DRA-14. EXAMINATION OF PAST CLIMATOLOGICAL DATA AND ESTIMATION OF MAXIMUM FUTURE CLIMATOLOGICAL EVENTS

J. Hamilton, M. Fredlund, and V.T. McLemore, January 19, 2009 (T. Chatwin)

1. STATEMENT OF THE PROBLEM

Will there be a significant statistical difference in climate in the coming 100 years? 1000 years? Which climate datasets should be used in the hydrological modeling associated with the present Questa weathering study? What should be modeled as the extreme events for 100 years and 1000 years? Climate plays a critical role in understanding the overall water balance for any hydrological models of a rock pile. Climate is an important factor in determining the stability of a rock pile through matric suction and water saturation, and the role of fluids in chemical reactions and chemical transport as the rock pile ages and weathers. A second important factor is the role of extreme weather events in rock-pile stability. An extreme event could saturate a rock pile and cause a catastrophic event. Some recent years have seen excessively high precipitation above the averages for the previous 100 years.

2. PREVIOUS WORK

The meteorological record from 1980 to 2003 for four NWS Stations near the Questa site was compiled and analyzed by John Sigda and Richard Lynn as a project task in 2004-2005. Those stations were Red River, Cerro, Eagle Nest and Taos (Appendix 1). These data were used in evaluating parameters to be used for the hydrological and slope stability modeling (Sigda, 2004; Shannon, 2006). Other data examined include Frederick et al. (1977), Hershfield (1961), Miller et al. (1973), National Climatic Data Center (2003), Priestley and Taylor (1972), and Shaw et al. (2002).

Previous hydrological numerical models (SoilVision, 2006, 2008) have made use of the 100-year dataset provided by Golder (2005a). In the previous Golder report, the 100 years of climate data was estimated based on climate records near the Questa site obtained for the past ~20 years. A comprehensive climatic analysis of the Questa mine site was conducted by Golder (2005b).

The Golder analysis was based on actual data collected from 2000-2004 (i.e., 1548 days of data) for TP4 and TP6/7. The 100-year climate data from the Red River weather stations was then scaled to match the precipitation data from the TP4 and TP6/7. This provided a moderate dataset based on TP4 dataset and a high dataset based on the TP6/7 dataset. Each of these newly-created datasets did not contain actual data from the TP4 or TP6/7 locations, only the scaled data. The two generated data sets cover years 1909 to 2004.

The Golder (2005b) dataset was reviewed by SoilVision Systems Ltd. (2006) and the wet, average, and dry one-year and five-year scenarios were extracted for the numerical modeling program. The resulting datasets are presented in Tables 1 and 2.

TABLE 1. Five-year climate datasets selected for use in the numerical modeling program. RH in the tables stands for relative humidity. Potential evaporation in the tables was calculated by Golder using the Penman method.

Model	Years	Precipitation		Potential Evaporation		Temp	RH
		Total	Avg Annual	Total	Avg Annual	Avg	Avg
		in	in/year	in	in/year	deg C	
Wet	1990-1994	91.55	18.31	201.58	40.32	6.9	48%
Average	1934-1938	74.64	14.93	225.23	45.05	7.4	47%
Dry	1950-1954	48.46	9.69	219.09	43.82	6.7	46%

TABLE 2. One-year climate dataset for use in the numerical modeling program.

Model	Year	Precipitation		Potential Evaporation		Temp	RH
		Total	Avg Annual	Total	Avg Annual	Avg	Avg
		in	in/year	in	in/year	deg C	
Wet	1994		21.67		39.30	7.2	48%
Average	1935		15.01		44.59	7.3	47%
Dry	1954		9.34		42.63	6.3	47%

A study was performed by the University of Utah Department of Civil and Environmental Engineering to determine the maximum expected event for the 100-year and 1000-year periods (Burian and Talbot, 2007). This study took an approach used by engineers to design bridges and dams for the maximum event.

