Comparison of Winter Terrain Distribution in Six Utah Ski Resorts using ArcGIS

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Table of Contents

List of Figures

List of Tables

Introduction

Salt Lake City is a popular winter destination for visitors around the world. There are not many places with six ski resorts less than 40 miles from an international airport. Utah quantifies ski-season success by tracking the number of *skier days* which is defined as one person visiting a ski area for all or any part of a day or night for the purpose of skiing or snowboarding[1]. This number for all ski resorts in Utah has grown from 3.83 million in 2011 to 4.58 million in 2017[2]. This report focuses on just six resorts near Salt Lake City which can be seen in Figure 1.
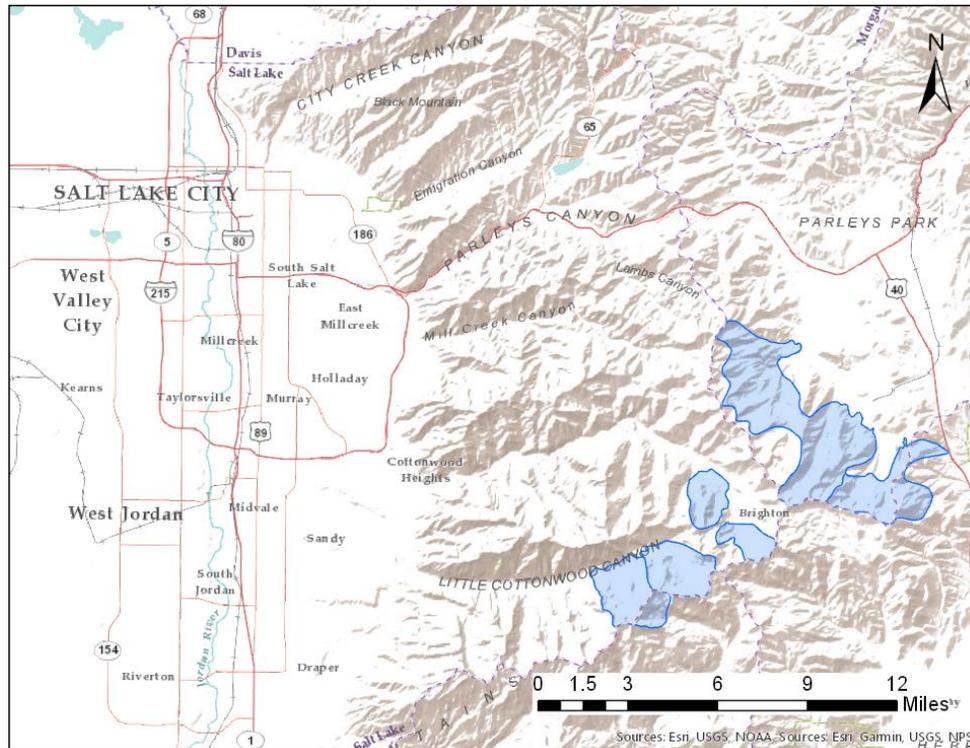
FIGURE 1 SIX SKI RESORTS NEAR SALT LAKE CITY, UTAH

When visitors come to Salt Lake City, they are often faced with the tough decision of picking at which resort(s) to ski. There are an overwhelming number of variables to consider including lift ticket cost, location, weather, lodging, rentals, lessons, and terrain type. Most of this information can be found at each resort's website. Additionally, the nonprofit organization Ski Utah has created a tool where users can see a side-by-side comparison of these ski resorts. The purpose of this project is to expand this comparison. ArcGIS will be used to complete some simple calculations to understand terrain distribution at these resorts. This information may prove to be useful to consumers when choosing a ski resort. ArcGIS has provided a means to calculate slope to understand terrain difficulty across the six resorts.

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[1] Lee, Jason

[2] ibidem

DEFINING TERRAIN DIFFICULTY

Across North America, ski resorts classify difficulty the same way. Green circles represent beginner terrain, blue squares represent intermediate terrain, and black diamonds indicate advanced or expert terrain as seen in Figure 2A. Some resorts have additional designations such as double-blue squares or double-black diamonds shown in Figure 2B. These signs are placed all around the mountain to direct skiers to terrain[3] [4].

