Examining the Economic Impacts of Climate Change on Colorado Ski Communities Through 2050

By
Stephen Shelesky
University of Colorado at Boulder

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Thesis Advisors:

Dale Miller, Department of Environmental Studies, Committee Chair
Mark Williams, Department of Geography
Phil Graves, Department of Economics

Abstract

This thesis explores the relationships between snow quality, skier visits, and economic revenue in Colorado. The ski industry is an integral part of the Colorado economy, providing thousands of jobs and billions in economic revenue. Recently, climate change has begun to pose an intensifying threat, eyeing one of Colorado's most iconic and key industries. Determining the range of potential economic effects due to climate change's impact on the ski industry is the primary goal of this thesis. To forecast economic changes for Colorado, a series of regression analyses are conducted, built upon historical environmental and economic data. It is found that Snow Water Equivalent (SWE) is a significant driver of skier visitation in Colorado, therefore also affecting economic revenue. However, results show that precipitation has a much larger influence of SWE in comparison to temperature. This contests the original postulation in this thesis, as temperature was initially thought to be more significant. It is concluded that the Colorado will suffer some economic loss due to the impacts of climate change on the ski industry. However, quantifying this accurately is difficult given the nature of the data and uncertainty in climate models. This thesis finds it to be in the best interest for ski resorts and ski communities to innovate and adapt now, to allow for proper resilience no matter the magnitude of changes that may occur.

Keywords: climate change, Colorado, ski industry, linear regression analysis, snow water equivalent, retail sales revenue

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Preface

This thesis is being submitted to the University of Colorado Boulder in partial fulfilment of the requirements to receive honors designation in Environmental Studies May 2016. The work found in this thesis is entirely original with proper acknowledgements and references made where others work was used. The motivation for this thesis came from my love for snow and snowboarding which first developed when I moved to Colorado in 2012. However, climate change undoubtedly poses a threat to snow, skiing, and the towns and businesses that thrive in-part to the ski industry. This inherent threat to one of my passions, drove me to research both the magnitude and expected implications climate change could pose on Colorado ski communities.

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Introduction

With currently unchecked greenhouse gas (GHG) emissions, climate change is continuing to thrive and pose an ever-intensifying threat. Globally, there are a multitude of industries that depend on a stable climate to maintain successful business. When the climate is disrupted, as it is being currently, billions of dollars are put at stake by jeopardizing these key industries. In Colorado, the outdoor recreation industry is a significant contributor to the state economy, largely because of the massive ski industry (Colorado Ski Country USA and Vail Resorts, 2015). With 25 ski resorts, some of which are world renowned, located in Colorado, there is a lot at stake when considering climate change. However, “our understanding of how climate variability affects the sector and how the sector has adapted to climate remains very limited” (Scott et al., 2004). Particularly because “relative to other economic sectors (e.g. forestry and agriculture) tourism has been largely neglected by the climate change impact research community” (Scott et al., 2004). My thesis statement is: increased temperatures will cause average snowpack to deteriorate in 2050 resulting is fewer skier visits and decreased economic revenue for Colorado.

Considering “winter tourism and the ski industry more specifically, have been repeatedly identified by climate change assessments and scientific literature as particularly vulnerable to global climate change, Colorado could certainly be impacted” (Scott et al., 2006). With that being said, it is relatively certain that ski companies will face a direct impact from climate change and need to adapt. Likewise, the many businesses and industries that have become successful in accordance with the ski industry will also be affected. Namely, the local restaurants, small shops, and other businesses that have come to thrive in ski towns will certainly be impacted. While certain businesses in ski towns are driven by local use, a majority rely on a consistent amount of visitors arriving each season. Overall, many counties in Colorado are uniquely positioned because of their reliance on outside dollars to maintain economic prosperity. If it is found that snowpack and skier visits are tightly correlated, then the era of climate change may put a lot in jeopardy. Among the many impacts climate change will have on Colorado, the effect on the ski industry poses both a social and economic problem.

The purpose of this thesis is to determine, based on various climate models, the potential range of economic impacts on ski dependent economies in Colorado by 2050. To satisfy the objective, an array of methods is created and employed. Specifically, numerous simple and multiple regression analyses are being performed to examine the historical relationship between certain environmental and economic variables. The key relationships being studied are that of snowpack and skier visits and skier visits and retail sales revenue. Further, three main forecasts are being made for 2050: snowpack (expressed as Snow Water Equivalent), skier visits, and retail sales revenue. The results of each prediction will vary based on the temperature and precipitation model being applied. This thesis hypothesizes that increased temperatures in Colorado will adversely affect snowpack and reduce skier visits and economic revenue. However, theses methods are further clarified and explained in the "Methods" chapter of this thesis.

Overall, this thesis intends to measure the partial magnitude of climate change on Colorado by exploring the economic significance of the ski industry. By accurately providing this information, those subject to the impacts will be better able to adapt and develop resilience to climate change. For ski resorts themselves, having this information will be critical in helping determine where new investments (e.g. snowmaking infrastructure) are best made. The same principle applies to the other involved industries as they have also begun, and will need to continue adapting. Although the economic outlook will be forecasted in this thesis, my hope is that the affected industries will be able to minimize economic loss with proper resilience strategies. With that being said, more established resorts with plentiful capital may be better suited to maintain business in a changing climate.

Background

The Colorado ski industry is unique and encompasses numerous qualities that differentiate it from those of other states. As a state, diverse topography and climates characterize Colorado as we know it. Therefore, climate change will have both varied and widespread impacts making exploration of historical climate patterns crucial. Additionally, the state economy is equally individual from that other states being defined by particular key industries. The purpose of this section is to provide an understanding of all the aspects described prior. Additionally, similar studies that have been conducted will be acknowledged and probed for both significance and shortcomings.

The Colorado Ski Industry

In modern history, Colorado has always been recognized as a renowned ski destination which all began when Howelsen opened it's slopes in 1915. Today, Colorado supports the largest ski industry in the United States consisting of 25 resorts. In aggregate, "42,116 acres of skiing, 323 lifts, and 2,427 trails" (Colorado Ski Country USA, 2015) are had among the resorts. Further, Colorado boasts a large variety of terrain from expansive bowls to groomed runs and legendary glades to competition-worthy terrain parks. The immense offerings in Colorado have made it a desirable destination, "drawing over 12.6 million skiers during the 2013-2014 season alone" (Blevins, 2014). Furthermore, Colorado "accounts for more than 20 percent of ski and snowboard visits in the United States" (Colorado Ski Country USA, 2015) With that being said, many local economies within the state are reliant on their accompanying ski resort. Currently, 14 counties boast ski resorts in Colorado being: Summit, Pitkin, Eagle, Gunnison, Boulder, Routt, Chaffee, Mesa, La Plata, San Juan, Grand, Garfield, San Miguel, and Mineral.

The current structure of the industry in Colorado is interesting, as independently owned resorts are becoming scarce. With "Aspen Skiing Company owning Aspen Mountain, Aspen Highlands, Buttermilk, and Snowmass Ski Area in south-central Colorado. Then, Vail Resorts holds Vail Mountain, Beaver Creek Resort, Breckenridge Ski Resort, and Keystone Resort not including their out-of-state acquisitions. Further, Intrawest owns Steamboat Ski Resort and Winter Park Resort, while Powdr Corp owns Copper Mountain Resort. Finally, Crested Butte Mountain Resort is held by Triple Peaks LLC" ("Who Owns Which Mountain Resorts, 2015). However, "Colorado Ski Country USA (CSCUSA) is a non-profit trade association that represents the ski industry for the state, conducting public policy, public relations, and marketing" (Colorado Ski Country USA, 2015). Note that CSCUSA only binds 21 resorts together as Vail Resorts is excluded from the association.

The overwhelming consolidation of the ski industry in Colorado could be of benefit as climate change becomes a more prominent influence. "Large corporate entities like Intrawest, Vail Resorts, and American Skiing Company, may be less vulnerable to the impacts of climate change because of more diversified business operations, regionally diversified resort portfolios, and higher amounts of capital" (Scott, 2003). Generally speaking, resorts under a corporate umbrella are much better equipped to weather years with low snowfall when compared to smaller operations. Take California for example; where bad winter and minimal snow have plagued resorts in recent years. An article from Bloomberg recently noted that in early 2015 some smaller resorts such as China Peak, Badger Pass, Dodge Ridge, and Sierra at Tahoe were forced to close early due to insufficient snowpack. In contrast, Heavenly, owned by industry-giant Vail Resorts has been equipped with plentiful snowmaking equipment, covering 73 percent of its 4,800 acres. Large scale snowmaking provides a clear advantage, which gives Heavenly and other comparable resorts a leg up. However, Vail Resorts still reported a 28% decline in Lake Tahoe skier visits during the 2014-2015 season. In contrast, some smaller resorts only have the cash reserves to survive one or two bad seasons before permanently closing. With that being said, corporate owned Colorado resorts may too be at an advantage when weather fails to cooperate. (Spence, 2015)

Further differentiating Colorado from other states with prominent ski industries, is that it caters largely to destination skiers. To clarify, destination skiers are those that come from out of state, often by flying, to visit any given ski resort. “In a 2014 demographic study conducted by the National Ski Areas Association (NSAA) it was found that rocky mountain resorts drew the most diverse guests, geographically speaking. In fact, only 45.4 percent of skiers originated from the rocky mountain region, while 20.2 percent came from the south region and 11.6 percent the Midwest region. Additionally, the pacific region generated 7.4 percent of the visits, while the northeast region also contributed 8.5 percent. This is a significant contrast to the Pacific Northwest ski industry where 93.1 percent of visitors came from within the region” (National Ski Areas Association, 2014). In Colorado, “more than seven million skier visits were generated by destination skiers in addition to those driven by the 500,000 residents during the 2013-2015 season” (Colorado Ski Country USA and Vail Resorts, 2015). For reference, the rocky mountain region consists of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.

The Colorado State Economy

Colorado supports a diverse economy, fueled by an array of industries that serve as the backbone. The Colorado Office of Economic Development and International Trade recognizes 14 key industries: "Advanced Manufacturing, Aerospace, Bioscience, Creative Industries, Defense & Homeland Security, Electronics, Energy & Natural Resources, Financial Services, Food & Agriculture, Health & Wellness, Infrastructure Engineering, Technology & Information, Tourism & Outdoor Recreation, and Transportation & Logistics." (Colorado Office of Economic Development & International Trade, 2015). While many of these industries are familiar, having Tourism & Outdoor Recreation as a "key" industry is uncommon in other states. Taking this further, "in June 2015, Governor Hickenlooper appointed Luis Benitez as the state's first Director of the Colorado Outdoor Recreation Industry Office" (Colorado Office of Economic Development & International Trade, 2015). This noteworthy action resembles Colorado's commitment to maintaining the outdoor industry as an essential piece of the state economy.

Statistically, the outdoor recreation and tourism industries are nothing short of impressive. In "2011 Colorado welcomed a record 57.9 million travelers, and in 2010 a record $14.6 billion were spent by travelers" (Colorado Office of Economic Development & International Trade, 2015). Tourism aside, the outdoor recreation industry contributes over "$34.5 billion in annual economic activity and creates 313,000 jobs, while also adding nearly $20 million to the states Gross Domestic Product (GDP)" (Colorado Parks and Wildlife, 2014). Considering skiing, snowboarding, and other winter sports are the keystone to Colorado's outdoor recreation industry, it can be inferred that a lot of this economic activity is the result of these sports.

Recently, an economic impact study backed by Colorado Ski Country USA and Vail Resorts detailed the ski industry's contribution. Not only did the report find that the ski industry "generates $4.8 billion in annual economic impact but that it also supports over 46,000 jobs in Colorado." Further, the industry's role in generating economic activity and jobs for local tax bases was stressed. It stated "Colorado communities near ski resorts have experienced strong growth in taxable sales, funding infrastructure and other quality of life amenities." Overall, "this report confirms the importance of the ski industry to Colorado, both as an economic driver and globally recognized symbol of our state." (Colorado Ski Country USA and Vail Resorts, 2015).

Climate Change in Colorado

The habitability of earth is large due in part the greenhouse effect, which works to regulate atmospheric temperature. Briefly, short wave radiation from the sun get absorbed by the earth's surface and longer-wave infrared radiation is reemitted back into the atmosphere. However, greenhouse gasses (GHG) in the atmosphere are capable of trapping this infrared radiation and remitting it back to earth, causing warming. Prevalent greenhouse gasses include carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), sulfur oxide (SOx), and water vapor (H_2O). While these gasses exist naturally, humans have added a substantial amount to the atmosphere primarily through the combustion of fossil fuels. Consequently, the additional greenhouse gasses have expedited the warming process. (Williamson et al. 2008)

The rapid addition of greenhouse gasses to the atmosphere has caused our global climate to respond with warming surface temperatures and adverse effects on both human and natural systems. The most recent Intergovernmental Panel on Climate Change (IPCC) Synthesis Report states "evidence of observed climate change impacts is strongest and most comprehensive for natural systems. Further, it details that many regions are experiencing changes in precipitation and the melting of snow and ice, which is altering hydrological systems" (IPCC, 2014). In Colorado, one of the primary concerns is snowpack as this not only fosters a ski environment but also provides the water essential to both humans and ecosystems. Additionally, "climate change has long been seen as a potential threat to snowpack and ecosystems in the American West… and higher temperatures will result in earlier snowmelt and decreased snowpack" (Katzenberger et al., 2006).

On average, "statewide temperatures have increased by 2.0°F over the past 30 years and 2.5°F over the past 50 years" (Lukas et al. 2014). However, in Colorado, changes in climate are more subjective due to its mid-continental location, high elevations, and the complex topography of the mountains, plains, and plateaus" (Lukas et al. 2014). Further, "beyond Colorado's mountainous topography, there are several major air mass movements affecting the region" (Katzenberger et al., 2006). Therefore, the relative increase in temperatures will vary spatially throughout the state. Notably, the "North Central Mountains warmed the most at 2.5°F while the San Juan Mountains in Southwestern Colorado have only experienced 0.2°F warming. Additionally, minimum temperatures have increased more so than maximum temperatures in the last 50 years. In other words, the nighttime lows are increasing more than the daytime highs.

Further, the largest changes in annual temperatures have occurred at higher altitudes, and winter a summer temperatures have increased more than spring and fall (Williamson et al., 2008). With climate change intensifying, it is expected that Colorado will see both further temperature increase and higher precipitation. According to the US Environmental Protection Agency, temperatures at the highest elevations may increase by 5-6 degrees Fahrenheit during summer in winter over the next 100 years. (Williamson et al., 2008) Overall, it must be understood that Colorado is a relatively complicated place to both measure and forecast changes in climate. However, considering global climate is regulated by the amount of greenhouse gasses present, there are many potential scenarios for Colorado. Therefore, the affects on the ski industry will vary spatially and depend on respective temperature and precipitation changes.

Literature Review

Climate change assessments on the ski industry have been conducted in Austria, Australia, Japan, Canada, Switzerland, and the United States. Even though differences in methodology exist, all of the studies project varying negative consequences for the industry. (Scott et al., 2007) However, many studies fail to address the potential economic loss or do so briefly. In Colorado, two primary studies have performed economic analyses of the state ski industry in the face of climate change. Namely, "Climate Change and Aspen: An Assessment of Impacts and Potential Responses" from 2006 and "Climate Impacts on the Winter Tourism Economy in the United States" from 2012. The former was exclusive to Aspen while the latter was nationwide yet bearing results specific to Colorado.

Climate Change and Aspen: An Assessment of Impacts and Potential Responses

Perhaps the most relevant to Colorado, "Climate Change and Aspen: An Assessment of Impact and Potential Responses" is an incredibly comprehensive report on the impact of climate change on an isolated portion of the industry. The report detailed potential impacts on mountain snow, local ecology, stream flow, and socioeconomic factors. However, the sections on mountain snow and socioeconomic were most relatable to this thesis. Overall, the study found that temperature was increasing while precipitation was decreasing for the Aspen area. Additionally, it stated that the ski season will start later and end earlier, with skiing in Aspen being completely ended by 2100 under the high emissions scenario. These results are comparable to those found in other studies around the globe in being that something bad will happen, it is just the magnitude that is uncertain. While the scientific analysis and projections of snowpack were relatively sound, certain aspects of the socioeconomic impacts study reduced the reports credibility.

The report uses climate models to make projections about snowpack for Aspen mountain at two milestones being 2030 and 2100. This report and others have all noted “analysis of snowpack as the most well-suited indicator of climate change” (Katzenberger et al., 2006). When considering the acceptable operating levels for snowpack as detailed by Aspen Skiing Company, the report was also able to estimate changes in season length. In brief, snowpack was linked to changes in skier visits to develop a coefficient that can be later applied to forecast changes in skier visits at the defined milestones. However, the report made some false claims regarding impact on skier days, particularly when discussing historical correlations.

Specifically, it claimed “that the correlation between snowfall and skier days was much tighter before the advent of snowmaking in 1982. Since then the correlation has been dampened but we maintain they are still related” (Katzenberger et al. 2006). This statement seems to be false, because very limited correlation is seen before the addition of snowmaking. Instead skier visits strongly trend upward regardless of changing snowfall. These were observations made from the graphs provided in the report. With that being said, during the horrible 1976-1977 and 1980-1981 seasons, skier visits are seen to sharply decline. During these seasons Aspen Mountain was forced to open late due to very minimal snowfall. But this still fails to explain why skier visits climbed during 1968-1969 season even though snowfall was similar to that of the seasons listed prior. Overall, the original statement is a bit far-stretched when the presented data only minimally supports it. Granted, the report considers “snowmaking as an important hedge against climate variability” so finding a “dampened” relationship as result supports this.

Another shortcoming of the report is the recognition of skier visits and snowpack as being a solely linear relationship. Alternatively explained, this means skier visits will decline in accordance with snowpack at a constant rate. This fails to recognize that skier visits will likely face sharp decline before snowpack hits zero. According to “Aspen Mountain managers snowpack should be at least 14 to 15 inches in depth to allow for adequate skiing” (Katzenberger et al., 2006). Therefore, if a climate model forecasts that this will not be attained, the linear model becomes flawed. Without enough snow depth, the resort may have to close completely and skier visits will drop to zero. More realistically, it is likely that ski seasons will be shortened rather than a thing of the past all together. However, it widely accepted that ski resorts need to be open for 100 days to remain profitable. In summary, the relationship between skier visits and snowpack is only linear to a certain threshold. The threshold may be that it is no longer profitable to keep the lifts turning, or that the mountain is simply no longer skiable. Regardless, this threshold will be reached before snowpack is completely gone and this needs to be appropriately considered.

Climate Impacts on the Winter Tourism Economy in the United States

Produced for Protect Our Winters, a nonprofit, and the Natural Resources Defense Council, this report measured the impacts of climate change on the ski industry on a national scale. However, the report was further segmented by region, one of which being the Central Rocky Mountains. For that region, which includes Colorado it was determined that “under a higher-emissions scenario, Rocky Mountain mean snow depth in winter (Dec-Apr) is expected to drop to zero. Specifically, the report concluded that there was 7.7% change in skier visits for Colorado when comparing high to low snowfall years, leading to potentially significant economic loss" (Burakowski et al., 2012). While these findings are certainly alarming, the large scale of this project created some limitations and less precise methods.