A subsequent study was then performed by SoilVision Systems Ltd. comparing more recently available climate data from the years 2000 to 2007 to the Golder data. The study attempted to address the question: "What climate dataset should be used for the present Questa Mine study?" The overall impression of the QWRPASP team was that there has been an overall increase in the amount of precipitation in recent years. The report recommended that the previous average and wet years be replaced in future modeling efforts with the datasets from years 2000 (wet) and 2006 (average).

3. TECHNICAL APPROACH

The Red River precipitation data from the Golder study was corrected for snowfall. East, Central, and West longitudinal factors were then applied to the dataset. Potential evaporation was calculated using climate parameters based on the Priestly-Taylor method.

Climate records for years 2000 to 2007 have been obtained at the TP5 test plot near the top of the Capulin waste rock pile. These readings are in close proximity and are at a similar elevation as the Goathill North pile and will be used to make a comparative study of climate. An average annual value is calculated for each parameter.

4. CONCEPTUAL MODEL(S)

The conceptual model is based on the previous records of the NWS (2008). The climate at the Questa mine site is predominantly semi-arid. Water balance of the system includes the effect of cold snowy winters and moderate warm summers with the potential for high rainfall events in July and August. The summer high rainfalls have sometimes caused mudslides and flash floods that have blocked the highway, which runs by the front rock piles. Overall precipitation for the Red River drainage area averages 20.6 inches of precipitation per year (i.e. rainfall not including snowmelt)

5. STATUS OF COMPONENT INVESTIGATIONS

A climatic summary for Red River area is presented in Table 3.

TABLE 3. Monthly climatic summaries from 1/1/1915 to 4/30/2007 for Red River, NM (from Western Regional Climate Center, 2007). Approximate elevation is 8600 ft.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg max temp (°F)	36.6	39.2	44.3	53.6	62.6	72.7	76.0	73.6	68.7	58.5	45.0	37.6	55.7
Avg min temp (°F)	4.6	8.2	14.8	22.2	28.9	35.3	41.0	40.3	33.7	25.2	14.3	6.3	22.9
Avg total prec (inches)	1.09	1.19	1.81	1.79	1.72	1.28	2.90	3.14	1.70	1.55	1.32	1.15	20.65
Avg total snowfall (inches)	20.7	21.5	29.9	21.8	7.3	0.1	0	0	0.5	8.3	18.4	19.2	147.8
Avg snow depth (inches)	9	9	6	2	0	0	0	0	0	0	2	6	3

The following analysis presents comparisons between the previous seven years (i.e. years 2000-2007) and the Golder (2005) datasets.

Precipitation

Since the year 2000 the total precipitation has been decreasing until the year 2002 when a value of 11.28 inches was recorded. Thereafter, there was a general increase until 2007. In 2005, an unexpected sharp increase was observed (about 42% more than expected). Comparing the wet, average and dry years from the Golder (2005b) dataset, the fluctuations are 12.6% and 4.3% higher than the wettest year, while others fluctuate around average value (Fig. 1). The years 2000-2005 are exceptions to the average observations. The average value for the previous eight years was 16.65 in or 11.1% more than the average for the 100-year dataset. The exceptions are the years 2000 and 2005, which are 12.6% and 4.3% higher than the average values.

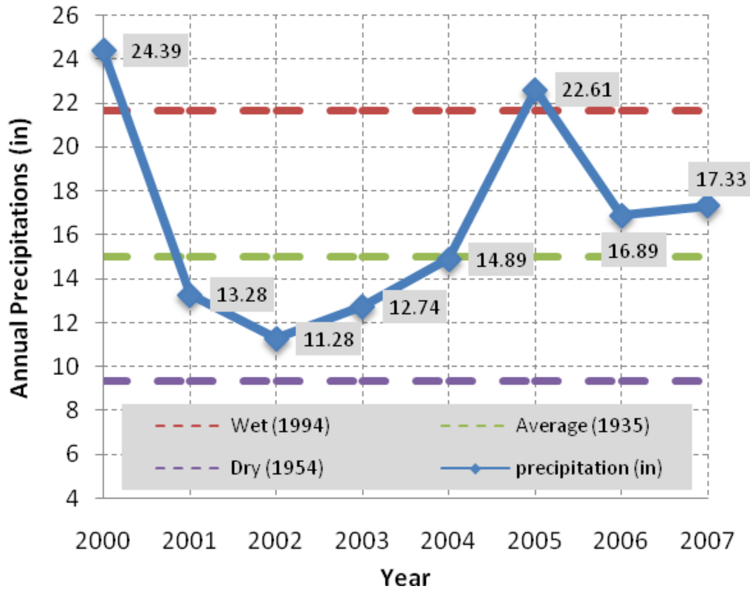

FIGURE 1. Precipitation values for the past seven years.

