KEYSTONE SKI AREA

WATER QUALITY STUDY

Executive Summary

June 2001

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EXECUTIVE SUMMARY

Introduction and Background

The Keystone Ski Area, located in Summit County, Colorado, uses snowmaking to enhance the reliability of early season skiing, maintain adequate snow coverage on high skier traffic areas, and supplement natural snow during periods of drought. The water supply source for the snowmaking system is the Snake River, which is contaminated by acid drainage from numerous abandoned mines and natural sources. At the location where snowmaking water is diverted, concentrations of zinc persistently exceed water quality criteria for aquatic life, and concentrations of cadmium and copper occasionally exceed aquatic life criteria. Concentrations of manganese persistently exceed the drinking water supply standard.

There are approximately 1,861 acres of skiable terrain within the Keystone Ski Area at elevations ranging from 9,300 to 12,200 feet. The snowmaking system currently covers about 668.5 acres of ski slopes located within the drainage basins of Camp Creek, Keystone Gulch (including the Mozart Creek tributary of Keystone Gulch) and Jones Gulch. The extent of utilization of the snowmaking system varies from year to year depending on weather conditions, skier traffic patterns and other factors. The ski area is planning to continue expanding snowmaking coverage as needed to enhance the reliability and quality of their product, pending Forest Service review and approval.

This study was designed and conducted in cooperation with the USDA Forest Service, and provides a thorough evaluation of water quality and other environmental impacts associated with metals in the snowmaking water supply. In addition, it provides information about other water quality impacts related to ski area development and operation.

Study Purpose and Methodology

The primary focus of this study was to examine the transport and fate of metals in water used for snowmaking and to identify potential impacts of these metals on streams, aquatic life, soils, groundwater and plants. The study involved extensive sampling of environmental media that are potentially exposed to snowmaking including:

- artificial and natural snow prior to spring snowmelt and during snowmelt;
- snowmelt water before contact with soils and vegetation;
- surface water drainage before it reaches streams;
- streams that receive snowmelt drainage and reference streams that do not receive drainage from snowmaking areas;

- soil water and groundwater in areas that are exposed to snowmaking and in reference areas that are not exposed to snowmaking;
- soils from ski slopes that receive snowmaking, reference ski slopes that do not receive snowmaking and reference areas that have not been exposed to ski area development and snowmaking; and
- macroinvertebrates in streams that receive snowmaking runoff and in reference streams.

The information developed from the sampling efforts listed above was used to characterize metals concentrations in each media and the degree of impact associated with snowmaking. It is important to note that the sample collection efforts for this study were focused upon the spring snowmelt period when the greatest potential impacts were expected to occur.

Study Results

Snowmaking Source Water (Snake River)

During the 1999-2000 season the Keystone Ski Area diverted 587 acre feet of Snake River water for snowmaking on approximately 668.5 acres of ski slopes and trails, resulting in an average application rate of about 10.5 inches of water per acre. Snowmaking was initiated on September 27, 1999 and continued through January 24, 2000, with peak water diversion rates occurring in early to mid-December. Based upon historical data, total zinc and manganese concentrations in the Snake River source water during the snowmaking season averaged about 350 µg/L and 230 µg/L, respectively.

Natural and Artificial Snow

Snow samples were collected on March 6, 2000 after the conclusion of snowmaking and prior to spring snowmelt. Reference sites where no snowmaking occurred were located in Keystone Gulch, on the Go Devil ski slope in the Snake River drainage and in Jones Gulch, while sampling sites that received snowmaking were located on the Frenchman ski slope in the Camp Creek drainage.

Comparison of the chemistry of natural and artificial snow demonstrates that elevated concentrations of zinc, manganese, and to a much lesser extent copper, are present in the artificial snow. The distribution of metals within the snowpack and between locations in snowmaking areas was highly variable due to mixing with natural snow and grooming activities. In addition, concentrations of zinc and manganese in Jones Gulch snow samples were somewhat elevated compared to other reference Keystone sites and USGS reference sites in Colorado, suggesting that there is some impact due to wind drift from snowmaking areas into Jones Gulch.

