Powder Mountain Bike Resort Master Plan

J. Dayton Crites
Utah State University

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POWDER MOUNTAIN BIKE RESORT MASTER PLAN

by

J. Dayton Crites

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF LANDSCAPE ARCHITECTURE
(Plan B)

Approved:

__________________________  __________________________
Sean E. Michael, PhD         David L. Bell
Major Professor    Committee Member

__________________________
Ryan C. Bosworth, PhD
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah

2013
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ABSTRACT

Powder Mountain Bike Resort Master plan

by

J. Dayton Crites, Master of Landscape Architecture

Utah State University, 2013

Major Professor: Dr. Sean E. Michael
Department: Landscape Architecture and Environmental Planning

In the last decade ski resorts worldwide have developed mountain bike specific recreational facilities in an effort to increase summer revenues. Their success has been mixed, with some becoming quite profitable, but others closing summer operations after only a few low-revenue years. With minimal information regarding bike park design currently available, the planning and design of these facilities remains largely a grassroots effort.

This thesis project develops a methodology that approaches the creation of mountain bike resorts on ski mountain terrain based on landscape architectural best practices, sustainable trail construction techniques, and site-specific requirements. For this project, the terrain of Powder Mountain, a privately owned ski resort above Eden, UT, was selected due to the management’s interest in the study’s relevance to expanding recreational summer offerings, and the proximity to Utah State University.
This research analyzes the Powder Mountain landscape and infrastructure to develop a Master plan, outlining trail corridors, feature placement, and terrain suitability for future trail development. The basis for these design decisions were analyses from site visits, case studies, and GIS analyses. In addition, a worldwide survey of mountain bike park user experiences was conducted to further understanding of the elements of an ideal mountain bike resort. Throughout the process, these findings were augmented by consultation with professional mountain bike park designers and refined through an iterative design process to create a Master plan based on landscape architectural best practices that will guide the development of summer mountain bike recreation facilities on Powder Mountain.

(205 pages)
Skiing and mountain biking are a popular active recreations enjoyed by millions worldwide. Both utilize hillsides to construct downhill courses that allow for a controlled and enjoyable descent. The skiing industry relies on consistent snowpack, and the mountain biking industry relies on a consistent lack of snowpack. Many mountain resorts have seen these similarities between the two sports and have built infrastructure to accommodate both sports on one mountain. Yet little research exists into the best way to design a mountain bike resort at a ski mountain.

This thesis project develops a methodology for the creation of mountain bike resorts on ski resort terrain based on landscape architectural best practices, sustainable trail construction techniques, and site-specific requirements. Powder Mountain, a privately owned ski resort above Eden, UT, is the focus site for this project.

This research analyzes the Powder Mountain landscape and infrastructure in order to develop a Master plan, outlining trail corridors, feature placement, and terrain suitability for future trail development. The analyses for this project stem from site visits, case studies, and GIS analyses. Local trail and resort case studies and a worldwide survey of mountain bike park user experiences were conducted to further understanding of the elements of an ideal mountain bike resort. Throughout the process, these findings were augmented by consultation with
professional mountain bike park designers and refined through an iterative design process to create a Master plan based on landscape architectural best practices that will guide the development of summer mountain bike recreation facilities on Powder Mountain.

(205 pages)
ACKNOWLEDGMENTS

If it was not for the support of my family and friends, I would never have arrived at a point where I could have imagined beginning this project. Throughout the process, a great number of friends and professionals have been a great help. There is not enough room to thank everyone whose casual comments or poignant insight improved the quality of this work, but I would like to thank the following people in particular for their continued support and devotion to this project:

Sean E. Michael, PhD – for his intensity that served as the distiller for some of my ideas in need of fermentation.

Chris Bernhardt – for lending his professional expertise and time, and offering the perspective of a professional mountain bike park planner and designer.

David Bell – for the straightforward insight.

Ryan Bosworth – for introducing new ideas and offering the grounded perspective of an economist.

Kristen Munson – for being my beautiful wife and steadfast supporter.

Every moment I’ve spent on a mountain bike in the trails of northern Utah.

J. Dayton Crites
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CHAPTER I
INTRODUCTION

Project Background and Context

Mountain Biking has its roots in the late 1970s, with groups of men and women taking beach cruiser bicycles to the top of mountain roads and trails and enjoying the thrills and views as they rolled back down. As the sport evolved, bicycle technology evolved from steel to carbon fiber frames and from five to thirty speed drivetrains. Likewise, the types of trails desired by the mountain biking population have evolved, from adopted hiking trails and dirt roads to trails purpose built for the mountain bike experience with wide switchbacks, smooth banked turns, rolling, rhythmic trail surfaces, and technical challenge features. Yet the thrill of arriving at a high ridge or mountaintop and letting gravity pull you back down has gone unchanged. This thrill is identical to that which draws so many to ski slopes every winter.

The ski industry has not been unaware of this parallel. Since the early-1990’s, ski resorts have experimented with mountain bike lift access in the summer months as a means to expand operations into a year round venture and increase profitability. There are signs that mountain bike resort development is a growing industry, as a review of the 1998 - 99 ski season by the British Columbian government found that 64 percent of ski resorts had installed summer lift operations, up from 12 percent in 1991 (Assets, B.C. Land Corporation, 2000).

However, according to a 2011 National Ski Area Association report, the overall economic impact of mountain biking recreation on ski resort terrain has been relatively minimal
in comparison with winter sports, with summer revenue in total averaging 9.7 percent of total revenue for the 107 North American resorts surveyed (RRC Associates, NSAA Economic Analysis Final Report, 2011). Currently minimal data exist to explain this trend, though theories have been informally ventured. These ideas can be found in online forums and the occasional blog, but little study has been undertaken to verify them. Nonetheless, they are worth considering:

- Mountain biking is seen as a more ‘extreme’ sport than skiing, with the danger and challenge associated with off road cycling perceived as much higher than that of downhill skiing or snowboarding.

- Many mountain bike resorts develop a large variety of challenging intermediate and advanced trails, with few designed for beginner riders. This is exemplified by the resorts offering lift accessed mountain biking along the Wasatch Front.

- Many ski resorts are hesitant to invest in mountain bike facilities as there are few data regarding what users will pay for mountain bike facilities, and little understanding regarding success or failure of summer operations.

- The design of mountain bike trails and features at resorts has been, for the most part, a grassroots effort, and room exists for an improvement of trail design and planning techniques.
These setbacks are issues that should be addressed through the informed design techniques and approaches of landscape architecture. Landscape architecture is a profession that provides its practitioners the tools needed to analyze large landscapes such as ski resorts, and to determine the land’s suitability for various uses. Using the lens of landscape architecture the grassroots practice of mountain bike resort design can evolve. It can provide trail networks that are sustainable, accessible, and engaging for all riders and all skill levels. They can be designed to be as unique as the landscape they traverse. This thesis seeks to develop a methodology and approach that will allow mountain bike resort design to do just that.

Goals and Objectives of this Research

The goal of this research is to develop a mountain bike resort master planning methodology and apply it in the creation of a mountain bike resort master plan. An appropriate methodology must deliver the best possible design in both an ecological and social sense. Ecologically sensitive design creates trail alignments and feature placements that impact the land as little as possible and complement the existing landscape. Socially sensitive design appeals to the greatest number of users possible with unique, memorable and pleasant experiences. The methodology is then applied to a master plan for Powder Mountain that can be used to guide future summer development.

This master plan seeks to provide a framework to create and build a mountain bike resort that achieves commercial success by designing for, and being enjoyed by, a wider range of users.
than ever before. In order to provide such a framework, the methodology used to build the master plan focused on the following four goals:

- Utilization of a user survey and case studies to better understand consumer preferences, including types of trail design that appeal to the largest number of mountain bike resort users, how much they are willing to pay for the experience, and what types of features or facilities make a difference between a valued or non-valued experience.

- Apply landscape architectural best practices such as the McHargian overlay method, iterative design processes and Kaplan’s outdoor preference studies to the design of trails and features on the site.

- Design a set of trail and feature experiences unique to Powder Mountain and that convey a sense of place.

- Develop a set of trail experiences at Powder Mountain that cater to all mountain bike riders, not only the experts and thrill seekers, but the family and beginner experience as well.

**Significance**

The survey conducted as part of this research provides willingness to pay data to be utilized by ski resorts to better understand the economic viability of mountain bike resort development. Additionally, the survey’s data regarding user preferences of mountain bike resort features shed some light on how paying customers react to these facilities.
By incorporating survey data, case study research, GIS analysis, and extensive on-site inventory into the final design of the Powder Mountain bike resort master plan, this research establishes the first thorough and evidence-based approach to the design and planning of mountain bike resorts. The result is a design that is defensible on the basis of environmental impacts, user experience, and economic feasibility.

Mountain bike resorts have the potential to reinvigorate the ski industry and provide year-round benefits to resorts’ local economies. However, their potential has not been fully realized, due in part to design flaws that cater to expert riders over novice and intermediate cyclists. This research seeks to form the basis of a new era of mountain bike resort design, that if properly applied to more resorts throughout the world, could expand the sport of mountain biking and the economies of mountain communities.
CHAPTER II
LITERATURE REVIEW

Terminology and Mountain Bike Marketing

Mountain bike trails, mountain bike parks, mountain bike resorts – all three share much in common, but retain subtle differences. In common vernacular, the terms are at times used interchangeably, and official definitions can vary widely. For the purposes of this thesis, these terms should be defined and separated. All three are designed expressly for mountain bike use. Individually, a mountain bike trail refers to a single, natural surface path that may or may not contain skills features such as jumps, elevated balance features, rock obstacles or other challenges. A mountain bike trail is linear in form, and likely connects to a network of trails. A mountain bike park is a free-access park, typically built for community recreation and contains skills features and natural surface trails. A mountain bike park’s footprint is smaller than a network of trails, and contains a reduced amount of features and skills challenges. A mountain bike resort is a paid access area, typically on ski resort land with lift access to high points and ridges of mountains, and may contain both mountain bike trails and mountain bike parks within its boundaries. It is common to refer to a mountain bike resort as a mountain bike park or lift accessed mountain bike park, but for this thesis the term ‘mountain bike resort’ will be used.

This term choice is not accidental. Due to the connotations of difficult and dangerous stunts, tricks, and extreme challenges that are associated with ‘skate park’, ‘snowboard terrain park’ and ‘bike park’, and a need to broaden the appeal of mountain bike-based recreation, the
term ‘mountain bike resorts’ will be used in this paper when describing lift accessed mountain bike facilities, and ‘mountain bike parks’ when describing mountain bike facilities that are designed as public facilities with an emphasis on stunt based riding.

This shift in terminology is intended to broaden the appeal of the mountain bike trails and features installed on a ski mountain. Mountain bike promoters’ myopic focus on stunt-based riding carries great appeal to some, and can be visually stunning and emotionally gripping, but the promotion of the sport as an ‘extreme’ pursuit stops a great number of people from participating. The images in Figure 1 are taken from the front page of the Whistler and Angel Fire Bike Parks’ websites. This marketing of mountain biking as extreme, rather than family friendly can be seen as limiting the success of mountain bike resort facilities on ski resort land.

Figure 1. Current mountain bike resort marketing
The author hypothesizes that a shift away from stunt-based riding and towards relaxation and recreation has the potential to attract a much larger audience to mountain resorts. This hypothesis is reflected in the marketplace, as downhill specific mountain bike equipment sales are minute in comparison with cross-country and all-mountain mountain bike sales. Paul Aeita, marketing manager of Mountain Racing Products, a supplier of suspension forks and chainguides for numerous bicycle brands indicates that consumer interest in “dual crown [downhill specific forks] is extremely limited, some small fraction of one percent. Most of them are going to e-bike [electronic bike] customers. Single crown [forks] in the 140mm – 160mm travel will be our biggest growth area this year and next” (P. Aeita, personal communication, January 15, 2013). Bicycle manufacturers tell much the same story. Keith Hnatiuk, demand planning manager for Specialized Bicycles, indicated that “our ‘gravity’ bikes sell at less than 1 to 10 to xc/all-mountain” (K. Hnatiuk, personal communication, January 16, 2013). If the lift access market could tap into the broader riding styles that exist, it is plausible that lift tickets could significantly increase sales.

**Trail Standards**

*Trail Construction Standards*

Mountain bike specific, natural surface trail design standards have been well established by the International Mountain Bicycle Association (IMBA) and are outlined in their publication *Trail Solutions: IMBA’s Guide to Building Sweet Singletrack* (Webber & Felton, 2004). This book documents construction standards regarding natural surface trails, (e.g., average slope vs.
outslope, switchback techniques, etc). The publication also establishes a trail difficulty rating system that provides guidelines to classify a trail’s difficulty based on surface, tread width, average and maximum grades, as well as technical trail feature placement and construction. A chart outlining the book’s trail guidelines is included in Figure 2. The guidelines form the basis of trail recommendations developed as part of this thesis. IMBA’s publication is chosen as the reference point due to its coverage of many aspects of trail design as well as siting of trails.
## Trail Difficulty Rating System

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<tr>
<td>Trail Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72&quot; or more</td>
<td>36&quot; or more</td>
<td>24&quot; or more</td>
<td>12&quot; or more</td>
<td>6&quot; or more</td>
</tr>
<tr>
<td>Tread Surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardened or surfaced</td>
<td>Firm and stable</td>
<td>Mostly stable with some variability</td>
<td>Widely variable</td>
<td>Widely variable and unpredictable</td>
</tr>
<tr>
<td>Average Trail Grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 5%</td>
<td>5% or less</td>
<td>10% or less</td>
<td>15% or less</td>
<td>20% or more</td>
</tr>
<tr>
<td>Maximum Trail Grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max 10%</td>
<td>Max 15%</td>
<td>Max 15% or greater</td>
<td>Max 15% or greater</td>
<td>Max 15% or greater</td>
</tr>
<tr>
<td>Natural Obstacles and Technical Trail Features (TTF)</td>
<td>None</td>
<td>Unavoidable obstacles 2&quot; tall or less</td>
<td>Unavoidable obstacles 8&quot; tall or less</td>
<td>Unavoidable obstacles 15&quot; tall or greater</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoidable obstacles may be present</td>
<td>Avoidable obstacles may be present</td>
<td>Avoidable obstacles may be present</td>
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<tr>
<td></td>
<td></td>
<td>Unavoidable bridges 36&quot; or wider</td>
<td>Unavoidable bridges 24&quot; or wider</td>
<td>May include loose rocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TTF’s 2’ high or less, width of deck is greater than 1/2 the height</td>
<td>TTF’s 4’ high or less, width of deck is less than 1/2 the height</td>
<td>Many sections may exceed criteria</td>
</tr>
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**Figure 2. IMBA Trail Solutions construction standards**
These trail construction standards are echoed elsewhere in the literature, and not only for mountain bike trails. The United States Forest Service’s *Trail Construction and Maintenance Notebook* (Hesselbarth, Vachowski, & Davies, 2000), a standard educational document that guides all Forest Service sanctioned trail building and repair, contains many of the same recommendations as IMBA’s book. Construction techniques are extensively covered, with emphasis on bench cut trail construction and a variety of drainage techniques to minimize the erosive effects of water runoff.

One study found that trail position, trail slope alignment angle, grade, water drainage, and type of use are significant determinant factors on trail degradation (Olive & Marion, 2008). Further studies have analyzed trail erosion due to mountain bike use in various locations, and find that mountain bike use on trails generates comparable or less damage than hiking or multi-use trails, and significantly less trail erosion than equestrian or ATV trails (Bjorkman, 1996; Thurston & Reader, 2001; White et al, 2006).

A study published in the *Journal of Sustainable Tourism* echoes the findings listed above but looks at rider preferences alongside erosion, and offers an important trail design caveat. There exist rider preferences for abrupt downhill sections, steep slopes, curves and jumps. Even though these elements can diminish trail sustainability if constructed in excess, they should be part of any design intended to appeal to a large mountain bike user group (Goeft & Alder, 2001). This finding is confirmed by another study that investigated mountain bike user preferences of 406 mountain bikers across the United Kingdom, the United States, Australia and New Zealand. The study illustrated a number of measurable preferences, such as the presence of rocks, roots,
and gullies; all, on average, added to mountain biking experiences (Symmonds, Hammitt, & Quissenbury, 2000). Yet few studies exist that more fully investigate mountain bike user preference of trail features, particularly those that are man-made and designed to challenge the rider, such as those features found at a mountain bike park or resort.

**Trail Design Standards**

Trail design has long been, and remains, an art form practiced by men and women on the ground with tools and time. General trail alignments, however, have often been pre-designed with the aid of topographic maps and experienced trail builders using pen and pencil. This approach, referred to as the ‘office method’, was found to be the most reliable way of designing trail alignments in a study that compared the office method to a GIS least-cost path analysis (Ferguson, 1998). More recent studies have utilized advanced GIS techniques to create trail alignments, and have used computer analysis to align trails that seek to avoid impact to sensitive ecological areas. This process creates trail alignments that respond to sensitive areas, but fail to respond to hillside slope, elevation, and other nuanced terrain data, and still require a form of the office method to develop final alignments (Boers & Cottrell, 2007).

**Trail Feature Standards**

Trails are the basic ingredient of mountain bike resorts, but technical trail features or skills-based features are perhaps their most distinctive aspects. In large part, these skills features are what differentiate a mountain bike resort from a similar resort that simply allows mountain bikers to ride on an existing trails network and utilize its lift system. This is an important distinction, as a potential customer for a mountain bike resort can always ride trails for free on
the public lands that commonly surround ski resort terrain, but these trails rarely contain skills features, and never offer a lift ride back to the top.

In addition to IMBA’s manual, the Whistler Blackcomb Trails Guidelines (DeBoer, 2003) outline further specifics for technical trail feature construction and fall zone guidelines. Pump tracks, a popular dirt course that allows the rider to move in a circuitous pattern by pumping the bicycle through steeply undulating terrain is a design feature well explored in the self-published work *Pump Track Bible* (McCormack, 2003).

The Whistler Blackcomb trail guidelines, as well as standards established by Alpine Bike Parks and the City of Boulder, CO, during construction of community bike parks serve as reference points for the construction of durable skills features that minimize risk. A number of their standards are included in the appendix of this document to serve as a reference, but the design and construction details of skills features is beyond the scope of this thesis.

Throughout this document, terms will be used to describe certain technical trails features. These terms range from the self-explanatory (e.g., jump) to obscure (e.g., table top). A full list of these terms can be found in the Glossary at the end of this document.

**User Conflict and Trail Design**

A significant amount of research exists on user conflict between hikers, mountain bikers, and equestrians in recreational environments. Regardless of these perceived conflicts, many ski resorts offer a mix of activities to encourage more visitors to patronize their summer operations. Studies have documented conflict between hikers and mountain bikers utilizing the same
recreational area in Colorado, (Carothers, Vaske, & Donnelly, 2001) though other studies have found little conflict between the user groups in recreational areas in Western Australia (Chiu & Kriwoken, 2003). A plausible reason for this variance in conflict levels could be due to user densities in and around a given recreational area. One study that looked at user preferences and impressions while visiting Whistler Blackcomb Resort looked across users and saw little conflict between hikers and mountain bikers utilizing the resort, but saw significant conflict arise between non motorized and motorized recreational uses. It should be noted that this lack of conflict could be due to the resort isolating uses on hiking or mountain biking specific trails, rather than the shared trail networks that are studied in the aforementioned studies (Needham, Wood, & Rollins, 2004).

