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Date: January 7, 2011

Mr. David Bustos
Biologist
White Sands National Monument

Re: Annual progress report for hydrologic investigation at White Sands National Monument

Dear David,

I have attached the 2010 annual report for the Hydrologic Investigation at White Sands National Monument. This report describes tasks that are underway or have been completed during 2010. In this report, we also discuss some of the data that we have collected and some preliminary results. Please let me know if you have any questions.

Regards,

Talon Newton
Hydrogeologist

Hydrologic Investigation at White Sands National Monument : 2010 Annual Report

Introduction

This report is an annual progress report for the Hydrologic Investigation at White Sands National Monument, which began in November 2009. The purpose of this report is to briefly describe tasks that are under way or have been completed since the project began, and to discuss preliminary findings. We are currently on schedule for accomplishing the tasks as agreed between the NMBGMR and WHSA. Table 1 shows a list of all the tasks along with the status of each task. The following sections of this report will address each individual task by describing what has been done along with preliminary results.

Table 1 List of tasks and status of each task.

Task	Status	Comments
Compilation and evaluation of existing data	completed	
Monitoring of water levels	In progress	
Vadose Zone Experiments	In progress	
Water Chemistry and age dating analyses	In progress	Amendment to original task agreement increased the number of samples collected and the typed of analyses being performed
Assesment of aquifer interactions	To begin soon	Plans to drill deep observation well(s) are being developed.
Geophysical surveys	In progress	This task was added by an amendment to the original task agreement.
Interpretation of data	In progress	
Development of Conceptual hydrologic model	In progress	
Final Report	To begin in future	

Compilation and evaluation of existing data

The first task in the task agreement between WHSA and NMBGMR was to compile hydrogeologic data that has been collected by WHSA. After receiving these data from WHSA, it appeared that this compilation of data had already mostly been done. The available water level data for existing monitoring wells was compiled into a single spreadsheet. These data include water level measurements that were collected intermittently

between 1997 and 2008 by different people. This data was discussed in more detail in an earlier quarterly report.

Monitoring of Groundwater Levels

We are monitoring groundwater levels in several monitoring wells and piezometers within the monument, most of which were installed prior to this study. However, some piezometers were installed by the NMBGMR. Several of these monitoring wells and piezometers contain data loggers that take continuous water level measurements on an hourly basis. Water levels have been measured manually by WSHA personnel on a bimonthly basis.

WSHA monitoring wells and piezometers

Locations of existing monitoring wells (MW-##) and piezometers (PZ-##) are shown in Figure 1. Monitoring wells MW-1 – MW-10, which are located within and outside the dune field, range in depth from 6 to 12 m deep and are generally screened over the entire water column. Existing Piezometers are located within the dune field and are usually less than 6 feet deep and are also screened over the entire water column.

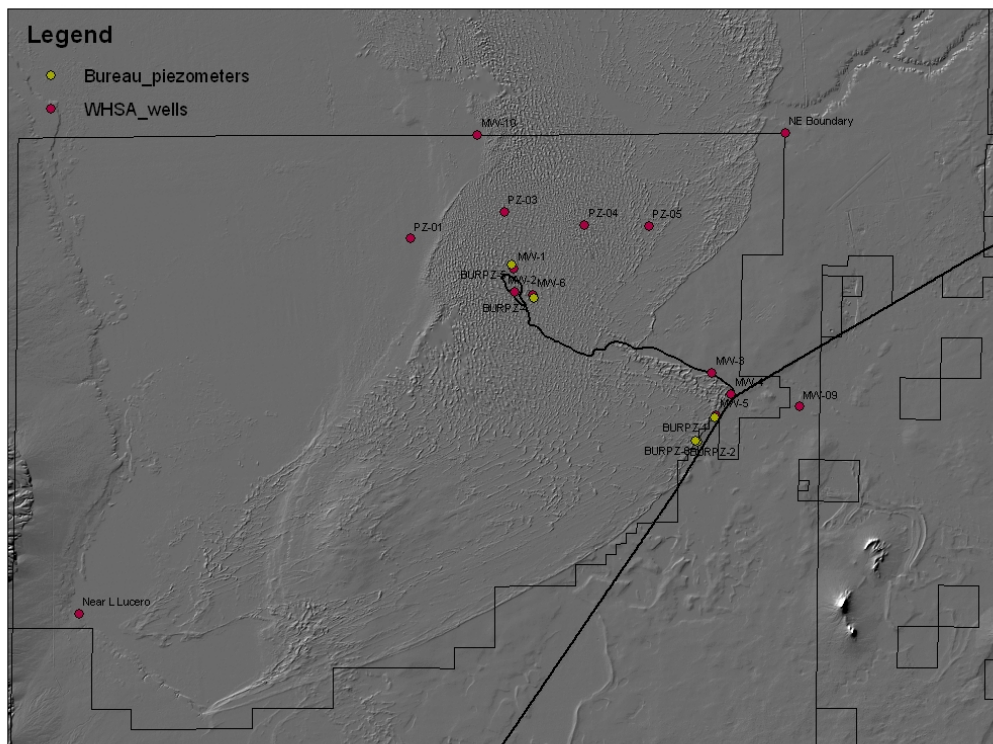


Figure 1 Location of existing and recently installed monitoring wells and piezometers

Bureau of Geology Piezometers

The NMBGMR installed six shallow piezometers in order to provide additional information about the shallow groundwater system beneath the gypsum dunes. Figure 1 shows the locations of these piezometers (BURPZ-1 – BURPZ-6). Four of the piezometers are located along the dirt road that extends south from the Administration Building along the east side of the "edge-of-the-dunes", not far from WHSA monitoring well 5 (MW-5) (Figure 1). The other two piezometers are located within the "heart-of-the-dunes" along the loop drive (Figure 1). The piezometers are screened over a relatively short depth interval, and sealed above the screened interval with bentonite (Figure 2).