Potential Evaporation (PM FAO)

Potential evaporation appears to have decreased over the past seven years with the highest and lowest values observed in 2002 and 2007, respectively. Except for years 2005 and 2007, which are below the wettest year, other years have a value of potential evaporation that is less than the average and dry years values, but more than wettest year values. Surprisingly, the potential evaporation in 2007 showed the lowest value in recent years, which falls 18.8 % below average.

Please see Figure 2 for more details on potential evaporation over the past seven years. The average value of the previous eight years was 9.7% less than the average for the 100-year dataset.

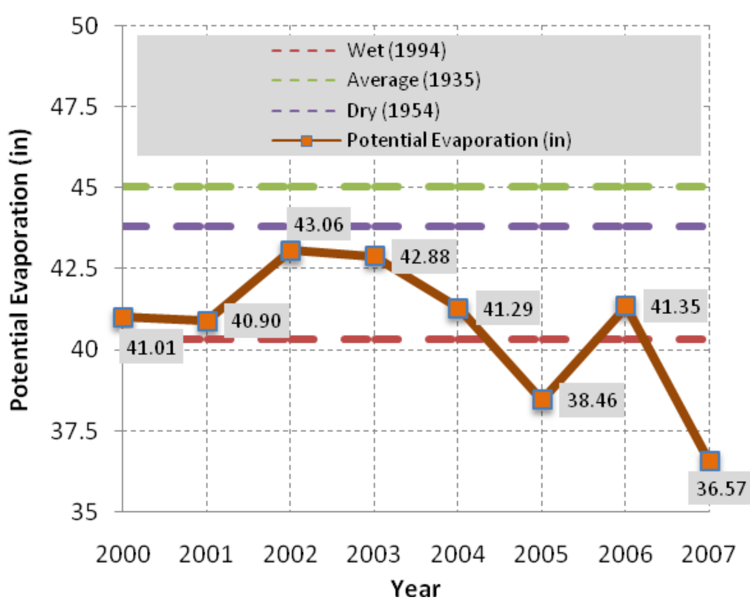

FIGURE 2. Potential evaporation values for years 2000 to 2007.

Temperature

Temperature has been slightly increasing over the past four years but decreased between 2000 and 2004 (Fig. 3). The highest temperature of 8.4^{o} C occurred in 2000. The temperature was 14% higher than average. The lowest value of 4.7^{o} C occurred in 2004 and was 36.9% less than average year's value in last 100 years.

All temperatures recorded after 2001 are located below the wet, average and dry year lines shown on the graph. The average temperature over the last eight years is 23.6% less than the average temperature for the 100-year dataset.

It should be noted that the temperature ranges for the past seven years fall well outside the averages temperature for the wet, dry, and average years. This is because the criteria for selecting the wet, dry, and average years were based solely on precipitation rates.