First, when developing a correlation between skier visits and snowfall, the report only utilized differences in "high" vs. "low" snowfall. For Colorado, the "high" years used were 2008 and 2003 while the "low" years were 2002 and 2004. Even though these years serve as extremes in either case, this seems like data was cherry-picked to support their conclusion. Further, by only using four total years to develop a correlation, the sample size is incredibly small. For the results to be truly significant, skier visits and snowfall data should be examined for a much longer time frame. The incredibly small sample size discredits much of this study, as it is no surprise a strong correlation exists between extremes. Further, the small sample size increases the likelihood that external factors aside from snowfall influenced skier visits.

To determine economic impact, the study used "IMPLAN (Impact analysis for planning) to provide a snapshot of economic activity for a given moment in time, using economic multipliers. Further, IMPLAN will estimate employment, wages, and economic value added for any given year" (Burakowski et al., 2012). To determine the change in skier resort revenue "the difference in skier visits for higher- and lower-snowfall years was multiplied by the average total revenue per skier visit within the region". Understandably, sweeping averages for regions need to be determined, but this will skew results as well. For the rocky mountain region per day skier visit revenue was estimated at $82.59, which may be true in most places. However, Colorado is above average in terms of major, destination ski resorts. Other states in the region are lucky to have one resort as profitable as Vail or Aspen, but Colorado has many. Therefore, it can be assumed that average per-day skier revenue is higher for Colorado. Further, the report acknowledged that the "economic multiplier calculated by IMPLAN and economic value added multiplier were slightly above average when compared to other studies" (Burakowski et al. 2012). This statement further discredits the study and provided further evidence for manipulating data to reach a desired conclusion.

Economic Impacts of Climate Change on Colorado

In 2008, The Center for Integrative Environmental Research at the University of Maryland conducted an assessment about the economic impacts of climate change on Colorado. This report was part of a larger series that studied economic impacts on individual states nationwide. Due to the nature of Colorado's economy, the ski industry dominated a significant portion of the report. Additionally, the report noted that too much concern with climate change was over the assumed costs associated with reducing GHG emissions. Whereas "the costs of inaction are frequently not calculated…. These costs include such expenses as rebuilding or preparing infrastructure to meet new realities" (Williamson et al., 2008). Therefore, state and local policy makers should make proper decisions to adapt certain systems, such as water or public health that may be impacted. This obsession with the cost reducing GHG emissions is reasonable, considering the effects of climate change will be variable by location. Instead, properly investing in local mitigation and adaptation would likely be a better use of funds. The goal of the series of reports, such as this one examined here, is to equip policy makers with information curtailed to their state. Therefore, identifying vulnerable industries and systems is particularly beneficial.

Similar to other studies, climate data are derived from the Canadian and Hadley climate change models. However, the report mentioned that "additional regional, state and local studies are used to expand on this work, as well as new calculations derived from federal, state, and industry data sources" (Williamson et al., 2008). Some economic data was directly relatable to forecasted climate changes derived from numerous climate models. But similar to Burakowski et al. 2012 IMPLAN was used to measure ripple effects and further elaborate on future economic conditions. Ripple effects are “indirect effects that are triggered as impacts on individual sectors in the economy ripple through to affect others (sectors)”(Williamson et al., 2008). To clarify, direct impacts are easily quantifiable, like jobs or output, and usually traceable to a single source. However, ripple effects usually consist of indirect or induced impacts that happen when one sector relies on another for certain goods and services. For example, the supplier of food and beverages to a local restaurant would be indirectly impacted by slow business at the store front.

Expectedly, tourism was found to be the most jeopardized in Colorado due to it’s strong reliance on skiing and other winter recreation. The only climate scenario examined was continued emissions, whereas atmospheric CO_2 would reach 700 parts per million (ppm) by 2100. Under this scenario, “the snowline could increase by 328-1,312 feet and the snow season could become 30 days shorter…. potentially imperiling the industry” (Williamson et al., 2008). However, this was based under the assumption that “the typical ski resort needs 100-105 days of skiing to secure the average industry profit margin of 6.5-7 percent” (Williamson et al. 2008). Finally, the report claimed that “total economic loss of over $375 million and 4,500 jobs could be had by 2017 with just a 1 percent decrease in tourist visits” (Williamson et al. 2008).

Overall, this report was not intended to be a study on the Colorado ski industry which provides some justification for certain omissions. However, there are a very limited amount of studies that examine the relationship between climate change, skiing, and the economy in Colorado. Therefore, a broad economic report such as this was sufficient in providing additional insight into the Colorado ski industry in the era of climate change. Perhaps the largest incompetency in this report is the failure to thoroughly detail methodology for results. While many alarming conclusions were reached, the report hardly provided any background on the process for analyzing data. Instead, one was inclined to surmise based on the rather arbitrary methods described. Further, the report only researched a single climate scenario, being ignorant of other potential futures.

Methodology

The methods for this thesis involve preforming numerous simple linear regressions and one multiple linear regression between both environmental and economic variables. The environmental variables include Snow Water Equivalent (SWE), temperature, and precipitation. While economic data will be sales tax revenue derived from county retail sales reports compiled by the Department of Revenue and skier visit statistics from numerous sources. Further, the correlation coefficients found between differing variations of the historical data will serve as the framework that future forecasts are modeled from. All data for this thesis ranges from 1993 to 2014 to align with available aggregate skier visit statistics for Colorado. The only exception is retail sales revenue which ranges from 1999 to 2014, as this data is not individualized by county prior to that date. The ultimate goal is to forecast 2050 skier visits and quantify how the economy may respond in a dollar value. To reach this result, regressions will be conducted between the following variables: SWE and temperature, SWE and precipitation, SWE and precipitation/temperature, SWE and skier visits, and skier visits and retail sales revenue. Determining the influence of temperature and precipitation on SWE will be crucial as this will allow the application of climate models to forecast 2050 SWE.

First, the relative contribution of each ski resort to aggregate skier visits will be determined and calculated as a percentage. This will be completed using high-resolution skier visit statistics that is readily available until 2005-2006 ski season. After this season, skier visit statistics became propriety making statewide skier visits the only available option. Therefore, it is being assumed that each areas contribution during the 1993-2006 timeframe is relatively comparable to current times. The purpose of this step is to eliminate ski areas with insignificant contributions to statewide skier visits. Specifically, those that contribute less than 1.5 percent will be excluded unless they exist in the same county as a more substantial resort. This will allow for more accurate economic analysis later in the study by eliminating counties that likely receive insignificant economic benefit from their local ski area.

Next, the historical data from each of the environmental factors will be collected for the same timeframe of 1993 to 2014. Each of the factors, being SWE, temperature, and precipitation will be examined for any apparent trends. All environmental data is being derived form SNOTEL weather stations located within reasonable proximity to ski areas being included within the study. Specifically, a total of 18 stations are being utilized in this study to allow for an adequate amount of data. Each of the stations was selected based on proximity to the respective ski area, elevation, and installation year. Following data collection, numerous linear regressions are performed to determine the significance of any given relationship between economic or environmental variables.

Both the data collection and analysis process for all environmental variables will be the same. Therefore, the variables being considered are SWE, temperature, and precipitation. All SNOTEL stations take a reading for each one of these variables daily, for temperature average for that day is recorded by the station. However, for temperature and precipitation total accumulation is recorded, meaning the value never decreases throughout the season, but rather increases until peak in late April or May. Regardless, all of the daily recording will be documented from November 15th – April 15th of each season being studied. The prior dates were chosen because they best correspond with typical ski season length in Colorado. All of the daily data points for the respective variable will be averaged for each month and then again across all months, creating a season long value. Once this is conducted for every season, the data will once again be averaged across all seasons, to create a single mean for that station. Because 18 stations are being considered, this process will be completed for each one. As result, each station will essentially bear a historical mean representing the environmental variable being studied.

Next a series of regressions will be run between all of the environmental variables. Because this thesis is using SWE to represent snowpack, the goal of these regressions is to determine the relative influence either temperature or precipitation on SWE. In return, forecasting 2050 SWE will be practical using only precipitation and temperature scenarios from various climate models. To apply the climate scenarios, the forecasted change in either temperature or precipitation will be applied to a total mean in the respective variable. For example, if a 2 degree F increase in temperature is forecasted and the mean temperature across all stations, for all seasons is 10 degrees F, then a temperature of 12 will be used to model SWE. The climate models being applied are six variations of Representative Concentration Pathways (RCPs), which are detailed in the data section of this thesis. The regressions being conducted are: SWE and temperature, SWE and precipitation, and SWE and temperature/ precipitation. All three of these regressions will develop a correlation coefficient bearing differing levels of significance and therefore different potential SWE values for 2050.

Next, regressions will be run utilizing the economic variables, being skier visits and retail sales revenue. But first, a regression must be run between skier visits and SWE to determine the level of correlation and significance. This is an imperative relationship in this thesis as SWE will portray how much snow quality motivates skier visits. By applying the results of this regression to the new SWE values determined from the prior regressions, skier visits will be predicted. Therefore, snow quality, through SWE, is solely being used to forecast skier visits, no other external variables are being considered.

Finally, retail sales revenue will be collected from the County Sales Report for each county being included in this thesis. Because retail sales revenue is regularly reported, this is considered a reliable measure of economic performance. This data is being collected from 1999-2014, while not ideal, this should still provide enough data points for a regression. Notably, inflation is also being respected, as the average Consumer Price Index for each year is being used to bring all values to 2014 dollars. Therefore, all dollar values will be uniform across the board reducing any possible distortion of results. These values are collected for each county from November to April and summed for the respective season. Once a sum is developed for every county, all of the sums will be added to created a value representative of all counties. As result, there will be a "statewide" sum of retail sales revenue for each season. This same process will be applied to all seasons, to allow the dataset to align with seasonal skier visits. Next a regression will be run between skier visits and the "statewide" sums of retail sales revenue. By applying the results of this regression to the forecasted 2050 skier visits, potential economic change will be quantified.

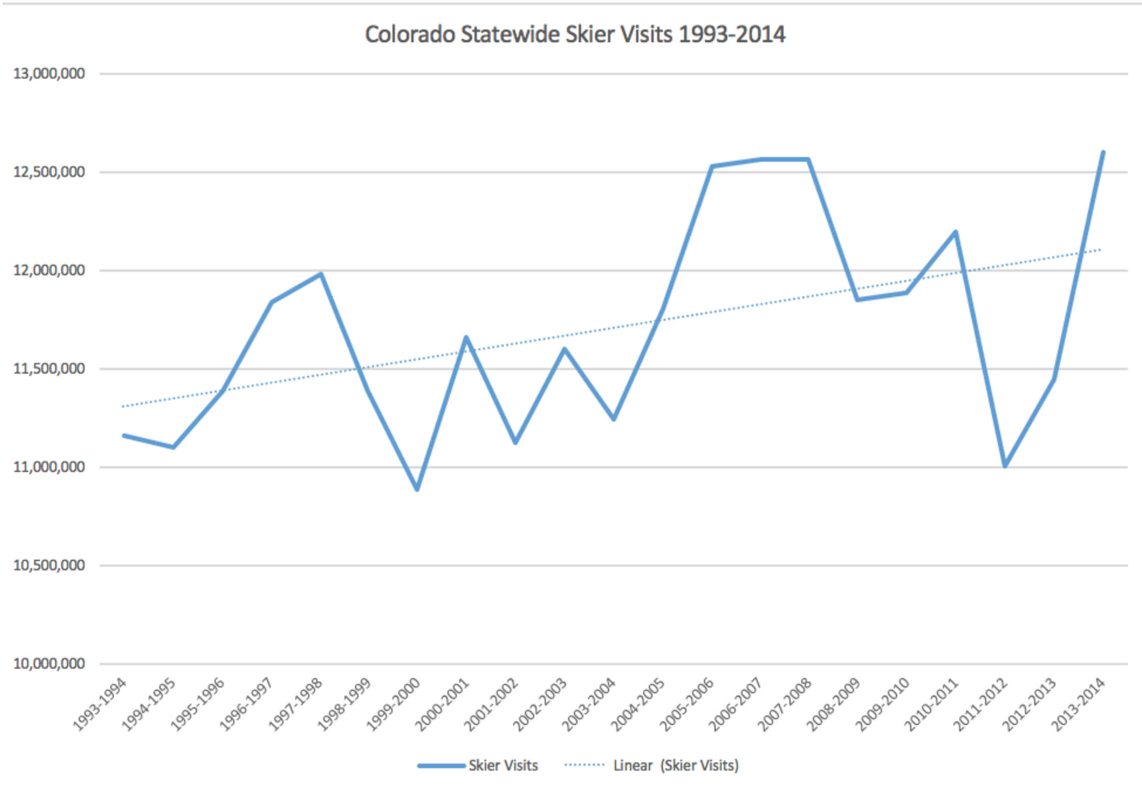
Data

Colorado Skier Visits 1993-2014

Colorado boasts more skier visits than any other state in the country, claiming more than 20 percent of all ski and snowboard visits in the United States" (Colorado Ski Country USA, 2015). With that being said, typical season visits range from 10.8 million to the record-breaking 12.6 million visits recorded during the 2013-2014 season. Below in Table 1A the skier visit statistics are detailed for all the seasons studied, spanning 1993 to 2014. This data will be later used to develop a correlation with snow quality, being represented by SWE in this thesis. Because skier visit statistics have become largely proprietary, they were collected from a variety of sources detailed in the bibliography. Overall, an upward trend is observed in skier visits, with an average growth rate of .73 percent. Significantly, a large growth of 10.09 percent was observed between the 2012-2013 and 2013-2014 ski seasons. **Table 1A** details skier visits with seasonal growth rates and **Graph 1A** serves to accompany the data.

Season	Skier Visits	Growth Rates
1993-1994	11,164,232	
1994-1995	11,105,106	-0.53%
1995-1996	11,387,058	2.54%
1996-1997	11,844,523	4.02%
1997-1998	11,979,719	1.14%
1998-1999	11,389,561	-4.93%
1999-2000	10,892,263	-4.37%
2000-2001	11,666,672	7.11%
2001-2002	11,128,131	-4.62%
2002-2003	11,605,777	4.29%
2003-2004	11,245,231	-3.11%
2004-2005	11,800,000	4.93%
2005-2006	12,533,108	6.21%
2006-2007	12,561,221	0.22%
2007-2008	12,570,000	0.07%
2008-2009	11,850,000	-5.73%
2009-2010	11,881,889	0.27%
2010-2011	12,200,000	2.68%
2011-2012	11,010,584	-9.75%
2012-2013	11,445,000	3.95%
2013-2014	12,600,000	10.09%
Average	11,707,623	0.73%

Table 1A: CO statewide skier visits and corresponding growth rates



Graph 1A: CO statewide skier visits and linear trend line

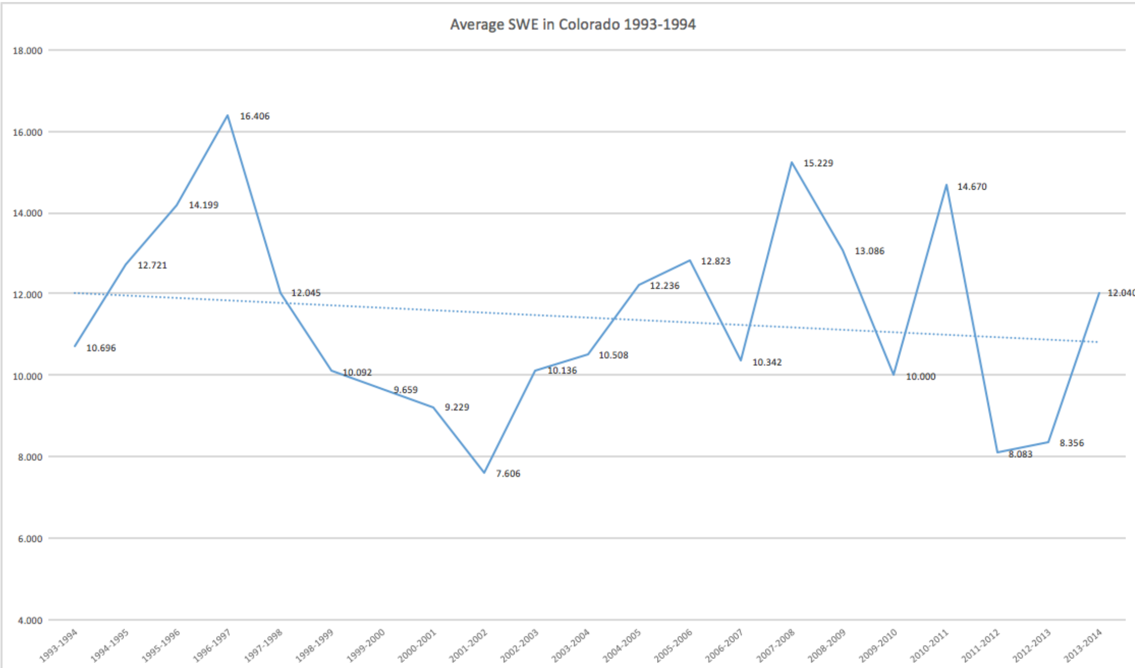
Snow Water Equivalent (SWE)

Currently, the most accurate measure for snowpack in Colorado comes from an array of SNOTEL (short for Snow Telemetry) stations located statewide. Installed, operated, and maintained by the Natural Resources Conservation Service (NRCS), SNOTEL stations automatically collect snowpack and other climatic data. While SNOTEL stations have begun reporting actual snowpack depth (inches) in recent years, the common unit of measurement is Snow Water Equivalent (SWE)(NRCS, 2015). SWE is the amount of water contained within the snowpack, essentially converting to the depth of water that would exist if the snow were to melt. In order to calculate SWE, the density of the snow must be known so it can be multiplied by the snow depth in inches. For example, 36" of snow at 10% water density would yield a SWE of 3.6

inches. Therefore, snow with higher water density will be a much higher SWE, in Colorado our snow typically has low water density ranging from value-value**.

The data for snowpack was derived from 18 different SNOTEL stations spatially located throughout Colorado. The variance in both elevation and location of the stations is to best reflect the positioning of ski resorts. However, decisions were also made on the age of each individual SNOTEL station. Because this thesis studies skier visits beginning in 1993, stations constructed in more recent years were not considered. Consequently, not all SNOTEL stations utilized were closest in proximity to the respective ski resort, but were the best choices for the purpose of this thesis.

Each of the SNOTEL stations automatically takes a recording of the SWE everyday of each month. Considering the average ski season in Colorado runs November through April, data on SWE was collected for those months. Specifically, data ranged from November 15th – April 15^{th} each year, as this best aligns with season length at most ski resorts. Next, SWE from each month at each station was averaged to create a value representative of the entire ski season. Once the average was determined for individual stations it was averaged again to represent the entire state. In **Graph 1B** SWE is plotted for the studied range with a linear trend line. Although a slight down trend is observed, this is not significant.



