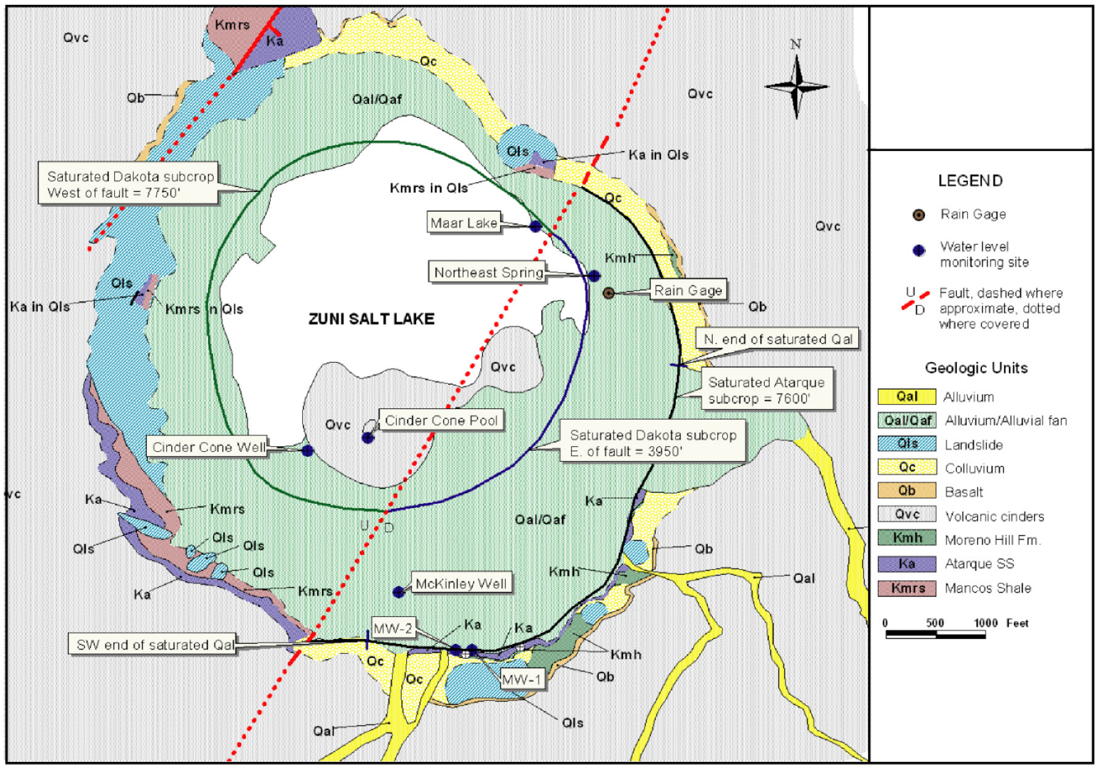
2005-2006 FINAL REPORT:
SUMMARY OF TECHNICAL ACTIVITIES, DATA COLLECTION AND ANALYSIS FOR ZUNI SALT LAKE PROTECTION



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INTRODUCTION

Under a grant provided by the Lannan Foundation in 2005, Glorieta Geoscience, Inc. (GGI) was retained by the Zuni Tribe to provide technical support in hydrology and geology for protection of ground water and earth resources in the vicinity of Zuni Salt Lake (ZSL) and the ZSL Sanctuary Zone in west-central New Mexico. GGI's technical support activities included: 1) Water level monitoring around ZSL; 2) establishment of on-site precipitation monitoring program; 3) analysis of groundwater discharge to ZSL; 4); preliminary geochemistry analysis; 5) interaction with Bureau of Land Management (BLM) and technical support for development of regulatory protection and designation as BLM Area of Critical Environmental Concern (ACEC - ground water protection zone) for ZSL Sanctuary Zone; 6) technical support work for development of ground water/surface water protection under New Mexico Office of State Engineer (OSE) regulations; and 7) evaluation of data requirements for compilation of a multi-layer ground water model.

ON-SITE PRECIPITATION MONITORING PROGRAM

A Rainwise®Inc. rain gage and RainLog® data logger were installed in the ZSL maar, on the northeast side of the maar lake (Figure 1), on November 18, 2005. The rain gage began recording daily rainfall totals on November 18, 2005, and the data were downloaded on November 8, 2006. The rain gage and data logger functioned well, and rainfall data were recorded for this time period (Figure 2). Rainfall data are used in conjunction with transducer data and staff gage readings from the maar lake to obtain an estimate of ground water discharge to ZSL for comparison with calculations of ground water discharge to the lake based on Darcy's Law calculations, as described below.

GROUND WATER MONITORING PROGRAM

In conjunction with the Zuni Tribe, GGI continued and expanded upon previous work monitoring water levels in the vicinity of Zuni Salt Lake. The purpose of this monitoring program is to establish a baseline of water level data in and around the lake. Establishment of hydrologic baseline data will allow potential impacts of ground water diversions, including aquifer dewatering related to mineral extraction or other uses to be identified in the future, and may be used to help develop a water rights claim. The following section summarizes results of water level monitoring activities at the lake.

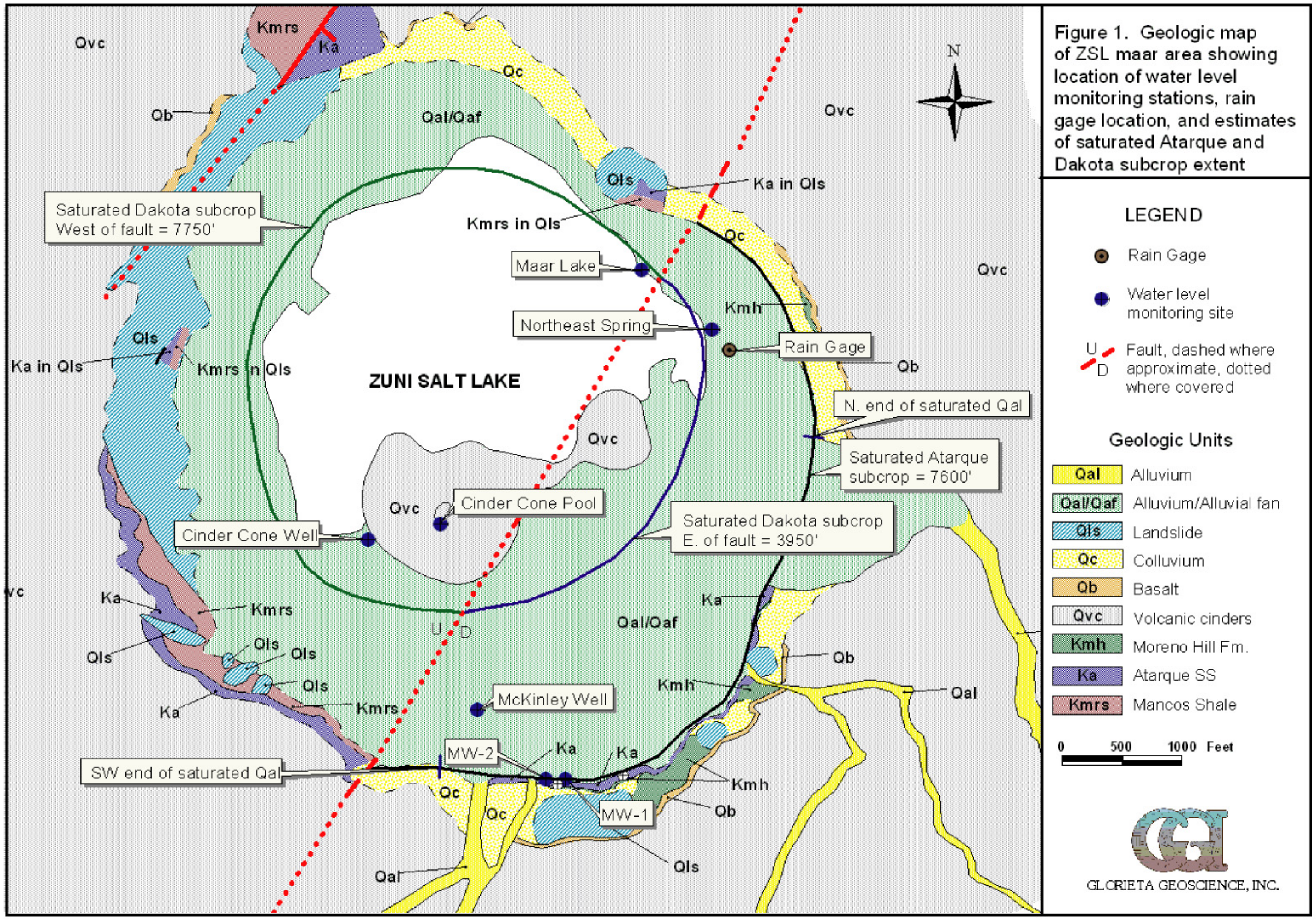

Figure 1. Geologic map of ZSL maar area showing location of water level monitoring stations, rain gage location, and estimates of saturated Atarque and Dakota subcrop extent