Snow Meltwater

Snowmelt samples were collected using snow lysimeters to capture meltwater prior to contact with soils and vegetation. These sample results showed that zinc, manganese, sulfate, and other ions associated with artificial snow eluted out of the snowpack early in the snowmelt cycle before most of the snow had melted. For example, 44 to 61 percent of the zinc was released from the snowpack with the first 30 percent of the meltwater over a period of 7 to 10 days. This "ionic pulse" of metals and other constituents resulted in peak zinc and manganese concentrations in meltwater that were up to 7.6 and 10.0 times higher (respectively) than average concentrations in the snowpack. The highest zinc and manganese concentrations and most pronounced elution effect occurred in the lysimeters with the slowest early melt rates. These results were generally consistent with the findings from research studies of ion releases in meltwater from natural snow (Johannessen and Henriksen 1978; Bales 1992).

These elevated concentrations are of concern because during early snowmelt stream flows are relatively low and their capacity for dilution and assimilation of pollutants is thus limited. During this period, however, a relatively high portion of the zinc from the snowpack tended to be in particulate form so that it was more readily filtered out of the runoff before it reached the streams. In addition, during early snowmelt, most of the runoff infiltrates to the ground and is routed through soils before it reaches the streams (Caine 1989). The soils have the capacity to adsorb and filter out some percentage of the metals.

Snowmelt Drainage

Snowmelt drainage samples were collected from waterbars on the Mozart (Mozart Creek basin) and Schoolmaster (Camp Creek basin) ski slopes to determine water quality characteristics in surface water runoff before it reached the streams. Snowmelt drainage samples were also collected from a small tributary of Jones Gulch. As with the snow lysimeter results, the highest concentrations of metals in both the Mozart Creek and Camp Creek snowmelt drainages occurred early in the runoff. Concentration trends were similar for both of the waterbar drainages.

Peak concentrations of total zinc and manganese in the Mozart snowmelt drainage were 159 and 286 μg/l respectively and occurred on April 28, 2000. As with the snow lysimeters, there were clear trends of decreasing concentrations of zinc and manganese with time, but peak snowmelt drainage concentrations were much lower than the peak lysimeters concentrations. Iron concentrations, however, did not follow this pattern. The elevated concentrations of total iron were associated with elevated total suspended solids and occurred much later in the runoff cycle than manganese and zinc, suggesting that elevated iron concentrations were associated with erosion caused by surface runoff.

Impacted and Reference Streams

Concentrations in impacted and reference streams were compared to water quality criteria for aquatic life even though these criteria may not be legally applicable to all of the stream reaches that are the subject of this study. Where applicable, measured stream concentrations were also compared to drinking water supply (manganese and iron) and agricultural water quality standards (manganese). The drinking water supply standards for manganese and iron are primarily aesthetic-based rather than health-based criteria, but are considerably more stringent than the aquatic life criteria. Concentrations in impacted streams (Camp Creek and Mozart Creek) are also compared to reference streams (Keystone Gulch and Jones Gulch).

Camp Creek

In Camp Creek, the drainage basin most heavily impacted by snowmaking, cadmium, lead, and silver concentrations were near or below detection limits, indicating water quality for these parameters was similar to the reference sites. Dissolved copper concentrations ranged from < 0.5 µg/l to 3.6 µg/l, and were generally higher than the concentrations found at the reference sites in Jones Gulch and Keystone Gulch. While these concentrations were somewhat elevated, they were below the acute (6.8 µg/l) and chronic (4.8 µg/l) hardness-based aquatic life criteria. The elevated total copper concentrations also appeared to coincide with elevated iron and aluminum concentrations, suggesting that erosion could be a contributing factor.

