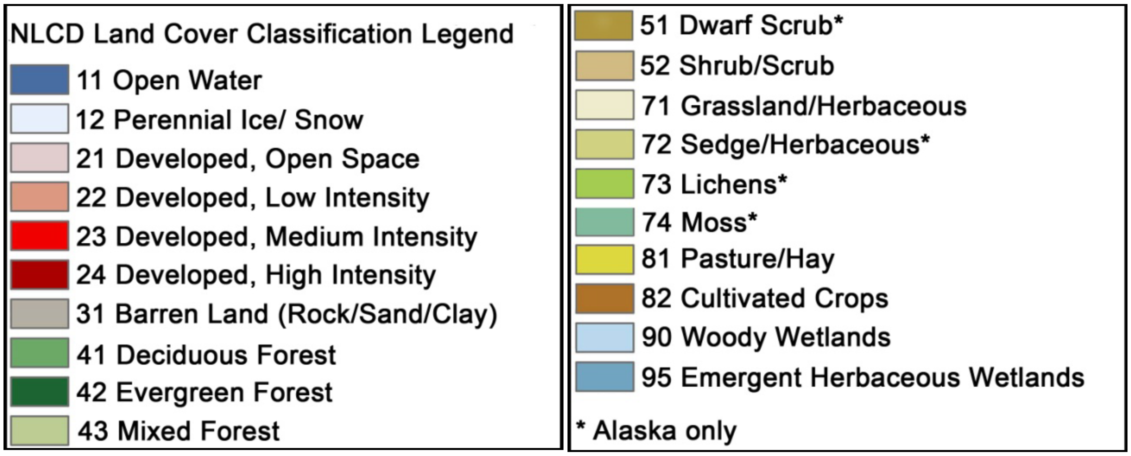

Figure 4: National Land Cover Classifications (United States Geological Survey, 2012b)

For soil suitability, the Gridded Soil Survey Geographic (gSSURGO) Database provided by the US Department of Agriculture includes a wealth of soil information. The database includes a raster layer projected in USA Contiguous Albers Equal Area Conic with map unit grid values. These map units can be joined to dozens of variables such as drainage, soil organic compound percentage, water contents, etc. It covers most of the United States at 10-meter resolution (Natural Resources Conservation Service Soil Survey Staff, 2013). Unlike the other datasets used in this project, there are significant gaps in coverage for some areas that could affect the HLZ analysis and should be taken into account by the analyst.

For this project, I used US Census Bureau TIGER street data obtained from the USGS National Map Server. It comes in North American Datum 1983. This street information covers the entire United States and uses a variety of state, county and municipal datasets (United States Census Bureau, 2013).

Table 1 displays a summary of the data sources used for this project:

Table 1: Data Sources

Data Source	Producer	Spatial Resolution	Format	Projection
National Elevation Dataset	United States Geological Survey	1/3 arc seconds (10 meters)	ArcGrid, GRIDFLOAT, or IMG	North American Datum 1983 (NAD83) Geographic
Digital Obstacle File	Federal Aviation Administration	N/A	Table	World Geodetic System 1984 Geographic
National Land Cover Database (2006 or 2001)	United States Geological Survey	30 meters	GeoTiff	NAD 83 Albers Conical Equal Area Projection
Gridded Soil Survey Geographic (gSSURGO)	United States Department of Agriculture	10 meters	Geodatabase Raster	NAD 83 USA Contiguous Albers Equal Area Conic Projection
TIGER Street	US Census Bureau	N/A	Shapefile	North American Datum 1983 (NAD83) Geographic

IV) GIS Criteria and Classifications:

The script tool uses elevation, land cover, and soil raster data along with vertical obstructions, roads, and an area of interest (AOI) feature class as inputs. The user will also have the choice to select between day or night conditions and whether the analysis is being conducted in a forest, urban, or barren/grassland environment.

Several sources provide typical geospatial criteria for a helicopter landing zone. Army Field Manual FM 3-21.38 establishes (HLZ) criteria (Department of the Army, 2006). Chapter 4 describes the specific minimum landing diameter, slope, surface conditions, and obstruction ratios for seven categories of helicopters. It also contains guidance on changing the landing zone criteria based on night conditions. The Federal Aviation Administration has published similar but less-detailed criteria for different types of civilian helicopters (Federal Aviation Administration, 2012). The dimensions of the landing zones are slightly different from the US Military standards and the slope has a more conservative maximum of 5 degrees. Helicopter landing zones are also common in wilderness rescues; Allen & Cooper (2012) suggest geospatial criteria for helicopter rescue and aeromedical transport. They also describe flight service ceilings for typical types of helicopters and recommends a safety factor of 50% for landing zone sizes at night. Based on these sources, I have compiled the criteria for both day and night operations for five families of helicopters (Tables 2). An experienced geospatial analyst can modify these criteria by changing the data dictionaries in the Python script.

Table 2: Maximum and Minimum Criteria for Different Helicopter Types for (Day/Night)

Helicopter Type (Day/*Night*)	Max Ceiling (Meters)	Min. LZ Area (Sq. Meters)	Min. LZ Width (Meters)	Highly Suitable Slope Range (Degrees)	Moderately Suitable Slope Range (Degrees)	Barely Suitable Slope Range (Degrees)	Unsuitable Slope Range (Degrees)
Light Observation (OH-6 Little Bird, OH-58D Kiowa)	4500	625 *(1444)*	25 *(38)*	0 - 2.99	3 - 4.99	5 - 7	> 7
Light Utility and Attack (AH-1W Super Cobra, UH-1N Huey)	4000	1225 *(2809)*	35 *(53)*	0 - 2.99	3 - 4.99	5 - 7	> 7
Medium Utility and Attack (UH-60L Black Hawk, AH-64D Apache)	3300	2500 *(5625)*	50 *(75)*	0 - 5.99	6 - 10.99	11 - 15	> 15
Heavy Cargo (CH47D Chinook, CH-53E Stallion)	5500	6400 *(14400)*	80 *(120)*	0 - 5.99	6 - 10.99	11 - 15	> 15
Sling Load or Unknown Helicopter	3000	10000 *(22500)*	100 *(150)*	0 - 2.99	3 - 4.99	5 - 7	> 7

Vertical obstruction distance should follow a planning factor of approximately 10 to 1 (Department of the Army, 2006). For example, if a tree is 171 feet tall, the safe distance would be 1,640 feet away (Figure 5). This is based on a maximum obstruction angle of six degrees. This factor can be reduced to 5 to 1 if necessary, or an clearance angle of twelve degrees. At night, the angle is four degrees, a planning factor of approximately 14 to 1.

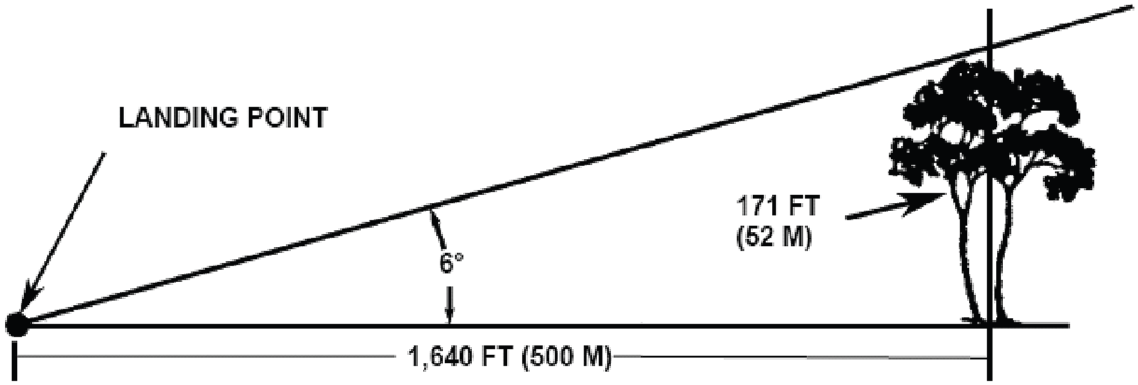

Figure 5: Daylight Vertical Obstruction Safe Distance (Department of the Army, 2006)

If we know the obstacle height, the safe distance would be ([Obstacle Height AGL] / Tangent(angle)) based on basic geometric principles. Table 3 shows the highly, moderately, and barely suitable safe distance formulas based on obstacle ratios or clearance angles during the day and at night.

Table 3: Vertical Obstruction Criteria (Day and Night)

Vertical Obstruction Critieria	Highly Suitable Obstacle Ratio / Clearance Angle	Moderately Suitable Obstacle Ratio / Clearance Angle	Barely Suitable Obstacle Ratio / Clearance Angle	Unsuitable Obstacle Ratio / Clearance Angle
Day	> 10 to 1 6°	> 7.5 to 1 9°	> 5 to 1 12°	< 5 to 1 12°
Night	> 14 to 1 4°	> 10 to 1 6°	> 7 to 1 8°	< 7 to 1 12°

Desirable land cover for helicopter operations would include open areas such as grasslands, fields, golf courses, and farms. Undesirable land cover would include trees, dense urban cities, and swamps. Table 4 shows NLCD land cover types broken into highly suitable, moderately suitable, barely suitable, or unsuitable categories.

Table 4: USGS Land Cover Classification in Highly, Moderately, and Barely Suitable Categories

Land Cover Type	Highly Suitable Land Cover	Moderately Suitable Land Cover	Barely Suitable Land Cover	Unsuitable Land Cover
11: Open Water				X
12: Perennial Snow/Ice			X	
21: Developed, Open Space		X		
22: Developed, Low Intensity				X
23: Developed, Medium Intensity				X
24: Developed, High Intensity				X
31: Barren Land			X	
41: Deciduous Forest				X
42: Evergreen Forest				X
43: Mixed Forest				X
*51: Dwarf Scrub			*X	
52: Shrub/Scrub				X
71: Grassland/Herbaceuous	X			
*72: Sedge/Herbaceous		*X		
*73: Lichens		*X		
*74: Moss		*X		
81: Hay/Pasture	X			
82: Cultivated Crops		X		
90: Woody Wetlands				X
95: Emergent Herbaceuous Wetlands				X

* Alaska only

The Gridded Soil Survey Geographic (gSSURGO) database contains many descriptive elements within the Mapunit aggregated attribute table. For helicopter landing zone (HLZ) applications, the dominant condition for the drainage class seemed particularly helpful. If terrain has poor drainage, it is more likely to be a wetland or be liable to sink under a helicopter's weight, potentially trapping it or causing an accident. The highly suitable, moderately suitable, barely suitable, or unsuitable categories for soil drainage are shown in Table 5. Because there are significant gaps in the gSSURGO data, this criterion is optional and can be excluded from the analysis.

Table 5: Soil Drainage Classification in Highly, Moderately, and Barely Suitable Categories

Soil Type Drainage	Highly Suitable Soil	Moderately Suitable Soil	Barely Suitable Soil	Unsuitable Soil
1 Excessively drained	X			
2 Somewhat excessively drained	X			
3 Well drained	X			
4 Moderately well drained		X		
5 Somewhat poorly drained			X	
6 Poorly drained				X
7 Very poorly drained				X

The last criteria considered for a helicopter landing zone is the distance from roads. Although a landing zone can occur anywhere within an area of interest, it is frequently more useful to be near a road to facilitate the transportation of supplies, personnel, or casualties. However, landing immediate adjacent to a road is not ideal as telephone poles, power lines, and other vertical obstacles can hinder flight. While not every road might have these obstacles, I choose to rank 0-50 meters from a road as barely suitable. Refer to Table 6 below.

Table 6: Road Distance in Highly, Moderately, and Barely Suitable Categories

Road Distance Criteria	Highly Suitable Road Distance (Meters)	Moderately Suitable Road Distance (Meters)	Barely Suitable Road Distance (Meters)	Unsuitable Road Distance (Meters)
Day and Night	50 - 399	400 - 799	0 - 49, 800 +	N/A

V) Methodology:

The script clipped all datasets into the area of interest and then projected the data into the appropriate North America Datum 1983 UTM zone. Next, it excluded all elevations that exceeded the maximum flight ceiling for the selected helicopter. The tool subsequently created a slope below this flight ceiling and calculated distances from vertical obstructions (using a series of buffers based on the height above ground field and the appropriate formula) and roads (using Euclidean distance). See Figure 6.