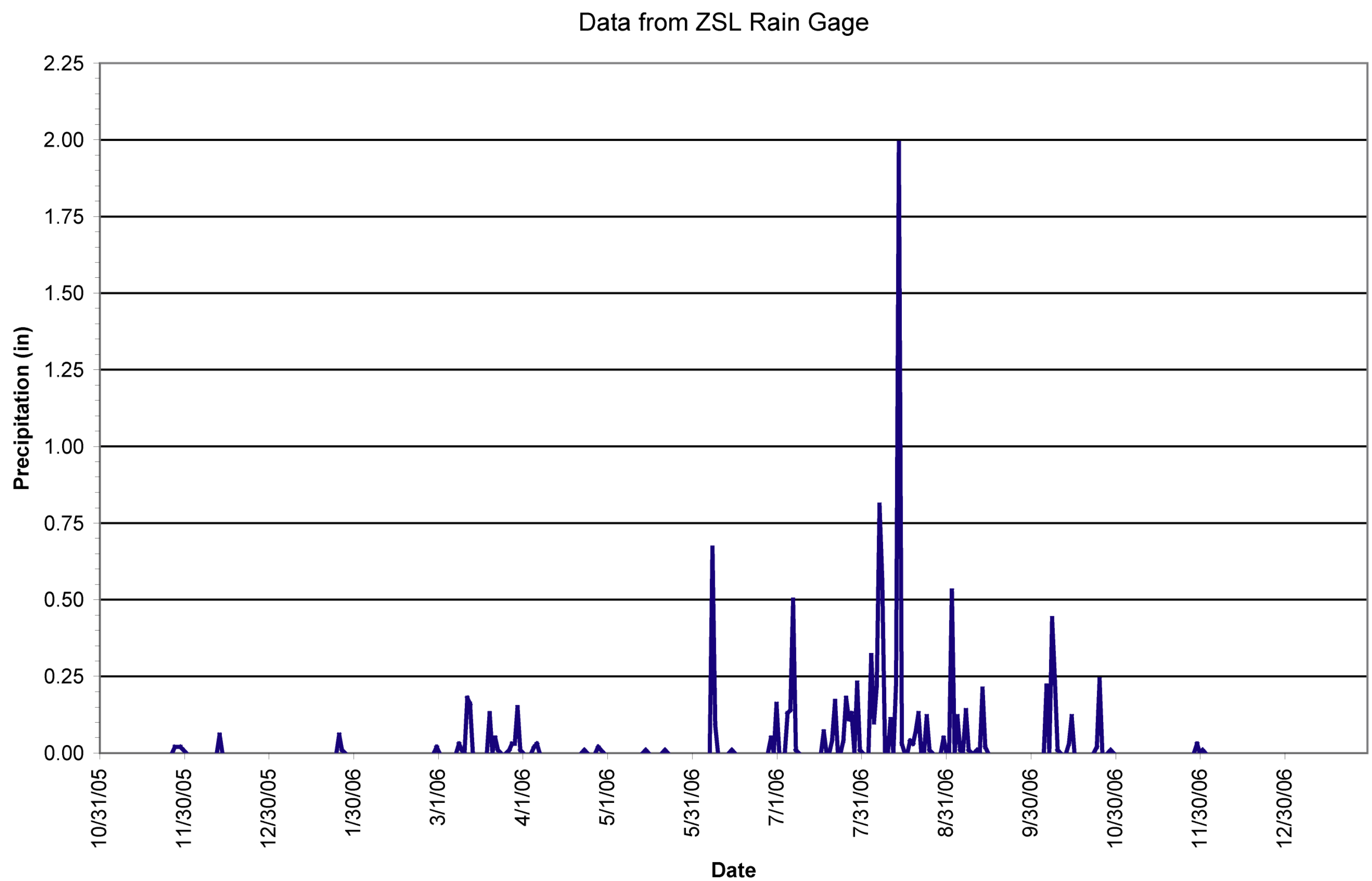

Figure 2. Data collected from the ZSL rain gage between 11/17/05 and 12/14/06. Location of gage shown in Figure 1.

Transducer Installations

Five transducers were installed in and near Zuni Salt Lake on December 10-11, 2003. The instruments are In-Situ Inc. manufactured miniTroll transducers with a pressure range of 15 psi (34.65 ft) and an accuracy of ± 0.035 ft. Transducers were set in each of the two monitoring wells in the southwest portion of the maar (ZSL-MW1, completed into the Atarque Sandstone, and ZSL-MW2, upper Atarque Sandstone recharged from alluvium), in the cinder cone pool, in the lake along the north shore, and in a spring box in the northeast portion of the maar (inferred to be an Atarque spring). On November 9, 2006 a sixth transducer (In-Situ Level Troll 500) was installed in an existing well at the base of the large cinder cone on the south side of the lake (the cinder cone well). Drilling and completion records for this well have not been found, but the depth of the well as measured by GGI is approximately 104 feet. Based on this depth, it is assumed that the well is monitoring water levels in the cinders filling the central portion of the maar. The water in the Cinder Cone Well is a brine (TDS >100,000 mg/l; Riesterer and Drakos, 2005) and is interpreted to be fed both from the maar lake and/or Cinder Cone pool, and from fresh ground water sources discharging into the maar alluvium. The 'McKinley Well', located between the cinder cone well and the monitoring wells on the southern edge of the maar, does not have a transducer installed but water levels have been manually measured in the well since December, 2002. Completion information for the McKinley well has not been found. GGI measured a total depth (TD) of 51.4 ft (with a 2.9 ft stick up) and Myers (1992) reports a TD of 47.65 ft. Myers (1992) reports that water in the McKinley Well is brackish (electrical conductivity = 2330 μS), based on a sample collected in 1986; however, the sample collected by GGI in November 2005 had a conductivity of 970 μS (TDS=560 mg/l), indicating that the alluvial water at this location is currently non-brackish (fresh). Water in the McKinley well is interpreted to be alluvial groundwater. Water levels in the other wells are also measured manually when data are downloaded from the transducers to verify the accuracy of transducer readings. Locations of transducers are shown on Figure 1.

2005-2006 water level data summary

Prior to November 2005, all of the transducers had stopped collecting data due to battery failure. On November 17, 2005, batteries were replaced in the transducers, water levels were measured manually, and transducer tests were re-started. The transducer in the maar lake had previously been removed because rising lake level had submerged the end of the cable. The transducer at this site was replaced in November 2006 with an In-Situ Level Troll 500 transducer with the end of the cable set at a higher elevation to avoid submergence in the future.

The transducers in MW-1 and MW-2 recorded data continuously from November 17, 2005 through December 14, 2006 (the most recent tranducer download). Throughout this period, the transducer in MW-2 appeared to function normally, and transducer readings correspond closely to manual measurements. Readings from the transducer in MW-1 drifted significantly over the measurement period, with a 5.8 ft difference in the transducer and manual readings occurring between November 17, 2005 and November 9, 2006. To address this issue, the transducer readings were corrected using a proportional adjustment (described below) to match measured water levels on the dates the manual measurements were recorded.

For example, on 1/19/06 the transducer reading was 30.716 ft below the measuring point (bmp, top of casing) while the manual measurement taken on that date was 29.62 ft bmp, a difference of 1.096 ft. On 2/17/06, the transducer reading was 31.182 ft bmp and the manual reading was 29.54 ft bmp, a difference of 1.642 ft. Over the interval between the two manual measurements, the transducer reading had drifted 0.546 ft (1.642 ft – 1.096 ft = 0.546 ft). During this period, transducer readings were recorded hourly, with a total of 696 readings recorded. To adjust for the observed drift, 7.84×10^{-4} ft was subtracted from each transducer reading (0.546 ft / 696 readings = 7.84×10^{-4} ft/reading) so that the adjusted transducer reading at the end of the period was equal to the measured water level. This process was repeated for each interval between manual measurements, with the correction value calculated to correspond to the specific interval measured. This correction assumes a constant rate of drift between each manual measurement. While this does not appear to be the case (the correction factor added to transducer measurements is not identical between measurement periods), the corrections are generally for a one-month time period and the error introduced by this method is likely very small. While individual drift-corrected transducer measurements may not be 100 percent accurate, the trends reflected in the corrected data provide an accurate representation of variations in water level over time.

The transducer in the Northeast Spring recorded data from November 17, 2005 to August 22, 2006, at which time the transducer stopped recording. This transducer was removed by Zuni personnel and taken to their office for maintenance. The transducer was replaced in the Northeast Spring and a new test started on November 9, 2006, and the transducer was operational as of December 14, 2006. The transducer in the Cinder Cone Pool was operational from November 17, 2005 to July 28, 2006. At that time the transducer was removed from the pool by Zuni personnel and taken to their office for maintenance.

Prior to November 9, 2006, all transducers collected data on one-hour intervals. On November 9, each of the transducers was re-programmed to collect water levels at 12 hour intervals.

Water level data from all of the transducers were compiled and normalized to show variation from the water level measured on November 17, 2005 (rather than absolute water levels) in order to allow comparison of data from the various sites. Data are included for the time period from November 17, 2005 through December 14, 2006, which corresponds to the time period after the rain gage was installed at the lake, allowing a comparison of water levels to precipitation (Figure 3). Where gaps exist in the transducer data, manual water level measurements were added to Figure 3 to supplement the data set and aid in interpretation. Previous water level data (without precipitation data) have previously been summarized in reports to the Zuni Tribe (e.g. GGI, 2004). However, drift in the transducer installed in MW-1 was not recognized prior to compilation of data for this report. Because of this, GGI's preliminary interpretation of the data was that MW-1 and MW-2 exhibited opposite water level trends (i.e. water level rose in MW-2 over the same period that it fell in MW-1). However, after correcting the data for drift as discussed above, the relationship between MW-1 and MW-2 is more complex than a simple inverse relationship; water levels in MW-1 correspond to regional changes in the Atarque aquifer while MW-2 responds to changes in the alluvial aquifer. Controls on water levels in these wells are discussed further below.

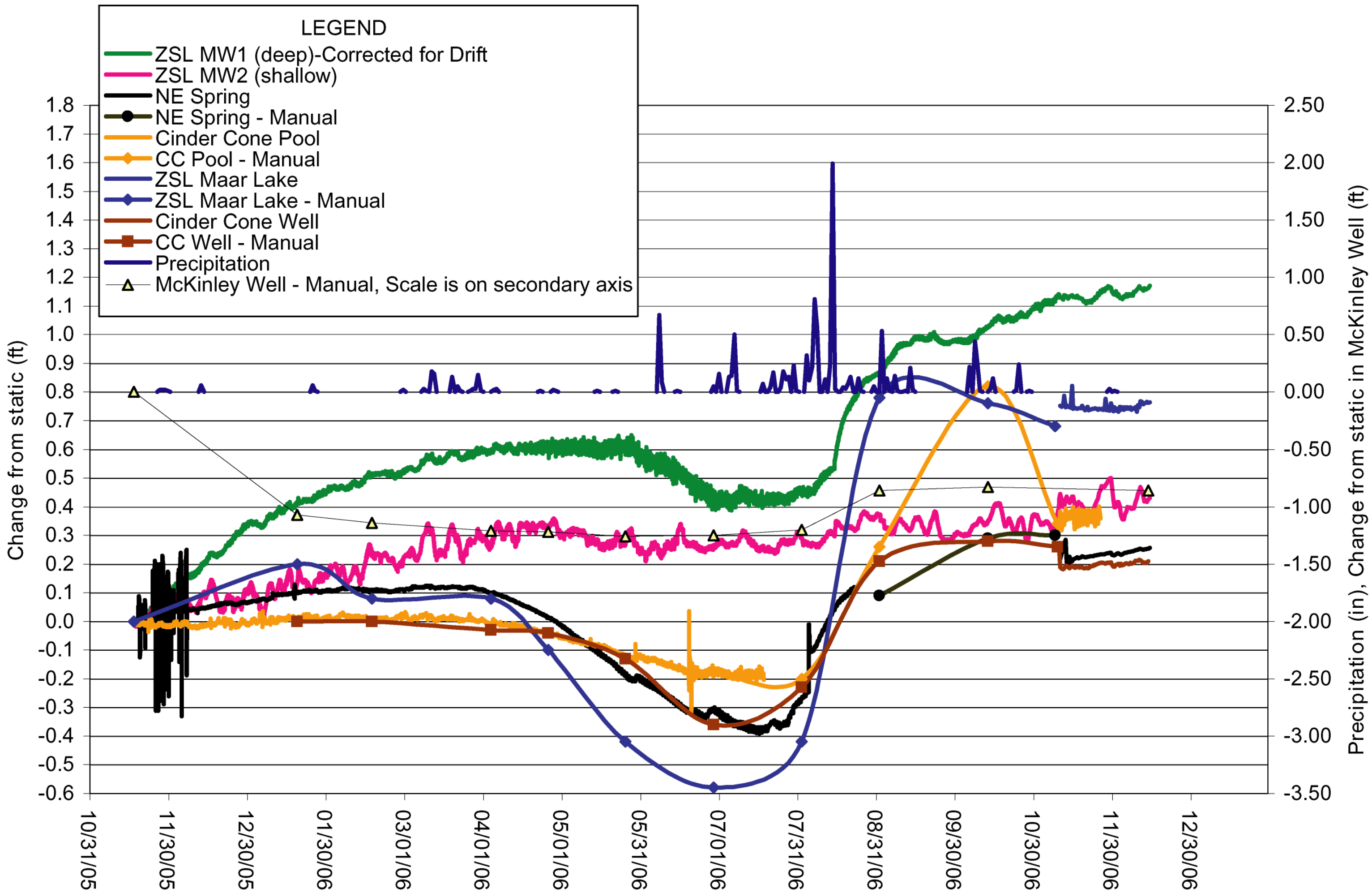

Figure 3. Variations in water levels at monitoring stations around Zuni Salt Lake compared to water levels measured at each site on 11/17/05 (Cinder Cone Well water level measured on 1/19/06). Note that precipitation and the McKinley well are plotted on the secondary Y-axis to the right of the graph.