FIGURE 2 A) TYPICAL SKI SIGN IN NORTH AMERICA B) POSSIBLE VARIATION IN SKI SIGN

According to trails.com, these classifications are defined based on percent slope where easy terrain has a slope less than 25%, intermediate terrain has a slope between 25%-40%, and expert terrain has a slope greater than 40%. Figure 3 summarizes this distinction.

In addition, slopes less than 6% can be categorized as flat. For the purpose of this project, two additional categories were added which included slopes between 40%-60% which were considered intermediate-expert and slopes larger than 100% which were classified as technical. This terrain will likely have many drop-offs, cliffs, and highly technical terrain. For the purpose of this project, the terrain difficulty is defined only based on the variable percent slope. This assumption is limiting. There are many other factors that may influence terrain difficulty. Other factors include accessibility, wind, rocks, maintenance, and ski run width. Because the same method is applied to all resorts, use of percent slope alone will provide an adequate comparison from one resort to another.
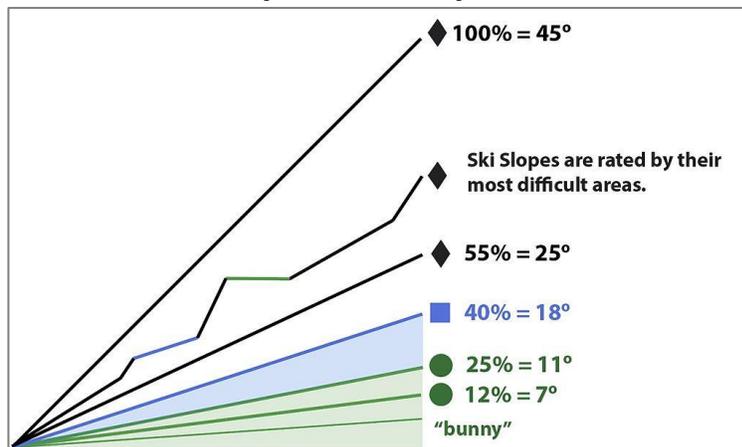
FIGURE 3 SKI TERRAIN DIFFICULTY BY PERCENT SLOPE

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[3] *Killington Mountain - Vermont*