Graph 1B: Seasonal SWE with linear trend line 1993-2014

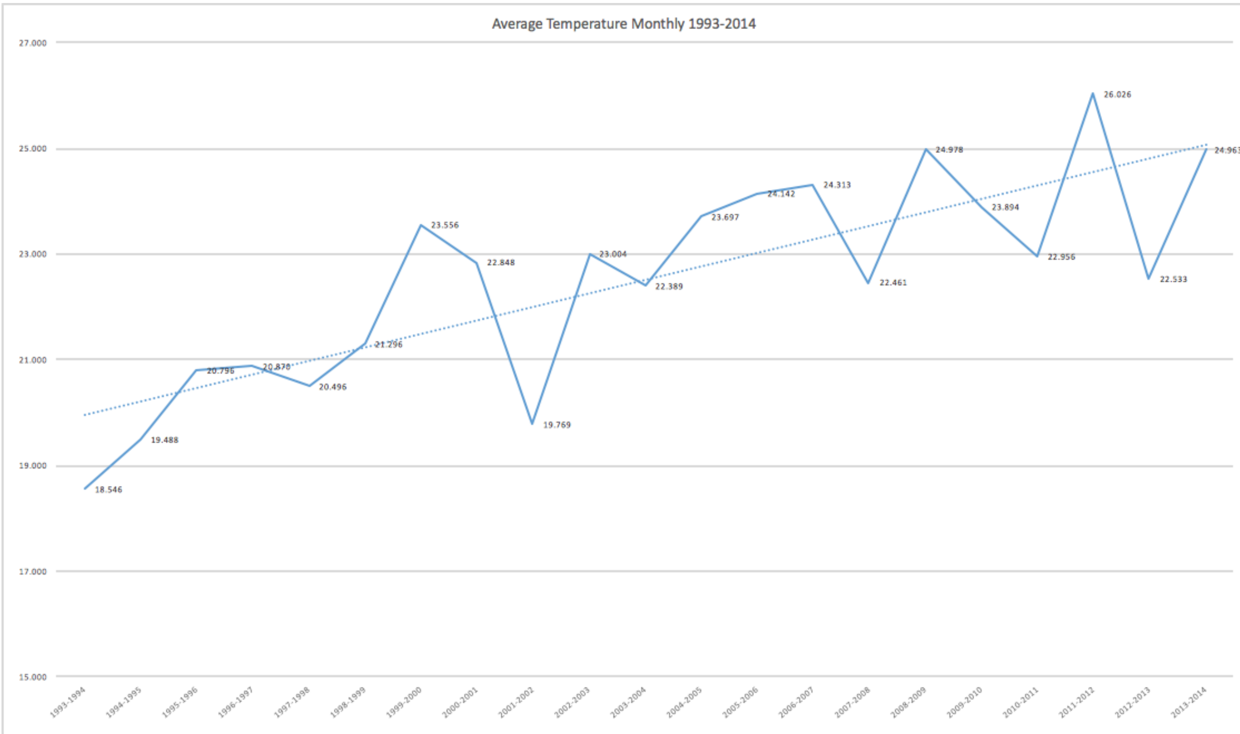
Precipitation 1993-2014

Although there is a lack in consensus over future precipitation in Colorado, this factor has been considered as well. Exactly like the other environmental data used in this thesis, precipitation was also derived from all 18 SNOTEL stations. To clarify, the type of SNOTEL stations measure precipitation accumulated in inches, therefore the value gradually increases November through April. First, the precipitation value for each day of the month was recorded and then averaged for that month. Once this was completed for each month, the mean was taken to develop a value representative for all months of that year. The steps described prior were performed for the years 1993 until 2014 like that of SWE and temperature. Additionally, this process was completed for all 18 stations, then the mean from each station was used to create a aggregated mean across all stations.

As anticipated, there was no significant trend in precipitation found and it varies greatly from season to season. However, the data did indicate that precipitation was in very slight decline since 1993, but not enough to draw any meaningful conclusions. These findings are somewhat consistent with the uncertainty in future precipitation models, as historical data lacks any defined trends. Perhaps utilizing data from more than 18 stations would bear a more significant result, but that fails to be true among those examined.

Average Temperature 1993-2014

Temperature data was derived from the same 18 SNOTEL stations used to collect information on SWE. Similar to SWE, temperature is collected daily, with recordings happening numerous times throughout the day. The average monthly temperature was taken from November 15th through April 15th each year from 1993 to 2015. After the average monthly temperature was derived, the entire data from the year was averaged as well to create a season-long value. This was performed for each station, therefore a yearly value for all 18 stations was created. Next, the yearly values for each station were averaged again, to create an station average for all seasons studied. The “station average” is what was used to develop any correlation and observe trends within. The results from all stations, displayed in **Graph 1C** portray the profound temperature increase that is occurring in the mountainous region of Colorado. However, this result was somewhat anticipated as it is consistent with climate models.



Graph 1C: Average seasonal temperature with linear trend line 1993-2014

2050 Temperature and Precipitation Projections

Three different climate change scenarios are being utilized in this thesis, each assuming different emissions scenarios. In 2014, "Climate Change in Colorado" was published detailing future climate change in Colorado to support water resources management and adaption. This report contains temperature and precipitation projections on a statewide scale, both of which will be used in this thesis. The projections were generated from four different Representative Concentration Pathways (RCPs) each being a different emissions scenario. To clarify, RCPs are "defined by their total radiative forcing, or the cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter" (IPCC, 2014). However, RCPs "are not fully integrated scenarios, but rather consistent sets of projections of only the components of radiative forcing that are meant to serve as input for climate modeling" (RCP Database, 2016)

Both RCP 4.5 (medium-low emissions scenario) and RCP 8.5 (high emissions scenario) were deemed significant and utilized for the models in "Climate Change in Colorado". Therefore, the results from RCP 4.5 and RCP 8.5 with serve as the source for projected temperatures in Colorado. To specify, RCP 4.5 represents a "stabilization scenario where total radiative forcing is stabilized before 2100 by employment of a range of technologies and strategies for reducing GHG emissions" (RCP Database, 2016). On the contrary, RCP 8.5 "is characterized by increasing GHG emissions over time representative for scenarios in the literature leading to high GHG concentration levels" (RCP Database, 2016). Considering radiative forcing reflects a change in energy in the atmosphere due to GHG emissions, RCPs essentially measure how the climate will react to altered GHG concentrations.

Under RCP 4.5, Lukas et al. 2014 projects that Colorado will experience a 2.1 to 5.1 degrees F temperature increase during winter months. With that being said, slightly larger temperature increases are projected for summer months. More dramatically, RCP 8.5 projects a 3 to 6.4 degrees F temperature increase during winter months. For the purpose of this thesis a range of temperatures will be employed, spanning both scenarios from 2.1 to 6.4 degrees F. As detailed in the methods section, the historical correlation coefficient between SWE and temperature will be applied to these future temperatures for the purpose of also projecting SWE.

To work with data that falls in more realistic percentiles, the forecasts from RCP 2.5 are also being considered. In fact, RCP 2.6 projects anywhere from 1.8 to 4 ˚F increase in temperature by 2050 during winter months. While this climate model was not deemed significant in "Climate Change in Colorado" it has been included to develop 2050 SWE, skier visit, and retail sales revenue projections from a more widely ranged data set.

While there is much less consensus about future precipitation, "climate models consistently project an increase in annual precipitation for the northernmost states and a decrease in precipitation for the southwestern states" (Lukas et al. 2014). Under RCP 4.5 33 of the 37 model runs project a large increase in precipitation, being the most significant change out of all four seasons. However, in RCP 4.5 the projected precipitation change ranges from -0.7 % to 13.4% speaking to the lack of agreement among models. Although, when analyzing the higher emissions scenario RCP 8.5, the projected precipitation change ranges from 2.1% to 18.9%, yielding more significant results. Further, RCP 2.6 forecasts a -2.9 to 10.7 percent change in precipitation. Of course, these values range across all percentiles so the extremes are unlikely under every RCP model. The scenarios being employed from each model are detailed in **Table 1B.**

Representative Concentration Pathways (RCP) Climate Models			
RCP	Percentile	Temperature Increase	Precipitation Change
2.6	25th	2.3 Degrees F	+/- 4.8%
2.6	50th	3 Degrees F	+/- 6.9%
4.5	50th	3.5 Degrees F	+/- 5.8%
4.5	75th	4 Degrees F	+/- 2.9%
8.5	50th	4.8 Degrees F	+/- 10.4%
8.5	90th	6.4 Degrees F	+/- 18.9%

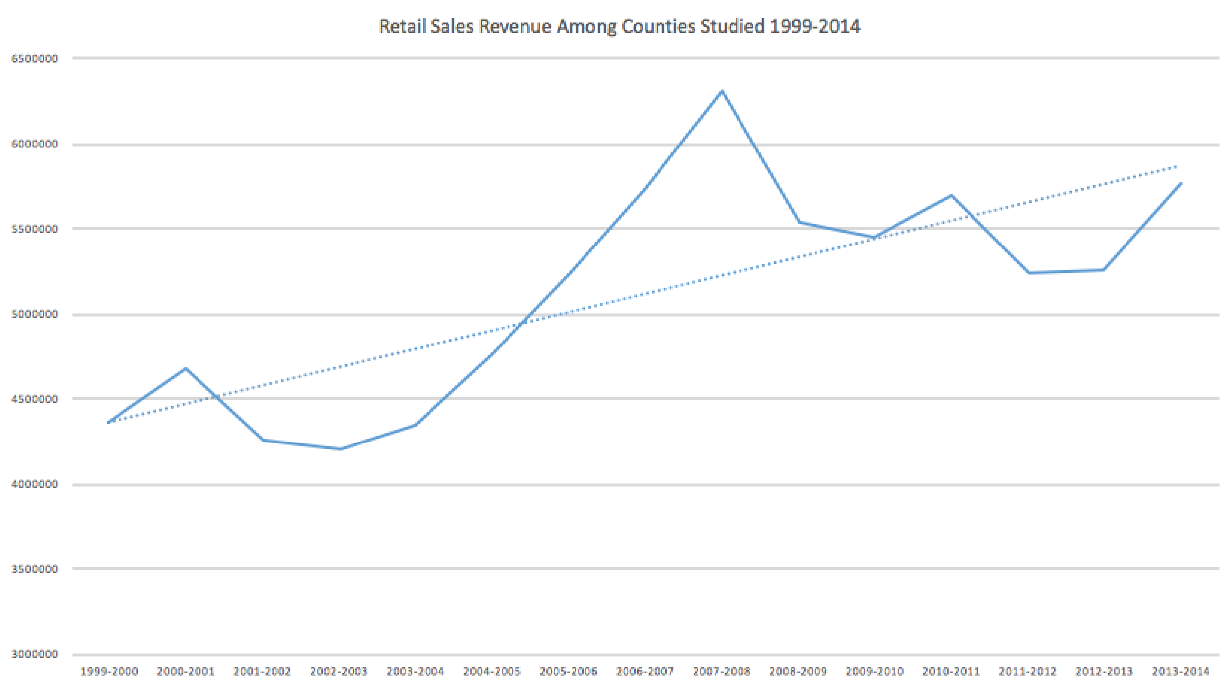
Table 1B: RCP Climate Models

County Sales Revenue

Assessing the potential economic loss or gain under each of the climate scenarios requires quantitative measure of economic conditions in Colorado. Therefore, total sales revenue compiled from Colorado Retail Sales and Sales Tax Summaries reports is being utilized as this is the most reliable and readily available data. Retail Sales Reports are compiled annually with information that is self-reported and submitted via the Colorado Retail Sales Tax Return (Form DR 0100). Overall, a trend in retail sale revenue shows values growing on average since 1999. This distinct trend is visible in **Graph 1C,** where a growth pattern is apparent.

Because only select counties are being examined in this thesis it is imperative that each Retail Sales Report details the data on a county basis, rather than just statewide. Consequently, this limitation restricts data to 1999 through present day. Therefore, the correlation between sales revenue and skier visits will only be developed using information from 1999-2014. Although it would be best for sale revenue to data to date back to 1994, the available years will be adequate. While reports exist for many decades prior they fail to detail this information by county, which as stated earlier is a crucial factor. To account for inflation, the CPI index was used to bring all values into 2014 dollars.

Further illustrating the methodology, the monthly retail sales revenue for each county was recorded, during each ski season studied. Next, the revenue (November-April) was aggregated to create a seasonal value. Once this step was performed for each county, all of the seasonal values were aggregated again to create a sum that encompasses all of the counties as one. Because skier visits are only available on a statewide basis, aggregating all of the counties was necessary to properly develop a correlation. Finally, a regression was run between the sum of seasonal retail revenue from all counties and the corresponding seasonal skier visits.


Retail Sales Revenue Among Counties Studied 1999-2014
6500000
6000000
5500000
5000000
4500000
4000000
3500000
3000000
1999-2000
2000-2001
2001-2002
2002-2003
2003-2004
2004-2005
2005-2006
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014

Analysis

Contribution of Individual Ski Resorts to Aggregate Skier Visits

With the intent of accurately assessing the industries economic impact, the relative contribution of individual resorts to aggregate skier visits needs to be assessed. Consequently, this will result in certain resorts, and their respective counties being eliminated from this study. Therefore, resorts found to contribute less than 1 percent to total skier visits will no longer be included. However, an exception is made for resorts that fall in this category provided they are located in a county with at least one substantial ski resort. The purpose of this step is to only study counties where skiing is likely an important economic driver. Counties that only include minimally visited ski resorts are unlikely to be primarily supported by the industry.

Following the 2003-2004 ski season, skier visit statistics became largely proprietary business information and unavailable to the general public. However, CSCUSA has provided individualized skier visit statistics for each of the resorts from the 1993-1994 to 2003-2004 seasons. With that being said, each resorts contribution to aggregate visits is being calculated using data from this time frame. Therefore, it is being inferred that the contributions are similar to that of more recent seasons. First, the skier visits from each resort are averaged among the seasons listed prior. Once this value is had for every resort, the numbers are totaled to determine the mean for the entire state over the same time frame. Next, the individual resort mean is divided by the state-wide mean to determine the respective resorts contribution.

The results detailed in “Table 1A” below will be briefly summarized here. Notably, Sunlight (Garfield County), SolVista, Powderhorn (Mesa County), Arrowhead (Eagle County), and Silverton (San Juan County) are all excluded due to contributions of less than 1 percent.

However, Silverton mountain first opened in 2002 meaning there is very little data on skier visits. While, Arrowhead became part of Beaver Creek Resort after the 1995-1996 season, serving as explanation for it's low contribution. Additionally, Cuchara Mountain was excluded due to inconsistent openings stemmed from ownership changes. Further, Eldora Mountain Resort (Boulder County) is also left out due to it's location in Boulder County. With the city of Boulder being located within the same county, Eldora does not serve as a major economic driver. Both Ski Cooper (Eagle County) and Howelson Hill (Routt County) failed to meet the threshold but were excepted due to their proximity to major resorts. In summary, 8 ski areas that were open between 1993-2004 are now being eliminated from the study.

Resort	Average Visits 1993-2004	Contribution	County
Aspen Highlands	144,607	1.27%	Pitkin
Aspen Mountain	327,357	2.87%	Pitkin
Buttermilk Mountain	160,222	1.41%	Pitkin
Crested Butte	440,767	3.87%	Gunnison
Cuchara Mountain	26,125	0.23%	Huerfano
Durango Mountain	300,615	2.64%	La Plata
Howelsen Hill	15,219	0.13%	Routt
Silverton	2,991	0.03%	San Juan
Snowmass	749,187	6.57%	Pitkin
Steamboat	1,023,113	8.97%	Routt
Telluride	332,518	2.92%	San Miguel
Wolf Creek	163,974	1.44%	Mineral
Arrowhead	24,697	0.22%	Eagle
Beaver Creek	630,251	5.53%	Eagle
Breckenridge	1,362,785	11.95%	Summit
Copper Mountain	918,518	8.06%	Summit
Keystone	1,117,291	9.80%	Summit
Vail	1,553,461	13.62%	Eagle
Winter Park	985,254	8.64%	Grand
Arapahoe Basin	243,986	2.14%	Summit
Berthoud Pass	16,967	0.15%	Grand
Eldora Mountain	208,389	1.83%	Boulder
Loveland	244,626	2.15%	Summit
Monarch	145,137	1.27%	Chaffee
Powderhorn	71,863	0.63%	Mesa
Ski Cooper	66,731	0.59%	Eagle
SolVista	83,708	0.73%	Grand
Sunlight	87,180	0.76%	Garfield
TOTAL	11,401,570	100.00%	

Table 2A: Contribution of individual ski resorts to aggregate skier visits

SWE and Skier Visits

Assessing the historical relationship between snowpack and skier visits is imperative in determining the potential impacts of future climate change. The purpose of this step is to determine the relative level of correlation between the two variables. While a strong correlation may indicate a grim outlook, a weaker correlation could bear the opposite results. However, it must be noted that this thesis is using snowpack as the sole determinate in one's decisions to go skiing. While other factors, such as economic wellbeing are likely influential, they are being excluded for simplicity.

Because SWE is the "product of snow depth and snow density" it serves as an indicator for snow conditions during that time. The operability of any given ski resort is largely dependent on precipitation and snowpack as an adequate base is required for skiing. Therefore, SWE works to represent snow base in this thesis because quantitative information about ski area snow bases is not readily available. With that being said, SWE is what this entire thesis hinges on, being the primary indicator of "snow conditions" that one may experience at a ski resort during any given season. A correlation was run between seasonally averaged SWE, aggregated from all SNOTEL stations and the corresponding statewide skier visits.

The correlation coefficient found is **.504** meaning a medium to strong correlation exists. This finding is significant and indicates that snow quality, expressed through SWE, is an important factor in one's decision to ski in Colorado. However, the failure for a stronger correlation to exist alludes to other factors prominently influence on those skiing in Colorado. When looking at **Graph 2A** it is obvious where skier visits deviate from SWE, speaking to the presence of other influences.