Data Interpretation

Based on the water level and precipitation data collected between November, 2005 and December, 2006, some general observations can be made about the water levels in and around Zuni Salt Lake. Interpretations for each monitored location are summarized below:

1) *ZSL Maar Lake*

   A. From November 17, 2005 through January 19, 2006, water levels in the lake rose 0.2 feet, despite a relative lack of precipitation (0.13 inches recorded over this two month interval). It is likely that surface water runoff into the lake was negligible during this time period due to the small, low-intensity storm events that were recorded. This suggests that either groundwater contribution over this period was greater than evaporation, or that precipitation in the form of snowfall may not be accurately recorded by the rain gage (see discussion in groundwater discharge section).

   B. From April to July 2006, the water level in the lake dropped significantly (~0.5 ft), despite over an inch of rainfall accumulation. This most likely reflects the overriding effect of higher evaporation during the warmer spring and early summer season.

   C. Summer monsoons in July and August raised the level of the lake by over 1.4 ft (see discussion in groundwater discharge section), suggesting that direct precipitation and/or overland flow contribute significantly to the water level in the lake, but that a threshold precipitation limit may need to be exceeded in order to override evaporation effects.

2) *Cinder Cone Pool*

   A. Water level in the Cinder Cone pool declined slightly from November 2005 to the beginning of the monsoons in July 2006 (0.2 ft of decline over this time period). This is significantly less than the decline observed in the maar lake (0.58 ft) over the same time period. This may be the result of lower evaporation at the cinder cone pool because it has a smaller surface area, is shaded for much of the day, and is sheltered from wind by the walls of the cinder cone. It may also indicate a greater groundwater inflow into the Cinder Cone Pool, greater seepage out of the Maar Lake, or both.

   B. Water levels in the cinder cone pool rose significantly (1.02 ft) from August 2 to October 13, 2006, following the summer rains. Unlike the maar lake, the rise in water level in the cinder cone pool shows an approximately one-month lag following the peak rainfall events of July and August. This suggests the rising water level in the cinder cone pool is less a result of direct precipitation or overland flow and may be caused by increased groundwater contributions resulting from the rainfall events. Note that the timing of water level rise in the maar lake and cinder cone pool cannot be evaluated in detail because transducers were not collecting data at either site during this time period.

3. *Northeast Spring and ZSL MW-1*

A. The northeast spring and MW-1 have previously been interpreted by GGI to be fed by groundwater discharge from the Atarque Sandstone. This interpretation is supported by the groundwater monitoring data, which show similar water level fluctuations for both sites. The timing of water level changes is slightly different at the two sites, with MW-1 lagging slightly (generally < 1 month) behind the NE spring. This may be a result of the generally east to west flow in the Atarque aquifer resulting in a longer flow from the recharge area to MW-1 with respect to the NE spring.

B. Both the northeast spring and MW-1 responded to the summer monsoon events with rising water levels. Unlike the maar lake and the cinder cone pool, water levels in both the northeast spring and MW-1 continued to rise throughout the period of measurement, indicating delayed recharge to groundwater from precipitation and limited evaporation effects in the Atarque aquifer.

C. Transducer data from the NE spring in November and December, 2005, show large (~0.5 ft), rapid fluctuations. The cause of these data spikes are unknown, but after December 8 they disappear from the data set and, from that time on, the data appear reliable. Smaller scale (<0.1 ft) fluctuations occur in the data from MW-1 between April and July, 2006. As with the NE Spring data, the cause(s) of these fluctuations is unclear. The variations in MW-1 are small enough that they do not obscure the overall trend in the data, although they do make it difficult to discern the exact timing of large scale changes in water level trends (i.e. it is difficult to determine exactly when water levels began to decline in the spring of 2006 or began to rise in the summer of 2006). Prior to ~April 6 and after ~August 14 the rapid variations in water levels disappear.

4. *ZSL MW-2*

A. Water levels in MW-2 are unique with respect to the other sites monitored. From March to October, 2006, the water level in the well rose slightly (approximately 0.1 ft on average), but did not rise dramatically during the monsoons. During this period, precipitation events recorded at the rain gage appear to correspond to spikes in the water level data from MW-2, perhaps reflecting ‘pulses’ of recharge to the unconfined shallow alluvial aquifer. However, water levels prior to March and after October do not clearly correspond to precipitation events.

5. *Cinder Cone Well*

A. Monitoring of water levels in the cinder cone well began in January 2006. Water level fluctuations in the cinder cone well are generally similar to the cinder cone pool (Figure 3), suggesting a direct link between the two. However, water levels in the cinder cone well and cinder cone pool diverge during and for 1-2 months after times of significant precipitation when the water level in the cinder cone pool is higher than in the well. This most likely reflects the influence of direct precipitation and overland flow on the pool that causes its level to briefly rise above the level in the well until the two levels eventually equilibrate.

6. *McKinley Well*

A. Only manual measurements exist for the McKinley Well; a transducer has not been installed.

B. The McKinley well appears to respond to large precipitation events such as the summer monsoons, but due to the lack of intermediate data points between the manual measurements it is unclear if the response is somewhat instantaneous as in MW-2 or if it occurs as a gradual rise in water level over time.

C. Because both the McKinley well and MW-2 monitor water level fluctuations in the alluvial aquifer, the responses of the two wells may be compared. After April, 2006, variations in water level in the McKinley well appear to be similar to those observed in MW-2, although the magnitude of changes in the McKinley well is greater than in MW-2 (from August to December, 2006, water level in the McKinely well rose approximately one foot while water level in MW-2 rose approximately 0.15 feet). However, from November to April, 2006, water level in the McKinley well declined by over one foot, while water level in MW-2 rose over 0.3 feet in the same period. The cause of this difference is unclear. It is possible that MW-2 is monitoring alluvium feeding into the maar that is not influenced by deeper groundwater sources (note the difference in water levels between MW-2 and MW-1) while the McKinley well is monitoring alluvium that receives recharge both from alluvial/surface water sources and deeper groundwater sources (e.g. alluvium in MW-2 and Atarque in MW-1 both contribute water to the cinders/alluvium into which the McKinley well is completed).

GROUND WATER DISCHARGE FROM ATARQUE AND DAKOTA AQUIFERS TO ZUNI SALT LAKE AND PRELIMINARY WATER BALANCE CALCULATIONS

The following calculations provide estimates of discharge from the Atarque and Dakota aquifers into the Zuni Salt Lake maar. Regional ground water flow in both the Dakota and Atarque aquifers is from east to west (Myers, 1992; unpublished data from Salt River Project {SRP} test and observation wells). Based on previous mapping and the drilling program conducted in the ZSL maar, GGI has shown that the Atarque discharges to the maar on the east and south sides of the lake, on the east side of the Smith Springs fault. The arcuate length of the Atarque outcrop on the east side of the Smith Springs fault (Figure 1) is therefore used in calculations of the cross sectional area of the Atarque, as described below. The arcuate length that should be used for calculating the Dakota cross sectional area is less well defined, but is evaluated as follows.

1) The gradient in the Dakota is from east to west, so discharge from the Dakota to ZSL would likely occur on the east side of the maar.

2) Offset on the Smith Springs fault is 50 ft, which is nearly enough to offset the entire saturated thickness of the Dakota against the Mancos shale, and result in an impermeable boundary in the Dakota.

3) However, it is possible that ZSL is a regional sink, and that discharge from the Dakota occurs around the entire circumference of the maar vent (the strip of Dakota aquifer between the Smith Springs and ZSL faults is saturated and discharges to ZSL).

4) We therefore use a range for the length of the Dakota discharging to the maar, with the arcuate length of Dakota on the east side of the Smith Springs fault as the low end and the circumference of the Dakota around the maar vent as the high end estimate (Figure 1) Our measurement of the Dakota subcrop arcuate length assumes that the vent diameter decreases somewhat with depth, but approximates the projection of the ZSL lake shore where it intersects the Dakota Sandstone.

<u>Darcy's Law Calculations</u>

According to Darcy's Law, flow through a porous media is calculated as:

Q = KIA, where

Q = the aquifer discharge
K = aquifer hydraulic conductivity
A = cross sectional area of the aquifer, or length (**L**) x width (**W**);
Length = aquifer saturated thickness or **b**, width = length of aquifer within maar
I = aquifer gradient

Atarque aquifer

K = aquifer hydraulic conductivity = 1.0 ft/day (Drakos and Riesterer, 2003 – based on AT-36 pumping test)
b = aquifer saturated thickness = 40 ft (as measured in ZSL MW-1)
L = length of saturated Atarque Sandstone around the lake = 7,600 feet as estimated by GGI from field mapping program
I = aquifer gradient :
regional gradient (Myers, 1992) = approx. 0.004 ft/ft

The Atarque aquifer is in hydrologic communication with ZSL and the cinder cone pool. The Zuni Conservation Program surveyed the monitoring wells, the cinder cone pool, and the shoreline of ZSL (but not the water surface due to muddy conditions along the lake shore) on 12/05/02. Because the actual cinder cone pool water surface was surveyed, the cinder cone pool elevation is used to calculate the local gradient from the Atarque to ZSL and the cinder cone pool. Local gradient from MW1-cinder cone pool calculated as follows:

> distance ZSL#3-cinder cone pool = 2260 ft; distance ZSL#3-ZSLMW1 = 100 ft; total dist. = 2360 ft; Δ elev. = 29.6 + 6.8 ft. = 36.4 ft; average DTW bgs in MW1 from 12/05/02 to 11/09/06 = 27.8 ft; therefore, Δ elev. between Ka water table in MW1 and cinder cone pool = 36.4 – 27.8 = 8.6 ft; therefore the gradient from MW1-cinder cone pool = 8.6 ft/2360 ft = 0.004 ft/ft.

The regional and local gradients are coincident with one another; thus, 0.004 ft/ft is used.

As shown above, $A = L \times b = (7{,}600 \text{ ft}) \times (40 \text{ ft}) = 304{,}000 \text{ ft}^2$

$Q = (1.0 \text{ ft/day}) \times (0.004) \times (304{,}000 \text{ ft}^2) = 1216 \text{ ft}^3\text{/day}$;

$1216 \text{ ft}^3\text{/day} = 9096 \text{ gal/day} = 6.32 \text{ gpm}$, or 10.2 acre-ft/yr

This discharge calculation from the Atarque may under-represent actual Atarque discharge. This could be a result of applying the K determined from the AT-36 pumping test to the Atarque at ZSL, where the saturated thickness is much less, and where large open fractures were encountered. GGI recommends conducting a short-term (200-500 minute), low-discharge (approximately 2-5 gpm) pumping test using one of our car-battery powered sampling pumps, if we are doing other fieldwork at the lake, to determine a site-specific K.

Actual Atarque aquifer contribution to ZSL would be reduced by evapotranspiration within the maar alluvium between the Atarque outcrop and the maar lake.

Dakota Aquifer

Pumping tests were conducted by SRP on FL-36 in 1983, and on FL-36(OB1) and FL-36 in 1994. Average values from these data sets gives a transmissivity (T) of around 5600 gpd/ft, or 750 ft^2/day. Thickness of the main body Dakota sandstone (Kdm) ranges from 55 ft at FL-36(OB1) to 105 ft at FL-36 and FL-36(OB2) (SRP, 1983; PAP, 1994); an average thickness in the area where the pumping tests were conducted is 80 ft. K in the Dakota can be calculated by rearranging T = Kb;

$$K = T/b = (750\ ft^2/day)/(80\ ft) = 9.4\ ft/day$$

GGI measured Kdm thickness on west side of ZSL fault near Zuni Salt Lake on 4/1/03; the section ranges from 50 to 60 ft thick. For the Darcy's law calculation, an average measured thickness of 55 ft is used, representing the nearest data point to the lake. This is also within the range of thickness values obtained from SRP wells; the minimum thickness reported was 32 ft from FL-36(OB3), and as discussed above other Kdm thicknesses observed in the SRP wells ranged from 55 to 105 ft.

The following values are used for our Darcy's law calculations for the Dakota aquifer:

K = aquifer hydraulic conductivity = 9.4 ft/day
b = aquifer saturated thickness = 55 ft
L = length of Dakota Sandstone around the lake; minimum = 3950 ft, east of Smith Springs fault, maximum = 11,700 ft, the circumference of the maar vent (Figure 1)
I = aquifer gradient: from FL-36(OB1) to ZSL = 600 ft/64,000 ft = 0.009 ft/ft

As shown above, A_{min} = L x b = (3,950 ft) x (55 ft) = 217,250 ft^2 (using minimum length)

$$Q_{min} = (9.4\ ft/day) \times (0.009) \times (217,250\ ft^2) = 18,380\ ft^3/day;$$

$$18,380\ ft^3/day = 137,480\ gal/day = 95\ gpm, \text{ or } 153\ acre\text{-}ft/yr$$

A_{max} = L x b = (11,700 ft) x (55 ft) = 643,500 ft^2 (using maximum length)

$$Q_{max} = (9.4\ ft/day) \times (0.009) \times (643,500\ ft^2) = 54,440\ ft^3/day;$$

$$54,440\ ft^3/day = 407,200\ gal/day = 280\ gpm, \text{ or } 450\ acre\text{-}ft/yr$$

It is GGI's opinion that, because the regional Dakota aquifer gradient is from east to west, the minimum discharge measurement is the more likely solution for the Dakota discharge calculation. However, without additional data the solution for the maximum discharge measurement cannot be discounted. Because Dakota aquifer discharge to ZSL is directly up the maar vent, evapotranspiration losses in the maar alluvium will likely not have a great effect on the amount of water that discharges from the Dakota to ZSL.

Discharge Calculations for Other Aquifers

The shallow alluvial aquifer, and deeper Chinle, San Andres/Glorieta, and Yeso Formation aquifers are additional possible ground water sources for ZSL. The alluvial aquifer south of ZSL discharges at Smith Spring; however, GGI has observed flow of approximately 2 gpm or less during visits to the spring. Drainages entering the maar from the south and east have cut through the maar wall and likely contribute a small volume of ground water to the lake. This contribution could be estimated using the MW2 saturated thickness (12 ft), the gradient from MW2 to the cinder cone pool (approximately 0.02 ft/ft), the arcuate length from Smith Spring to the north edge of the alluvial fan on the east side of the maar (4900 ft; Figure 1), and an estimated alluvial K of 1 ft/day.

The approximate area of the Qal aquifer is (4900 ft) x (12 ft) = 58,800 ft^2

Therefore, estimated Q from alluvium = (1.0 ft/day) x (0.02) x (58,800 ft^2) = 1200 ft^3/day;

1200 ft^3/day = 9000 gal/day = 6 gpm, or 9.7 acre-ft/yr

This estimate of discharge from the alluvial aquifer is an approximation, but suggests that discharge from the alluvial aquifer may approach the Atarque aquifer discharge to ZSL.

Of the deeper aquifers, the Chinle is the most likely significant ground water source for ZSL. High gross α has been measured in samples from ZSL, the cinder cone pool, and the cinder cone well (Appendix A). High gross α has also been measured in Chinle wells on the main Zuni Reservation (Riesterer and Drakos, 2005); therefore, the Chinle could be a ground water contributor to ZSL. Data on Chinle wells in the ZSL area are not available; however, it is likely that the Chinle is less productive than the Dakota and

Atarque aquifers. Preliminary geochemical analysis indicates that the San Andres/Glorieta likely does not contribute significant water to ZSL. Due to its greater depth and typically poor production, the Yeso is also likely not a significant source of water for ZSL (King, 2001). For the purpose of calculating a water balance for ZSL, based on data presently available, the San Andres/Glorieta and Yeso aquifers could be excluded from consideration as contributors to ZSL. The Chinle may be considered if additional data indicate that it is a significant ground water source for ZSL.

Use of Precipitation and Maar Lake Water Level Data to Estimate Ground Water Discharge into ZSL

The main Zuni Salt Lake water level monitoring program, used in conjunction with the precipitation data, may be used to obtain an independent estimate on ground water contribution to ZSL. These data may also be used in the future to calibrate a surface water runoff model for the maar. As an example:

August 2006 was a very wet month in New Mexico. Between 8/2 and 9/1/06, the rain gage at ZSL recorded a total of 4.82 inches of precipitation, with a maximum daily total of 1.99 inches on 8/14/06, and fourteen days of 0 (<0.01 in.) precipitation (Figure 2).

On 8/2/06 the staff gage reading in the maar lake was 0.68 ft, and on 9/1/06 the staff gage reading was 1.88 ft. The water level in the lake rose 1.2 ft during August. Based on our measurement of the lake area from the USGS topographic map, the fully wetted lake occupies an area of 6,850,000 ft^2. Assuming a cylindrical volume (bathymetric data are not available for ZSL), a lake level rise of 1.2 ft represents an increase in lake volume of (6,850,000 ft^2) x (1.2 ft) = 8,220,000ft^3

= 61,486,000 gal

= 189 acre-ft

While recognizing that our figures do not take into account antecedent conditions or evaporation during the time periods of no precipitation, and that unusually large precipitation events (such as the 1.99 in. rainfall recorded on 8/14/06) likely exceed a threshold for producing surface runoff that is not usually reached, we can calculate a rough estimate of precipitation-vs.-(surface water + precipitation) contribution to ZSL:

(189 acre-ft)/(4.82 in precipitation) = 39 acre-ft inflow to lake/in. precipitation

July 2006 was also a very wet month in New Mexico. Between 6/29 and 8/2/06, the rain gage at ZSL recorded a total of 1.97 inches of precipitation, with a maximum daily total of 0.5 inches on 07/07, and 20 days of 0 (<0.01 in.) precipitation (see Figure 3).

On 6/29/06 the staff gage reading in the maar lake was 0.52 ft, and on 8/2/06 the staff gage reading was 0.68 ft. The water level in the lake rose 0.16 ft during July. A lake level rise of 0.16 ft represents an increase in lake volume of

$$(6{,}850{,}000\ ft^2) \times (0.16\ ft) = 1{,}096{,}000 ft^3$$
$$= 8{,}198{,}000\ gal$$
$$= 25.2\ acre\text{-}ft$$

For the July data set:
(25.2 acre-ft)/(1.97 in precipitation) = 12.8 acre-ft inflow to lake/in. precipitation
Our calculation based on the July data gives a lower value for inflow-vs.-precipitation. This may be a result of not exceeding a runoff threshold, or could be related to a power function relationship in the runoff-vs.-precipitation calculation.

For comparison, as a method of calculating ground water inflow into ZSL, a dry winter period when there would be minimal evaporation or evapotranspiration was selected. Between 11/17/05 and 1/19/06, the rain gage at ZSL recorded a total of 0.13 inches of precipitation recorded during a very dry time period. This was likely insufficient to produce a runoff event within the maar.

On 11/17/05 the staff gage reading in the maar lake was 1.10 ft, and on 1/19/06 the staff gage reading was 1.30 ft; however, windy conditions were noted. Windy conditions create wave action that makes it very difficult to obtain accurate staff gage readings. Based on the staff gage readings, the water level in the lake rose 0.2 ft during the winter months between 11/17/05 and 1/19/06. A lake level rise of 0.2 ft represents an increase in lake volume of:

$$(6{,}850{,}000\ ft^2) \times (0.2\ ft) = 1{,}370{,}000 ft^3$$
$$= 10{,}247{,}600\ gal$$
$$= 31.4\ acre\text{-}ft$$

For the winter data set:
(31.4 acre-ft)/(0.13 in precipitation) = 242 acre-ft inflow to lake/in. precipitation, which is

an unreasonably high inflow-vs.-precipitation value and likely represents ground water inflow into the lake. (It is also possible that the rain gage is not accurately measuring snowfall that could have occurred during this time period; weather station data from Quemado could be researched to determine if any significant snowfall occurred). This was a time period of very low evapotranspiration and evaporation (the Laguna Station reports 1 in. evaporation in November, and 0 evaporation in December and January). If we assume 0.5 in. evaporation between Nov. 17 and 30 and 0 evaporatin in December and January, then total lake level rise is 0.24 ft, and the increase in lake volume prior to evaporation is approximately

$$(6{,}850{,}000 \text{ ft}^2) \times (0.24 \text{ ft}) = 1{,}644{,}000\text{ft}^3$$

$$= 12{,}300{,}000 \text{ gal}$$

$$= 37.7 \text{ acre-ft}$$

If entirely due to ground water inflow into ZSL, this represents approximately19 acre-ft/month. 19 acre-ft/month x 12 months = 228 acre-ft/yr, which is 65 acre-ft/year greater than our low-end estimate of groundwater inflow from Dakota + Atarque aquifers (153 + 10 = 163 acre-ft/yr). This could indicate that our estimate of discharge from the Atarque and Dakota is too low, and/or discharge from the Chinle (plus some contribution from the alluvium) could account for the 65 acre-ft/year difference in estimates. With the transducer reinstalled in the maar lake, this calculation can be refined based on daily (12-hour interval) automatic lake level measurements, backed up by manual readings.

The estimate of 228 acre-ft/year ground water inflow is significantly lower than obtained using our high-end estimate of groundwater inflow from Dakota + Atarque aquifers (450 + 10 = 550 acre-ft/yr), and also assumes no contribution from the Chinle. This indicates that either our high-end estimate for Dakota discharge to ZSL is too high, or that inaccuracies in our lake level measurements (and/or lake volume measurements based on the assumption of a cylindrical area) have resulted in underestimation of ground water discharge to ZSL. As stated above, continued monitoring should lead to a refinement of our estimates of ground water discharge to ZSL.

Recommendations for Additional Data Collection for ZSL Water Balance

Pan evaporation

Evaporation from the lake can be estimated from pan evaporation data available from the Laguna station, which has a period of record from 1914 to 2005 (we assume they are still recording in 2006). Applying the pan evaporation data to Zuni Salt Lake and performing associated calculations will take 2 to 4 hours.

Evapotranspiration

Air photos can be used to calculate the area of marshy vegetation and willows around the lakeshore, and sparse juniper vegetation throughout the rest of the maar floor. Evapotranspiration could be estimated for these vegetation types using published data. This type of analysis will take approximately 8 hours.

Short-term Pumping Test on ZSL MW1

GGI recommends conducting a short-term (200-500 minute), low-discharge (approximately 2-5 gpm) pumping test using one of our car-battery powered sampling pumps, to determine a site-specific K. We would need to drive to the well (MW1) to have enough battery power to run the pump for several hours. The pumping test should be combined with fieldwork to finalize the ZSL maar geologic map for our proposed New Mexico Bureau of Geology publication to maximize efficiency.

Continue Lake Level and Precipitation Monitoring

Continue lake and precipitation monitoring, initially focusing on dry winter time periods, to estimate total ground water discharge to ZSL. Use in conjunction with Darcy's Law calculations and geochemistry analysis to estimate annual ground water discharge from the Atarque, Dakota, Chinle, and Alluvium to ZSL. This analysis will take approximately 8 hours.

Revise and Update Water Budget Spreadsheet

Data obtained from calculations of ground water inflow into ZSL, pan evaporation, evapotranspiration, and preliminary estimates of surface water runoff, would be used as inputs to revise and update the Water Budget Spreadsheet previously prepared by Kirk Bemis. This analysis will take approximately 6 hours.

These items are included in the attached budget spreadsheet in Appendix B.

WATER QUALITY DATA AND GEOCHEMICAL MODELING

Geochemical data have been collected during various phases of the ZSL hydrogeologic investigation and one additional sample, from the McKinley well, inferred to be completed into alluvium and cinders on the maar floor (Figure 1), was collected and analyzed under the recent Lannan Grant funding. A summary of laboratory analyzes for the McKinley Well, Smith Spring, NE Spring, Cinder Cone Pool and main ZSL from this and previous phases of the ZSL investigation are included in Appendix A. For completeness, data from the Zuni well inventory are also included.

General Chemistry

Samples collected during the ZSL investigation were plotted along with samples collected during the Zuni well inventory investigation (Riesterer and Drakos, 2005) on a Piper diagram to allow for a comparison between lake geochemistry and the geochemistry of possible ground water sources (Figure 4). Based on the Piper plot, samples from the Permian San Andres/Glorieta, the Cretaceous Crevasse Canyon, and the main reservation Quaternary alluvial aquifers exhibit distinctly different geochemistry than is observed for ZSL and the cinder cone pool (Figure 4). The Triassic Chinle, Cretaceous Dakota, Atarque, and Moreno Hill, and the ZSL area Quaternary alluvial aquifers are all plausible contributors to ZSL based on the Piper plot. However, GGI's mapping at ZSL maar has demonstrated that the Moreno Hill Formation is not in direct hydrologic communication with the lake. The high gross α measured in samples from ZSL and the cinder cone pool (see Appendix A) is suggestive of some contribution of water from the Chinle, which is typically high in gross α. An attempt to model a Chinle sample as a source for ZSL was unsuccessful (see below).

Isotope Geochemistry

Several samples were analyzed for the stable isotopes $\delta^{18}O$ and $\delta^{2}H$, and two samples were analyzed for tritium (^{3}H). $\delta^{18}O$ and $\delta^{2}H$ data are plotted against the Global and Placitas meteoric water lines (Figure 5). With the exception of the McKinley well sample, all samples plot below both meteoric water lines, likely indicating that secondary fractionation due to evaporation prior to infiltration, has occurred. A second possibility is that the waters are ancient and were recharged in a different climatic regime, although

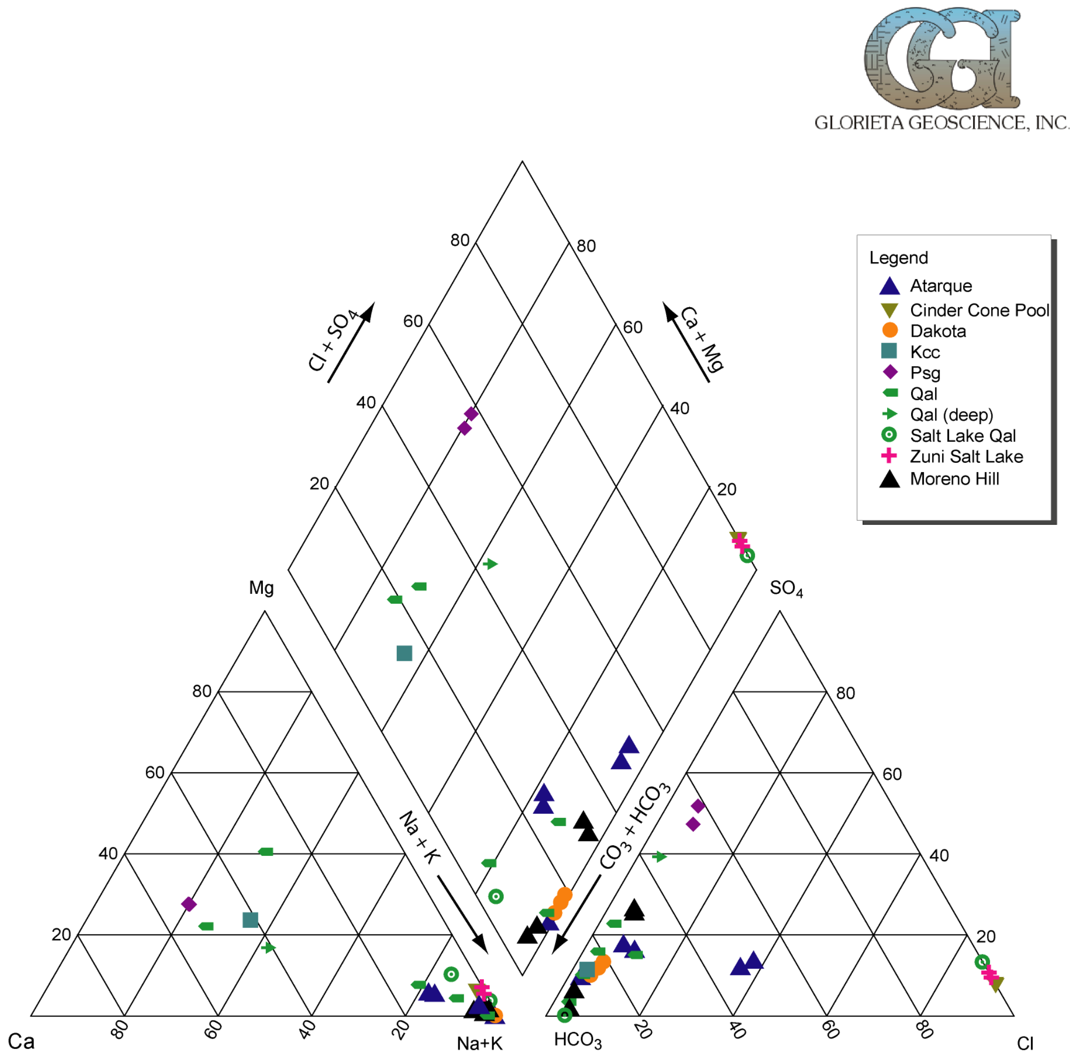

Figure 4. Piper diagram showing major cation and anion concentrations of water samples collected at various locations discussed in text.

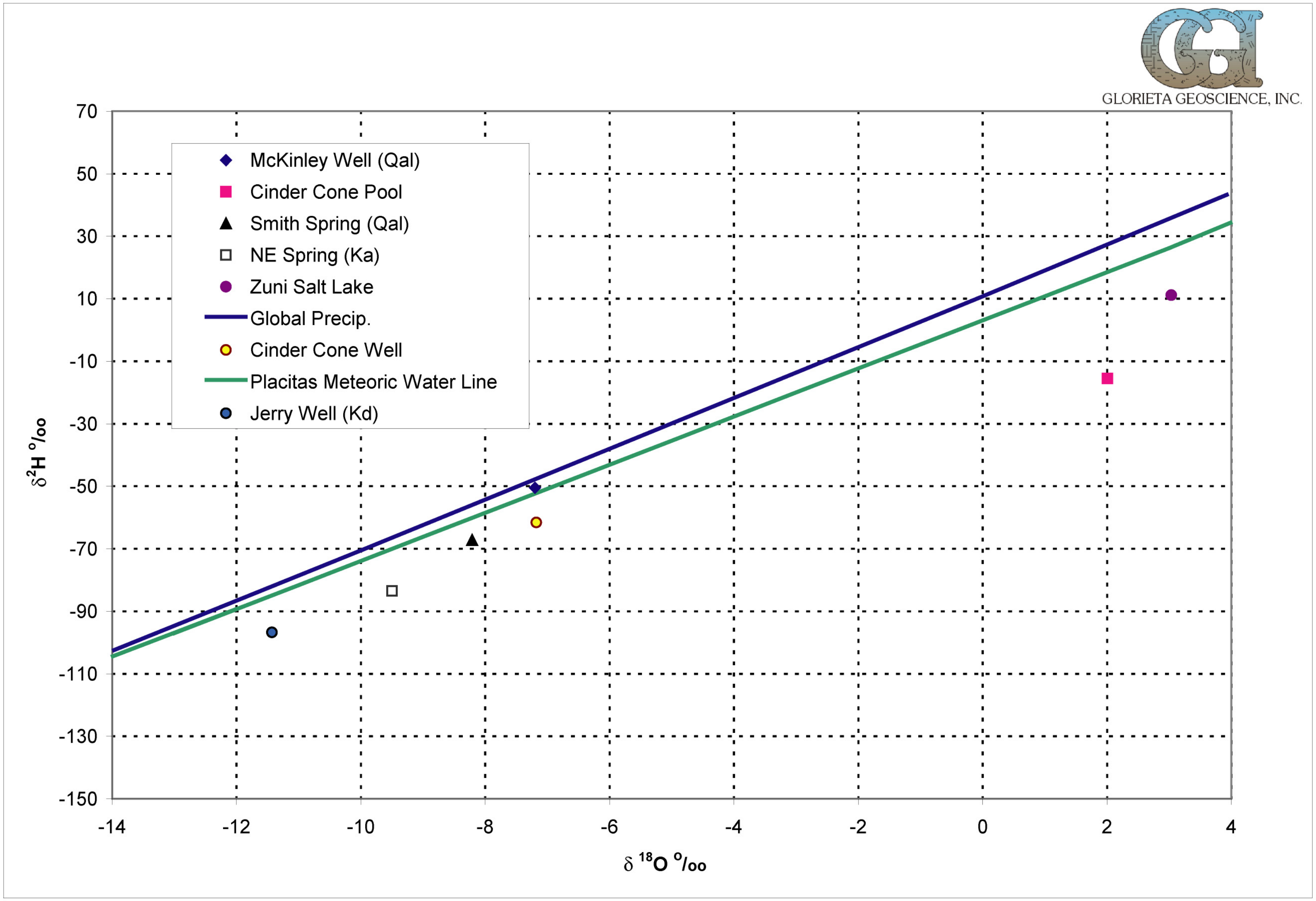

Figure 5. Plot of $\delta^{18}O$ vs. $\delta^{2}H$ for Zuni Salt Lake and Potential Source Waters

this explanation is unlikely for the Smith Spring and cinder cone well samples. The samples from Zuni Salt Lake and from the cinder cone pool exhibit highly enriched values typical of closed lake basins that have undergone intensive evaporation, and are similar to values obtained from closed East African lake basins (Mazor, 1991). These data are also suggestive that the cinder cone well lies on a mixing line between the cinder cone pool and Smith Spring.

The McKinley well and cinder cone well were analyzed for tritium. The McKinely well result (3.93 Tritium Units {TU}) indicates modern (< 5-10 year old) recharge (Clark and Fritz, 1997). This is consistent with the McKinley well plotting on the Placitas Meteoric Water Line (Figure 5). The sample collected from the ZSL cinder cone well has a tritium concentration of 0.86 ± 0.18 T.U., indicating a mixing of pre- and post-1952 recharge (Clark and Fritz, 1997). The high salinity of the water in the ZSL Cinder Cone Well indicates it is in hydrologic communication with the hyper-saline Zuni Salt Lake and/or the hyper-saline pool in the cinder cone, or is fed by a saline ground water source. Both the lake and the pool are fed by a mix of deep recharge from underlying Cretaceous and older aquifers, discharge from alluvium, and direct precipitation (Bradbury, 1971). It is the mixing of these three sources that likely results in the tritium concentration observed in the Cinder Cone Well. This interpretation is consistent with the interpretation that the Cinder Cone well represents mixing of water from the Cinder Cone Pool and Smith Spring.

The small isotopic data set collected thus far shows the potential for a more in-depth analysis if a more extensive database was compiled. It would be of particular interest to determine if the Atarque and Dakota aquifers receive significantly older recharge than does the alluvial aquifer, and if the Cinder Cone Pool and main ZSL are isotopically distinct.

Zuni Salt Lake Geochemical Modeling

An investigation of possible Zuni Salt Lake source waters was undertaken using geochemical inverse modeling techniques. Available geochemical sample analyses from the major aquifers near Zuni Salt Lake (ZSL) were compared to ZSL analyses using an inverse modeling program in PHREEQCI v. 2.8.2. Inverse modeling in this context applies mass balance equations for various elements to find sets of minerals and gases that, when reacted in appropriate amounts, can account for the differences in composition between aqueous solutions. An example, similar to what is used here to model Zuni Salt Lake water sources, can be found in Example 17 of the Appendix in the PHREEQC Users Guide (Parkhurst and Appelo, 2006). This example uses inverse modeling to genetically link two water compositions during Black Sea water evaporation. The evaporation model is applicable to the ZSL problem, as the main geochemical control in the area is the evaporation of dilute waters to form brines in a closed hydrogeologic system.

Modeling Approach

Several different aquifers may be important sources of ZSL water, including the Yeso Formation (Kirk, 1996), the Dakota Sandstone, Atarque Sandstone and Alluvial aquifers (King Engineering, 2001). In the inverse modeling approach, mole balances in one aqueous solution (source waters) are adjusted by additions or subtractions of mole amounts, which represent chemical reactions, to match a final composition (ZSL). These reactions include mineral dissolution/precipitation, out- or in gassing of carbon dioxide and other gases, and water loss through evaporation. The user lists potential phases from hydrologic and geologic data sources, and the program calculates possible models that can account for the variation in composition between two or more water types. The output in the model includes the amount of mole transfers, i.e. chemical reactions, the speciated cation/anion balance, and the total molar change applied to each element after all mole transfers have occurred. The total molar change is a result of the global uncertainty, and accounts for any discrepancies in the two aqueous solutions not accounted for in mole transfers. A low global uncertainty indicates the source aqueous solution was altered very little to model the final aqueous solution. For the purposes of this study, models that had the lowest global uncertainty and lowest balance error are considered to be the most likely source waters. Table 1 illustrates the results from the model runs. Note that samples for the Chinle (Trc ZHS) and San Andres/Glorieta (Psg Rainbow) aquifers are from the main Zuni Reservation approximately 60-70 miles north of ZSL. Nearby samples for the Yeso Formation aquifer that exhibit acceptable charge balance are not available, and the Yeso is generally a much less productive aquifer that the others considered in this study, so the Yeso was not modeled.

Results

Model outputs indicated that the Dakota OB1 well sample, and the 50:50 mixture of Dakota OB1 sample with the Atarque MW1 sample, have the lowest global uncertainty, lowest cation/anion imbalance, and precipitate/dissolve minerals that have been observed at ZSL. Other samples were also able to model the Psg Rainbow, Smith Spring alluvium, and the Moreno Hill well samples, but with higher degrees of change to the original aqueous solution (high global uncertainties). This suggests that the most likely sources for the ZSL are the Dakota and Atarque aquifers, as represented by Atarque MW1_ZSL and Dakota OB1. However, other Atarque and Dakota samples (AT-36 and FL-36) could not be modeled. The alluvial aquifer, San Andres and Glorieta aquifers are possible contributors as well. While Moreno Hill solutions can be modeled with low uncertainty, there is not geological evidence that this aquifer is in hydrologic connection with ZSL. The Chinle (ZHS) sample could not be modeled. These model results should be considered a preliminary analysis, and the geochemical variability between different Atarque and Dakota samples must be evaluated to determine why some samples are consistent with ZSL geochemistry and others are not.

Future Work

In order to discern the source of groundwater supplying Zuni Salt Lake, geochemical modeling should be linked to the ZSL water balance through a water year. The influence of each parameter in the water balance (precipitation, evaporation, runoff and seepage) will affect the mass balance of each element in the lake.

The resulting dissolution/ precipitation of salts can then be modeled geochemically using PHREEQC. Comparison of lake water through the year, and bromide and/or sulfur, oxygen and deuterium isotope mass balance, can be used as independent measures for model verification. A thorough investigation of all carbonate and sulfate minerals in the vicinity of the lake will provide tools for forwarding modeling (i.e. modeling the direct consequences of evaporation on mineral precipitates and resulting lake water composition) and could help further constrain inverse models of the type explored here. If requested, GGI will provide Zuni with a budget estimate for performing additional geochemical modeling.

TABLE 1: RESULTS OF ZSL PHREEQC MODELING

	Global Uncertainty	Speciated Balance	CO2	Calcite	Halite	Trona	Mirabilite
				PHASE MOLE TRANSFERS			
ZSL Shore_1992							
Qal Smith Spring	0.7	4%		-0.075	1.5	-0.6	-0.073
Qal Nutria	6.95	-8.54%		-0.035	1.71	-0.042	-0.058
Moreno HillKmh_ss_bc_12 samples	0.8	-3.09%		-0.158	1.11	-2.81	-1.25
Atarque MW1_ZSL	0.5	-10.53%		-0.087	1.6	-0.479	-0.069
Atarque AT-36 1999	100						
Atarque AT-36 1999 (Model 2)	100		1.99	-19.85	-0.078		-3.6
Dakota FL36_1999 (low calcium)	No Models						
Dakota OB1	0.5	2.77%		-0.079	1.7	-0.36	0.071
Trc ZHS	No Models						
Psg Rainbow	0.5	-4.95		-0.12	1.7	0.0085	-0.0046
Mixture 80:20 Atarque/Dakota	0.5	-6.95%		-0.096	1.6	-1.7	-0.12
Mixture 50:50 Atarque/Dakota	0.5	-2.77%		-0.084	1.7	-0.715	0.021

* Did not attempt models with over 100 Global Uncertainty
* If there are multiple models, the model with Mirabilite vs. no mirabilite is listed

MODELING STATUS

In previous work for Zuni Pueblo, GGI developed a single layer MODFLOW model of the Atarque Sandstone aquifer to calculate the potential hydrologic effects of proposed ground water diversions from the formerly proposed Fence Lake Mine (FLM). Documentation for this model is included as Appendix C of Drakos and Riesterer (2003). GGI also constructed a model in 1997 to evaluate pumping effects in the Dakota aquifer from the proposed Fence Lake Mine diversions (Drakos and Lazarus, 1997). GGI ran a one-layer, two dimensional MODFLOW™ ground water depletion model with a transmissivity of 700 ft^2/day (5200 gpd/ft) and storage coefficient of 0.00049 for the Dakota Sandstone Aquifer. These aquifer coefficients were derived from Dakota Sandstone pumping tests and are consistent with values used by Myers (1992) and Core (1996). GGI ran the model for 40 years at two discharges, the 85 gpm (137 acre-ft/yr) proposed mine discharge, and 600 gpm, which was based on SRP's water rights declarations as of 1997. Estimated drawdown at Zuni Salt Lake resulting from pumping 85 gpm for 40 years was between 4 and 5 feet , and estimated drawdown resulting from pumping 600 gpm for 40 years was 30 to 35 feet likely drying up the lake (Drakos and Lazarus, 1997).

The following data and digital coverages were compiled for GGI's 2003 model, which could be modified and reconfigured as a multilayer model focused on the Zuni Salt Lake Sanctuary Zone ACEC.

1) Model area and model grid. Model grid will need to be modified (existing model grid is focused around FLM and ZSL.
2) Geologic structures
3) Extent of Atarque, Mancos, and Dakota, both outcrop area and subcrop
4) Wells from OSE data base, and FLM wells
5) Alluvium; may need to add or modify alluvial data
6) General hydrologic properties of formations
7) Aquifer anisotropy research

The required tasks to create multilayer superposition model that will include Alluvium, Moreno Hill, Atarque, Mancos, Dakota, Chinle, and possibly undifferentiated Permian are as follows:

1) Review and update and/or develop hydrologic parameters for additional units
2) Determine whether or not volcanics in southern part of the model are in hydrologic communication with aquifers of concern
3) Expand extent of Alluvium as needed
4) Delineate extent of saturated Moreno Hill Formation
5) Adjust extent of model boundaries, if necessary
6) Adjust model grid spacing
7) Research stratigraphy underlying volcanics in southern part of model
8) Evaluate hydrologic effect of geologic structures and anisotropy
9) Model construction, preliminary model runs
10) Assign existing wells to aquifers
11) Evaluate cumulative effects of existing wells on ZSL
12) Based on test scenarios, examine depletion effects on new diversions on ZSL

The time estimate for compilation and testing of this type of model is 350-450 man-hours.

INTERACTION WITH GOVERNMENT AGENCIES

GGI participated during extensive negotiations with Bureau of Land Management (BLM) and technical support for development of regulatory protection and designation as BLM Area of Critical Environmental Concern (ACEC - ground water protection zone) for ZSL Sanctuary Zone, and provided technical support work for development of ground water/surface water protection under New Mexico Office of State Engineer (OSE) regulations. GGI also met with the New Mexico Bureau of Geology (NMBOG) to discuss publication of a geologic map and cross sections of the ZSL Maar and vicinity as a NMBOG Open File Report, and publication of an accompanying article in New Mexico Geology. The NMBOG has stated its interest and will support these publications. The attached budget covers costs for completion of the geologic map and preparation of the Open file report and article. GGI will contribute in-kind professional services for the publications.

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Appendix A.

Laboratory Data Sheets

Parameter	Units	EPA Std.	Crater	ZSL/ZSL-2	Smith SPR #1	ZSL NE SPR #1	Smith SPR #1
Date			9/6/2001	9/6/2001, 9/24/01	2/20/2002	2/20/2002	2/12/2003
Location			Cinder Cone Pool	ZSL main lk			
Temperature	^{o}F	none					
pH	s.u.	6.5 - 8.5*	8.22		8.4	8.6	8.4
Conductivity	mhos/cm	none			1200	1600	
TDS	mg/l	500*	**143000**		**770**	**930**	**960**
Alkalinity, Total	mg/l	none	207		481	411	480
Hardness	mg/l	250*	**9090**	**7900**	81	51	
Color	C.U.	15 *	10				
Odor	T.O.N.	3*	1				
Surfactants	mg/l	0.5*					
Turbidity	N.T.U.	5*	1.1				
Cyanide	mg/l	0.2	ND		ND	ND	
Ammonia	mg/l	none					
TKN	mg/l	none					
CO3	mg/l	none	ND		21	31	11
HCO3	mg/l CaCO3	none	207		460	380	470
Cl	mg/l	250*	**77500**		44	190	51
F	mg/l	4	0.68		1.9	1.2	1.9
Nitrate	mg/l	10	0.12		ND	0.8	
Nitrite	mg/l	1	ND				
Sulfate	mg/l	250*	**9300**		100	94	91
Bromide	mg/l	none					
Phosphorus, Orthophosphate	mg/l	none					
Ca	mg/l	none	558	554	22	10	19
Na	mg/l	100*	**58100**	**41100**			**260**
K	mg/l	none			4.9	5.8	4.9
Mg	mg/l	none	1880		6.6	6.2	6.7
Al	mg/l	.05-.2*	0.004	ND			
Sb	mg/l	0.006	0.0013	0.0026	0.0013	ND	
As	mg/l	0.01	ND	ND	0.0021	0.0059	
B	mg/l	none					
Ba	mg/l	2	0.0608	0.0599	0.045	0.025	
Be	mg/l	0.004	ND	ND	ND	ND	
Cd	mg/l	0.005	ND	ND	ND	ND	
Cr	mg/l	0.1	0.021	0.0173	0.0051	0.0029	
Cu	mg/l	1	0.0438	0.029			
Fe	mg/l	0.3*	ND	ND	ND	ND	
Pb	mg/l	0.015	ND	ND			
U	mg/l	0.03	**0.0425**	**0.0398**			
Mn	mg/l	0.05*	ND	ND	ND	ND	
Hg	mg/l	0.002	ND	ND	ND	ND	
Ni	mg/l	0.1	0.0331	0.025	0.001	ND	
Se	mg/l	0.05	ND	ND	ND	0.0021	
Si	mg/l	none					
Silica	mg/l	none					
Ag	mg/l	0.1*	ND	ND	ND	ND	
Tl	mg/l	0.002	ND	ND	ND	ND	
Zn	mg/l	5.0*	0.018	0.015			
RADIONUCLIDES							
Gross	pCi/l	15	**2080**	**2370+/-1520**	9.3+/-2.8	<4.6+/-2.9	
Gross	pCi/l	15	**880**	**510+/-233**	10.5+/-4.2	<7.5+/-4.7	
Ra-226	pCi/l	total	ND	ND	<0.2+/-0.1	<0.2+/-0.1	
Ra-228	pCi/l	5	1.9		<1.1+/-0.5	<1.1+/-0.5	
ISOTOPES							
^{18}O			2.01	3.035	-8.21	-9.5	-8.21
^{2}H			-15.59	11.15	-67.23	-83.52	-67.23
Tritium (^{3}H)				19.6+/-4.29			
^{234}U				1.00+/-0.92			
^{235}U				12.4+/-3.22			
^{238}U							

Notes: * = secondary (esthetic) standard. All others are primary (health related) EPA drinking water standards.

ND = below laboratory detection limits

Parameter	ZSL NE SPR #1	McKinley	Jerry (Kd)	Z7R	New PSG	ZSL Cinder Cone	Rainbow
Date	2/11/2003	11/17/2005		9/13/2005	8/31/2005	8/31/2005	8/30/2005
Location							
Temperature							
pH	9.6	8.45		7.54			
Conductivity		970		720	1200	140000	1200
TDS	**910**	560		400	**800**	**110000**	**1100**
Alkalinity, Total	410	530		300	280	420	280
Hardness		82		240			
Color							
Odor							
Surfactants							
Turbidity							
Cyanide							
Ammonia							
TKN							
CO3	12	12		ND	ND	140	ND
HCO3	400	520		300	280	270	280
Cl	190	15		7.6	30	**58000**	33
F	1.2	0.14		0.28	0.49	ND	0.52
Nitrate		ND		ND	0.13	ND	0.1
Nitrite		ND		ND	ND	ND	ND
Sulfate	89	ND		38	**330**	**12000**	**280**
Bromide		ND		ND	ND	ND	ND
Phosphorus, Orthophosphate		ND		ND	ND	ND	ND
Ca	9.3	11		61	130	71	130
Na	**330**	180		58	52	**41000**	53
K	7.6	41		2	5.1	290	5.3
Mg	4.9	13		21	41	830	41
Al							
Sb							
As		ND		ND	**0.01**	**0.014**	**0.016**
B					0.081		0.076
Ba					0.023		0.02
Be							
Cd					ND		ND
Cr					ND		ND
Cu					ND		ND
Fe					0.029		ND
Pb					ND		ND
U		ND					
Mn							
Hg					ND		ND
Ni					ND		ND
Se					ND		ND
Si				6.2	7.3	ND	6.8
Silica				13	16		15
Ag							
Tl							
Zn					0.14		0.012
RADIONUCLIDES							
Gross				4.7	2.4	**238**	4.4
Gross							
Ra-226							
Ra-228							
ISOTOPES							
^{18}O	-9.5	-7.2	-11.43			-7.18	
^{2}H	-83.52	-50.5	-96.78			-61.6	
Tritium (^{3}H)		3.93				0.86	
^{234}U							
^{235}U							
^{238}U							

Parameter	Old Sawmill	Nutria	Pescado	WWB-3	Z-8	BR4	ZHS	Zuni H-1	ZS-102
Date	8/30/2005	8/30/2005	8/30/2005		8/30/2005	8/30/2005	8/29/2005	8/29/2005	8/30/2005
Location									
Temperature									organics
pH		7.83	8.01		**9.96**	**8.77**		**8.57**	
Conductivity	920	1200	630	13000	1400	1200	2300	1400	
TDS	**590**	**730**	470	**8100**	**780**	**710**	**1300**	**870**	
Alkalinity, Total	270	480	300	280	430	360	340	410	
Hardness		**440**	**250**		6.3	6.7		17	
Color		10	**20**		**50**	ND		ND	
Odor		1.7	ND		ND	ND		ND	
Surfactants		0.06	0.04		**0.11**	ND		ND	
Turbidity		**15**	2		**32**	ND		0.5	
Cyanide		ND	ND		ND	ND		ND	
Ammonia				ND					
TKN				ND					
CO3	ND	ND	ND	ND	210	26	14	16	
HCO3	270	480	300	280	210	330	320	390	
Cl	15	13	7.4	**3400**	120	32	150	99	
F	0.4	0.47	0.31	0.23	1	2.8	3.5	1.2	
Nitrate	0.17	ND	ND	**28**	ND	ND	0.24	2.6	
Nitrite	ND	ND	ND	ND	ND	ND	ND	ND	
Sulfate	180	140	56	**1100**	58	160	**450**	150	
Bromide	ND			26			ND		
Phosphorus, Orthophosphate	ND			ND	ND	ND	ND	ND	
Ca	77	76	70	640	2	2.5	9.9	6.3	
Na	89	85	39	**1900**	**280**	**230**	**440**	**300**	
K	2.7	1.7	2.1	2.4	1.6	ND	2.2	ND	
Mg	19	62	18	91	ND	ND	ND	ND	
Al		ND	ND		**0.026**	ND		ND	
Sb		ND	ND		ND	ND		ND	
As	ND	ND	ND	0.002	ND	ND	0.002	0.003	
B				1.4					
Ba		0.039	0.11	0.033	0.04	0.023		0.035	
Be		ND	ND		ND	ND		ND	
Cd		ND	ND	ND	ND	ND		ND	
Cr		ND	ND	ND	ND	ND		ND	
Cu		ND	ND	ND	ND	ND		ND	
Fe		0.087	**1**	ND	**1.1**	ND		ND	
Pb		ND	ND	ND	ND	ND		ND	
U		*0.017*	*ND*		*0.0027*	*0.0015*		***0.044***	
Mn		**1.4**	**0.38**		0.018	0.0086		ND	
Hg		ND	ND	ND	ND	ND		ND	
Ni		ND	ND	ND	ND	ND		ND	
Se		ND		**0.067**	ND	ND		ND	
Si	5.6	4.8	8.9	4.8			4.7		
Silica	12	10	19						
Ag		ND	ND		ND	ND		ND	
Tl		ND	ND		ND	ND		ND	
Zn		0.053	0.11	0.031	ND	0.64		ND	
RADIONUCLIDES									
Gross	3.4	**29.2**	1.8	**185**	4.9	**23.5**	**17.3**	**36.7**	
Gross		7.1	ND		2.4	4.9		10.5	
Ra-226		ND	ND		ND	ND		ND	
Ra-228		ND	ND		ND	ND		ND	
ISOTOPES									
^{18}O									
^{2}H									
Tritium (^{3}H)									
^{234}U									
^{235}U									
^{238}U									

Parameter	Sample ID	ZSL#1	ZSL#2	FL-36a	FL-36b	FL-36c	ZSL-1a
	Ref.	1	1	2	3	3	2
Date	Date Collected	12/5/2002	12/5/2002	8/22/1983	9/1/1983	10/1/1983	7/29/1992
Location		Well ZSL#1	Well ZSL#2	Main Dakota SS	Main Dakota SS	Main Dakota SS	Cinder cone pool
Temperature	Temp. (^{o}c)	12.1	17.5				
pH	pH (s.u.)	7.5	7.5				8.1
Conductivity							
TDS	T.D.S.			395			150000
Alkalinity, Total		480	510				
Hardness							
Color							
Odor							
Surfactants							
Turbidity							
Cyanide							
Ammonia							
TKN							
CO3							
HCO3	HCO3	510	480	314	311	221	232
Cl	Cl	34	52	11	11	11	83000
F		2.2	2.3				
Nitrate							
Nitrite							
Sulfate	SO4	110	110	35	31	28	10000
Bromide							
Phosphorus, Orthophosphate							
Ca	Ca	27	33	1.6	0	1.2	747
Na	Na	230	250	162	163	156	48000
K	K	3	3.1	0.4	0.4	0.4	270
Mg	Mg	8.3	9.6	0	0	0.1	1910
Al							
Sb							
As							
B							
Ba							
Be							
Cd							
Cr							
Cu							
Fe							
Pb							
U							
Mn							
Hg							
Ni							
Se							
Si							
Silica							
Ag							
Tl							
Zn							
RADIONUCLIDES							
Gross							
Gross							
Ra-226							
Ra-228							
ISOTOPES							
^{18}O							
^{2}H							
Tritium (^{3}H)							
^{234}U							
^{235}U							
^{238}U							

	ZSL-1b	ZSL-1c	ZSL-1d	ZSL-1e	ZSL-2a	ZSL-2b	ZSL-2c
Parameter	3	3	3	3	2	3	3
Date	9/30/1992	12/11/1992	3/16/1993	6/12/1993	7/29/1992	9/30/1992	12/11/1992
Location	Cinder cone pool	Cinder cone pool	Cinder cone pool	Cinder cone pool	Smith Spring	Smith Spring	Smith Spring
Temperature	6.1	8				15.5	3.3
pH	8.1	8.1	8.2	8.3	8.7	8.4	8.4
Conductivity							
TDS					1600		
Alkalinity, Total							
Hardness							
Color							
Odor							
Surfactants							
Turbidity							
Cyanide							
Ammonia							
TKN							
CO3							
HCO3	190	200	210	198	573	536	437
Cl	77000	76000	50000	79000	50	53	210
F							
Nitrate							
Nitrite							
Sulfate	9300	9900	7200	9200	120	110	140
Bromide							
Phosphorus, Orthophosphate							
Ca	851	743	492	793	22.2	27.3	22
Na	53200	46000	39500	51100	270	296	274
K	361	332	240	313	4.4	5.2	4.5
Mg	2000	1820	1330	1850	7.9	9.3	11.2
Al							
Sb							
As							
B							
Ba							
Be							
Cd							
Cr							
Cu							
Fe							
Pb							
U							
Mn							
Hg							
Ni							
Se							
Si							
Silica							
Ag							
Tl							
Zn							
RADIONUCLIDES							
Gross							
Gross							
Ra-226							
Ra-228							
ISOTOPES							
^{18}O							
^{2}H							
Tritium (^{3}H)							
^{234}U							
^{235}U							
^{238}U							

	ZSL-2d	ZSL-2e	ZSL-3a	ZSL-3b	ZSL-3c	ZSL-3d	ZSL-4a	ZSL-4b	ZSL-4b
Parameter	3	3	2	3	3	3	2	3	3
Date	3/16/1993	6/12/1993	7/29/1992	9/30/1992	12/11/1992	6/12/1993	7/29/1992	9/30/1992	12/11/1992
Location	Smith Spring	Smith Spring	ZSL Shore	ZSL Shore	ZSL Shore	ZSL Shore	ZSL	ZSL	ZSL
Temperature	10.5	15.3		18.5	10.4			5	6
pH	8.5	8.4	7.7	7.4	7.5	7.5	7.8	7.8	7.9
Conductivity									
TDS			140000				330000		
Alkalinity, Total									
Hardness									
Color									
Odor									
Surfactants									
Turbidity									
Cyanide									
Ammonia									
TKN									
CO3									
HCO3	509	472	397	319	313	322	514	337	352
Cl	68	2700	71000	70000	66000	85000	186000	180000	121000
F									
Nitrate									
Nitrite									
Sulfate	130	430	9800	9800	8700	10000	36000	29000	11000
Bromide									
Phosphorus, Orthophosphate									
Ca	18.8	42.6	265	268	289	238	277	293	252
Na	305	1640	43600	45600	40800	48500	111000	116000	73400
K	4.7	29	265	349	321	334	998	1030	695
Mg	11.7	69.7	1520	1380	1400	1520	5370	4650	3080
Al									
Sb									
As									
B									
Ba									
Be									
Cd									
Cr									
Cu									
Fe									
Pb									
U									
Mn									
Hg									
Ni									
Se									
Si									
Silica									
Ag									
Tl									
Zn									
RADIONUCLIDES									
Gross									
Gross									
Ra-226									
Ra-228									
ISOTOPES									
^{18}O									
^{2}H									
Tritium (^{3}H)									
^{234}U									
^{235}U									
^{238}U									

	ZSL-4c	ZSL-4d	ZSL-5a	ZSL-5b	ZSL-5c	ZSL-5d	ZSL	Cinder
Parameter	3	3	2	3	3	3	4	4
Date	3/16/1993	6/12/1993	7/29/1992	9/30/1992	3/16/1993	6/12/1993		
Location	ZSL	ZSL	Windmill Well	Windmill Well	Windmill Well	Windmill Well	ZSL	Cinder cone pool
Temperature				6	13.6	16.6		
pH	7.8	7.6	8.7	8.5	8.7	8.5		
Conductivity								
TDS			3400					
Alkalinity, Total								
Hardness								
Color								
Odor								
Surfactants								
Turbidity								
Cyanide								
Ammonia								
TKN								
CO3								
HCO3	297	352	497	410	397	425	235	246
Cl	116000	240000	220	220	220	2000	113100	54500
F								
Nitrate								
Nitrite								
Sulfate	14000	28000	110	120	120	360	14650	7550
Bromide								
Phosphorus, Orthophosphate								
Ca	243	510	10	10.1	10.9	15.4	345	280
Na	106000	122000	340	346	366	1580	75000	36100
K	480	922	5	6.9	6.6	16.2	498	229
Mg	1920	4750	5.3	5	5.6	41	2550	1117
Al								
Sb								
As								
B								
Ba								
Be								
Cd								
Cr								
Cu								
Fe								
Pb								
U								
Mn								
Hg								
Ni								
Se								
Si								
Silica								
Ag								
Tl								
Zn								
RADIONUCLIDES								
Gross								
Gross								
Ra-226								
Ra-228								
ISOTOPES								
^{18}O								
^{2}H								
Tritium (^{3}H)								
^{234}U								
^{235}U								
^{238}U								

Appendix B.

Budget Spreadsheets for Additional Work

ESTIMATED BUDGET FOR FIELD WORK AND REPORT PREP FOR NM BUREAU OF GEOLOGY OPEN FILE REPORT AND GEOLOGY JOURNAL

Budget represents cost to Tribe; GGI will contribute an equal amount of time (including second field trip); Tribe will pay field expenses for second field trip

1. Labor (hrs)	**Rate**	**Unit**	**Task 1.** Field work (two 3-day trips)	**Task 2** Publication Prep	**Task 3.** Admin	**TOTAL**	
Prin/Sr. Geohydrologist	$95.00	hr.	15	8		23	$2,185.00
Sr. Geologist	$85.00	hr.	30	40	2	72	$6,120.00
Sr. Hydrologist	$85.00	hr.				0	$0.00
Staff Hydrol/Geol	$75.00	hr.	30	40		70	$5,250.00
Field Technician	$45.00	hr.				0	$0.00
Office Manager	$30.00	hr.			2	2	$60.00
Total Labor							**$13,615.00**
Office Exp.	5.00%	lbr					**$680.75**
2. Equipment							
Mileage	$0.345	ea	1200	300		1500	$517.50
12 V pump	$65.00	ea.	1			1	$65.00
10% equip.							$6.50
Subtotal Equipment							**$589.00**
3. Subcontractor							
Per Diem *	$75.00	day	6			6	$450.00
Subtotal Subcon							**$450.00**
Subtotal Labor, Exp., Subs, & Off.							**$15,334.75**
6.6875% Gross Receipts							**$1,025.51**
TOTAL							**$16,360.26**

* Per diem will be billed at cost (GGI will supply their own steaks; per diem is reduced accordingl

GLORIETA GEOSICNECE, INC.

ESTIMATED BUDGET FOR ADDITIONAL ZSL DATA COLLECTION

Transducer and rain gage data downloaded by tribal personnel, provided to GGI in electronic format.

1. Labor (hrs)	**Rate**	**Unit**	**Task 1.** Annual precip.and transducer data anyl.	**Task 2.** ZSL water balance	**Task 3.** Geochemistry data base and anyl; incl. sample time while in field for other tasks.	**Task 4.** Admin	**TOTAL**	
Prin/Sr. Geohydrologist	$95.00	hr.		2			2	$190.00
Sr. Geologist	$85.00	hr.	10	10	18	2	40	$3,400.00
Sr. Hydrologist	$85.00	hr.					0	$0.00
Staff Hydrol/Geol	$75.00	hr.	30	10	18		58	$4,350.00
Field Technician	$45.00	hr.					0	$0.00
Office Manager	$30.00	hr.				4	4	$120.00
Total Labor								**$8,060.00**
Office Exp.	5.00%	lbr						**$403.00**
2. Equipment								
Mileage	$0.345	ea					0	$0.00
12 V pump	$65.00	ea.					0	$0.00
10% equip.								$0.00
Subtotal Equipment								**$0.00**
3. Subcontractor								
2H, 3H, 18O analysis	$350.00	ea			4		4	$1,400.00
Subtotal Subcon								**$1,400.00**
Subtotal Labor, Exp., Subs, & Off.								**$9,863.00**
6.6875% Gross Receipts								**$659.59**
TOTAL								**$10,522.59**