[4] *Deer Valley Blog*

DATA SOURCES

Only a few data sources were necessary to complete the ArcGIS analysis. The Utah Automated Geographic Reference Center (AGRC)[5] provided feature sets for ski area boundaries and ski lift locations and elevations. Figure 4 shows the six relevant ski resorts: Brighton, Solitude, Alta, and Snowbird which are accessible through the Cottonwood Canyons from the Salt Lake valley; and Park City and Deer Valley which are accessible through Interstate-80, with their base in Park City, Utah. The National Map[6] provided 1/3 arc-second or 10m Digital Elevation Model (DEM) data. These data provide enough information to understand the basic terrain distribution in these six ski resorts.
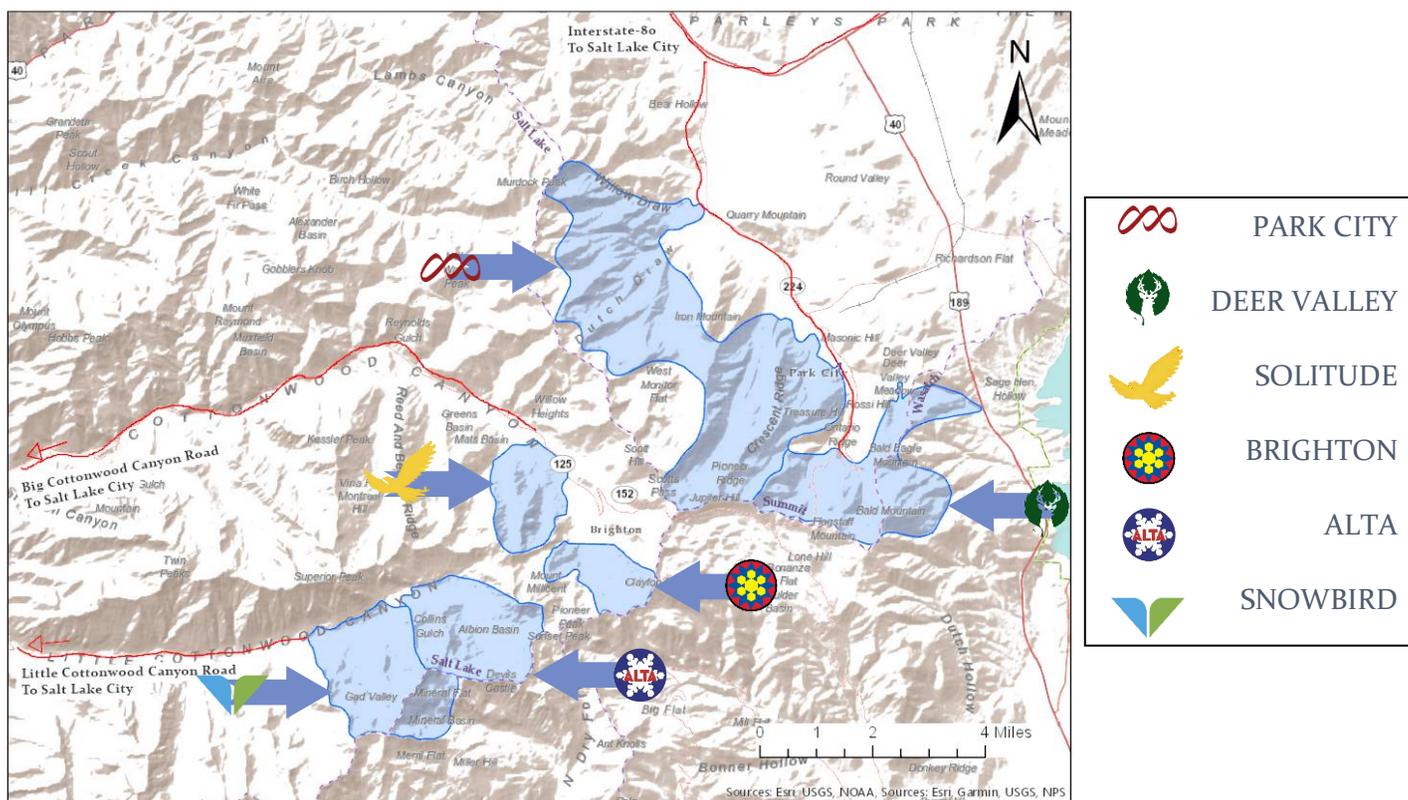
FIGURE 4 SIX SKI RESORTS NEAR SALT LAKE CITY COVER NEARLY 18,000 ACRES OF THE WASATCH FRONT

The non-profit organization Ski Utah also provided some useful information to compare each resort side-by-side. Table 1 summarizes this information. The adult and child lift ticket pricing is the online-price for a full-day ticket during the 2018-2019 peak season (between December 25th-December 31st). The area is the full acreage of the resort defined by the AGRC ski resort boundary. Salt Lake City International Airport (SLCIA) is the closest airport for all resorts. Base and peak elevation were provided by Ski Utah and represent the lowest and highest points in the resort respectively.

TABLE 1 RESORT STATISTICS SUMMARY

	Adult Lift Ticket	Child Lift Ticket	Area (Acre)	Miles from SLCIA	Base Elevation (ft)	Peak Elevation (ft)
Alta	$110	$57	2,210	32	8,530	11,068
Snowbird	$96	$45	2,660	29	7,760	11,000
Solitude	$82	$58	1,340	33	7,994	10,488
Brighton	$75	$45	990	35	8,755	10,500
Park City	$142	$91	8,606	32	6,800	10,000
Deer Valley	$180	$116	3,250	36	6,570	9,570

Methods
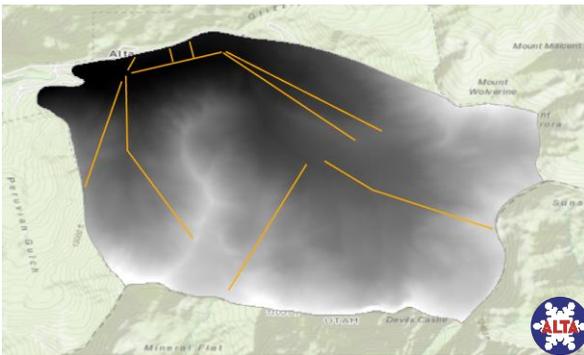
FIGURE 5 10 M DEM OF ALTA SKI RESORT

Alta Ski Resort was used initially to perform the analysis. Once complete with this one resort, the methodology was applied to all other ski resorts, and a side-by-side analysis was completed.