Dissolved iron concentrations ranged from 50 to 330 µg/l, with the highest concentration occurring on May 7, 2000. Determination of whether the stream meets the domestic water supply standard for dissolved iron is based upon the 85th percentile of the data (WQCC, Regulation No. 31, section 31.8(2)(b)). The 85th percentile concentration was 139 µg/l, which is well below the domestic water supply standard of 300 µg/l for dissolved iron. Total iron concentrations ranged from 110 to 7,740 µg/l, with the highest concentrations occurring on the rising limb of the hydrograph on May 2, 2000. Although some of the individual concentrations exceeded the chronic aquatic life criterion for iron, determination of whether the stream meets the aquatic life standard for total iron is based upon the 50th percentile of the data. The 50th percentile of the total iron data was 430 µg/l, which is well within the aquatic life criterion of 1,000 µg/l for total recoverable iron.

Zinc concentrations in Camp Creek were substantially higher than concentrations at the reference sites. Dissolved zinc concentrations were highest during the initial rising limb of the hydrograph (~April 20th to early May). Peak dissolved zinc concentrations of 47 µg/l were below the acute (63.7 µg/l) and chronic (64.0 µg/l) hardness-based aquatic life criteria. The peak total zinc concentration of 89 µg/l was well below agricultural (2,000 µg/l) and domestic water supply (5,000 µg/l) standards.

Manganese concentrations in Camp Creek were also considerably higher than at the reference sites. The peak total manganese concentration was 219 μg/l, while the highest concentration in the reference streams was 30 μg/l. Concentrations of dissolved and total manganese were also most elevated during the rising limb of the hydrograph and were also elevated during falling limb. The peak dissolved manganese concentration was 40 μg/l, and the peak total manganese concentration was 219 μg/l. The highest dissolved manganese concentrations were well below the acute (2,349 μg/l) and chronic (1,298 μg/l) aquatic life criteria, and also below the domestic water supply criteria of 50 μg/l.

Mozart Creek

The Mozart Creek drainage receives the second largest amount of snowmaking coverage (124 acres) relative to the size of the drainage basin (900 acres). Similar to Camp Creek, cadmium, lead, and silver concentrations were near or below detection limits, indicating water quality for these parameters was similar to the reference sites. Dissolved copper concentrations ranged from < 0.5 to 1.6 μg/l, and were similar to, if not lower than the concentrations found at the reference sites in Jones Gulch and Keystone Gulch.

Dissolved aluminum concentrations ranged from 10 to 41 μg/l, with the highest concentration occurring during relatively high flows on the rising limb of the hydrograph. Concentrations were higher than those observed at the Keystone Gulch and Jones Gulch reference sites where dissolved aluminum ranged from 3 to 32 μg/l, but lower than concentrations downstream in the lower reach of Keystone Gulch. These concentrations were well below the acute (750 μg/l) and chronic (87 μg/l) aquatic life standards for dissolved aluminum.

Dissolved iron concentrations ranged from 60.0 to 180 μg/l, and the highest concentrations were well below the drinking water supply standard of 300 μg/l. Total iron concentrations ranged from 160 to 8,720 μg/l, with the highest concentrations occurring on the rising limb of the hydrograph, between April 28th and May 3rd in conjunction with early peak flows. The 50th percentile of the total iron data was 380 μg/l, which is well within the aquatic life standard of 1,000 μg/l. The timing of the elevated total iron concentrations indicates that they were probably associated with erosion at lower elevations within the watershed and/or with resuspension of stream sediment.

Zinc concentrations in Mozart Creek were substantially higher than concentrations at the reference sites. Dissolved zinc concentrations were most elevated during the initial rising limb of the hydrograph, with the peak concentration (26 μg/l) occurring on May 2nd. Dissolved concentrations were well below the acute (58.6 μg/l) and chronic (58.9 μg/l) aquatic life standards. The peak total zinc concentration (82 μg/l) also occurred on May 2nd, and was well below the applicable standards for total recoverable zinc of 2,000 μg/l for agriculture and 5,000 μg/l for drinking water supply.

Manganese concentrations in Mozart Creek were also considerably higher than concentrations in Keystone Gulch and Jones Gulch. Again, dissolved and total manganese concentrations were most elevated during the rising limb of the hydrograph and also somewhat elevated during the falling limb of the hydrograph. The peak dissolved manganese concentration was 35 μg/l, and the peak total manganese concentration was 316 μg/l.