Management suggestions of separate trail uses have been adopted beyond Whistler alone, and are in place in a number of locations, public and private, throughout North America. A number of the trails investigated as part of the case studies in this thesis are of the separate use design.

**Economic Impacts of Mountain Biking**

Mountain biking, like many recreational pursuits, has developed into a significant economic force. The number of participants purchasing equipment, spending money on travel and lodging, dining and shopping creates important economic contributions to local and regional economies.
The Outdoor Foundation found in their 2010 study of American outdoor participation that cycling (including road biking, mountain biking, and BMX) was the fourth most popular outdoor activity among Americans, and that cyclists participate in their sport more often than any other sporting group outside of runners and joggers (Outdoor Foundation, 2010). A parallel study from the Outdoor Foundation, the 2012 Active Outdoor Recreation Economy, found that Americans spend over $81 billion on cycling sports every year. They put that figure in perspective by comparing it to the $51 billion spent annually on airplane tickets and fees (Outdoor Foundation, 2012).

As for mountain biking specifically, the sales of bicycles alone are a significant economic force. *Bicycle Retailer and Industry News* calculated that mountain bikes account for 31.7 percent of all bicycle sales in the United States, gathering over $1 billion in sales in 2010 (Weibe, 2011).

Many communities have found mountain biking and mountain biking tourism can bring sustained economic growth to their region. A recent article in *Bike Magazine* states “The proliferation of trails in Grand Valley is such that Fruita, once a sleepy little farm town with an unemployment problem, is the geographic hub in the expansive wheel of riding opportunity.” (Ferrentino, 2013). A 1997 study found that Moab’s trail network contributes an annual value of $8 million to the local economy (Fix & Loomis, 1997).

A study by the Western Canada Mountain Bike Tourism Association (2006) found that of major mountain biking areas in Southwestern Canada, the trail systems in Squamish, North Shore and Whistler generated $10.6 million to the local economy during the summer of 2006. Of
this, $6.6 million is attributed to the Whistler region, and this two thirds majority is largely credited to the existence of a world class mountain bike park located at Whistler Blackcomb Resort. The $6.6 million figure is independent of the $16.6 million spent over the summer at the resort itself. These findings suggest that the allure of a high quality mountain bike resort can have significant impact not just for the resort itself, but for the entire region (Western Canada Mountain Bike Tourism Association, 2006).

The vitality of mountain bike economies at Whistler and Moab are unique. The same level of success should not be assumed for every site considering mountain bike recreation as an economic driver. But there are important parallels between these regions that illustrate what makes a mountain bike destination successful. Both Whistler and Moab offer unique trail experiences that draw national and international visitors. Both offer escape into a recreational pursuit that is unique and memorable. Both offer cyclists a chance to utilize gravity to the fullest extent – Whistler with its chair lifts outfitted to hold bicycles, and Moab with its multitude of shuttle services willing to drive cyclists to the top of the La Sal Mountains or slick rock rims so that they may descend back into town. Both offer a wide range of opportunities to recreationalists, even if they have no interest in riding bicycles.

Yet many North American mountain resorts have yet to see the type of success exhibited by Whistler. A 2011 National Ski Areas Association (NSAA) funded report found that 72 percent of ski areas polled (n=107) report some summer operations revenue. This varies significantly by region, with 90 percent of southeastern United States resorts and 84 percent of northeastern resorts reporting summer revenue, whereas only 66 percent of mid-western ski areas
report summer revenue. Summer revenue is still a small portion of overall revenues, as the average share of summer revenue was found to be 9.7 percent of total annual revenues. Of these summer revenues, food and beverage were the largest single source income (26.1 percent of summer revenue) whereas lift tickets (chairlift/sightseeing/mountain biking) account for 6.3 percent of revenue. Yet the highest average summer revenue seen in the study takes place in the Rocky Mountain Region, home of Powder Mountain Resort (RRC Associates, NSAA Economic Analysis Final Report, 2011).

The relatively recent growth of mountain bike park construction firms can also be seen as a sign of a burgeoning industry. A cursory review of the Professional Trail Builder’s Association website (www.ptba.com) allows for a review of all professional trail builder companies that specialize in mountain bike park design and construction. Of the 14 companies that specialize in mountain bike park design and construction, only six were established prior to 2002.

Utah has seen limited success with mountain bike resorts. Brian Head Resort, outside of Cedar City, UT, began operations in 1990, and in email correspondence with Ken Jenson, mountain bike park manager for Brian Head, he indicated that the bike park “makes a tidy profit, enough to justify our meager salaries. With your population base [Cache, Box Elder Weber and Davis Counties] you should be able to do much better.” (K. Jenson, personal communication, March 11, 2011).

In a similar email correspondence with Chuck English, mountain manager of Park City’s Deer Valley, he states that the bike park investment has been a profitable venture, “Not counting
the capital cost of the lift or the power to run it, we started to see a positive cash flow within a couple of years.” He also indicated another valuable benefit: employee retention. “We employ 16 to 20 people who otherwise would need to find work in the summer and we might lose them in the winter.” Having grown from 1 to 3 lifts in operation since they opened, English said that “[we] have seen good profit levels in the last few years which is attributable to our proximity to a metropolitan area…It [Deer Valley Mountain Bike Resort] brings a level of activity to our resort in the summer and helps our other businesses like retail, rental, lessons and dining.” (C. English, personal communication, August 16th, 2011).

Yet for the modest benefits cited by Deer Valley and Brian Head management, the development of mountain bike resorts has a long way to go. With the recent addition of Canyon’s mountain bike resort, only three of Utah’s 14 mountain resorts have installed mountain bike terrain. And of these three, none offer a beginner route extending from the top to the bottom of the mountain. In comparison, Whistler, arguably the most successful mountain bike park in the world, has three distinct beginner rated trails that allow a first-time mountain biker to experience the whole of the mountain, from top to bottom (Whistler Trail Map, 2012).

Even the federal government has recently indicated their approval and support of mountain bike resorts at ski areas. The Ski Area Recreational Opportunity Enhancement Act (S.382/H.R. 765) was signed into law by President Barack Obama on November 7th, 2011. This act allows ski resorts operating on public land to offer summer guests a wider range of activities, including zip lines, mountain biking and mountain bike parks, ropes, and Frisbee golf courses. Introduced by Senator Mark Udall of Colorado, the act has the overt purpose of increasing
summer revenue in mountain economies, and it is no accident that mountain bike recreation development is prominently featured within the bill.

**Climate Change and Mountain Resorts**

The federal government’s support of expanded activities on ski terrain could plausibly be related to current climate change forecasts. In 2007, the Intergovernmental Panel on Climate Change (IPCC) published a comprehensive report of recent studies and models indicating the rate at which the planet is warming, and their worldwide implications. Though the report is global in scope, specific chapters address North America, and the mountain recreation specifically: “Without snowmaking, the ski season in western North America will likely shorten substantially, with projected losses of three to six weeks (by the 2050’s) and seven to 15 weeks (2080s).” The report does have a bright side for resort economies. Visits to Canada’s national parks system are projected to increase by nine to 25 percent (2050s) and 10 to 40 percent (2080s) as a result of a lengthened warm-weather tourism season (Parry 2007).

Yet according to some sources, the IPCC’s global focus causes it to paint an overly optimistic picture for North American mountains. A 2012 study focused specifically on winter tourism in the United States found that currently, 88 percent of NSAA resorts use artificial snow, and with a four to 10 degree Fahrenheit temperature difference predicted by the end of the century, Rocky Mountain snowpack could be reduced from 25 percent to 100 percent (Burakowski & Magnusson, 2012).

The general consensus among reports studying the effect of climate change on snowpack changes and the winter resort industry is that some, but not all, mountain resorts can survive
through the next fifty to eighty years, and in order to do so, ski resorts must consolidate to those favored with higher elevations and northern latitudes, invest in man-made snow, and diversify offerings. Mountain bike resorts could be the salvation that a snowless winter requires.

The trend is not forecasted for North American resorts alone, as European resorts fare little better. The Organization for Economic Co-operation and Development’s (OECD) report *Climate Change in the European Alps* (OECD, 2007) predicts that by 2050 average temperatures across the European Alps may increase 1-5 degrees Celsius. This increase is predicted to cause between 18 and 33 percent of ski resorts within the European Alps to no longer be able to rely on natural snowfall during winter months.

In light of this forecasted trend, it may become a matter of survival for ski resorts to become more than just destinations for winter recreation. Alternative summer recreation facilities have met with some success, but the cost of installation is much higher than mountain bike installations. A recent summer coaster installation, spanning just over a half mile on Minnesota’s Spirit Mountain, cost $2.2 million to install, while a waterpark in Silver Mountain, ID required an investment of more than $20 million (NSAA Journal, June 2012). These installations’ price tags far exceed what it costs to build a network of trails and create a mountain bike resort. According to Chris Bernhardt, director of IMBA’s Trail Solutions, the more labor intensive, mountain bike specific trails can cost between $10 and $20 per linear foot, with technical skills features costing $30 to $50 per linear foot (C. Bernhardt, personal communication, May 1st, 2011). Utilizing the mean values in these estimates, a ski area could create a mountain bike resort with over 20 miles of trail and features for less than $2 million.
And unlike a mountain coaster, mountain bike attractions have the ability to generate additional revenue via additional equipment sales and rentals.

**Summary**

Based on various studies, climate change models, conversations with mountain resort managers and observation of economic trends, mountain bike resorts appear to have the potential to increase revenues and profits of ski resorts and mountain town economies alike, and this potential will only grow as climate change reduces ski season lengths and snowlines. Taking into account climate change along with a relaxation of regulations on trail development on federal land, and the economic benefits of mountain bike tourism, it appears that mountain bike resorts have the potential to significantly increase their contributions to mountain resort’s regional economies. Yet for all these apparent benefits, there exists little discourse on the best way to design a mountain bike resort, or what elements of a mountain bike resort influence a user’s experience and sense of value. It is these gaps in the literature that this study seeks to address and, by doing so, to provide tools that allow a wider range of ski resorts to reach a greater level of success in designing mountain bike resorts. Specifically, it seeks to:

1. Establish tools and design strategies to broaden the appeal of mountain bike resorts to all skill levels of riders.

2. Establish methods of computer-aided trails planning that increase efficiency and insight to create an ecologically sound and socially enjoyable trail networks.

3. Develop a mountain resort design methodology that provides optimal returns on investment by improving workflow efficiencies in trails planning and design.
CHAPTER III

METHODS

This research seeks to develop methods for the design of mountain bike resort infrastructure that can be applied to future resort design. The major steps in developing these methods were the following:

- Literature review to understand existing mountain bike resort design and history, mountain bike trails and feature construction standards, and the economic value and necessity of mountain bike facilities.

- Case studies of one beginner, one intermediate, and one advanced mountain bike trail. Case studies also included an inventory of existing and potential mountain bike resorts along the Wasatch Front.

- Creation and distribution of an online survey designed to indicate mountain bike park and mountain bike resort user preferences.

- GIS and physical site inventory and analysis of chosen site of Powder Mountain, UT. Information gathered from these efforts was utilized to create a set of suitability maps indicating terrain suitability for the construction of trails, features, and switchbacks.

- Synthesis of the aforementioned elements to create a master plan document to guide the development of a mountain bike resort at Powder Mountain, UT.
Case Studies

Case studies of regional mountain bike resorts, mountain bike parks and trails were undertaken during the summers of 2010-2012 in order to better understand how trail, skills feature, and resort design decisions influence the overall mountain bike recreational experience.

In these case studies, a variety of factors were measured using on ground measurements, personal GPS units, and online resources. A key online resource has been the user-generated ride data website, www.strava.com. Strava.com is a site designed to allow runners, cyclists, and nearly any traveler with a global positioning system (GPS) device to upload their GPS-recorded activities online and compare and share them with the Internet community. For the case studies, site visits and strava.com information were used to gather the following data for each trail considered:

- Approximate trail tread width
- Average and maximum trail downslope
- Approximate average turn radii
- Trail surface type
- Skills feature inventory, placement, and construction
- Maximum, mean, and minimum strava.com rider speed (it should be noted that these numbers are likely similar to, but not representative of actual averages, minimums, and
maximums of rider speed on trail. Strava is used as online competition, and as such, the averages are likely higher than the real world averages of all cyclists on a given trail).

Case study sites were selected in order to provide a regional sample of trails suitable for beginner riders (Green Canyon, Logan, UT), intermediate (Rush trail, Draper, UT) and expert (Road to Arcylon, Park City, UT). These trails were selected as representative of mountain bike trail skill levels based on the author’s experience, a sample size greater than 100 recorded riders on Strava.com, their location within 100 miles of the project site, and a number of informal interviews with other mountain bike riders along the Wasatch Front.

In addition to the selected trails, an overview of all Wasatch Front ski resorts that currently offer mountain bike resort facilities was conducted to better determine what competition exists, or could come to exist that would affect the future development of a mountain bike resort at Powder Mountain, and to understand what presently exists in the mountain bike resort marketplace for Wasatch Front residents. In addition to the mapping of Wasatch Front resort locations, the following data were gathered and recorded for each mountain:

- Location and name of resort
- Date mountain bike resort was founded
- Number of lifts in operation during summer season
- Additional summer recreational uses
- Summer lift ticket price and/or season pass price
- Number of mountain bike trails available and listed skill levels of each
- Mountain bike skills features offered
- Vertical feet of descent
- Summer hours and schedule

**Mountain Bike Park and Resort Survey**

Little or no data currently exists to evaluate or rate mountain bike resorts and parks, and to discern what separates a good mountain bike park or resort from a bad one. To address that issue, a survey was created in conjunction with the staff at the International Mountain Bike Association (IMBA) that seeks to better gauge mountain bike park user preferences, user’s willingness to pay for mountain bike resort access, and to gather knowledge of the geography of mountain bike resorts worldwide, both planned and existing.

The survey was designed as an online survey that would be presented to respondents who would self-elect to take the survey. As such, it cannot be considered a random sampling, but should be looked at as representative of the views held by mountain bikers who presently hold an interest in mountain bike parks and/or the sport at large and express that interest by visiting mountain bike associated websites. The online method of survey distribution generated more
responses than would have been feasible with more traditional pen and paper methods. Google’s form creator (docs.google.com) was used to create the form and compile initial results.

The design of the survey (see Appendix B) sought to answer a number of questions, but the overall theme was to glean from the data how users perceive the mountain bike resorts and mountain bike parks they have experienced, and what factors affect that experience. In addition to this knowledge, IMBA sought to utilize the survey to better identify the processes that lead to the creation of mountain bike parks, both how they are funded and lobbied for, as well as which land owners or agencies tend to participate.

The survey was officially launched on June 13, 2012. The initial announcement was distributed through IMBA’s email list, to approximately 50,000 email addresses. This mailing achieved nearly 500 responses within 48 hours. A link to the survey was shared online through IMBA’s and the author’s Facebook networks, as well as blogs and websites specifically selected to reach a demographic that has an interest in mountain bike parks. Links to the survey received front page coverage on www.bikerumor.com, www.imba.com, www.allhailtheblackmarket.com, www.bikemag.com, and www.pinkbike.com. For each posting on a distinct website, a significant jump in responses was recorded. Most significant of these response contributions was the website www.pinkbike.com, as their posting of the survey link on their front page resulted in a total response count increasing from 950 on July 24, when the link was promoted, to 2390 when the survey was officially closed on August 1, 2012.
The results from this survey played a direct role in fine tuning the design and final recommendations of the Powder Mountain Bike Park Master plan. A full discussion of the survey findings and implication follows in the Results chapter.

**Site Inventory and Analysis**

Site inventory and analysis is a crucial building block of the landscape design process. This thesis applies Landscape Architecture best practices as established by Ian McHarg in his book “Design with Nature” (McHarg, 1968) to Powder Mountain’s terrain. The general process entails developing detailed inventory maps of site elements, both natural and man-made. These inventory maps are then overlaid upon one another in order to reveal patterns of concurrence and exclusion of important site criteria.

**Site Location**

Within the entirety of the Powder Mountain property, this thesis project focused specifically on the slopes serviced by Hidden Lake and Sundown lifts. This particular focus was requested by Powder Mountain management, as these slopes and lifts would be the first to be considered for mountain bike resort development. The site boundary used was established to encompass the landscape that could be accessed from the summit of Hidden Lake and Sundown Lifts, without having to move uphill to reach the lower lift access points.
Inventory list

To fully comprehend the function of the landscape at Powder Mountain, inventory was gathered on site and through online databases. The data collected included the following elements:

- **Slope**: The slope of a hillside on site is a critical factor in determining the suitability of the area for trail placement, skills features, switchbacks, and rest areas. Slope also plays a role in the perceived challenge of a trail corridor, as trails that cross steeper slopes increase the sense of danger associated with a trail. The slope data and all other Digital Elevation Model (DEM) based data were calculated with ArcMap GIS systems using a 5 meter DEM accessed from the Utah AGRC (gis.utah.gov).

- **Aspect and Solar Gain**: The cardinal direction a mountainside faces effects solar exposure that can in turn can change vegetation, soil type as well as overall summertime temperature. This aspect data were used to plan for on site soil tests and to better study a two-dimensional aerial image of the site. Using the DEM, a solar gain model was created to illustrate typical solar gain on the slopes between April and June, when snowmelt recedes and the resort could open for mountain bike use.

- **Elevation**: Elevation details allow for the planning of trails that do not require any more uphill pedaling than intended by the designers.
- Soils: Soils determine how much water a given area of soil will hold, and therefore influence erosion and vegetation factors. Within the focus area of Powder Mountain, 13 unique soil types were identified by the National Soils Survey Database (NSSD) (soils.usda.gov), yet due to three similar types of loam composing over 95 percent of the study area, and the differences between them having little effect on trail construction, the site’s soil class has been classified as gravelly loam. This data were inventoried via the NSSD with ArcMap GIS systems and verified by soil samples on site.

- Winds: Though winds have little effect on trail placement, any skills features that would allow a rider to jump through the air should be well shielded from strong wind gusts. Though no wind collection devices exist on the site, Powder Mountain management and staff have indicated that North/Northwest Winds prevail throughout the summer. Winds are strong throughout the year on Powder Mountain, enough to occasionally close lift operations in the winter.

- Drainages: Water, in the form of precipitation or snowmelt, is the main factor in trail erosion and maintenance. In order to design long lasting and durable trails, all drainages, streams, and bodies of water were identified on site. Though these drainages may provide pleasant aesthetic elements, their identification primarily assisted in identifying trail corridors that do not lie within or along significant drainages. The drainage and hydrology data were developed using the DEM and was refined and modified by on site observations.
- Roads: The site, having long served as a ski resort, contains a single paved access road and a large network of dirt roads. Some of these roads are utilized by service vehicles, while others appear to be abandoned. Any skills features that present the opportunity for enhanced risk should be located near access roads for emergency purposes, and trail routing should in most cases avoid paralleling or overlapping utilized access roads due to erosion and maintenance concerns created by vehicular traffic on natural surfaces. Abandoned road corridors provide potential trail corridors with established grades that can reduce trail construction costs. The road network was mapped using aerial imagery accessed via the Utah ARGC (gis.utah.gov) and refined and modified by site visits.