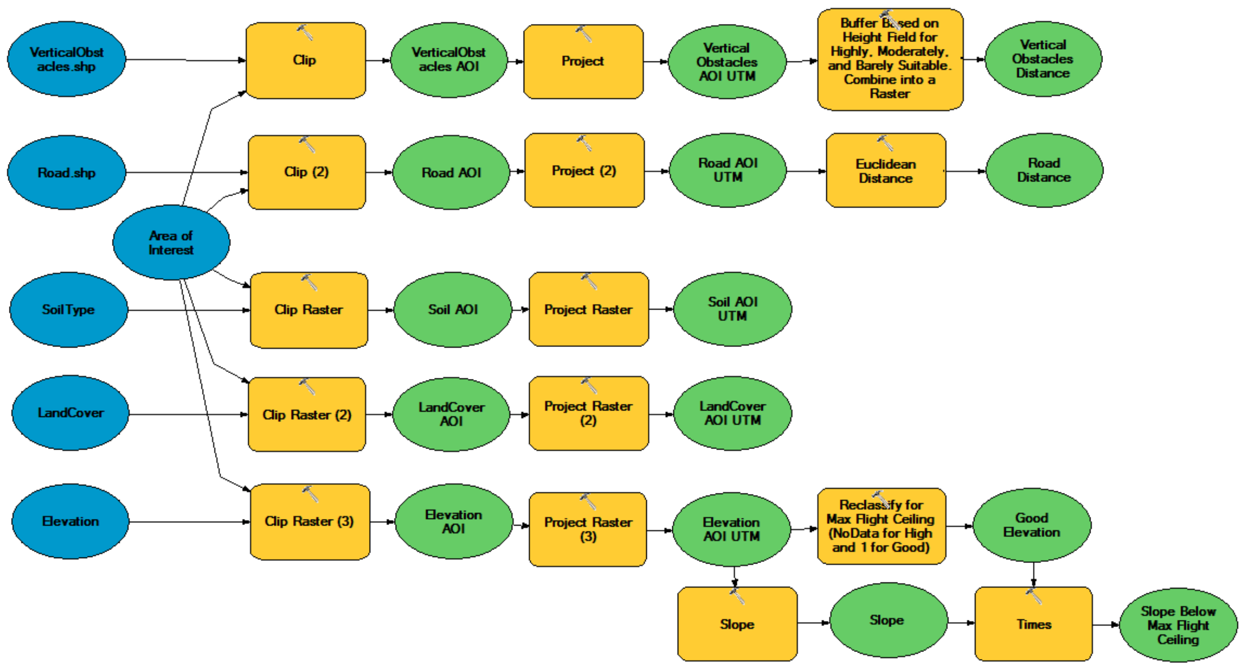

Figure 6: Script Flowchart Part One: Preparation of the Input Data

Five raster layers were created to classify the slope, land cover, soil type, distances from vertical obstructions, and distances from roads into categories of highly suitable, moderately suitable, barely suitable, and unsuitable. The five reclassified layers were combined with the "Weighted Overlay" tool. The weights are determined by the operating environment (forest, urban, barren/grassland). If any layer was unsuitable, the pixel became unsuitable.

The resulting site configuration suitability raster was converted into vector format, and dissolved to break apart multipart polygons. The tool selected HLZ sites with greater than the minimum surface area based on the helicopter type. Zones that met the area criteria but were too thin were eliminated using the minimum width calculated in the minimum bounding geometry tool. The vector representation of the sites was converted back into a surface area suitability raster with the area field as the new grid value. The large HLZ sites were assigned attribute values of highly suitable, moderately suitable, or barely suitable based on a Natural Breaks (Jenks) classification of the zone surface areas. The more suitable sites have larger surface area.

A "Weighted Sum" overlay combined the site configuration suitability raster (the result of the first weighted overlay) with the area suitability raster to create a final suitability raster. The site configuration is 75% of the weight while the area is 25%. The "Zonal Statistics" tool, using the vector representation of the sites as the selecting feature and the final suitability raster as the value layer, calculated the average of the grid values for each site. Joining the Zonal Statistics table to the final HLZ site polygon allowed the sorting of the suitability of each helicopter landing zone (Figure 7).

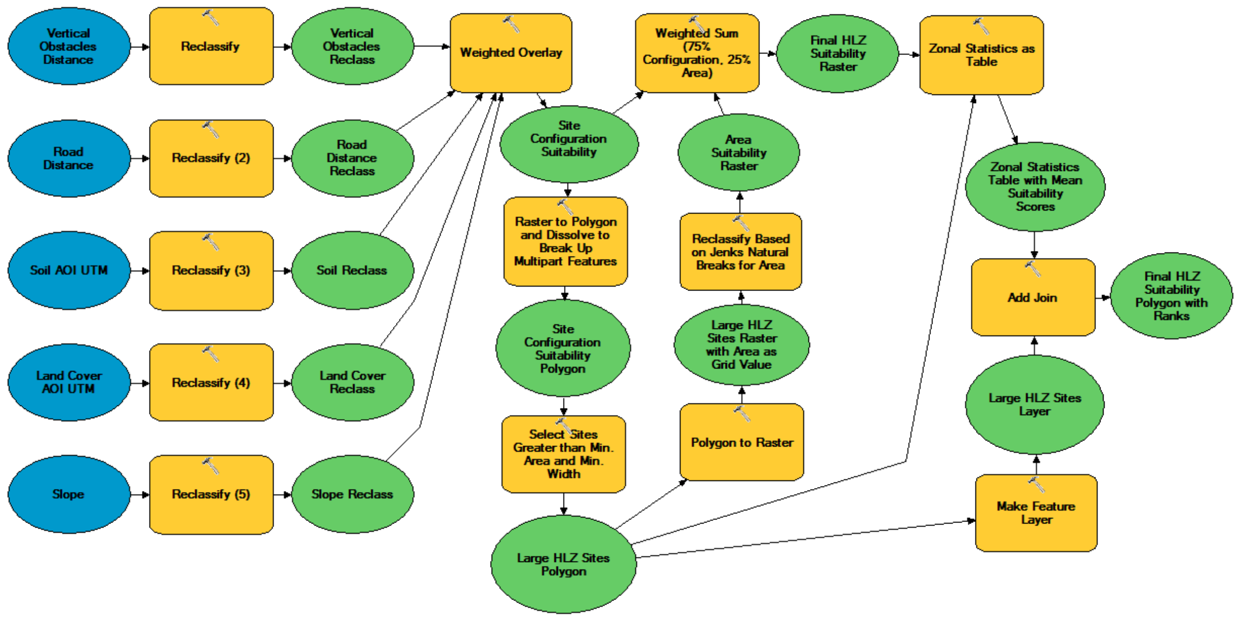

Figure 7: Script Flowchart Part Two: Suitability Reclassification and Weighted Overlays

VI) Analytic Hierarchy Process:

An important part of my project was the determination of the weights for creating the site suitability raster and the combined final suitability raster. I used the Analytic Hierarchy Process (AHP), developed by Thomas Saaty in the 70's and 80's. The AHP has been used in the geography field for years and is an established and simple system for multi-criteria weighting. It requires setting an overall goal and a hierarchy of objectives, attributes and criteria (Boroushaki & Malczewski, 2008). Figure 8 shows the HLZ decision hierarchy.

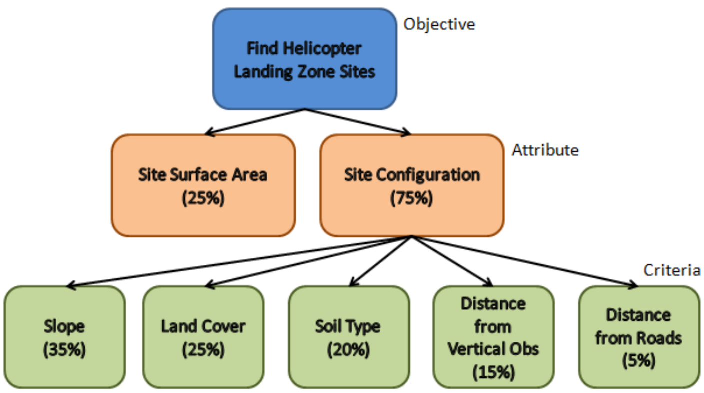

Figure 8: An Analytic Hierarchy for a Helicopter Landing Zone Analysis with Sample Weights

The weights at each level of the hierarchy must add up to 100%. To determine the actual weights, a pairwise comparison was done for two criteria at a time until all criteria were compared with each other. For the site configuration criteria of slope, land cover, soil type, distance from vertical obstructions, and distance from roads, there were ten total pairs of comparisons (Table 7).

Table 7: Pairwise Comparison for Five HLZ Criteria

Criteria 1		Criteria 2
Slope	vs.	Land Cover
Slope	vs.	Soil Type
Slope	vs.	Vertical Obs. Distance
Slope	vs.	Road Distance
Land Cover	vs.	Soil Type
Land Cover	vs.	Vertical Obs. Distance
Land Cover	vs.	Road Distance
Soil Type	vs.	Vertical Obs. Distance
Soil Type	vs.	Road Distance
Vertical Obs. Distance	vs.	Road Distance

For each comparison, the weaker candidate receives a value of one. The stronger candidate is assigned a value from one to nine. The score indicates the relative importance of the stronger criteria vs. the weaker criteria. The fundamental scale for pairwise comparisons is shown in Table 8.

Table 8: The Fundamental Scale for Pairwise Comparisons (Wikipedia, 2012)

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities of 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

I surveyed thirty geospatial and imagery analysts from the US Army, US Marine Corps, and the National Geospatial-Intelligence Agency for their pairwise comparison values in forest, urban, and barren/grassland conditions. The experience level of the participants varied from one to twenty years. An example of a completed pairwise comparison for a forest environment is shown in table 9.

Table 9: Sample Pairwise Comparison for Five HLZ Criteria in a Forest Environment (Illustrative Values Only)

Criteria 1			Criteria 2	
Slope	2	vs.	Land Cover	1
Slope	3	vs.	Soil Type	1
Slope	4	vs.	Vertical Obs. Distance	1
Slope	6	vs.	Road Distance	1
Land Cover	3	vs.	Soil Type	1
Land Cover	2	vs.	Vertical Obs. Distance	1
Land Cover	5	vs.	Road Distance	1
Soil Type	3	vs.	Vertical Obs. Distance	1
Soil Type	4	vs.	Road Distance	1
Vertical Obs. Distance	3	vs.	Road Distance	1

I input the survey results into an AHP Excel spreadsheet (Goepel, 2012). The spreadsheet automatically determined the consistency ratio of each survey. A score of 15% or less was considered acceptable. Anything higher than 15% indicated inconsistent answers. For example, a user could determine that slope is more important than land cover and that land cover is more important that soil type. To be consistent, slope should also be more important than soil type. I rejected ten surveys based on poor consistency scores. Most of these surveys came from analysts with less than two years of experience. For each valid survey, the winning value of the pairwise comparison received the assigned number while the losing value received the inverse score. In simple terms, I determined the scores by summing each row and dividing that value by the total sum of all the criteria values. For a sample pairwise comparison, the scores would look like Table 10.

Table 10: Priority Weighting for the Five HLZ Criteria (Illustrative Values Only)

Criteria	Slope	Land Cover	Soil Type	Vert Obs.	Road Dist.	Sum	Priority
Slope		2	3	4	6	15	39.3%
Land Cover	1/2		3	2	5	10.5	27.5%
Soil Type	1/3	1/3		3	4	7.666	20.1%
Vert Obs.	1/4	1/2	1/3		3	4.083	10.7%
Road Dist.	1/6	1/5	1/4	1/3		0.945	2.4%

Based on the survey results from the 20 geospatial and imagery analysts who produced consistent results, the weights I used in my HLZ script are shown in Table 11. Since this is an opinion based survey, not everyone agreed on which criteria were more important. The forest had a 74.9% consensus score between the participants while the barren/grassland had 65.6% and urban had 72.2%. Vertical obstruction distance was valued the most for all three environments. Urban environments rated vertical obstructions as 45% of the total suitability while the other two had it around 30%. Land cover was second highest for forest environments while slope was the second highest for barren/grassland and urban areas. Road distance appears to be the least important criteria, finishing fourth in the urban area and last in forest and barren/grassland regions.

Table 11: Weighting Criteria Generated by an AHP Calculator for Forest, Barren/Grassland and Urban Environments)

Criterion	Forest Weight	%	Barren/Grassland Weight	%	Urban Weight	%
Overall Most Important	Vert. Obs. Dist	31%	Vert. Obs. Dist	29%	Vert. Obs. Dist	45%
	Land Cover	30%	Slope	27%	Slope	17%
	Slope	23%	Soil Type	19%	Land Cover	16%
	Soil Type	9%	Land Cover	16%	Road Dist.	14%
Overall Least important	Road Dist.	7%	Road Dist.	9%	Soil Type	8%

Vertical obstructions, land cover, slope and road distance data should be easy to obtain anywhere in the United States and most areas of the world. Soil data is harder to find. In instances where the analyst decides to drop the soil data due to a lack of availability, the weighting criteria would look like Table 12.

Table 12: Weighting Criteria Generated by an AHP Calculator without Soil Type as a Factor (Goepel, 2012)

Criterion	Forest Weight	%	Barren/Grassland Weight	%	Urban Weight	%
Overall Most Important	Vert. Obs. Dist	35%	Vert. Obs. Dist	36%	Vert. Obs. Dist	51%
	Land Cover	34%	Slope	33%	Land Cover	18%
	Slope	23%	Land Cover	19%	Slope	16%
Overall Least important	Road Dist.	8%	Road Dist.	12%	Road Dist.	15%

VII) **Discussion of Methodology:**

To better explain the scripting methodology, I will provide an example of the analysis results for an HLZ study in a region west of Denver, Colorado (Figure 9).