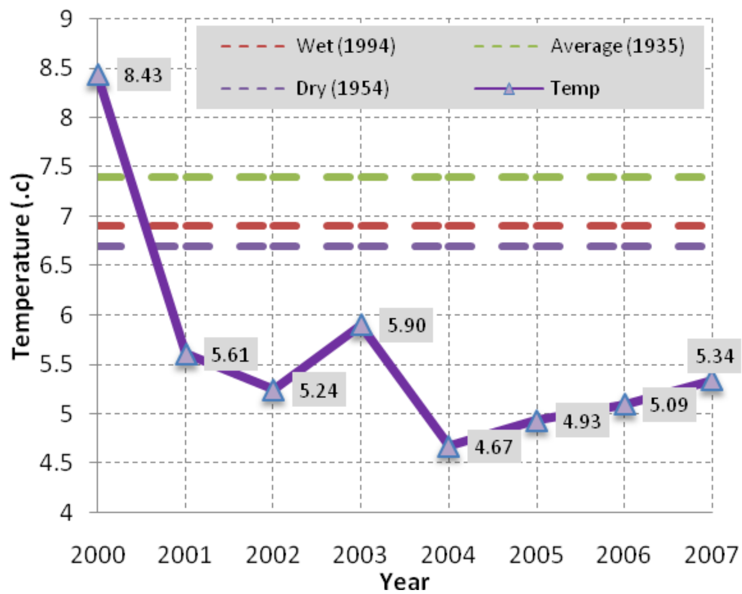

FIGURE 3. Temperature values for years 2000 to 2007.

Relative Humidity (RH)

The highest relative humidity during the past eight years was experienced in the year 2000. Relative humidity then sharply decreased until 2002, when the relative humidity was 3.4% below the average value for the 100-year dataset. Relative humidity then increased linearly to a value of 53.04%, which is 12.9% more than the 100-year average. Relative humidity then fill to the estimated average value in 2006 and reached a value of 51.0% 2007.

As it can be seen in Figure 4 that since 2000, the relative humidity has been fluctuating but the average eight-year value is 6.6% more than the average value for the 100-year dataset. The average eight-year value is also 10.5% higher than the wettest year ever.

Relative humidity rates fall outside the average values for the previous 100-year dataset. The difference is believed due to the fact that the previous dry, wet, and average year were selected based only on precipitation data only.

6. RELIABILITY ANALYSIS

Perhaps nothing is as unreliable as trying to predict the weather and then comparing daily weather to short- (years) and long-term (>decades) climate changes. Not only is there short-term variability, but also long-term climatic cycles and trends, and global influences such as El Niño and La Niña. Global climate change (warming) is clearly real, but the cause is still debated and the future efficacy of man's efforts to mitigate climate change is unknown. Likewise, the maximum (1000-year) climatic event cannot be predicted with any degree of certainty. Nevertheless, it is believed that water saturation in the rock piles will be limited by the rate of infiltration that can take place, and that this is much more important than the total precipitation, the excess of which, above the ability of the rock pile to saturate, simply adds to the runoff. It is also noted that large precipitation events do not correlate directly with large infiltration values. Large infiltration events tend to be caused through successive storms of a longer duration.

The best available data for the area has been obtained from the NWS, the Questa site data, and the Golder Report and the data from all sources has been analyzed and weighted. Therefore the results of this study, with regard to present and future climate conditions that will be used for numerical modeling, are considered reliable.

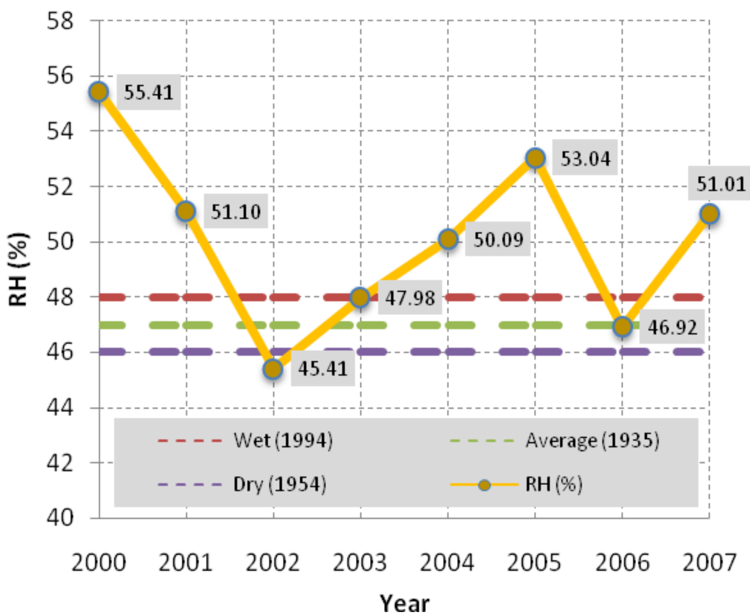

FIGURE 4. Relative humidity (RH) values for years 2000 to 2007.