- Vegetation: Vegetation type and density can greatly influence the challenge of constructing a trail, as well as the trail riding experience. In addition, trailside vegetation has been shown to reduce erosion on the trail tread. Based on site visits and assisted by aerial photography, vegetation was inventoried to delineate major vegetation type and density of growth. Throughout the site, vegetative cover was divided into categories of light, medium and heavy vegetation. These categories refer to the density of trees and woody plants and shrubs creating the understory. Light vegetation typically refers to aspen strands that are widely spaced and contain only grasses and small shrubs less than 2 feet tall on the ground plane. In these areas, a hiker can move freely about with little impedance from growth. Medium vegetation refers to pine and aspen areas that grow more closely together than light vegetation, yet still allow a hiker to move easily throughout the area. Vegetation on the ground plan may rise up to 3 or 4 feet in some
areas, but is not constant. Areas of heavy vegetation are typically composed of scrub oak strands on site, and are composed of such dense growth pattern that hiking through these areas requires severe effort.

- **Power lines:** Powder Mountain offers night skiing under the Sundown lift, and a series of fixed high powered lights are located alongside open ski runs. The approximate location of these lights was mapped using an aerial image during a site visit. Based on assumption of straight-line/shortest distance wiring between poles, an inventory of light poles and likely power line locations was developed to project potential of underground electrical wiring.

- **Snowpack:** Using figures provided by Powder Mountain management, ski runs on site will open with snowpack as low as 30 inches and mid-season base is approximately 144 inches. These data assist in the development of skills feature dimension guidelines by establishing a maximum height (30 inches) for any features placed on slopes open early or late season.

- **Views and experience type:** A partially subjective measure, but important nonetheless, is the inventory of highly scenic views and their locations on site. After three site visits and reviewing hundreds of photos, key areas on site were identified for unique vegetation, excellent views, or scenic water features. These points of interest provide opportunities for rest areas, trail intersections, or trail corridors that focus or hide particular views, and are further discussed in the Results chapter of this thesis.
Inventory elements collected through site visits were gathered during the summer of 2012, by traveling on foot for a minimum of 7 hours each day. A contour line traverse method was used to examine nearly all regions of the site that could be accessed for future trail development. Certain areas of dense vegetation growth limited access, and were not traversed as thoroughly. These site visits helped confirm and modify the data that were gathered through digital means and interviews with Powder Mountain staff.

Site Analysis

Site analysis is an assessment of a site’s various attributes as identified in the site inventory. Data obtained from the site inventory were carefully analyzed in terms of its implications for trail alignment, skills feature placement and rest area/switchback placement.

A number of inventory elements were found to have a uniform effect on the site, such as winds, soils, and snowpack. Though subtle variations exist within these categories, their variations are not perceived to affect trail construction or suitability in any way. Other inventory elements were found to inform overall design decisions yet not particular trail routings. These factors included power lines, aspect and elevation.

The remaining factors were considered primary factors of trail and site design, due to their direct effect on trail construction, maintenance, and experience. These primary factors include hillside slopes, drainages, roads, and vegetation density. In order to combine these factors and analyze their interactions, a GIS overlay technique was utilized.
Inventory elements were assigned values that related directly to their enhancement or limitation as related to trail construction and sustainability. The values were established based on the literature review and interviews with experts in trail design. An in depth phone interview with Christ Bernhardt, director of IMBA Trail Solutions, and a face to face interview with Judd DeVall, principal of Alpine Bike Parks, resulted in a series of values given to various slopes, drainages, vegetation types, and roads on site. These values were then combined in a GIS overlay method to develop trails, rest areas, and skills feature suitability maps of the site.

This overlay method sought to combine each of the primary factors to create maps that illustrate their combined effect on the siting and placement of three major design elements of the Powder Mountain bike resort master plan:

- Trail corridors
- Rest areas and switchbacks
- Mountain bike skills features
Trail Corridors

This design element includes all trail tread to be developed for mountain bike specific use. The relation of this element to the analysis factors is as follows (all percentages indicate percent slope):

- Slopes
  - Ideal hillside slopes are between five and 35 percent, allowing for easy bench cut trail construction, a technique that resists runoff and erosion issues associated with snowmelt, as well as allowing for the construction of a wide range of trail types and widths.
  - Acceptable slopes are between two and five percent or 35 to 40 percent. These slopes provide a greater challenge to the trail builder, and can be more susceptible to erosion, but do not rule out potential construction routes.
  - Undesirable slopes are those between zero and two percent and those greater than 40 percent. The shallow slopes are likely to pool and collect water and severely damage the trail surface. Hillsides steeper than 40 percent are prone to swift erosion and make establishment of a stable trail surface difficult.
- Drainages

  o Ideal trail corridors lie 50 feet or more from a major drainage, and may cross minor drainages perpendicularly, with appropriate trail construction techniques. Drainages, as major conduits of water runoff pose a significant hazard to any natural surface trail.

  o Acceptable trail corridors cross major and minor drainages perpendicularly, but do not run parallel or near parallel to either. Minor drainages are unlikely to acquire large amounts of runoff and trail construction can use a variety of armoring or elevation techniques to mitigate the erosion hazard posed by the minor drainages. Crossing a major drainage is possible, but requires expensive trail construction techniques to elevate the trail surface to allow water to move below and not damage the trail surface.

  o Undesirable trail corridors lie within 50 feet of, and run parallel or near parallel to a major or minor drainage.

- Vegetation

  o Ideal trail corridors lie within areas of light to medium vegetative cover. Vegetative cover provides a moderate amount of erosion control, shade cover to improve comfort in summer months, and does not restrict trail building efforts.
Acceptable trail corridors lie within areas of heavy to no vegetative cover. Heavy vegetative cover creates a trail corridor with a higher maintenance need and a higher construction cost. A complete lack of vegetative cover is more prone to erosion and damage during spring runoff.

There are no vegetation conditions that prohibit trail construction.

- Roads

Ideal trail corridors lie at least 100 feet away from a roadway. Assuming that the vast majority of trail users and ski resort visitors seek an escape from roadways and a sense of getting away from it all, an ideal trail corridor should not be contaminated by auditory or visual influences of motorized vehicles on roads.

Acceptable trail corridors lie within 100 feet of a roadway. Emergency access, ease of construction, routing concerns or other issues may require placement of trail corridors nearby roadways.

Undesirable trail corridors lie within a major roadway, yet may cross them. Due to the impact of motorized vehicles, such as heavy duty service trucks on natural surface roadways, a consistent and safe riding surface is near impossible to maintain on these roads.
Rest Areas, Switchbacks and Pull Outs

This design element includes multiple components, particularly trail switchbacks, rest areas, and pull outs. All of these share attributes of being easier to construct and maintain on lower slopes, and are typically experienced on foot or at lower speeds, as opposed to trail corridors that are intended to be experienced at higher speeds.

- Slopes
  
  - Ideal rest areas and switchbacks are to be constructed on zero to five percent slopes. This makes sustainable construction of these spaces less difficult, as well as providing a stable place to widen a trail and allow users to remove themselves from the trail.
  
  - Acceptable rest areas and switchbacks utilize terrain on five to 35 percent slopes. These slopes do not preclude construction of facilities or rest areas, and still allow for easy widening of the trail tread.
  
  - Undesirable rest area and switchback locations are slopes greater than 35 percent. Though switchbacks can be constructed on steeper terrain when needed for routing purposes, slopes of 35 percent or greater eliminate the ability to construct facilities or major rest areas. Minor rest areas and pullouts for trail users can still be constructed in these areas, however.
- **Drainages**
  
  o Ideal rest areas and switchbacks lie within 50 feet of a major or minor drainage. This criteria assists in creating a trail network with a unique experiential environment that includes the sound of running water when trail users pull over to rest.

  o Acceptable rest areas and switchbacks are greater than 50 feet away from any drainages.

  o Undesirable rest areas and switchbacks lie directly within drainages. Like trail corridors, drainages provide an erosive force that would damage these areas and require heavy maintenance.

- **Vegetation**
  
  o Ideal rest areas and switchbacks should be located within medium or light vegetative cover. This allows for shade during the heat of the day and would not overly impede construction.

  o Acceptable rest areas and switchbacks occur within areas of heavy or no vegetation. Heavy vegetation would impede construction and require more maintenance, and no vegetation would be more susceptible to erosion, however both are acceptable areas for switchbacks or rest areas.
• There is no vegetation category that creates undesirable conditions for rest areas, switchbacks, or pullouts.

- Roads

  • Ideal rest areas and switchbacks are within 100 feet of emergency access roads, but designed to block views and sounds from the roads. Rest areas are likely spaces for an injured mountain biker to stop, and should be easily accessible by emergency vehicles.

  • Acceptable switchbacks or rest areas lie greater than 100 feet from roadways.

  • Undesirable rest areas and switchbacks are located directly within roadways.
Mountain Bike Skills Features

This design element considers all areas in of trail construction that will include more than simply trail tread. Rollers, berms, risers, ladders, and drops are just some of the many features that require additional earth moving, additional risk, and increased maintenance. Yet they are a key element to differentiate one mountain bike resort from another.

- Slopes

  o Ideal skills feature areas are located on slopes between 10 and 30 percent. These areas are sloped enough that when constructing a bench cut trail, the displaced earth creates ideal fill material with which to create skills features.

  o Acceptable skills feature areas are located on slopes of zero to 10 percent and 30 to 40 percent. Like ideal conditions, these slopes provide enough outslope to create skills features with cut earth, yet lie just outside ideal conditions.

  o Undesirable skills feature areas are located on slopes greater than 40 percent. These extremes limit the construction of features as well as their durability and safety.

- Drainages

  o Ideal skills feature areas are located within 50 feet of a major or minor drainage, but are not constructed directly on top of drainage surfaces. This location will allow for easy water access when constructing or maintaining the features, as
earthen features require occasional watering to maintain their form. Skills features should also be designed around water features to create a memorable experience for trail users.

- Acceptable skills feature areas are located greater than 50 feet away from major or minor drainages.

- Undesirable skills feature areas are located directly within a major drainage. Like trails and rest areas, drainages pose maintenance and erosion hazards to any natural surface feature.

- Vegetation

  - Ideal skills feature areas are located within light, medium, or heavy vegetative cover. This location allows improved shielding from Powder Mountain’s strong winds. Protection of users from wind is particularly important on any features that may launch a rider airborne.

  - Acceptable skills features: Same criteria as ideal skills features.

  - Undesirable skills features are located in areas devoid of vegetative cover. These regions typically serve as ski runs during the winter season, and construction of skills feature underneath open runs poses an undesirable risk.
- Roads

  o Ideal skills features are located within 100 feet of a roadway. Emergency access is particularly important to preserve for any areas containing highly advanced features with a high degree of risk.

  o Acceptable skills features are located in any area greater than 100 feet from a roadway.

  o Undesirable skills features areas are located directly on major access roads.

By assigning values to ideal, acceptable, and undesirable elements of the landscape in relationship to trail, rest area, or feature construction needs, a GIS overlay method was used to produce a series of three suitability maps that outline the land’s suitability for each of the three categories. These combined suitability maps provide the basis for the location of the future Powder Mountain Bike Resort trail corridors.

Multiple drafts of the suitability maps were developed and tested through discussion with trail construction experts. In order to create suitability maps in a GIS system, each attribute listed above as ideal, acceptable, or undesirable was assigned a numeric value. The higher the value, the more desirable the attribute. When combining multiple inventory maps to create suitability maps, all values were weighted equally.

For trail corridor suitability maps, ideal slopes were assigned a value of three, acceptable slopes a value of two, and undesirable slopes received a value of zero. The interior of drainages
were assigned zero, 50 foot buffers on either side of drainages were assigned a value of one, and all other areas assigned a value of two. Vegetation maps assigned a value of three to low and medium density vegetation, and a value of two to heavy vegetation or a lack of vegetation. Paved roads and a 100 foot buffer on either side were assigned a value of zero, unpaved roads and their 100 foot buffer were assigned a value of one, and other areas assigned a value of three.

Rest area suitability maps assigned ideal slopes a value of three, acceptable slopes a value of two, and undesirable slopes a value of zero. On these maps, drainages were assigned a value of zero, but 50 foot buffers on either side were assigned a value of three, and all other areas received a value of two. Medium and light vegetation cover received a value of three, and heavy and no vegetation received a value of two. Paved access roads and a 100 foot buffer received a value of zero, access roads and their 100 foot buffer received a value of two, and all other spaces received a value of one.

Feature construction suitability maps assigned ideal slopes a value of three, acceptable slopes a value of two, and undesirable slopes a value of zero. Drainages received a zero value, with 50 foot buffers on either side receiving a value of three, and other spaces a value of two. Vegetation of all types received a value of three, and areas lacking major vegetative cover received a value of zero. Roads were assigned a value of zero for paved roads and their 100 foot buffer, and a value of two for unpaved access roads and their 100 foot buffer, and a value of one for all remaining spaces.
All inventory features were multiplied by one another to generate a composite map that illustrated the terrain through values that correspond to the land’s suitability for trail corridor construction, rest area suitability, or feature construction suitability.

**Trail Corridor Identification**

The use of suitability maps allows for a large scale terrain analysis that identifies areas suitable for, as well as off limit to trails much faster than other methods available. GIS methods exist that can use these suitability data to develop trail alignment recommendations. The most widely recognized is the Least-Cost-Path (LCP) analysis. LCP allows the GIS software to construct a path from one point to another in the data by tracing the path that incurs the fewest cost, or unsuitable variables. However, this method has proved less than ideal for siting recreational trails, as it seeks to make the shortest path possible at a certain grade, resulting in a trail alignment composed of constant switchbacks, rather than a long, looping trail that allows for a more relaxed and gradual descent and ascent of the mountain. The use of this tool and its shortcomings are documented in the Literature Review. Though advanced methods in GIS technology may exist to resolve this issue, they were not uncovered as part of this thesis, and the office method was utilized, by creating trail alignments with the aid of a topographic map and the suitability maps.

The suitability maps, printed at matching scales and orientation, allow for the use of a trace-paper overlay process that illustrates options available for the ‘best’ trail alignments on site.
Beginning with the switchback suitability map, a layer of trace paper is overlaid in order to manually identify areas of ideal suitability for switchbacks and rest areas, as well as areas of undesirable suitability. Areas not marked are assumed to be acceptable.

This trace paper is then removed and applied to the trails suitability map, where approximate trail corridors were drawn that sought to remain within areas of ideal or acceptable trail corridor status and maintain a constructed slope of under 25 percent, while making switchbacks and turns at ideal locations wherever possible.

This trail alignment trace layer is then finally placed upon the feature suitability map layer, in order to look for regions of high feature suitability that coincide with the trail corridor. These areas were identified as ideal areas for feature construction. Areas where trails cross drainages were also noted to indicate armoring or elevation techniques to reduce trail tread erosion. This three-step process is then repeated multiple times to create alternative designs.

The alternative trace paper designs are then compared to individual suitability maps for adherence to slope requirements, drainage crossing requirements, and location in regards to ideal views and vegetative cover. Multiple adjustments are made based on the author’s knowledge of the mountain and a need to reach certain viewpoints, and provide a variety of experiences throughout the trail network. After developing multiple options, the ‘most suitable’ trail corridor network is selected.

Once initial corridors are placed through the trace overlay method, they are scanned back into the GIS and digitized. These digitized corridors are then printed on maps that include 10
and 50 foot contours placed upon the site’s aerial imagery, at 1”=200’ or smaller scale, scales large enough to utilize a manual scale and the established contour lines to further refine the trail corridors.

This refinement process seeks to remain within the general region of the trail corridors and feature locations established earlier, but utilize small scale contour lines and an engineer’s scale to ensure that none of the proposed trail corridors exceed the slope guidelines put forth in IMBA’s trail construction guidelines. (e.g. for every 150 feet of trail, the vertical gain must not be greater than 10 feet) This process also allows for design at a smaller scale, and enables the designer to focus on details, such as vegetation type, contour variation, and views, that are not part of the suitability analysis.

After refining the trail corridors and feature locations, they are then placed back in the GIS system and converted into a slope raster to confirm that no trail slopes exceed the aforementioned guidelines, and that the beginner, intermediate, and expert trails adhere to the same guidelines. Another round of manual trail modifications ensues until the final trail corridor alignment is reached, along with approximate locations for skills feature and rest area development.
**Master plan Creation**

By this point, trail corridors, feature locations, and trail types have all been generally located. What remains is the development of a master planning document to illustrate in detail each proposed trail, describe its characteristics in terms of length, feature type and frequency, and estimate build costs, skill levels, and phasing. This information can be found in the Results chapter of this thesis.
CHAPTER IV

RESULTS

Mountain Bike Trail Case Studies

The design process requires, consciously or unconsciously, the synthesis of prior design exposure into a new solution. For this thesis project, a review of trail design was undertaken in the form of case studies. The three trails selected serve as evidence of an analytical approach to trail design features. They are not intended to be conclusive findings, nor are they comprehensive of the broader trail research undertaken by the author every chance possible during the course of this thesis.

Three trails were chosen in an attempt to examine distinctions between an advanced, intermediate, and beginner trail. These distinctions are based on informal interviews and rides with mountain bikers in the Northern Utah area, as well as published trail maps that identify each trail’s difficulty rating. Site visits to each trail were used to measure feature dimensions and layout, turn radii, tread surface type and width, as well as gather general impressions. The information regarding a trail’s actual length, elevation change, average and maximum grades, minimum, maximum, and average rider speeds was derived from Strava.com, a website that collects GPS tracks uploaded by runners and cyclists for online comparisons of distances, speeds, times, and routes.
Green Canyon, located east of North Logan, UT was chosen as the beginner trail case study. Rush trail, southeast of Draper, UT was selected as the intermediate trail case study. Road to Arcylon, located northwest of Park City, UT was picked as the advanced/expert trail case study. Of these three trails, only Green Canyon is designed to be ridden both uphill and down, and designed for all trail user types. The case study focus of Green Canyon, however, focuses only on the downhill experience, as these studies were chosen to relate to a mountain bike resort experience, where the chairlifts alleviate the uphill transit. A summary of case study findings follows the individual descriptions below.

*Green Canyon – Beginner Trail Experience*

![Figure 3. Green Canyon](image)

Green Canyon lies at the floor of a canyon that leads into the Mt. Naomi Wilderness Area. The trail descends 995 feet over 3.7 miles, with an average downhill grade of five percent. The trail tread width varies from two to five feet throughout the trail, and surface type is smooth.
with only a few sections containing significant exposed rocks or roots. The overall orientation of the trail is east to west, and though the trail is winding in nature, and corners and curves often, there are only two 180 degree switchbacks that coincide with the only extended portions of the trail to exceed a 10 percent slope. At the time of data gather, Strava.com contained 119 unique mountain biker’s ride data for this trail.

The turn radii in Green Canyon varies, with the most challenging switchbacks having turn radii of approximately five feet, and the easier turns throughout the rest of the trail having radii of eight to 10 feet. A number of the turns on the trail have been built with small berms, small walls that raise the trail surface from horizontal to an angle, encouraging mountain bike riders to lean farther into the turn and ride through faster and more securely. No berm on Green Canyon exceeds 1.5 feet in height. The trail does not create any severe hillside exposure experiences. Exposure refers to trail cut sections that lie across a steep hillside and can promote fear of falling off trail for new riders or anyone with a fear of heights or ledges.

