Technical Memorandum

DATE: January 8, 2013
TO: Scott Campbell
FROM: Charles G. Brockway, Ph.D., P.E.
SUBJECT: Analysis of Annual Water Usage for Snowmaking at River Run
Sun Valley Company / Water Permit 37-8575A

A. Background

The Sun Valley Company operates a snowmaking system on the River Run side of the mountain, and has done so since approximately 1990. The system relies on groundwater pumped from a high-yielding shallow well, which is injected into the Big Wood River and rediverted from the river to the pressurized distribution system. The usage is authorized under water right 37-8575A, currently being licensed by IDWR. The purpose of this study is to evaluate water usage data and recommend an appropriate annual volume to place on the license. Annual water demand for snowmaking is highly variable and is a function of the timing and magnitude of natural snowpack accumulation and potentially also may be affected by climatological parameters such as temperature.

The volume allowed on the license should be greater than the average in order to be sufficient to cover years with high water use with a high level of reliability. When faced with data variability, the typical approach is to characterize the data statistically and determine a level for which the probability of exceedance is acceptably low. The choice of exceedance probability is somewhat arbitrary but should be a function of the exigency of the particular water use. Since snowmaking at Sun Valley is critical to the commercial viability of the resort, the selected exceedance probability should be very low, e.g. 0.01 (1%). This means that the water usage would be exceeded in 1% of the years or once every 100 years, on average.

Two general approaches were taken in this analysis:

1. Direct statistical analysis of the recorded annual snowmaking volume.
2. Regression analysis of the historical data with meterological parameters that are likely to affect the amount of water used for artificial snowmaking.

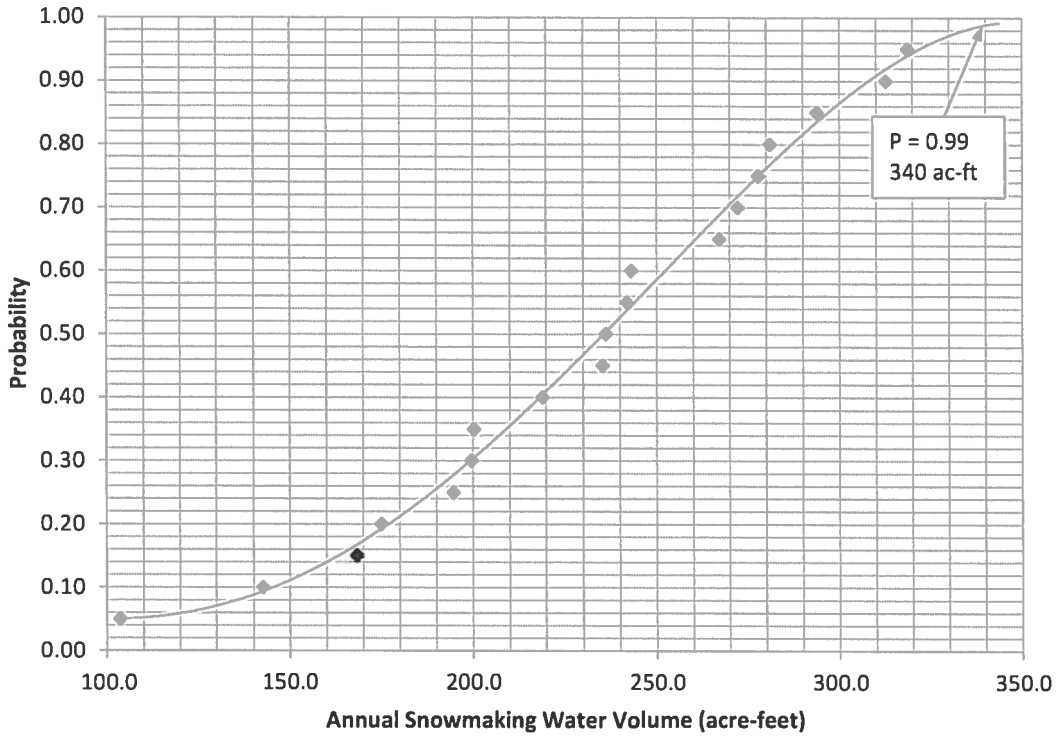
Each season, the total volumetric water withdrawal for snowmaking purposes has been recorded by the company (see table below). The system has remained in its current configuration and operational status since the 1993-94 season and therefore all data from that season through the present should be comparable. The recorded volume has ranged from 33.8 million gallons (103.7 ac-ft) in 1996-1997 to 103.9 million gallons (318.8 ac-ft) in 2000-2001.