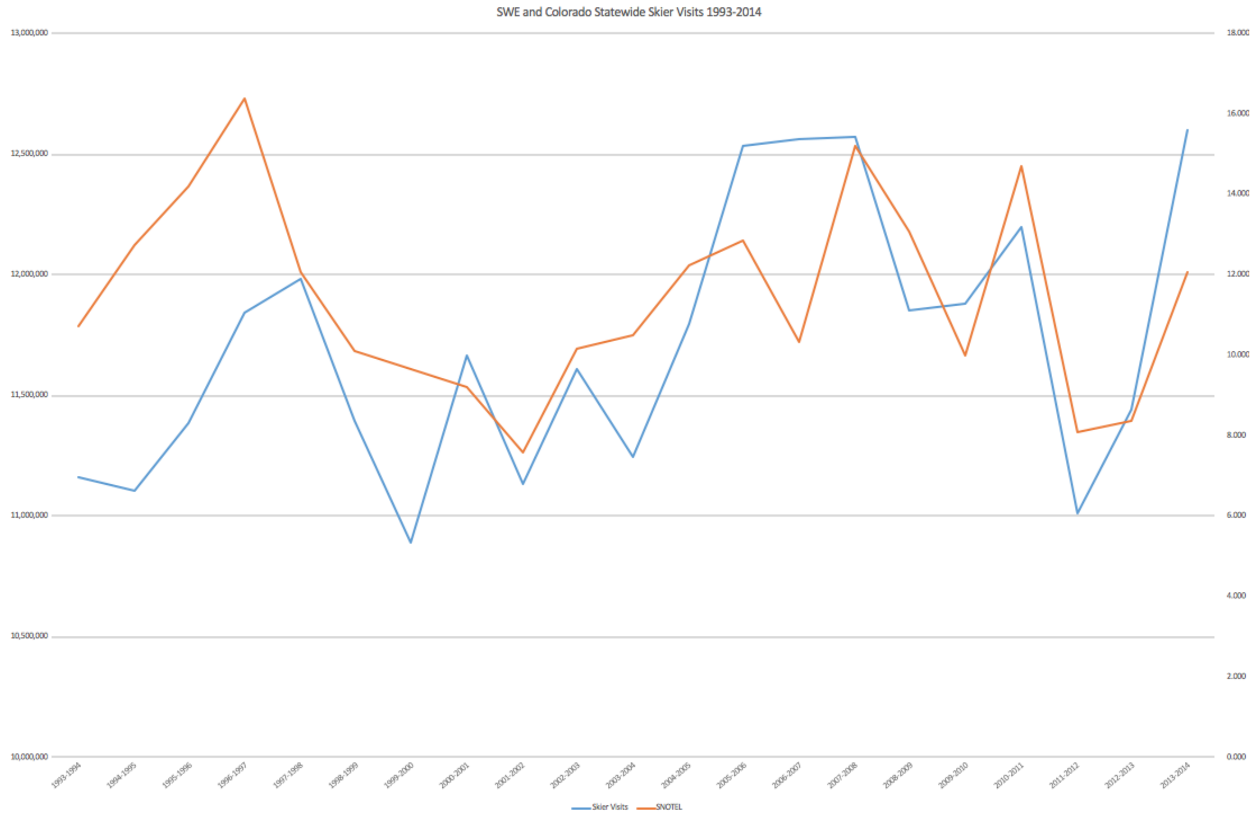
The Colorado Ski Industry possesses a number of qualities that serve as potential explanation for the correlation coefficient that was found between skier visits and SWE. Namely snowmaking technology and skier demographics, both of which could influence skier visits. In short, snowmaking as serves as a technical adaptation to supplement natural snowfall when necessary. While the typical clientele of Colorado ski resorts often travels long distance and possess more wealth than skiers elsewhere. As will be explained, the factors described prior likely motivate those who ski in Colorado along with snow quality or SWE in this case.

When temperatures accommodate, snowmaking technology allows ski resorts produce snow on key trails where an adequate snow base is imperative to resort operability. In Colorado, this technology has allowed resorts like Arapahoe Basin and Loveland Ski Area to open incredibly early, often in mid-October. However, the technology is also an important hedge when temperatures natural snow does not fall. The "Thanksgiving holiday is particularly important for ski resorts and is often a target for stating the season" (Katzenberger et al., 2006). At Aspen Mountain, "snowmaking has added more certainty to the opening date and has become an integral part of early season operations (Katzenberger et al., 2006).

In Colorado, there is not shortage of snowmaking technology with 20 resorts boasting the coping resource (CUCSA, 2016). Many resorts don't shy away from snowmaking either, Vail can cover over 450 acres with fake snow, while Steamboat can cover 375 acres. The plentiful snowmaking coverage likely provides some piece of mind for guest as well. As the technology has provided more certainty in opening dates, it also provides certainty in the guests' decision to visit any given resort. With this technology being so widespread throughout Colorado, there is likely a level of reassurance that guests feel when making the decision to ski or not.

Moving on, Colorado is unique in the demographic profile of skiers that visits its resorts. Specifically, a majority of skier visits are driven by destination skiers with "out-of-state residents generating more than 7 million skier visits, of about 12.6 million during the 2013-2014 season" (CUCSA, Vail Resorts 2015). Furthermore, many guests visiting Colorado resorts are extraordinarily wealthy, at "Vail 50 percent of all skiers have salaries greater than 250k/year and 25 percent of those make more than 500k/year" (Vail Resorts, 2014). While Vail represents just one resort, it accounts for nearly 14 percent of all skier visits in the state, according to the findings in this thesis. Also, one can surmise that Beaver Creek, Aspen Snowmass, and Telluride may draw similarly wealthy guests, creating a comparable situation.

The overwhelmingly destination fueled skier market in Colorado allows for some inferences to be made. First, it is reasonable to assume that many destination skiers make the decision to ski prior to any knowledge or information about snow conditions. This is primarily because many guests will plan their trips in summer months or other times prior to ski season beginning. Secondly, the wealthy clientele may choose to ski regardless of snow quality for many reasons.



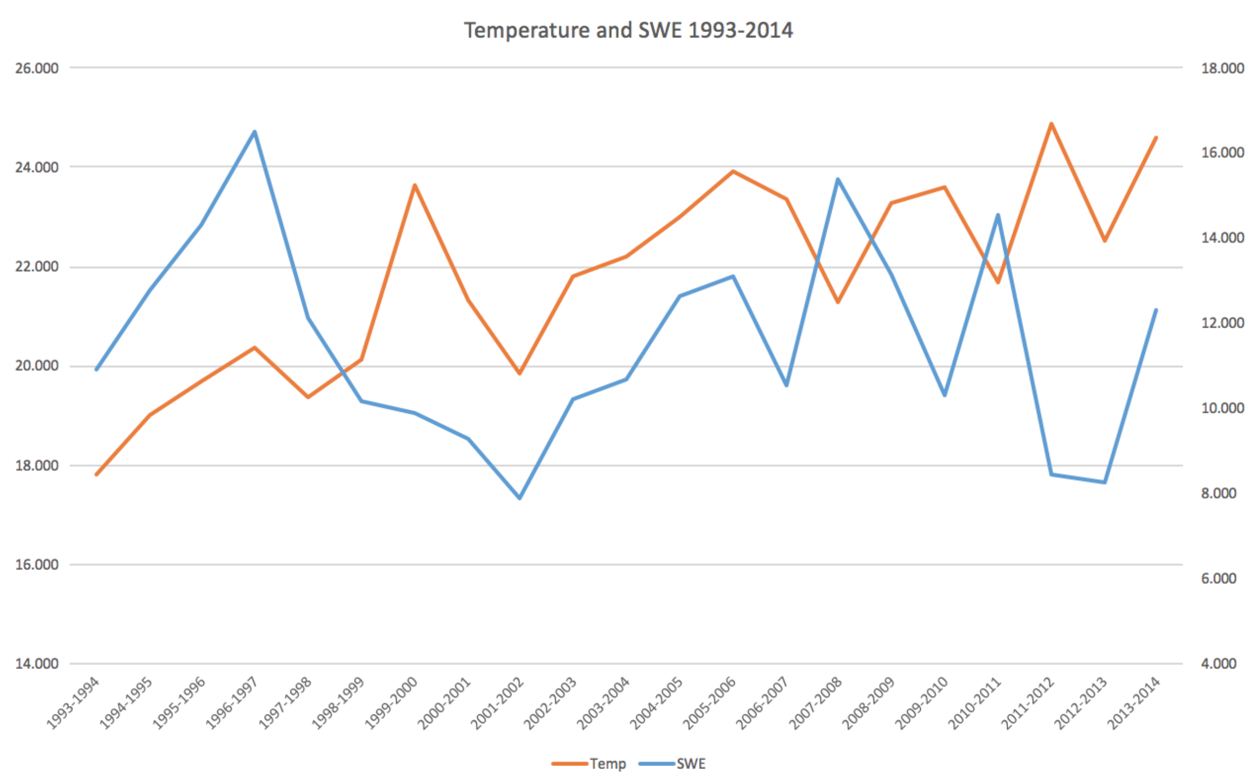
Graph 2A: SWE and Colorado Statewide Skier Visits 1993-2014

Temperature and SWE

Serving as a vital relationship in this thesis, that between temperature and SWE provides the base in which future analysis will be conducted. As discussed prior, there is a moderate to strong correlation between SWE and skier visits. Therefore, the projected average SWE in 2050 for Colorado will also provide insight to skier visits during that time as well. Because there is more confidence in future temperature patterns rather than precipitation, this relationship will allow future SWE to be forecasted for 2050 therefore yielding skier visits. Temperature has largely been considered a factor to influence SWE as "the properties of snowpack can be often inferred from temperature, solar radiation, and precipitation" (Sospedra-Alfonso, 2015).

In this thesis, a correlation coefficient of **-0.22** was found, indicating a weak inverse relationship. While the correlation was far more insubstantial than anticipated, the type of relationship, being that it is negative, supports this thesis. As temperatures have increased, SWE has slightly decreased in response. When observing each component individually, there are clear trends, with temperature rapidly increasing and SWE decreasing, although at a slower rate. Perhaps, the slow response time of SWE (to decline) is partially responsible for the weak correlation, but other possible explanations will be investigated following.

This result is somewhat unexpected and fails to reject the null hypothesis for this thesis. Therefore, temperature is not the primary influence on SWE and another variable must be drawing the majority. Although not yet determined, it is likely that precipitation is this variable, holding the most ability to shift SWE. The possibility of precipitation holding this role will be later explored in this chapter. The observed relationship between SWE and temperature is displayed in **Graph 2B**.

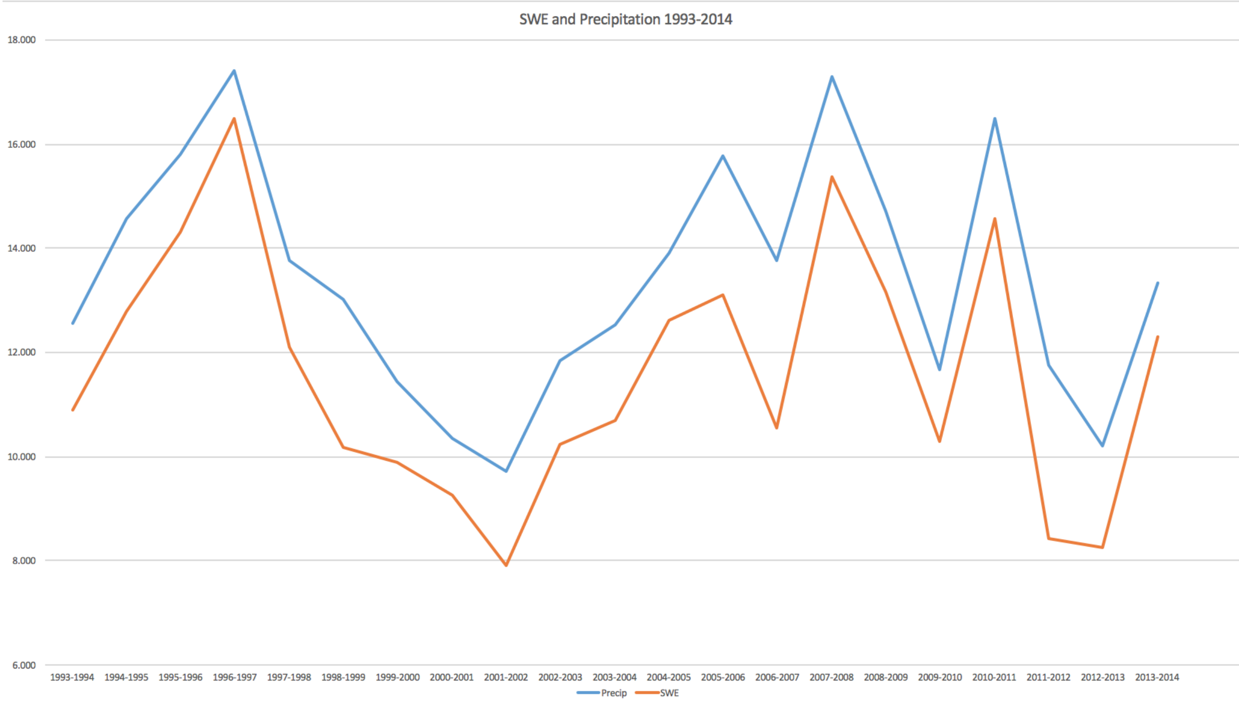


Graph 2B: Temperature and SWE 1993-2014

Precipitation and SWE

The relationship between precipitation and SWE will help determine the relative magnitude of precipitation's influence on SWE, compared to that of temperature. Considering the climate models for 2050 utilized by this thesis forecast precipitation scenarios as well, this is another important relationship to consider. Further, because precipitation and skier visits have correlation coefficient almost identical to that of SWE, future skier visits could theoretically be calculated solely using precipitation data. However, given the lack of consensus on future precipitation this would not be reliable by itself, but is being considered none the less.

In this thesis, a correlation coefficient of **.96** was found between precipitation and SWE indicating an almost perfect positive correlation. This relationship is visibly apparent in **Graph 2C** where the two variables track almost identically across all years studied. When considering the weak relationship that exists between SWE and temperature, this shows that precipitation has much stronger influence over SWE. However, this is somewhat expected because of the threshold in temperature that is required for it to truly influence SWE. While more precipitation almost directly increases SWE, it seems that temperature would have to change snow into rain for it to negatively influence SWE.



Graph 2C: SWE and Precipitation 1993-2014

Temperature/ Precipitation and SWE

Serving as the only multiple regression in this thesis, this analysis measures the relationship between precipitation, temperature, and SWE. Given the much stronger influence of precipitation on SWE, it is likely that the correlation coefficient among all three variables will be very similar. In fact, the coefficient found was **.96** when rounded to two decimal places, meaning it is exactly the same as that of precipitation and SWE even with temperature in the equation. Even though this regression is the most comprehensive, it will not be the primary test used to draw conclusions from and forecast skier visits. Because of the large uncertainty in future precipitation models, any forecasts with precipitation in the equation need to be taken with less significance.

Precipitation and Skier Visits

Considering SWE and precipitation are so closely correlated, a relationship similar to that of SWE and skier visits is expected between SWE and precipitation. For precipitation and skier visits a correlation coefficient of **.533** was found, bearing a value close to that of SWE and skier visits, where the correlation coefficient was **.503**. Considering the almost perfect, positive correlation that existed between SWE and precipitation, the close proximity of these coefficients is somewhat predictable. While this statistic will not be used in the study, it is included to further demonstrate the influence of precipitation on SWE.

SWE in 2050

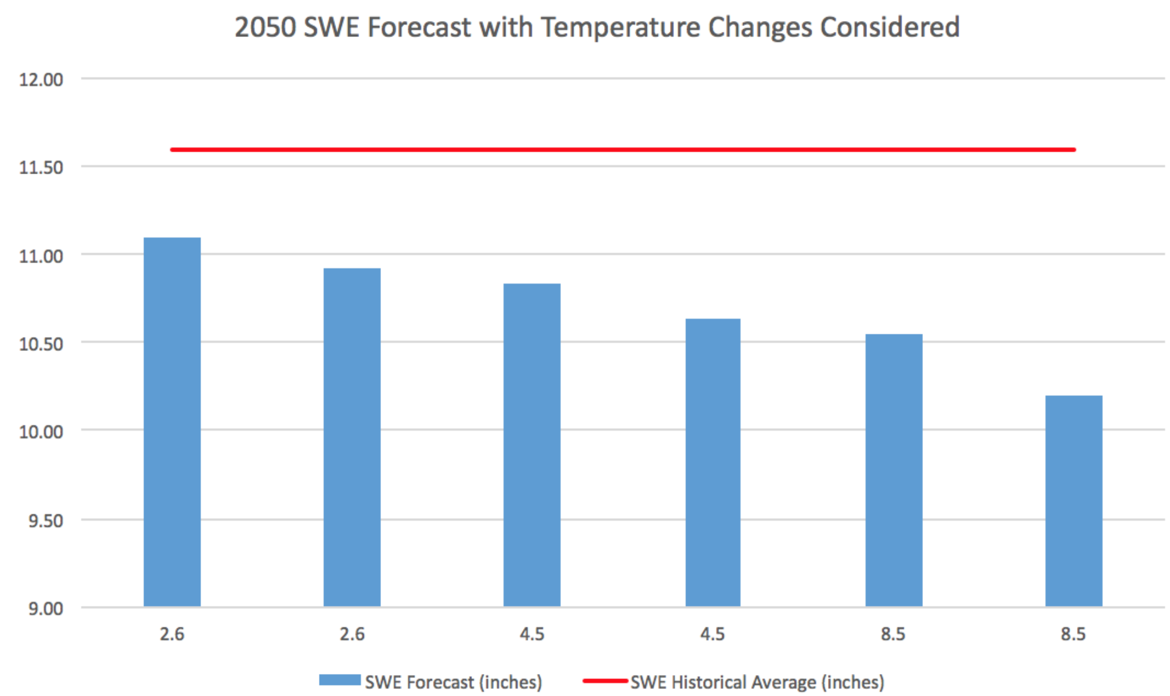
Determining the SWE in 2050 requires applying the results from three different regressions, all of which were previously detailed. To restate, the three regressions of which results are being utilized are SWE and temperature, SWE and precipitation, and SWE and temperature/ precipitation. Including all of these regressions allows for total inclusion and the best possible range of results. Considering there is some uncertainty over precipitation in particular it is important to include SWE and temperature alone, even though the correlation coefficient was much less substantial. The first SWE forecast being presented is that generated from the regression of SWE and temperature. Following this analysis, those generated from the regression of SWE and precipitation and the multiple regression of SWE and precipitation/ temperature will be presented.

2050 SWE with Temperature Changes Considered

Because of the incredibly weak inverse correlation found between SWE and temperature (**-.18**) the impacts on 2050 SWE are expected to be minimal even with the largest temperature increases. Below in **Table 2D** and **Graph **** the forecasted SWE with all temperature scenarios considered are displayed. However, all scenarios do forecast the average 2050 SWE to be below the historical average of **11.6** inches. Although this is not all that unexpected as for every **1 F˚** change in temperature, SWE responds with a **.22-inch** change. Considering the moderate correlation between SWE and skier visits, these results indicate that both skier visits and retail sales revenue can be expected to decline under all temperature forecasts. Therefore, temperature changes can have a significant impact on SWE even with the weak correlation, provided the changes are large enough. On a cautionary note, weak correlations are often disregarded in studies, but considering the correlation had a significant p-value it is still being included.