The highest dissolved manganese concentration of 35 μg/l was well below the acute (2,273 μg/l) and chronic (1,255 μg/l) aquatic life standards, and also below the domestic water supply standard of 50 μg/l. The peak total manganese concentration (316 μg/l) was higher than the standard of 200 μg/l for agriculture, but the 50th percentile of the data was 27 μg/l, which was well below the standard.

Macroinvertebrates

Macroinvertebrate samples were collected in Jones Gulch, Camp Creek, Mozart Creek, and Keystone Gulch. In order to minimize the natural variation that can occur between site locations, samples were collected from stream reaches of similar habitat and elevation near locations where water quality samples were collected. The Jones Gulch site was considered the reference site because it was the least impacted by snowmaking. Three quantitative samples of macroinvertebrate communities were collected at each location, and population densities and species lists were developed for each sampling site. The species diversity, distribution and abundance results were used in various metrics and indices to provide information regarding water quality and habitat conditions.

Interpretation of macroinvertebrate data using the provided indices suggests that all stations had water quality that rated from "fair" to "excellent." Camp Creek consistently had the lowest quality ratings for every index or metric. Indices that were specifically used to test for the presence of metals suggest that some of the observed impact in Camp Creek was metals related. The fact that all other index values detected a negative impact suggests that other forms of stress also influence the Camp Creek site. It is likely that much of this stress may be attributed to channelization and culverts that exist upstream of the sampling site location. Comparison of most metric values for the other three sites were similar, however, metal-related indices suggest that some impact from metals may also be present in Mozart Creek.

Soils

Two general types of soils were sampled at the Keystone Ski Area: loamy soils and wetland soils. Reference soils not exposed to artificial snow were collected for both soil types. Soil samples were collected on May 10, 2000, during snowmelt runoff and on June 8 and 9, 2000, immediately following snowmelt. Soil sampling locations were within the Camp Creek, Keystone Gulch, Snake River (on the Go Devil run), and Mozart Creek watersheds.

Although only 11 soil samples were collected at two different times, there is an indication that some soils exposed to snowmaking do contain higher concentrations of zinc and manganese, two metals strongly associated with snowmaking source water, relative to the reference soil concentrations. Based on these limited results, it is not possible to statistically characterize the differences between reference and impacted soils or changes in soil metals concentrations over time due to snowmaking.

Loamy Soils

Mean zinc and copper concentrations on the Schoolmaster ski trail in the Camp Creek basin were somewhat elevated compared to average reference site loamy soil concentrations. Zinc concentrations in three replicate samples were relatively consistent and averaged 55 mg/kg, nearly twice that of reference sample loamy soils which averaged 29.7 mg/kg, but less than the world mean average of 64 mg/kg. Copper concentrations averaged 26 mg/kg, approximately 2.5 times that of reference sites loamy soil, but the same as the USA average concentration for various soils. Manganese concentrations averaged 263 mg/kg in Camp Creek basin loamy soils and were lower than the average concentration of 317 mg/kg in reference soils and the world mean concentration of 490 mg/kg.

Zinc, copper and lead concentrations in Camp Creek basin soils on the Frenchman ski trail were very similar to reference concentrations and lower than world and USA mean concentrations. Cadmium concentrations averaged 0.11 mg/kg, which was almost twice as high as in reference soils but well below the world mean concentration of 0.53 mg/kg. The highest manganese concentration (849 mg/kg) was approximately 2.5 time higher than the average reference loamy soil values and 1.7 times higher that the USA mean concentration. However, reference sample concentrations ranged from 205 to 751 mg/kg, indicating that the natural variability of manganese in reference soils may be high.