Season	Water Year	Gallons	Ac-Ft
1990-91	1991		
1991-92	1992	43,103,700	132.3
1992-93	1993	57,028,100	175.0
1993-94	1994	101,933,700	312.8
1994-95	1995	54,817,200	168.2
1995-96	1996	46,505,595	142.7
1996-97	1997	33,798,818	103.7
1997-98	1998	65,052,179	199.7
1998-99	1999	*	*
1999-00	2000	63,434,521	194.7
2000-01	2001	103,882,200	318.8
2001-02	2002	79,208,230	243.1
2002-03	2003	71,359,214	219.0
2003-04	2004	95,774,792	293.9
2004-05	2005	76,976,313	236.2
2005-06	2006	65,262,572	200.3
2006-07	2007	91,581,593	281.1
2007-08	2008	88,718,953	272.3
2008-09	2009	76,690,202	235.4
2009-10	2010	87,059,500	267.2
2010-11	2011	78,830,400	241.9
2011-12	2012	90,523,400	277.8

* System not used in 1998-99, data excluded

B. Direct Statistical Analysis

The data was first subjected to a statistical analysis to determine basic descriptive statistics and also to determine whether a probability distribution could be fitted to the data. It was found that no standard distribution such as normal, lognormal, or weibull could be accurately fitted to either the raw data or a log transformation of the data. Therefore, percentiles were defined empirically by ranking the data and calculating plotting positions using the formula $P = m / (N + 1)$ where P is the probability, m is the rank, and N is the number of data values. The resulting curve is shown below:



By fitting a smooth curve through the recorded data, the volume at any given probability level can be estimated, as follows:

Probability, P	Exceedance Probability	Annual Water Usage (acre-feet)
0.50	50%	236
0.75	25%	278
0.80	20%	286
0.90	10%	308
0.95	5%	321
0.98	2%	334
0.99	1%	340

At P = 0.99, or a 1% exceedance probability, the annual water usage would be 340 acre-feet.

C. Correlation with Meterological Parameters

Additional analysis was performed to determine whether the water usage data could be correlated to meteorological parameters recorded at three locations: 1) the Chocolate Gulch SNOTEL site located 7 miles north of Ketchum, operated by the Natural Resources Conservation Service; 2) the meteorological station at the Ketchum Ranger Station, operated by the National Weather Service; and 3) snowfall and snow depth data recorded by the sun valley company at its recording point at 9000 feet above MSL on the mountain.

It may be postulated that snowmaking water use is likely inversely correlated with the amount of snow that naturally falls. The ambient air temperature is also likely to affect water usage, since the amount of water needed to make a given amount of snow depends on the air temperature. Data examined included:

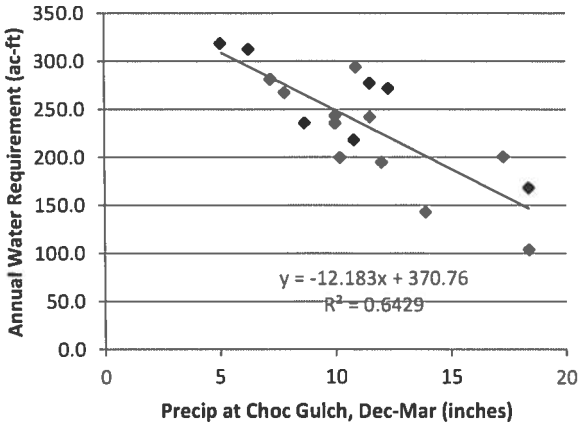
- Total precipitation – available at Chocolate Gulch and Ketchum.
- Total snowfall – available at Ketchum and on mountain
- Snow depth – available at Ketchum and on mountain, not recorded at Chocolate Gulch prior to 2003
- Snow water equivalent – available at Chocolate Gulch
- Average daily temperature – Chocolate Gulch
- Average minimum daily temperature – Chocolate Gulch
- Average maximum daily temperature – Chocolate Gulch