Technical trail features are few in Green Canyon, but three informal dirt jumps exist, as well as a rock feature designed as a balance feature. The dirt jumps are designed so that the upper surface of the jump lies flush with the landing. This design minimizes risk by effectively lowering the apogee of the rider’s arc into the air relative to the ground. All technical trail features in Green Canyon are placed outside of the main trail tread, and as such, the rider must opt in, rather than opt out, of the potentially thrilling, potentially frightening option.
Rush Trail – Intermediate Trail Experience

Figure 4. Rush trail

Rush trail lies within Corner Canyon, a popular recreational area located at the edge of a residential section of Draper, Utah. The trail descends 446 feet over 2.1 miles with an average grade of 4.1 percent. The trail rarely exceeds a 10 percent slope. The width of the trail tread varies from three to five feet, and the tread surface is extremely smooth, with intentionally placed skills features and minor erosion areas the only areas where the tread surface becomes rough. At the time of data gather, Strava.com recorded 1,008 riders data on Rush trail.

The trail descends from a bluff to the valley below, and contains a large number of 180 degree switchbacks and turns as it drops downhill. These switchbacks and turns, however, are what make this trail distinct from any other along the Wasatch Front. Nearly every switchback has a minimum radius of 10 feet, and is built up with 1 to 2 foot berms to allow a rider to carry more speed through the turn. The trail contains a section with moderate exposure to steep downhill slopes.
Technical trail features are numerous on this trail, from rocks placed in the trail to serve as jumps to the trail forming its own jumps and landings as it moves down the hillside. Features and jumps range approximately between one to three feet in height. The majority of technical trail features are placed in the middle of the trail, making it more difficult to easily avoid them. The structure of these features, however, is such that they pose little to no risk should a cautious rider slowly roll over them. All jumps are constructed so that no severe ledges or drops are created. The main technical trail feature of is the number of turns being banked, and the trail sculpted to a sine-wave like surface on the straight sections, allowing riders to shift their weight through these turns and rollers to gain additional forward momentum. This aspect of the trail creates a sensation of speed that makes the trail feel faster than its 4.1 percent average slope would suggest. See Figure 5 for illustration.

Figure 5. Rush trail jump to turn
A challenge in the navigation and safety of this trail is the placement of certain jump features less than 20' before the next turn. The jump features encourage an increase of speed, and the turn immediately following demands a sharp decrease in speed. This can lead to riders entering the turn too quickly and losing control.

Road to Arcylon – Expert Trail Experience

Road to Arcylon is a trail located nearby Park City, Utah, within a small public park bordering a residential development. A short trail, it drops 346 feet in elevation over .7 miles for an average descending grade of 8.8 percent. The trail rarely exceeds 12 percent grade. Significantly steeper and more challenging than other trails reviewed in this case study, it is a
good example of an expert level trail constructed for public use. At the time of data gathering, Strava.com recorded 110 unique riders’ data for this trail.

The summit of the trail greets riders with copious amounts of signage warning of the challenging nature of the trail. The difficulty has less to do with trail surface or width, but more with the speed of the trail and the size of the features. The trail tread retains the three to five foot width in common with other reviewed trails, and the trail surface is very smooth, with the exception of purposely placed rock features, the most challenging of which is located at the very beginning of the trail to provide a self-electing safety check. If a rider feels uncomfortable with the first feature, the rest of the trail is unlikely to be appropriate for their skill level.

The trail navigates a series of switchbacks as it moves downhill, all of which have very large radii and significant berm construction. Berms are built between one and two feet high. One hundred and eighty degree switchbacks are built with 16 to 18 foot radii. Features are spaced widely, with approximately 30 feet separating jump landings from the next feature or a significant turn. These large turns and tall berms combined with the steeper downhill slope of this trail create a trail experience that encourages faster speeds than most.

The technical trail features on this trail are distinctive, and identical in some ways to the types of technical features that have become standard at a mountain bike park or resort. A great number are built from pressure treated wood timbers, and securely constructed to resist corrosion and remain firmly connected to their foundations. A number of the wooden features create steep drop-offs or are constructed with separate landings that increase risk significantly. These
features range from two to five feet tall, and maintain the 2:1 height to width ratio for trail features specified in the Whistler Trails Guidelines (DeBoer 2003). All features that require the rider to become airborne to safely ride them are placed to allow a choice to ride the feature or ride smooth trail around them. Features that do not require the rider to become airborne to navigate them safely are placed in the center of the trail with no optional lines present.

Summary

A brief summary of the trail case study findings is detailed in the chart below. What may appear to be small details in the orientation or overall slope of a trail can equate to significant differences in a trail’s perceived difficulty. Regardless of trail experience type, however, are the similarities in trail tread surface. All three trails selected for this case study have 3-5 foot wide treads, and are smoother surfaces than many other trails in the region.
<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Length (miles)</th>
<th>Avg. Grade (%)</th>
<th>Max. Slope (%)</th>
<th>Avg. Rider Speed (mph)</th>
<th>Max. Rider Speed (mph)</th>
<th>Min. Rider Speed (mph)</th>
<th>Sample Turn Radius (feet)</th>
<th>Bermed Turns</th>
<th>Feature Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginner</td>
<td>3.7</td>
<td>5</td>
<td>10</td>
<td>12.1</td>
<td>18.7</td>
<td>5.5</td>
<td>8'</td>
<td>Some</td>
<td>Few features, all optional, no aerial requirements. Dirt and stone construction</td>
</tr>
<tr>
<td>Intermediate</td>
<td>2.1</td>
<td>4.1</td>
<td>10</td>
<td>11.15</td>
<td>17</td>
<td>5.3</td>
<td>10'</td>
<td>All</td>
<td>Many features. Some optional. No aerial requirements. Dirt and stone construction.</td>
</tr>
<tr>
<td>Expert</td>
<td>0.7</td>
<td>8.8</td>
<td>12</td>
<td>13.7</td>
<td>22</td>
<td>5.4</td>
<td>18'</td>
<td>All</td>
<td>Many features. Some optional. Some aerial requirements. Dirt, stone and wooden construction</td>
</tr>
</tbody>
</table>

Table 1. Case study summary

Through analyzing the results of these case studies with the intention to utilize the information to design a mountain bike resort that appeals to all skill levels of riders, certain trends are visible, and design recommendations can be made.

Trail slope should not exceed 10 percent for more than short distance on beginner or intermediate trails. It should not exceed 15 percent on expert trails. Average trail slopes should be around five percent for beginner or intermediate trails and slightly lower slopes are not a problem. Beginner trails should seek to avoid areas of greater than 25 percent hillside slope, particularly if not a wooded area, as this can create an intimidating sense of exposure to falling off the hillside.
All trails built specifically for mountain bike use should utilize bermed turns as much as possible. Berms allow for faster, safer, and more confidence inspiring riding than a similar turn without the banked walls of a berm. The faster a trail is designed to be experienced, the larger the turn design and the larger a berm should be included. Both Rush trail and Road to Arcylon are mountain bike specific trails, and as such, have most, if not all, turns and switchbacks constructed with berms. The switchbacks are constructed with a larger radius than a hiking trail constructed on similar terrain. These wide turns with bermed walls benefit advanced mountain bikers by allowing for and encouraging faster speeds and more secure turning, and do not discourage novice mountain bikers by requiring the balance required to slowly pilot a vehicle with a 5 foot wheelbase through a 180 degree turn with a 4 foot radius.

Feature development on beginner trails should be limited to earthen features that do not require rider and bike to be aerial in order to safely proceed. This does not rule out features on which one can become airborne. However, on a trail designed for beginner usage, features should remain under three feet in height over the trail tread. This assures that beginners will not get in over their head, and that larger features will not intimidate new riders. Beginner trail features should all be located to the side of the trail in order to allow riders to opt in, but not have to change course to opt out of the challenge. Intermediate and advanced trail features can be located within the trail tread, but should always provide a ride around line should the feature require aerial completion. Regardless of skill level, all features should be placed a minimum distance of 30 feet from a significant turn in the trail or the following feature, unless the intention
is to significantly slow the rider, in which case signage and/or technical trail features should help accomplish that goal.

Additional considerations should be taken to consider sight lines when placing features. The largest and highest risk features on Road to Arcylon are visible from a minimum of 35 feet away on the trail, and this should be taken as a minimum sight distance for any features designed greater than two feet tall.

Downhill trail design should also incorporate ‘stops’ or rest points approximately every quarter to eighth of a mile, in order to allow riders a chance to rest and pull off the trail. This is more important on downhill trails as the high speeds inherent in downhill trail riding coupled with fatigue and no opportunity to slow down can create an unsafe environment and unpleasant riding experience. Orientated towards views, rest areas can provide a chance to rest, to regroup with friends that may be riding at different speeds, or to pull over and let a faster rider pass safely. This last point is an important one, as the Strava.com data show the fastest riders can average 13 mph faster than the slowest. For both riders to enjoy the trail as best as possible, safe passing areas and established stopping/resting zones are critical trail design ingredients.

These recommendations are not intended to be seen as scientific facts, but are derived from these case studies as well as a reflection on a wide variety of trail experiences, including trails in California, Utah, Idaho, Oregon and South America. They should be seen as a preliminary set of findings in one geographic region, and should be compared to other mountain bike trail research for comparison and verification.
Mountain Bike Resort Inventory and Market Analysis

For any business to embark on a venture as intensive and costly as constructing an extensive mountain bike trail network on ski resort terrain, it is important to know what similar efforts are underway within the same region, and what those efforts offer in terms of potential competition.

To consider Powder Mountain’s potential success in mountain bike resort development, a mountain bike resort inventory and cursory market analysis were undertaken by researching the services offered by other resorts along the Wasatch Front. This inventory looked at the spatial relationship of resorts to the population centers of the Wasatch Front and to other resorts.

Assessing and studying individual resort trail maps, researching lift ticket prices, and taking site visits to all Northern Utah resorts that currently offer lift accessed mountain bike trails produced a Powder Mountain competition inventory. These results are detailed in table 2. The list included in this resort inventory is limited to Wasatch Front resorts, as the Southern and Central Utah resorts of Brian Head and Eagle Point are assumed to not be in direct competition with Powder Mountain due to their location.
Spatial Analysis

A map was created to look at the location of mountain resorts with ski-lift infrastructure in the Northern Wasatch. Driving distances from these resorts were estimated by creating 50 and 100 mile buffers around each resort. Municipal boundaries were then placed on the map and color coded to indicate vicinity population differences (see Figure 7).

The resulting map shows a significant amount of competition among the resorts with direct access to the Salt Lake City population. Within Summit County, Park City Resort, The Canyons and Deer Valley offer lift accessed mountain biking opportunities. However, farther north into Ogden Canyon and beyond, there are no lift accessed mountain bike offerings beyond Snow Basin, and the trails located there are trails that, for the most part, are converted hiking trails and contain no bike park features or design elements constructed for mountain bike use.

This regional overview seems to indicate that should Powder Mountain bring mountain bike specific trail design to their property, they would offer a unique facility that could draw on populations within Box Elder, Weber, and Cache Counties. Existing mountain bike resort facilities along the Wasatch Front currently require residents in these counties to spend more time and money to reach them than a mountain bike resort at Powder Mountain would require (see Figure 7).
This map illustrates the distribution of mountain resort competition throughout northern Utah, and their location in proximity to major urban centers within the state.

Figure 7: Competition Inventory
<table>
<thead>
<tr>
<th>Ski Resort</th>
<th>Location</th>
<th>Bike Park &amp; Date</th>
<th>Summer Lift Schedule</th>
<th>Additional Summer Uses</th>
<th>Summer Lift Ticket Price</th>
<th># of MTB Lifts</th>
<th># of MTB trails</th>
<th>Vert. Feet (via mtb lifts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder Mountain</td>
<td>Ogden</td>
<td>TBD</td>
<td>TBD</td>
<td>Rock Crawler Tours, MotoCross Event</td>
<td>TBD</td>
<td>2</td>
<td>TBD</td>
<td>2200</td>
</tr>
<tr>
<td>Canyons</td>
<td>Park City</td>
<td>Yes/2011</td>
<td>Daily</td>
<td>Hiking, Zipline, Events, Disc Golf, Horseback, Pedal Boating, Putt-Putt Green,</td>
<td>$27</td>
<td>1 Gondola, 1 lift</td>
<td>Easy: 2 Med: 2 Hard: 3</td>
<td>1100</td>
</tr>
<tr>
<td>Wolf Mountain</td>
<td>Eden</td>
<td>No/2006</td>
<td>Saturday &amp; Sunday</td>
<td>Used to do Sightseeing</td>
<td>$35</td>
<td>1 (when in operation)</td>
<td>Currently 0</td>
<td>1000</td>
</tr>
<tr>
<td>Sundance</td>
<td>Park City</td>
<td>No</td>
<td>Daily</td>
<td>Hiking, Fly Fishing, Equestrian Tours, Golfing</td>
<td>$20</td>
<td>1</td>
<td>Easy: 0 Med: 6 Hard: 0</td>
<td>800*</td>
</tr>
<tr>
<td>Snowbird</td>
<td>Cottonwood Canyon</td>
<td>No</td>
<td>Daily</td>
<td>Alpine Slide, Hiking, Ropes Course, Zip Line, Climbing wall, Equine Tours, ATV tours, Fly Fishing</td>
<td>$16</td>
<td>1 Gondola, 1 lift</td>
<td>Easy 5 Med: 5</td>
<td>2900</td>
</tr>
<tr>
<td>Solitude</td>
<td>Cottonwood Canyon</td>
<td>No</td>
<td>Daily</td>
<td>Disc Golf, Fishing, Mountain Biking, Hiking</td>
<td>$16</td>
<td>1 Lift</td>
<td>Easy: 2 Med: 5 Hard: 3</td>
<td>780</td>
</tr>
<tr>
<td>Park City</td>
<td>Park City</td>
<td>No</td>
<td>Daily</td>
<td>Alpine Slide, Hiking, Zip Line, Climbing wall</td>
<td>$20</td>
<td>2</td>
<td>See Notes</td>
<td>3100</td>
</tr>
<tr>
<td>Snowbasin</td>
<td>Huntsville</td>
<td>No</td>
<td>Daily</td>
<td>Disc Golf, Hiking, Events</td>
<td>$18</td>
<td>1</td>
<td>Easy: 3 Med: 10 Hard: 0*</td>
<td>3000</td>
</tr>
</tbody>
</table>

Table 2. Mountain resort service inventory
Table 2 illustrates the existing services offered by mountain bike resorts along the
Wasatch Front. Only two of these resorts offer mountain bike specific trails and skills features. Of these two (Deer Valley and The Canyons) both have weaknesses that Powder Mountain’s future development should seek to avoid.

Deer Valley offers the largest lift accessed trail network in the study area. However, its lifts are fixed-grip, low speed models that do not offer the high-speed access that consumers desire that Powder Mountain’s Hidden Lake lift can supply. Deer Valley’s trails, though extensive, contain numerous examples of fall-line trails that are steep, badly eroded, and only offer enjoyment to the most masochistic and reckless of downhillers. In addition, the development in and around Deer Valley creates a sensation of riding through a mildly urbanized area, rather than an area where one has an opportunity to get in touch with nature and ‘escape’. Deer Valley’s features do not adhere to existing feature design guidelines, and a number are in states of disrepair. Deer Valley does not offer any beginner level trails from the top of the lift to the bottom.

The Canyons Resort offers significantly improved feature construction than that of Deer Valley. However, their mountain bike resort is focused on a series of trails underneath a single lift that runs approximately 600 feet uphill. This creates a compact and restricted experience of the mountain bike resort. The trails accessed via this lift are exclusively focused on mountain bike skills features, and as such, are extremely challenging, with non-optional jumps ranging between 3 and 6 feet tall, and large wooden skills features placed throughout the area.
Of the other mountains in this inventory, Wolf Mountain and Snow Basin are located closest to Powder Mountain. Neither offers mountain bike specific trails, though Snow Basin’s network does act as a draw for a number of mountain bikers, and it hosts a cross-country mountain bike race series every summer. Snow Basin also offers no beginner trails that extend from the summit of the mountain bike lift to the resort base. Wolf Mountain had previously offered mountain bike access, and no longer does. Snow Basin, should it develop a mountain bike resort, could be a significant competitor, but should Powder Mountain develop mountain bike specific trails, the distinction between the two resort’s summer offerings would be very clear, as Snow Basin’s trail network is a multi-use trail that offers no technical trail features or other mountain bike specific design elements.

Powder Mountain’s landscape offers advantages that few mountains in the region can boast. The Hidden Lake lift accessed terrain contains vegetation, views, and a lack of infrastructure that create a sensation closer to that of a national park than a ski lift.
Figure 8. Powder Mountain scenery

The size of Powder Mountain terrain accessible at Hidden Lake lift combined with that of Sundown lift has the potential for a greater number of miles of trail than any other regional resort. Additionally, there are no lift accessed mountain bike specific trails available in the canyons north of Ogden, and for the potential customers of Brigham City, Logan, and Ogden, Powder Mountain would be a first choice for mountain bike recreation. These factors all provide opportunities for the future mountain bike resort facilities to become economic successes, augmenting and driving the development of Powder Mountain’s future business.

Summary

This cursory case study of Wasatch Front resorts provides insight into the design of a mountain bike resort on Powder Mountain by identifying potential advantages of a Powder Mountain bike park, such as its potential to be the only mountain bike specific resort north of the
Salt Lake Valley, as well as the only mountain bike resort serviced by a high speed quad in all of Utah.

**Mountain Bike Park User Preference Survey**

To better understand user’s perceptions of mountain bike resort experiences, a survey was developed that would provide insight to mountain bike park and mountain bike resorts worldwide. The survey was designed to identify mountain bike resort customer’s years of experience on a mountain bike, average lift ticket prices paid, duration of trips to mountain bike resorts, locations of mountain bike parks and mountain bike resorts, geographic concentrations of mountain bike resort users, and user preferences for various mountain bike resort facilities. A full transcript of the questionnaire can be found in the appendix. The survey was developed as an online form utilizing Google Docs’ form builder. (docs.google.com) This allowed the survey to be distributed by sharing a publicly accessible link that could be shared with anyone with access to an internet browser.

The survey effort began on June 10, 2012, by including the URL for the survey form in an online newsletter distributed by IMBA. This effort reached over 50,000 email inboxes across North America and gathered approximately 500 responses. From that point onward, efforts were made to share the link through Facebook posts, Twitter feeds, and blogs. This resulted in a steady climbing of survey results over the next few weeks. For every web page or blog that posted the survey’s link in a prominent position on the main page, the total count would surge
upwards for a day or two. By July 10 2012, nearly 1,000 survey responses had been completed. The survey slowly gathered responses for the rest of the month, until the link received promotion on Pinkbike.com, a popular website dedicated to mountain biking. Over the course of a couple days, that front page post on Pinkbike gathered another 1,000+ survey responses to leave the survey closing with 2,389 responses in total.

This distribution method was not intended to gather a randomized sample, but to achieve a sample that investigates passionate mountain bikers’ preferences. The term ‘passionate mountain biker’ is used because all online forums that shared the survey written for and read by that particular audience.

This distribution method limited the analysis by under sampling mountain bikers who were new the sport, only moderately interested to the sport, or those that had mostly negative experiences with mountain bike recreation. Due to survey being distributed online, the digital bias is present in these results, by requiring survey respondents to use a computer and the Internet in order to complete the survey. Yet the Internet based form offers a great advantage in increasing the number of respondents and automatically tabulating results. A more traditional pen and paper survey effort might gather 10 to 50 surveys completed per day, whereas the online survey received hundreds a day for multiple days, with nearly 1,000 surveys being completed the first day the effort was published on pinkbike.com.