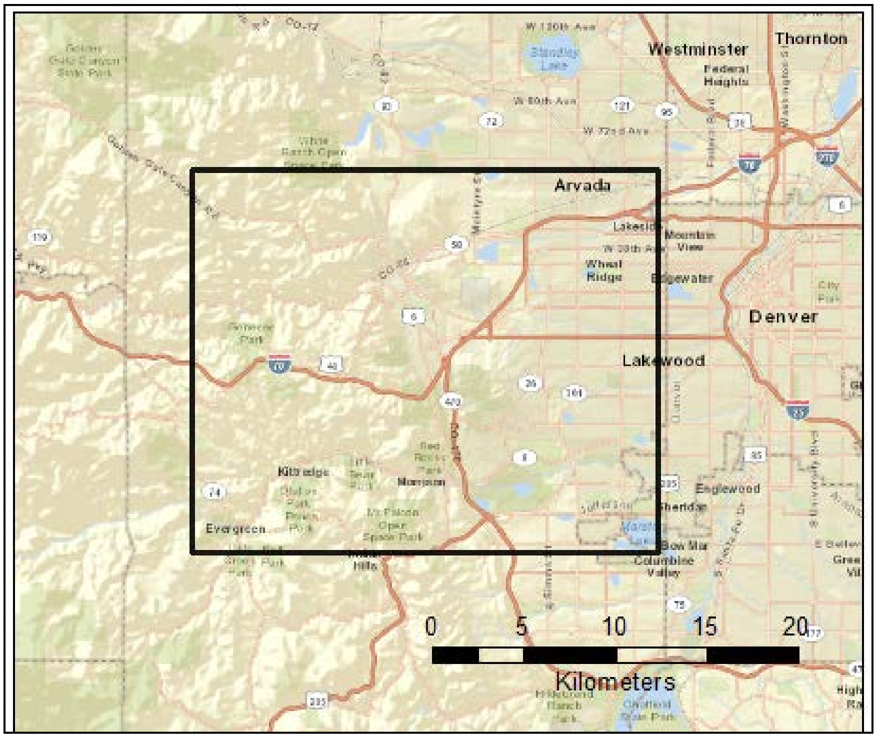

Figure 9: Geographic Area of Interest in Colorado. Background Map from ESRI Online – *World Street Map* (Environmental Systems Research Institute, 2013a)

I used the criteria from a medium-utility helicopter during daylight conditions. To maintain consistency, all of the input layers are projected and reclassified into values of barely suitable (yellow) moderately suitable (yellow-green), or highly suitable (green). Any unsuitable areas are shown white. Figure 10 to 14 show all five input layers and their reclassified results:

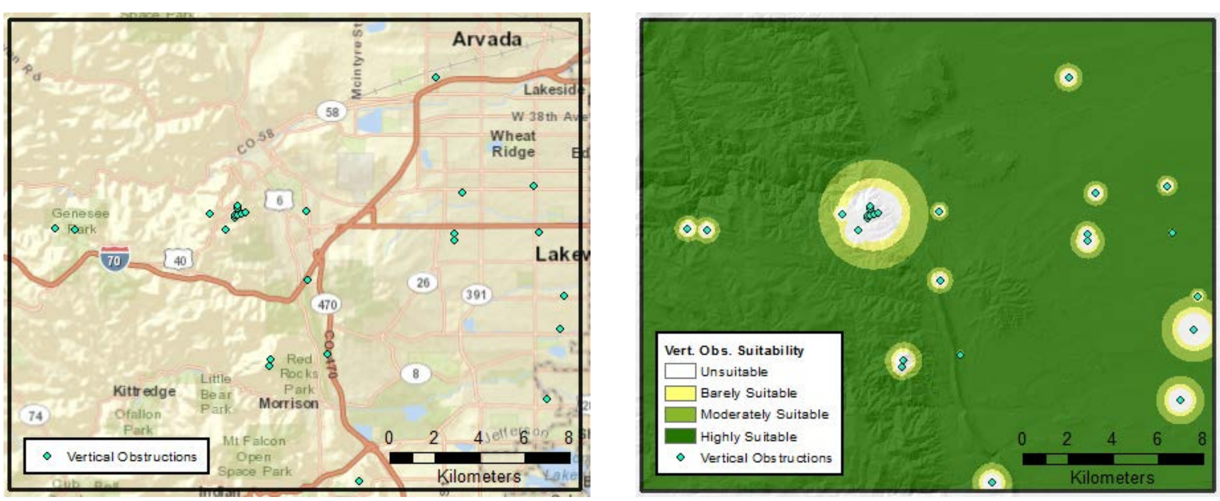

Figure 10: Vertical Obstacles Distance Reclassified. Background Map from ESRI Online – *World Street Map* (Environmental Systems Research Institute, 2013a)

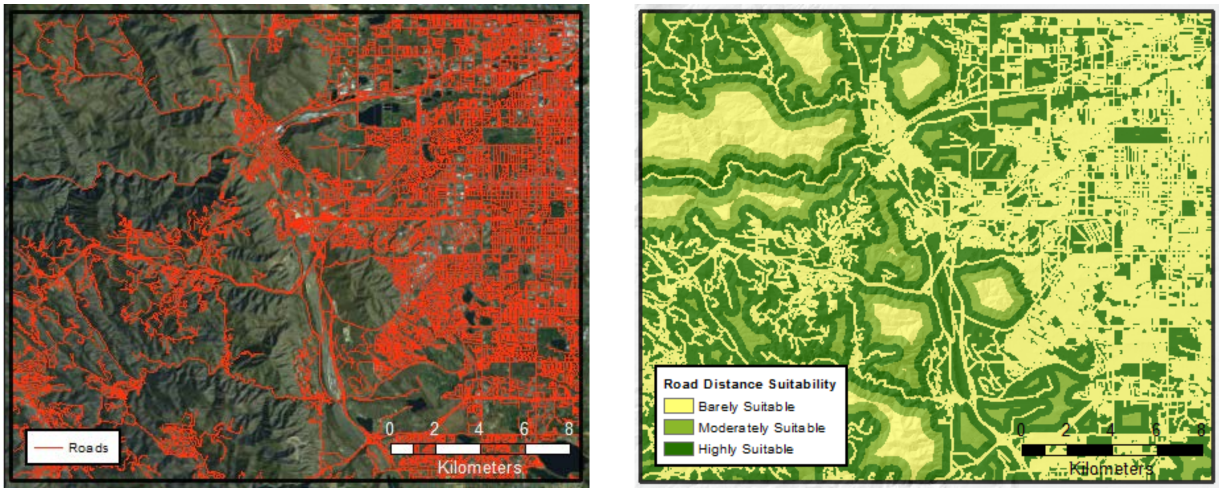

Figure 11: Road Distance Reclassified. Background Image from ESRI Online – *World Imagery* (Environmental Systems Research Institute, 2013b)

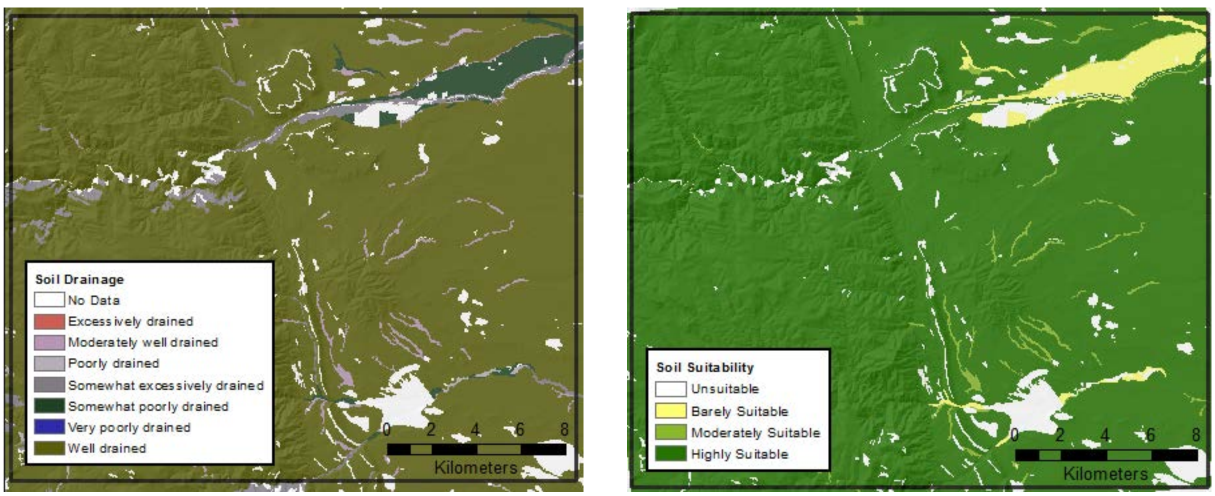

Figure 12: Soil Drainage Reclassified.

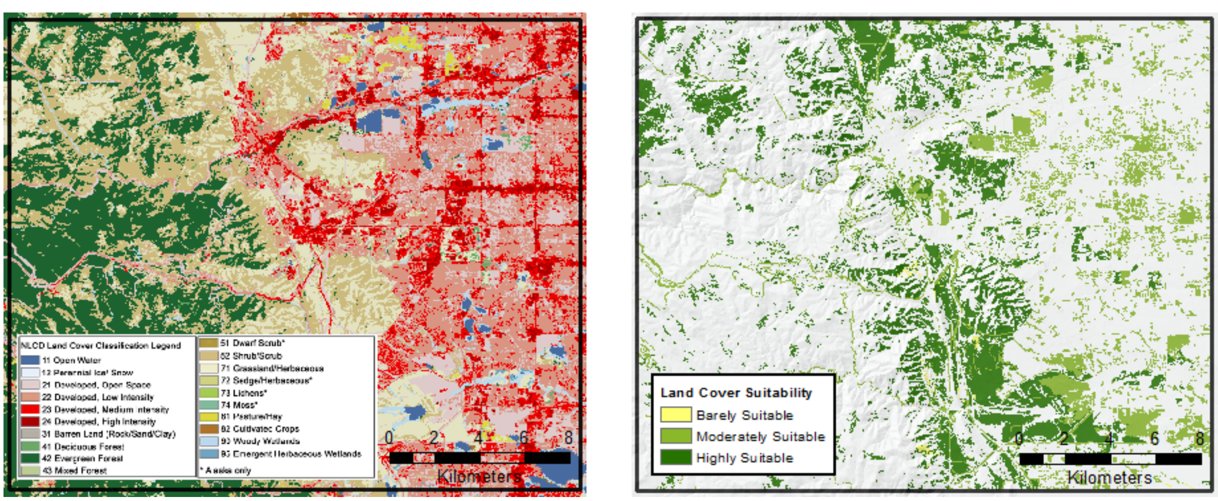

Figure 13: Land Cover Reclassified.

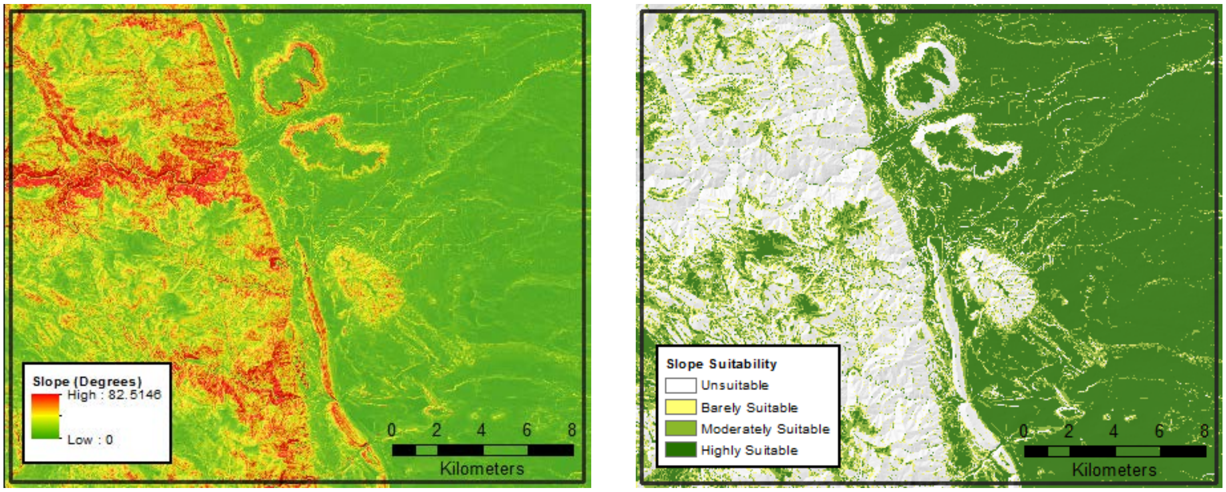

Figure 14: Slope Reclassified.