Zinc concentrations on the Mozart ski slope in the Mozart Creek basin ranged from 33 to 68 mg/kg, with an average concentration of 55 mg/kg. This was about 1.9 times higher that the average reference concentration of 29.5 mg/kg but less than the world mean zinc concentration (64 mg/kg). Copper and cadmium concentrations averaged about 1.7 and 2.1 times reference site averages respectively, but were well below USA and world mean concentrations. Manganese concentrations in Mozart soils ranged from 245 to 1,640 mg/kg and averaged 620 mg/kg, which is about 2 times higher than the average reference concentration (317 mg/kg) and 1.3 times higher than the USA mean concentration.

Wetland Soils

Zinc and copper concentrations in the wetland reference soil (60 and 18 mg/kg, respectively) were approximately twice those in average loamy reference soil (29.7 and 9.5 mg/kg, respectively). Average manganese concentrations in the wetland reference soil (204 mg/kg), on the other hand, were approximately 100 mg/kg lower than in the loamy reference soil (317 mg/kg). Wetland soils generally have a higher affinity for

metals because of the presence of organic matter (Safaya et al. 1987). However, the percentage of organic carbon in the wetland reference soil (0.53 %) was very similar to organic matter percentages in the samples from loamy soil on the Go Devil run (0.28 to 0.51 % TOC).

Average zinc concentrations for two impacted wetland soil samples collected on the Frenchman ski trail (Camp Creek basin) were 94 mg/kg (average of two replicates, 40 and 148 mg/kg) and 520 mg/kg, the highest concentrations measured in all the soil samples. These zinc concentrations were 2.5 and 8.7 times higher than those in the reference wetland soil sample. There was a large amount of variability in zinc concentration in both the impacted wetland soils and in reference soils.

Copper concentrations in impacted Camp Creek wetland soils (21.0 and 22.7 mg/kg) were only slightly higher than those in reference wetland soil (18 mg/kg). Concentrations of manganese, iron, cadmium, and lead were also approximately the same as or only slightly higher than background wetland soil concentrations.

Spring and Soil Water

Two spring samples and six soil water samples were collected at the Keystone Resort in May and June 2000. The spring samples were both collected in a wetland on the Frenchman slope in the Camp Creek drainage. The soil water samples were extracted from several of the soil samples discussed above by pressure filtration. Soil water samples were collected from three locations in the Camp Creek drainage: one from a loamy soil collected on May 10, 2000, and two from wetland soils collected on June 8, 2000. One background wetland soil water sample was collected from a small spring area in the Keystone Gulch drainage in June 2000, and two soil water samples were collected from loamy soils in the Mozart drainage on June 9, 2000.

The sample collected from the spring at the top of the Frenchman wetland (flow ~5 gpm), had concentrations of metals that were near or below detection levels. The sample collected from a smaller spring just downgradient from the top of the wetland had somewhat elevated concentrations of iron and manganese (450 and 67 µg/l, respectively), but zinc and copper concentrations were low (8 and 2 µg/l, respectively). In general, the quality of water from the two spring samples was among the best of any water sample collected at the site. Both locations are in areas exposed to artificial snow where snowmaking has been ongoing since 1981.

The highest total zinc and copper concentrations measured in soil water were from the loamy soil sample collected on May 10, 2000 on the Schoolmaster ski slope (Camp Creek basin). Total zinc and copper concentrations in this sample were 100 and 50 µg/l, respectively, although laboratory detection limits for many of the constituents were high for this sample. Total iron concentrations were not higher than those in other soil water samples and manganese concentrations were not determined.

Total zinc and copper concentrations in the two soil water samples from the Frenchman wetland soil samples (Camp Creek basin) were elevated compared to most other soil water samples, and were 4 to 5 times higher than those in the baseline wetland soil water sample. However, dissolved copper and zinc concentrations were relatively low.

Vegetation Survey

A vegetation survey at Keystone Resort was conducted in September 2000 to assess and compare the general status of ski slope vegetation in areas where snowmaking takes place and reference areas that are not impacted by snowmaking. The locations surveyed included all of the sites from which soil samples had been collected in April and May of 2000. At each location, the general condition of vegetation was assessed to ascertain whether any obvious differences existed that could be associated with differences in the input of metals from snowmaking water.