2050 SWE Forecast with Temperature Changes Considered					
RCP Model	Percentile	RCP Temp Scenario (˚F)	Temp Historical Average (˚F)	Temp Prediction (˚F)	SWE Forecast (inches)
2.6	25th	+2.3	21.78	24.08	11.09
2.6	50th	+3.1	21.78	24.88	10.92
4.5	50th	+3.5	21.78	25.28	10.83
4.5	75th	+4.4	21.78	26.18	10.63
8.5	50th	+4.8	21.78	26.58	10.55
8.5	90th	+6.4	21.78	28.18	10.19

Table 2B: 2050 SWE Forecast with Temperature Changes Considered



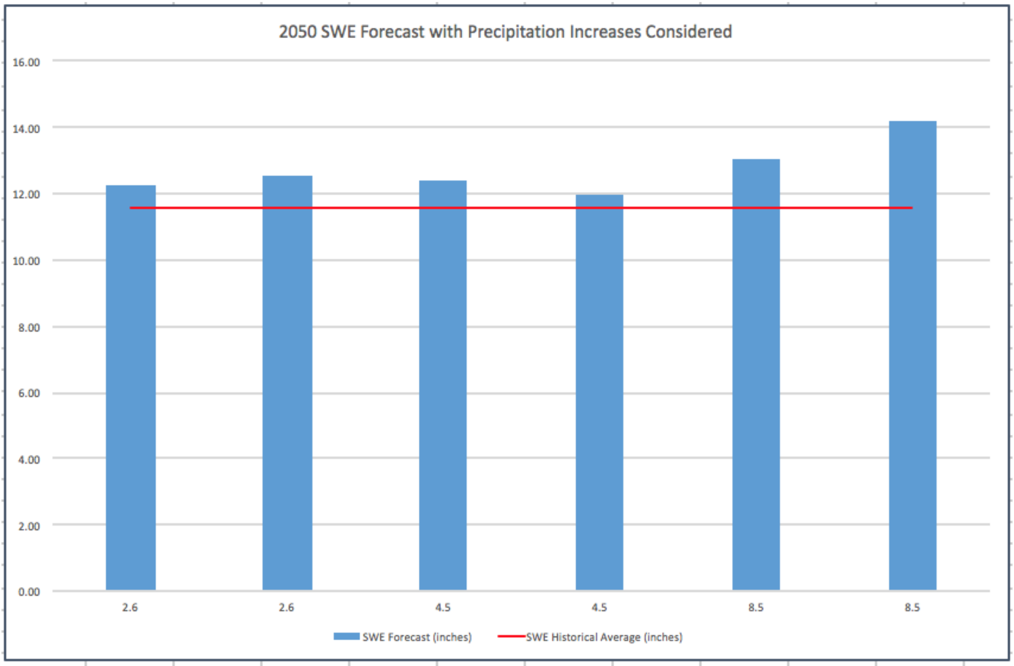
Graph 2D: 2050 SWE Forecast with Temperature Changes Considered, Compared to Historical Average

2050 SWE with Precipitation Changes Considered

Although all RCP climate models forecast an increase in precipitation in Colorado, this thesis is considering potential decreases as well. As stated many times, there is little consensus in precipitation future precipitation trends for Colorado, therefore it is justified to consider decreases as well. Further, the historical precipitation trends found in this thesis, show a slight downward trend since 1993. Therefore, whatever increase is predicted by each RCP is also being partnered with the corresponding decrease. The 2050 SWE with precipitation **increases** considered is displayed in **Table 2C** and **Graph 2E**. While the 2050 SWE with precipitation **decreases** considered is displayed in **Table 2D** and **Graph 2F**. Without temperature considered, the regression finds that all 6 climate models with a precipitation increase would lead to SWE being higher than the historical average in 2050. However, the regression also finds the average SWE in 2050 would be below the historical average under all 6 climate models if precipitation decreases. Again, there is little consensus over future precipitation forecasts for Colorado, meaning these results must be considered cautiously.

2050 SWE Forecast with Precipitation Increases Considered					
RCP Model	Percentile	RCP Precip Scenario (% change)	Precip Historical Average (inches)	Precip Prediction (inches)	SWE Forecast (inches)
2.6	25th	+4.8%	13.43	14.073	12.25
2.6	50th	+6.9%	13.43	14.356	12.53
4.5	50th	+5.8%	13.43	14.208	12.38
4.5	75th	+2.9%	13.43	13.818	11.99
8.5	50th	+10.4%	13.43	14.826	13.01
8.5	90th	+18.9%	13.43	15.97	14.17

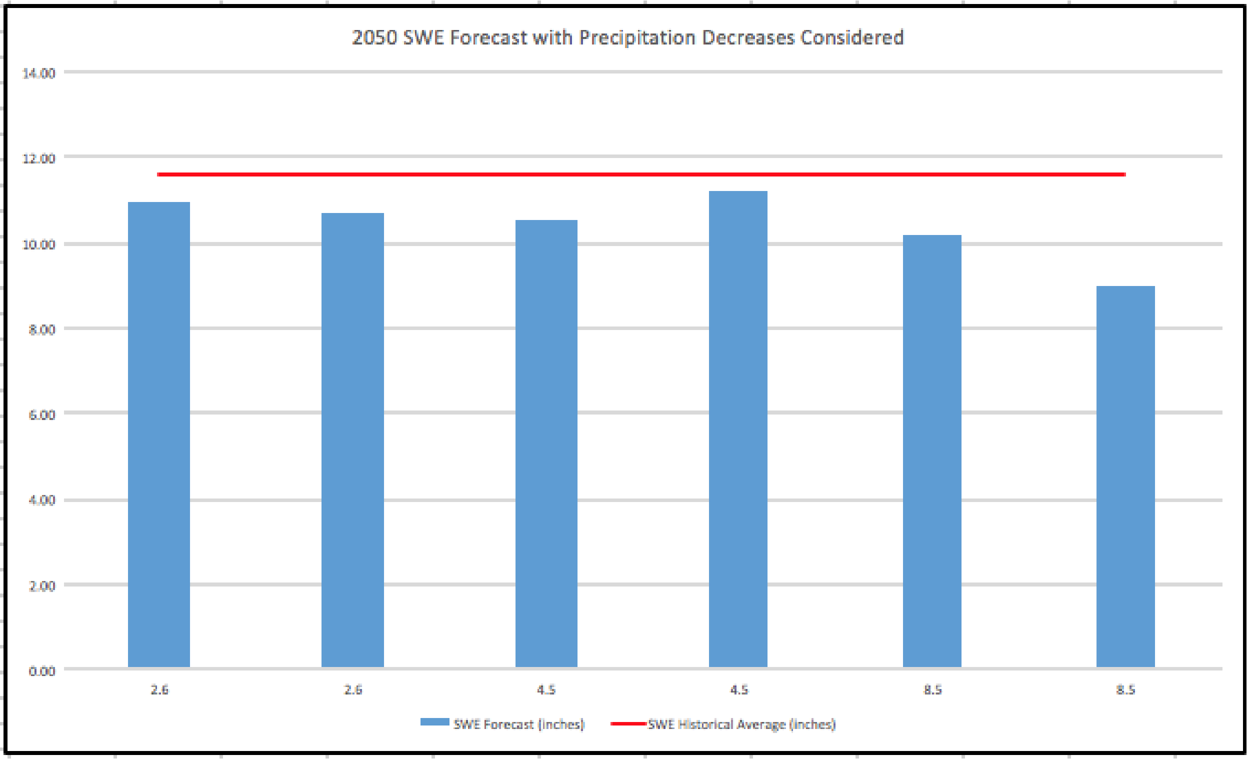
Table 2C: 2050 SWE Forecast with Precipitation Increases Considered



Graph 2E

2050 SWE Forecast with Precipitation Decreases Considered					
RCP Model	Percentile	RCP Precip Scenario (% change)	Precip Historical Average (inches)	Precip Prediction (inches)	SWE Forecast (inches)
2.6	25th	-4.8%	13.43	12.78	10.94
2.6	50th	-6.9%	13.43	12.50	10.69
4.5	50th	-5.8%	13.43	12.65	10.54
4.5	75th	-2.9%	13.43	13.04	11.20
8.5	50th	-10.4%	13.43	12.03	10.18
8.5	90th	-18.9%	13.43	10.89	9.03

Table 2D: 2050 SWE with Precipitation Decreases Considered



Graph 2F

2050 SWE with Temperature and Precipitation Changes Considered

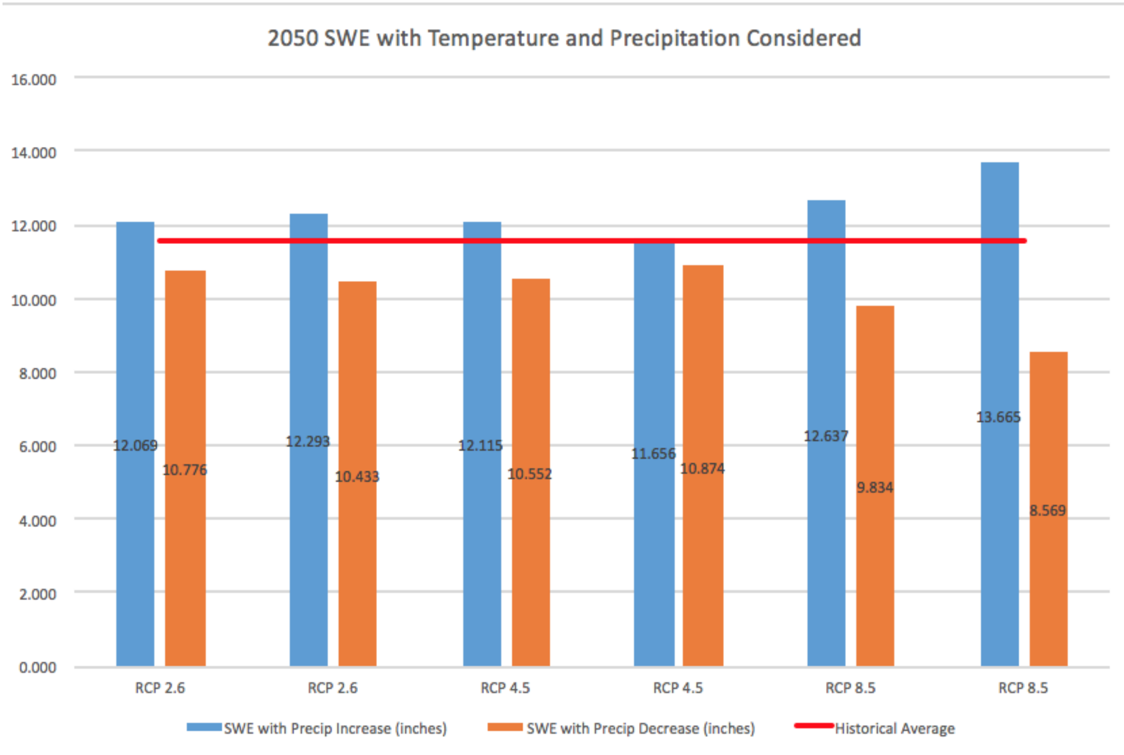
While precipitation has been found to have a more substantial influence on SWE, it is not exclusive of temperature. Taking both into consideration produces the most reliable and inclusive forecast of SWE. The multiple regression analysis found a correlation coefficient of **.96** when both variables were considered. Inherently, this coefficient would indicate that results will likely be very close to those found from the regression between SWE and precipitation alone. However, because the inclusion of both variables bear slightly different results, it is worth analyzing this regression. The results considering temperature increase and precipitation decrease are displayed in **Table 2E,** while the results considering temperature increase and precipitation increase are displayed in **Table 2F**. However, all results are plotted on **Graph 2G** helping to visualize the profound differences between the precipitation increase and decrease scenarios. Again, under all precipitation increase scenarios the 2050 SWE average is higher than the historical average. While under all precipitation decrease scenarios the 2050 SWE average is lower than the historical average. However, including temperature increase dampens the results when with precipitation increase and exaggerates the results when with precipitation decrease. To clarify, this is in comparison to SWE forecast made solely from precipitation models, with no regard for temperature.

2050 SWE Forecast with Temperature Increases and Precipitation Decreases Considered				
RCP Model	Percentile	Temp Prediction (˚F)	Precip Prediction (inches)	SWE Forecast (inches)
2.6	25th	24.08	12.78	10.776
2.6	50th	24.88	12.50	10.433
4.5	50th	25.28	12.65	10.552
4.5	75th	26.18	13.04	10.874
8.5	50th	26.58	12.03	9.834
8.5	90th	28.18	10.89	8.569

Table 2E: 2050 SWE with Temperature Increases and Precipitation Decreases

2050 SWE Forecast with Temperature Increases and Precipitation Increases Considered				
RCP Model	Percentile	Temp Prediction (˚F)	Precip Prediction (inches)	SWE Forecast (inches)
2.6	25th	24.08	14.073	12.069
2.6	50th	24.88	14.356	12.293
4.5	50th	25.28	14.208	12.115
4.5	75th	26.18	13.818	11.656
8.5	50th	26.58	14.826	12.637
8.5	90th	28.18	15.97	13.665

Table 2F: 2050 SWE with Temperature Increases and Precipitation Increases



Graph 2G: 2050 SWE with Temperature and Precipitation Increases/ Decreases Considered

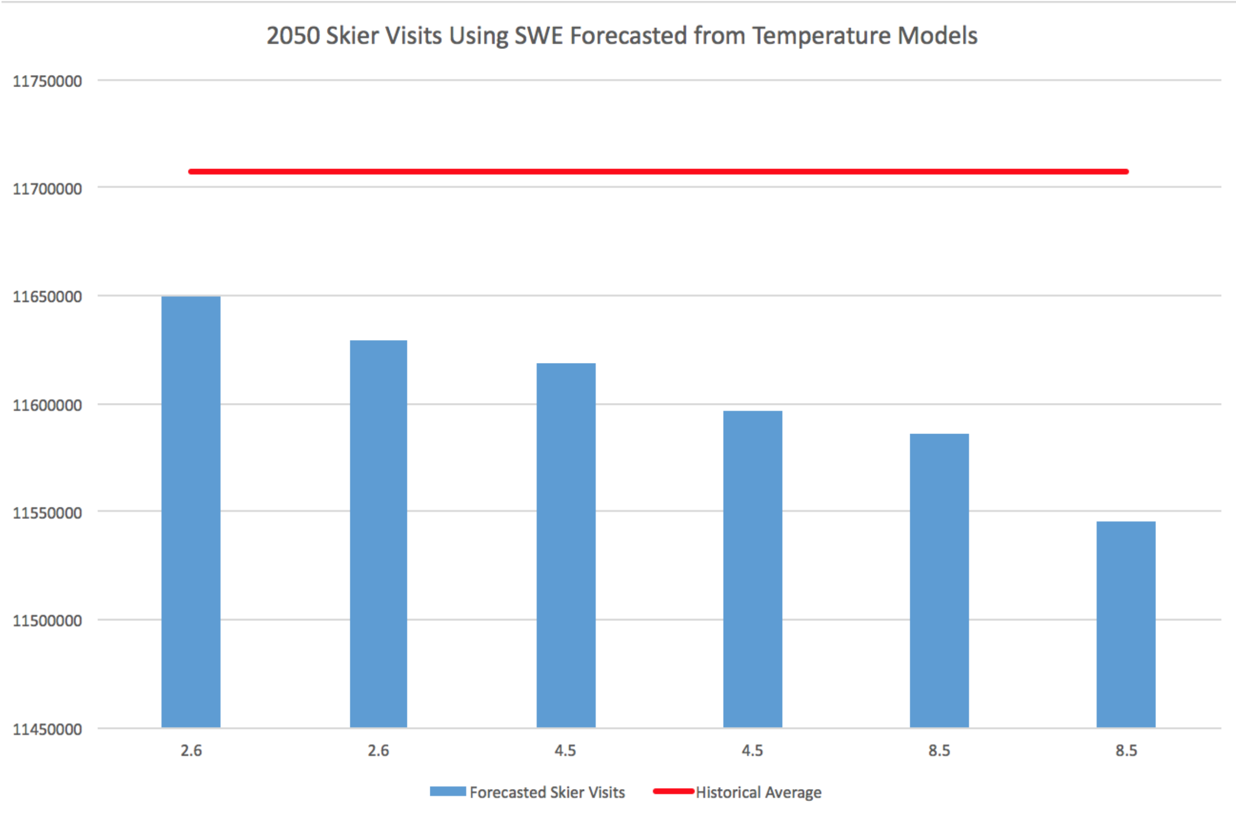
Skier Visits in 2050

Now that multiple possibilities for SWE in 2050 have been calculated, it is time to apply these results to those found in the regression between SWE and skier visits. As previously stated, SWE and skier visits have a moderate correlation with a coefficient of **.5**. This indicates that SWE has the ability to significantly influence skier visits in Colorado. Following the format of the previous section, skier visit scenarios will be calculated using temperature and precipitation as individual variables in a simple regression as well as temperature/precipitation in a multiple regression. The SWE scenarios found in the regression between SWE and temperature increase/ precipitation decrease result in the largest decline in skier visits. Following, the SWE scenarios from the regression between SWE and precipitation decrease result in the second largest loss, then SWE and temperature. Conversely, SWE and precipitation increase would result in an increase in average skier visits. In summary, the greatest effects on skier visits are comparable to the SWE values that were most impacted by the various temperature and precipitation scenarios.

2050 Skier Visits with Temperature Changes Considered

The 2050 skier visit forecasts portrayed in **Table 2G** were calculated using the 2050 SWE forecasts generated by projected temperature changes. Of the three SWE scenarios considered (temperature, precipitation, temperature/precipitation), this scenario resulted in the most minimal negative change to average skier visits. However, in all temperature scenarios, 2050 average skier visits are shown to be below the historical average. Considering, average 2050 SWE was below the historical average in all temperature scenarios, these results are expected. All of the results are visualized in **Graph 2H**.