The reclassified inputs are combined into a site configuration weighted overlay. The percentage weights are determined by the AHP discussed in Section VI. The site configuration weighted overlay is converted to a polygon and the large HLZ sites with sufficient area and width are selected. A site area overlay is generated with higher suitability scores going to larger areas (Figure 15). Both the site configuration and area overlay are combined to create an HLZ suitability raster (Figure 16).

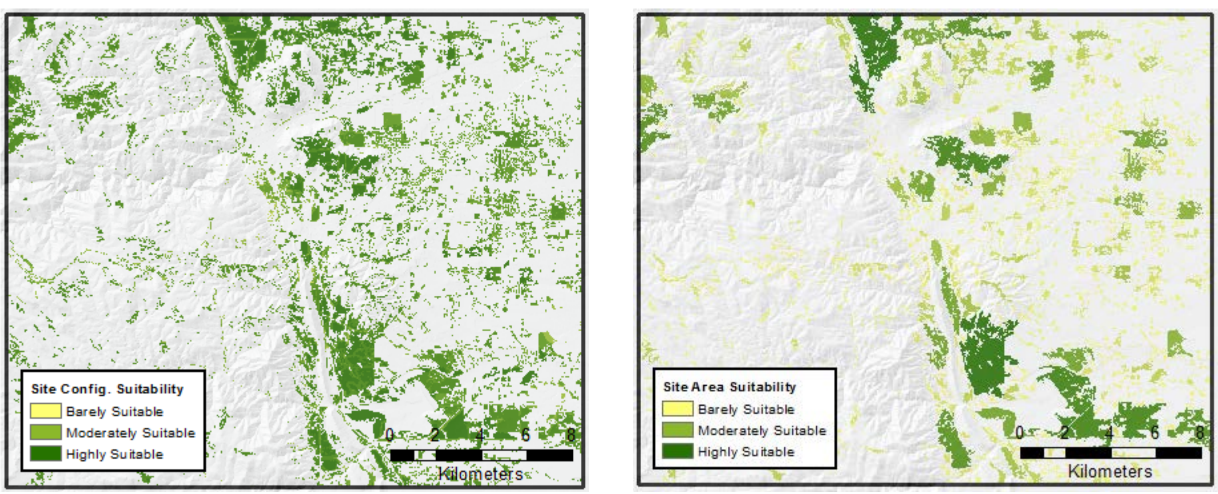

Figure 15: Site Configuration Weighted Overlay (left) and Site Area Overlay (right).

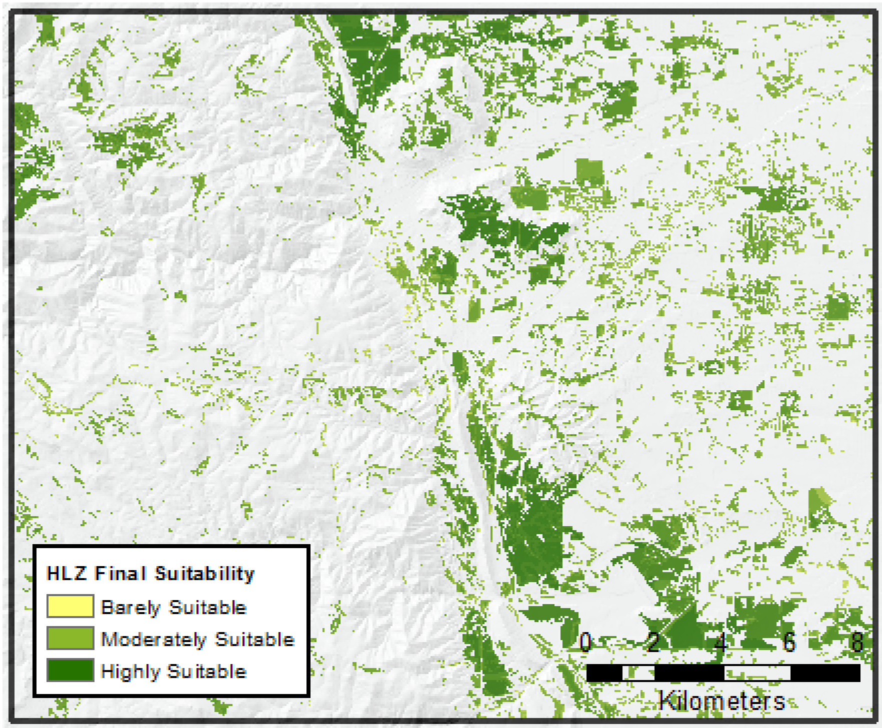

Figure 16: HLZ Final Suitability Overlay (Site Configuration and Area Combined).

The script calculates the average score for each individual site so the resulting HLZ sites can be rank-ordered by scores. Without these scores, there are 2,774 possible sites that meet the criteria for landing a helicopter in this area of Colorado. In Figure 17, these sites are presented in a simple go/no-go representation on the left. Clearly, seeing the top 15 sites narrows down the options considerably and makes the results more usable.

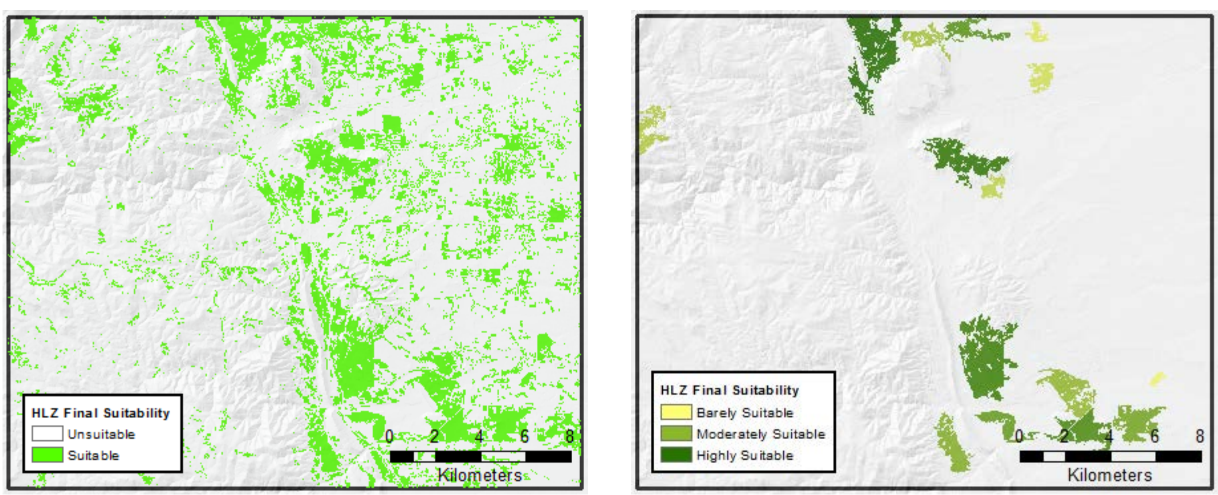

Figure 17: Simple Go/No-Go Solution (Left) vs. Top 15 HLZ Sites (Right).

VIII) **Results:**

The script tool successfully identifies ideal HLZ landing areas using medium resolution datasets. It works rapidly and can process large areas of interest. This 530 square kilometer AOI took less than three minutes to process on a laptop. Due to the AHP weighting, the HLZ sites can be rank-ordered to aid a geospatial analyst in identifying the best candidate sites in a manner that is consistent and repeatable. For the study area west of Denver, 2,774 sites met the HLZ criteria as acceptable landing zones. By breaking the criteria of vertical obstruction distance, slope, land cover, soil type, and road distance into ranges of highly, moderately, and barely suitable, the most acceptable sites can be easily identified. Furthermore, the AHP environmental weighting will produce different results depending on which criterion are most important for the selected environment. Figures 18, 19, and 20 show the top 15 sites using the AHP weighting for urban, barren/grassland, and forest environments.

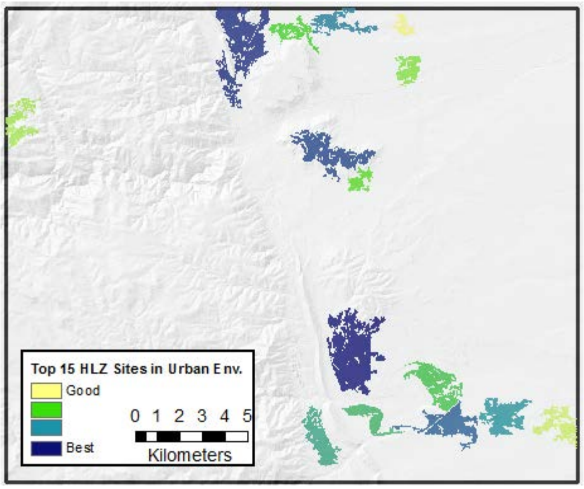

Figure 18: Top 15 HLZ Sites in an Urban Env.

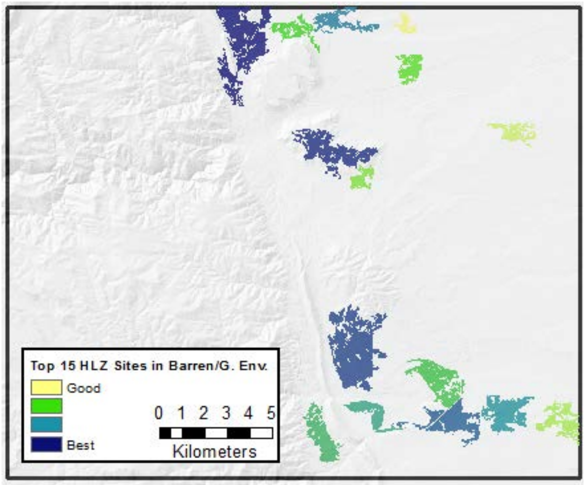

Figure 19: Top 15 HLZ Sites in a Barren/Grassland Env.

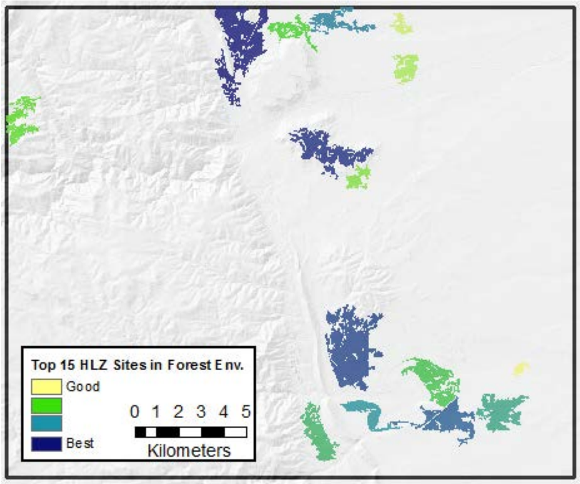

Figure 20: Top 15 HLZ Sites in a Forest Environment.

In this region of Colorado, forest is the most dominant land cover with 43.41% of the land cover (Table 13), so Figure 20 would be the most valid result, especially in the western half of the map. Urban may be more appropriate for the eastern half.

Table 13: Percent of Land Associated with various Families of Land Cover Types

Land Cover Type	Percent of Total
Water: Open Water, Woody Wetland and Emergent Herbaceuous Wetlands	3.83%
Urban: Developed Open Space, Low Intensity, Medium Intensity, and High Intensity	38.77%
Forest: Deciduous, Evergreen, Mixed, Shrub	43.41%
Barren/Grassland: Barren Land, Grassland/Herbaceuous, Hay/Pasture, Cultivated Crop	13.99%

The rank-ordered results allow an analyst to focus efforts on studying just a few of the most highly rated HLZ sites instead of randomly picking sites or just relying on the overall size. Figure 21 below shows an imagery overview of a highly rated HLZ site in a forest environment. This area is known as South Table Mountain Park, a flat, large mesa with little vegetation and no vertical obstructions.