7. CONCLUSION OF THE COMPONENT

Sigda (2004) noted the following conclusions, which were taken into account:

- Temperature extremes are inversely related to site elevation at the four stations. Daily variations in temperature span roughly 30° C at all four stations.
- Daily, monthly, and annual rainfall statistics are typically much higher for the Red River station than the other stations (Appendix 1). Rainfall increases with increasing elevation. The association between median annual rainfall and elevation appears to be well represented by a linear function for the three lower

elevation stations, but the regression model far under-predicts median annual rainfall at the Red River station.

- Comparing temperature and precipitation data from Red River and from the various Questa meteorological stations is needed to determine whether the two locations behave in sufficiently similar fashion that past (or future) Questa site weather can be simulated using data from the Red River station.

The primary influence of the hydrological system on the slope stability of a rock pile is a change in the pore-water pressures. The criteria used for selecting climate data to use for the hydrological model should be based on precipitation rates. Ideally, the influence of storm intensities should be taken into consideration. However, data regarding storm intensities is not available for the current site.

The TP5 location was used for the numerical modeling process for the following reasons:

1. The data collection site is closer geographically to the Goathill North rock pile than the Red River weather data,
2. The TP5 site is similar in elevation to that of the Goathill North rock pile,
3. The dataset is more recent.

The driest year on record (1954) is still reasonable to use when considering dry conditions the modeling program. It is recommended that the average and wet years data should be replaced with the data shown in Table 4 for numerical modeling.

TABLE 4. New recommended 1-year climate datasets.

Model	Year	Precipitation Avg Annual in/year
Wet	2000	24.39
Average	2006	16.89
Dry	1954	9.34

The extreme event data obtained in the Burian study is presented in Table 5.

TABLE 5. Estimates of rainfall intensities for range of durations and return periods (table created at NWS Precipitation Data Frequency Server http://hdsc.nws.noaa.gov/hdsc/pfds/).

Precipitation Intensity Estimates (in/hr)																		
ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	2.54	1.93	1.60	1.08	0.67	0.39	0.28	0.17	0.10	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.00
2	3.29	2.50	2.07	1.39	0.86	0.50	0.36	0.21	0.13	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01
5	4.43	3.37	2.79	1.88	1.16	0.66	0.46	0.27	0.16	0.08	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
10	5.34	4.06	3.36	2.26	1.40	0.80	0.55	0.32	0.19	0.10	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
25	6.65	5.06	4.18	2.82	1.74	1.00	0.68	0.39	0.23	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
50	7.70	5.87	4.85	3.26	2.02	1.16	0.79	0.45	0.26	0.13	0.08	0.05	0.03	0.02	0.02	0.01	0.01	0.01
100	8.86	6.74	5.57	3.75	2.32	1.34	0.91	0.51	0.29	0.15	0.09	0.05	0.03	0.03	0.02	0.01	0.01	0.01
200	10.10	7.69	6.35	4.28	2.65	1.53	1.04	0.59	0.33	0.17	0.10	0.06	0.04	0.03	0.02	0.02	0.01	0.01
500	11.89	9.05	7.48	5.03	3.12	1.81	1.23	0.69	0.39	0.20	0.11	0.06	0.04	0.03	0.02	0.02	0.01	0.01
1000	13.39	10.19	8.42	5.67	3.51	2.05	1.39	0.77	0.43	0.22	0.12	0.07	0.05	0.04	0.02	0.02	0.01	0.01

8. REFERENCES CITED

Burian, S. and Talbot, N., 2007, Extreme Rainfall Event Characteristics in North Central New Mexico: unpublished report to Molycorp, Inc., Department of Civil and Environmental Engineering University of Utah.