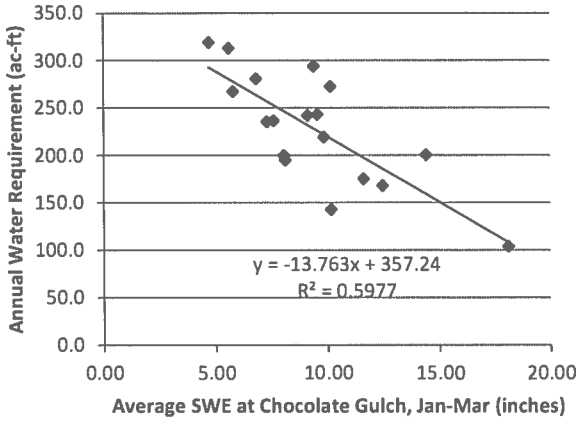
The above data was analyzed for the period November through March and all possible shorter combinations of months in that period, where the data was available.

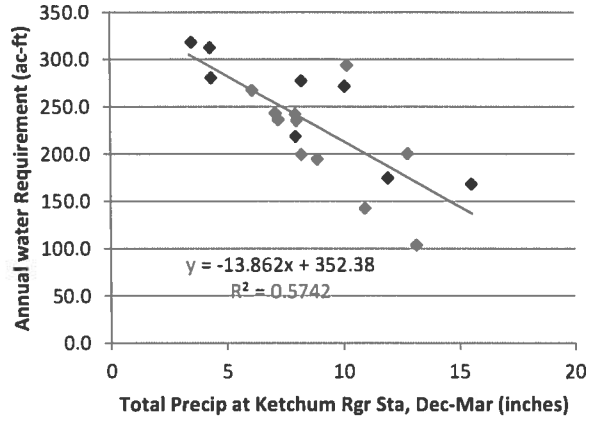
Reasonably strong correlations (R-squared greater than 0.50) were found for four (4) of the indicator variables. For these regressions, a prediction equation was developed to relate annual snowmaking water requirement to the particular indicator. Then, the value of the indicator variable having a P-value of 0.99 (exceedance probability 1%) was estimated using a fitted probability distribution. The best-fit distribution was a lognormal distribution for precipitation at Chocolate Gulch and a normal distribution for precipitation at Ketchum, snow water equivalent, and snow depth. The 1% exceedance value of the indicator variable was then used in the regression equation to determine the annual snowmaking water requirement.

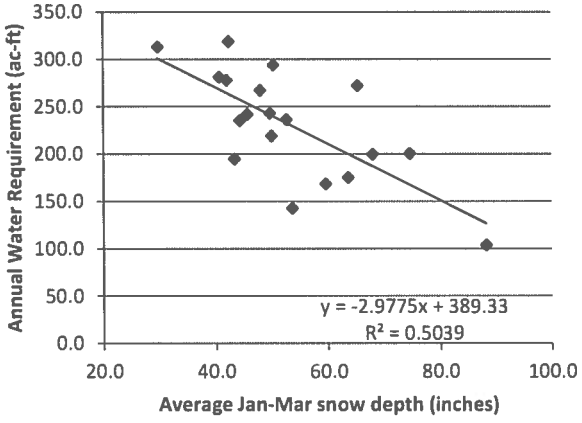
In addition to using the 1% exceedance value of the indicator variable, the regression equation was used to determine the annual snowmaking water requirement with the indicator variable equal to its value in the 1976-1977 season. This season is remembered as the worst snow season in recent memory, and in some quantitative respects it was the driest year of record.