The survey of vegetative conditions indicated no discernable difference between areas that receive artificial snow and those that do not receive snowmaking in terms of plant species composition and vegetation density. In many areas that have been extensively disturbed by ski area development, native vegetation is becoming reestablished. The major apparent variable controlling the species composition is the time elapsed since the creation of the ski slopes and last revegetation efforts. If the additional snow from artificial sources has had an effect on the compositions of vegetation in wetland or upland areas on ski slopes, it was not readily apparent.

General estimates of ground cover (live vegetation plus litter plus standing dead plus rock >1 cm diameter) on upland ski slopes were estimated to range from 40% to 70% and were not consistently lower or higher in areas affected by snowmaking. Accumulation of standing dead and litter is limited by the relatively high rate of decomposition enhanced by the long period of saturation beneath the snowpack. In wetland areas, there was similarly no observable reduction in the ordinarily very high total ground cover compared to reference wetlands.

No evidence of serious erosion was encountered on the slopes. However, total ground cover on the ski slopes was less than that of the original forest ecosystem due to the absence of tree cover and the associated heavy litter of fallen needles, branches, and boles that characterizes most subalpine forests. As a consequence of the more limited ground cover, the ski slopes are likely to lose some sediment during spring runoff and thunderstorms because there is less ground cover. Also, drainage conveyances along roads and water bars tend to concentrate flows and erosive forces causing some localized erosion problems.

Conclusions

- Sampling results for artificial snow and streams that drain areas where snowmaking occurs showed that concentrations of aluminum, cadmium, copper and lead were well below aquatic life criteria.

- Trace metals associated with Snake River snowmaking source water (primarily zinc and manganese) were considerably elevated in the artificial snow, snowmelt water and waterbars that drain areas covered by snowmaking compared to reference areas.

- Results from the lysimeter and snowmelt drainage studies have shown that zinc, manganese, sulfate, and other ions associated with artificial snow eluted out of the snowpack early in the snowmelt cycle before most of the snow was melted. The highest zinc and manganese concentrations and most pronounced elution effect occurred in the areas where the slowest early melt rates occurred. The results of this investigation suggest that the ionic pulse from the artificial snowpack is somewhat delayed relative to the natural snowpack.

- Zinc and manganese concentrations in streams draining areas covered by snowmaking were elevated but were within water quality criteria for aquatic life during the 2000 snowmelt runoff season.

- Occasional exceedences of the aquatic life standard for total iron were observed in Camp Creek and Mozart Creek. These events were associated with erosion during periods of rapid snowmelt and were not the result of metals in snowmaking source water.

- Macroinvertebrate population and diversity data indicated water quality that ranged from fair to excellent at the Keystone Ski Area sampling sites. Indices for metals impacts to macroinvertebrates indicate a mild impact at the Camp Creek site and a lessor impact at the Mozart Creek site.

- Metals concentrations in Keystone Ski Area loamy soils from snowmaking areas were generally found to be higher than ski area reference sites but were similar to or less than world/US average concentration ranges.

- Zinc concentrations in two wetland soil samples collected on the Frenchman ski slope were considerably higher than concentrations in reference wetland soils, suggesting the possibility of impacts from snowmaking areas that drain to the wetland.

- Samples collected from springs located in the vicinity of the wetland on the Frenchman ski slope in the Camp Creek drainage had iron and manganese concentrations that were somewhat elevated. For all other parameters, the quality of water from the spring samples was among the best of any water sample collected at the site.

- Total zinc and copper concentrations in two soil water samples from the Frenchman wetland (Camp Creek basin) were elevated compared to most other soil water samples, and were 4 to 5 times higher than those in the baseline

wetland soil water sample. Dissolved copper and zinc concentrations were relatively low.

- Plant communities within snowmaking and non-snowmaking areas, including natural and revegetated areas, were found to be healthy in terms of species composition and cover.

- The data quality evaluation for this study indicates that the overall quality of the data is acceptable for the analyses conducted. The results from analysis of blank samples indicate that both dissolved zinc concentrations, and possibly total concentrations, for this project are biased high by 5 to 20 µg/l.