Frederick, R.H., Myers, V.A., and Auciello, E.A., 1977, Five- to 60-minute precipitation frequency for the Eastern and Central United States: NOAA Technical Memorandum NWS HYDRO-35, National Weather Service, Office of Hydrology, Silver Spring, Maryland.

Golder Associates, 2005a, Mine Rock Water Balance Study: unpublished report to Molycorp, Inc.

Golder Associates, 2005b, Fourth Monitoring and Modeling Report: unpublished report to Molycorp, Inc.

Hershfield, D.M., 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: Technical Paper No. 40, U.S. Department of Commerce, Weather Bureau, Washington, D.C.

McLemore, V.T., Ayakwah, G., Boakye, K., Campbell, A., Donahue, K., Dunbar, N., Gutierrez, L. Heizler, L., Lynn, R., Lueth, V., Osantowski, E., Phillips, E., Shannon, H., Smith, M. Tachie-Menson, S., van Dam, R., Viterbo, V.C., Walsh, P., and Wilson, G.W., 2008, Characterization of Goathill North Rock Pile: revised unpublished report to Molycorp, Tasks: 1.3.3, 1.3.4, 1.4.2, 1.4.3, 1.11.1.3, 1.11.1.4, 1.11.2.3, B1.1.1, B1.3.2.

Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation-frequency atlas of the Western United States: NOAA Atlas 2, 11 vols., National Weather Service, Silver Spring, MD.

National Climatic Data Center, 2003, Data Documentation for Data Set 3200 (DSI-3200) Surface Land Daily Cooperative Summary of the Day, March 18, 2003: National Climatic Data Center, 51 Patton Ave. Asheville, NC 28801-5001

Priestley, C. H. B., and Taylor, R. J. 1972. On the assessment of the surface heat flux and evaporation using large-scale parameters: Mon. Weather Rev., v. 100, p. 81-92

Shannon, H. R., 2006, Fluid Transport through a Variably Saturated Rock Pile hill slope system: M.S. thesis, New Mexico Tech, New Mexico, http://geoinfo.nmt.edu/staff/mclemore/Molycorppapers.htm, accessed November 19, 2006.

Shaw, S., Wels, C., Robertson, A., and Lorinczi, G. 2002, Physical and geochemical characterization of mine rock piles at the Questa mine, New Mexico; *in* Tailings and 30 Mine Waste '02, Proceedings of the Ninth International Conference on Tailings and Mine Waste: Fort Collins, Colorado, USA, 27-30 January, p. 447-458.

Sigda, J., Mclemore, V., Shannon, H., and Hoffman, G., 2004, Meteorological Record for Four NWS Stations Near the Molycorp Questa Site: 1980-2003: unpublished report to Molycorp, Inc.,Task 1.11.2.

SOILVISION. SYSTEMS LTD, 2006, Seepage Numerical Modeling Report: internal report submitted to Molycorp, Inc., Saskatoon, Saskatchewan

SOILVISION. SYSTEMS LTD, 2008, Characterization Of Recent Climate Data: internal report submitted to Molycorp, Inc., Saskatoon, Saskatchewan

9. TECHNICAL APPENDICES

Burian, S. and Talbot, N., 2007, Extreme Rainfall Event Characteristics in North Central New Mexico: unpublished report to Molycorp, Inc., Department of Civil and Environmental Engineering University of Utah.

Sigda, J., Mclemore, V., Shannon, H., and Hoffman, G., 2004, Meteorological Record for Four NWS Stations Near the Molycorp Questa Site: 1980-2003: unpublished report to Molycorp, Inc., Task 1.11.2.

SOILVISION. SYSTEMS LTD, 2006, Seepage Numerical Modeling Report: unpublished report to Molycorp, Inc., Saskatoon, Saskatchewan

SOILVISION. SYSTEMS LTD, 2008, Characterization Of Recent Climate Data: internal report submitted to Molycorp, Inc., Saskatoon, Saskatchewan

APPENDIX 1. Summary of weather stations in the vicinity of the Questa mine. All locations are in NAD 27, UTM zone 13. NWS—National Weather Service. NRCS—Natural Resources Conservation Service (McLemore et al., 2008).