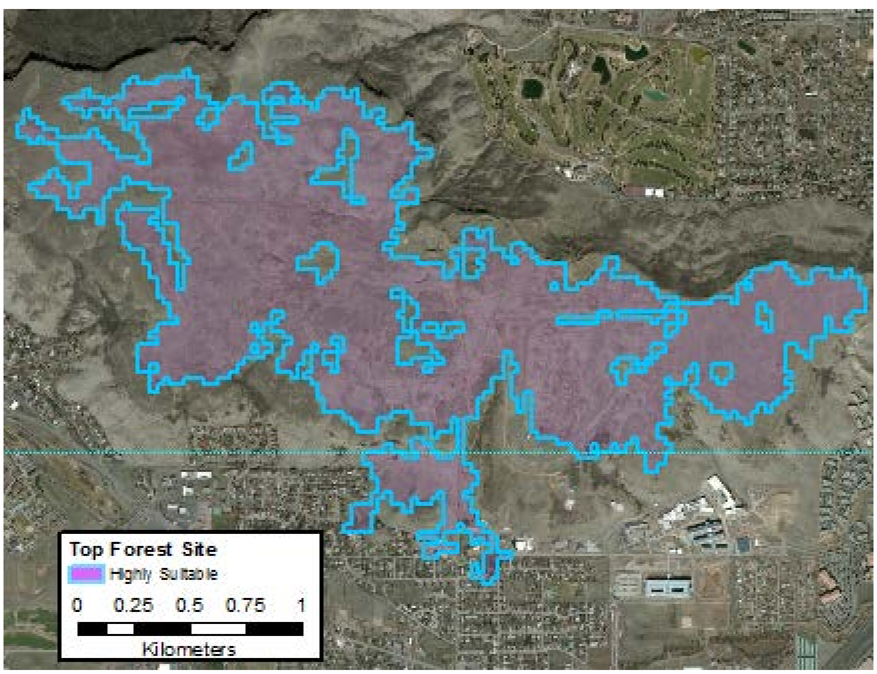

Figure 21: Imagery Overview of South Table Mountain Park HLZ Site. Background Image from ESRI Online – *World Imagery* (Environmental Systems Research Institute, 2013b)

IX) Discussion:

All of the possible sites meet the minimum criteria for landing a helicopter. However, depending on the weighting used for the various environmental conditions, the ranking of the sites differed. Indeed, several of the sites are not included in all three lists. Refer to Table 14 below.

Table 14: Top 15 Ranked Sites by Forest, Urban, and Barren/Grassland Weightings. Orange sites are not present in all three weightings.

	Top 15 Forest			Top 15 Urban			Top 15 Barren/Grassland		
Rank	Site ID	Mean Suitability Score	Area (Square Meters)	Site ID	Mean Suitability Score	Area (Square Meters)	Site ID	Mean Suitability Score	Area (Square Meters)
1	B	8.48272	4,623,300	A	8.48003	5,408,100	B	8.51864	4,623,300
2	C	8.47745	2,843,100	B	8.44170	4,623,300	C	8.49311	2,843,100
3	A	8.44833	5,408,100	C	8.37108	2,843,100	A	8.40352	5,408,100
4	E	8.27948	2,282,400	E	8.28450	2,282,400	E	8.38772	2,282,400
5	J	8.07882	1,278,900	J	8.08885	1,278,900	J	8.13212	1,278,900
6	K	8.00585	1,152,900	F	7.94480	2,127,600	F	8.04537	2,127,600
7	F	7.95590	2,127,600	G	7.94093	1,820,700	K	8.00937	1,152,900
8	G	7.90868	1,820,700	K	7.86885	1,152,900	G	7.92388	1,820,700
9	D	7.76083	2,286,000	D	7.86624	2,286,000	D	7.86535	2,286,000
10	L	7.66126	1,067,400	L	7.72070	1,067,400	L	7.65809	1,067,400
11	I	7.65793	1,356,300	O	7.60665	588,600	N	7.63727	944,100
12	O	7.60665	588,600	N	7.57650	944,100	O	7.60321	588,600
13	N	7.58151	944,100	I	7.41656	1,356,300	H	7.53478	1,449,000
14	P	7.40263	427,500	H	7.41320	1,449,000	M	7.49790	964,800
15	Q	7.39881	226,800	P	7.40737	427,500	P	7.47684	427,500

Despite the different rankings, within the top 15 sites for forest, barren/grassland, and urban environments, thirteen sites occur on all three lists. One forest and urban overlap exists, and another urban and barren/grassland overlaps exists. There is also one site that only appears in the barren/grassland list and another that only appears in the forest list (Figure 22).

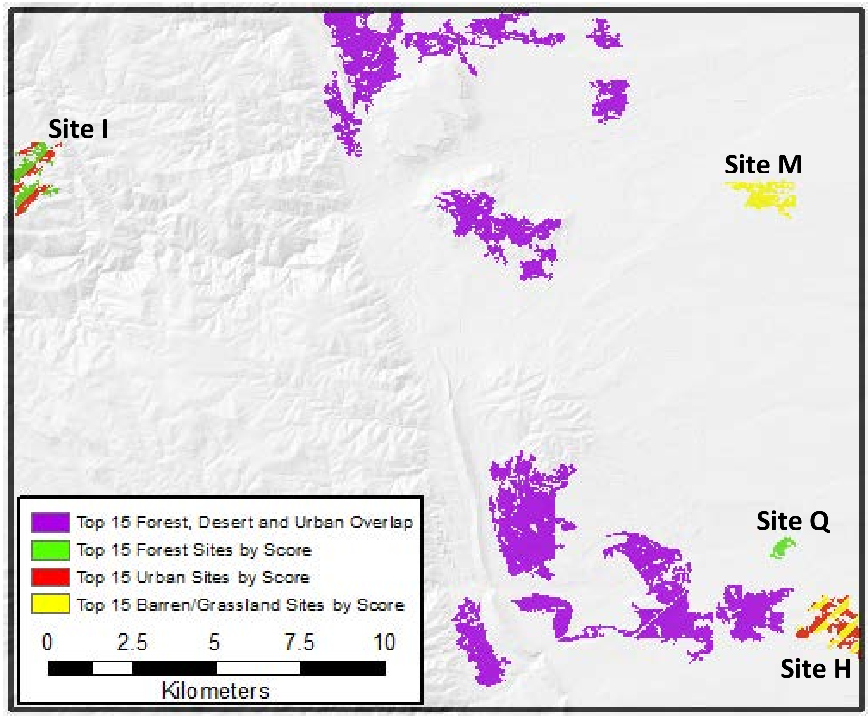

Figure 22: Top 20 HLZ Sites using Forest, Barren/Grassland, or Urban Environmental Weighting.

The different site result ranks are primarily due to the AHP environmental weights shown in Table 11 in section VI. Although the results are similar, an in-depth look at why sites “H”, “M”, “I”, and “Q” are not present in all three lists can help reveal the logic of the script as well as potential limitations.

Several criteria have almost no impact on the results. First, there are only 26 vertical obstructions in 530 square kilometers. Therefore, almost all areas are highly suitable. Second, the soil data is also nearly entirely highly suitable because Colorado has very good soil drainage.

The distance from roads and slope criteria do produce some differences. The roads in the denser city are too close and are classified as barely suitable due to the 0-50 meter utility pole avoidance buffer. The roads in the mountains are far apart and are affected by the barely suitable classification for distances greater than 800 meters. Therefore, the suburbs, located along the middle of the area of interest, have the most ideal road spacing. The suburbs are also fairly flat, resulting in highly suitable slope. Figure 23 shows the highly suitable road distance and slope criteria. Note most of the top sites, indicated in blue, occur in the suburbs, where road distance and slope are both highly suitable.

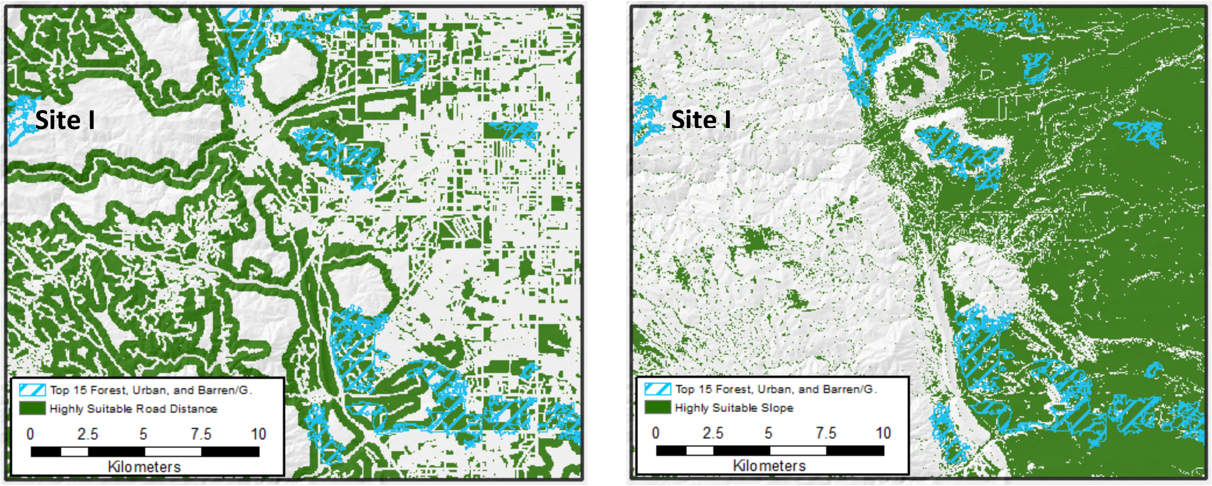

Figure 23: Highly Suitable Road Distances (Left) vs. Highly Suitable Slope (Right). The blue polygons represent the top 15 forest, urban and barren/grassland sites.

The only site that does not lie in the highly suitable road and slope areas is Site "I", which is outside of the road distance and has only a gentle slope. Site "I" is ranked 11th in the forest environment, which is affected by a moderate slope weight of 23%. In an urban environment, Site "I" is ranked 13th, most likely due to its road weighting rising to 14%. Finally, Site "I" is not listed in the top 15 for in a barren/grassland due to its high weight of 27% on slope and 9% on roads.

Sites "H", "M", and "Q" are all affected by the land cover data. This criterion is by far the most restrictive and limits the suitable area to only 23% of the region (Table 15).

Table 15: Suitable areas for the 530 km² study area

Criterion	Suitable Area (Sq Kms)	% of Study Area that is Suitable
Vert. Obs. Dist	519	98%
Land Cover	122	23%
Slope	367	69%
Soil Type	506	95%
Road Dist.	530	100%

As shown in Figure 24, Site "H" and "M" have little highly suitable land cover. Both barren/grassland and urban environments assign a land cover weight of 16%. Site "M" is ranked 14th in the urban list despite the unsuitable land cover due to low slope. Site "H" is ranked 14th in urban and 13th in the barren/grassland environment because it also benefits from good slope and road distance. Site "Q" is completely within highly suitable land cover. Since the land cover weight is worth 30% in a forest environment, "Q" is ranked 15th in a forest despite a relatively small area.

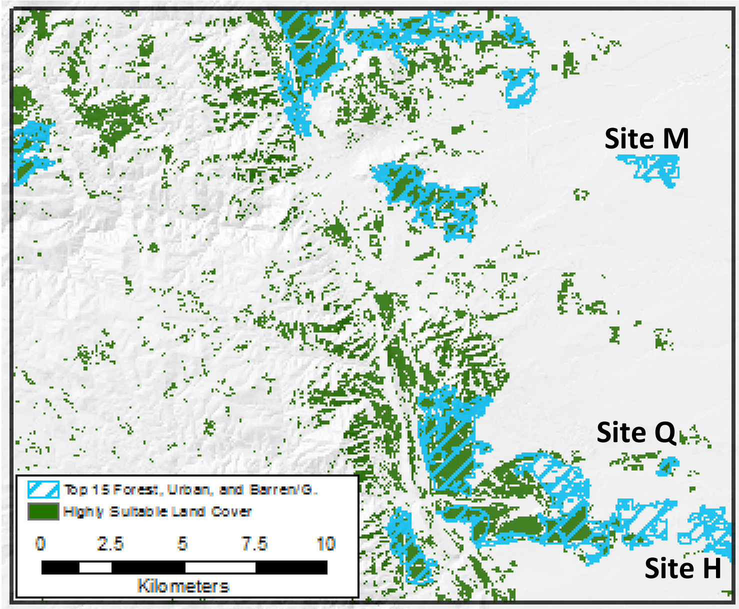

Figure 24: Highly Suitable Land Cover. The blue polygons represent the top 15 forest, urban and barren/grassland sites.

Despite the script tool's functional success, there are some limitations that can be improved upon. For example, edge effects on the boundary of the study area can impact the results. In Figure 25, the black boundary line cuts the suitable area in half. This can be offset by using a larger area of interest boundary than your actual study area.

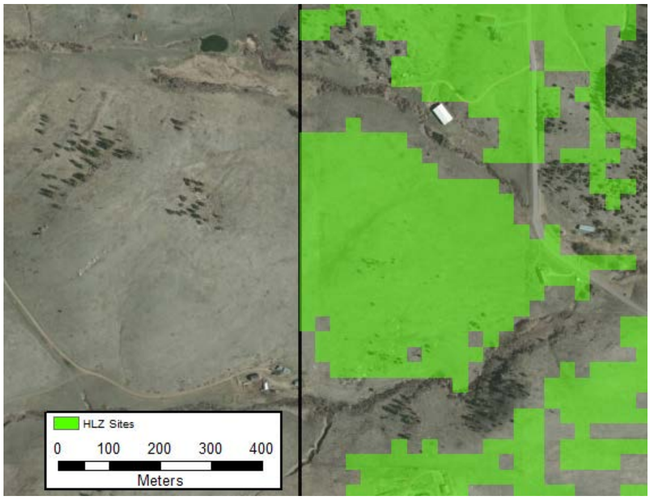

Figure 25: Edge Effect Limiting the Size of a Suitable Landing Zone. Background Image from ESRI Online – *World Imagery* (Environmental Systems Research Institute, 2013b)

I also considered five categories of helicopters: light observation, light utility/attack, medium utility/attack, and heavy cargo. The criteria associated with these categories are reasonable but could be further refined. For example, my script does not factor into account the criteria for hover and partial touch-down landing zones. The US Army Corps of Engineers

Waterways Experiment Station created a computer program called FTHEL that established an automated procedure for evaluating HLZ sites (Parks, 1976). Parks provided detailed descriptions of the criteria for determining if a site can be used for full-touch down vs. hovering and the minimum departure angle for different types of helicopters when they are loaded to point where vertical takeoff is not possible. These types of zones would require much more specific knowledge about the helicopter such as its weight, payload, and approach/departure angles. Weather is also an important consideration for HLZ sites, especially wind conditions while landing and recent rainfall.