Figure 5 shows the 10m DEM within the Alta ski resort boundary which was obtained using the *Extract by Mask* tool and the resort boundary. The orange lines are the ski lifts and are displayed for reference. The lighter shades on the map represent higher elevations. Figure 6 shows Alta after the *Slope* tool was applied. The areas with the lighter color are a higher percent slope and represent more difficult terrain. In order for this information to be useful, terrain difficulty had to be defined based on percent slope.

FIGURE 6 PERCENT SLOPE OF ALTA SKI RESORT

To make sense of Figure 6, a layer definition was created to categorize the terrain. The percent-slope designations explained earlier were applied to visualize the terrain. Table 2 summarizes this layer definition. The first column is the difficulty rating and the third column is the color applied to the map.

TABLE 2 SLOPE LAYER DEFINITION

Flat	0% - 6%	
Easy	6% - 25%	
Intermediate	25% - 40%	
Intermediate-Expert	40% - 60%	
Expert	60% - 100%	
Technical	> 100%	

The percent slope layer definition was used to visualize the data as shown in Figure 7. This map is useful and can be used to understand the terrain distribution across the resort. 50m contour lines are shown for reference.

This information was then quantified to calculate the area within each classification. The *Reclassify* tool to was used to transform the raster from a continuous set of values ranging from 0.265% to 569.8% to a discrete set of values: 1 through 6 where each number represents a terrain classification. This change allowed the grid cells in each classification to be counted. Using the *Calculate Field* tool, the total area and percentage of area for each category was found.
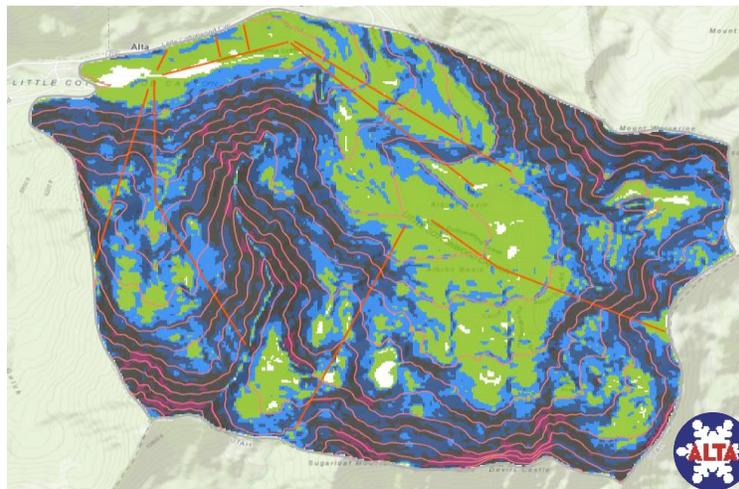
FIGURE 7 TERRAIN DIFFICULTY FOR ALTA SKI RESORT

This same methodology was applied to all six ski resorts allowing each resort to be compared side-by-side. A full size map showing all six resorts and their terrain difficulty can be found in Appendix A.

Results

Terrain difficulty as shown in Appendix A begins to illustrate the variation in terrain across the six resorts. Two charts have been created that offer side-by-side resort comparisons. First Figure 8 shows the terrain distribution in each resort by percentage of area. A few useful observations can be made from this graph. Snowbird has the highest percentage of expert terrain and the smallest percentage of easy terrain. Brighton has the highest percentage of easy and intermediate terrain and the smallest percentage of expert terrain. From personal experience, this conclusion matches the perception when visiting these resorts. Snowbird typically attracts expert-level skiers who want to be challenged with a variety of difficult terrain. Brighton, however, is a popular resort for new skiers and has one of the largest programs for youth and adult ski lessons.