Forecasted Skier Visits Using SWE Generated from Temperature Models				
RCP Model	Percentile	Temp Forecast ˚F	2050 SWE (inches)	Forecasted Skier Visits
2.6	25th	+2.3	11.09	11649371.48
2.6	50th	+3.1	10.92	11629110.87
4.5	50th	+3.5	10.83	11618980.57
4.5	75th	+4.4	10.63	11596187.40
8.5	50th	+4.8	10.55	11586057.10
8.5	90th	+6.4	10.19	11545535.90

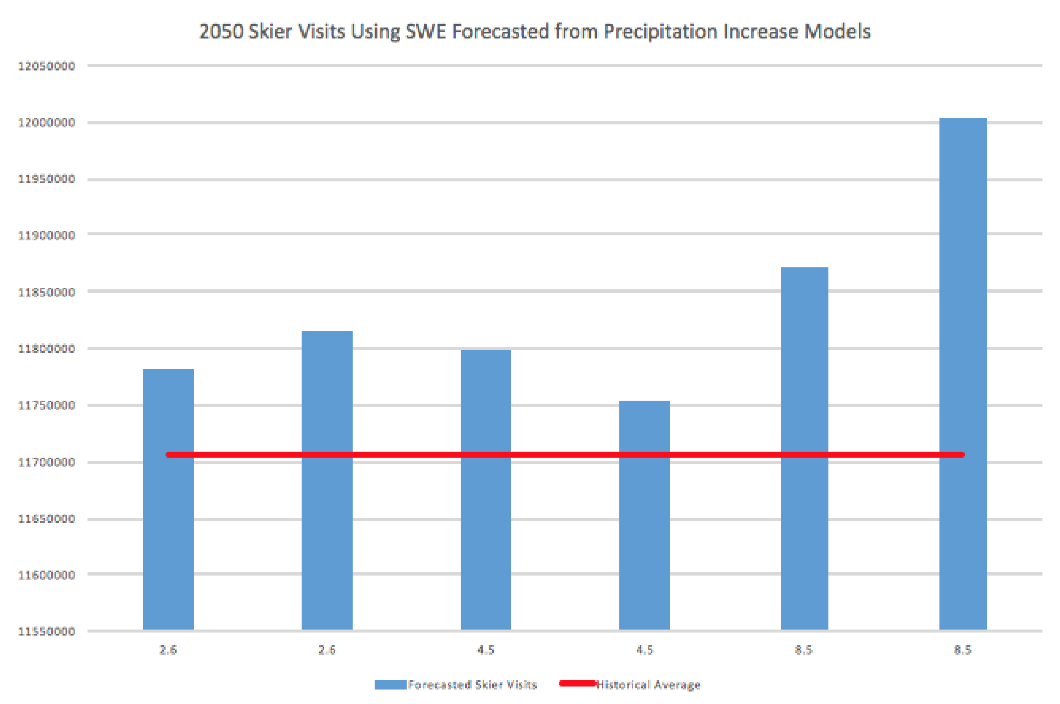


2050 Skier Visits with Precipitation Changes Considered

This set of 2050 skier visit forecasts, was generated using the 2050 SWE forecasts calculated exclusively from precipitation increase and decrease scenarios. The results indicated that average skier visits in 2050 would increase (above historical average) if precipitation increased and decrease (below historical average) if precipitation decreased. However, it is important to recognize that temperature is not at all considered in this scenario. The results for precipitation increase scenarios are displayed in **Table 2H** and **Graph 2I.** These results show that 2050 skier visits will be above the historical average in all precipitation increase scenarios and vice versa with precipitation decrease scenarios. Therefore, these results are consistent with the 2050 average SWE projections in both precipitation increase and decrease scenarios.

Forecasted Skier Visits Using SWE Generated from Precipitation Increase Models				
RCP Model	Percentile	Precip Forecast (% change)	2050 SWE (inches)	Forecasted Skier Visits
2.6	25th	+4.8%	12.25	11782966
2.6	50th	+6.9%	12.53	11816079
4.5	50th	+5.8%	12.38	11798762
4.5	75th	+2.9%	11.99	11753128
8.5	50th	+10.4%	13.01	11871074
8.5	90th	+18.9%	14.17	12004932

Table 2H

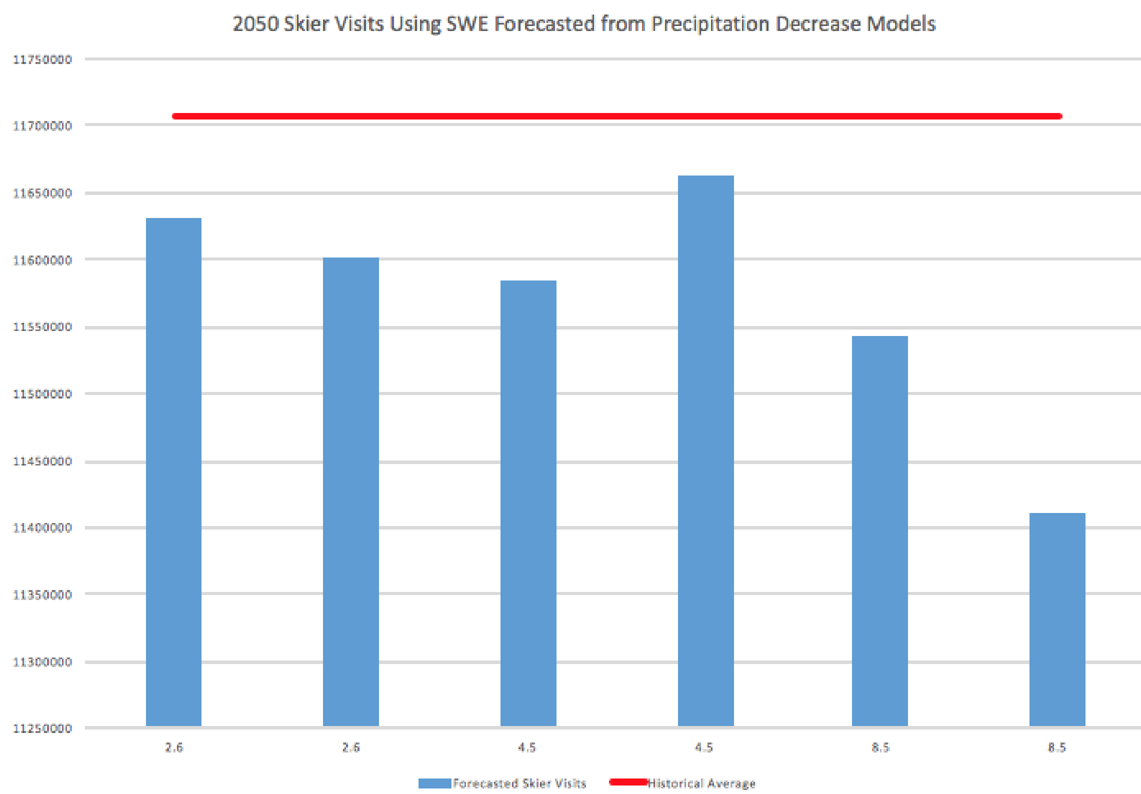


Graph 2I

The 2050 skier visits displayed in **Table 2I** was generated using the 2050 SWE forecasts calculated exclusively using precipitation decrease scenarios. As visibly apparent in **Graph 2J**, 2050 average skier visits will be below the historical average in all precipitation decrease scenarios.

Forecasted Skier Visits Using SWE Generated from Precipitation Decrease Models				
RCP Model	Percentile	Precip Forecast (% change)	2050 SWE (inches)	Forecasted Skier Visits
2.6	25th	-4.8%	10.94	11632141
2.6	50th	-6.9%	10.69	11602843
4.5	50th	-5.8%	10.54	11585326
4.5	75th	-2.9%	11.20	11661978
8.5	50th	-10.4%	10.18	11544150
8.5	90th	-18.9%	9.03	11410642

Table 2I



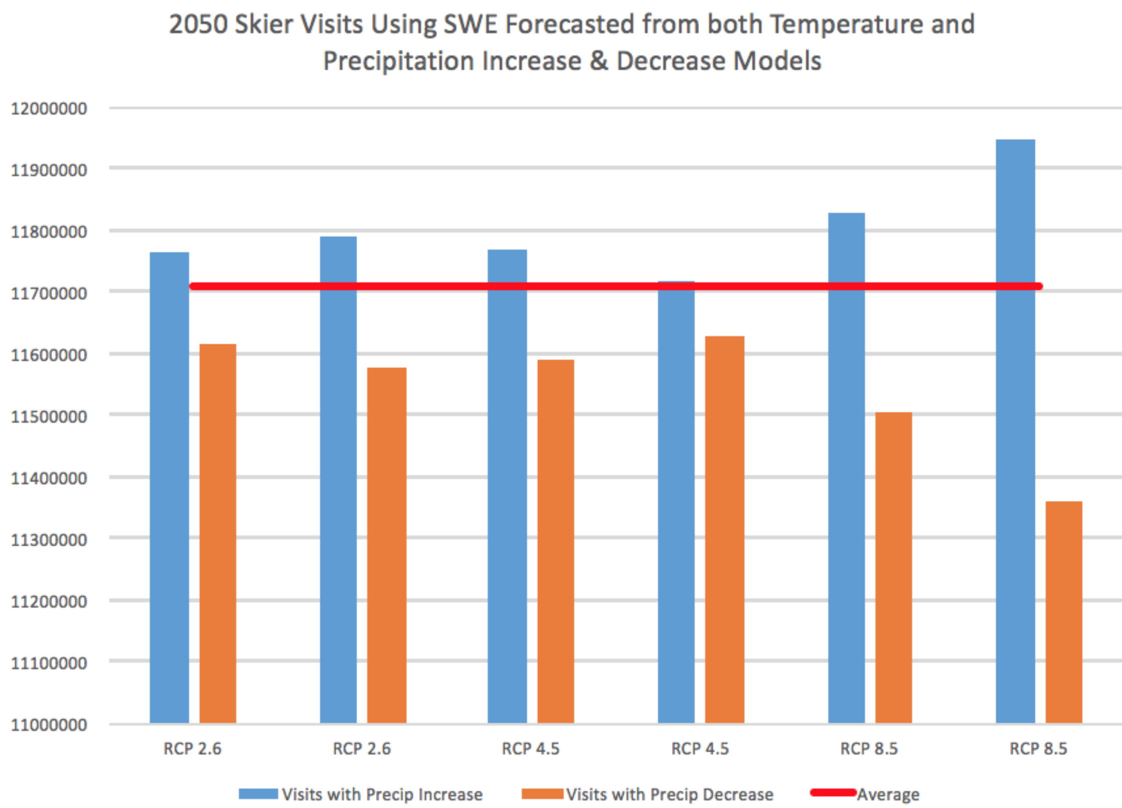
Graph 2J

2050 Skier Visits with Temperature and Precipitation Changes Considered

Serving as the most comprehensive of the 2050 skier visit forecasts, the results in **Table 2J** and **Graph 2K** were generated using SWE calculated from temperature increase scenarios, and both precipitation increase and decrease scenarios. Being fairly consistent with other scenarios examined, precipitation is still the dominant factor in determining skier visits. In other words, even with temperature considered, average skier visits only increase above historical average when precipitation increases and vice versa. However, when analyzing the actual data points, temperature clearly dampens the effects of precipitation increase. In other words, skier visits swell less in precipitation increase scenarios, but visits decline more in precipitation decrease scenarios. This is complimentary to the effects seen on SWE when precipitation scenarios were applied in addition to temperature. Overall, skier visits will still be above the historical average with precipitation increase and below the historical after with precipitation decrease. However, the increase is less severe, while the decrease is more dramatic when precipitation is included with temperature.

Forecasted Skier Visits Using SWE Generated from Temperature and Precipitation Models Combined					
RCP Model	Percentile	2050 SWE Precip Increase	2050 Skier Visits	2050 SWE Precip Decrease	2050 Skeir Visits
2.6	25th	12.069	11762385	10.776	11612785
2.6	50th	12.293	11788284	10.433	11573111
4.5	50th	12.115	11767635	10.552	11586815
4.5	75th	11.656	11714558	10.874	11624148
8.5	50th	12.637	11828073	9.834	11503804
8.5	90th	13.665	11946954	8.569	11357490

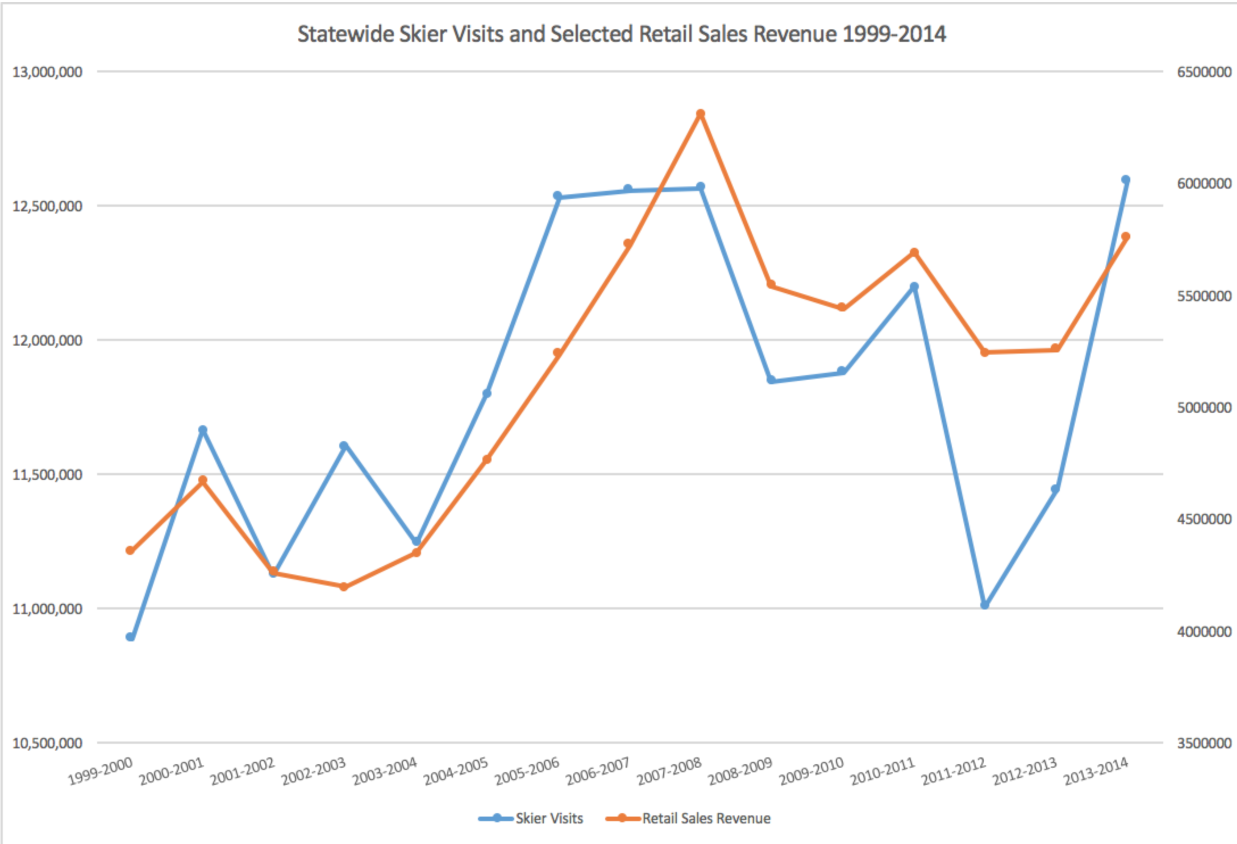
Table 2J: 2050 Skier Visits with Temperature Increases and Precipitation Increases/ Decreases Considered



Graph 2K

Retail Sales Revenue and Skier Visits

Retail sales revenue from each county considered in this thesis was used to represent the economic contribution of skier visits to Colorado. To restate, the counties considered were: Pitkin, Gunnison, La Plata, Routt, Eagle, San Miguel, Summit, Grand and Chaffee. As stated in the "Data" section of this thesis, high-definition data, detailing individual counties is only available from 1999 to present day. Therefore, the correlation coefficient is being produced from both skier visits and county retail sales revenue data from 1999 – 2014. The correlation found a strong, positive relationship of **.748** which alludes to the importance of skier visits in driving retail sales. Precisely, for every change of **1** in skier visits, retail sales revenue responded with a **.82** change. More significantly, this means that a change of 100,000 in skier visits would result in a **$82,000 (**thousands of dollars, 000) shift in retail sales revenue. Note, all data on retail sales revenue in this thesis is in "thousands of dollars as this is how it was presented by the Department of Revenue. The relatively close relationship is visually apparent in **Graph 2L** where both variables are seen to track closely together.



Graph 2L: Statewide Skier Visits and Retail Sales Revenue 199-2014

Economic Impacts in 2050

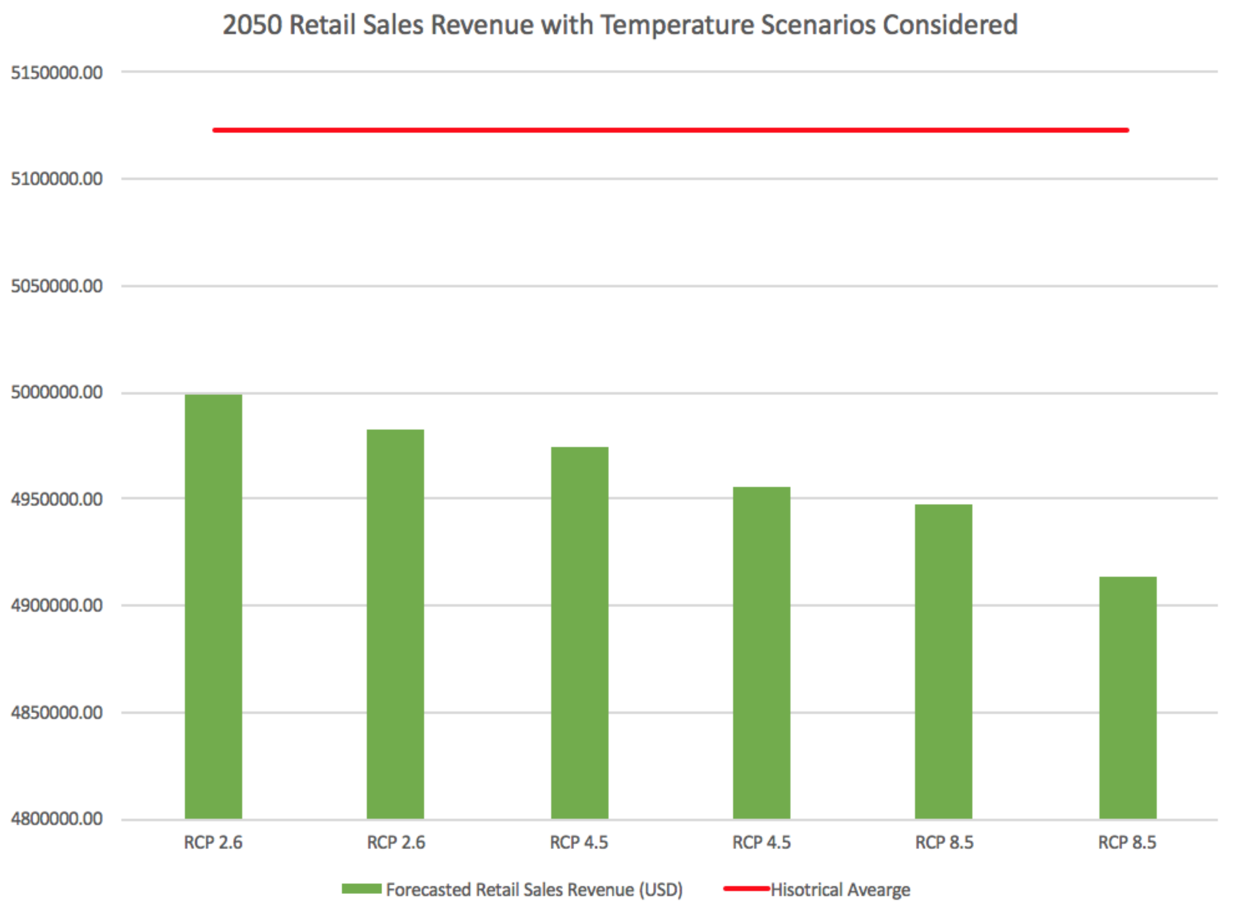
Given the rather strong correlation, climate-induced changes in skier visits has the potential to drastically alter economies in Colorado ski towns and statewide. The 2050 skier visits forecasted under all different temperature and precipitation scenarios are being employed here to model average retail sales revenue in 2050. The values are calculated by applying the results from the regression between skier visits and retail sales revenue.