Scatterplots of the four best relationships are shown below:

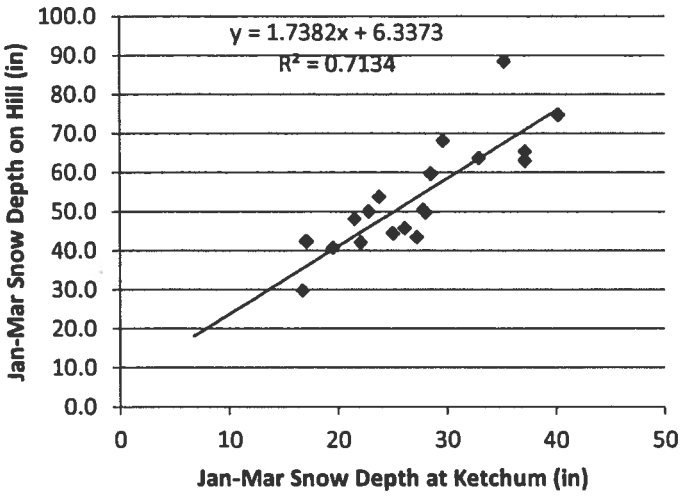








It is unfortunate that the snow depth on the hill during the 1976-1977 was not recorded, as this could potentially be the best indicator of the snowmaking that would have been required that year. However, the 1976-1977 period can be reconstructed by relating snow depth on the hill to snow depths for the same period at the Ketchum Ranger Station. A regression relationship between the average January-March snow depth at these two points yields a relatively high r-squared of 0.713 with the scatterplot shown below:

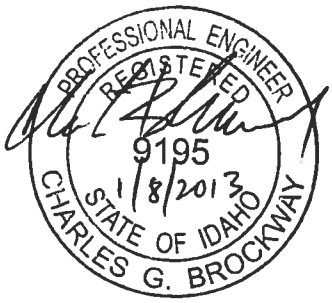


The average January-March snow depth at Ketchum in 1977 was 3.32 inches. Applying the above regression equation yields an estimated snow depth on the hill for the same period of 12.1 inches. Then, applying the regression relationship between snow depth on the hill and annual snowmaking water requirement yields an estimated volume of 353.3 acre-feet.

D. Summary and Conclusion

A summary of the **all** analyses, including the direct statistical analysis and the regression analyses is provided in the following table. The highlighted cells in the table reflect the predicted annual water usage which ranges from 314.6 to 353.3 acre-feet.

For licensing purposes, the highest defensible value should be selected so that all reasonable future variability in water usage will be covered by the water right. This is analogous to the licensing of an irrigation right, where a volume such as 4.0 ac-ft/acre is allowed, which is meant to cover the highest-use crop in a hot and dry season with a reasonable irrigation efficiency. In the case of 37-8575A, the recommended volume for licensing is 353.3 acre-ft/year based on the 1977 snow depth analysis as described above.



Method / Indicator	Period of Record	R^2	99% level of indicator variable	1977 level of indicator variable	Water use with indicator variable at 99% level	Water use with indicator variable at 1977 level	Method used to determine 99% level
Probability distribution fit on snowmaking data alone	1993-2012	n/a	n/a	n/a	340	n/a	Plotting positions and fitted curve
Precipitation at Chocolate Gulch, Dec-Mar	1994-2012	0.643	4.85 inches	Note (1)	311.7	Note (1)	Fitted lognormal
Average first-of-month SWE at Chocolate Gulch, Jan-Mar	1936-2012	0.532	1.06 inches	1.58 inches	341.2	332.4	Fitted normal
Total precipitation at Ketchum Ranger Station, Dec-Mar	1973-2012	0.574	0.91 inches	2.72 inches	339.8	314.6	Fitted normal
Average first-of-month snow depth recorded by Sun Valley Co, Jan-Mar	1967-2012	0.504	17.5 inches	12.11 inches Note (2)	337.2	353.3	Normal fit
Average first-of-month snow depth at Ketchum Ranger Station, Jan-Mar	1973-2012	0.394	n/a	n/a	Analysis not performed, R2 too low		n/a
Average minimum temperature at Chocolate Gulch, Dec-Mar	1994-2012	0.400	n/a	n/a	Analysis not performed, R2 too low		n/a
Snowfall at Ketchum Ranger Station, Dec-Mar	1972-2012	0.396	n/a	n/a	Analysis not performed, R2 too low		n/a
Snowfall recorded by Sun Valley Co., Dec-Mar	1967-2012, 2 seasons missing	0.287	n/a	n/a	Analysis not performed, R2 too low		n/a

Notes:

1) Period of record does not include 1977.
2) Not measured during 1976-1977 season. Estimated by relating snow depth on the hill with snow depth at Ketchum station.