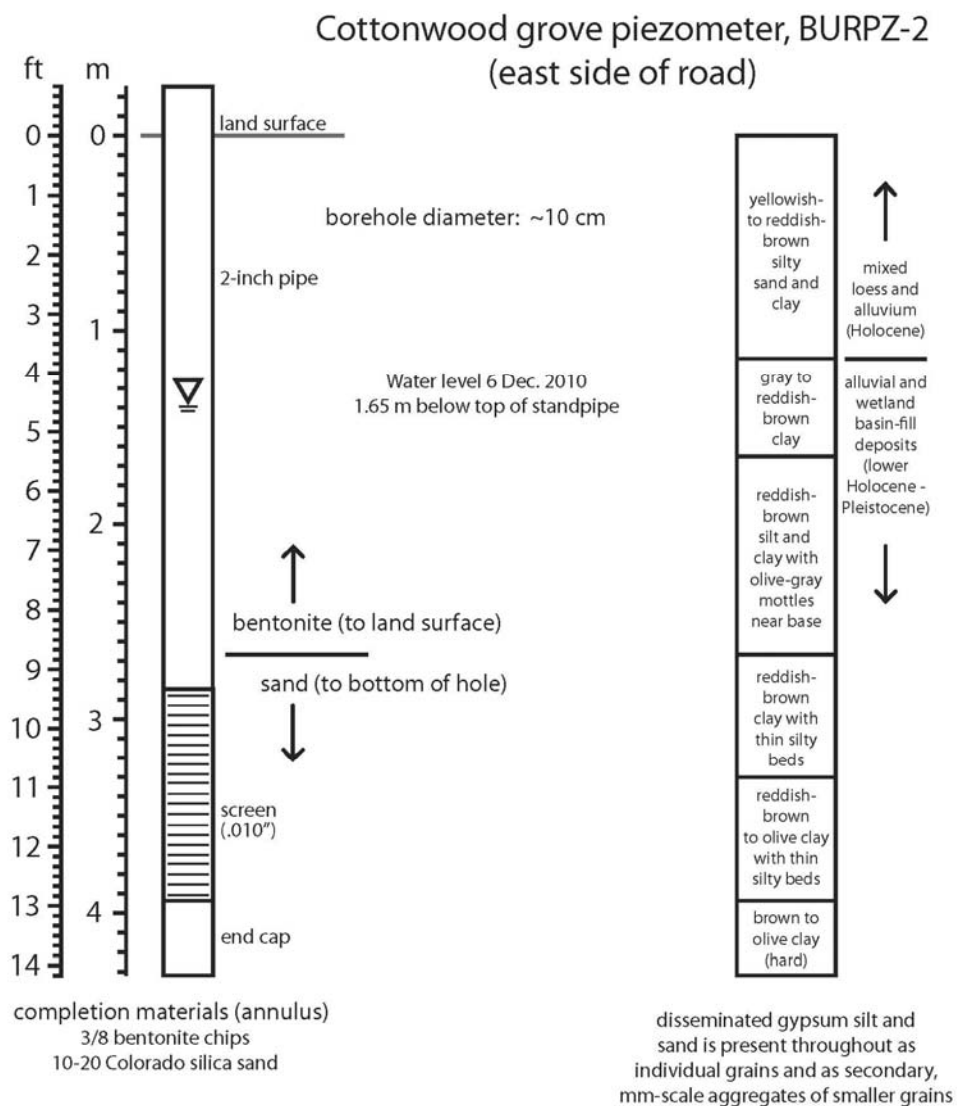


Figure 2 Well log for BURPZ-2, a shallow piezometer installed by NMBGMR

Preliminary Results

Figure 3A and B show continuous water level data. Figure 3A shows depth to water below the ground surface. Water levels in wells to the west and within the dune field are significantly shallower than those in wells located to the east of the dune field. Although precipitation data for WHSA was not readily available for the time of interest, it is apparent that water levels within the dune field do respond to individual rain events. These responses are characterized by a sharp increase in water level followed by a gradual decline. These fluctuations represent local recharge through the sand dunes. The water level in the well near Lake Lucero shows fluctuations that appear to be related to recharge in the dune field. Water levels in wells east of the dune field do not respond to individual precipitation events, but instead show gradual fluctuations that appear to be related to mountain snow melt in the Spring of 2010.

Figure 3B shows water level elevations for wells that we had accurate elevations for. Although the depth to water is deeper in wells east of the dune field, water level elevations in these wells are generally higher than those in wells within the dune field. However, piezometers installed by NMBGMR along the eastern edge of the dunes show that groundwater levels in the dunes are slightly higher than groundwater levels just east of the edge of the dunes (data not shown).