Finally, my analysis is highly dependent on the quality of the input data. The road and elevation data should not present huge quality issues, but the soil drainage and land cover can be misclassified. Furthermore, the FAA vertical obstructions data appears to be missing man-made features. There should probably be more than 26 vertical features that threaten aviation in a 530 square kilometer region of western Denver. Many of these data quality issues could be overcome by using high resolution lidar datasets. However, for my script I choose to focus on medium resolution datasets since lidar is only available in limited areas of the United States (United States Geological Survey, 2012a) and data processing is computationally intensive to run in large study areas. As lidar become more available and faster to process, this option may be a good replacement for the 30-meter NLCD, 10-meter NED, and the FAA DOF. In its current state, my script can serve as a tool to indicate the best HLZ candidate sites to consider for follow-on analysis using lidar or imagery.

X) **Summary:**

Helicopter landing zone suitability analysis is used to identify safe landing locations for military operations, medical evacuations, and logistics planning. I have described the development and methodologies of an ArcGIS script tool using Python that automates the HLZ analysis process in order to improve accuracy, speed, and repeatability. The script was pre-loaded with common helicopter types and their corresponding HLZ criteria based on day or night conditions to include the maximum ceiling, acceptable slope, and minimum surface area. Also taken into account were suitable land cover and soil classification values, and distances from vertical obstructions and roads. Values were reclassified to represent highly, moderately, and barely suitable ranges. These results were combined with a weighted overlay based on the operational environment (urban, forest, barren/grassland). The weights were determined using the Analytic Hierarchy Process (AHP) and a pairwise comparison of criteria conducted by 30 geospatial analysts. The final HLZ sites feature class includes an overall suitability assessment so the user can rank-order the results. These results can be used as a starting point for further imagery or lidar analysis.

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Appendix 1: Helicopter Landing Zone Analysis Script Tool Reference Guide

I) Introduction:

This script tool determines suitable helicopter landing zones based on elevation, land cover, vertical obstructions, roads, soil type, and an area of interest (AOI) feature class in a UTM projection. The script will project and clip all vector and raster datasets to match the AOI feature (as long as the base datum for all datasets is either NAD 1983 and/or WGS 1984) before proceeding with the site selection. The user will pick a helicopter type and the script will use the relevant day or night criteria to reclassify the slope, land cover, vertical obstruction distance, road distance, and soil type into barely suitable, moderately suitable, and highly suitable values. Based on the predominant land cover type, the user will select forest, urban, or barren/grassland for the environment. A weighted overlay will combine all the reclassified data with the appropriate environmental weighting, based on an analytic hierarchy process evaluation of 20 experienced geospatial analysts, to create a site configuration raster. The script will select the suitable sites that are larger than the minimum area and minimum width for the helicopter type. These large sites are converted into an area suitability raster. A weighted sum overlay (75% site configuration, 25% area) creates the final HLZ suitability raster. Zonal statistics determines the mean suitability grid code value contained in every large HLZ polygon. Finally, the script joins the zonal statistics to the large HLZ polygons to determine rank-ordered HLZ sites based on the mean suitability score.

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Date: 23 July 2013

II) Download and Open the Script Tool:

Download the HLZ python script tool in a TBX format and a folder with sample data at:

https://docs.google.com/file/d/0B10pCijOTB8aQ1dpT1R4ZzhMeE0/edit?usp=sharing

You can also download the HLZ python script tool without any data at:

https://docs.google.com/file/d/0B10pCijOTB8ac3puVk5KTUlTRlE/edit?usp=sharing

Once you have downloaded the zip file, extract it to a folder. The “Helicopter Landing Zone Analysis Script Tool with Multi-Criteria, Weighted Overlays” tool is located in the “HLZ_Tools.tbx”. You can open the script tool by browsing to the tool within ArcCatalog or within ArcMap’s Catalog window (Figure 1).

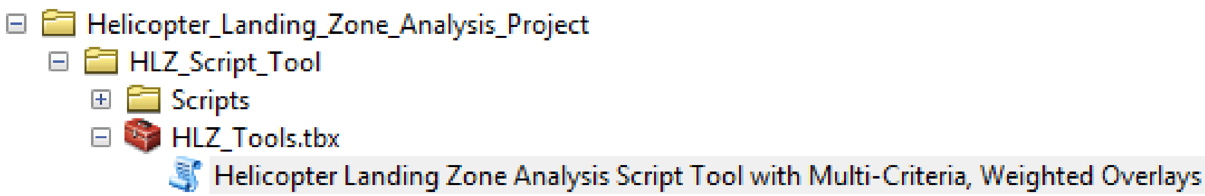


Figure 1: The script tool in the Catalog Window

Alternatively, you can open the script tool within your ArcToolbox window. Right-click on the “ArcToolbox” text at the top of the window > select “Add Toolbox…” > browse to “HLZ_Tools.tbx” > Left-click “Open”. The “HLZ_Tools” toolbox should appear in your ArcToolbox.

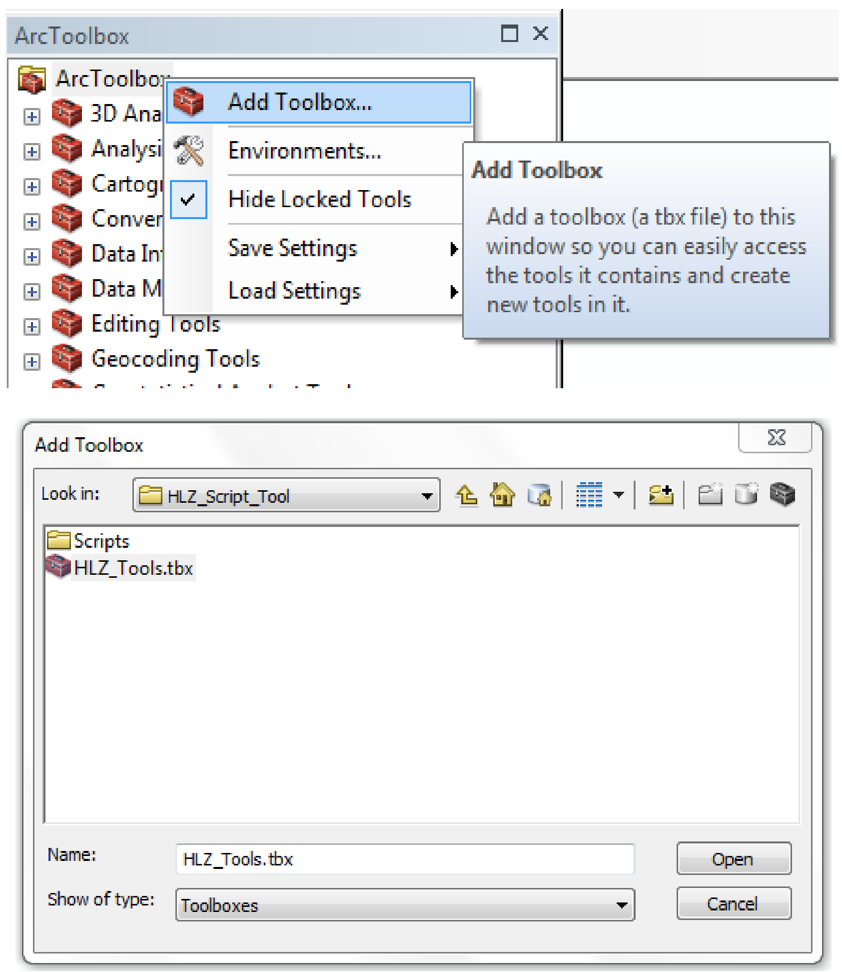


Figure 2: Add the HLZ_Tools.tbx to your ArcToolbox

Expand the “HLZ_Tools” toolbox in the Catalog window or ArcToolbox to see the “Helicopter Landing Zone Analysis Script Tool with Multi-Criteria, Weighted Overlays” tool. Double-click it to open the script tool.

III) The Script Tool Interface:

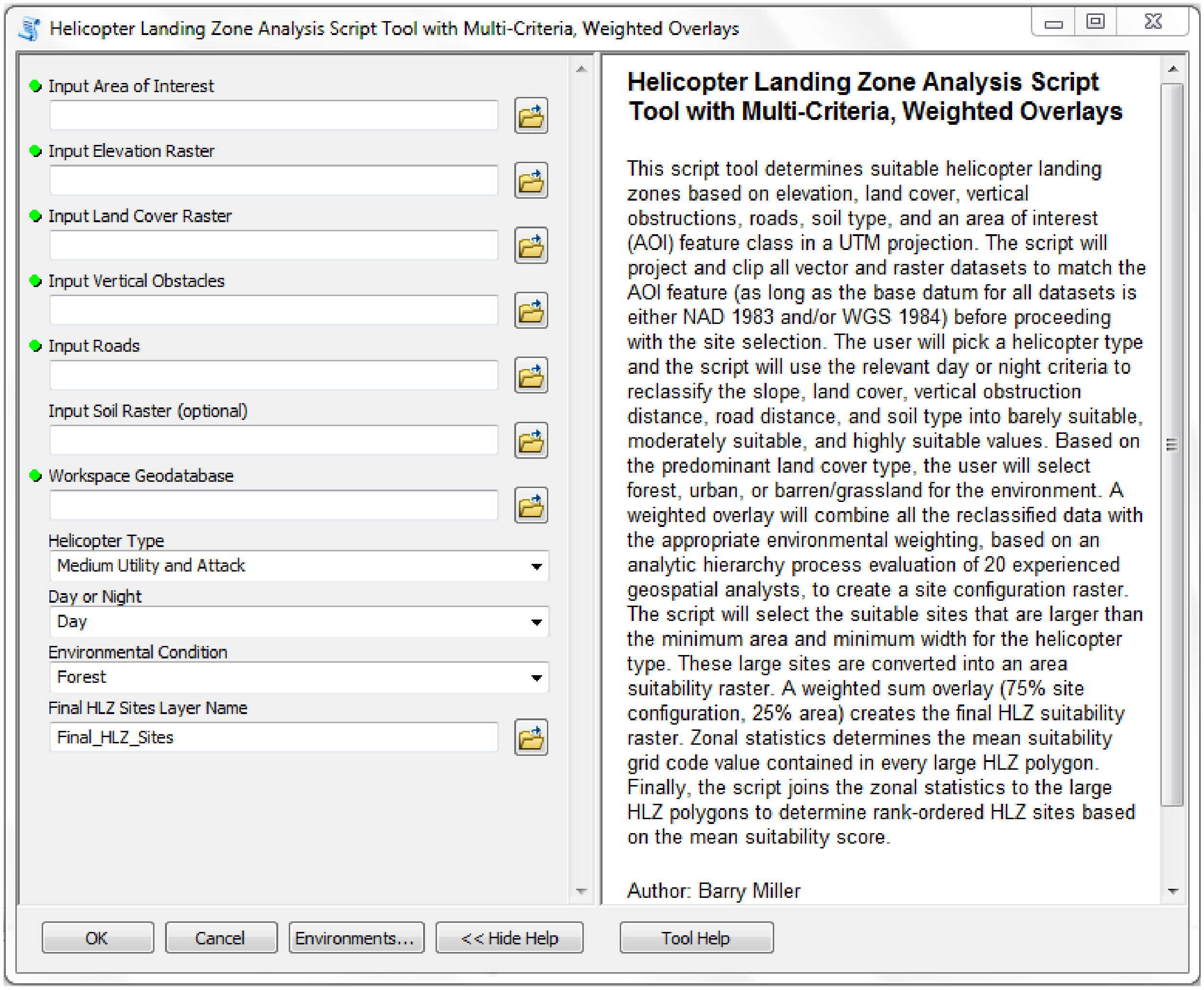


Figure 3: HLZ Script Tool Interface

If you have the sample data, “Hawaii_Sample_Data.gdb”, you can browse to the provided data files to fill in each parameter. You can also drag and drop the appropriate ArcMap layers into the script tool if you have opened everything in advance in an ArcMap session. A brief explanation of each of the parameters is listed below:

Input Area of Interest (Polygon feature class or feature layer)

The area of interest feature class should be in a NAD 1983 or WGS 1984 and projected into the appropriate UTM zone.