The results of the survey were divided into three categories. These categories related to the three types of survey that a respondent was allowed to choose between: lift access bike parks,
community bike parks, or bike park development. The latter category was included to assist IMBA in efforts to learn how and where community bike parks are being developed.

*Overall Survey Trends*

The survey had a far greater reach than expected. Though North American respondents composed the majority of completions (n=1552), 203 responses came from the European Union, with the majority of those coming from England and the Alps regions of Germany, Italy, and France. Australia and New Zealand were represented by 59 responses, and 23 other respondents reported from locations as diverse as Japan and Chile, Singapore and Greece. Though every effort was made to correlate postage codes with respondent locations, a percentage error is likely present in these geographic data, as the survey asked for a postal code or zip code, and at the time of survey development, the author was unaware of the similarity between certain Australian, New Zealand, and European four digit postal codes.

![Figure 9. North American survey response distribution and density](image-url)
When beginning the survey, respondents had the choice between four sub-surveys within the form. They could choose either a mountain bike resort user survey, a community bike park user survey, or a bike park development survey, for those who played a role in the development of a community bike park. A fourth option existed for any survey respondents who had never ridden a bicycle at a mountain bike resort or park.

The lift access bike park survey sought to elicit responses regarding experiences at lift accessed mountain bike resorts. The community bike park survey sought to extract responses regarding experiences at community bike parks. The bike park development survey sought to obtain responses regarding experiences surrounding the planning, design, and building of community bike parks. The final survey sought to elicit responses regarding experiences of those who had never visited a bike park of any type.

The majority of respondents answered the lift access bike park survey (n=1252), followed by the community bike park survey (n=635), bike park development survey (n=226) and the no bike park survey (n=276) responses. Three hundred and twelve unique community bike park locations were reviewed and 170 unique lift accessed parks were reviewed.

All survey respondents were asked to select what type of riding style they identify with. Though respondents were allowed to choose more than one style, the results trended towards equal majorities of trail/all mountain and freeride/downhill riders. However, cross country riders, a rider style less associated with the jumps and skills feature of bike parks, were a
significant third place, with 50 percent of respondents selecting that riding style. This is illustrated in Figure 10.

![Rider Types Chart](image)

**Figure 10. Survey rider style categories**

This 50 percent cross country ridership coupled with 73 percent trail/all mountain is a relevant distinction due to the current practice of marketing ski resort mountain bike facilities to the freeride and downhill demographic (see Figure 1), an approach that may be missing the larger mountain bike demographic.

Overall, riders responding to this survey were well experienced mountain bikers. Thirty seven percent of respondents have been riding mountain bikes for over 10 years, and another 26
percent of respondents have been riding 5 to 10 years. Only nine percent (n=215) have been riding for two years or less.

Figure 11. Survey respondent’s riding experience

All survey respondents stated how recently they had been to a mountain bike park or resort. A majority (72 percent) visited a park or resort within the last month. It could be assumed from this majority that bike park visits are recurring instances, rather than annual pilgrimages. Response percentage declines sharply with time. Ten percent of respondents reviewed a park that they had been to less than six months ago, 16 percent reviewed a park they had visited less than a year ago, and only three percent reviewed a park they visited one to three
years ago, and less than one percent reviewing a park they visited over three years ago. These results are portrayed in Figure 12.

Figure 12. Bike park visitation timeframe
Of locations surveyed, Whistler Blackcomb received the greatest number of reviews (n=257). Northstar at Tahoe received the second most with 77, and Valmont Bike Park, located in Boulder, CO received the most of any community bike park, with 53 responses.

Respondents reported the price for lift tickets at the bike parks they visited. Average daily lift ticket price among respondents was $40 (foreign currency adjusted to USD), with the maximum lift ticket price reported as $70 at Thredbo, New South Wales. Respondents were also asked if the price paid was worth the experience. Ninety one percent of respondents indicated that the price was worth the experience, with only nine percent indicating that it was not.

Respondents were asked if they traveled specifically to visit the resort or community park that they were reviewing. Lift access parks appear to generate more trips than community bike parks, with 91 percent of respondents traveling specifically to ride at a resort, likely due to the remote location of mountain lift infrastructure. However, community bike parks still generate a significant number of trips, with 83 percent of respondents traveling specifically to ride there. This variation between community bike parks and mountain bike resorts is illustrated in Figure 13.
Figure 13. Community and lift access bike park travel rates

Though both community and lift access mountain bike parks seem to generate trips to their region, along with associated economic benefit, lift access bike parks likely generate a greater amount of economic benefit due to lodging costs. Eighteen percent of community bike park visitors surveyed stayed nearby for greater than two days, whereas 62 percent of lift access bike park visitors surveyed remained in the area more than two days. Twenty percent remained at the park for greater than five days. These results are illustrated in Figure 14.
Both community and lift access bike park respondents indicated that mountain bike facilities have no major conflicts when installed adjacent to (or even overlapping with) other recreational uses. Ninety-five percent and 96 percent of respondents, respectively, found that there were no problems with alternate uses nearby their bike park. Eighty-seven percent of the lift access resorts reviewed combine mountain biking with additional uses.

After these questions, respondents were asked to indicate their feelings regarding features of the mountain bike area reviewed. For each aspect of the park, reviewers indicated if the element of the park was “Absolutely mind blowing”, “Good stuff”, “Reasonable”, “Needs work”, or “Just Plain Bad”. These responses were translated into a one through five scale, with five being the most positive rating and one being the most negative. The averages of these scores were then tabulated in order to see variance of overall scores as well as averaged scores.
for each category and question. These average scores were then sorted in relationship to unique mountain bike park locations.

Locations were sorted based on number of reviews. Assuming that the more reviews a park received, the more representative of the public’s opinion the averaged park score would be, locations that received a high number of reviews were extracted for individual review and comparison. Lift access parks that received more than 10 unique reviews were grouped. Only three community parks received more than 10 reviews, and in order to provide a greater comparison among parks, the minimum number of reviews for community parks was lowered to six which resulted in 12 community bike parks extracted from the data.

These scores allowed a simple comparison between all highly reviewed parks to see what elements of their design are valued least and valued most. Area charts were created to allow a comparison of top rated parks to lowest rated parks. This visual comparison looked at the differences between the community bike parks Valmont and Collonade, with overall scores of 4.38 and 3.37, respectively. Differences were visualized between lift access mountain bike resorts of Whistler and Canada Olympic Park, with scores of 4.36 and 2.93, respectively. These comparisons strive to illustrate that which matters most in designing and building a good mountain bike resort or community bike park.

In these reviews, users appear more critical of the lift access experience, perhaps in part due to the fee required to access lift accessed resorts, and higher expectations that come along with paid entry, as compared to free entry at community bike parks. The lowest score for a
highly reviewed community bike park was Collonade at 3.37, whereas the lowest score a highly reviewed lift access resort received was Canada Olympic Park at 2.93.

**Lift Access Park Variations**

Within lift access parks surveyed, the biggest differences in quality ratings between Whistler and Canada Olympic parks come down to trails and features. Feature placement was the single most disparate rating, with Whistler receiving a score 2.59 points higher than Canada Olympic park. Trail ratings followed as the second most disparate rating, with Whistler receiving 2.03 more points in the trail conditions category, and 2.43 more points in the trail routing category. This finding strengthens the trail case study’s recommendation of placing all technical trail features a minimum of 30 feet away from any switchback or turn to allow riders time to navigate trail obstacles.

Additionally, these findings emphasize the need for resorts to invest in trail construction and maintenance before investing resources in lift access or facilities. Facilities, lift access and lift ease of use were closely ranked between highest and lowest ranked parks, with a .05 difference between Whistler and Canada Olympic Park on lift lines, a .15 difference in lift ease of use, and a .73 difference in facilities access. A graphic representation of these data is shown in Figure 15.

Survey respondents answered questions regarding what additional recreational facilities exist at the mountain bike resort reviewed. This revealed a lack of certain design elements in global lift access mountain bike resort design. Only 19 percent of all parks reviewed contained
children-specific trails. Twenty five percent contained no beginner level riding. And only 30 percent contained pump tracks. These are significant figures, as they illustrate that a great number of mountain bike resorts are failing to develop the facilities needed to attract beginner riders.
Figure 15: Lift access mountain bike park scores
Community Bike Park Variance

Overall, the scores separating the highest (Valmont) and lowest (Colonnade) ranked community bike parks differed much less than their lift access (fee based) counterparts. A major difference in the distribution of the data, however, is in the review of facilities at community based parks. The lift access data showed little variation in the categories of facilities among parks, yet in community access parks, parking and restroom facilities are the two most disparate categories between highest and lowest ranked park. This seems to indicate an importance to community park designers and planners that considering parking and restrooms and other service facilities is just as important (if not more so) than the actual mountain bike features installed in the park. Yet the data still show a large disparity in trail and feature condition, as well as including a variety of features. Feature variety separates the two parks by 1.22 points, followed by trail conditions (1.10) and feature condition (1.08).
**Rider Preferences**

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Figure 16. Community bike park scores
The majority of community bike parks, unlike the lift access mountain bike resorts contained both pump tracks and beginner level trails. However, only 26 percent contain children specific trails. Although, at present there is no clear cut distinction between a proper beginner trail and one designed for first-time riders beyond perhaps the length of the route.

In addition to rider preferences, the bike park development survey asked respondents in what capacity, if any, they had contributed to the existence of the community mountain bike park they reviewed. As these parks are typically funded by some combination of federal, state, or local tax dollars, and often require matched funding from private citizens or in-kind donations of labor and materials, the intention was to see what percentage of people contribute to the creation of community parks. Sixty-eight percent of respondents had no hand in the development of the community bike park reviewed. Thirty-two percent of respondents were volunteer labor, financial sponsor, or volunteer planner or advocate for bike park development. This result seems to illustrate the type of active community support that can exist for community mountain bike parks in general. These responses are illustrated in Figure 17.
Bike Park Survey Summary

This survey project is the first of its kind, as minimal data have been gathered regarding mountain bike park/resort user preferences and demographics. The studies that exist focus on one resort or another, rather than the world wide phenomena of mountain bike parks. As such, and as a sub focus of this thesis, it provides significant avenues for further inquiry that will be discussed in the Conclusions chapter of this thesis. The data contain information that the author has not yet found the funding, time, or ability to investigate. Zip codes of respondents combined with locations of mountain bike parks or resorts reviewed would generate information on average travel distances to mountain bike resorts. A further analysis of user preferences and statistical differences between them could reveal more nuanced insights into user preferences of lift access mountain bike resorts and community mountain bike parks.
Yet these initial findings of the mountain bike park survey indicate trends in the geographical distribution of mountain bike resorts, mountain bike resort user experience, length of stay at resorts, and user demographics.
Site Inventory and Analysis

Terrain and Facilities

The site’s terrain was inventoried through both site visits and a 5 meter digital elevation model from gis.utah.gov. As Powder Mountain staff was uncommunicative and did not provide site boundaries, those boundaries were assumed by analyzing the publicly available Powder Mountain ski map and determining the range of terrain that was serviced by the two lifts that are under consideration for summer activities. Sundown and Hidden Lake were the two existing lifts that Powder Mountain is considering developing for future mountain bike resort use.

Sundown lift is the first lift seen upon arrival at Powder Mountain Resort. Its base rests at an attractive wooden lodge with a large patio that is conducive to summer resort activities. The lift is a fixed grip double chair that ascends 600 feet to a ridge overlooking the northern Salt Lake Basin and the upper Weber Valley. A large parking lot sits just above the lodge and lift facilities. The lift accesses approximately 138 acres of downhill terrain, and is bounded in by roads and ridges that drop outside the Powder Mountain property, as well as private homes to the northeast. More terrain is potentially accessible with climbing the access road extending to the north of the summit.

All the land on the Powder Mountain site is privately owned, and is not subject to federal landowner requirements as many ski resorts are.
Figure 18. Powder Mountain terrain and lifts
Figure 19: Powder Mountain slopes inventory
To the east, approximately a half mile of paved and 1.3 miles of unpaved road separate Sundown’s access parking lot from the summit parking area with immediate access to the summit of Hidden Lake lift. This access point is quite unique among ski resorts in the region, in that the rider begins at the top of the mountain and proceeds downhill before sitting on a lift their first time. Beautiful views at the summit open up into Cache Valley to the north and south into the upper Weber Valley. Hidden Lake is a high speed quad chair that summits at 9,300 feet, with its base 1,300 feet below. The slopes surrounding the southwestern side of the upper Hidden Lake parking lot are gentle and provide potential for warm-up, beginner or children’s trails at the summit. The lift accesses approximately 1,000 acres of downhill terrain, and does not share any borders with private residential properties.

Powder Mountain property allows for a western connection between the Sundown summit that would not have to cross a highway or access road as it would going east. However, these slopes are some of the steepest of the site and would make sustainable trail construction challenging and expensive.
Views

Summer views were assessed through three daylong site visits spent hiking the slopes accessible from Hidden Lake and Sundown lifts. Winter views were assessed during a winter conditions site visit, but are not included here as part of a summer resort planning process. As with nearly any mountain, the most expansive views occur at the summits, and Powder Mountain’s views from the summit are no different.

Figure 20. Sundown summit facing southeast

Figure 21. Hidden Lake summit facing southwest

Aside from summit views, both Hidden Lake and Sundown lifts access terrain with impressive views, yet the views of Hidden Lake terrain are more consistently impressive.
Notable on Sundown is the rocky southern slope – when facing south to southwest, the viewer is greeted with beautiful slopes across the road, covered in dense pine and aspen cover. This view changes drastically when pivoting northwards, however, as the presence of private residences and the main access road significantly reduces the sensation of escaping to a remote mountain.

![Figure 22. Sundown slopes facing north](image)

Hidden Lake offers impressive views throughout its terrain, most notably those views from the site’s namesake lake facing north, as well as views from the eastern hillsides looking northwest into Cache Valley and beyond. Unlike Sundown’s slopes and many other ski resorts in the region, the views from these slopes feel more akin to a national park or forest preserve, rather than a well-known ski resort. The intersection of shallow slopes and fantastic views create opportunities for the development of mid-slope ‘parks’ that can offer rest, a chance to soak in views, and opportunities for mountain biking groups of varying skill levels to regroup and socialize. These views and spaces are uniquely Powder Mountain and should be exploited in the development of mountain bike terrain.
Vegetation

Four major vegetation groupings have been identified on Powder Mountain terrain. They are referred to as open spaces, pine association, aspen association, and scrub oak association. The open spaces contain little to no vegetative cover, with grasses and small shrubs forming the extent of vegetative groundcover. It is these slopes that are most often used in winter months as highly trafficked ski slopes. This vegetation type makes trail construction easier, but can erode more rapidly than a similar slope with more significant vegetation.

Pine association occurs in a number of places on the mountain, contains significant undergrowth between the larger older pines, and provides the most significant shade on the mountainside. Pine association provides opportunities for good trail corridors, and the deadfall typically found within these regions can potentially be used for feature fill or construction. Trails built within pine association will be better protected from erosion than their fully exposed counterparts, however the density of undergrowth and large trees can make construction difficult. Care should be taken to avoid cutting down pines unless necessary.
Aspen association is perhaps the most common type on the mountain, with large strands of aspen covering much of Hidden Lake slopes, as well as a number of strands occurring on Sundown slopes. The wide spacing between trees of many of the aspen groves create ideal trail corridors, and the dappled shade creates a pleasant experience under the canopy. There is less deadfall within the aspen corridors and trail construction should be able to proceed relatively easily within.

Scrub oak associations occur only on west and southwest facing slopes on the mountain, and are particularly dense growths. Their 5 to 6 foot height and dense growth provide little shade and blocks more wind than sun. Trail construction through these regions may be more difficult than others, and corridors passing through scrub oak should be regularly maintained, as this plant species is swift to grow and could easily create a riding hazard.
Figure 24a. Sundown vegetation and views
Figure 25. Sundown vegetation and views

1. Sundown’s top of lift view far surpasses that of the competition at Deer Valley or the Canyons.

2. Eastern side of Sundown offers valley views and shallow grades ideal for viewpoints or skills features.

3. This open ridge is full of stumps and boulders, which are uncommon in the overall landscape.

4. Old road grades offer breaks in the vegetation and upsloped trunk, ideal for trail construction.

5. Just west of the lift section, a rocky ridgeline offers views and unique trail surface opportunities.

6. Open expanses of meadow offer good views and excellent sightlines for potential trails.
Figure 26: Hidden Lake Vegetation and Experience
Figure 27. Hidden Lake views

1. Southern views from top of lift

2. Northern views from top of lift

3. A gentle & undeveloped slope to the west of the lift could be developed as recreation near parking areas.

4. Hidden Lake’s namesake provides an easily accessible and unique landmark.

5. Huge pines and a babbling brook create a peaceful, introverted space.

6. This western corridor of aspen, between a major drainage and steep slopes create a natural trail corridor.

7. This gently sloped, open ridgetop is bordered by well spaced aspens on either side and is marked by a distinctive pine at the base.

8. An open meadow leading into dense pines is a surprise after the aspens that precede it.
Soils

Data collected from the national soils database (https://websoilsurvey.nrcs.usda.gov) were studied via the GIS and the official soil descriptions located online (https://soilseries.sc.egov.usda.gov/osdname.asp). The findings of the online soil survey were verified by on site samples. Due to similarities throughout the area, the soils data were not included in the suitability analysis, but on another site, these widely-available soils data could provide important decision making data regarding where to put trails.

In the study area, the main distinction between soil types occurs between the Hidden Lake and Sundown drainage basins. There are two major types of soils within the Hidden Lake area, and one major type within the Sundown area. Though there are differences in subtleties of soil formation, acidity, and other features important to farming or geology, the soils are very similar in regards to trail construction and maintenance. Hoskin series and Lucky Star series are both stony, loamy soils with the Hoskin series containing larger stones that should be accounted for during trail construction. Larger stones should be removed from any load bearing earthen trail features such as berms or jumps. Hoskin is also noted to have a more rapid runoff rate, that increases the speed at which the soil dries in the spring. This, combined with the eastern aspect that coincides with all of the Hoskin soil in the focus area, creates an excellent area to develop trails that can open for use earlier in the season than the rest of the mountain.

The majority of the Hidden Lake area is composed of Lucky Star series gravelly silt loam that is well drained soil with moderate permeability with slow to medium runoff. The smaller
stones in some areas of this soil could increase the ease of trail construction, and the Lucky Star series should perform similar to other soils on site when dry.

The Sundown lift accesses an area that is largely composed of Poleline Stony loam, a gravelly loam that is well drained, with slow to medium runoff.

Throughout the site, trail construction should follow standard trail construction guidelines as referenced in the literature review, and the soil will provide a stable and resilient surface for a long-lived trail network. However, the existence of small to medium size stones throughout a majority of the soils on site should be taken into account when building beginner or intermediate trails. Though advanced mountain bikers may appreciate the additional challenge and thrills of rocky and challenging trails, a smoother trail surface would be more appealing to beginner and intermediate riders. To create such a surface, topsoil can be imported, or stony materials can be removed from the trail surfacing.
Figure 28. Powder Mountain soils distribution
Hydrology

The site’s hydrology is composed of Hidden Lake and a series of small springs and drainages created by snowmelt. Site visits were utilized to take note of the volume of water flowing on site and apparent erosion issues in both early spring and fall. Based on stream order, (number of drainages feeding into another drainage) the map has been classified into major and minor drainages.