There are certainly some limitations with this comparison. These percentages do not consider the resort size. Park City is more than 8 times larger than Brighton, and although Brighton has the highest percentage of easy runs, it does not have the highest acreage of easy runs. An additional comparison was made to understand this relationship.
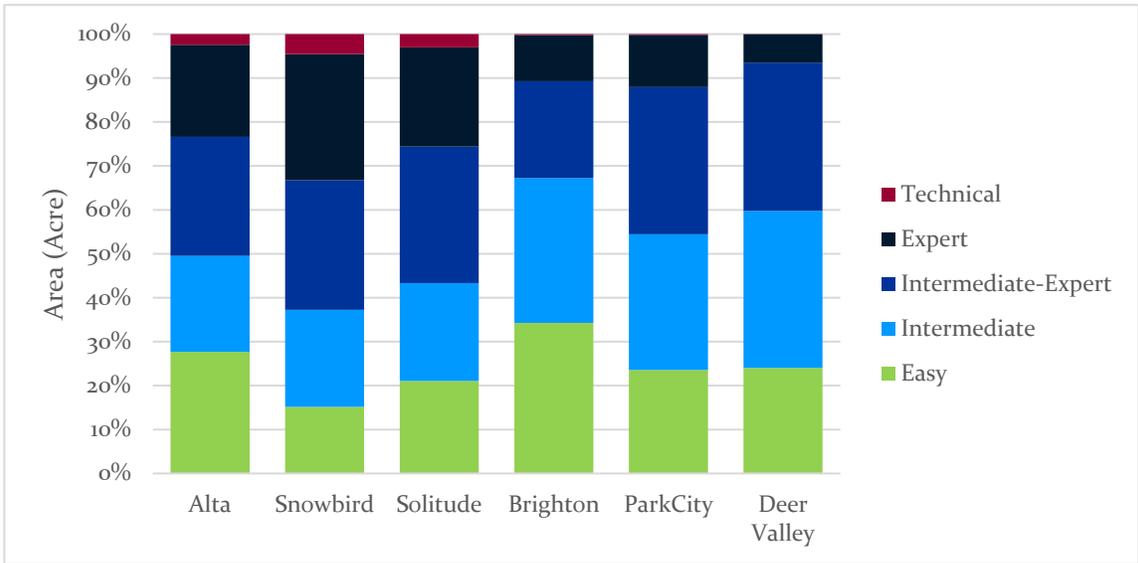
FIGURE 8 TERRAIN DIFFICULTY DISTRIBUTION BY PERCENTAGE