Input Elevation Raster (Raster dataset or raster layer)

The elevation raster can be NGA Digital Terrain Elevation Data or USGS National Elevation Data. Ensure the datum is either North America Datum 1983 or World Geodetic

System 1984. It does not need a projected coordinate system. LIDAR or another type of elevation data will also work as long as it is a raster.

Input Land Cover Raster (Raster dataset or raster layer)

The land cover raster should be the USGS National Land Cover Database. Ensure the datum is either NAD 1983 or WGS 1984. It does not need a projected coordinate system. You can load your own land cover dataset or modify the NLCD acceptable values within the Python script. Do this only if you are experienced with Python scripting. You would need to go to **line 159** and change the acceptable reclassification values shown below. Within the script, a 9 is highly acceptable, a 5 is moderately acceptable, a 1 is barely acceptable, and NODATA is unacceptable.

landCoverReclassValues = "11 NODATA;12 1; 21 5;22 NODATA;23 NODATA;24 NODATA;31 1;41 NODATA;42 NODATA;43 NODATA;51 1;52 NODATA;71 9;72 5;73 5;74 5;81 9;82 5;90 NODATA;95 NODATA"

The land cover types for NLCD are shown in Table 1. The NLCD original values are coming from the "Value" field of the raster. This can be changed to a different field in **line 594**.

arcpy.gp.Reclassify_sa(projectedLandCover, "Value", landCoverReclassValues, Rec_LC, "NODATA")

Table 1: USGS Land Cover Classification in Highly, Moderately, and Barely Suitable Categories

Land Cover Type	Highly Suitable Land Cover	Moderately Suitable Land Cover	Barely Suitable Land Cover	Unsuitable Land Cover
11: Open Water				X
12: Perennial Snow/Ice			X	
21: Developed, Open Space		X		
22: Developed, Low Intensity				X
23: Developed, Medium Intensity				X
24: Developed, High Intensity				X
31: Barren Land			X	
41: Deciduous Forest				X
42: Evergreen Forest				X
43: Mixed Forest				X
*51: Dwarf Scrub			*X	
52: Shrub/Scrub				X
71: Grassland/Herbaceuous	X			
*72: Sedge/Herbaceous		*X		
*73: Lichens		*X		
*74: Moss		*X		
81: Hay/Pasture	X			
82: Cultivated Crops		X		
90: Woody Wetlands				X
95: Emergent Herbaceuous Wetlands				X

* Alaska only

Input Vertical Obstacles (Point feature class or feature layer)

The vertical obstacles feature class should be the FAA Digital Obstacle File, which describes all man-made aviation obstacles which affect aeronautical charting products. The DOF is a table with coordinates in degree minute second format. The table has to be converted into decimal degree format for display in ArcGIS. The obstacle height measurements are given in feet above ground level in a field called “Height_AGL”. If you use a different vertical obstacles file, ensure there is a field called “Height_AGL” in feet so the script will function properly.

Input Roads (Line feature class or feature layer)

The roads feature class can be any road data such as the TIGER streets from the US Census Bureau which is published on the USGS National Map. Ensure the datum is either North America Datum 1983 or World Geodetic System 1984. It does not need a projected coordinate system.

Input Soil Raster (Optional raster dataset or raster layer)

The soil raster must be the USDA Gridded Soil Survey Geographic (gSSURGO) Database. Ensure that the Mapunit aggregated attribute table (muagatt table) has been joined to the gSSURGO (MuRaster_10m raster) by the Map Unit Key (MUKEY field) so that dominant condition for the drainage class (drclassdcd field) attribute is available for suitability classification. Refer to page 8 of the gSSURGO User Guide that comes bundled with your data download from USDA for detailed directions on how to join the fields.

The soil raster is an optional input. You can load your own soil dataset or modify the USDA acceptable values within the Python script. Do this only if you are experienced with Python scripting. You would need to go to **line 160** and change the acceptable reclassification values shown below. Within the script, a 9 is highly acceptable, a 5 is moderately acceptable, a 1 is barely acceptable, and NODATA is unacceptable.

soilReclassValues = "'Well drained' 9;'Somewhat excessively drained' 9;'Somewhat poorly drained' 1;'Moderately well drained' 5;'Excessively drained' 9;'Poorly drained' NODATA;'Very poorly drained' NODATA"

The soil drainage original values are coming from the “drclassdcd” field of the raster. This can be changed to a different field in **line 607**.

arcpy.gp.Reclassify_sa(projectedSoil, "drclassdcd", soilReclassValues, Rec_Soil, "NODATA")

Workspace Geodatabase (Geodatabase)

The output folder is where the intermediate and final output data will be stored. It must be a file geodatabase that you create in advance. It can be the same as the geodatabase where your input data is stored.

Helicopter Type (String)

Pick a helicopter type from the following choices (Light Observation, Light Utility and Attack, Medium Utility and Attack, Heavy Cargo, or Sling Load or Unknown). The data dictionary in the script contains all five helicopter groups and their respective maximum flight ceiling (meters), minimum landing zone area (sq meters), minimum landing zone width (meters), highly suitable slope (degree),moderately suitable slope, barely suitable slope, and unsuitable slope. Here are some examples for each family of helicopter: Light Observation (OH-6 Little Bird, OH-58D Kiowa), Light Utility and Attack (AH-1W Super Cobra, UH-1N Huey), Medium Utility and Attack (UH-60L Black Hawk, AH-64D Apache), and Heavy Cargo (CH47D Chinook, CH-53E Stallion). You can modify the data dictionary in the Python script if desired in **lines 183 to 193**. Do this only if you are experienced with Python scripting. Table 2 shows the current criteria.

Table 2: Maximum and Minimum Criteria for Different Helicopter Types for (Day/Night)

Helicopter Type (Day/*Night*)	Max Ceiling (Meters)	Min. LZ Area (Sq. Meters)	Min. LZ Width (Meters)	Highly Suitable Slope Range (Degrees)	Moderately Suitable Slope Range (Degrees)	Barely Suitable Slope Range (Degrees)	Unsuitable Slope Range (Degrees)
Light Observation (OH-6 Little Bird, OH-58D Kiowa)	4500	625 *(1444)*	25 *(38)*	0 - 2.99	3 - 4.99	5 - 7	> 7
Light Utility and Attack (AH-1W Super Cobra, UH-1N Huey)	4000	1225 *(2809)*	35 *(53)*	0 - 2.99	3 - 4.99	5 - 7	> 7
Medium Utility and Attack (UH-60L Black Hawk, AH-64D Apache)	3300	2500 *(5625)*	50 *(75)*	0 - 5.99	6 - 10.99	11 - 15	> 15
Heavy Cargo (CH47D Chinook, CH-53E Stallion)	5500	6400 *(14400)*	80 *(120)*	0 - 5.99	6 - 10.99	11 - 15	> 15
Sling Load or Unknown Helicopter	3000	10000 *(22500)*	100 *(150)*	0 - 2.99	3 - 4.99	5 - 7	> 7

Day or Night (String)

Pick day or night operations. At night, the minimum landing zone area and width are increased for safety.

Environmental Condition (String)

Pick the dominant environmental condition in the area of interest among the following three choices: forest, urban, or barren/grassland. This choice will influence the weighted overlay percentages assigned to each input dataset. You can modify these percentages in the Python script in **lines 628 to 647** with all factors or **lines 653 to 659** without soil as a factor. Do this only if you are experienced with Python scripting and ensure the total of all the weights adds up to 100%. Table 3 and 4 show the current weighting criteria.

Table 3: Weighting Criteria Generated by an AHP Calculator for Forest, Barren/Grassland and Urban Environments

Criterion	Forest Weight	%	Barren/Grassland Weight	%	Urban Weight	%
Overall Most Important	Vert. Obs. Dist	31%	Vert. Obs. Dist	29%	Vert. Obs. Dist	45%
	Land Cover	30%	Slope	27%	Slope	17%
	Slope	23%	Soil Type	19%	Land Cover	16%
	Soil Type	9%	Land Cover	16%	Road Dist.	14%
Overall Least important	Road Dist.	7%	Road Dist.	9%	Soil Type	8%

Table 4: Weighting Criteria Generated by an AHP Calculator without Soil Type as a Factor

Criterion	Forest Weight	%	Barren/Grassland Weight	%	Urban Weight	%
Overall Most Important	Vert. Obs. Dist	35%	Vert. Obs. Dist	36%	Vert. Obs. Dist	51%
	Land Cover	34%	Slope	33%	Land Cover	18%
	Slope	23%	Land Cover	19%	Slope	16%
Overall Least important	Road Dist.	8%	Road Dist.	12%	Road Dist.	15%

Final HLZ Sites Layer Name (Layer)

The name of your final HLZ sites layer generated by the script. A feature class will be created in your workspace geodatabase automatically. If you sort descending on the MEAN field, the higher scores are the most ideal sites.

IV) **Execution and Intermediate Outputs:**

When all the layers have been selected in the script tool, click "OK". The script will run and may take several minutes. You will receive a processing message similar to below:

```
Executing: HLZscriptTool "C:\WCGIS\GEOG596B Individual Studies -
Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\HI_Area_of_Interest"
"C:\WCGIS\GEOG596B Individual Studies -
Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\Elevation" "C:\WCGIS\GEOG596B
Individual Studies - Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\LandCover"
"C:\WCGIS\GEOG596B Individual Studies -
Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\VerticalObstacles"
"C:\WCGIS\GEOG596B Individual Studies -
Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\Roads" "C:\WCGIS\GEOG596B
Individual Studies -
Capstone\Data\Hawaii\Hawaii_Sample_Data.gdb\SoilDrainage" "C:\WCGIS\GEOG596B
Individual Studies -
Capstone\Data\Hawaii\HI_Workspace_Day_Forest_MediumHelo.gdb" "Medium Utility
and Attack" Day Forest Final_HLZ_Sites
Start Time: Sun Jul 28 23:42:32 2013
Running script HLZscriptTool...
A Medium Utility and Attack helicopter has a maximum flight ceiling of 3300
meters and can land on a maximum slope of 15 degrees.
It requires at least 2500 square meters of suitable landing area and a
minimum landing zone width of 50 meters during the Day.
The spatial reference of your area of interest feature class is:
NAD_1983_UTM_Zone_4N.
All datasets will be clipped and those not already in this spatial reference
will be re-projected.
Your elevation dataset is in: GCS_North_American_1983
A datum transformation parameter is not needed.
Your landcover dataset is in: Albers_Conical_Equal_Area
A datum transformation parameter is not needed.
Your vertical obstructions dataset is in: GCS_WGS_1984
The datum transformation parameter is: NAD_1983_To_WGS_1984_1
```

```
Your road dataset is in: GCS_North_American_1983
A datum transformation parameter is not needed.
Your soil dataset is in: Hawaii_Albers_Equal_Area_Conic
A datum transformation parameter is not needed.
Temporary area of interest files were created to assist with clipping your
input data.
All input datasets were clipped to the AOI successfully.
Your clipped elevation raster was projected to NAD_1983_UTM_Zone_4N
successfully!
Your clipped land cover raster was projected to NAD_1983_UTM_Zone_4N
successfully!
Your clipped vertical obstacles were projected to NAD_1983_UTM_Zone_4N
successfully!
Your clipped roads were projected to NAD_1983_UTM_Zone_4N successfully!
Your clipped soil raster was projected to NAD_1983_UTM_Zone_4N successfully!
Calculated vertical obstruction day distances.
Reclassified vertical obstructions distance layers into highly, moderately,
and barely suitable values and combined them into one raster.
Reclassified road distances into highly, moderately, and barely suitable
values.
Reclassified the slope below the maximum ceiling into highly, moderately,
and barely suitable values.
Reclassified the land cover into highly, moderately, and barely suitable
values.
Reclassified the soil data into highly, moderately, and barely suitable
values.
Calculated a weighted overlay table with soil data in the weights.
Created a site configuration weighted overlay in a/an Forest environment.
Successfully queried for landing sites that exceed 2500 square meters and
have a minimum width of 50 meters.
Successfully converted the large HLZ area polygon into a reclassified raster
layer with nine Natural Break zones.
Combined the site configuration and site area layers into a final HLZ
suitability raster layer.
Calculated zonal statistics for each HLZ site and joined the statistics to
the large HLZ sites polygon.

Congratulations!  You have found all suitable sites that are larger than
2500 square meters with a minimum width of 50 meters.
A Medium Utility and Attack helicopter should be able to land at these sites
based on slope, elevation, land cover, vertical obstruction, road, and/or
soil data.
However, use imagery or another source to validate these results.  Your
datasets are not perfect and this script cannot make up for input data
errors.  If you sort descending on the MEAN field, the higher scores are the
most ideal sites.
Please preview the helicopter landing zone file at the following path:
C:\WCGIS\GEOG596B Individual Studies -
Capstone\Data\Hawaii\HI_Workspace_Day_Forest_MediumHelo.gdb\Final_HLZ_Sites_
Day_Forest
Completed script HLZscriptTool...
Succeeded at Sun Jul 28 23:45:12 2013 (Elapsed Time: 2 minutes 40 seconds)
```