Station	Location	Period	Authority	Elevation (ft)	UTM easting	UTM northing
Lobo Peak		1947-1957	NWS	10350	441949.915	4063436.836
Red River		1915 to present	NWS	8676	461073.137	4067949.792
Midnight mine		1957-1976		10427	459881.166	4078124.292
TP-1	tailings		Molycorp			
TP-4	Sugar Shack South near WRD-5, upper bench		Molycorp	9280	454219.000	4060731.000
TP-7	lower bench Sugar Shack South near WRD-3		Molycorp	8705	454245.000	4060396.000
TP-5	Capulin, near WRD-8		Molycorp	9805	453070.900	4063231.000
Taos		1931 to present	NWS	6965	459888.009	4026358.043

Latir Lake		1966-1976	NWS	8806	456947.123	4085534.480
Elizabethtown		1931-1948	NWS	8470	467246.565	4061453.482
Anchor mine		prior to 1928	unknown	10600	462852.649	4078110.813
Taos Pueblo		2003-present	NWS	6990	438773.897	4035417.869
TP-2	tailings		Molycorp			
North Costilla		1979 to present	NRCS	10600	469988.630	3993041.741
Red River Pass 2		1979 to present	NRCS	9850	464307.895	4070708.895
ST-2	midslope on Sugar Shack West near WRD-6		Molycorp	8650	453462.100	4060811.000
Cerro		1931-present	NWS	7650	439052.437	4074550.394
Tres Piedras		1931 to present	NWS	8140	406246.108	4065601.820
San Cristobal		1947-1958	NWS	8110	438933.719	4057911.189
TP-3	tailings		Molycorp			
ST-3	plateau area in Spring Gulch near WRD-1		Molycorp	9075	455737.000	4062543.000
TP-6	lower bench Sugar Shack South near WRD-3		Molycorp	8705	454245.000	4060396.000
Hondo Canyon			NWS	10509	453847.464	4061515.211
ST-1	midslope on Sugar Shack South near WRD-4		Molycorp	8915	45440.000	4060607.000
Skardaa		1940-1983	NWS	8280	406388.174	4078544.259
mill site		1995 to present	Molycorp	8055	456087.000	4061204.000
Eagle Nest		1931-present	NWS	8260	468708.669	4054052.550
Philmont Ranch		1941-1961	NWS	7610	488090.086	4061399.129

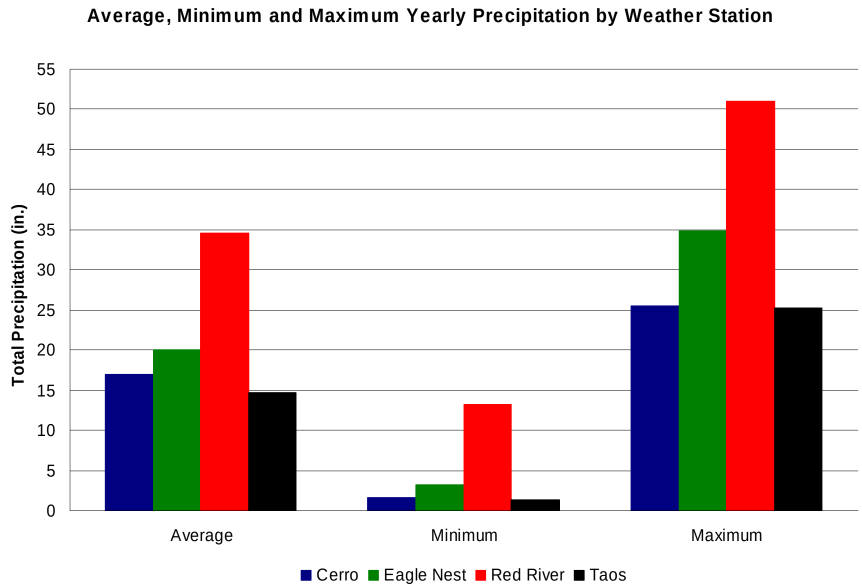

FIGURE 1-1. Summary of yearly precipitation by weather station.