2050 Retail Sales Revenue with Temperature Increases Considered

This portion of analysis forecasts 2050 average retail sales revenue using the skier visits that were modeled for 2050 using SWE values generated exclusively from various temperature scenarios. With skier visits and SWE both forecasted to be below historical average in 2050 in all temperature scenarios, it is no surprise that the same is true for retail sales revenue. These results show that 2050 forecasted average retail sales revenue falls below the historical average in all temperature scenarios. The results are displayed in **Table 2K** and visualized in **Graph 2M.** As apparent the most severe losses are had when the most extreme climate scenarios (RCP 8.5) are applied.

2050 Retail Sales Revenue with Temperature Scenarios Considered				
RCP Model	Percentile	Temp Forecast ˚F	Forecasted Skier Visits	Forecasted Retail Sales Revenue (USD)
2.6	25th	+2.3	11649371.48	4999074.22
2.6	50th	+3.1	11629110.87	4982393.11
4.5	50th	+3.5	11618980.57	4974052.56
4.5	75th	+4.4	11596187.40	4955286.31
8.5	50th	+4.8	11586057.10	4946945.76
8.5	90th	+6.4	11545535.90	4913583.55

Table 2K



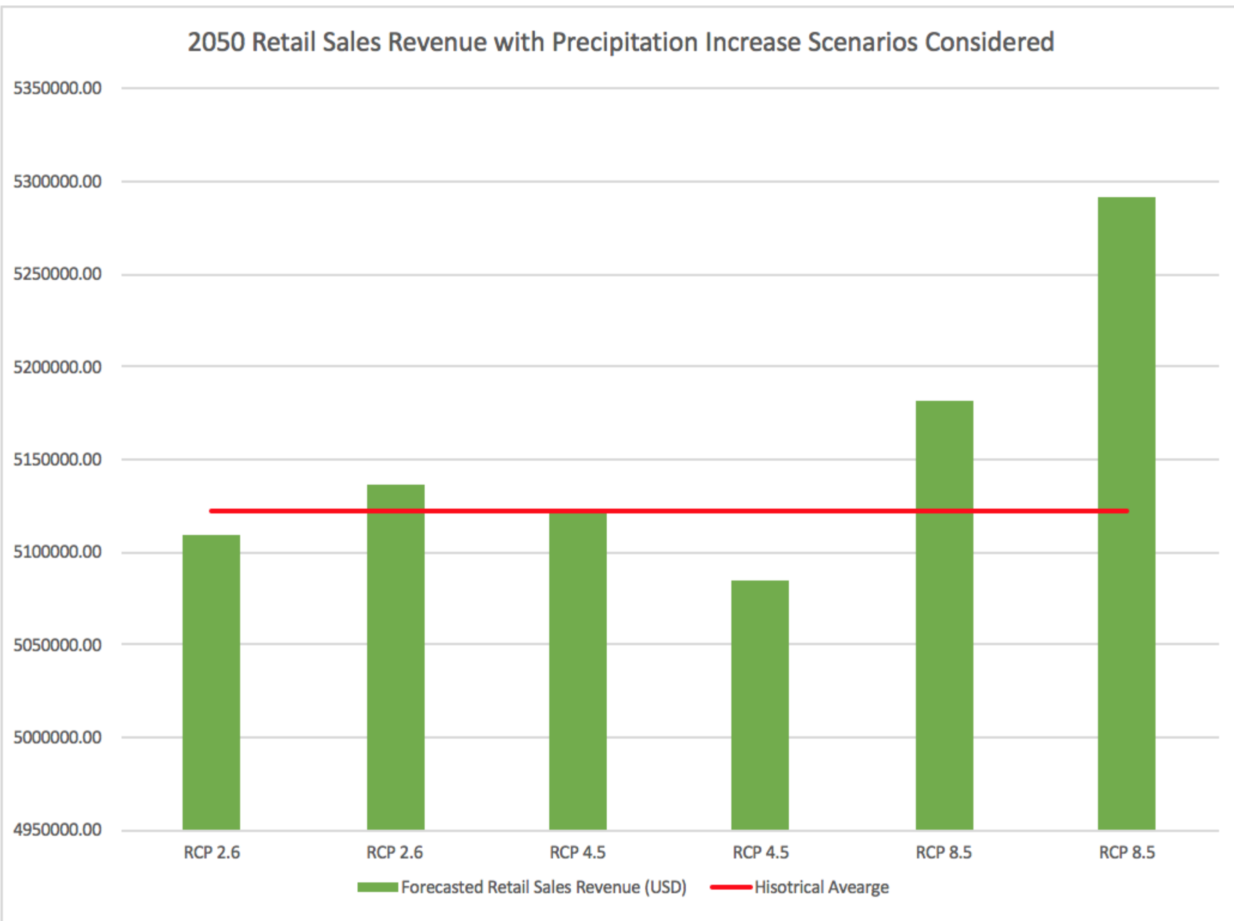
Graph 2M

2050 Retail Sales Revenue with Precipitation Increases Considered

This portion of analysis forecasts 2050 average retail sales revenue using the skier visits that were modeled for 2050 using SWE values generated exclusively from various precipitation increase scenarios. Even with precipitation increase, the forecast indicated that average 2050 retail sales revenue would still be below the historical average with the exception of the most extreme scenarios (RCP 8.5) and the 50th percentile RCP 2.6 scenario. These results are displayed in **Table 2L** and **Graph 2N.**

2050 Retail Sales Revenue with Precipitation Increase Scenarios Considered				
RCP Model	Percentile	Precip Forecast (% change)	Forecasted Skier Visits	Forecasted Retail Sales Revenue (USD)
2.6	25th	+4.8%	11782966	5109065.94
2.6	50th	+6.9%	11816079	5136329.27
4.5	50th	+5.8%	11798762	5122071.41
4.5	75th	+2.9%	11753128	5084500.04
8.5	50th	+10.4%	11871074	5181607.59
8.5	90th	+18.9%	12004932	5291816.96

Table 2L



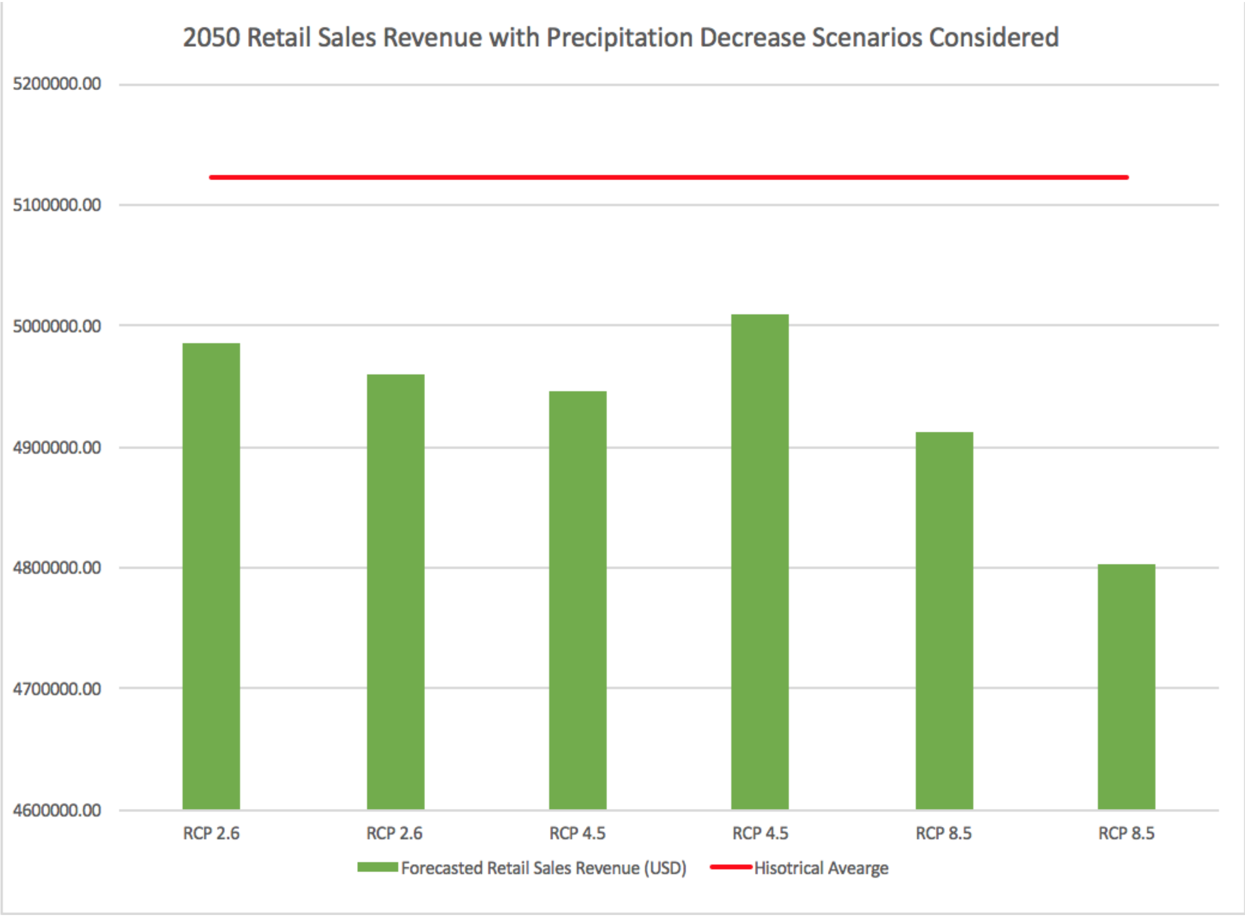
Graph 2N

2050 Retail Sales Revenue with Precipitation Decreases Considered

This portion of analysis forecasts 2050 average retail sales revenue using the skier visits that were modeled for 2050 using SWE values generated exclusively from various precipitation decrease scenarios. The results show forecasted average retail sales revenue in 2050 to be below the historical average under all precipitation decrease scenarios. The results for precipitation scenarios can be seen in **Table 2M** and **Graph 2O.**

2050 Retail Sales Revenue with Precipitation Decrease Scenarios Considered				
RCP Model	Percentile	Precip Forecast (% change)	Forecasted Skier Visits	Forecasted Retail Sales Revenue (USD)
2.6	25th	-4.8%	11632141	4984887.73
2.6	50th	-6.9%	11602843	4960765.83
4.5	50th	-5.8%	11585326	4946343.50
4.5	75th	-2.9%	11661978	5009453.63
8.5	50th	-10.4%	11544150	4912442.41
8.5	90th	-18.9%	11410642	4802522.05

Table 2M



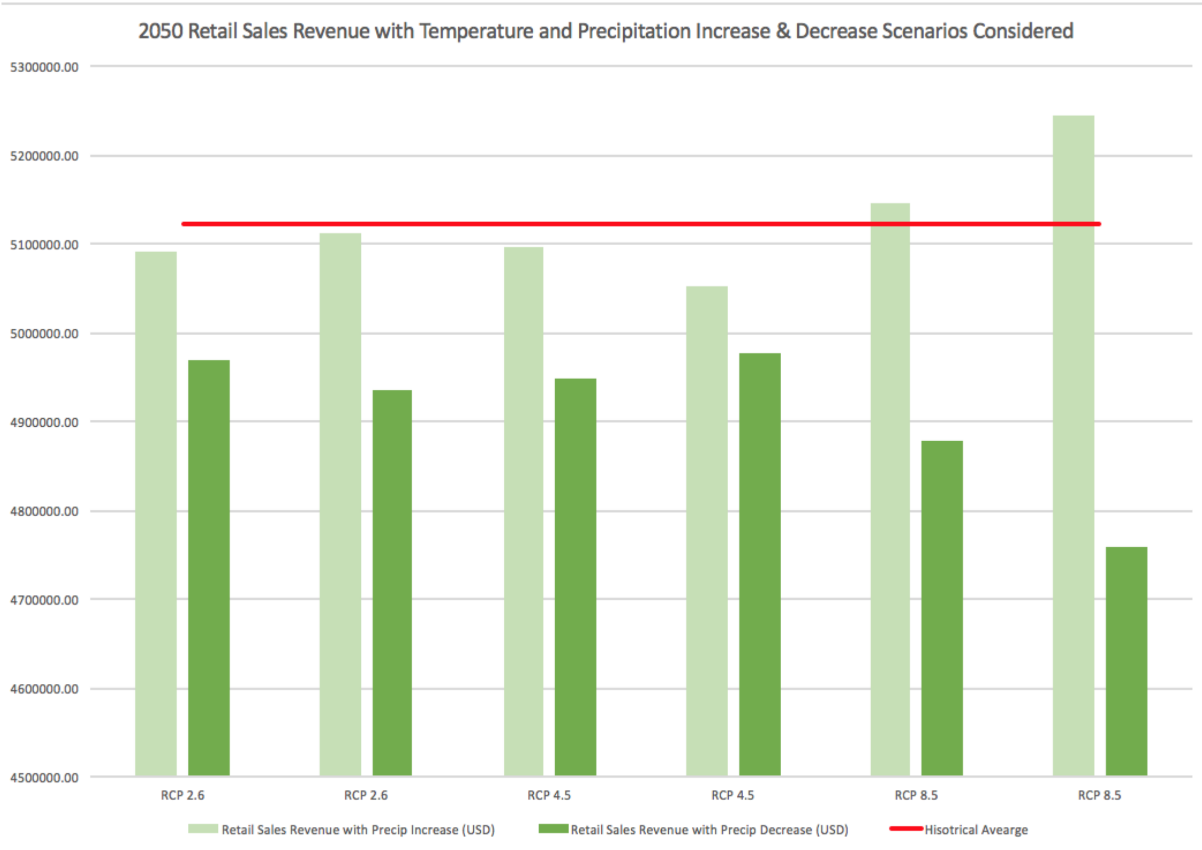
Graph 2O

2050 Retail Sales Revenue with Temperature and Precipitation Changes Considered

This portion of analysis forecasts 2050 average retail sales revenue using the skier visits that were modeled for 2050 using SWE values generated from both temperature and precipitation scenarios. When temperature comes in as an additional variable, only the most extreme precipitation scenarios (RCP 8.5) drive the retail sales revenue over historical average. This alone demonstrates the significance of including temperature as well, as it brought the RCP 2.6 scenario below the historical average. Therefore, these results somewhat counter those found when forecasting 2050 retail sales revenue from precipitation increase scenarios alone. Like the results seen in 2050 skier visit forecasts, including temperature also made the retail sales revenue in precipitation decrease scenarios even more severe. Further, the increases were less intense which is why the RCP 2.6 scenario was forecasted below the historical average when temperature was also applied. These results are displayed in **Table 2N** and **Graph 2P.**

2050 Retail Sales Revenue with Temperature and Precipitation Increase & Decrease Scenarios Considered					
RCP Model	Percentile	Skier Visits with Increase	Retail Sales Revenue (USD)	Skier Visists with Decrease	Retail Sales Revenue (USD)
RCP 2.6	25th	11762385	5092121.38	11612785	4968951.46
RCP 2.6	50th	11788284	5113444.96	11573111	4936286.68
RCP 4.5	50th	11767635	5096443.69	11586815	4947569.57
RCP 4.5	75th	11714558	5052744.21	11624148	4978307.15
RCP 8.5	50th	11828073	5146204.08	11503804	4879224.45
RCP 8.5	90th	11946954	5244081.82	11357490	4758759.87

Table 2N



Graph 2P

Summary of Results

This section will simply restate results in terms of how much change will occur in SWE, skier visits, and retail sales revenue. Previously, specific forecasts were made, but this section will detail how much each forecasts deviates from the historical average. The purpose of this is to best display which climate models will drive the largest changes in skier visits and retail sales revenue. However, it may become obvious that some results are similar because the effects on skier visits and retail sales are entirely determined by SWE.

Each of the tables below displays the changes are forecasted to occur in accordance with the climate model listed. The scenarios highlighted in red indicate the highest potential economic loss, while those in yellow indicate the highest possible gain. As anticipated, the extremes on both ends only occur when the most sever climate model was applied. Interestingly, some economic loss was forecasted even when skier visits were above the historical average. This depicts some of the problems that can occur when working exclusively with averages. However, as seen in **Table 2O,** some substantial losses in economic revenue can be had even with just temperature scenarios applied. The remainder of the forecasted changes are displayed in **Tables 2P, 2Q, 2R, 2S**

Change in SWE, Skier Visits, and Retail Sales Revenue Forecastes in Colorado Through 2050 with Temperature Increase Considered					
RCP Model	Percentile	Temp Forecast (˚F)	Forecasted SWE Change (inches)	Forecasted Skier Visit Change (Thous)	Forecasted Retail Sales Revenue Change (USD/Thous)
RCP 2.6	25th	+2.3	-0.51	-58251.52	-123460.78
RCP 2.6	50th	+3.1	-0.67	-78512.13	-140141.89
RCP 4.5	50th	+3.5	-0.77	-88642.43	-148482.44
RCP 4.5	75th	+4.4	-0.97	-111435.60	-167248.69
RCP 8.5	50th	+4.8	-1.00	-121565.90	-175589.24
RCP 8.5	90th	+6.4	-1.41	-162087.10	-208951.45

Table 2O

Change in SWE, Skier Visits, and Retail Sales Revenue Forecastes in Colorado Through 2050 with Precipitation Decrease Considered					
RCP Model	Percentile	Precip Forecast (% Change)	Forecasted SWE Change (inches)	Forecasted Skier Visit Change (Thous)	Forecasted Retail Sales Revenue Change (USD/Thous)
RCP 2.6	25th	-4.8%	-.66	-75482.21	-137647.27
RCP 2.6	50th	-6.9%	-.91	-104780.27	-161769.17
RCP 4.5	50th	-5.8%	-1.06	-122297.40	-176191.50
RCP 4.5	75th	-2.9%	-.39	-45644.87	-113081.37
RCP 8.5	50th	-10.4%	-1.42	-163473.11	-210092.59
RCP 8.5	90th	-18.9%	-2.57	-296980.58	-320012.95

Table 2P

Change in SWE, Skier Visits, and Retail Sales Revenue Forecastes in Colorado Through 2050 with Precipitation Increase Considered					
RCP Model	Percentile	Precip Forecast (% Change)	Forecasted SWE Change (inches)	Forecasted Skier Visit Change (Thous)	Forecasted Retail Sales Revenue Change (USD/Thous)
RCP 2.6	25th	+4.8%	+.66	+75342.62	-13469.06
RCP 2.6	50th	+6.9%	+.934	+108456.22	+13794.26
RCP 4.5	50th	+5.8%	+.78	+91138.86	-463.58
RCP 4.5	75th	+2.9%	+.39	+45505.28	-38034.96
RCP 8.5	50th	+10.4%	+1.42	+163450.53	+59072.59
RCP 8.5	90th	+18.9%	+2.57	+297309.03	+169281.95

Table 2Q

Change in SWE, Skier Visits, and Retail Sales Revenue Forecastes in Colorado Through 2050 with Temperature Increase & Precipitation Decrease Considered				
RCP Model	Percentile	Forecasted SWE Change (inches)	Forecasted Skier Visit Change (Thous)	Forecasted Retail Sales Revenue Change (USD/Thous)
RCP 2.6	25th	-.82	-94838	-153583.54
RCP 2.6	50th	-1.16	-134512	-186248.32
RCP 4.5	50th	-1.04	-120808	-174965.43
RCP 4.5	75th	-.72	-83475	-144227.85
RCP 8.5	50th	-1.76	-203819	-243310.55
RCP 8.5	90th	-3.027	-350133	-363775.13

Table 2R

Change in SWE, Skier Visits, and Retail Sales Revenue Forecastes in Colorado Through 2050 with Temperature Increase & Precipitation Increase Considered				
RCP Model	Percentile	Forecasted SWE Change (inches)	Forecasted Skier Visit Change (Thous)	Forecasted Retail Sales Revenue Change (USD/Thous)
RCP 2.6	25th	+.47	+54762.03	-30413.62
RCP 2.6	50th	+.70	+80661.31	-9090.04
RCP 4.5	50th	+.52	+60011.84	-26091.31
RCP 4.5	75th	+.06	+6935.16	-69790.79
RCP 8.5	50th	+1.04	+120450.01	+23669.08
RCP 8.5	90th	+2.07	+239330.72	+121546.82

Table 2S

Discussion

This thesis intended to examined a few key relationships between both environmental and economic variables with the prerogative of forecasting 2050 economic loss when various climate models are applied. Originally, it was hypothesized that temperature increases would lower SWE in 2050 causing skier visits and retail sales revenue to decline due to strong correlations among the variables. This thesis found that Colorado will experience some economic loss in 2050 because of a decline in skier visits due to a lower than historical average SWE. Further, it is likely that Colorado will experience a shorter ski season as maintaining an adequate snow surface in November and April will be hindered by warmer temperatures. However, it was also determined that precipitation has a much more profound influence on SWE in comparison to temperature, which only minimally effects SWE. Additionally, the SWE forecast was typically indicative of how both skier visits and retail sales revenue will respond. In other words, when SWE is below the historical average skier visits and retail sales revenue would be as well. This means that an increase in SWE, which occurred when precipitation increases were applied, skier visits and retail sales revenue could grow as well. Overall, SWE, skier visits, and retail sales revenue all share relationships that can be affected by temperature and precipitation change.

Because SWE almost solely determines the outcome of both skier visits and retail sales revenue, it is arguably the most important variable. Initially, it was anticipated that temperature would be the primary influence on SWE, but the weak correlation between the two variables rejects this. One major factor that could have had influence is the elevation of the SNOTEL stations from which temperature data was derived. In fact, the 18 SNOTEL stations utilized had an average elevation of 10,222 feet, which is relatively high. However, these stations were chosen on three factors, being elevation, location, and installation year. The elevation was intended to be close to that of the ski resorts being studied, which averaged a base elevation of

8,931 feet and summit elevation of 11,500 feet. Therefore, the average elevation of the SNOTEL sites falls around the average mid-mountain elevation of the ski resorts. Further, location of each SNOTEL site was chosen to be within close proximity of an adjacent ski resort being studied. Unfortunately, the installation year hindered the ability to use data from the most proximate station. For example, Beaver Creek Resort had a SNOTEL station installed in it's base village during 2006, but was not used in this thesis. The only SNOTEL stations used were those installed prior to 1994, allowing for the most complete data inline with skier visits. Consequently, consideration of elevation for each station was slightly impacted by both location and installation year restrictions.

Returning to the main point, elevation has shown to impact SWE and the magnitude of the influence from both temperature and precipitation. Notably, a study conducted in Switzerland found that "the influence of temperature and precipitation on snowpack variability vary approximately linearly with elevation." More importantly, "the impact of temperature tends to decrease with altitude, whereas that of precipitation tends to increase." Given the high elevation of the SNOTEL sites considered this could explain why a weak correlation coefficient was produced. (Sospedra-Alfonso, 2015). The presence of this effect in Colorado could be further explored as that would impact the results of this thesis.

Another possible explanation comes from the influence of precipitation on SWE. Because the weak correlation found between temperature and SWE, it was apparent that another factor must have the primary influence on SWE. This thesis confirmed that precipitation is the primary influence on SWE, drastically shadowing temperature. Specifically, precipitation could have helped to compensate when temperatures were high. Essentially, if warm temperatures cause SWE to decline, increased precipitation could have filled the void. However, this postulation is made exclusively from the findings in SWE and temperature. Although, it is largely accepted that precipitation typically increases with warmer air temperatures. Specifically, "higher air temperatures increase atmospheric water vapor holding capacity, creating increased precipitation intensity" (Ye et al., 2016). Further, the Ye et al. report found "precipitation intensity to increase at a rate of 1-3% per degree of air temperature increase in the study area." While these findings are not confirmed for Colorado, it is worth further research and analysis.

Even though future precipitation in Colorado may be uncertain, this thesis confirms that precipitation is best capable of dramatically changing SWE. For ski areas, this creates a range of possibilities that could actually be in their favor, because snow quality and quantity could potentially increase. When some of the precipitation increase models were applied, SWE, skier visits, and retail sales revenue were all forecasted to be above the historical average in 2050. This thesis also found that the three variable listed prior would also increase even when temperature increase was added into the equation. However, the addition of air temperature did dampen the increase effects, but further decline effects. Overall, this would indicate that climate change could potentially create a scenario that would be beneficial to ski areas and the local economies.

While an increase in precipitation could benefit ski areas by 2050, there will be a distinct threshold where this will no longer hold true. Eventually average temperature will exceed 32 ˚F causing much of the increased precipitation to fall as rain, not snow. The results of this thesis indicate that this threshold will not be hit 2050, however more distant models show that this could potentially occur before 2100. (RCP Database, 2016) Granted this is speaking to average temperature, so 32 ˚F will no be consistently maintained for the entire season. For ski areas, an average winter temperature above 32 ˚F will most likely mean a drastically shortened ski season, although this could occur under some of the 2050 scenarios as well. In summary, increased precipitation would be conducive to ski resort business, until temperature increases cause precipitation to fall as rain rather than snow.

One of the larger limitations of this thesis is the reliance on averages for all calculations made in the analysis chapter. Unfortunately, because skier visit statistics were restricted to statewide it was difficult to properly wait the other environmental and economic variables proportionally. The main concern over using averages is because Colorado is such a large state with diverse climates and geology throughout. This means that climate change will likely have varied impacts entirely dependent on location. Further, economic impacts will also range by location as certain ski resorts draw substantially more visitors than others.

Beginning with variation in environmental data, there is often a distinct difference in snow conditions between the southern and northern Colorado mountains. In other words, Steamboat may have a banner season, while Telluride performs well below average. However, this difference can be even more profound with “average annual snowfall at Cubres in the southern mountains being nearly 300 inches; but less than 30 miles away in the San Luis Valley; snowfall is less than 25 inches” (Western Regional Climate Center, “Climate of Colorado). Further other variables also have the ability to influence snow patterns as “temperature decreases and precipitation generally increases with altitude, but these patterns are modified by the orientation of mountain slopes with respect to the prevailing winds and by the effect of topographical features in creating local air movements” (Western Regional Climate Center, “Climate of Colorado). These dramatic differences that can exist between different regions of Colorado allude to the problem with generalizing data. Even though, every ski resort will likely see some decline in SWE and therefore skier visits and retail sales revenue by 2050, the severity will be highly variable, not uniform as averages suggest.

Much like that of SWE, the magnitude of change in skier visits and retail sales revenue will not be consistent throughout the state either. Namely, the economic impacts will be dampened near some ski areas but exaggerated at others. For one, those resorts that are more adversely impacted by climate change will suffer a larger loss in both skier visits and retail sales revenue. In the "Analysis" chapter, the unique demographics of Colorado skiers was outlined, being mostly defined by wealthy, destination visitors. However, this generalization about Colorado skiers is not true for all resorts, as Vail, Beaver Creek, and Aspen-Snowmass represent the pinnacle of wealthy ski destinations in Colorado. These resorts that attract the top-wealth bracket will likely be less affected by any changes in snow quality. Additionally, these top-tier resorts often boast superior snowmaking capabilities, allowing for adequate conditions in even the driest of years. Overall, it is also difficult to generalize economic data just because of the immense diversity among Colorado ski destinations and the clientele they attract. In reality, the averages indicate that some Colorado ski towns will probably lose significantly more revenue than others, simply because of the positioning of certain competitors in the industry.

Moving on, in terms of economic outcome, the results in this thesis were relatively consistent with those found in similar studies. These studies, mainly the "Climate Change and Aspen: An Assessment of Impacts and Potential Responses" and the "Climate Impacts on the Winter Economy in The United States" were both referenced in the "Background" chapter of this thesis. In these two reports, both indicated that skier visits and economic revenue would decline in the circumstance that climate change progresses. The Aspen report found that skier visits, economic revenue, and jobs would decline in the event that precipitation decreased. Conversely, the report found that an increase in precipitation would be of benefit to Aspen by raising all three economic variables. This result in Aspen, corresponded to the forecasts in this thesis, particularly the response to precipitation changes. However, the Aspen report ignored the ability for temperature to have any influence on any of the variables studied. Disregarding temperature seems to be illogical considering the higher confidence in temperature models when compared to precipitation in Colorado.

Next, the “Climate Impacts on the Winter Economy in The United States” report, had somewhat equivalent results to this thesis, although more extreme. The reason for the exaggeration in the report is easily explained by it’s methods, which simply explored the range in visits from a high snow year to a low snow year. Drawing results in this fashion was ignorant of other variables that could impact one’s decision to ski. Further, it is unlikely that the worst of the worst snow years will be the new normal by 2050. Maybe these results are somewhat representative of the ultimate climate disaster, but one that would be much further out. However, this report still found economic loss somewhat close to the values forecasted under the most dramatic RCP 8.5 precipitation decrease climate models in this thesis. Interestingly, the projections for skier visits were far more dramatic than that found in this thesis. Even though, jobs were another variable considered by both reports, something excluded from this thesis. Although jobs were disregarded it is expected that they would similarly decline with skier visits and retail sales revenue.

Further Research

Some exclusions in this thesis, such as the lack of consideration for snowmaking as a technical adaptation and the ignorance of summer operations as a substitute naturally allow for further research. However, some of the results in this thesis that did not turn out as expected also provide room for additional research to find explanations. Namely, it would be interesting to determine if precipitation increased with higher temperatures. While much research supports this conclusion, studying it among the locations throughout Colorado in this thesis would be constructive. Further, researching the effect of elevation on SWE would also help to reinforce the results from this thesis. Previous studies have indicated that elevation can impact the influence of either temperature or precipitation on SWE, as one may be more dominant depending on altitude.

In recent years, snowmaking technology has revolutionized the ski industry, allowing for earlier opening dates and helping to deliver adequate snow surface conditions. As stated prior in this thesis, Colorado has no shortage of snowmaking and many resorts are increasing their capabilities yearly. Therefore, it would be reasonable to somehow include this into the analysis, as snowmaking can serve as a partial substitute for natural snow. Researchers such as Scott et al. have found that "the existing core ski season at three study areas could be maintained in 2050, with the exception of the warmest scenario, if ski areas are prepared to invest in greater snowmaking" (Scott et al, 2007). Granted the ski areas in the Scott et al. study were in Canada, somewhat differentiating the study from those that would be conducted in the United States. However, including snowmaking in the methodology would be beneficial to any study measuring the impacts of climate change on ski areas.

Of course there are limitations with including snowmaking that should be considered as well. Generally speaking, artificial snow surfaces provide a lower quality of skiing and riding that may be less desirable to certain visitors. Therefore, guaranteeing an opening day can only go so far as people do not want to ski a few trails at Vail, when there should be more than 100 open. Further, snowmaking is costly due to the necessity for water, electricity, and labor. Finding a balance between snowmaking and overall profitability for the resort will be key. For this reason, including a cost-benefit analysis in any future studies that include snowmaking would be essential. Finally, to clarify, studies, such as those by Scott et al have been done with the inclusion of snowmaking, but none in Colorado thus far.

Next, even more recently than snowmaking, investment in summer operations has become a primary concern for ski areas. In February 2016, Vail Resorts announced a new summer program dubbed “Epic Discovery” claiming to be the “first-of-its-kind comprehensive on-mountain summer adventure featuring components such as zip lines, canopy tours, alpine coasters, wildlife trail exploration, and interactive learn-through-play activities, which will debut at Vail and Heavenly in June and at Breckenridge in 2017” (Vail Resorts, 2016). These types of investments are not exclusive to Vail Resorts, but the profound investment by the largest industry leader is significant in it’s own right. These types of moves to motivate visitors to return in the summer indicate the desire for resorts to secure profits in seasons other than winter, in the event that weather does not cooperate. With that being said, it would be beneficial to research the contribution of summer operations to overall economic revenue in Colorado. Even though climate change may affect winter operations, summer activities could supplement this loss allowing ski resorts to remain desirable. Determining just what this contribution to revenue is should be studied in factored into any economic forecasts for Colorado ski communities.

Recommendations

Because climate change will certainly reshape the Colorado skiing experience to some extent, resort operators and in-town business owners a like will need to adapt. For the ski area operator this will involve both preserving the winter experience and innovating new ways to drive revenue in the off-season. The fate of business owners will be almost entirely reliant on the ski areas ability to maintain visitation, as it was shown that skier visits and retail sales revenue are very strongly correlated. Therefore, the primary goal should be maintaining steady visitation to ski areas, regardless of season. Naturally, compensating for lower winter visitation in alternative seasons will not be ideal for all businesses. Namely, the many businesses that rely on snow, such as snowmobile touring companies, will not benefited by increased summer visits.

Chiefly, ski area operators must focus on maintaining a high level of snow quality throughout the entire season. This will come by investing in snowmaking infrastructure in areas where it is necessary and has the potential to enhance the guest experience. This means, it should be installed on key trails that either receive heavy use or are iconic trails that guests anticipate skiing. Many resorts already include snowmaking infrastructure where needed, but being able to open more trails when natural snow is lacking will entice guests. Of course, this will never totally supplement the tree, bowl, and other off-piste skiing that is expected in Colorado. However, improved snowmaking will still help ski resorts achieve their desired opening dates with more expansive terrain if investments are made properly. With guests booking vacations often months ahead of time it is clearly in the resorts best interest to provide a good skiing experience, even in the early season.

As discussed in the “Further Research” chapter, investments in summer operations have become a chief priority for ski resorts. This represents yet another way that resorts are attempting to maintain steady visitation. Given the results from this thesis, continuing to drive off-season visitation is recommended for Colorado ski resorts. Enhancing the guest experience throughout the entire year will further establish loyalty, something that may be key to ski resorts well being in future years.

One final recommendation for ski resorts it to be the change when it comes to climate change, through lobbying. The Aspen Skiing Company has already made its voice heard in our federal government, serving as a significant lobbying force for climate legislation. In fact, "Aspen Skiing Company has made our number 1 priority using the snowports community as a level to drive policy change" (Aspen-Snowmass, 2016). While Aspen-Snowmass is the height of environmental stewardship in the industry, they recognize the importance of making efforts beyond their local town. By partnering with organizations such as Protect Our Winters, Aspen has shown unwavering commitment to making change in Washington. After all, local efforts will be rendered insignificant if our country and the world fail to act. Given the necessity of the ski industry to so many communities nationally, it would be recommended that other resorts follow Aspen and demand federal change.

Expanding year-round operations, adapting to changing snow conditions, and lobbying will protect the economic interest of both ski resorts and businesses in the surrounding communities. Preserving the winter experience through snowmaking will help ski resorts in the short term, but severe climate changes will eventually make this ineffective. For this reason, motivating visitation throughout all seasons will best allow resorts and their communities to sustain business in future climates. However, minimizing the effects of climate change would be the best scenario for both the ski industry and ski communities. The industry is most capable of doing this through lobbying efforts in Washington DC. In summary, resorts will need to adapt as their essential product, snow, is changing with the climate. Innovating new ways to keep guests visiting will be a challenge that some will overcome and some will not. However, industry leaders like Vail Resorts, Intrawest, and Aspen Skiing Company should use their stature to sway the federal government, as this will help all parties.

Conclusion

The ski industry is an integral part of Colorado, serving as a major economic contributor and driver of state visitation. However, this industry is under threat by climate change which is looming future temperature and precipitation changes for Colorado. By exploring the relationship between environmental and economic variables, the ability for climate to alter Colorado's economy through the ski industry was confirmed. With that being said, a large amount of uncertainty still exists when attempting to forecast future economic and environmental conditions. Even though the results are generalized due to averaged data in this thesis, it is likely that ski areas will be affected variably based on location. To cope with these future challenges from climate change, ski areas will need to innovate and adapt to secure their own profits and continue to foster local economies.

Through economic contribution alone, the ski industry asserts its value to both Colorado and its residents. However, the ski industry is also an integral part of so many Coloradan's lives including those that have come to own successful businesses in ski communities. Preserving the viability of the ski industry will both save jobs and keep local economies thriving in ski towns. Because of the relationship between snow, skier visits, and economic revenue, climate change is capable of disrupting this current well-being. This thesis found that significant economic losses could be had under some more severe climate models, but the future for Colorado is still largely uncertain.

Even though some losses were quantified, it is difficult to accept these results as precisely representative of environmental and economic conditions in 2050. For no other reason, 2050 is the foreseeable, but still distant future, somewhat reducing the accuracy of any forecasts. Further, entirely trusting climate models for 2050 is also difficult, especially when they contest the observed trends. Particularly, many climate models are forecasting increased precipitation, even though this thesis found a downward trend historically. Climate change in it self is dynamic, so the severity for Colorado is uncertain, even though temperatures certainly will continue to warm. Therefore, Colorado, it's ski industry, and ski communities will be affected, but some models indicate the outcome may not be critical, but other portray just the opposite.

Regardless, relationships exist between both snow quality and skier visits and skier visits and economic revenue. Therefore, any change in snow quality has the ability to induce some economic loss for Colorado and it's many ski communities. For this reason, it is still in the best interest for ski resorts and ski communities to dynamically adapt in accordance with climate change. Because there is such a range of possible outcomes, these parties will have to read and constantly reassess climate change as it progresses. However, building resilience now is still important, as there is certainty that some change will occur, even if magnitude is less concrete. Further, each Colorado resort and its surrounding community will have to adapt differently, as the effects will vary spatially. While this thesis generalized results based on statewide averages, it is unlikely that all places will be affected in a uniform fashion. To determine regional impacts, more detailed analyses would need to be done as the climate models utilized were comprehensive for Colorado as well.

In summary, this thesis was most successful in portraying the relationship that exists between snow quality and the economy in Colorado. Unfortunately, due to generalized and averaged data, it is difficult to entirely trust the reliability of forecasts made in this thesis. With that being said it is likely that some Colorado ski communities will experience effects similar to those forecasted, depending on the climate scenario. However, only time will tell as 2050 is distant, providing resorts and their adjacent communities with the time to adapt. If proper adaptions and resilience strategies are employed, Colorado ski communities could thrive just as they do today, even in an altered climate.

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