Figure 9 provides an additional comparison to understand the distribution by acreage. Notice that Park City is significantly larger than the other resorts and has a separate axis on the right-hand-side which is three-times larger than the left-hand-side axis. From this graph; Alta, Deer Valley, and Park City have the largest acreage of easy terrain. Snowbird has the largest amount of technical terrain which supports the previous
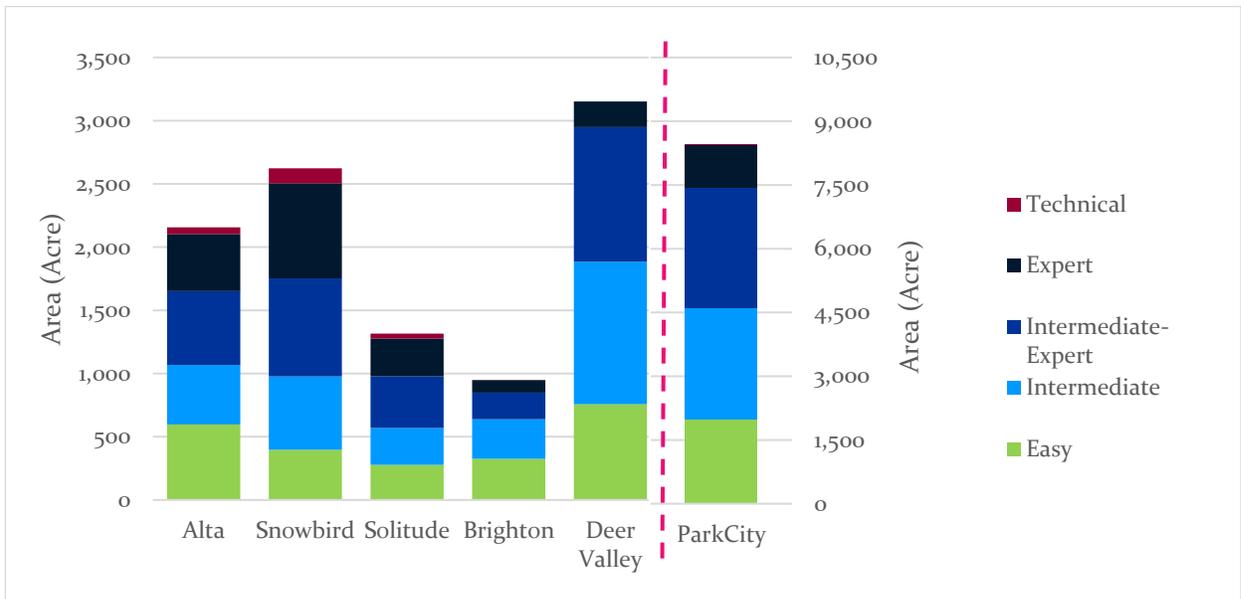
FIGURE 9 TERRAIN DIFFICULTY DISTRIBUTION BY ACREAGE

statement that Snowbird typically attracts highly skilled skiers. Both Figure 8 and 9 provide quantified insight into each resort. These two graphs could provide visitors with more information about terrain difficulty at each resort.

Model Improvements

With every methodology comes some limitations and assumptions that must be evaluated. Figure 10 shows three areas of interest within Alta Ski Resort. First area *A* is known as the resort base. This area has been classified as easy terrain where in reality it is not a skiable section of the resort. Areas like this exist in each resort and will skew the percentages at each resort. Next, area *B* is on the top of a mountain edge. This ridge is classified as intermediate and beginner terrain, but in reality this is very technical terrain. This ridge takes up a very small area and is unlikely to skew the data. Lastly, area *C* is a section that is un-skiable. This pass is known as *Catherine's Pass* and is an alpine meadow where skiers would get stuck if they tried to ski through this area. Sections like this throughout the resort will skew the data with more areas qualifying as easy terrain.
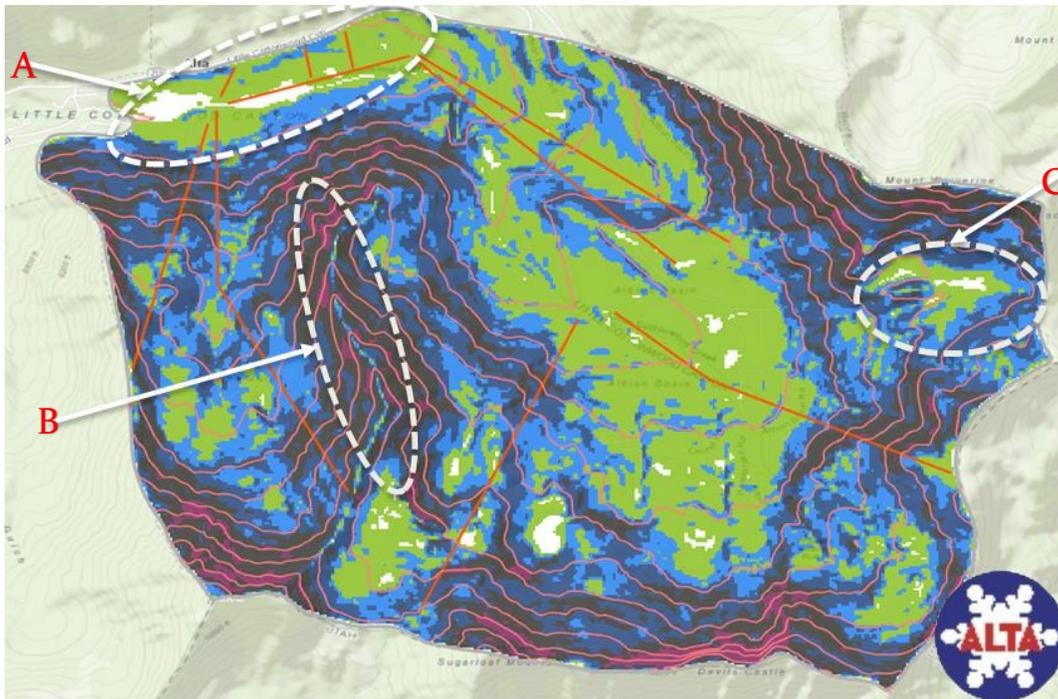
FIGURE 10 LIMITATIONS TO TERRAIN DIFFICULTY CLASSIFICATION