For purposes of trail design, hydrology can play an important role in providing the cooling presence of water on a hot day, and create a relaxing atmosphere as it does by the base of Hidden Lake lift. However, trails that cross drainages are at risk for enhanced erosion in these areas. Some of the major drainages, particularly at lower elevations have eroded all of the topsoil within the drainage and should not be crossed by future trail alignments. However, anywhere trails corridors need to cross drainages are ideal locations for feature construction, particularly wooden causeways or other elevated structures that would allow water to flow underneath them. This placement would allow trails to cross all but the largest drainages and provide additional interest for trail riders.
Figure 29. Powder Mountain drainages
Solar Aspect and Solar Gain

Using the digital terrain model of the site, maps were created to identify the dominant cardinal direction of the mountain slope faces, as well as accumulated solar gain to the mountain’s surface between the months of April and June.

Both maps provide information that allows a trail planner to identify regions that receive more sunlight through the spring. However, the solar exposure map provides more detailed information as it takes into account the sun path and the creation of hillside shadows on the terrain. For this reason, the solar exposure map is used to understand the sun’s effect on snowmelt rather than an aspect map.

The areas identified as significant and high exposure on the solar exposure map are the first on site to dry in the spring. This allows trails on these slopes to open earlier and extend the profitable season of the mountain resort.
Figure 30. Powder Mountain solar gain - April 1st through June 1st
Roads

There currently exists a network of access roads throughout the site. All but the entry road are natural surfaced dirt roads with varying surface conditions. Roads that are currently in use were included in the suitability analysis as poor locations for trail corridors, as the motorized travel quickly creates a rocky and rutted surface type that is less than ideal for mountain bike travel.

However, skills feature locations were considered highly suitable if they came within 100 feet of a roadway. This proximity enhances emergency vehicle response time should an accident occur on or near skills features, and also provides easier access for supply vehicles bringing construction and maintenance materials to skills feature areas.

There also exist a number of road beds on site that do not appear to be in regular use. Encroached by vegetation and constructed at a gentle downhill slope, these areas could be easily converted into trail alignments. When corresponding with recommended trail corridors, these road beds should be used for trail construction.
Figure 31. Powder Mountain road network
Powerlines

The slopes below Sundown lift are utilized for night skiing at Powder Mountain. To provide illumination, a network of large overhead lights has been installed. The approximate location of each light pole was noted on site and converted into the following map. Powder Mountain staff has confirmed that the lights’ power lines are buried underground. Though not verified, line of sight powerline placement was assumed between light poles. These locations were noted on inventory maps and considered during the trail corridor design process.

The existence of light poles and power lines on the Sundown lift provides advantages and disadvantages. Should mountain bike trails be constructed on slopes accessed by Sundown lift, there would be a potential to develop nighttime races or nighttime riding opportunities, a completely unique offering that would distinguish Powder Mountain from any other resort in the world.

Yet care must be taken by trail contractors building on Sundown terrain, as the damaging or disturbing of the underground power line network is a significant risk when building trails, particularly when using excavating machinery.

Snowpack

According to Powder Mountain staff, the resort opens once 30” of base snow is recorded on site. Because of this figure, feature construction that is to remain in place through the winter season should be designed to a maximum of 24” in height. Features that seek to extend this
figure to a larger number should either be removable or placed such that they will not interfere with downhill skiing in early or late season conditions.

Also, permanent feature construction of any significant height should be avoided on open, gladed areas that are groomed throughout the winter season. The impact of the heavy machinery used to create smooth ski slopes would likely damage any sub-surface structures.

Suitability

Hidden Lake or Sundown?

At the onset of this project, Powder Mountain staff requested a trails plan terrain accessible from Sundown and Hidden Lake lifts. These lifts have direct access to facilities, parking and gentle slopes that are supremely suitable for mountain bike trail construction. After in depth research of the landscape, its features, and mountain bike resort design on the Wasatch Front and beyond, the author strongly encourages Powder Mountain to develop mountain bike terrain primarily on Hidden Lake terrain for the following reasons:

- First Impression: You only get one chance. Hidden Lake, in comparison with Sundown is simply more impressive. Hidden Lake contains incredible views throughout the entire site. The vegetative cover is such that one gains a sense of escape, and being secluded in a forest, rather than just riding trails built under chairlifts, as is the feeling at competing resorts Deer Valley and The Canyons.
- Bigger: In order to compete with existing mountain bike resorts such as Deer Valley, size is needed to develop a trail network whose complexity and variations bring customers back again and again to continue exploring a vast area, rather than a small circuit that can easily be ridden in its entirety in a couple of hours.

- Speed: Should Powder Mountain develop terrain on Hidden Lake, it would be the first Wasatch Front resort to develop mountain bike specific terrain that is accessible by high-speed quad. Though Snowbasin’s terrain is accessible via high-speed gondolas, it is not built to be mountain bike specific. Mountain bikers would find the Hidden Lake lift more attractive than the Sundown lift for the same reasons skiers do: faster lifts mean less time waiting in line or sitting on a chair, and more time doing what they came to the mountain to do.

- Suitability: Gentler slopes and increased vegetative cover create a landscape underneath the Hidden Lake lift that is significantly more suitable to mountain bike specific trail design and feature construction than the terrain underneath Sundown. However, the marginally steeper terrain underneath Sundown does provide enhanced options for advanced level trails. Hidden Lake also contains a greater amount of eastern facing slopes that receive more constant sun in springtime months.

These are the major reasons that trails should first be developed on Hidden Lake terrain, and then consider Sundown terrain as future expansion opportunities. The downsides of Hidden Lake have to do with higher energy costs of operating the high speed quad lift and cost to
It would also likely be difficult to connect Sundown and Hidden Lake trail networks outside of the existing road connections. Should both trail networks be developed, a connector trail that would allow customers to traverse the mountain and connect one area to another would create a scale of a mountain bike resort rivaled by few. However, that connection would require some uphill pedaling and a portion of terrain between the two areas is steep enough to make trail construction very difficult.

**Trails Suitability**

As discussed in the Methodology chapter, slopes, hydrology, roads and vegetation layers were all combined in a GIS mapping system to develop a series of suitability maps for Hidden Lake and Sundown terrain.

On all suitability maps, dark greens indicate ideal suitability, with less suitable areas following a gradient to yellow and darkening to red to indicate unsuitable areas. This maps allow at-a-glance analysis of the sum of features upon a large landscape.

Hidden Lake’s trails suitability map illustrates hillsides that are largely suitable for trail construction, with a need to avoid major drainages, steep slopes, and the main access road. Areas of mild slope with moderate to light vegetation, away from roads and drainages form the areas most suitable for trail construction.
Sundown’s trails suitability map illustrates many of the same tendencies of Hidden Lake’s terrain, but with fewer highly suitable vegetated areas and the addition of a number of overly steep regions creating significant difficulties for future trail construction.
Figure 32. Hidden Lake trails suitability

Legend
Ski Lifts
- Ski Lifts
Trails Suitability
- Unsuitable
- Poor
- Moderate
- Good
- Highly Suitable
Figure 33. Sundown trails suitability
Switchback Suitability

The suitability for switchbacks and rest areas on site is much more restricted than that of trail corridors, largely due to their need for shallow slopes and a ski mountain’s lack of those slopes. However, significant pockets of suitability exist on site.

Hidden Lake’s switchback suitability shows a series of islands throughout the site where slopes are shallower. They are most prominent upon the mountain ridges and valleys, but enough low slope areas exist throughout the site to facilitate easy trail construction. Very few areas of absolute unsuitability exist on site. These can easily be avoided during final trail construction.

Sundown’s switchback suitability is similar to Hidden Lake’s with the addition of more unsuitable areas of excessive slope.
Figure 34. Hidden Lake switchback and rest suitability
Figure 35. Sundown switchback and rest suitability
Feature Construction Suitability

Feature suitability maps are marked by large swaths of unsuitable land that represent open ski runs on site. These areas should not contain significant features as they could pose safety hazards during the winter season, particularly in years of little to no snow or early and late in the season.

Hidden Lake’s feature suitability shows that the majority of vegetated areas on site are suitable for feature construction, with the exceptions of areas of very dense scrub-oak vegetation or excessive slopes. Opportunities exist for excellent feature construction throughout the site, and areas next to water sources, marked in the dark green on the map, should not be ignored, as water sources would facilitate maintenance of earthen structures, and can provide a cooling effect in the summer months.

Sundown’s feature suitability map shows much more limited areas of feature suitability, as a great majority of the site is composed of open, gladed ski runs. Opportunities still exist, but are much more limited than Hidden Lake’s.
Figure 36. Hidden Lake feature suitability
**Trail Corridor Development**

Utilizing the suitability maps developed for the site, a first draft of trail corridors was then created. Trace paper overlays allowed the author to identify suitable switchback areas, ideal trail corridors and suitable feature placement areas in order to create initial trail corridor alignments.

![Figure 38. Trace overlay elements](image)

**Design Principles**

Though computer based analysis provides the suitability maps and the inventory maps, much of the design was developed through design principles established through personal experience, case study, and research of existing mountain bike resorts. While designing trail
corridors that correspond to suitability maps, the following three design principles were kept in mind when developing final recommendations.

- Design for All: The trail network at Powder Mountain’s future mountain bike resort should be designed to appeal to all skill levels, from the first time mountain biker to the professional. A great deal of a ski resort’s success is due to the sport having a broad appeal, and a mountain bike resort should be no different. This requires at least one beginner level trail extending from top to bottom of the mountain.

- Expansion Opportunities: The trails identified are merely the first phases of a larger network. Areas on site are identified that could serve as future expansion trails, without having to utilize additional lifts on site.

- One Trail, Multiple Experiences: One trail should have multiple options. This applies to feature design and trail routing. If there is only one way to ride a trail, a customer may grow bored with the experience and the value associated with it. However, if there are multiple ways to experience the trail, the result will be numerous optional trail segments that can only be experienced through multiple trail rides, and the ‘newness’ of the trail would remain high for many visits.
Having completed several iterative designs of trail alignments using the trace overlay method, the best trail routings for Hidden Lake and Sundown were selected. These designs were then geo-referenced into the GIS. At this point, the lines represented little more than general trail corridors, and not exact trail alignments, as they were created looking at maps scaled to 1":750' and 1":250' on Hidden Lake and Sundown, respectively. These general corridors were then printed out at larger scales of 1":200’ and 1":100’ for Hidden Lake and Sundown. Using an engineer’s scale and contour lines representing 10 and 50 foot intervals, and by referencing design principles, views, and other inventory elements of the site, a more exact trail network was designed.
This refined draft of the trail network was then inserted into the GIS and reanalyzed for adherence to IMBA’s trail guidelines, ensuring that no trail exceeds 15 percent slope and that at least one trail maintains a five percent slope or less to adhere to beginner trail guidelines.

Figure 40 shows the results of GIS corridor slope analysis (green, orange, yellow and red cells represent flat to moderate to excessive slopes, respectively) compared with the resolved trail, represented in blue. This method is not a perfect one, as the best digital information available for the site is a five meter resolution DEM. The data resolution is significantly coarser than the approximate one meter width of a constructed trail. Due to this resolution, the slope corridor analysis often saw the trail corridor moving back and forth between two cells of significantly different elevations and indicated that the trail was continually exceeding 15 percent grade, when in reality, the trail is following a contour line or descending under five percent
grade. Due to these errors, the original corridors did not need refining in every location indicated by the GIS, but the analysis did provide indication of areas of significant slope that were in need of modification.

This project describes a methodology that allows a designer to quickly and confidently design trail corridors that respond to the environmental variables of a large scale site. However, it should be noted that the final trail design and actual built routes of these trails will likely deviate from the trail corridors noted. With limitations of five meter DEM resolutions and no ability to accurately pinpoint every tree, shrub, and rock on site, an on-ground GPS routing of the final trail siting to be built is crucial to the completion of a constructed trail network that achieves the design principles set forth in this thesis. The trail corridors illustrated in this master plan are intended to facilitate and focus an expert trail builder’s work to the sections of the site best suited for their work. In addition, the mapping and selection of trail corridors allows for initial cost estimates that can assist a resort when making financial decisions regarding mountain bike resort development.

Final Design

The following sections outline the final elements of the Powder Mountain bike resort master plan. Hidden Lake and Sundown areas are discussed as separate and unique trail networks, each with their own strengths and weaknesses.
Certain design principles and recommendations apply to the entire site. Signage types and locations, feature placement and construction principles, and the development of rest areas, pump tracks, and outlooks are discussed in their application to the mountain resort design as a whole, rather than one trail at a time. In addition, feature placement and signage location are design elements that should be located so as to take advantage of views, vegetation, topography, and other subtle variations best identified in the field. As such, recommendations discussed here are intended to be general guidelines to inform final trail construction and design.

**Signage and Risk Management**

Mountain biking, like skiing, is an inherently dangerous activity. As such, it is critically important to establish clear and consistent signage warning riders of challenges that they would face while at the resort. The most basic signage dictates the perceived challenge level of a given trail. Drawing upon the standard symbols of ski terrain, nearly all mountain bike resorts have adopted the green circle, blue square, and black diamond trail markings in order to signify trail difficulty. This convention should be followed in future Powder Mountain trail signage. Figure 2 illustrates these difficulty markings and their associated trail types.

However, trail difficulty markers are only one aspect of signage that should be considered for a mountain bike resort. Whistler Blackcomb, as a world renowned mountain bike resort with a wide network of beginner, intermediate, and expert trails, has created an excellent risk management program, including signage. The following signage recommendations closely
mimic the messaging present at Whistler Blackcomb, but apply a unique design intended to reflect Powder Mountain Resort’s unique offerings.

- Way finding Signage: Way finding signage should be prominently placed at intersections, designed so that the signs will not rotate or shift and cause confusion for visitors to the resort. In addition to signage placed at intersections, confirmation signage should be placed 200 feet into a trail corridor to confirm a rider’s choice of trail and assure them of their direction. At a minimum, wayfinding signage should indicate trail name and trail difficulty. Additional information can be provided to describe the trail features in greater detail and give distances to other landmarks upon the resort. Figure 41 illustrates one type of wayfinding signage found at the modern community bike park of Valmont.
Flow and Technical Trail Descriptions: Along with the trail difficulty descriptors, these symbols should be used to describe the particular experience found within a trail section. They should be placed on trail description literature as well as on wayfinding signage in the field.
- Trail Closed/Off Limits Signage: This signage should be consistent and bold and be placed in conjunction with rope completely blocking off any trail corridors closed due to construction, maintenance, snow, or any other reason.

- Steep Trail Signage: Like ski trails, mountain bike trails often rapidly change in trail slope and steepness. This signage allows riders to prepare for sudden changes in trail
grade. These signs should be placed to the side of trails approximately 100 – 200 feet before any sudden grade change that reaches over 15 percent downhill slope for more than twenty feet.

Figure 44. Grade change signage

- Jump Lip Flags: All features (jumps) that are designed with a ‘lip’ that require riders to become airborne for successful completion of the feature should be marked with orange flags on either side of the jump’s highest point. These flags should be visible from the trail at least 100 feet ahead of the feature.
Figure 45. Jump lip indicators

- Gap Jump Signage: Suitable only on expert-only trails, gap jumps require less material to construct larger features, but can pose significant hazards should a rider not carry enough speed to reach the landing section of the jump. All gap jumps should be clearly marked as such with signage placed approximately 50 – 100 feet prior to the jump.

Figure 46. Gap jump signage
- **Teeter Totter Signage**: A popular feature at many resorts, the teeter totter is a wood balance beam placed on a fulcrum that pivots as the rider crosses the fulcrum. Once the rider is past the obstacle, a counterweight returns the teeter-totter to its original position, ready for the next rider. Because of the feature’s tendency to move underneath the rider, all teeter totters should be clearly marked with signage placed approximately 50 to 100 feet prior to the feature.

![Teeter Totter Signage](image)

*Figure 47. Teeter totter signage*

- **No Stopping Signage**: These signs, in conjunction with rest areas, serve to reduce accidents and conflicts mid-trail. They should be placed alongside the trail within 40 feet of the landing zone of aerial features. Signage should also be placed alongside any high speed trail segment or a section with visibility limited due to turns and/or vegetation.
Figure 48. No stopping signage

- Bike Pullout Signage: These signs should mark small rest areas and pullouts that will allow riders to pull aside of the major trail area to rest, regroup with friends, or allow faster riders to pass. These signs should be placed to the same side of the trail that the pullout is located.

Figure 49: Trail pullout signage
- Easy Route Signage: This sign should be located on all trail maps and signposts that indicate how to find the easiest route to the base.

![Figure 50. Easiest way down signage](image)

- Trail merge signage: These signs should be placed alongside trail corridors that approach trail intersections. They should be placed between 100 and 200 feet before arriving at a trail intersection itself.
Intersection Design

The trail network as proposed in this document contains a small number of intersections. This is intended to facilitate resort navigation, reduce rider conflicts mid trail, and provide as much uninterrupted trail riding experience as possible. Intersections should be combined with rest areas that would allow for multiple riders to pull off the main trail surface. These rest areas should serve as natural waypoints where riders can wait for others, rest, and relax.

Trail intersections that contain the beginning of a trail should contain a rest area to one side of the trail tread, prominent way finding signage, and should allow for views of oncoming traffic at least 200 feet up the trail. Should a trail that starts at an intersection be more challenging than the trail it departs from, a gateway feature should be placed at the trail start, as well as signage. A gateway feature allows riders to understand the type of challenges they could
face farther down the trail and gauge their own ability to navigate that level of trail. Gateway features are discussed in more detail below.

Trail intersections that contain the end of a trail as it merges with another should also contain a rest area to one side of the trail tread, prominent way finding signage, and allow for views of oncoming traffic at least 200 feet up the trail. The trail that merges into the through trail should be designed to slow merging traffic and allow for views between riders on both trails. This line of sight is important in order to preserve rider safety. Vegetation and other obstacles should be removed in order to provide a view corridor that stretches 100 to 150 feet back from the trail’s intersection point. This allows riders on either trail to be able to see one another. These recommendations to preserve line of sight stem from best practices in transportation engineering and have been calculated based upon rider speeds of 15 to 20 miles an hour. The following diagrams represent two types of intersections that are found as part of the Powder Mountain Master plan. They are not intended to be prescriptive, but serve as guidelines for safe and understandable intersection design.
Figure 52. Trail beginning intersection

Figure 53. Trail ending intersection
Features

Skills features, or technical trail features are an integral part of mountain bike resort design. Features are what make mountain bike resorts unique from the large network of public trails that often surround them. Features, and the thrills and spills that go along with the aerial stunts and sense of flight that can be gained from successfully navigating skills them are a major focus of modern mountain bike resorts. Much of this focus should not change, and on intermediate to advanced trails, features should be a central part of final trail design, and emphasized in marketing materials. However, caution should be taken to deemphasize the feature-based nature of beginner and some intermediate trails, and to provide an experience that is more accessible to novice and beginner mountain bikers, and thus to broaden the appeal of a mountain bike resort.

Opt In vs. Opt Out

When placing features in the field, it is important to realize if the features are placed to create an opt in experience or opt out experience. Opt in feature placement locates the skills feature outside of the main trail tread, and riders must consciously choose to alter their path and opt in to the feature, or do very little to avoid it. Opt out feature placement locates the skills feature within the main trail tread, and provides an alternate line to bypass the skills feature. This requires the rider to consciously alter their course if they seek to avoid the feature, or do very little different to ride through it.
All features outside of rollers and berms located on beginner level trails should be the opt-in design. This allows beginner riders to avoid the intimidation that comes when facing a sudden and unexpected obstacle, and just to focus on enjoying the trail. Yet more advanced riders would be able to find challenge and thrill in the same trail by opting in to the trail’s technical features.

The majority of features on advanced intermediate and advanced level trails should be opt-out design. This allows for a trail that seamlessly transitions from one feature experience to the next, without having to change direction or seek to find entry to features located just off trail. Lines that bypass trail features should be maintained in all cases, allowing intermediate riders to progress to more advanced skill levels and examine features closely before attempting to ride them.
Feature Types and Suitability

Among mountain bike resorts, there exist a wide variety of feature types, but most can be classified into four major types: aerial features, balance features, technical features, and rhythm features. All features should be constructed with safety in mind. The Whistler Trails Standards (DeBoer, 2003) contains a number of safety guidelines regarding skills features. The following paragraphs outline the different types of features that may be encountered on a mountain bike specific trail.

Aerial features encourage or require a mountain biker to become momentarily airborne while riding. The size of these features is directly related to their challenge level. Names of features in this class include jumps, drops, and wall rides. They can be constructed of wood, earth, concrete, stones, or other durable materials.

Figure 55. The author clears an aerial feature in an undisclosed location
Balance features require balanced riding to navigate a narrow beam structure elevated off the ground. The height of these features of the ground combined with their width of tread is what defines their challenge level. The narrower the balance feature or the higher off the ground it is, the higher the skill level required to navigate the feature. They are typically wooden features, though they can be built of concrete, steel, or other durable materials. Elevated balance features can also serve an important purpose in sustainable trail design, in that they can form bridges over eroded trail surfaces, drainages, or other areas that are unsuitable for trail construction. As such, the feature placement maps (Figures 64 and 65) indicate locations that balance features can elevate the trail to avoid drainage areas.

Figure 56. The author navigates a balance feature at Deer Valley Resort
Technical trail features are a class of features that require precision bicycle handling to navigate, often requiring slower speeds, the ability to lift the front or both wheels, and are typically constructed of rocks or other immovable obstacles. The more difficult a feature is to ride across, the higher its difficulty level.

Rhythm trail features incorporate the forward motion of the bicycle and rider into undulations and turns that require no slowing and emulate the sensation of a roller coaster. These features include pump tracks, rollers and berms, whether earthen or made out of other materials. Advanced riders can turn certain rhythm features into aerial features, yet these features do little to deter even the most novice riders.
The following points are intended to serve as approximate recommendations for the suitability of various feature types within different skill level trails in the Powder Mountain master plan.

- Beginner trails should contain:
  - Rhythm features one to two feet in height
  - Balance features less than two feet in height

- Intermediate trails should contain:
  - Rhythm features one to three feet in height
- Aerial features four feet or less in height
- Balance features four feet or less in height
- Moderate use of technical trail features

- Advanced trails should contain:
  - Rhythm features larger than otherwise found at the resort
  - Aerial features less than six feet in height
  - Balance features less than six feet in height
  - Significant use of technical trail features

  - Note: features greater than six feet in height are accessible to few mountain bikers, and pose an unnecessary risk, and should generally be avoided

This master plan document does not seek to place individual features or propose their particular design. The decision of what features to use and where to place them along the trail is to be left up to the trail contractor and Powder Mountain staff. Each decision should be informed by on the ground observations during the course of walking trail corridors. However, areas within trail corridors that would be most suitable for feature construction have been outlined as part of the Powder Mountain Master Plan (Figures 62 and 63).
**Gateway Features**

The beginning of all intermediate and advanced trails should contain a ‘gateway’ feature that is indicative of the challenge level that would be found elsewhere along the trail’s path. For intermediate trails, this could be a low-lying balance feature or a small technical feature. For advanced trails, it should be a very difficult technical feature or a minor aerial feature that requires flight, such as a drop or jump. The concept of gateway features was first established by IMBA and recorded in their publication *Trail Solutions* (Weber & Felton, 2004).

Gateway features are recommended to avoid riders finding themselves on a trail that is beyond their ability. By placing gateway features at the beginning of a trail, riders who are of an appropriate skill level proceed easily, and those that are of an inappropriate or minimally acceptable skill level would be more likely to choose another trail. This design is intended to reduce the unfortunate and unsafe occurrence of riders finding themselves unable to comfortably and safely ride the trail they have chosen.

**Switchback to Feature Minimum Distances**

Features should not be placed within 50 feet of major turns or switchbacks, with the exception of wall rides and rhythm features, both of which often form the support for a turn or switchback. This recommendation avoids a common design flaw of mountain bike resorts and parks, in that coming away from a feature at speed, a rider is forced to suddenly slow for a sharp turn, and many riders are unable to slow easily, causing skidding and excessive trail erosion at best, and crashes at worst.
Features should be placed a minimum of 50 feet outside of the end of a major turn or switchback in order to allow riders time to gauge the feature and their ability/desire to ride it. Features placed too close to the end of a major turn or switchback can cause a rider to approach the feature before having any idea what the feature is or how to prepare for it, often causing such surprise as to result in a loss of control and potentially dangerous situations.

**Rest Areas and Pump Tracks**

In an effort to plan a mountain bike resort that broadens the appeal of lift accessed mountain biking, pump tracks and scenic rest areas are seen as design elements that can greatly improve the appeal and enjoyment of the resort to a broader spectrum of mountain bikers, rather than the ‘extreme’ crowd that is currently the targeted demographic.

Figure 59. Pump track in use by the author
Pump tracks are low risk, closed circuit rhythm features that allow the rider to propel his or herself by a pumping motion, and teaches handling skills that are useful in all areas of mountain biking. Hugely popular at community bike parks, they are still relatively rare at lift access resorts. The survey conducted as part of this thesis indicated that only one in three resorts worldwide contains a pump track. Placed mid-mountain, pump tracks combined with rest areas encourage customers to stop for a minute, practice some loops on the track, sit around with friends, and soak in the beauty around them.

Pump track locations have been identified for both Sundown and Hidden Lake networks, and are identified in Figures 64 and 65. Their sites are selected based on view inventory and areas of reduced slope, as they require areas of low slope to allow riders’ momentum to carry them multiple circuits through the course. A schematic design for the priority pump track on each network is provided in Figures 66 and 67.
Rest Areas

Rest areas should be located on all trail corridors, placed approximately every quarter mile, or 1300 feet. These areas can be varied in dimension and impact, but should allow for a minimum of three mountain bikers to pull off the main tread and be safely out of the way of oncoming traffic. The switchback and rest area suitability map provided as part of this thesis should assist in location of future rest areas. However, as their footprint is small and the DEM used for this analysis was limited to 5 meter resolution, the exact siting of rest areas has not been included as part of this thesis and should be refined by the trail builder on site.

Trail Construction

When constructing trails on mountain resort land, machine built trails are typically the most economical option, due to the speed with which a skilled operator of a trail building machine can create new trail. However, machine built trail creates a much larger footprint initially, and does not look as polished or ‘natural’ as hand built trail for the first few seasons, until vegetation along the edge of the trail corridor recovers and narrows the machine cut corridor to one more similar to a hand built trail.

The trails chosen as part of the Powder Mountain Master plan are provided with a cost estimate assuming machine built trails. Should Powder Mountain seek to build trails that connect to Forest Service land and existing trails, or develop connector trails that provide a
highly scenic, highly removed experience, hand built trails, though more costly, would be preferable.

**Powder Mountain Trail Network Summary**

The trail network is designed to create a range of experiences that would appeal to a broad range of mountain bikers, and create a variety of trail types, from trails that inspire confidence in the most beginner riders to those that challenge and excite the expert. In order to fully realize this potential, the network is seen as complete when both Hidden Lake lifts and Sundown lifts are operational and accessing their respective trail networks. A final stage of connecting the network is proposed in order to establish a connector trail between the two networks, to allow those willing to pedal the approximately three mile distance to explore a remote and scenic area of the resort.

However, this connector trail is beyond the scope of this initial master plan, as the terrain that links the two areas does not adhere to the trail corridor suitability guidelines developed as part of this thesis. This does not preclude a trail corridor from ever being developed, but does create difficulty.

Figures 55 and 56 outline the proposed trail network layout for Hidden Lake and Sundown lifts, respectively. Hidden Lake’s trail network is intended to be developed starting with the two perimeter trails, forming a circuit that will allow Powder Mountain to host not only
lift access mountain biking recreation, but also provide an excellent venue for mountain bike races which could expand interest in the resort’s future offerings. Hidden Lake’s perimeter trails, with a seven and 5.5 percent average grade, respectively could create an excellent cross country or enduro style course, and the trails of Sundown, with average slopes closer to nine percent, provide better downhill, four-cross, or enduro race opportunities.

Should Hidden Lake perimeter trails be the first opened at the resort, they will welcome beginner and intermediate riders to smooth trail surfaces and incredible views, ample rest stops, and thrilling expert riders with feature placements that encourage high speeds and fast turns. These beginner accessible and expert enjoyable trails will connect Hidden Lake from base to summit, offering a length and range of trails offered by no other resort along the Wasatch Front.
Figure 60. Hidden Lake trail network
Figure 61. Sundown trail network
Figures 64 and 65 outline the locations for potential feature placement on Powder Mountain. The feature placement maps are broken down into 3 feature types: pump tracks, skills features, and balance features. The latter identify areas where the trail corridor crosses a natural drainage, and would be well served by an elevated trail surface or balance feature. These features should be built with sufficient width to be accessible to all riders, as the intent is to protect the natural soils from erosion.
Figure 64. Hidden Lake feature placement
Legend
Potential Feature Locations
- Skills Feature
- Drainage Crossing/Skills Feature
- Pumptrack Location

Figure 65. Sundown feature placement
The following pages provide detailed information regarding each trail alignment proposed, establishing intended trail experience, length, location, average grade, profile, feature types, skill level, and a cost estimate. Cost estimates are derived from 2011 communications with Chris Berhnardt, principal of IMBA’s Trail Solutions, a world renowned trail design/build organization. The Trail Solutions cost estimates are as follows:

- Mountain Bike Specific Singletrack: $5 to $20 per linear foot
- Gravity Fed “Flow Trails”: $10 to $20 per linear foot
- Elevated trail features (ladders/bridges/etc): $20 to $50 per linear foot

In order to provide an rough cost estimate for trails on Powder Mountain property, $15 per linear foot will be assumed for all trails. This figure excludes the cost of trail feature construction. These figures include design, construction labor, and expenses for the trail alignment. It should be taken into account that costs vary greatly by nature project scope, terrain, vegetation, and length of the build season. These figures are purely approximate and a professional contractor should be consulted for more accurate figures.
Hidden Lake Trail Descriptions

Playground

The gentle slopes surrounding the Hidden Lake Summit create ideal opportunity for Powder Mountain’s most inviting and first time mountain biker friendly trail. Approximately .6 miles of trail can be developed in this area. Playground should be designed as beginner trail filled with rhythm features and peppered with optional balance and technical features.

A short trail like this requires little commitment, and has perhaps some of the best views of the entire site. This trail could be developed as a low cost alternative to visiting the whole park, with the intention of attracting visitors to ride who otherwise wouldn’t come. A free trail on a mountain peak would be an enticing draw, attracting more customers than ‘extreme’ riding might alone. As the location of the entire trail is immediately adjacent to the upper lodge, visitors to this trail would be enticed to take full advantage of food service offered at the mountain summit. A constraint on this trail’s location is strong winds across the ridge. Vegetation buffers should be considered to shield visitors from the wind and provide the best summit experience possible. Construction cost estimate is $47,520.

World View

A long, scenic 4.5 mile beginner level trail, World View is meant to be a cornerstone of Powder Mountain’s future summer recreation plan. With grades averaging 5.1 percent, the trail is less steep than many beginner trails along the Wasatch Front. Yet with construction
techniques that incorporate a significant amount of rhythm features, a pump track located midway through the trail where views are most stunning and optional small balance and aerial features located throughout, it would be a thrilling trail for all riders to experience. Due to its gentle slopes, it would make an ideal candidate for uphill travel should Powder Mountain seek to host any mountain bike races that would require self-powered ascents, or the trail could open for cross country mountain bike recreation without incurring the expense of operating chair lifts.

This trail corridor should be considered the backbone of an expansive network of beginner friendly trails, the creation of which would serve to broaden the appeal of Powder Mountain and mountain bike recreation at large. As many of the competitors along the Wasatch front offer little to no beginner-accessible terrain, the development of this trail will address a yet-untapped consumer demand in the region.

The slopes to the east of this trail corridor are excellent options to create alternative routes down to Hidden Lake lift while maintaining the same gentle 5 percent grade of Worldview trail. The pump track location identified in Figure 64 or the quarter mile segment of trail preceding it on the uphill slope provide ideal locations to link to this expansion trail. These alternative routes should be seen as more important than developing a resort with a large number of expert only trails as they will be more accessible and more enjoyable to a wider number of visitors. Construction cost estimate for the primary corridor is $356,400.
Endor

Designed as a beginner/intermediate trail, Endor averages a 7.3 percent downhill slope over its 3.3 mile length. The entire middle section of the trail requires no major switchbacks, and is conceived as a high speed, moderately challenging trail. The high speeds possible on such an alignment create a need to preserve sight lines and rest areas throughout this corridor to maintain safety for all riders.

An intermediate trail due to potential rider speed, the majority of features created on this trail should be large rhythm features, with berms and rollers created accommodate and take full advantage of the rider speed this trail fosters. Endor should become the downhill segment of any potential cross country or enduro style race routes on site. Its most memorable aspect should be the high speeds made possible to maintain while traversing through its main corridor, designed to surf its way down the mountain’s contours.

Additionally, this trail should be one of the first constructed due to its location on a slope that receives a large amount of solar exposure in the spring that would open the trail for mountain bike access earlier than the rest of the mountain. The trail intersects with an expert level trail, Endor’s Moon. Construction cost estimate is $261,360.

Endor’s Moon

An advanced level trail, similar in percent slope to Endor, Endor’s Moon also descends the last 1.4 miles through similar terrain. However, this trail is to be constructed with a large
number of advanced skills features, from large jumps to wall rides to elevated balance features and steep drops. Sudden grade changes should be utilized in final trail corridor construction to create a thrilling experience. Its memorable character is due to sizable features nestled deep in an aspen forest. Construction cost estimate is $110,880.

Showoff

Designed as an advanced/intermediate trail, Showoff takes advantage of abandoned road grades that wind underneath Hidden Lake lift. The 3.5 mile trail descends at an average 8.8 percent downhill grade directly underneath the lift, and would provide entertainment and interest for all riders taking the quad lift back to the top, and inspire them to take another run and come back again. It should be designed to include features of all types. Its memorable characteristic should be the flow of riding produced by the switchbacks throughout its length being built up with large radii and berms and/or wall rides. Construction cost estimate is $277,200.

Willy Nilly

Designed to be a beginner/intermediate trail, Willy Nilly begins with a gentle traverse, taking a 3.6 mile ramble down the eastern side of the mountain, intersecting with Cru’s Trail midway. Its vegetative cover ranges from a pine forest traverse to sparse aspen runs, dropping down through scrub oak and sage brush towards the bottom. It accesses hidden meadows en route, including some with significant spring runoff creating picturesque stream environments. Care should be taken to construct rest areas at sites that take full advantage of these scenic areas on the trail, thus creating a memorable intermediate trail that is full of rhythm features, small
aerial features, numerous balance features, beautiful rest areas and views. Construction cost estimate is $285,120.

_Cru’s_

A 1.5 mile intermediate trail that gently winds through a basin at 5.2 percent slope, Cru’s combines a gentle slope with a plethora of small skills features that are constructed to encourage aspiring mountain bikers to test out newfound skills. No gap jumps or large drops should be present on this trail, though significant rhythm features, table tops, small drops, and low-lying balance features should be placed throughout this trail. This trail allows riders to build skills and confidence to expand their comfort zone from the beginner trails of Worldview to more challenging routes such as Endor’s Moon.

The final portion of the trail winds around a scenic overlook that is perfectly suited for a pump track and rest area. Construction cost estimate is $118,800.

_Sundown Trail Descriptions_

_Brown Pow_

An intermediate trail measuring 1.6 miles long, Brown Pow is the longest trail in the Sundown network. The trail begins by traversing just below the exposed rim of the Sundown basin before winding through a series of switchbacks in a large strand of Aspens, below which the trail connects up with Crossover for the final quarter mile of trail. The trail averages a 10 percent downhill slope with the beginning traverse averaging much less.
Midway through the downhill switchbacks, the trail opens up to a flat area that looks out upon the main Powder Mountain development and the canyon road which accesses the site. This location provides an excellent site for a mid-trail pump track, one that would be surrounded by pleasant views and could serve as viewing entertainment from the road or Sundown’s base lodge patio.

The trail should focus on medium scale rhythm features, particularly where lack of vegetation features make the installation of permanent features problematic. The high slope of this trail and all others in the Sundown network create an intermediate to intermediate/advanced skill level trail. This trail, more than any other on the Sundown slopes, spends a good portion of its length within strands of aspen, and the trail’s final construction should take full advantage of the wide aspen spacing to weave future riders among the beautiful trees. Construction cost estimate is $126,720.

Crossover

A .9 mile long intermediate trail which traverses from the upper southern portion of the Sundown slope, across to the lower northern hillside, at a relatively constant 10 percent downhill slope, Crossover contains multiple lengthy stretches between switchbacks, and spends all but a few short stretches outside of dense tree cover. The emphasis on this trail should be fast and continued speed, with large rhythm features coupled with large-radius turns constructed throughout to allow for a continuous high speed experience. Due to minimal vegetation cover,
there should be minimal permanent feature construction throughout the trail, and focus more on earthen rhythm features.

Like Brown Pow, the average slope of this trail creates an intermediate/advanced trail corridor that will appeal to experienced riders more than novices. The good sightlines on this trail, however create an ideal corridor for a high speed trail that will not intimidate riders looking to try to improve their skills. Construction cost is $71,280.

*Basilisk*

Named for the fictional creature created whole from pieces of others, this trail combines all the varied environments of the Sundown slopes into one continuous, chimerical experience. Starting out from the summit, this 1.3 mile long advanced/intermediate trail descends at a 9.5 percent downhill slope towards the base lift. Basilisk begins by traversing the western edge of Sundown’s ridgeline, passing through many areas with significant rock outcroppings and incredible views which are unique in scale and size not just to Sundown, but to the studied Powder Mountain site as a whole. Technical trail features utilizing these boulders at the ridgeline would add an inimitable character to this upper portion of trail.

Following the rocky ridgeline, the trail corridor descends to an open, gladed meadow on the southern edge of the Sundown slopes. It is here that a mid-trail pump track would offer fantastic views and a unique mid-mountain experience, as well as a point to contemplate the trail intersection between Basilisk or the connection over to Dropped and Rocky’s.
Basilisk continues into dense pine vegetation, which will provide excellent wind protection from the wooden features that should be constructed within the wooded areas. The trail makes multiple switchbacks that should be constructed to allow for high speed turns leading into medium to large technical trail features. The end of the trail joins with the lower portion of Crossover to return to the base lift. Construction cost is $102,960.

**Dropped**

An expert only trail, Dropped begins immediately after the southern pump track location and leads a high speed, 12 percent downhill run through nearly three quarters a mile of Sundown’s rocky southeastern slopes. The average slopes on this trail are higher than anywhere else on the mountain, and the exposed, rocky terrain it crosses, creates a natural environment for stone technical trail features to be added.

This trail crosses few major drainages and winds through steep yet sparsely wooded areas. Opportunities for large scale technical trail and trails that offer significant exposure to the steepest slopes on the eastern side of Sundown. The need to construct multiple switchbacks through the latter half of the trail provides an opportunity to construct a slow speed but highly technical trail, with roots, rocks, tight turns, and technical features creating a trail which will attract the bold and passionate mountain bikers. Cost estimate is $59,400.

**Rocky’s**

In many ways a parallel trail to Dropped, Rocky’s is intended to appeal to the expert crowd. Descending half a mile at an average 12 percent downhill slope between the upper and
lower sections of Dropped, the trail is named for a predominance of stone outcroppings throughout its corridor as well as a certain indomitable pugilist. This trail should incorporate both technical switchbacks and low speed, high-skill trail sections in its beginnings, but then end out with a high speed run which surfs the hillside as it descends to meet up again with Dropped.

The trail contains steep slopes, rocky terrain, steep exposures, and should be designed with the expert rider in mind. Cost estimate is $39,600.
Pump Track Schematic Designs

The pump tracks located midway through various trails in the Powder Mountain bike resort network are critical design elements that provide unique and memorable features that are accessible and enjoyable by all levels of riders. They are sited at key locations on site that offer the key criteria of excellent views, shallow grades, and ample space that allow for construction of a pump track and other rest facilities such as benches, shade structures, and bicycle repair stations. The locations are detailed in Figures 64 and 65. These figures are schematic designs created specifically for the site, with rest areas and pump tracks oriented to take full advantage of views on site, fit within the area of shallow slopes on site, and provide a unique and varied riding experience.

Though Figures 64 and 65 indicate multiple pump tracks within both the Hidden Lake and Sundown slopes, the pump tracks illustrated in the following figures are chosen as those of primary importance and should be considered part of the first phase of construction within the Powder Mountain bike resort.
REST AREA & BENCHES

Figure 66. Hidden Lake Pumptrack
Figure 67. Sundown Pumptrack
CHAPTER V

CONCLUSIONS

In our modern era, there is pressure on every business to maximize efficiency and boost profitability. Ski resort business is no different. In an era when climate change will reduce snowpack across North America, the development of mountain bike facilities may become a crucial and necessary step for the long-term success of many mountain resorts.

The techniques developed through this thesis for GIS analysis of terrain offer advantages over traditional trails planning techniques by providing a method to quickly read large scale mountain terrain in its entirety. This process compiles multiple levels of information that can be utilized as one cohesive document to build sustainable trail alignments based on the defensible science of trails maintenance and construction.

The supplemental research created through this thesis provides research findings useful to any who seek to better understand mountain bike recreation. The survey data gathered as part of this thesis provide unique insights into mountain bike resort demographics, user preferences, as well as a sampling of mountain bike resort and mountain bike user spatial distribution. The case study research into competing resorts and popular mountain bike trails around Powder Mountain provides a template for future projects attempting to site or plan mountain bike resort facilities.

However, as with many studies, the knowledge gained by the work is only eclipsed by the opportunities for future studies brought up by the same effort.
The survey work alone presents multiple opportunities for future study. It is a large dataset that could present additional significant findings were more resources devoted to its analysis. Separations of the bulk dataset into meaningful groups could yield significant insight. For instance, if survey responses were separated into geographic regions, they could offer insight into regional preferences in bike park design. Analysis of responses between and among groups that have varied mountain biking experience could deliver insight into design considerations for different skill levels. A more rigorous statistical analysis of the results could potentially tease out a greater understanding of which mountain bike resort design element has the greatest impact on a user’s opinion of a mountain bike resort. These are only a few of the many questions that could be answered by a further analysis of the data generated by this project.

The GIS-based work of this thesis provides a method to quickly plan well thought out trail corridors. However, the trail corridors are not final trail alignments, and future developments in technology and publicly available GIS data could create opportunities to establish final trail contours from similar data. Should DEM data become refined to the two foot level, soils data improve, and vegetation inventory become more robust, a future study could develop highly detailed trails designs, and not just trails corridors. Detailed construction cost estimates and exact placing of features based on cut and fill could be created from a program defining the construction methods used by trail contractors. More detailed GIS information, such as LiDAR might be able to reveal areas of the soil on site that contain high percentages of stone in the soil and would need to be avoided for final construction. For these reasons and
more, much attention should be paid to the emerging GIS technologies as they relate to trails
planning.

As stated in the literature, a number of mountains, particularly Whistler Blackcomb, have
experienced great success with the development of mountain bike resorts. However, many more
have seen meager results come from significant investments. Though this thesis’ survey work
sought to shed some light on the reasons why these differences exist, it is far too coarse of a tool
to reveal those details which differentiate a successful mountain bike resort from a failed one.
Future research should involve detailed case studies to those resorts that prove resilient and those
that do not to better understand regional and local demographics and character, trail and feature
design, resort marketing and other factors that influence a resort’s success. Part of a study of
this nature could focus on the investment needed to create a successful park. How many trails,
or miles of trails, create an experience that is desired by the mountain bike community? Is trail
length or trail variety more important to a paying customer?

Moving forward, climate models will continually need to be updated and reviewed, to
better understand a warmer planet’s impact to mountain resort sports. A detailed study could
further the work cited in this study’s literature review and identify mountain resorts that are at
greater and lesser risk of losing the ability to guarantee a winter season of useful snowpack, and
make recommendations for those that are at greater risk to develop mountain bike facilities.

Finally, though it is the conviction of this author and support can be found in the survey
results, there has been little work done regarding how to reach the middle of the mountain bike
market’s bell curve in regards to mountain bike resorts. If mountain resorts can find how to draw the casual and beginner mountain biker to their resort, as well as those that value more in their recreational experience than big jumps and stunts, the sport as a whole will benefit.

This project reveals the advantages to be found at the intersections of technology and trail, and research and recreation. As climate change creates an environment with shorter ski seasons and longer summer seasons, mountain bike resort development will become an ever more integral part of mountain resort success. By applying GIS technology and informed research, this thesis provides the groundwork necessary to accommodate and encourage the success of mountain bike resorts across the world.
APPENDIX A: Glossary of Terms

*Berm:* A sloped wall of earth forming the outer radii of a trail’s curve. Berms are designed to allow a wheeled vehicle (bicycle) to translate centrifugal force into forward motion.

*Balance Feature (Ladder):* A technical trail feature which elevates a narrow portion of the trail tread above the ground level. The challenge of these features vary with their width, height, and length. The narrower, taller and/or longer a feature is, the more challenging it is to complete.

*Drop:* Any elevated trail surface that comes to an abrupt, pirate-plank like stop, and requires the rider to drop vertically onto an exit ramp.

*Flow:* A colloquial term used by the mountain bike community to describe high quality mountain bike trails. Though a trail with minimal flow may still be considered an excellent trail, the term is never pejorative. The term is used for trails in which construction of trail features and corridor alignment control rider speed without abrupt or sudden chokes to the rider’s movement down the trail.

*Jump (Table Top):* A earthen mound raised from the surrounding trail surface, with a ramped entry and exit path designed to allow a mountain bike rider to become briefly airborne over the solid center, or table top, of the jump. See Appendix C: Trail Feature Construction Document Example for illustrations of different jump types.
**Jump (Double):** A jump constructed of only the entry and exit ramps, without a solid center. These features are less expensive to construct but pose a greater risk to participants.

**Jump (Kicker):** A jump constructed of only the entry ramp. These jumps are suitable as small sizes on flat or gently sloped ground, or can be constructed larger when placed on steeper terrain.

**Pump track:** A closed bicycle track that creates a sine wave like profile, with all turns bordered by berms. Pump tracks allow mountain bike riders to practice balance, cornering and jumping skills by creating a smooth course that can be ‘pumped’ through, rather than pedaled, much as a child on a swingset pumps their legs to move the swing higher and higher.

**Rhythm feature:** Any technical trail feature that is not designed to boost riders airborne, such as a jump, drop or wall ride, but is intended to create a more undulating or winding trail without sacrificing rider speed is considered a rhythm feature.

**Technical Trail Feature (Skills Feature):** Any obstacle constructed and placed for the purpose of challenging or engaging a mountain bike rider can be considered a technical trail feature. Technical trail features can be natural, such as roots or rocks, but the term more often refers to man-made elements.

**Teeter Totter Features:** A type of balance feature that is constructed with a fulcrum that allows the feature to pivot once a rider’s weight has crossed the fulcrum point, and allow the rider to roll down the end of the feature to continue on the trail.
**Wallride:** An extended berm which curves upward into a wall structure and allows riders to utilize a high speed turn in order to briefly ride horizontally.
APPENDIX B: Survey Transcription

Opening Questionnaire (all respondents answer)

1. Hi, My name is IMBA, what’s yours?

2. Where are you from? A zip code is all we need here.

3. What’s your riding style?
   a. Cross Country
   b. Trail/All Mountain
   c. Freeride/Downhill
   d. BMX/Dirt Jump
   e. I have no idea what you’re talking about, I just ride my mountain bike.

4. How many years have you been riding mountain bikes?
   a. Less than two, and loving every day of it
   b. Two to Five – I can remember when no one else rode a 29er.
   c. Five to Ten – I remember when 4: was long travel
5. Lift Access Bike Park? Community Bike Park? Bike Park Development? What's a Bike Park? Based on the answer to this question, respondents would be directed to one of 4 forms

a. Lift Access Bike Parks. Choose this answer if you're most familiar with, or recently visited a lift access bike park at a ski resort.

b. Community Bike Parks. Choose this answer if you're most familiar with, or recently visited a community bike park, one built for and by the community.

c. Bike Park Development. Choose this answer if you have been or are involved with the development of a community bike park.

d. Bike Park? I don't think I've ever been to one.

**Lift Access Mountain Bike Park Questionnaire**

1. What was the name of the last mountain bike park you visited?

2. Where is that bike park located?

3. How long ago did you visit the park?
   a. Less than six months ago
   b. Six months to one year ago
   c. One to three years ago
   d. More than three years ago

4. How much did you pay to ride there?

5. Was the price you paid worth the Experience?
   a. You bet, I can’t wait to return
   b. Nah, not really.
6. Did you travel specifically to go ride at this bike park?
   a. Sure did
   b. No, I was travelling for other purposes

7. How long did your trip last?
   a. One day
   b. Two to five days
   c. More than five days

8. What features are present at this bike park?
   a. Beginner level trail riding
   b. Intermediate level trail riding
   c. Trails just for kids
   d. Pump track
   e. Skills area
   f. Technical trail features constructed from wood, dirt, or rock
   g. Dirt Jumps
   h. Flow trails or other gravity based trails
   i. Slope style and/or free ride trails
   j. Other

9. Tell us about the trail quality at that bike park
   a. Trail conditions: maintenance, soil conditions, etc. (1-5 scale)
   b. Trail routing: ease of access, views, traffic, etc. (1-5 scale)
   c. Trail signage: easy to navigate park, well marked features, etc. (1-5 scale)
10. Tell us about the skills features of that bike park
   a. Feature conditions: maintenance, structural integrity (1-5 scale)
   b. Feature design: impressive and unique? Or simplistic and ho-hum? (1-5 scale)
   c. Feature range: was there a full range of features offered, from beginner to expert and everything inbetween? (1-5 scale)
   d. Feature placement: were jumps/ladders/wallrides, etc put in the right place for rider speed and feature size? (1-5 scale)

11. Tell us about the lift experience at this bike park
   a. Lift ease of use (1-5 scale)
   b. Lifts ease of access: from trails, from parking (1-5 scale)
   c. Lift speed (1-5 scale)

12. Tell us about the lodge experience at this bike park
   a. Food and drink quality (1-5 scale)
   b. Ease of lodge/facilities access: from trails, from parking (1-5 scale)
   c. Quality of indoor spaces (1-5 scale)
   d. Quality of outdoor spaces: patios, parks areas, etc (1-5 scale)
13. Were there any non-mountain biking activities also taking place?
   a. None
   b. Sightseeing
   c. Equestrian tours
   d. Frisbee Golf
   e. Motorized Sports
   f. Hiking
   g. Other _________

14. If there were non-mountain bike activities, how do you feel they affected your experience?
   a. Negatively impacted my experience
   b. No impact to my experience
   c. Improved my experience
   d. n/a

(respondent is then presented with the thank you and goodbye page)

**Community MTB Park Questionnaire**

1. What’s the name of the last mountain bike park you visited?
2. Where is it located?
3. How long ago did you visit the park?
   a. Less than six months ago
   b. Six months to one year ago
   c. One to three years ago
   d. Greater than three years ago
4. Did you contribute to the development of this park?
   a. Yes, I was a volunteer worker at organized build/maintenance days.
   b. Yes, I contributed funds towards the completion of this park.
   c. Yes, I took part in the planning and advocacy that helped get this park built.
   d. No, but I’m sure thankful somebody brought this to the community.

5. Did you travel specifically to go ride at this bike park?
   a. Yes, I took the trip specifically to ride there
   b. No, I traveled for other reasons

6. How long did your trip to the park last?
   a. One day or less
   b. Two to five days
   c. More than Five Days
7. What features are present at this bike park?
   a. Beginner level trail riding
   b. Intermediate level trail riding
   c. Advanced trail riding
   d. Trails just for kids
   e. Pump track
   f. Skills Area
   g. Technical trail features constructed from wood, dirt, or rock
   h. Dirt Jumps
   i. Flow Trails or other gravity based trails
   j. Slopestyle and/or freeride trails
   k. Other

8. What were the trails like at the bike park?
   a. Trail conditions: maintenance, soil conditions, etc. (1-5 scale)
   b. Trail routing: ease of access, views, traffic, etc. (1-5 scale)
   c. Trail signage: easy to navigate park, well marked features, etc. (1-5 scale)

9. What were the skills features like at the bike park?
   a. Feature conditions: maintenance, structural integrity (1-5 scale)
   b. Feature design: impressive and unique? Or simplistic and ho-hum? (1-5 scale)
   c. Feature range: was there a full range of features offered, from beginner to expert and everything inbetween? (1-5 scale)
   d. Feature placement: were jumps/ladders/wallrides, etc put in the right place for rider speed and feature size? (1-5 scale)
10. What about the facilities at the park?
   a. Quality of vehicle parking (1-5 scale)
   b. Quality of public facilities (1-5 scale)
   c. Quality of non-bike space (picnic benches/shade & rest areas/observation areas) (1-5 scale)

11. Were there any non-mountain biking activities also taking place in or around the park?
   a. Hiking
   b. Ball sports
   c. Frisbee golf
   d. Dog park
   e. Skate park
   f. Equestrian uses
   g. Other________

12. If there were non-mountain bike activities, how do you feel they affected your experience?
   a. Negative impact on my experience
   b. No impact on my experience
   c. Positive impact on my experience
   d. n/a

/respondent is then presented with the thank you and goodbye page)
Mountain Bike Park Development

1. Are you a member of IMBA and/or an IMBA affiliated chapter, club or patrol?
   a. Yes
   b. No

2. If so, what is the name of the IMBA affiliated group you are with?

3. Thanks for providing info about a current bike park project. What is the name of the bike park you are telling us about?

4. Where is the bike park (planned or existing) located?

5. Is there a website associated with this park or project?

6. What is the status of the park?
   a. Planning phase – no site yet selected
   b. Planning phase – site selected
   c. Design phases (fundraising/design/approval)
   d. Construction Phase
   e. Existing
7. What funding sources are supporting this park?
   a. Individual donations
   b. Local business donations
   c. Corporate business donations
   d. Local government grants or funding
   e. State government grants or funding
   f. Federal government grants or funding
   g. Foundation grants
   h. Other

8. Which terms best describe the setting for this bike park?
   a. Underused land in remote or less than desireable location
   b. Un-utilized land in desireable location
   c. Land in light use for non-cycling recreational activities
   d. Land in heavy use for non-cycling recreational activities
   e. Other

9. What features are present at this bike park, or will be present once it is built?
   a. Beginner level trail riding
   b. Intermediate level trail riding
   c. Advanced level trail riding
   d. Trails just for kids
   e. Pump track
   f. Skills Area
g. Technical trail features constructed from wood, dirt or rock
h. Dirt jumps
i. Flow trails or other gravity based trails
j. Slopestyle and/or freeride trails
k. Other

10. What best describes the agencies that have or will have authority over this park?
   a. City parks or city parks/rec department
   b. County parks or County parks/rec department
   c. State parks agency
   d. Federal Agency
   e. Other

11. Who designed or will design this mountain bike park?
   a. Volunteers from the MTB community
   b. Volunteers with professional experience in design
   c. Professional trail builders
   d. Park and rec staff
   e. Other
12. What non-cycling facilities will/does this park have?
   a. Small parking lot
   b. Large parking lot
   c. Signage (wayfinding/entryway/informational)
   d. Restrooms
   e. Picnic area or pavilion
   f. Hiking and/or equestrian trails
   g. Other

No Bike Park Experience Questionnaire

1. So you haven’t been to any mountain bike parks, but are there any you’re aware of?

2. What are some major reasons you haven’t been to a mountain bike park?
   a. There aren’t any near me
   b. The cost of a lift ticket is prohibitive
   c. The terrain there is too challenging
   d. Not a family friendly activity
   e. Other ______________
Bike Park? Never Been Page

1. So you haven’t been to any mountain bike parks. Are you aware of any existing mountain bike parks?

2. How likely are you to visit a mountain bike park in the next year? (1-5 scale)

3. What are some of the major reasons you haven’t been to a mountain bike park?
   a. There aren’t any near me
   b. The cost of admission is prohibitive
   c. The terrain is too challenging
   d. It isn’t a family friendly activity

Thank You and Goodbye Page

1. Thanks for taking the time to share your thoughts. If there is anything else you’d like to share, feel free to add your comments below
Appendix C: Bike Park Construction Document Examples

T1.0 DIRT FEATURES
VARIES (LIP RADIUS)
VARIES (LIP HEIGHT)
VARIES (GAP DISTANCE)
VARIES (LANDING HEIGHT)
VARIES (FEATURE LENGTH)

TOP OF LIP AND LANDING TO BE RADIUSED

6" CUSTOM SURFACING MIX, TYP.

VARIES (LANDING RADIUS)
VARIES (LIP HEIGHT)
VARIES (GAP DISTANCE)
VARIES (LANDING HEIGHT)
VARIES (FEATURE LENGTH)

TOP OF LIP AND LANDING TO BE RADIUSED

CASE PAD

6" CUSTOM SURFACING MIX, TYP.

VARIES (LANDING RADIUS)
VARIES (LIP HEIGHT)
VARIES (STEP-UP HEIGHT)
VARIES (STEP-DOWN HEIGHT)
VARIES (GAP DISTANCE)
VARIES (LANDING HEIGHT)
VARIES (FEATURE LENGTH)

TOP OF LIP AND LANDING TO BE RADIUSED

CASE PAD

6" CUSTOM SURFACING MIX, TYP.

*FOR ESTIMATING PURPOSES ONLY. FINAL DIMENSIONS SUBJECT TO FINAL DESIGN BASED ON SITE CONDITIONS AND RIDE CONFIGURATION.

*FOLLOWING TRAIL CONSTRUCTION, ALL NON-RIDING AREAS IN TERRAIN PARKS TO BE DRESSED WITH 2" OF TOPSOIL (BY OTHERS). PLAN FOR POSITIVE OUTFLOW AND DRAINAGE ACCORDINGLY.
BIBLIOGRAPHY