In addition to the hydrologic data these monitoring wells and piezometers provide, information about the lithology of deposits beneath the dune area is also provided. Within the dune field, it is reasonably clear that the White Sands (eolian accumulations of gypsum sand) extend, broadly speaking, to a depth of 20 to 30 feet below interdune areas, and are underlain by older siliciclastic basin-fill deposits. These older deposits beneath the sand dunes and immediately to the east of the dunes consist of a mix of interbedded alluvial, eolian, and wetland deposits, of Pleistocene and Holocene age, which create a complex hydrogeologic framework of more permeable and less permeable (confining) beds. The depth scale of vertical heterogeneity in the basin-fill aquifer system underlying the dune field apparently ranges on the order of meters or less, and is therefore quite complex. Construction of a deeper well and performance of a pumping test (future goals of this project) will be needed to clarify the degree of connectivity between deeper (depth-scale 10s of meters) "regional" aquifer(s) and the shallow groundwater system that immediately underlies the sand dunes.

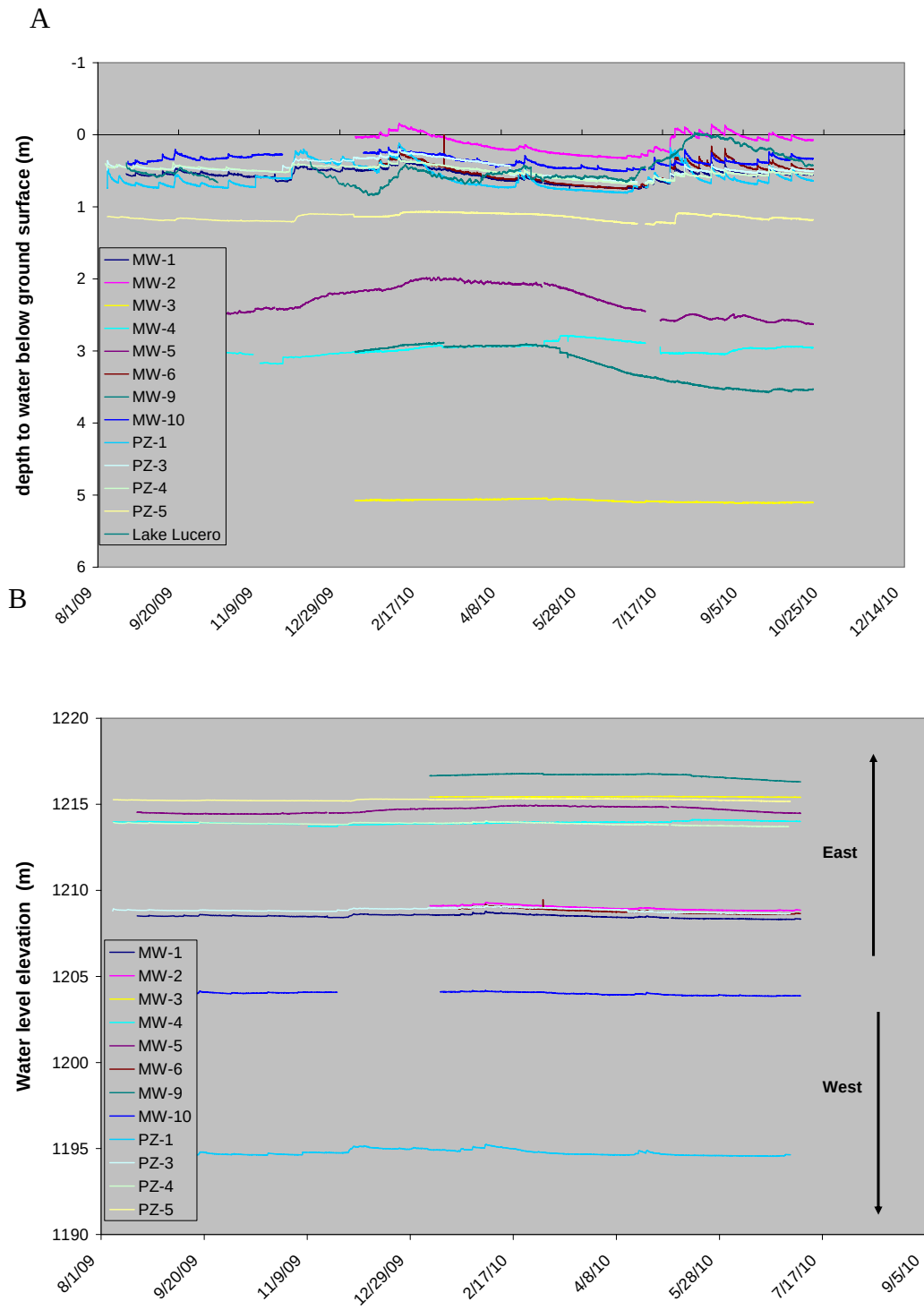


Figure 3 (A) depth to water below ground surface, (B) Water level elevation for wells and piezometers

Vadose Zone Investigation

Installation of Tensiometers

As part of the goal of assessing the sources of water that recharge the shallow aquifer within the dune field, we are conducting a vadose zone investigation to determine the significance of local precipitation contributing to groundwater recharge. For this part of the study, we are using instruments called tensiometers to measure the potential energy that causes water to flow upward in the unsaturated zone. This potential energy is usually called matric potential or soil suction, and is mainly due to capillary action, and adsorption of water to soil particles. A tensiometer is a long sealed tube containing water that is hydraulically connected to the soil by a porous cup that is buried at a known depth. Water is pulled from the tube through the porous cup into the surrounding soil until the pressure in the tensiometer equals that in the soil. This negative pressure is the matric potential. By measuring the matric potential in the sand dunes at different depths, we can determine whether pore water is moving upward or downward. The tensiometers we are using are equipped with pressure transducers that measure the matric potential on an hourly time interval.

We installed two groups of tensiometers in the dune field near MW-1. One group of three tensiometers was installed at the bottom of a dune (inter-dunal area) at the approximate depths of 0.3, 0.9, and 1.4 m below the surface. The deepest tensiometer in this group was installed under the water table. Another group of 5 tensiometers was installed at the dune crest at the approximate depths of 0.3, 0.9, 1.5, and 2.7 m below ground surface. These tensiometers require some maintenance, which is being done by NMBGMR and WHSA staff.

Preliminary Results

Tensiometer depths and matric potential data were used to calculate total head gradients at different depth intervals (Figure 4). Groundwater flows from high total head to low total head. In Figure 4, positive gradients indicate downward flow, and negative gradients indicate upward flow. For the dune crest (Figure 4A), it can be seen that in general, almost all gradients are positive, suggesting that groundwater primarily flows downward at the top of the dune. Upward gradients are observed between 0.3 and 0.9 m depth during June and early July before the beginning of the summer monsoons. The shallow hydraulic gradient increases as a response to individual rainfall events. For the inter-dunal area, the hydraulic gradients tend to plot near zero, indicating that pore water is usually not moving up or down. Again the shallow hydraulic gradient in the interdunal area indicates upward flow due to evaporation during June and early July. The hydraulic gradient between 0.9 and 1.5 m below the ground surface increases as a response to individual rainfall events.

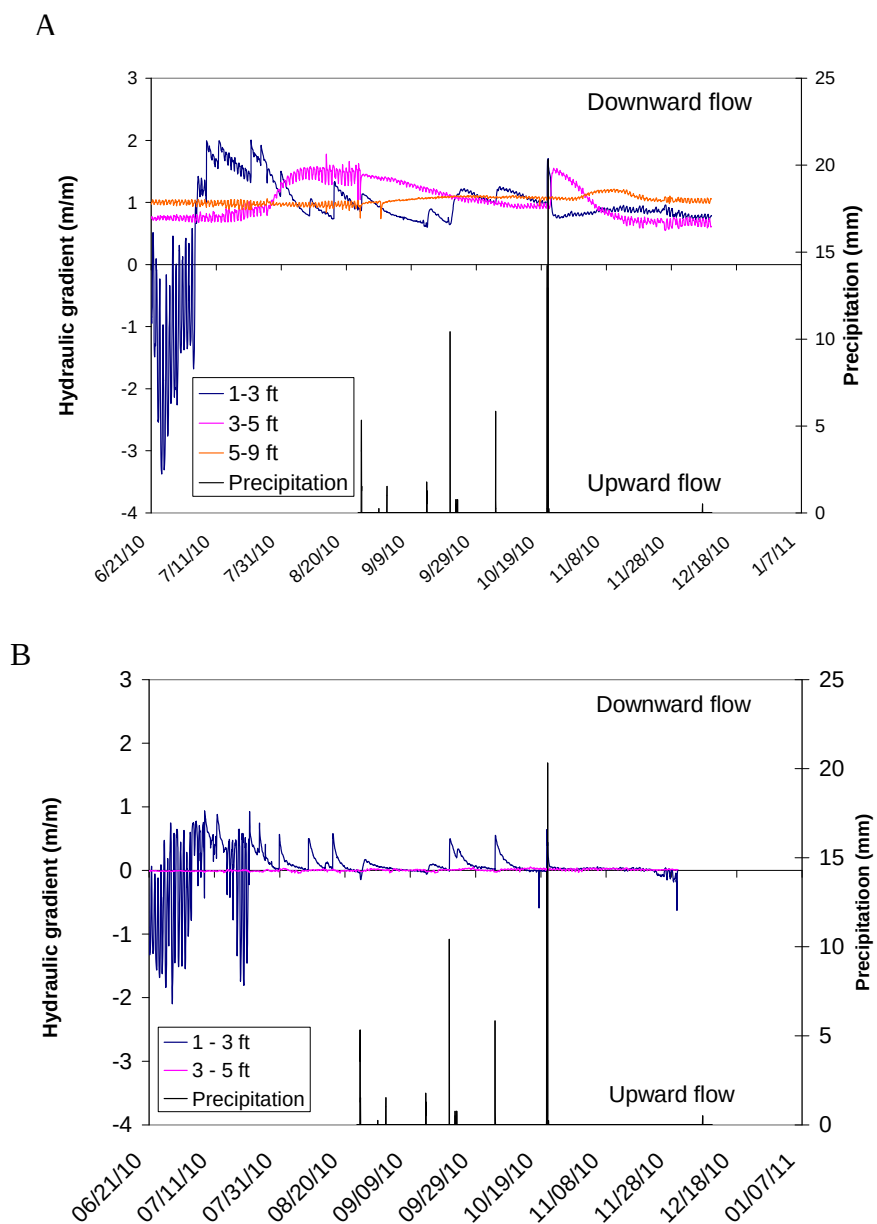


Figure 4 Hydraulic gradients for specific depth intervals determined for the dune crest (A) and the interdune (B). Negative values indicate downward flow, and positive values indicate upward flow. Precipitation data is also shown (right y-axis).

Water Chemistry and Age Dating Analyses

Sample Collection and Analyses

During 2010, we collect several samples from wells and piezometers on White Sands National Monument. These samples are undergoing a variety of analyses. General chemistry, trace metals, and the stable isotopes of hydrogen and oxygen will help to identify different water sources and to assess different physical and chemical processes that are occurring in the subsurface. Tritium, carbon-14, CFCs, and tritium-helium analyses will help to establish the age and/or residence times for the different groundwater sources. We are currently waiting for the results for most of these analyses. We will discuss the results that we have received below.

Preliminary Results

In the early part of 2010, we collected water samples from BURPZ-5, MW-1, MW-6, and MW-10, which were analyzed for general chemistry. Table 2 shows TDS values and dominant ions for these samples. Total dissolved solids (TDS) for these samples ranged from 3,687 mg/L to 10,598 mg/L. It appears that as TDS values increase, the dominant cation and anion gradually change from calcium and sulfate to sodium and chloride respectively. This trend may be due to extreme evaporation and/or the mixing of two different water sources. Interestingly, the lowest TDS sample was collected from BURPZ-5, which is installed on the top of a dune, while the highest TDS sample was collected from MW-1, which is located in an interdunal area approximately 175 m from BURPZ-5. The relatively low TDS value and the dominant ions of calcium and sulfate observed for groundwater directly beneath the dune crest, suggests that much of this water may be derived from the percolation of local precipitation through the gypsum sand, which is consistent with the observed downward hydraulic gradient observed in the same dune (see discussion about tensiometer data above).

Table 2 Total dissolved solids and dominant ions for water samples collected early 2010.

Well ID	Sample Date	TDS (mg/L)	Dominant Cation	Dominant Anion
BURPZ-5	5/21/2010	3,687	Calcium	Sulfate
MW-10	5/20/2010	4,620	Calcium	Sulfate
MW-6	1/10/2010	6,163	Sodium	Sulfate
MW-1	5/20/2010	10,598	Sodium	Chloride

During the week of December 6th, we collected water samples from 11 selected monitoring wells on White Sands National Monument. Table 3 lists the sample locations as well as the type of analyses that are being conducted for each sample.

Table 4 shows field parameters that were measured during sample collection in December. These parameters include pH, temperature, electrical conductance (EC), dissolved oxygen (DO), and oxidation reduction potential (ORP). EC values, which are generally proportional to TDS values range from 2404 $\mu\text{S/cm}$ (BURPZ-6) to 153,894 $\mu\text{S/cm}$

(Near Lake Lucero). EC measurements suggest that most water samples are brackish and water samples collected from the well near Lake Lucero and Lost River are brines. The presence of high dissolved solids in groundwater is usually due to dissolution of soluble minerals such as gypsum or halite over a long time period and/or evaporation of water which increases concentrations of highly soluble minerals. The stable isotopes of oxygen and hydrogen are useful in determining if water has undergone evaporation because water molecules made up of the lighter isotopes (H and ^{16}O) evaporate at a slightly higher rate than water molecules made up of the heavier isotopes of hydrogen and oxygen (2H and ^{18}O).

Table 3 List of wells that were samples along with the types of analyses that are being conducted. “y” indicates that the analysis is being performed, while “n” indicates that the analysis is not being performed for that particular sample.

Station	Sample Date	Gen Chem	Trace metals	Stable isotopes	Tritium	Carbon-14	CFCs	Tritium-Helium
MW-3	12/6/2010	y	y	y	y	y	y	y
MW-1	12/7/2010	y	y	y	y	y	y	y
MW-9	12/7/2010	y	y	y	y	y	y	n
BURPZ-5	12/7/2010	y	y	y	y	y	y	y
MW-10	12/8/2010	y	y	y	y	y	y	n
BURPZ-2	12/8/2010	y	y	y	y	y	y	y
BURPZ-6	12/8/2010	y	y	y	y	y	y	y
Near Lake Lucero	12/8/2010	y	y	y	y	y	y	n
Lost River	12/9/2010	y	y	y	y	n	n	n
MW-5	12/10/2010	y	y	y	y	y	y	n

Table 4 List of water samples and measured field parameters

Well ID	Date	pH	T (°C)	EC (μs/cm)	DO (mg/L)	ORP (mv)
BURPZ-6	12/8/2010	7.64	16.13	2404	3.86	116.2
MW-5	12/10/2010	7.35	18.27	3735	5.27	105
MW-3	12/6/2010	7.37	19.22	4193	3.6	116.2
BURPZ-5	12/7/2010	7.57	14.39	4538	4.17	87.8
MW-10	12/8/2010	7.69	16.07	5528	5.97	71.3
MW-9	12/7/2010	7.13	22.31	11728	0.17	-21.3
BURPZ-2	12/9/2010	7.61	18.45	12595	0.97	-110.5
MW-1	12/7/1010	7.56	15.07	12691	1.99	85.7
Lost River-1	12/9/2010	8.21	1.18	96423	7.27	54.4
NL Lucero	12/8/2010	6.73	21.11	153894	0.04	-295.1

This difference in evaporation rates results in the isotopic composition of the residual water continually becoming more enriched as evaporation is occurring. Figure 5 shows stable isotope data plotted as δD vs. $\delta^{18}O$. The data include stable isotopic compositions for all groundwater samples collected in December 2010 and 2 precipitation samples collected on the monument in 2010. The 2 precipitation samples plot very close to the global meteoric water line (GMWL). The groundwater samples are grouped by EC values where Low EC values range from 2,404 mS/cm to 5,528 mS/cm, medium EC values range from 11,728 mS/cm to 12,691 mS/cm, and high EC values range from 96,423 mS/cm to 153,894 mS/cm. MW-9 which is characterized by a medium EC value, plots on the GMWL and therefore shows no signs of having undergone evaporation. This well is located a significant distance from the dune field and therefore, probably represents regional groundwater that originated from precipitation in the Sacramento Mountains. The remaining medium EC waters and all of the low EC samples plot away from the GMWL and can be explained by some evaporation of regional groundwater and mixing with fresher local recharge from the dunes. The 2 high EC samples, Lost River and the well near Lake Lucero, plot the farthest away from the GMWL, which indicates a strong evaporative signature.

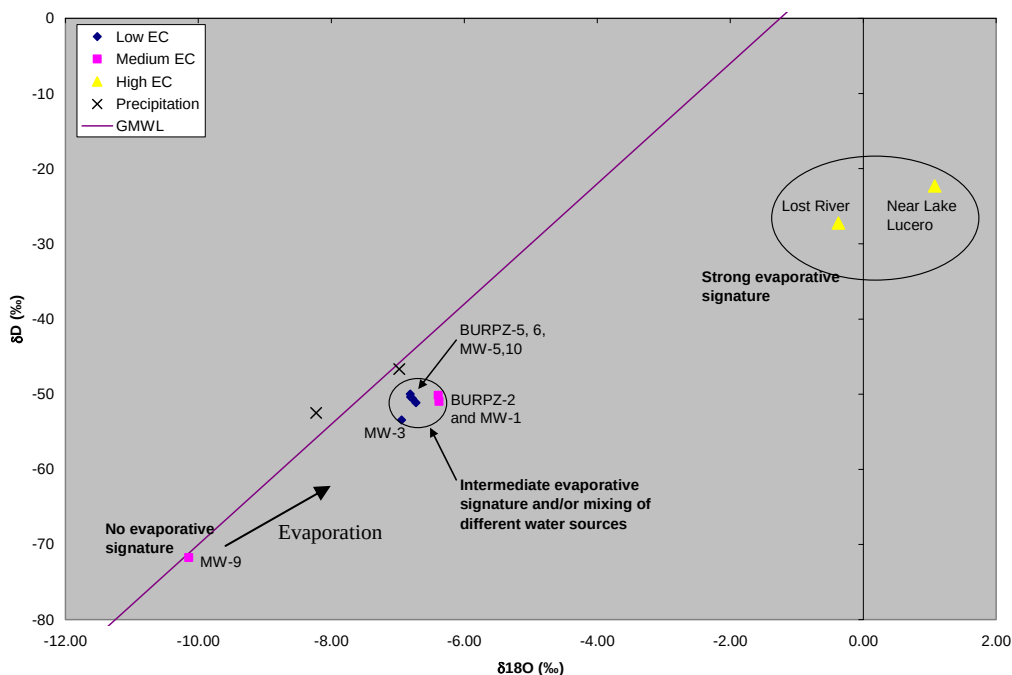


Figure 5 Stable isotopic data for groundwater and precipitation samples collected on the monument. Data are grouped by EC values. Low EC values range from 2,404 $\mu S/cm$ to 5,528 $\mu S/cm$. Medium EC values range from 11,728 $\mu S/cm$ to 12,691 $\mu S/cm$. High EC values range from 96,423 $\mu S/cm$ to 153,894 $\mu S/cm$.

Results of other chemical analyses will help to expand our interpretations and conclusions about the different water sources that contribute to the shallow aquifer beneath the dunes.

Assessment of Aquifer Interactions

The task of assessing aquifer interactions involves the installation of at least one deep well (>30 m) within the dune field (probably near MW-1) that penetrates a deeper aquifer beneath the dunes. NMBGMR staff will log this well, which greatly help us to understand the geologic relationship between the shallow and deep aquifers. In addition to the knowledge gained from the well log, we plan on conducting a pumping test where the deep well is pumped at a constant flow rate for several days. Water levels in the pumping well and adjacent shallow wells will be monitored. Pumping test data will allow us to characterize the deep aquifer and evaluate the interconnection between the two aquifers. We will begin the process of planning for the installation of the well in early and 2011.

Geophysical Surveys

Electrical Resistivity Surveys

During the week of December 6-10, 2010, science staff from the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) and National Cave and Karst Research Institute (NCKRI) conducted electrical resistivity (ER) surveys at White Sands National Monument. The purpose of these surveys was to characterize the local and sub-regional hydrology of the dune fields and adjacent areas within the Monument, and their relationship to regional hydrologic conditions in the Tularosa Basin. This report provides a brief description of the results of this work.

The basic operating principal for electrical resistivity surveys involves generating a direct current between two metal electrodes implanted in the ground, while the ground voltage is measured between two additional implanted electrodes. Given the current flow and measured voltage drop between two electrodes, the subsurface resistivity between the electrodes can be determined and mapped. Results of ER surveys are based on a computer-generated inverse model of measurements made in the field, and are referred to as the *apparent resistivity*.

Resistivity profiles detect vertical and lateral variations in resistivity in the subsurface. The presence of water or water-saturated soil or bedrock will strongly affect the results of a resistivity survey. Saltwater and brine have very low resistivity, ranging from <1 to a few tens of ohm-meters. Fresh water will show a much higher apparent resistivity, up to several thousand ohm-meters depending on dissolved solids content. Brackish water will display a spectrum of apparent resistivity values ranging from brine to pure water. Air-filled pore space in sediment above the water table will also have very high resistivity. In a relatively homogeneous system such as dune sand, the total dissolved solids (TDS) content of the groundwater in an area will be the principal factor controlling apparent resistivity. Dune sands are considered to be an exceptionally challenging environment for conducting electrical resistivity surveys, in part because of the very high contact resistance usually encountered between the electrodes and the sand. A secondary objective of this study was to determine the effectiveness of ER methods in the dune field environment at White Sands National Monument.

Preliminary Results

Resistivity surveys were conducted along 4 different transects within the monument (Figure 6). The first transect was located at the eastern edge of the dune field near the piezometers BURPZ-2, 3, and 6 and was oriented from southeast to northwest. This survey was done three times using different transect lengths and electrode spacing that allowed us to examine the apparent resistivity profile at different scales. On Monday, 12/6, we conducted a 28 electrode ER survey at 3 meter electrode spacing (Figure 7). The terrain-corrected resistivity profile shows a maximum depth of investigation of ~18 m (59 ft). A shallow zone of very low apparent resistivity on the southeast end of the profile probably results from a thin perched aquifer containing brackish water. A deeper zone of somewhat fresher water is suggested by higher resistivity values below 1204 m elevation, separated by a thin aquitard. Another pocket of fresher water is indicated by higher resistivity values in the dune area at the northwest end of the line. This high resistivity area appears to be connected with higher resistivity values further to the east, and suggests that the dunes may serve as a recharge area for the local hydrologic system southeast of the dune field. The other two surveys that were conducted in this area showed similar hydrologic features and suggested the presence of an extensive brine aquifer at greater depth beneath the perched fresher water systems within the dunes.

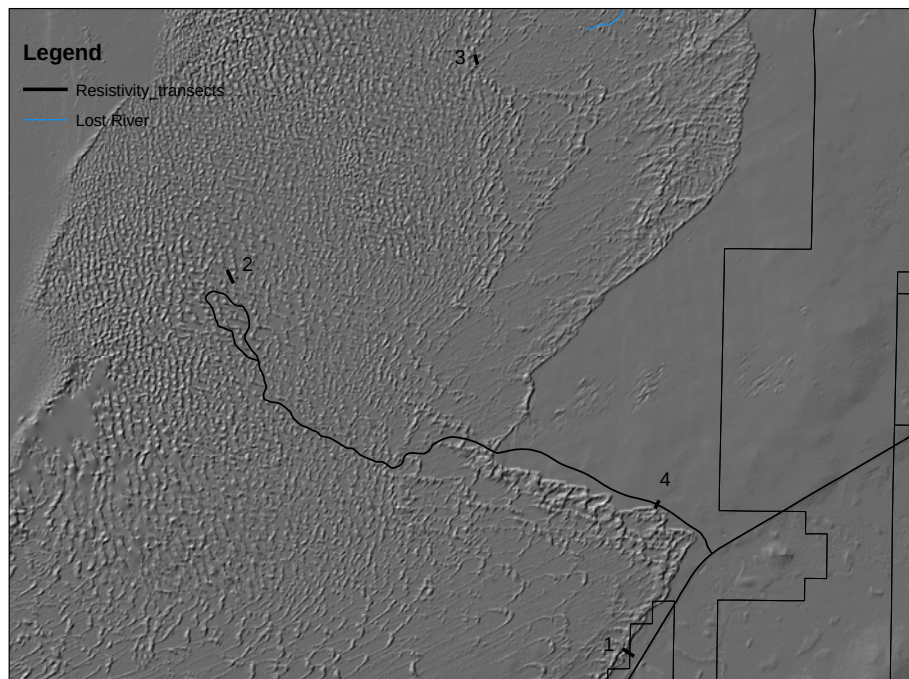


Figure 6 Locations of the 4 electrical resistivity transects.

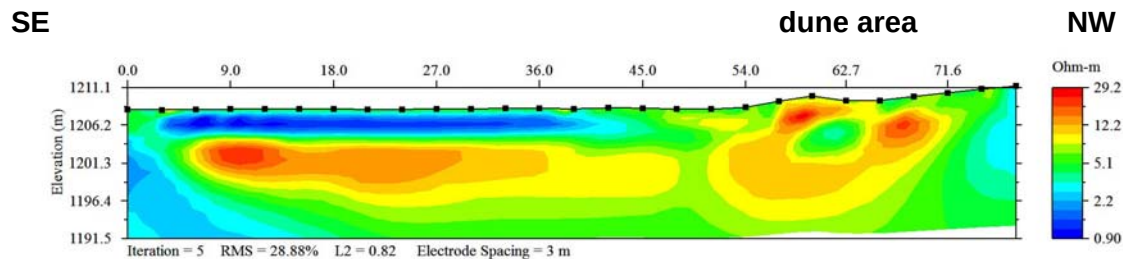


Figure 7 28 electrode SE-NW ER survey at eastern edge of dune field. Horizontal scale in this and all other figures is in meters.

On Wednesday, 12/8, we conducted a 42 electrode rollalong ER survey across the large dune in the film area (Figure 8), where NMBGMR personnel have a tensiometer, rain gage and other hydrologic equipment deployed. The rollalong method incorporates a 50% overlap and allows for longer resistivity survey lines. Using a 6 meter electrode spacing, we achieved a depth of investigation of ~32 m (105 ft). The most distinctive features of this survey are the extensive zones of low apparent resistivity beginning ~5 meters below ground level, an indication that the dunes are probably saturated with very brackish water. Small

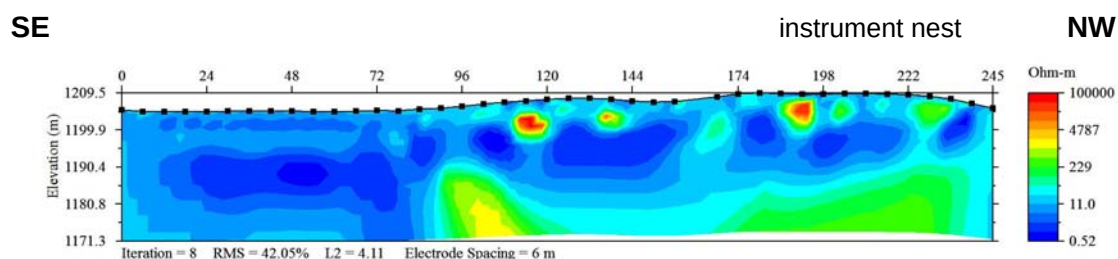


Figure 8 28 electrode ER survey across dune in film area. MW1 is located ~40 m from the southeast end of the survey line.

areas of very high resistivity, indicated by bright orange and red colors, are probably artifacts of the inversion process, and an indication of the high noise level of this data set.

On Thursday, 12/9, we transported the ER equipment to the northeast corner of the Monument, near the area where Lost River disappears beneath the dunes. We attempted to conduct a long survey of 672 meters over the projected path of Lost River. Although some of the data collected was compromised by logistical problems, we were able to recover 168 meters of the survey data (Figure 9). Using a 6 meter electrode spacing, we achieved a depth of investigation of ~36 m (118 ft). Two broad zones of very low resistivity below ~1190 m elevation probably represent brine-filled sand. A smaller zone of relatively high resistivity

below the 125 m position on the profile, ~20 m below ground level, suggests the presence of a lens of porous sand containing fresher water.

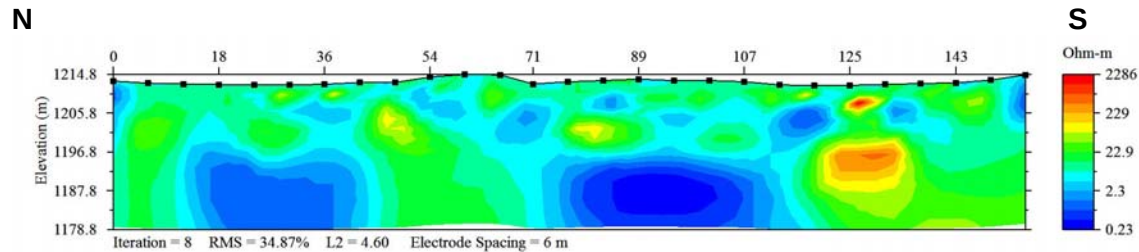


Figure 9 28 electrode ER survey over projected westward extension of Lost River. 6 meter electrode spacing.

On Friday, 12/10, we conducted a 28 electrode ER survey with 6 m electrode spacing near MW3 (Figure 10), extending across the access road into the monument and into the edge of the dune field. The shallow area of very high resistivity at the center of the profile is caused by highly compacted sediment and asphalt where the survey line crossed the road bed. A zone of relatively low resistivity ~5 m below ground level, shown in green and extending across most of the profile, probably represents a perched aquifer that is locally recharged by the nearby dunes. Underlying the perched aquifer is an extensive zone of very low resistivity ~15 m below ground level, suggesting the presence of an extensive brine aquifer at greater depth below the perched system.

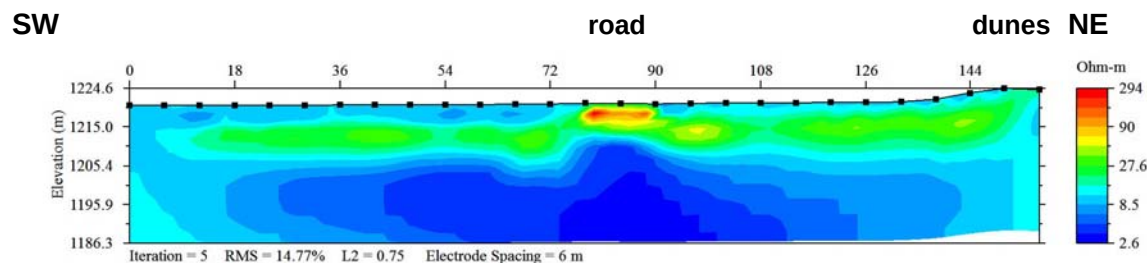


Figure 10 28 electrode ER survey, 6 m electrode spacing, near MW3.

Preliminary results of electrical resistivity surveys at White Sands National Monument clearly indicate that resistivity methods can be conducted in aeolian dune sand, in spite of very high contact resistance. Total dissolved solids content of groundwater contained within the dunes and adjacent areas appears to be the principal factor controlling apparent resistivity distribution. In most areas surveyed, shallow perched aquifers containing water of variable TDS overlie an extensive brine-filled aquifer system at greater depths (usually 15-20 m below ground level).

Preliminary Conclusions

Water level, chemistry, tensiometer, and electrical resistivity data all indicate that local precipitation percolates through the dunes to recharge the shallow aquifer beneath the dunes. Water chemistry and geophysical data suggest that much of the water present in the shallow aquifer is brackish and probably represents regional groundwater. Additional water chemistry and age dating results should help us to more conclusively identify the different sources that contribute to recharge in the shallow aquifer.

Future Work

Future work includes:

1. Collection of continuous water level data in observation wells and piezometers
2. Collection of tensiometer data
3. Interpretation of water chemistry and age dating data
4. Begin planning the installation of deep wells

For more information about the hydrologic investigation at White Sands National Monument, please contact Talon Newton at (575) 835-6668.