IMPROVEMENTS

Although evaluating all model limitations for each resort is out of the scope of this project, some improvements were made. To better understand the effect of including resort base in the percentage calculation, some adjustments were made on the Alta slope map.

These modifications were made using the *Raster Calculator* tool. The *SetNull* function changed the DEM raster with elevations less than 8636 ft or 2632 m to NO DATA and elevations greater than 8636 ft to 1. This elevation is the average elevation of the ski lift bases at Alta Ski Resort provided by the Utah AGRC. This raster was multiplied by the Percent Slope Raster, creating a raster without data in the ski resort base. Figure 11 shows this calculation, and Figure 12 shows the resulting map.
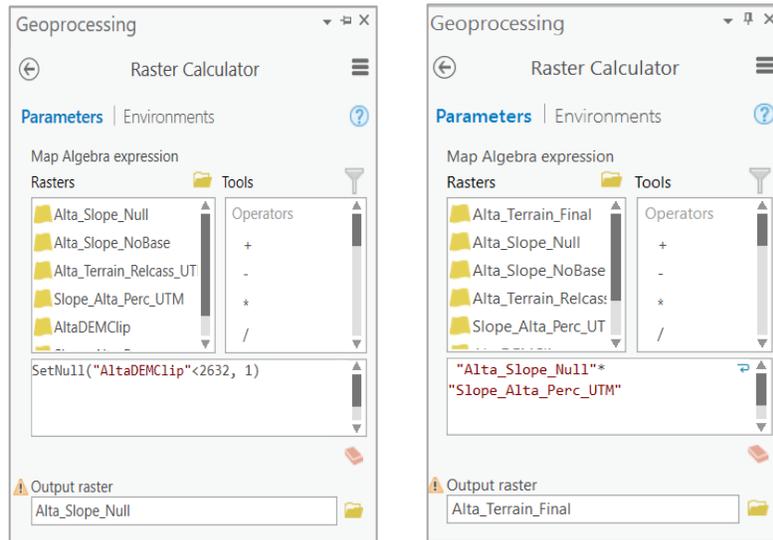
FIGURE 11 MODEL IMPROVEMENTS USING RASTER CALCULATOR
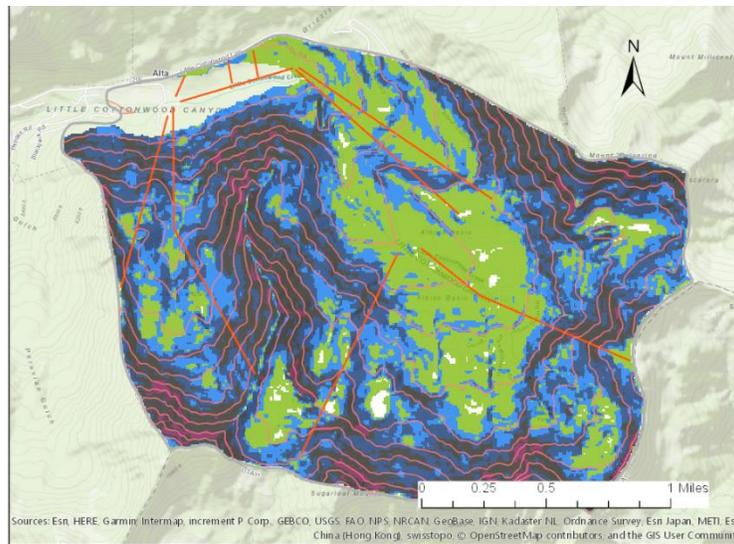
FIGURE 12 ALTA SKI RESORT WITH NO DATA AT RESORT BASE