Dozens of intermediate outputs will be generated by the four functions and 40+ tools run by the script tool. These intermediate outputs are available for you to preview. Refer to Table 5 for a brief description of each output in alphabetical order:

Table 5: I Output Files Generated by the HLZ Script Tool

Output File	Description
AOI_Elevation	A modified area of interest feature class in the same geographic projection as the elevation raster.
AOI_LandCover	A modified area of interest feature class in the same geographic projection as the land cover raster.
AOI_Road	A modified area of interest feature class in the same geographic projection as the road feature class.
AOI_Soil	A modified area of interest feature class in the same geographic projection as the soil raster.
AOI_VertObs	A modified area of interest feature class in the same geographic projection as the vertical obstacles feature class.
Elev_Clip	The elevation dataset clipped into the area of interest.
Elev_UTM_Clip	The clipped elevation dataset projected into the appropriate UTM zone.
EucDir_Road	The Euclidean direction generated on the roads dataset.
EucDist_Road	The Euclidean distance generated on the roads dataset.
Final _HLZ_Sites	The final HLZ sites feature class containing the suitable areas with a MEAN field for rank-ordering the sites from most to least suitable.
HLZ_Suit_Sum	The overall HLZ suitability raster containing the weighted sum of the site configuration and site area suitability. The site configuration is 75% of the weight while the site area is 25%.
Large_Site_ZonalStat	The zonal statistics table containing the average grid values from the overall HLZ suitability raster (HLZ_Suit_Sum) that are within each HLZ site.
Large HLZ_Area	Large HLZ area raster with grid values based on the size of each site in square meters.
LargeHLZ_Sites_Poly	HLZ sites polygon that are larger than the minimum area and satisfy the minimum width.
LC_Clip	The land cover dataset clipped into the area of interest.
LC_UTM_Clip	The clipped land cover dataset projected into the appropriate UTM zone.
Rec_Elev	Elevation raster reclassified to eliminate elevation values above the maximum flight ceiling.
Rec_LC	Land cover raster reclassified into highly, moderately, and barely suitable values.
Rec_Roads	Road distance raster reclassified into highly, moderately, and barely suitable values.
Rec_Slope	Slope raster reclassified into highly, moderately, and barely suitable values.

Output File	Description
Rec_Soil	Soil raster reclassified into highly, moderately, and barely suitable values.
Rec_VertObs	Vertical obstacles distances reclassified into highly, moderately, and barely suitable values.
RecVOHigh	The high vertical obstacles buffer raster reclassified so that everything outside the buffer is 1 and everything inside is 0.
RecVOLow	The low vertical obstacles buffer raster reclassified so that everything outside the buffer is 1 and everything inside is 0.
RecVOMed	The medium vertical obstacles buffer raster reclassified so that everything outside the buffer is 1 and everything inside is 0.
Road_Clip	The roads dataset clipped into the area of interest.
Road_UTM_Clip	The clipped roads dataset projected into the appropriate UTM zone.
Site_Area	The large HLZ areas broken into 9 Natural Breaks classifications based on size.
SiteConfig_Poly	The polygon conversion of the site configuration weighted raster.
SiteConfig_Poly_Dissolve	The polygon conversion of the site configuration weighted raster dissolved to break apart multipart features.
SiteConfig_Poly_Dissolve_Min_Geometry	The Minimum Bounding Geometry layer of the site polygons used to select for minimum width.
SiteConfigWt	The weighted site configuration raster. It represents the weighted overlay of five reclassified layers (slope, land cover, soil type, distances from vertical obstructions, and distances from roads). The weights are determined by the operating environment (forest, urban, barren/grassland).
SlopeDegree	The degree slope calculated from the elevation dataset.
SlopeMax_Ceil	The slope that is under the maximum flight ceiling for the selected helicopter type.
Soil_Clip	The soil dataset clipped into the area of interest.
Soil_UTM_Clip	The clipped soil dataset projected into the appropriate UTM zone.
Vert_Obs_Clip	The vertical obstacles dataset clipped into the area of interest.
Vert_Obs_UTM_Clip	The clipped vertical obstacles dataset projected into the appropriate UTM zone.
VertObsComb	The sum of the high, medium, and low reclassified vertical obstacle buffer rasters.
VO_Buffer_High_Dist	The vertical obstacles buffer created using the highly suitable distance.
VO_Buffer_Low_Dist	The vertical obstacles buffer created using the barely suitable distance.
VO_Buffer_Med_Dist	The vertical obstacles buffer created using the moderately suitable distance.
VO_High	The raster conversion of the high vertical obstacles buffer.
VO_Low	The raster conversion of the low vertical obstacles buffer.
VO_Med	The raster conversion of the medium vertical obstacles buffer.
VOHighMed	The sum of the high and medium classified vertical obstacle buffer rasters.

If you are running the script tool within ArcGIS 10.1, you may get the following error:

```
ERROR 999999: Error executing function.
Workspace or data source is read only.
```

Typically this error is caused when you have more than one ArcGIS program open or someone else is using your workspace geodatabase at the same time. If neither of these situations apply, than this error is a result of a bug with ArcGIS 10.1 and your virus protection software. Your anti-virus software is scanning the workspace geodatabase while you outputs are being generated. This can lock the workspace and prevent new outputs from being created. If you get this error, you will have to turn off your anti-virus software temporarily.

V) Final HLZ Sites Layer and Symbolization:

A layer file with your final HLZ sites should open automatically if you run the script in ArcMap. If you right-click on the layer and select Properties…, you can modify the symbology to view the MEAN values. Select 9 Natural Breaks classes and an appropriate color ramp. Refer to Figure 4 below for an example of the symbology settings.

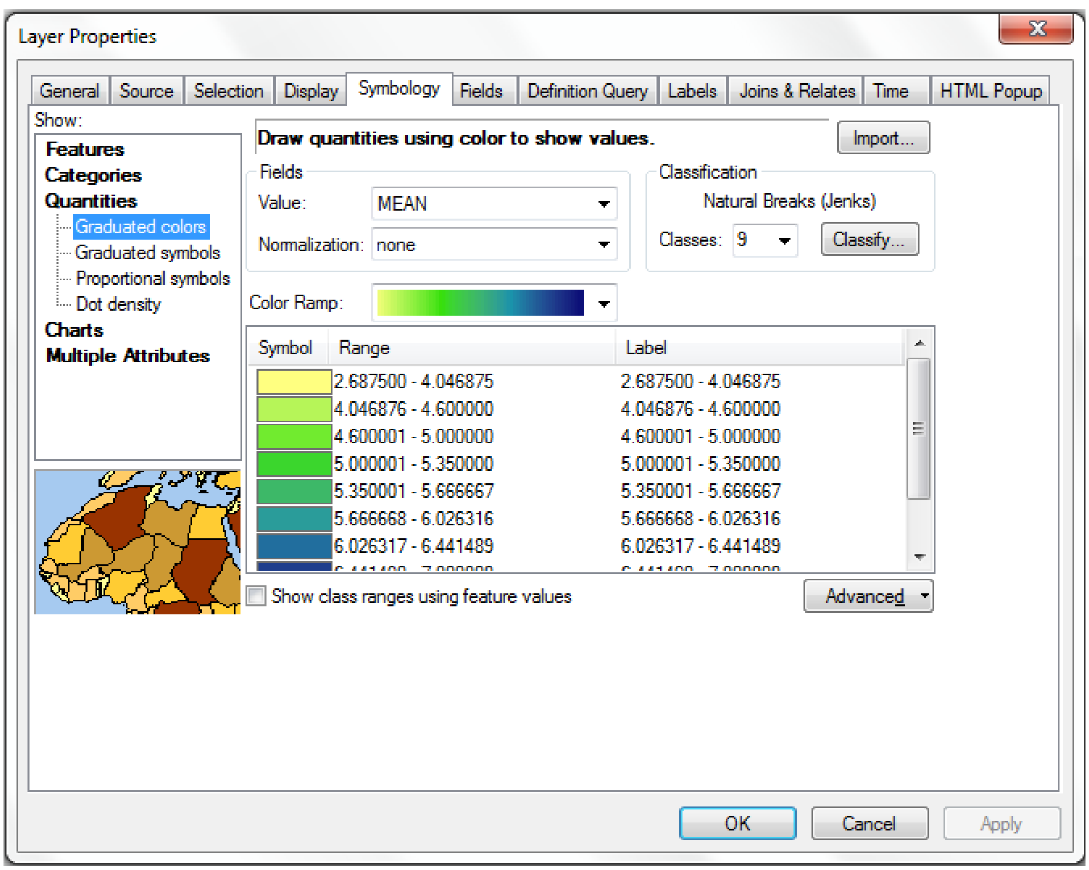
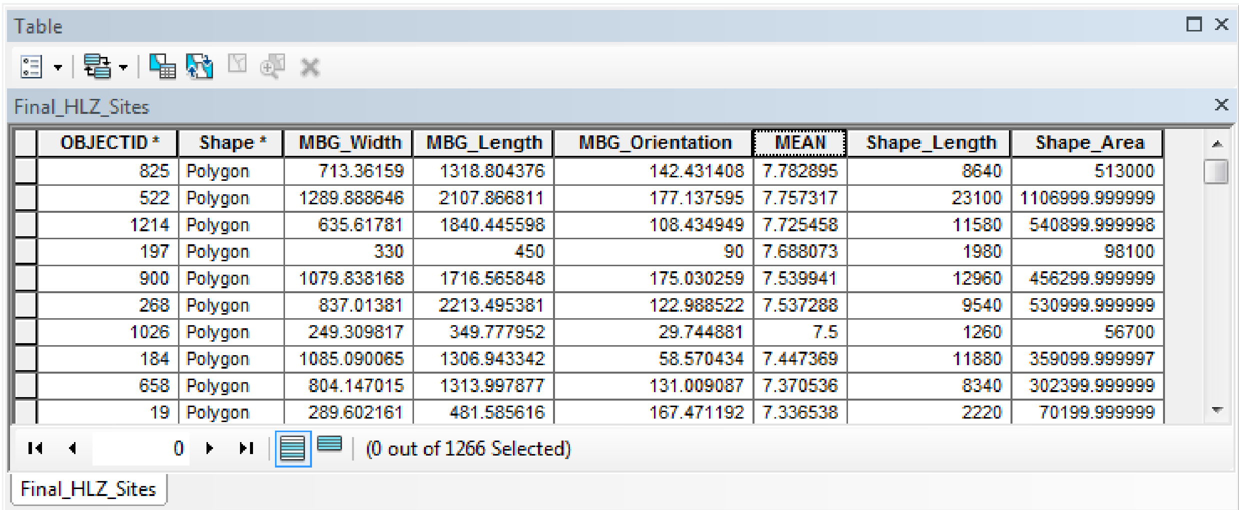


Figure 4: Final HLZ Sites Symbology

You can also view the attribute table for the final HLZ sites layer. If you right-click the layer and select Open Attribute Table a table similar to Figure 5 should open.



OBJECTID *	Shape *	MBG_Width	MBG_Length	MBG_Orientation	MEAN	Shape_Length	Shape_Area
825	Polygon	713.36159	1318.804376	142.431408	7.782895	8640	513000
522	Polygon	1289.888646	2107.866811	177.137595	7.757317	23100	1106999.999999
1214	Polygon	635.61781	1840.445598	108.434949	7.725458	11580	540899.999998
197	Polygon	330	450	90	7.688073	1980	98100
900	Polygon	1079.838168	1716.565848	175.030259	7.539941	12960	456299.999999
268	Polygon	837.01381	2213.495381	122.988522	7.537288	9540	530999.999999
1026	Polygon	249.309817	349.777952	29.744881	7.5	1260	56700
184	Polygon	1085.090065	1306.943342	58.570434	7.447369	11880	359099.999997
658	Polygon	804.147015	1313.997877	131.009087	7.370536	8340	302399.999999
19	Polygon	289.602161	481.585616	167.471192	7.336538	2220	70199.999999

Figure 5: Final HLZ Sites Attribute Table

Sort Descending on the MEAN field to see the highest values on top. These represent the best available sites. You could highlight these sites to identify where they are located and you can even export the top 10 or 20 sites for future analysis into a shapefile or a Google Earth KMZ. There are several additional attribute fields which are also useful. Refer to Table 6 for a short summary of each field.

Table 6: Final HLZ Sites Attribute Fields

Field	Description
OBJECTID	Unique numeric identifier for each HLZ site.
MBG_Width	Minimum bounding geometry representing the width of the shorter side of the resulting bounding rectangle.
MGB _Length	Minimum bounding geometry representing the length of the longer side of the resulting bounding rectangle.
Orientation	The orientation of the longer side of the resulting bounding rectangle.
MEAN	The average grid values from the overall HLZ suitability raster that are within each HLZ site. A higher value is a more suitable site.
Shape_Length	The perimeter of each HLZ site in meters.
Shape_Area	The area of each HLZ site in square meters.