Executive Summary

As atmospheric greenhouse gas (GHG) concentrations rise over this century and the climate continues to change, Park City is likely to warm substantially. Here, we present the results of a study for the Park City Mountain Resort using a site-specific technique for estimating potential changes in snow properties in response to future climate change scenarios. This report also addresses operational issues such as the ability to open on Thanksgiving, top-of-mountain snow depths during the Christmas holidays, and whether future ski seasons may end before the highly profitable spring break period in late March.

Specific objectives for this study were to estimate the length of the ski season, the timing of snowpack buildup and melt, and daily values of snow depth and coverage, from the bottom to the top of the mountain, for the years 2030, 2075, and 2100. This report presents the methods and results of climate model projections for a range of GHG emission scenarios, and the effects of projected climate change on snowpack characteristics for the Park City ski area.

Climate

The term "climate change" refers broadly to the changes in climate that are being exacerbated by the increasing atmospheric concentrations of GHGs. We create scenarios as tools to help us understand how regional climates may change and to understand how sensitive systems may be affected by climate change. Scenarios are plausible combinations of conditions that can represent possible future situations.

For this study, we developed scenarios for three periods: the 2030s, the 2070s, and the 2100s. These time periods are not selected to predict weather in a particular future year, but to estimate how average climate conditions may change. The 2030s are within the "foreseeable future" and planning horizons for some stakeholders, the 2070s capture mid-term climate change, and the 2100s capture long-term climate change. We project out to 2100 because it is likely that the current path of GHG emissions will lead to substantial changes in climate at least that far out into the future (although reduction of emissions could substantially reduce climate change over this century).

Future changes in GHG emissions depend on many factors, including population growth, economic growth, technology, government, and society. Out of seven scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), we selected four to use for the Park City study. Since likelihoods are not given for these scenarios, we use a range of them to reflect a wide range of potential future GHG concentrations.

We used three modeling approaches to examine potential future climate. The first is the "MAGICC/SCENGEN tool," which evaluates climate change estimates over General Circulation Model (GCM) grid boxes that are 5° across, roughly 300 miles in length and width. We used the following five GCMs that best simulate current climate over western North America:

- CSIRO – Australia
- ECHAM3 – Max Planck Institute for Meteorology, Germany
- ECHAM4 – Max Planck Institute for Meteorology, Germany
- HadCM2 – Hadley Model, United Kingdom Meteorological Office
- HadCM3 – Hadley Model, United Kingdom Meteorological Office.

We examined climate projections from MAGICC/SCENGEN using each of the five GCMs independently, and using an average of output from the five GCMs.

To obtain increased spatial resolution of changes in climate in the Park City area, we used two additional modeling approaches. One is the output from a regional climate model (RCM). RCMs are high-resolution climate models that are built for a region, e.g., the United States, and are "nested" within a GCM. We used the RCM "MM5," which has grid boxes 36 kilometers (about 20 miles) across. The model is "nested" in the Parallel Climate Model (PCM). We refer to this model run as the PCM RCM.

The second high-resolution modeling approach is called statistical downscaling. We developed the Statistical Downscaling Model (SDSM), which uses the statistical relationship between variables in a GCM and observed climate at a specific location such as a weather station. The approach assumes that the statistical relationship between the large-scale climate variables in a GCM and a specific location will not change with climate change. The advantage is that statistical downscaling can be used to develop a scenario for a specific location. For this study, we developed a scenario for the weather station located near the mid-mountain of the Park City ski area.

Climate Results

All of the emission scenarios project a substantial increase in temperatures for the region over the next 100 years. The degree of warming is most sensitive to assumptions about GHG emissions and the modeling approach used. Different assumptions about emissions result in projected warming ranging from 3.3° to 8.4°C (5.9° to 15.1°F) in Park City by 2100. This implies that by 2100, Park City's climate will resemble the current climate of Salt Lake City. Warming is projected to be more pronounced during the summer months than during the winter months. On average, the models project a decrease in annual precipitation. This is true regardless of the emissions scenario or modeling approach. However, due to variability between models, it is uncertain whether precipitation will decrease over the 21st century.

Mountain Snow

We used the Snowmelt Runoff Model (SRM), developed and maintained by the U.S. Department of Agriculture Agricultural Research Service, to examine snowpack characteristics in the Park City ski area. SRM requires geographic information systems (GIS) information (including a digital elevation model, land use/land cover, and estimates of snow cover) for implementation. The model area is sub-divided into elevation zones, which enables the SRM to generate refined estimates of snowpack coverage and melt in areas with large vertical relief, such as the Park City ski area.

We used the SRM to estimate the length of the ski season, the timing of snowpack accumulation and melt, and the snow depth and coverage (derived from satellite imagery) at a given time. The spatial extent modeled for this study was dictated by the current (2006) Park City ski area property boundaries. Our modeled area spanned a vertical distance of approximately 1,067 m (3,500 ft), ranging from the base area elevation of 2,100 m (6,890 ft) to the highest elevation within the ski area property at 3,170 m (10,400 ft). We modeled the area in four elevation zones averaging 265 m (872 ft) in height.

An examination of the historical data, combined with an analysis of the availability of high-resolution images available during the winter months, led us to choose the season of 2000-2001 as our baseline of historical average conditions. We first ran SRM to simulate snow and snowmelt patterns for the 2001 water year, and then modeled future climate change scenarios by scaling observed temperature and precipitation records by the projected monthly changes, unique to each climate scenario.

Mountain Snow Results

Using the climate change scenarios and the SRM, we estimate that the date when snow starts to accumulate at the base area will be delayed at least four weeks, and some scenarios predict no accumulation at all by 2100. This change in snow accumulation will be caused by an increase in air temperature. Thanksgiving and spring break snow depths at the base area are projected to be at or near zero for all scenarios in 2075. For the high-emission scenario in 2075, there is unlikely to be a persistent seasonal snowpack at the base area, and the snowline is projected to move up to approximately 2,900 m (9,500 ft). The top of the ski area will maintain skiable snow throughout the ski season in all but the highest emissions scenario, although snow depths are reduced by 15 to 65% compared to historical observations. By 2100, only the low-emission and SDSM scenarios project skiable snow at the base area, and only during December through February. Results for the mid-emission scenario for 2100 indicate that a persistent snowpack will only exist for the upper quarter of the mountain. For the high-emission scenario by 2100, there will be no persistent snow coverage at all.

An examination of the snowpack projections reveals that snowpack begins to be substantially impacted when winter temperatures warm more than approximately 2° to 3°C (4° to 5°F), regardless of scenario or year that threshold is reached. GCM results show that warming in the North American Rocky Mountains is approximately one-third greater than the global mean temperature (GMT). This implies Park City could experience a 2°C warming compared to a GMT warming of only 1.3°C (2.4°F). Such an increase in temperature could be reached by mid-century.

It is unlikely that early season reductions in snowpack can be offset with snowmaking by 2075, since according to the models, temperatures do not become cold enough for snowmaking until late November to early December. Additional snowmaking later into the winter months, however, could bolster the snowpack enough to maintain skiable snow later into the spring break season. The economic implications of additional snowmaking, and other potential adaptation strategies, such as downloading skiers in the spring, should be evaluated by ski area owners and operators in the face of a changing climate.