After this adjustment the change in easy terrain percentage is very small, a decrease of 1.6% as shown in Figure 13. This adjustment resulted in a small increase in percentage of expert and intermediate-expert terrain by 0.5% and 0.8% respectively. This is not a significant change and does not result in a large change in resort characteristics. Complications arose when this method was applied to other resorts. Deer Valley and Park City, for example, have multiple bases all at different elevations. There was no easy way to

isolate one ski resort base based solely on elevation. Unique analysis would need to be completed for each resort in order to remove the base at each resort.
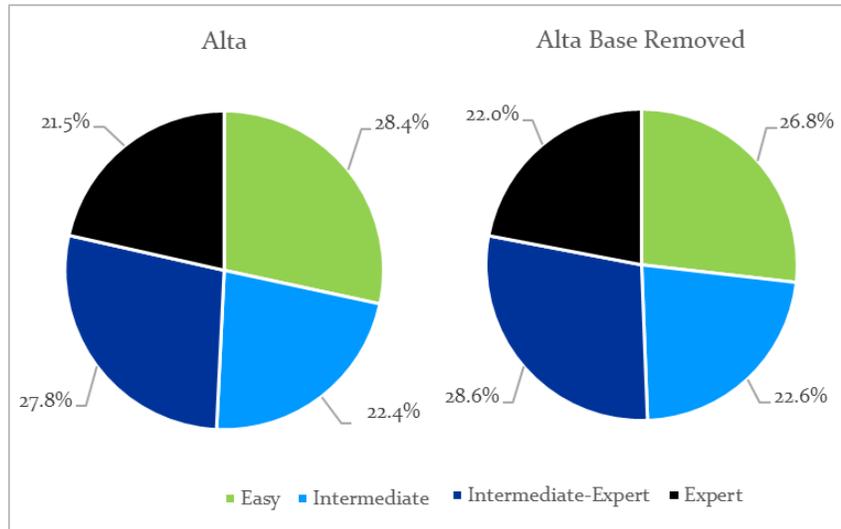
FIGURE 13 CHANGE IN PERCENTAGE AFTER REMOVING SKI RESORT BASE

Conclusion

ArcGIS-Pro proved to be a useful tool to understand ski terrain at six Utah ski resorts. With two very simple datasets, a 10m DEM and shapefiles of ski resort boundaries, a map showing terrain difficulty across six Utah ski resorts was able to be produced. This project produced a standardized visual of ski resort terrain. This is useful to visualize size and terrain distribution from one resort to another. Combined with the data from Ski Utah, this map provides enough information for visitors can pick the resort for their needs.

This methodology has made several assumptions. The resort base which is not a skiable area was included in the map of each resort. To understand if this affected the terrain distribution, the resort base of Alta Ski Resort was removed, and the analysis was repeated. There was 1.6% decrease in easy terrain which wasn't significant enough to change the resort characteristics. If an improved analysis were to be completed, several other limitations could be explored to understand the percent change and see a better representation of the resort terrain.

In conclusion, there have been several successes in this project. The visual map of Utah ski terrain will help visitors understand the characteristics of each resort. Visitors looking for a smaller resort with easy terrain may choose Brighton. And visitors who want to spend several days exploring a large amount of terrain may choose Park City. Regardless, visitors will be able to choose the resort for their needs to enjoy the Greatest Snow on Earth ®[7].

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[7] Yeti

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Appendix A

Terrain Distribution for Ski Resorts Near Salt Lake City

SKILIFTS

TERRAIN CLASSIFICATION
FLAT
EASY
INTERMEDIATE
INTERMEDIATE-EXPERT
EXPERT
TECHNICAL

Interstate-80
To Salt Lake City

Big Cottonwood Canyon Road
To Salt Lake City

Little Cottonwood Canyon Road
To Salt Lake City

N

0   1.25   2.5   5 Miles

Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS