

Hydrological Investigation at El Morro National Monument

Final report

To

National Park Service
U.S. Department of the Interior

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March 2007

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ACKNOWLEDGEMENT

We appreciate the gracious assistance that we have received over the course of this project by all personnel of the National Park Service. It has been a great pleasure for us to work at the El Morro National Monument.

INTRODUCTION

The sandstone bluffs at El Morro National Monument (ELMO-NM) house culturally important petroglyphs and inscriptions of American Indians, early Spanish settlers, and Anglo Americans. The relatively soft sandstone that allowed the inscriptions to be made also makes the rock susceptible to erosion. As a result, many inscriptions suffer from erosion processes that lead to deterioration.

The sandstone cliff at El Morro National Monument is extremely complex due to variation in topography, stratigraphic layering and temperature regime, due to the presence of numerous faults and cracks, and due to differences in exposure to sunlight and wind.

Earlier studies have outlined the prominent role that water plays in several processes that possibly cause the deterioration of the rock inscriptions: impact by rain drops on the bluff surface; freeze-thaw cycles with water in the pores or in cracks, chemical dissolution of pore cement and grains transported by water that may cause dissolution. The National Park Service (NPS) has asked the research group of Dr. Hendrickx at New Mexico Tech (NMT) to study the nature of the hydrologic processes at ELMO-NM. The recommendations made by Pranger (2002) form the direct cause for the involvement of NMT in this project.

Objectives

The project has three main objectives:

1. Study the general geohydrology of the site, which includes the cuesta top, the cliff and the (former) arroyo.
2. Study the behavior of moisture in the cliff, with emphasis on the area with the most inscriptions.
3. Study the seasonal variation of the moisture in the cliff wall and the arroyo soil.

The project started with a site visit on September 30, 2003, when the problems regarding the degeneration of the inscription surfaces and the contributions of a hydrological investigation towards these problems were discussed with the park staff and project leaders. During the project regular field visits have been made as reported in Appendices A-F. This report is the final report to finalize the project.

RESULTS

General hydrogeology

To understand the hydrology of the site we have focused on two main themes. Firstly, it is important to know the origin of the water in the pool. Is it predominantly fed by rainwater runoff, or are there significant contributions by water flowing through cracks in the rock or by vadose zone flow? Secondly, due to the recent rapid deteriorations of the

inscriptions at the northeast point it is of great importance to know if there is a perched water table that increases capillary rise of water into the rock.

To investigate the possibility of the presence of a (seasonal) perched water table near the pool and at the northeast point, a ground penetrating radar (GPR) survey was conducted (Appendix B) and piezometers were installed (see Appendices C and E for location sketches). Electromagnetic induction surveys were carried out to investigate the seasonal variability in soil moisture.

Northeast point

One piezometer (P4) was placed southeast of the northeast point, near a drain in the former arroyo (Figure C-6). This piezometer is located about 8 meters from the cliff wall and reaches a depth of 1.56 m below the surface. A second piezometer (P6) was installed closer to the NE point, between the cliff wall and the fence lining the foot path (Figure E-1). The bore hole reached a depth of 2.94 m and extended to solid sandstone, probably the below-ground extension of the cliff.

In July through September 2004 no water was detected in both P4 and P6. Also, the GPR survey in March 2004 did not reveal the presence of a (perched) water table at the northeast point. The electromagnetic surveys carried out at the northeast point show conductivity values that are significantly lower than those near the pool (Appendix C). Consequently, soil moisture content at the NE point is lower than near the pool. However, on August 8, 2006, after heavy rainfall piezometer P4 carried water while P6 was still dry.

Pool area

Two piezometers (P1 and P2) were placed south of the pool, in a higher topographic position than the pool surface. Both these piezometers were installed less than two meters from the cliff wall and reached depths of 2.43 and 3.08 m, respectively (Appendix C). Two piezometers (P3 and P7) were placed directly downstream (East) from the pool in the former arroyo (Appendices C & E). P3 reaches a depth of 2.19 m below the surface, which appears to be the maximum depth of the arroyo. However, the arroyo may have been partly filled in with boulders, limiting the depth of the auger hole. None of the auger holes struck ground water although in all holes the gravimetric moisture content showed a significant increase with depth (Figure C-7).

On August 20 and 21, 2004, as well as on August 8, 2006, water was observed in piezometers P1 and P2 which were placed under a rain water drop off and near the cliff wall south of the pool. Thus, a water table is present locally near the cliff wall after major rainfall events.

Seasonal variations in moisture conditions

Electromagnetic induction measurements of the variations in electrical conductivity in the former arroyo between the pool and the northeast point have been employed to measure the seasonal variations in moisture conditions at El Morro National Monument. Electrical conductivity is related to a range of soil properties, including texture, salinity, temperature, and soil moisture content. Table 1 gives electrical conductivity values for some materials that are commonly found in soils. More on the technique of electromagnetic induction can be found in a number of publications (Hendrickx and Kachanoski, 2002; McNeill, 1980).

In March 2004 EM31 electrical conductivity data were collected along two lines; one near the pool and one at the northeast point. In July 2004 one line at the northeast point was added (Line 3), and data from all three lines were collected in both July and August of 2004 (see Figures C-5 and C-6 for locations). Figure 1 shows the electrical conductivity changes with distance for the three lines. In both cases the distance of 0m is the intersection of the survey line with the wooden fence. Unfortunately, the steel reinforced footpath (the “inscription trail”) that runs along the pool and the cliff wall caused anomalies, as can be seen in the Figure B-1, C-1, C-2, D-2, and D-3. In Figure 1, the influenced readings have been omitted for clarity.

For all three lines the results indicate a steady increase in electrical conductivity (and thus moisture content) towards the cliff wall / pool. Within 10 to 15 meters of the pool and 15 to 20 meters of the cliff wall at the northeast point the electrical conductivity values show a sudden sharp increase. In Line 2 small increases in electrical conductivity around 22 and 38 meters coincide with topographic depressions. The baseline values for the electrical conductivity (that is, far away from the pool / cliff wall) are significantly higher in Line 1 than those in Lines 2 and 3 at the northeast point.

Comparison of EM31 measurement results from March, July, and August show clear variations in electrical conductivity (Figure 1). In July the electrical conductivity was one to two mS/m lower than in March. Taking soil temperature effects into account the true differences are probably three to four mS/m (Hendrickx and Kachanoski, 2002) which indicates a decrease in moisture content over the first 5 to 6 meters of the soil profile. However, in August the electrical conductivity has risen back to values just above those in March. Again, taking soil temperature effects into account there is no discernible difference which indicates similar soil moisture conditions in March and August 2004. Elevated soil moisture in March and August was, respectively, caused by snowmelt and summer monsoon precipitation. Figure 2 shows the difference in electrical conductivity between August (wet) and July (dry). The differences are largest near the cliff wall / pool, which indicates that the seasonal variations are not just related to precipitation differences but that the presence of the cliff has a significant impact.

Table 1. Electrical conductivity values for some materials commonly found in soils (Annan, 2001).

Material	σ (mS/m)
Air	0
Distilled Water	0.01
Fresh Water	0.5
Sea Water	3,000
Dry Sand	0.01
Saturated Sand	0.01-1
Limestone	0.5-2
Shales	1-100
Silts	1-100
Clays	2-1000
Granite	0.01-1
Dry Salt	0.01-1
Ice	0.01

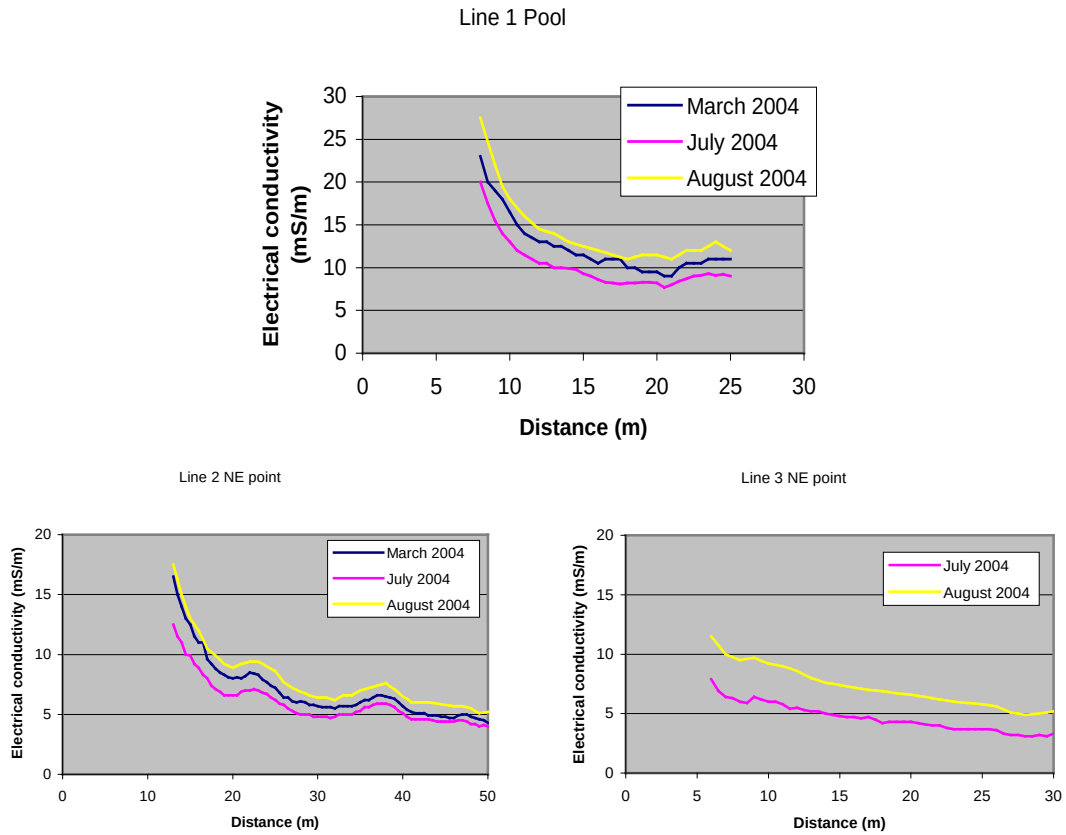


Figure 1. Comparison of seasonal electrical conductivity variations at the pool and the northeast point.

Hydrogeology of the pool

In recent history, the pool layout has been changed many times. The predominant alteration has been the construction of dams to increase the volume of the reservoir. The raised pool level has inundated several inscriptions and brought the water level closer to other inscriptions around the perimeter of the pool. A darker band in the rocks above the pool level represents the capillary rise. It is important to understand origin of the water in the pool and the behavior of the capillary water around the pool.

Currently, there exists no agreement on the origin of the pool water. Some previous studies believe that only rain water and surface runoff contributes to the water in the pool, this idea is supported by the small difference in chemical characteristics of rain water and the pool water (Sayre 1997). However, others believe that flow through reservoirs in cracks or through vadose zone flow in rocks and/or soil contributes to the pool level. To solve the question of the pool water origin we have set up a water balance for the pool:

$$\Delta L = P + R - E + Q(c + p + s) - Q(o + r + l)$$

where ΔL = change in water level in pool (mm)
P = influx through precipitation directly into the pool (mm)
R = influx through overland runoff and channelized flow (mm)
Qc = (delayed) influx through crack flow (mm)
Qp = (delayed) influx by water percolating through the rock pores (mm)
Qs = (delayed) influx by water percolating from the surrounding soil (mm)
E = loss due to evaporation from the pool (mm)
Qo = loss through overflow of the pool (mm)
Qr = loss through recharge to the groundwater (mm)
Ql = loss due to water laterally infiltrating rock surrounding the pool (mm)

We have done field tests to estimate the contribution of Qs and Qr, the combined contributions of P and R, and we have taken different measurements to estimate the components Qc, Qp, E, Qo and Ql.

To estimate component Qs, piezometers P1 and P2 were placed ‘upstream’, in a higher topographic position than the pool surface. The day after a large rainfall event on August 20, 2004 (Appendix D) water was found in P1, and in a puddle next to it, but not in any of the other piezometers. One day later, water was present in both P1 and P2. Water was not present during visits in July and September 2005. These observations rule out the possibility of ground water permanently feeding the pool from the upslope east side. Instead during large storms water is collected under the drop off (the same situation may be encountered near other drop offs along the inscription trail and other parts of the Monument) and percolate vertically. The water that was found in 2004 in P2 two days after the rainfall event probably entered the soil and piezometer laterally through the soil from water collected around P1 as well as through crack and vadose zone flow in the

cliff. The same phenomenon was observed on August 8, 2006, after heavy rainfall during the previous days. The water level in P1 was only 35 cm below the soil surface; P1 was in the center of a big puddle. Piezometer P2 also carried water but at a much greater depth (> 1 m) than P1².

The water samples collected from the piezometers and the pool were analyzed for Deuterium and $\delta^{18}\text{O}$ levels. In meteoric water (i.e., rainwater, fresh snow) the ratio between $\delta^{18}\text{O}$ and δD remains constant. Meteoric water theoretically should fall on the solid black line in Figure 3. Differences in isotopic composition for meteoric water can be due to different origins. All water samples labeled “P1 puddle” “P1” and “P2” were collected during a two day period in August 2004, yet their composition is very different. The sample from P2 has an isotopic signature more characteristic for snow, suggesting that this water has slowly percolated through the cliff and was “pushed out” by the precipitation event of August 20, 2004. The different signatures of “P1” and “P1 puddle” versus “P2” suggest that influx of water to the pool by percolation through the soil upstream of the pool (Q_s) is very small.

Water is composed of molecules of different weight. Because lighter water molecules evaporate easier than heavier molecules, evaporation changes the isotopic composition of the remaining water. This leads to a deviation from the meteoric water line. The four samples from the pool (two collected in August 2004, two in July 2005) have been subject to evaporation and have higher $\delta^{18}\text{O}$ values. Evaporation causes the $\delta^{18}\text{O}$ - δD ratio to change at a constant rate (dashed lines in Figure 3).

More data are needed to accurately identify the source of the water in the pool. Nevertheless, these results suggest that the combined effect of Q_c and Q_p is not negligible.

To measure component Q_r , piezometers P3 and P7 were installed directly downstream (east) from the pool in the former arroyo. None of the auger holes struck ground water but in all holes the moisture content increased with depth (Figure C-7). However, no water was observed during any of the other visits to the site. Also, the GPR survey in March 2004 (Appendix B) did not reveal the presence of a (perched) water table. Therefore, it seems unlikely that any water leaves the pool through horizontal groundwater flow. However, it is likely that recharge directly below the pool occurs. We have no data to measure the quantity of Q_r .

Overflow of the pool (Q_o) has been occasionally reported by park staff (F. Moosman, personal communication, 2004). However, we have found no evidence of overflow in 2004 and 2005. However, on August 6, 2006, there was clear evidence that the pool had overflowed into the arroyo.

On 07/01/2005 a sensor for continuous monitoring of the water level in the pool was installed at the north end of pool. The sensor was installed in a protecting pvc housing,

² Hendrickx visited El Morro on August 8, 2006, for the final project meeting without any measurement equipment. All observations on this day are estimates.

Difference August - July 2004

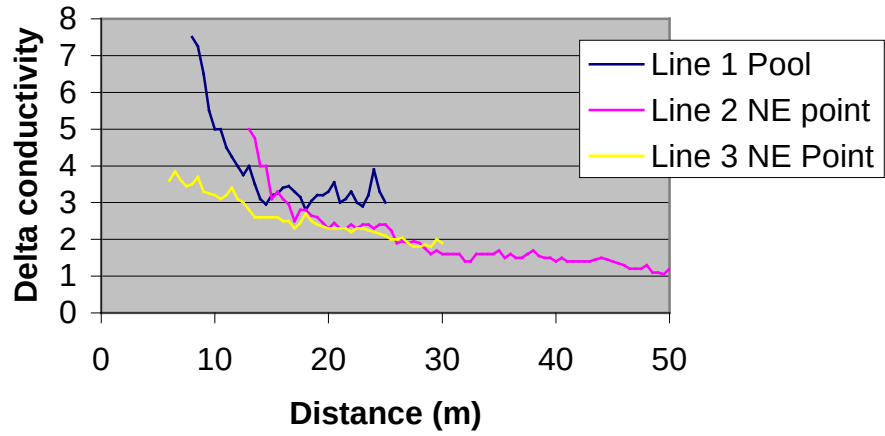


Figure 2. Differences in electrical conductivity between August and July

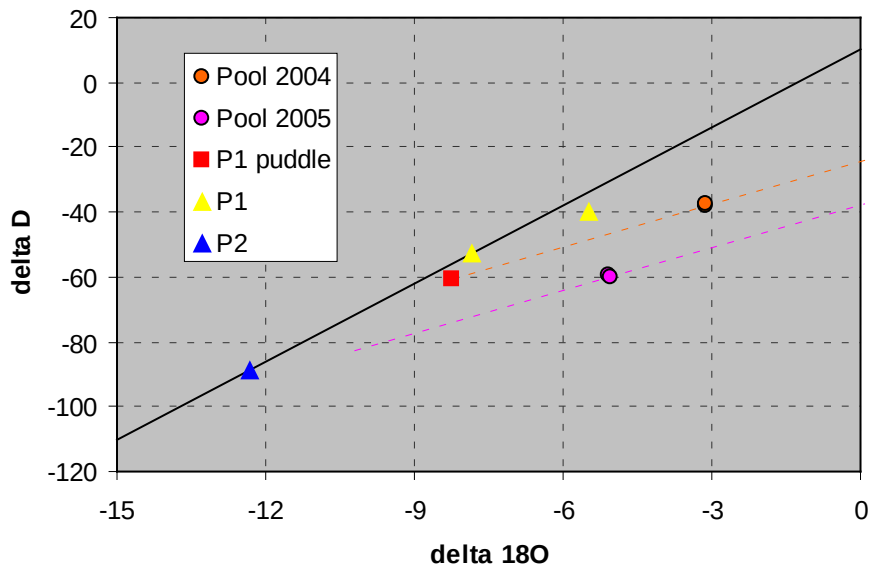


Figure 3. $\delta^{18}\text{O}$ and δD values for water samples from pool and piezometers.

which was attached to fence post lining the pool. A data logger attached to the system stores the pool water level every 10 minutes. The data help to analyze components P and R. Figure 4 shows the water level of the pool and corresponding precipitation events for a period from July to September 2005. Information on precipitation events was assembled from the Park Logbook (Appendix F). Table 2 presents specific information for each of the rainfall events and changes in pool level. Unfortunately, the rainfall data are not very accurate. Firstly, the data were collected at the visitor's center, which due to its distance from the pool may cause errors. Secondly, the data are collected only once a day, maximum, and although the approximate time of precipitation events is recorded in the logbook, some errors are likely. Changes in pool level were calculated from datalogger data (Table 2). The change in pool level over a 24 hour period (5th column) was calculated from midnight to midnight unless indicated otherwise.

In the absence of any rainfall events it is possible to calculate the change in pool water level due to evaporation (E, negative effect), recharge (Qr, negative effect), infiltration in the cliff (Ql, negative effect) and percolation through the cliff (Qc + Qp, positive effect). The recharge is expected to stay constant throughout time while the other variables may change. Figure 5 shows that for three one- to two-week periods (7/27-8/1, 8/23-8/31, and 9/13-9/26) the pool level decreased at a rate of 1 millimeter per 4.52, 5.29, and 5.49 hours, respectively. Although the rate of decrease in pool level is reasonably close between the three periods, the results indicate that later in the monsoon season, the pool level decreases more slowly. Therefore, we believe that water infiltrated on the top of the cliff increases inflow of water (Qc + Qp) in the pool. The process that is involved in the delayed inflow into the pool may be similar as that what caused the delayed inflow of water in P2 on August 22, 2004 (Appendix D).

The data collected directly after installation of the water level logger seemed to indicate the presence of diurnal cycles (Figure E-3). However, no such cycles were found in the data from July through September.

During rainfall events the water level of the pool changes at rates of up to 1cm per ten minutes for intermediate size rainfall events (5-6mm) and at rates of 1.5cm per ten minutes for larger events (Table 2). However, small rainfall events (0-2mm) do not result in changes in pool level (Figure 6). This is other evidence that supports the theory that small amounts of rainwater will pond on the surface of the rock and percolate through cracks and the pore system.

The pool is fed by three catchments, with an aggregate size of 1.55 acres (about 6273 square meters) (Pranger, 2002). The response time of the system is very fast, as can be expected from the small size of the catchment area. Some rainfall events cause very rapid changes in pool level (Appendix G). The ratio of rainfall amount over change in pool level is about 0.1 to 0.25 (Table 2). The pool has an approximate size of 3500 square feet (~380 square meters) (Sayre, 1997), which makes the ratio of the pool size over the catchment size about 0.06. This suggests that less than 50% of the rainwater reaches the pool through runoff (Figure 6).

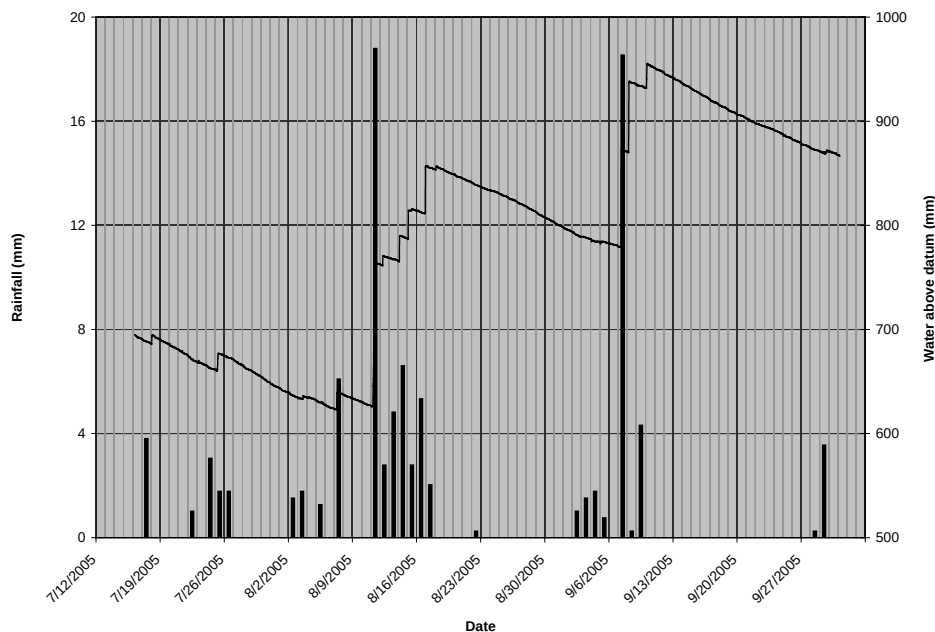


Figure 4. Water level of the pool and corresponding precipitation events (in millimeters). Detailed plots of the individual precipitation records in the pool level are given in Appendix G.

Table 2. Information on rainfall events and changes in pool level (July to September 2005). Information on precipitation events was assembled from Park Logbook. Changes in pool level were calculated from level logger data. The change in pool level over a 24 hour period (5th column) was calculated from midnight to midnight unless indicated otherwise. The last column gives the ratio of change in pool level over precipitation; values in *italic* are for rainfall events smaller than 4mm.

Month	Date and approx. time of event	Rainfall (inch)	Rainfall (mm)	pool Δd (mm, 24hrs)	pool Δd (mm, event)	event duration (min)	Δd/P
July	7/17/2005 15:00	0.15	3.81	3.96	8.23	100	<i>0.463</i>
	7/22/2005 15:00	0.04	1.016	-3.048	0	no event	
	7/24/2005 15:30	0.12	3.048	13.72	16.76	130	<i>0.182</i>
	7/25/2005 12:00	0.07	1.778	-3.35	0	no event	
	7/26/2005 0:00	0.07	1.778	-5.18	0	no event	
August	8/2/2005 15:00	0.06	1.524	-3.66	0	no event	
	8/3/2005 0:00	0.07	1.778	0.91	3.048	10	<i>0.583</i>
	8/5/2005 12:00	0.05	1.27	-5.18	0	no event	
	8/7/2005 0:00	0.24	6.096	-3.66	0	no event	
	8/11/2005 0:00	0.74	18.796	135.33 [^]	136.86	460	<i>0.137</i>
	8/12/2005 14:00	0.11	2.794	17.98	9.144	40	<i>0.306</i>
	8/13/2005 14:00	0.19	4.826	21.95	24.99	60	<i>0.193</i>
	8/14/2005 14:00	0.26	6.604	26.52	27.74	30	<i>0.238</i>
	8/15/2005 11:00	0.11	2.794	-3.048	1.524*	30	<i>1.833</i>
	8/16/2005 11:00	0.21	5.334	42.67	45.72	50	<i>0.117</i>
	8/17/2005 12:00	0.08	2.032	-0.305	3.048	40	<i>0.667</i>
	8/22/2005 12:00	0.01	0.254	-3.66	0	no event	
September	9/2/2005 18:00	0.04	1.016	-2.74	0	no event	
	9/3/2005 16:00	0.06	1.524	-3.35	0	no event	
	9/4/2005 15:00	0.07	1.778	-0.61	0	no event	
	9/5/2005 2:00	0.03	0.762	-2.13	0	no event	
	9/6/2005 20:00	0	0	91.44	93.88	50	
	9/7/2005 0:00	0	0	64.31	66.75	40	
	9/7/2005 15:30	0.73	18.542		160.63**	50+40	<i>0.115</i>
	9/8/2005 3:00	0.01	0.254	-3.35	0	no event	
	9/9/2005 15:00	0.17	4.318	19.51	23.47	70	<i>0.184</i>
	9/28/2005 12:00	0.01	0.254	-2.44	1.83	40	<i>0.139</i>
	9/29/2005 9:00	0.14	3.556	-0.61	3.048	150	<i>1.167</i>

[^] value calculated for 24hr period starting 17:24PM on 8/10/05

* event on 8/14/05; rainfall data collected on 8/15/05

** total of two separate events (recorded in pool level) on 9/6/05 and 9/7/05

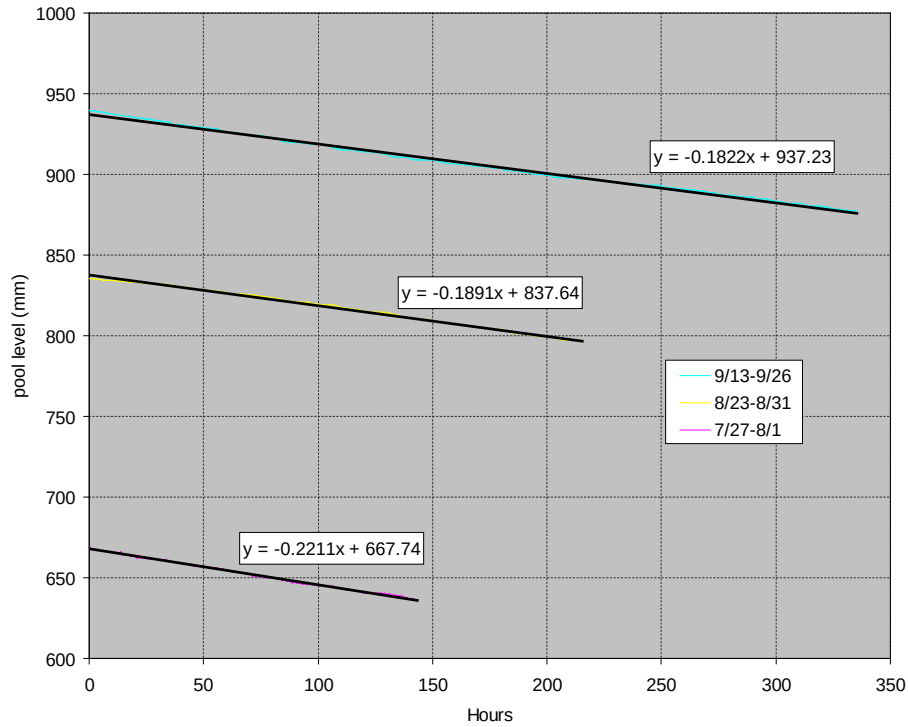


Figure 5. Decrease in pool water level during periods without precipitation; from bottom to top: 7/27-8/1, 8/23-8/31, and 9/13-9/26. See Figure 1 for reference.

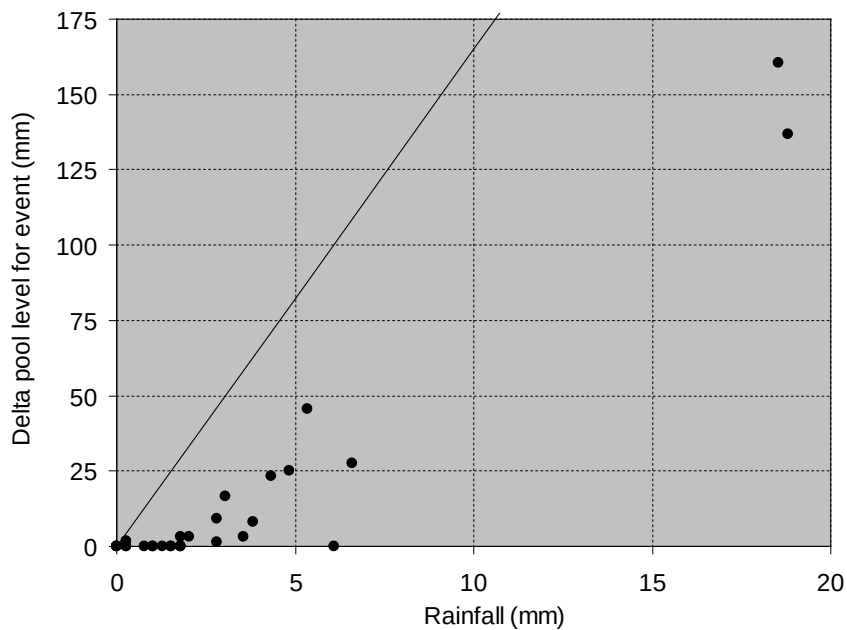


Figure 6. Cross plot of rainfall amounts and associated changes in water level in the pool. The duration of the individual events (as recorded in changes in pool level) is given in Table 1. The solid line is ratio of pool size over catchment size.

Water balance calculations

For the month of August we can approximate the water balance using the data in Table 2. The change in pool level (ΔL) = +155.14 mm (Figure 4). Precipitation P is estimated using the rain gauge data (Table 2, column 3) as 54.1 mm. R is estimated by subtracting the rainfall directly received by the pool from the change in pool level. Using the data in Table 2 R for August is about 204 mm. On a monthly basis using all P data R is about 3.8 times P. Using only rainfall events larger than 4 mm we find that R is about 5.3 times P. This increase is expected since larger rainfall events produce larger runoff volumes because a relatively smaller amount of precipitation becomes surface storage. A first estimate of E can be made assuming that the sum of all Q's equals zero. E is then equal to $P+R-\Delta L=54+204-155=108$ mm during August or 3.5 mm/day. This evaporation rate is considerably smaller than the potential evaporation rate during August which may be as high as 6 to 8 mm/day. Since a large part of the pool is mostly in the shade the energy for evaporation has to come from warm air and reflected radiation. This condition will result in an evaporation rate considerably lower than the potential evaporation rate of a pond exposed to full solar radiation and wind action.

The contribution of inflow and outflow through the surrounding rock and soil (the Q's) is very difficult to quantify for several reasons. First, there is no independent measurement of evaporation; secondly, this contribution will be rather small, perhaps on the order of 10 mm per month, i.e. one order of magnitude less than P, R, and E. Thus, a small error in the measurement or estimation of P, R, and E will result in a large error of the contribution of inflow and outflow through surrounding rock and soil.

In spite of the fact that the August 2005 water balance is based on precipitation measurements taken at a considerable distance from the rock, it demonstrates several important features of the pool hydrology. The most important supply for pool water—at least during the monsoon season—is runoff from the rock during precipitation events exceeding 2-4 mm; direct precipitation on the pool also adds to the water supply. The most important loss factor is evaporation. The joint contribution of inflow and outflow through the surrounding rock and soil is expected to be a fraction of the evaporation otherwise pool level fluctuations would be expected to be much larger during the year and between dry and wet years.

The August 2005 water balance not only demonstrates the major components of the water balance in the monsoon season but also that our research approach yields reliable novel data.

Capillary moisture in the cliff

To understand water and solute flow in the rock it is important to know physical properties of the material. The grain and pore size distributions, and its variations are of primary importance. As mentioned by Cross (1996) the sediment in the bluff can be subdivided in four basic categories. In August 2004 we have sampled 8 rock cores from

different stratigraphic units in the Zuni and Dakota Sandstone Units (see Appendix D for a description).

We have performed laboratory experiments to find the water retention characteristics and the maximum height of the wetting front. In addition to the laboratory measurements we will use grain size, porosity data from the report of Cross (1996) to estimate a variety of properties such as recharge rates, solute concentrations, seasonal variations in capillary rise, and effects of freeze-thaw cycles.

So far the experiments have not provided the desired results. The measurements take considerable time because the water pressure inside the rock cores must equilibrate with the soil water pressure in the sand of the water retention tank. Unfortunately, when the rock cores are exposed to humid conditions for such a long time they disintegrate which prohibits the measurement of their water retention properties with this technique. It is recommended to use a different technique to repeat the experiment (Vroon et al., 1988).

CONCLUSIONS

This report documents completed work of the hydrological investigation at El Morro National Monument by New Mexico Tech and concludes:

- 1) Combined interpretations from ground penetrating radar and electromagnetic induction surveys, as well as piezometer measurements show that there exists no permanent perched water table near the pool. This means that no water flows into or out of the pool through horizontal flow of groundwater except for short periods of time when perched ground water tables develop.
- 2) Piezometer observations in August 2004 and 2006 are evidence that during periods with heavy precipitation perched ground water tables do develop close to the cliff. Capillary rise into the cliff may lead to elevated moisture content and subsequent deterioration of the sandstone (see also Conclusion 4).
- 3) Automated monitoring of the water level in the pool showed excellent correlations with rainfall. During the monsoon season the major water sources are runoff from the rock and precipitation falling directly on the pool. The major water loss is evaporation. The water level and isotopic data strongly suggest that some rainwater and snowmelt infiltrates on the top of the cliff and percolates through cracks and the rock matrix to the pool. The quantity of this delayed inflow could not be determined with the available data nor could we determine how much water is leaving the pool by infiltration in the surrounding rock and soil.
- 4) Rock cores for measurement of water retention characteristics and hydraulic conductivity have been collected from a number of different stratigraphic layers. Laboratory measurements to estimate the water retention characteristics have been carried out, but due to disintegration of the cores during wetting, a different measurement technique is needed to obtain reliable results. Nevertheless, the observed deterioration of

the sandstone samples in the laboratory following wetting clearly demonstrates that any source of water (perched water tables next to the cliff, rising water levels in the pool, water flow through cracks after infiltration at the top of the mesa) will lead to accelerated erosion.

5) A ground penetrating radar survey, electromagnetic induction measurements, and a piezometer show that there exists no permanent and probably no temporary perched water table near the northeast point. Either rock physical and chemical properties need to explain the rapid deterioration of the rock at the northeast point, which has been observed in recent decades, or a source of water that generates on the top of the mesa.

6) Electromagnetic induction measurements near the pool and at the northeast point have demonstrated that the soil moisture content increases towards the cliff. Repeated measurements show a significant variation in moisture content during various seasons in the year.

RECOMMENDATIONS FOR FUTURE WORK

Pool water origin – The water level logger allows for accurate monitoring of the water level in the pool, which showed excellent correlations between rainfall events and pool water level. The water level and isotopic data strongly suggest that some rainwater infiltrates on the top of the cliff and percolates through cracks and the rock matrix to the pool. We anticipate that a fully automated weather station on the cliff top (with a secondary station for atmospheric conditions next to the pool) will provide valuable additional information to determine the response time of the system. The installation of water level loggers inside the piezometers will tell us how often the soil at the foot of the cliff becomes saturated. A denser sampling scheme for the isotopic composition of the pool water will allow drawing more binding conclusions on the residence time of the water in the rock.

Hydraulic Properties of the Rocks – In this study we learned that the sandstones are too soft for measurement of hydraulic properties without support. Other existing techniques need to be tried for determination of the rock hydraulic properties. This information is needed to better quantify capillary rise from the pool into the rock.

Arroyo excavation – The sequence of material found in the borehole, which was drilled for piezometer P7 (Table E-3) suggests that at 70-85 cm depth lies an older surface. White spots in the material between 40 and 70 cm suggest the presence of (weathered) bedrock, which may have originated in the 1930's rock fall. The material found between the surface and 40 cm depth is possibly recent fill. We believe that the original surface, before filling the arroyo, may have been 70-85 cm below the present surface. Inspection of soil pits in the arroyo may result in a better understanding of the original hydrological condition of the site but should not have as high a priority as instrumentation of the site.

How much exposure to moisture is needed to deteriorate the sandstone – The laboratory experiment clearly demonstrated that the sandstone disintegrates after exposure to

moisture. It is critical to find out the relationship between the duration of the exposure and the total amount of water infiltrated into the rock. If it is found that relatively small amounts of water during short periods of time will lead to deterioration of the sandstone, the NPS may consider to greatly eliminate exposure to moisture by managing the hydrology of El Morro. Possible management options are: 1. Lower the water level of the pool to reduce capillary rise into the inscriptions; 2. Cover the inscriptions to prevent wetting by wind swept precipitation or by runoff water cascading down the cliff; 3. On top of the mesa seal the entrances to cracks in the rock.



Figure 7. Rock cores and solid rock slabs in the water retention tank, in which the water level can be varied (Hendrickx's soil physics laboratory at New Mexico Tech)

Table 3. Lab results of water retention measurements in Hendrickx's soil physics laboratory at New Mexico Tech.

El Morro water retention			length (cm)	average radius (cm)	volume (cm ³)	weight (g)				
sample name	core section	location / strat.unit				11/27/2005	11/31/2005	12/2/2005	12/10/2005	12/13/2005
C1		DK6	9.5	1.1	36.11	78.7	75.6	27.4	27.2	27.1
C2	A	west of C1	6.5	1.15	27.01	60.7	57.4	61.8	61.4	61.3
C2	B	west of C1	4.7	1.15	19.53	44	41.5	43.7	43.6	43.5
C3		(picnic table)	10.5	1.2	47.50	97.4	91.7	100	100.5	100.5
C4	A	18.9m west of G	6.5	1.15	27.01	59.9	57.8	63.4	63.4	63.5
C4	B	18.9m west of G	3.2	1.15	13.30	29.4	28.3	31	31	31.2
C5		"VV"x"VV"	9.5	1.15	39.47	80.2	75.6	83.9	84.4	84.4
C6	A	UU	5.5	1.1	20.91	47.4	46.2	50.7	51	51.1
C6	B	UU	6	2.2	91.23	55.6	54.4	59.9	60.1	60.2
C7	A		4.5	1.15	18.70	41.5	37	39.9	39.9	40.1
C7	B		damaged			21.2	19.2	21.3	21.3	21.3
C7	C		2.5	1.15	10.39	25	22.6	25.3	25.4	25.3
Slab	A	NE point				53.5	53.5	59.4	59.5	59.6
Slab	B	NE point				69.1	69.1	77.2	77.5	77.3
Slab	C	NE point				139	139	153.6	154.4	154.3
Slab	D	NE point				102.2	102.2	112	112.5	112.3
water level								0	-7.2	-22

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Appendix A – Earlier Reports by New Mexico Tech

- A report on the visual assessment in September 2003
Remke van Dam
September 11, 2003
- Research proposal for hydrological investigation at El Morro National Monument
Remke Van Dam and Jan Hendrickx
November 17, 2003 (Revised version: January 29, 2004)
- Proposed locations for hydrological sampling
Remke Van Dam
April 5, 2004
- Summary of completed and scheduled work for first year
Remke van Dam
July 1, 2004
- Report FY 2004
Remke van Dam and Jan Hendrickx
September 6, 2004
- Interim report July 2005
Remke van Dam and Jan Hendrickx
July 15, 2005

Appendix B - Field visit March 2004

In March 2004 El Morro NM was visited with three objectives:

1. To measure the relative positions of the pool and the spring in Box Canyon
2. To study the general hydrogeology of the pool area and the northeast point using geophysical tools
3. To select sample collection sites and piezometer locations (documented in an earlier report)

1. GPS Surveying

A Global Positioning System was used to measure the relative positions and elevation of the pool and the spring in the Box Canyon. Commercial GPS systems like the one that was used give accurate horizontal positions, but the elevation estimation is prone to error, especially with the presence of the high cliff walls. Nevertheless, the results (Table B-1) suggest that the elevation of the spring is several meters above that of the pool.

Table B-1. GPS results for pool and box canyon spring

	North	West	Elevation
Box canyon spring 1	35°02'24.334"	108°21'12.111"	2239
Box canyon spring 2	35°02'24.315"	108°21'12.028"	-
Ridge between spring and pool	35°02'25.293"	108°21'08.402"	2274
Pool 1	35°02'25.682"	108°21'03.175"	2225
Pool 2	35°02'25.555"	108°21'04.850"	2217

2. Geophysics

Ground penetrating radar was used to image a possible perched water table near the north-east point and the pool. The survey lines were the same as those used for the electromagnetic induction survey. No water table could be detected near the pool and the northeast point. In both cases, the steel reinforced footpath of the inscription trail limited the performance of this method.

Electromagnetic induction was used to study the spatial variability in soil moisture content in the pool area and at the northeast point. At both locations a Geonics EM31 system was used to measure the bulk apparent electrical conductivity of the subsurface along transects. At both locations the results show a clear increase in conductivity towards the pool and cliff wall, respectively. In both cases the distance of 0m is the intersection of the transect with the wooden fence. The values that drop to zero are caused by the steel reinforced footpath.

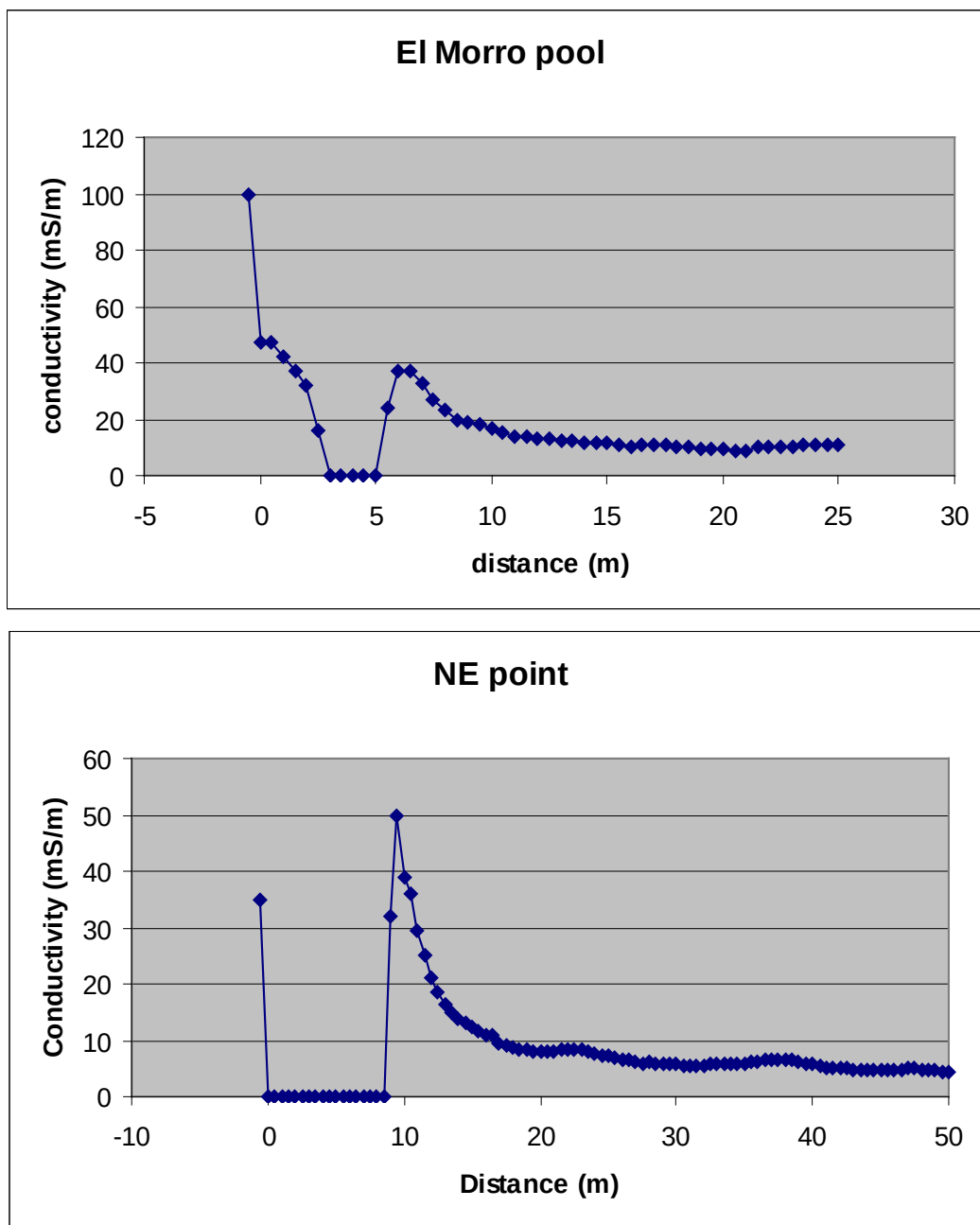


Figure B-1. Electrical conductivity variations at the pool and the northeast point.

A **thermal camera** was used to image the longwave radiation characteristics for the rock wall above the pool. The images were collected at the end of the night (one hour before sunrise) using a FLIR thermacam 3000 with a wide-angle lens. A sample image is presented in Figure B-2. The images show temperatures that differ up to 5 degrees celcius.



Figure B-2. Thermal camera image of the rock wall above the pool. The image showing horizontal temperature bands and vertical light-colored (=warm) structures.

Appendix C - Field visit July 2004

The July 12-14 fieldwork was used to:

1. Repeat geophysical measurements to assess seasonal variations in subsurface electromagnetic properties and thermal characteristics of the pool wall.
2. Install piezometers at several locations around the pool and at the northeast point

The water level in the pool was checked and found to be at 9 feet, 9 inches

1. Geophysics

A Geonics EM31 system was used to measure the bulk apparent electrical conductivity of the subsurface along 3 transects. Two of these transects were also used in the March fieldwork while at the northeast point one new transect (see sketch for location of piezometer 4) was measured. The measurements show a trend that is similar to that measured in March. All transects show a clear increase in conductivity towards the pool and cliff wall. Again, the values that drop to zero are caused by the steel reinforced footpath.

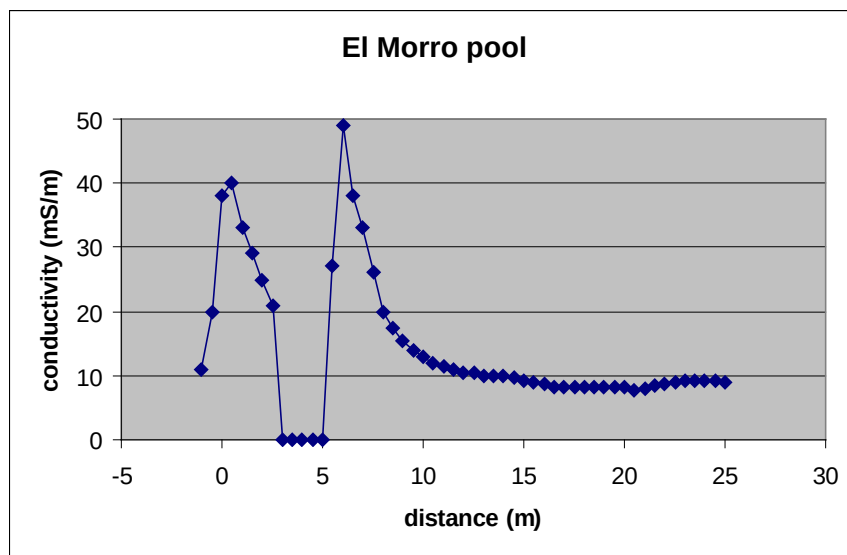
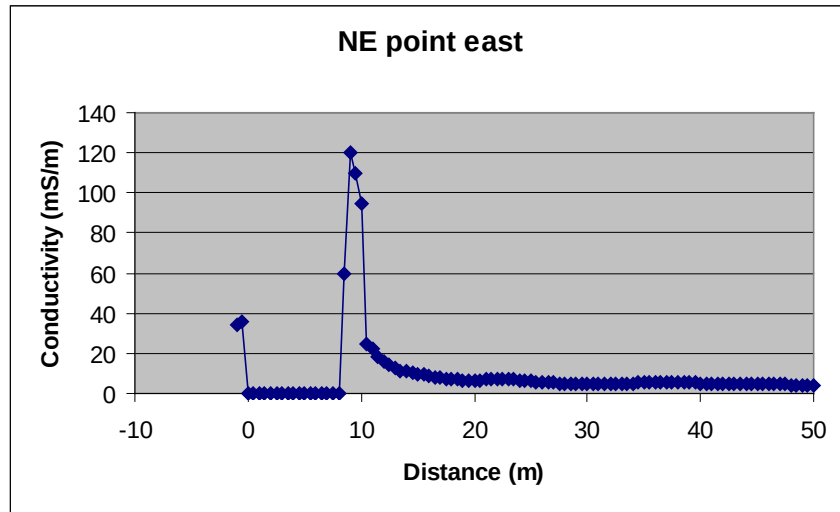


Figure C-1. Electrical conductivity variations at the pool.

Line 2:



Line 3:

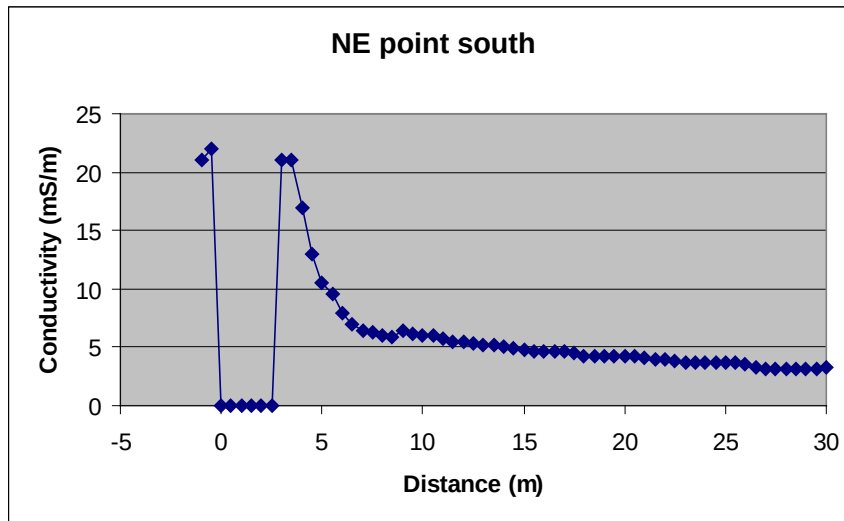


Figure C-2. Electrical conductivity variations at the northeast point.

2. Piezometer boreholes

Boreholes were augered at 4 points around the pool (one of which was not used to place a piezometer) and one location at the northeast point. From each borehole samples were collected for particle size analysis and measurement of gravimetric moisture content. Below, the boreholes and piezometers are characterized in terms of depth, location, and material properties. Also, a graph is shown with the distribution of gravimetric moisture content with depth for each hole.

Piezometer summary and description

Table C-1. Piezometer summary

#	Depth below surface (m)	Height above ground (m)	Total length of tube (m)
1	2.43	0.26	2.69
2	3.08	0.2	3.28
3	2.19	0.29	2.48
4	1.56	0.14	1.7
5	-	-	-

Comments:

- Zone of holes in PVC: 15cm-115cm above tube bottom
- 164 holes in each piezometer (5/32 inch diameter)
- Nylon mesh cloth is wrapped around to prevent sediment to enter the piezometer
- Piezometer diameter 1½ inch
- Height above ground was measured to top of white rim



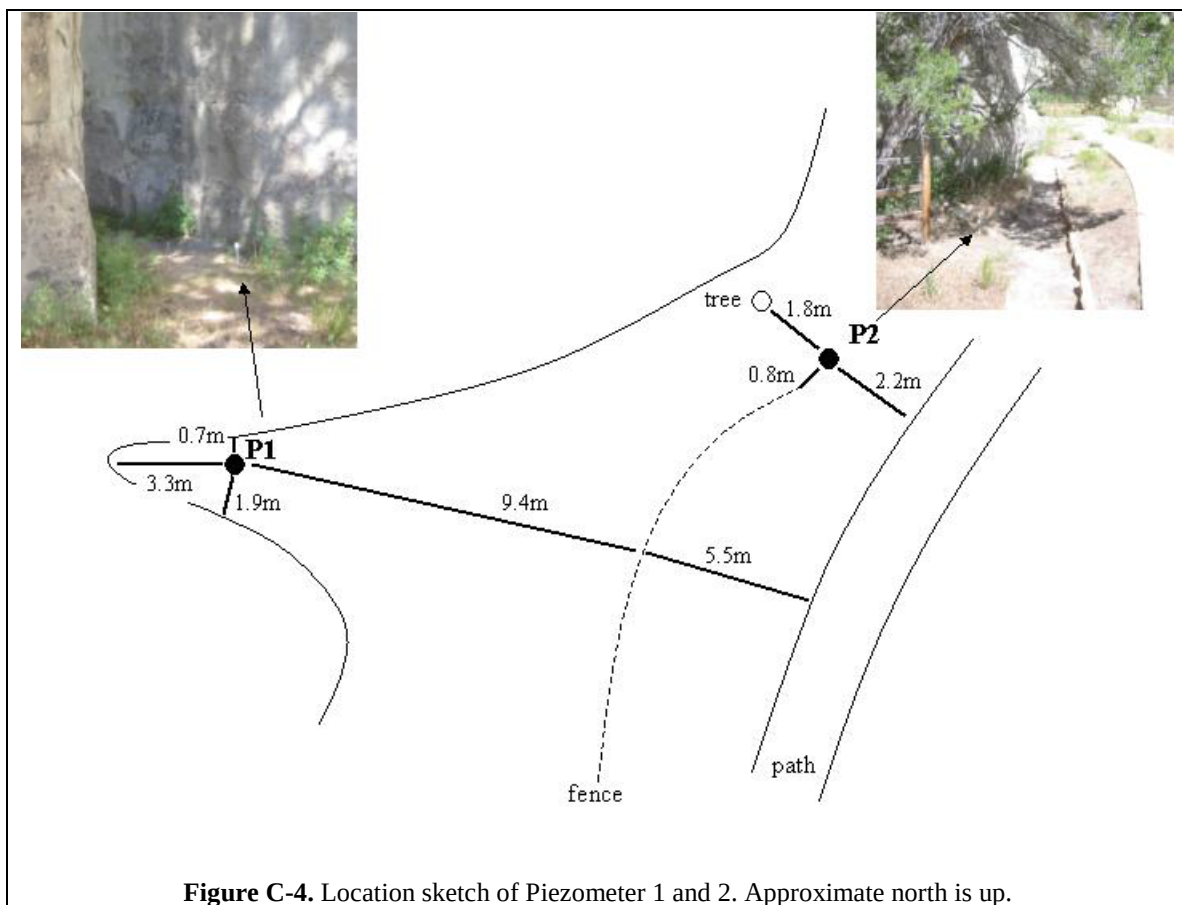
Figure C-3: Picture of two piezometers

Piezometer 1

Location: South of Pool @ drop off

Date: 7/13/04

Depth (cm)	Color	Grain size	Grain size sample	Gravimetric moisture sample	Remarks
0-50	lbr	MS-FS-Silt	0-50	30-40	Some gravel
50-100	lbr	MS-FS-Silt	50-100	80-90	Some gravel, some charcoal, some roots
100-150	lbr	MS-FS-Silt	100-150	130-140	Some gravel, uniform material
150-180	lbr	MS-FS-Silt	150-200	160-170	Brown nodules
180-195	lbr-orange	MS-FS-Silt		180-190	Coarse gravel present
195-200	whitish-orange	MS-FS-Silt		-	Oxidation-reduction features
200-250	whitish-orange	MS-FS-Silt	200-250	230-240	Some charcoal, many FeO concretions, some gravel
250	-	-	-	-	Solid rock



Piezometer 2

Location: South of Pool @ below tree

Date: 7/13/04

Depth (cm)	Color	Grain size	Grain size sample	Gravimetric moisture sample	Remarks
0-50	lbr	FS-Silt	0-50	30-40	
50-100	lbr	FS-Silt	50-100	80-90	Some roots
100-150	lbr-br	FS-Silt	100-150	130-140	MnO (or charcoal?)
150-200	br	FS-Silt	150-200	180-190	Some oxidation/reduction in lowest 5 cm
200-225	br	FS-Silt	200-250	220-230	Some oxidation /reduction
225-250	br-white	FS-Silt		230-240	White patches; FeO MnO nodules
250-300	br-white	FS-Silt	250-300	270-280 280-290	Oxidation/reduction features FeO nodules. White spots 1 piece of green gravel
300-315	br-white	FS-Silt	300-315	310-320	Brown (peaty?) material FeO nodules. White spots
320	white	-	320	-	Brown (peaty material) Bedrock? Weathered sandstone. Max depth.

Piezometer 3

Location: Directly east of pool

Date: 7/13/04

Depth (cm)	Color	Grain size	Grain size sample	Gravimetric moisture sample	Remarks
0-50	lbr	FS-Silt	0-50	30-40	Some gravel
50-70	lbr-wh	FS-Silt	50-100	-	Oxidation/reduction; Mn & FeO spots; white patches
70-100	lbr	FS-Silt		80-90	Oxidation/reduction; some MnO & dark brown spots
100-150	lbr-yellow	FS-Silt	100-150	130-140	Some gravel; some oxidation/reduction features
150-180	lbr	FS-Silt	150-200	-	Feels more moist
180-195	br	FS-Silt		180-190	Oxidation/reduction features; FeO, Mn & white spots
195-225	br-white	FS-Silt	200-225	210-220	
225	white	FS-Silt	225	-	Sandstone / bedrock? Max depth reached

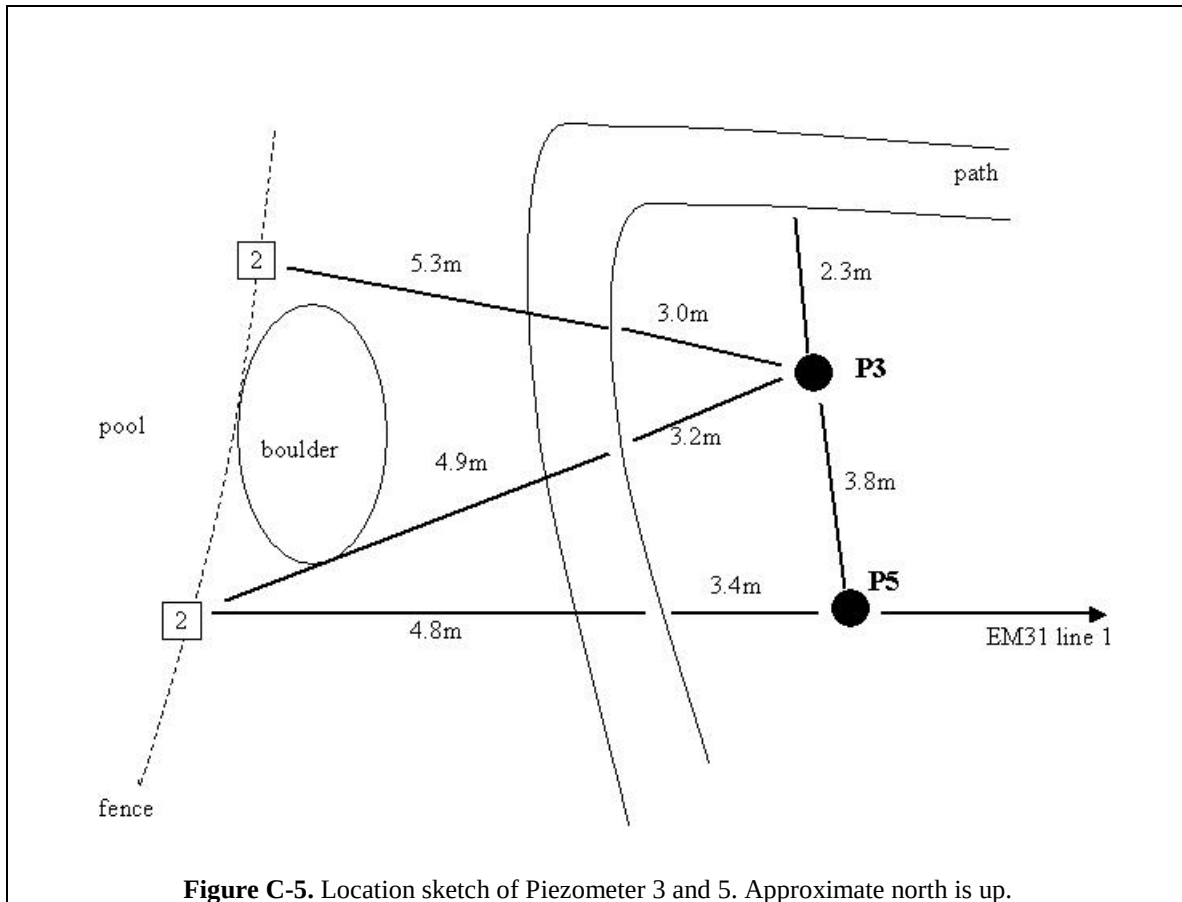


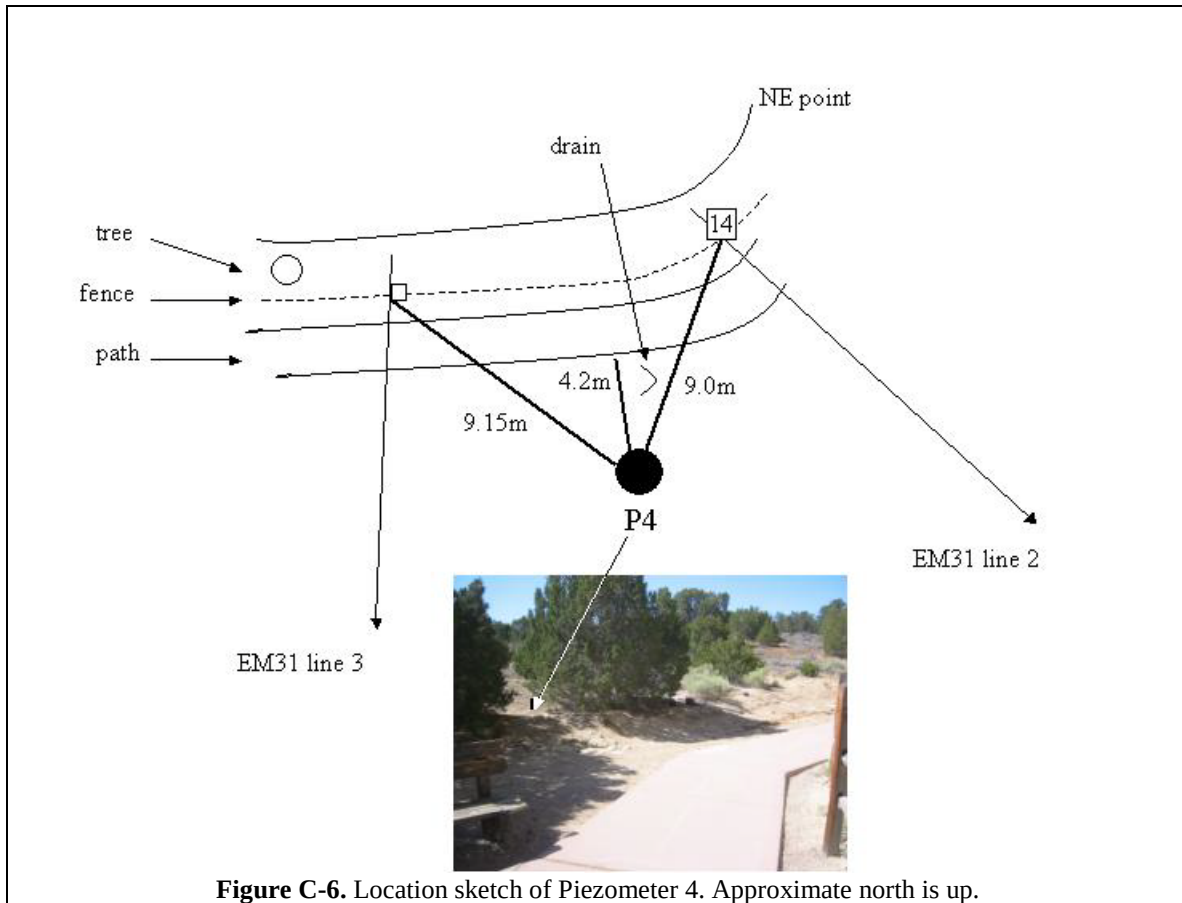
Figure C-5. Location sketch of Piezometer 3 and 5. Approximate north is up.

Piezometer 4

Location: NE point; south side, between two trees

Date: 7/13/04

Depth (cm)	Color	Grain size	Grain size sample	Gravimetric moisture sample	Remarks
0-50	lbr	FS-Silt	0-50	30-40	
50-100	lbr	FS-Silt	50-100	80-90	Very uniform; little silt/clay
100-150	lbr	FS-Silt	100-150	130-140	Very uniform; little silt/clay
					Impossible to drill further: sand too dry and loose



Piezometer 5

Location: Directly east of pool; 3.8 m South of piezometer 3

Date: 7/13/04

Depth (cm)	Color	Grain size	Grain size sample	Gravimetric moisture sample	Remarks
0-50	lbr	FS-Silt	0-50	30-40	Uniform; some gravel
50-80	lbr	FS-Silt	50-100	-	Uniform; some gravel
80-100	br	FS-Silt		80-90	
100-120	br	FS-Silt	100-130	-	
120-130	wh-br	FS-Silt			Hit rock @ 130 No piezometer placed; Location marked with rock

Gravimetric moisture content

Samples collected from the piezometer holes were used to estimate the moisture content at different depths in the arroyo and near the cliff. These measurements give an indication of the level of saturation in locations around the pool and near the northeast point. The three boreholes near the pool all show a significant increase in soil moisture content with depth. However, all these boreholes ended on bedrock without reaching a water table.

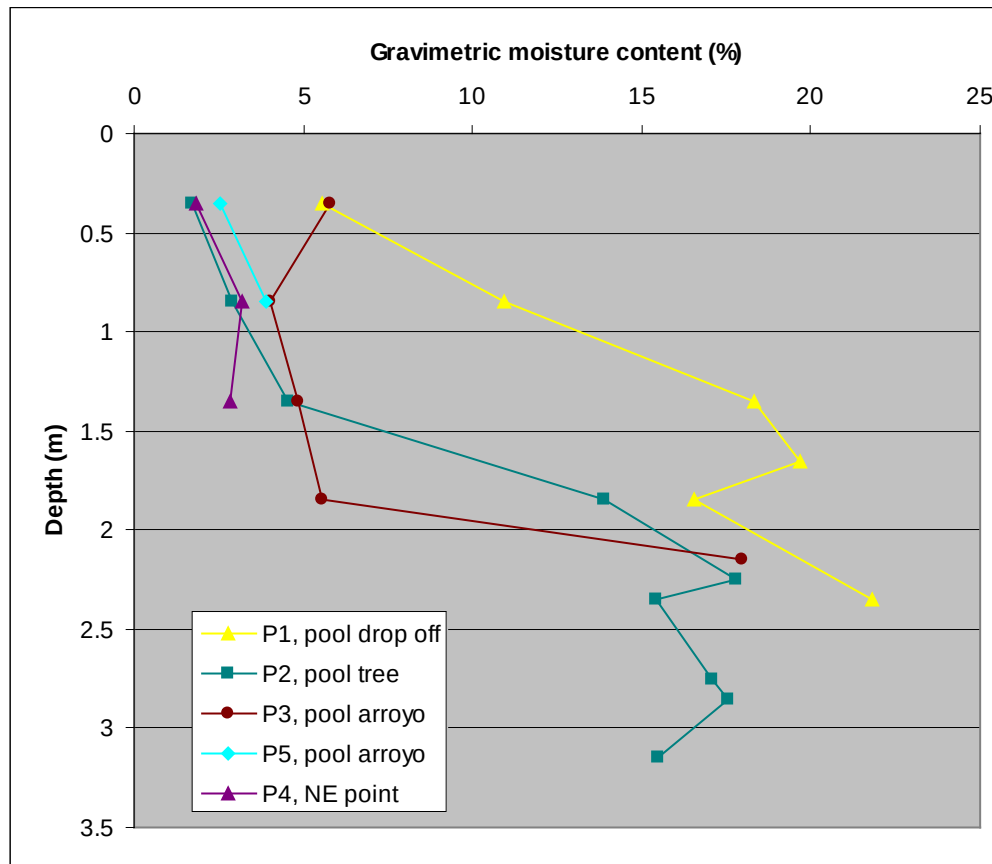


Figure C-7. Gravimetric moisture content for samples from different piezometer holes.

Appendix D - Field visit August 2004

The field visit from August 21-23 was used to:

1. Collect water samples from the pool and the recently installed piezometers.
2. Take rock cores for laboratory analysis of water retention characteristics.
3. Repeat geophysical measurements to assess seasonal variations in subsurface electromagnetic properties.
4. Discuss the progress of the project with Anne Oliver, Jake Barrow, and Kayci Cook Collins (IMSO-SF), Jim Kendrick and the superintendent, and Fred Moosman (El Morro park ranger).

1. Water samples

The water level in the pool was checked and found to be at 10 feet, 9.7 inches on Saturday August 21, 12.30PM. The next day at 5:30PM the water level in the pool was 10 foot, 9.4 inches. These water levels followed a large rainfall event that was recorded by the park staff on the evening of Friday August 20.

In addition to the level of the pool the water level in the piezometers was checked on both August 21 and 22. Water samples were collected from the pool and the piezometers (where possible) for subsequent analysis of Tritium content for determination of the age of the water. The water was sampled using bailers and collected in 0.5 liter sample bottles.

Saturday August 21:

- P1 Water @ 0.64 m below rim (0.38 m below surface)
2 sample bottles filled
Remark: small pool is present at bottom of drop off
- P2 No water
Bottom @ 3.3 m from rim
- P3 No water
Bottom @ 2.45 m from rim
- P4 No water
Bottom @ 1.7 m from rim
- Pool Water level @ 10 foot, 9.7 inches
2 sample bottles filled

Sunday August 22:

- P1 Water level has dropped (elevation measurement unreliable)
2 sample bottles filled
Remark: small pool has disappeared
- P2 Water @ 50 cm from bottom (2.38 m below surface)
2 sample bottles filled
- P3 No water
- P4 No water
- Pool Water level @ 10 foot, 9.4 inches

2 sample bottles filled

2. Rock samples

Rock samples were collected using a battery-powered drill and 1 inch diameter hollow drill bit that was water cooled. It was attempted to collect samples from a range of stratigraphic layers, including different types of sedimentary bedding. Below follows a summary and a more detailed description of the cores.

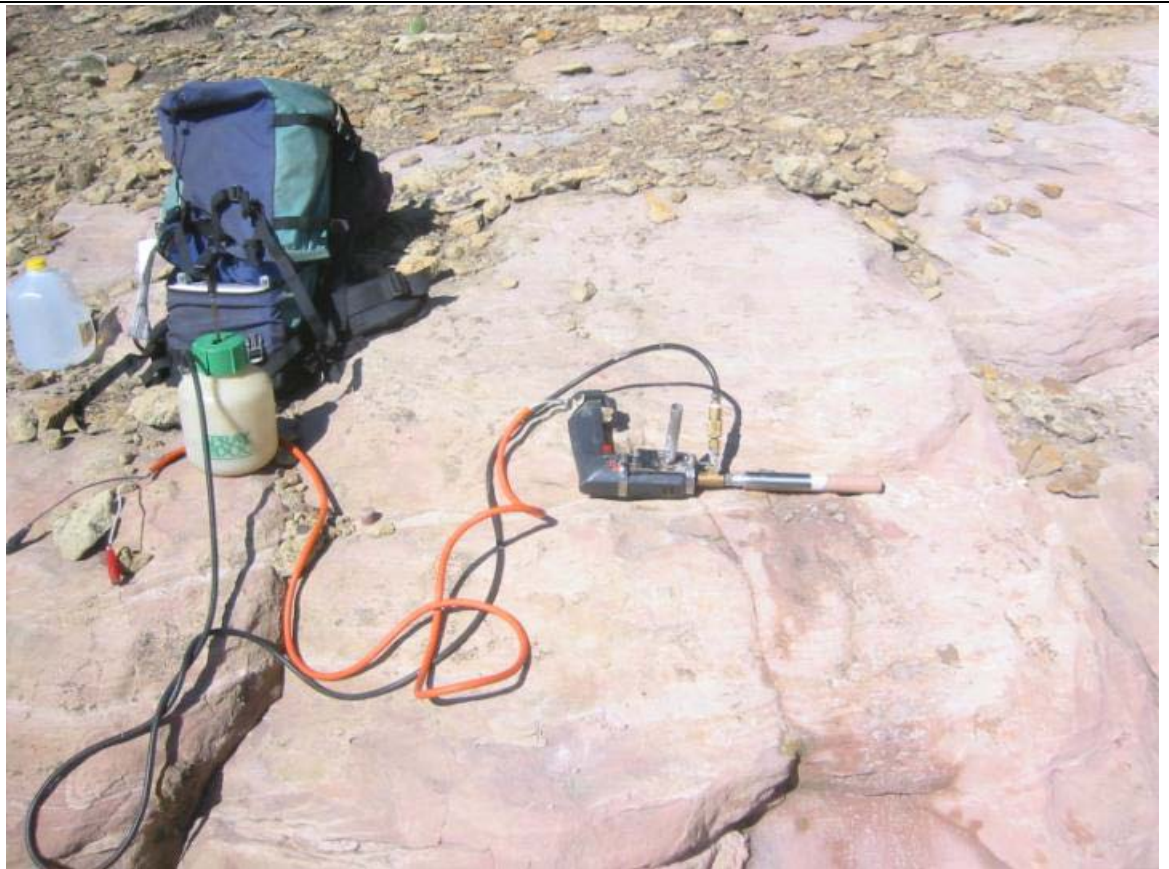


Figure D-1. Water-cooled, battery-powered rock core drill

Table D-1. Rock core summary

Core name	Stratigraphic position	Unit	Location	Orientation	Sedimentary characteristics
C1	2	Zuni	Mesa top	Vertical	-
C2	1	Dakota	Mesa top	Vertical	Conglomerate
C3	3	Zuni	9 Pine Cove	Horizontal	Parallel lamination
C4	4	Zuni	9 Pine Cove	Horizontal	Cross bedding
C5	5	Zuni	North Side	Horizontal	Parallel lamination / Wavy
C6	6	Zuni	North Side	Horizontal	Cross bedding
C7	7	Zuni	North Side	Diagonal	Cross bedding
C8	7	Zuni	NE Point	Unknown	Unknown

Rock Core 1

Location: On small ledge south of top of highest stairs
10 meters to handrail at top of stairs
Stratigraphic position: White Bleached Sandstone at top of Zuni Sandstone
Near sample BZ-1 (Cross,1996)
Sedimentary struct: Massive sandstone
Core orientation: Vertical

Rock Core 2

Location: On small ledge just west (uphill) of Core 1
11.5 meters from Core 1
13.7 meters from stairs handrail
Stratigraphic position: Dakota Sandstone (red)
Near sample DK4, DK5, DK6 (Cross,1996)
Sedimentary struct: Parallel lamination / conglomerate
Core orientation: Vertical

Rock Core 3

Location: Nine Pine Cove
Near picnic table and 1926 inscription treatment project
Drillhole behind pile of pine needles, just left of dropoff, which is
left of big boulder used for 1926 inscription treatment project
Stratigraphic position: Zuni Sandstone
Near sample DK4, (Cross,1996)
Sedimentary struct: Parallel lamination
Core orientation: Horizontal

Rock Core 4

Location: (Northeast) Nine Pine Cove
Under big boulder, just above ledge
18.9 meters left (west) of marker “-G”
Stratigraphic position: Zuni Sandstone, one stratigraphic layer above marker “-G”
Near samples RR1,2,3,4, (Cross,1996)
Sedimentary struct: Crossbedded sandstone
Core orientation: Horizontal

Rock Core 5

Location: North side
3.4 meters right of marker “VV”
2.6 meters left of marker “WW”
0.6 meters from top boundary layer
Stratigraphic position: Zuni Sandstone
Near samples VV1,2 (Cross,1996)
Sedimentary struct: Parallel lamination / Wavy lamination
Unit below cross bedded layer
Core orientation: Horizontal

Rock Core 6

Location: North side
2.2 meters right of marker “UU”
3.5 meters left of marker “VV”
Stratigraphic position: Zuni Sandstone, 3 units lower than Rock Core 5
Near samples TT1,2 (Cross,1996)
Sedimentary struct: Cross-bedded sandstone (same as ‘easy slabs’ above “TT”)
Core orientation: Horizontal

Rock Core 7

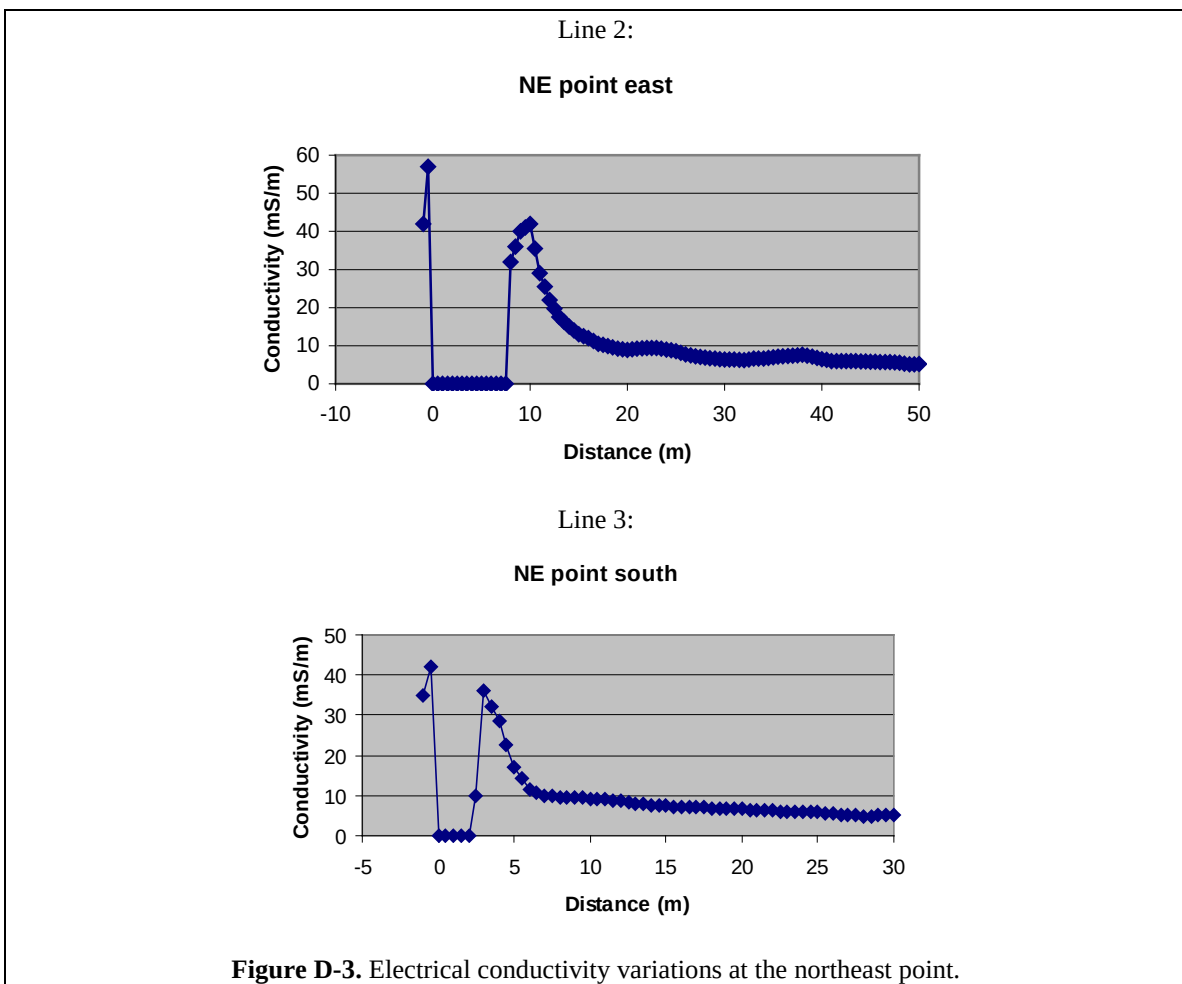
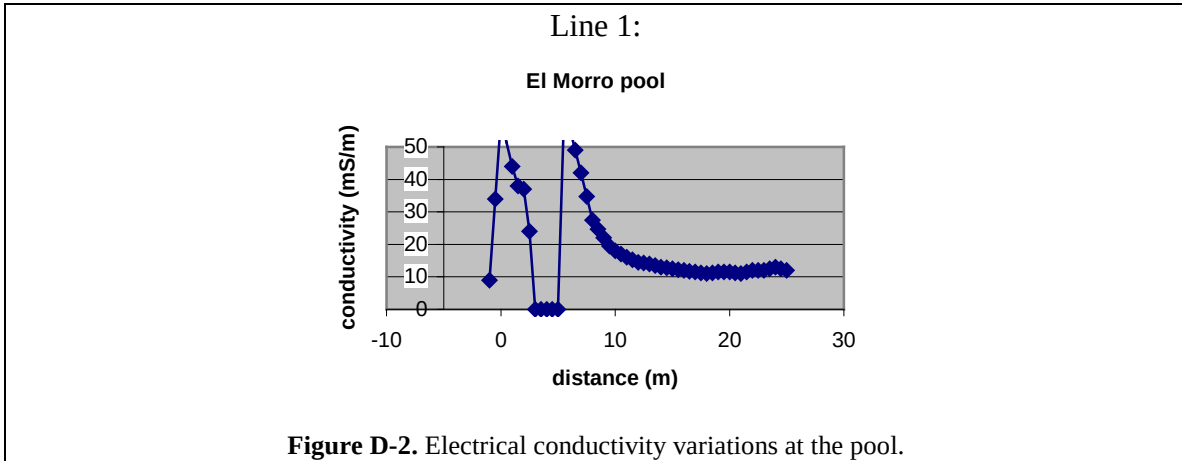
Location: North side
12 meters left of marker “FF”
In soft sandstone; behind tree, right of vertical crack/rill
15 cm below bounding layer
Stratigraphic position: Zuni Sandstone
Near sample Z1 (Cross,1996)
Sedimentary struct: Cross-bedded sandstone
Core orientation: Diagonal

Rock Slab 8

Location: Northeast point
Rock slab on surface, which fell off (from 4 meter height) in the 1990’s
Stratigraphic position: Zuni Sandstone
Sedimentary struct: -
Core orientation: -

3. Geophysics

A Geonics EM31 system was used to measure the bulk apparent electrical conductivity along 3 transects that were also used in the July fieldwork.



Appendix E - Field visits July 2005

The fieldwork on July 1 and July 8 was used to:

1. Install two new piezometers; one near the NE point and one near the pool.
2. Install a device for continuous monitoring of the water level in the pool.

1. Piezometers

We have installed two new piezometers (Table 1) to better understand the role of seepage water that accumulates in the soil at the bottom of the cliff at the end of rainstorms; as was observed for piezometer P2 in August 2004. The piezometers have the same layout as those installed in FY2004. The zone with holes in PVC is from the bottom to 115cm above tube bottom. Around 172 holes of approximately 5/32 inch diameter have been drilled in both piezometer that have a diameter of 1½ inch.

Table E-1. Piezometer summary. Height above ground was measured to the top of the white rim.

#	Depth below surface (m)	Height above ground (m)	Total length of tube (m)
6	2.94	0.20	3.14
7	0.83	0.22	1.05

On 7/1/05 one piezometer (P6) has been placed at the NE point between the cliff wall and the fence lining the foot path (Figure E-1). The bore hole reached a depth of 2.9 meter (Table E-2).

Figure E-1. Sketch showing location of piezometer P6 relative to cliff and other piezometers. The approximate north is up.

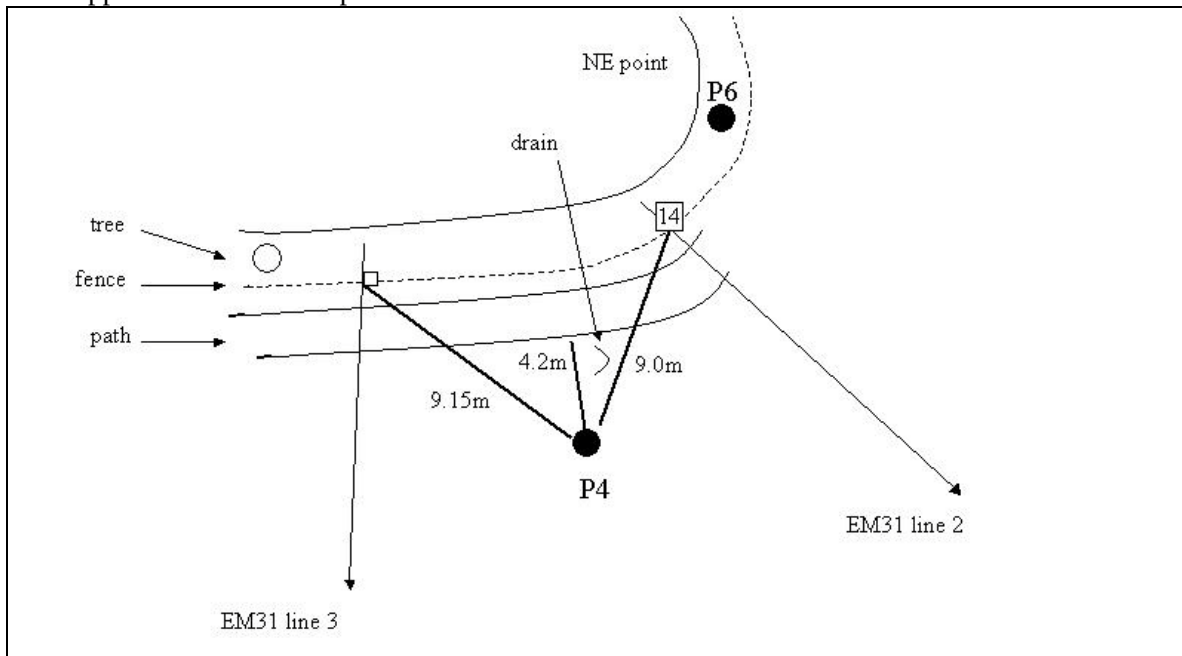


Table E-2. Soil description for piezometer P6.

Depth (cm)	Color	Grain size	Grain size sample	Remarks
0-30	Lbr	FS	0-30	2% gravel
30-60	Lbr	FS	30-60	5% gravel <1cm
	Slightly darker			gravel not from cliff
60-80	Lbr	FS	60-80	Coarser gravel 10% max 2cm diameter
80-100	Lbr	FS	80-100	Gravel 5%
				Clay smear in bore head
100-120	Br	FS-Loam-clay	100-120	Gravel <5%
120-160	Br	FS-Loam-clay	120-160	Gravel <2%
160-200	Br	FS	160-200	Gravel <2%
				White spots; possibly weathered sandstone
				Some roots, thick (5mm diam) and thin
200-230	Lbr	FS	200-230	Some charcoal or manganese concretions
				Gravel <2%
				Some roots
				Some carbonate or weathered sandstone
230-260	Lbr	FS	230-260	Similar but finer roots
				More carbonate or weathered sandstone
260-280	Yellowbrown	FS	260-280	Iron oxidation spots
				Otherwise identical to 230-260
280-290	Lbr to white	FS	280-290	With weathered sandstone
290				End of borehole; solid sandstone?

On 7/8/05 a second piezometer (P7) has been placed directly downstream (east) of the pool, next to the cliff wall (Figure E-2). This piezometer will be used for both monitoring of seepage water and overland flow during periods of high pool levels. The bore hole reached relatively shallow depths (Table E-3) and the sequence of material suggest that at 70-85 cm depth lies an older surface. White spots in the material between 40 and 70 cm suggest the presence of (weathered) bedrock, which may have originated in the 1930's rock fall. The material found between the surface and 40 cm depth is possibly recent fill.

Figure E-2. Sketch showing location of piezometer P7 relative to cliff and other piezometers. The approximate north is up.

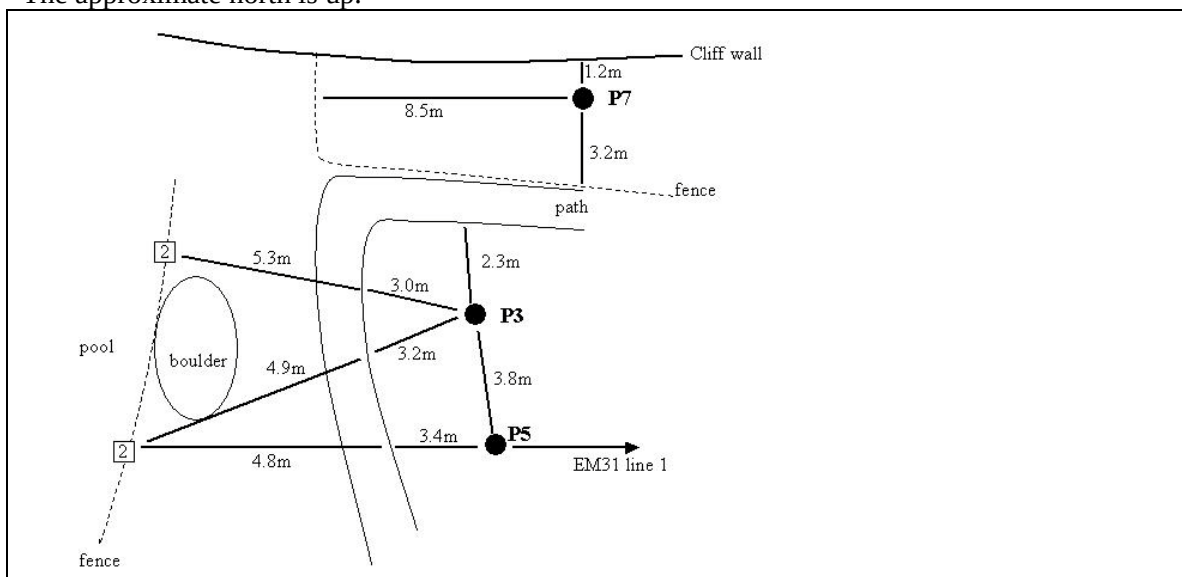


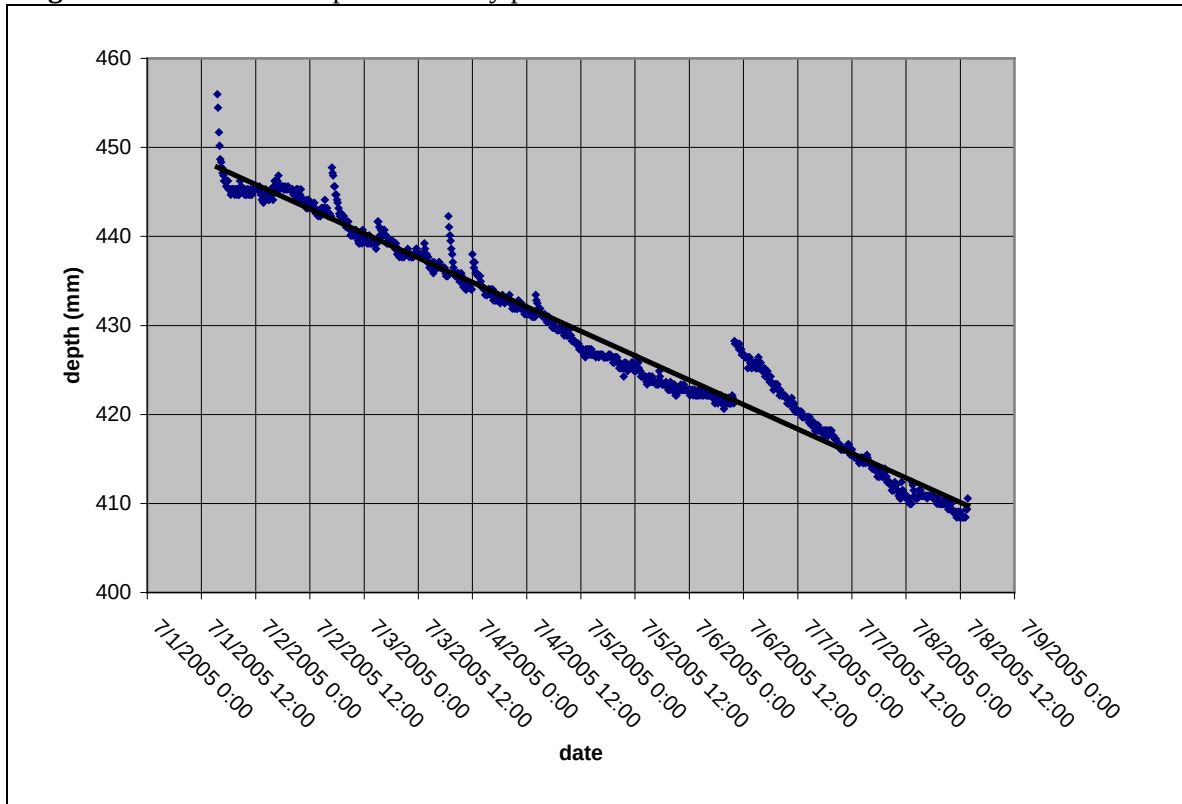
Table E-3. Soil description for piezometer P7.

Depth (cm)	Color	Grain size	Grain size sample	Remarks
0-40	lbr	FS	0-40	Dry
40-70	lbr	FS	40-70	~2% gravel Some white spots (sandstone?)
70-85	br	FS	70-85	Old soil Fresh roots ~10% Some gravel <2%
85	-	-	-	Solid rock

2. Water Level Logger

On 7/1/05 we have installed a waterlevel logger in a PVC tube at the north end of the pool. The datalogger has been attached to a fence post. We have set the initial data collection rate to one measurement every 10 minutes. This allows for ample battery life and space for data storage. These first data shows that the level logger provides accurate data (Figure E-3).

Figure E-3. Pool water depth for a 7 day period from 7/1/05 to 7/8/05



Appendix F - Field visit September 2005

The fieldwork on September 30, 2005, was used to:

1. Check piezometer water levels.
2. Download water level data from the pool monitoring device.
3. Copy logbook entries for precipitation events for July through September at the park headquarters.

1. Piezometer levels

No water was present in the piezometers near the pool (P1, P2, P3, P7) and near the NE point (P4, P6). See Appendices C and E for locations of piezometers.

2. Precipitation events

Precipitation events recorded at the visitor's center using the manual rain gauge have been assembled in Table F-1.

3. Water Level Logger

The water level records for the pool were collected; the battery was replaced. The dataset gives pool level from 7/8/2005 15:04 to 9/30/2005 17:44 (Figure F-1)

Figure F-1. Plot of pool water level (in millimeter above datum) versus time, for the period 7/12/2005 through 9/30/2005.

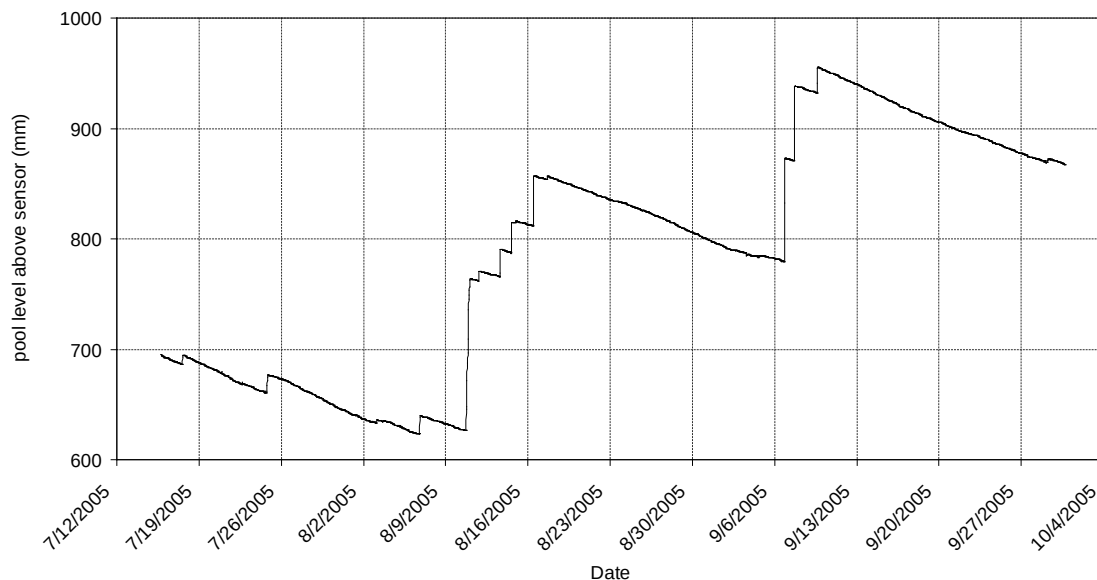


Table F-1. Date and approximate timing of rainfall events (when time of the event was unavailable, it has been substituted by a 12:00 timing) recorded at the visitors center (in inches).

Month	Date and time of event	Rainfall (inch)	Rainfall (mm)	Comments
June	6/11/2005 14:00	0.1	2.54	
	6/12/2005 12:00	0.19	4.826	
	6/24/2005 12:00	0.01	0.254	
	6/25/2005 12:00	0.03	0.762	
	6/26/2005 12:00	0.02	0.508	
July	7/8/2005 15:00	0.01	0.254	
	7/17/2005 15:00	0.15	3.81	
	7/22/2005 15:00	0.04	1.016	
	7/24/2005 15:30	0.12	3.048	
	7/25/2005 12:00	0.07	1.778	
	7/26/2005 0:00	0.07	1.778	
August	8/2/2005 15:00	0.06	1.524	
	8/3/2005 0:00	0.07	1.778	
	8/5/2005 12:00	0.05	1.27	
	8/7/2005 0:00	0.24	6.096	
	8/11/2005 0:00	0.74	18.796	
	8/11/2005 21:00	0		0 amount carried over
	8/12/2005 7:00	0		0 amount carried over
	8/12/2005 14:00	0.11	2.794	
	8/13/2005 0:00	0		0 amount carried over
	8/13/2005 14:00	0.19	4.826	
	8/14/2005 14:00	0.26	6.604	
	8/14/2005 23:30	0		0 not recorded
	8/15/2005 0:00	0		0 amount carried over
	8/15/2005 11:00	0.11	2.794	
	8/16/2005 11:00	0.21	5.334	
	8/17/2005 12:00	0.08	2.032	
	8/22/2005 12:00	0.01	0.254	
September	9/2/2005 14:00	0		0 amount carried over
	9/2/2005 18:00	0.04	1.016	
	9/3/2005 16:00	0.06	1.524	
	9/4/2005 4:00	0		0 amount carried over
	9/4/2005 15:00	0.07	1.778	
	9/5/2005 2:00	0.03	0.762	
	9/6/2005 20:00	0		0 amount carried over
	9/7/2005 0:00	0		0 amount carried over
	9/7/2005 15:30	0.73	18.542	
	9/8/2005 3:00	0.01	0.254	
	9/9/2005 15:00	0.17	4.318	
	9/28/2005 12:00	0.01	0.254	
	9/29/2005 9:00	0.14	3.556	

Appendix G - Pool water level on days with rain

Plots of pool water level (in millimeter above datum) versus time, for days with clear changes associated with rainfall events recorded at the visitor center.

The title of the plots gives the date of the dataset. The time information in the title of the plots is inaccurate and should be ignored.

