National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
White Sands Test Facility
P.O. Box 20
Las Cruces, NM 88004-0020

July 7, 2016

Reply to Attn of: RE-16-090

Mr. John E. Kieling, Chief
New Mexico Environment Department
Hazardous Waste Bureau
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505

Subject: Abbreviated Investigation Work Plan for the 600 Area Perched Groundwater

On February 11, 2016 NMED responded to NASA's November 25, 2015 *Additional Work Plan Requirements to Evaluate Potential Source of 600 Area Contamination* with direction to perform an additional 600 Area Site Assessment. NMED's February 11, 2016 letter included specific requirements for further characterizing the 600 Area perched groundwater zone and instructed NASA to submit an investigation work plan no later than June 30, 2016. On June 28, 2016, through verbal communication, NASA requested an extension to submit the investigation work plan no later than July 8, 2016, in which NMED approved. Enclosed is the Abbreviated Investigation Work Plan for the 600 Area Perched Groundwater. This submittal includes a paper copy of the report as Enclosure 1 and a CD-ROM with the report in PDF as Enclosure 2.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations. If you have any questions or comments concerning this submittal, please contact Antonette Sanchez of my staff at 575–524–5497.

for Timothy J. Davis
Chief, Environmental Office

2 Enclosures

cc:
Mr. Gabriel Acevedo
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505

ALBUQUERQUE
NM 870
11 JUL '16
PM 4 L

UNITED STATES POSTAL SERVICE

First-Class Mail
Postage & Fees Paid
USPS
Permit No. G-10

• Sender: Please print your name, address, and ZIP+4 in this box •

National Aeronautics and Space Administration RE-16-090

Mail Code:
Lyndon B. Johnson Space Center
White Sands Test Facility
Post Office Box 20
Las Cruces, NM 88004-0020

SENDER: *COMPLETE THIS SECTION*

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

MR. GABRIEL ACEVEDO
HAZARDOUS WAST BUREAU
NM ENVIRONMENTAL DEPARTMENT
2905 RODEO PARK DRIVE EAST, BUILDING 1
SANTA FE, NM 87505

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by *(Printed Name)* Alicia Fierro
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? *(Extra Fee)* ☐ Yes

2. Article Number
(Transfer from service lab) 7011 2970 0004 4020 2056

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

National Aeronautics and
Space Administration

Abbreviated Investigation Work Plan for 600 Area Perched Groundwater

July 2016

NM8800019434
NASA Johnson Space Center White Sands Test Facility
12600 NASA Road Las Cruces, New Mexico 88012

NASA Johnson Space Center White Sands Test Facility

Abbreviated Investigation Work Plan for 600 Area Perched Groundwater

July 2016

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

For Timothy J. Davis
Chief, NASA Environmental Office

July 7, 2016
Date

Abbreviated Investigation Work Plan for 600 Area Perched Groundwater

Primary Purpose	The National Aeronautics and Space Administration (NASA) proposes to perform a 600 Area perched groundwater (PGW) investigation at the NASA White Sands Test Facility (WSTF; Figure 1). The primary purpose of this abbreviated investigation work plan (AIWP) is to further evaluate a discrete PGW zone that exists on top of the bedrock surface below the closed 600 Area Hazardous Waste Management Unit (HWMU; Closure). PGW was first identified during the 600 Area Closure vadose zone investigation performed in December 2009 as a potential source of contamination in the vadose zone beneath and adjacent to the Closure. This investigation is designed to identify the source and migration pathway of the PGW and will include a refinement of subsurface geology at the 600 Area, including a reevaluation of relevant well log information; development of cross-sections; an attempt to expand the subsurface geophysical data, installation of additional soil borings to bedrock to confirm any leakage of wastewater from the 600 Area overflow lagoons or an up-gradient PGW source, and the potential installation of monitoring wells if PGW is located. The investigation will also further characterize the contaminants in PGW. Results of this investigation will be presented in the investigation report (IR) and used to determine whether additional investigation or remediation is necessary for PGW in the vicinity of the 600 Area Closure.
Background	Descriptions of the closed 600 Area HWMU, history of use and closure, surface and subsurface conditions, and the nature and source of any vadose zone or groundwater contamination have been presented to the New Mexico Environment Department (NMED) in several reports. These include the 600 Area Closure Investigation Work Plan (NASA, 2009), the 600 Area Closure Investigation Report (NASA, 2010), the revised 600 Area Closure Investigation Report (NASA, 2011), and the 600 Area Soil Vapor Extraction Pilot Test Investigation Report (NASA, 2012a). PGW was located on the top of poorly fractured to non-fractured andesite bedrock reached while installing soil borings during the 600 Area Closure investigation in 2009. Although subsurface investigation of the Closure was initiated in the late 1980s, the 2009 investigation incorporated the first use of air-rotary casing hammer (ARCH) drilling to the bedrock surface without the use of drilling fluids. This method was employed for the installation of multiport soil vapor monitoring wells to better characterize the vadose zone (NASA, 2010). PGW was encountered at the top of the bedrock surface in two soil borings installed adjacent to the north and east corners of the Closure (that were subsequently converted into two soil gas wells [SGW] wells [600-SGW-8 and 600-SGW-5]; NASA, 2010, 2011). PGW was later identified at two other locations installed using the ARCH drilling method; conventional groundwater well 600-G-138 installed to monitor the PGW identified at 600-SGW-5, and soil vapor extraction (SVE) well 600-SVE-1 installed to support a vadose zone SVE test below the 600 Area Closure (NASA, 2012a). At the time, PGW groundwater ranged in thickness from 2 to 4 feet (ft; Table 1). Since the PGW zone was identified, geophysical techniques have been utilized as a tool for the detailed evaluation of the bedrock surface in the 200 and 600 Areas (NASA, 2013). NMED has also identified geophysics as a potential method of investigation (NMED, 2016). A limited amount of geophysical data has been previously collected along a line located adjacent to and northeast of the 600 Area Closure, but this data proved difficult to

	interpret due to the effect of moisture in this area on seismic reflection lines (NASA, 2013). It was inferred that the conductive nature of the formation was due to potential leaking from the adjacent 600 Area overflow lagoons. Two low resistivity zones were observed along the geophysical line, which correlated with the placement of the two individual lagoon cells. Geologically relevant features could not be discerned. The PGW zone is inferred to be derived from two sources. The first source is mounding of the fractured bedrock aquifer at the hydrostratigraphic boundary between bedded limestone (east) and poorly fractured andesite (west) along the regional Hardscrabble Hill Fault (HHF) located upgradient and northeast of the 600 Area Closure (Figure 2). Recharge from Gardner Spring Arroyo (GSA) in the 200 Area could account for concentrations of trichloroethene (TCE) in PGW that are comparable to those in groundwater within the 200 Area. Slightly lower concentrations in PGW at 600 Area Closure well 600-G-138 compared to upgradient wells in the 200-D well cluster area could result from the effects of dilution. The second source of PGW is believed to consist of leakage from the 600 Area overflow lagoons. Nitrate concentrations in groundwater samples collected from PGW in monitoring well 600-G-138 are relatively high compared to most of the WSTF groundwater contaminant plume, indicating a source other than the fractured bedrock aquifer. The poorly fractured to non-fractured andesite bedrock lithologic unit associated with the PGW below the 600 Area HWMU is characterized by relatively low hydraulic conductivity based on lithological and hydrogeological information derived from the installation of 22 groundwater and soil vapor monitoring wells installed to bedrock in the vicinity of the 600 Area Closure (Table 1).
Site Conceptual Model	The 600 Area incorporates a large, mostly underdeveloped portion of WSTF that extends west for approximately three miles from the WSTF 100 Area (Figure 2). The 600 Area contains elements of the site's utility distribution system and associated support buildings. The 600 Area Closure is located on the east side of the 600 Area adjacent to the WSTF 100 Area, and comprises an engineered impermeable cap covering two historical hazardous waste impoundments that were clean-closed in the late 1980s (NASA, 2009). Figure 2 and Figure 3, which identify three geologic cross sections (lines A-A', B-B', and C-C') within the vicinity of the 600 Area Closure, were developed for this investigation following a review of the available borehole data (Table 1). Figure 3 includes the bedrock contours defined using available bedrock elevations from existing soil borings and boreholes. The bedrock was contoured using empirical Bayesian kriging in ArcGIS®[1] for Desktop 10.3. Figure 4 (cross-section A – A'), Figure 5 (cross-section B – B'), and Figure 6 (cross-section C – C') provide cross-sections that depict the site conceptual model. The subsurface beneath the Closure consists of approximately 140 to 150 ft of Quaternary to Tertiary heterogeneous alluvial fan deposits (increasing in thickness to the west as the bedrock pediment surface declines in elevation). The alluvium overlies poorly fractured andesite bedrock that has been penetrated by up to 880 ft below the ground surface (well 600-D; Figure 2). The andesite bedrock surface is indurated, shows minimal alteration, and is characterized by subtle undulations with bedrock highs and lows identified based upon bedrock interception depths recorded during borehole installation. To the northeast of the Closure, the regional HHF juxtaposes Tertiary andesite bedrock to the southwest against bedded Paleozoic limestones to the northeast that characterize bedrock in the 200 Area

[1] ARCGIS is a registered trademark of Environmental Systems Research Institute, Inc.

	(Figure 2). No other significant faults have been identified to date in the immediate vicinity of the 600 Area Closure. Data from conventional and multiport groundwater monitoring wells at the 600 Area Closure indicate that the regional groundwater aquifer resides in the andesite bedrock beneath the closure at depths ranging from 170 to 220 ft bgs and flows from east to west under the influence of a strong hydraulic gradient of approximately 0.05 ft/ft (Figure 4). Monitoring wells in the andesite are characterized by low recovery rates and dry holes, which are not uncommon within this poorly fractured unit. Seasonal recharge that contributes to the PGW is most significant during the North American Monsoon System season defined as June 15 through September 30 (National Weather Service, n.d.), although the WSTF area has received relatively low annual rainfall for several years. The 600 Area overflow lagoons that are also inferred to contribute to the PGW (Figure 2) are currently in the process of being evacuated and closed in accordance with the *Wastewater Lagoon Areas Closure Investigation Work Plan* (IWP; NASA, 2012b). Consequently, conditions in the area are currently subject to a changing hydrogeological environment. Complete evacuation of the sewage lagoons is anticipated by September 2016. Dewatering of the 600 Area overflow lagoons is expected to affect the thickness and potentially the existence of the PGW zone. This AIWP includes a brief discussion of PGW monitoring strategies that NASA intends to use in order to monitor the behavior of the PGW zone over time.
Hydrogeologic and Geochemical Objectives	The hydrogeologic objectives for this investigation are to: (1) refine the conceptual model of the bedrock surface within the vicinity of the 600 Area Closure; (2) identify the nature and distribution of PGW zone; (3) determine PGW migration pathways, and, (4) monitor the behavior of the PGW zone over time. NASA will also evaluate the feasibility of remediation of the PGW based on the results of this AIWP. This will be accomplished by several means: • Evaluating well log information from previous investigations in the 600 Area (completed as part of this AIWP [Table 1]); • Conducting a supplemental geophysical survey of the 600 Area bedrock surface to support the proposed soil boring locations; • Utilizing soil boring and monitoring well installation data obtained from the fieldwork investigation to refine and enhance the conceptual model presented in this AIWP; and, • Monitoring the PGW zone (where identified) over time. Table 1 lists the historical wells in the vicinity of the 600 Area Closure where PGW has been identified and includes drilling, installation, and hydrogeological data that was reviewed as part of the development of this AIWP. This review included available well files, lithologic cuttings, and borehole geophysical data where available. The geochemical objectives are to sample and further characterize the nature and distribution of the PGW, to develop the conceptual model and define a source(s) as best possible. Soil borings will be strategically located to investigate inferred bedrock depressions. Any soil borings that intercept the PGW zone will be converted to conventional groundwater monitoring wells that will be used to monitor the behavior of the PGW over time.

Geophysical Study	In order to support evaluation of the feasibility of a supplemental geophysical investigation, NASA retained the services of a geophysical consultant (Dr. Marianne Karplus from the University of Texas at El Paso). Dr. Karplus reviewed existing 600 Area Closure data, inspected the investigation site, and submitted a consultation report (Appendix A). The report concludes that seismic refraction and seismic reflection have the greatest probability of success with respect to resolving the imaging of up to 10 ft changes in bedrock at a depth of 135 to 180 ft below surface. It is believed that a dense geophysical survey directly over the 600 Area Closure may be helpful in remotely constraining the bedrock topography. Following a review of the results of a geophysical survey, soil boring locations presented in this AIWP will be refined where necessary in order to improve the probability of PGW identification. A map showing the revised soil boring locations will be submitted to NMED for final approval prior to the commencement of fieldwork. It is recommended that this geophysical survey be performed following evacuation of the 600 Area overflow lagoons (anticipated for late 2016), and when potential groundwater recharge is at an annual low (outside of the Monsoon System season).
Drilling Approach	The drilling objective is to advance soil borings to the bedrock surface at locations most likely to intercept PGW. Table 2 presents a summary of the planned PGW well locations, the anticipated bedrock lithology, and the anticipated bedrock/soil boring depths. NASA follows established internal procedures for safely installing quality boreholes. In order to best facilitate accurate identification of the PGW zone, drilling will be performed without the use of drilling fluids. Using the ARCH drilling method, which proved successful during the 600 Area Closure investigation (NASA, 2011) and the 200 Area Phase II Investigation (NASA, 2015b), a 9 5/8-inch (in.) diameter outer drive casing will be advanced behind the drill bit to prevent borehole collapse. Compressed air will be used to clean the boring of cuttings during bit advancement, and small amounts of non-chlorinated water may be added to the cyclone discharge at the surface when required for dust suppression. In the event that a borehole installation is unsuccessful (i.e., difficult drilling conditions), NASA may choose to install a twin boring located adjacent to the original site. The ARCH drilling method is most attractive because it precludes the use of any drilling fluids other than air, maximizing the potential for PGW identification during drilling and eliminating the need to purge drilling fluids from the well screen during monitoring well development. All drilling equipment and associated downhole tools and rigging will be decontaminated with a heated high pressure wash prior to arrival at WSTF. Before mobilization to the first soil boring and between individual soil boring locations, equipment will similarly be decontaminated on a pad located in the WSTF 600 Area. Activities and observations made during the installation of all boreholes will be recorded in the field logbooks and on the borehole lithologic logs. Lithologic sampling will be performed during the soil boring installation. Drill cuttings will be collected from the cyclone discharge on the drilling rig at 10-ft intervals. The lithology of the drill cuttings will be recorded by the field geologist on lithologic log forms along with other pertinent drilling information which will be submitted with the IR. Lithologic samples will include a sample of the uppermost bedrock surface unless drilling conditions preclude advancement of the soil boring to this depth.

Proposed Soil Boring Locations	NASA proposes the installation of six new exploratory PGW soil borings; 600-PGW-1 through 600-PGW-6. The location of each soil boring correspond to an area where perched water has been previously identified, or is inferred based on the review of hydrogeological information. Conventional PGW monitoring well 600-G-138 has already been installed adjacent to soil gas well 600-SGW-5 (where PGW was first identified), and provides the location for ongoing PGW extraction and remediation. Soil vapor extraction test well 600-SVE-1 is also located in the vicinity of this relatively low bedrock elevation and encountered PGW during installation. The six PGW soil borings are proposed at inferred low bedrock elevation areas located in the vicinity of the 600 Area Closure (Figure 2; Figure 3). Soil boring 600-PGW-1 is based on cross-section A-A' (Figure 4) and is located to evaluate the upgradient origin of PGW. Three soil borings are proposed below the Closure at probable PGW locations. Soil boring 600-PGW-2 is located within the identified PGW adjacent to well 600-SGW-8 (cross-section B-B'; Figure 5). Soil borings 600-PGW-3 and 600-PGW-4 are identified on cross-section C-C' (Figure 6). Two soil borings are proposed at downgradient locations 600-PGW-5 and 600-PGW-6 to evaluate subsequent downgradient movement of the PGW (cross-section C-C'; Figure 6). Based on the results of the geophysical survey, soil boring locations will be refined where necessary in order to improve the probability of PGW identification. A map showing the revised soil boring locations will be submitted to NMED for final approval prior to the commencement of drilling fieldwork.
Perched Groundwater Detection	Following the interception of bedrock within a soil boring, drilling will be advanced to approximately 2 ft below the bedrock surface. Once the downhole drilling equipment is removed from the borehole, groundwater detection and sampling equipment (including a downhole camera, a water level detector, and a disposable groundwater sampling bailer) will be used to investigate for the presence of PGW and sample where feasible. Each soil boring will be allowed to equilibrate overnight to allow sufficient time for groundwater recovery and ensure an accurate measurement of PGW thickness. As a guideline, PGW monitoring and extraction activities performed at well 600-G-138 indicate that at current hydrogeologic conditions the PGW zone at this location recovers in approximately 8 to 10 hours. If the presence of PGW is identified in any of the soil borings, the location will be completed as a conventional PGW well and monitored in accordance with a groundwater monitoring plan provided within the IR. If applicable, this monitoring plan may include the deployment of water level transducers to monitor the behavior of the PGW over time. Transducers may be able to correlate subtle changes in the 600 Area PGW thickness to the effects of mountain front recharge events that subsequently replenish groundwater to the 200 and 600 Areas along GSA.
Monitoring Well Completion	Monitoring wells will be completed within the soil borings where PGW is positively identified. NASA will use the NMED-approved 600-G-138 well completion design for wells proposed in this AIWP (Figure 7; NMED, 2012). NASA will follow the installation guidelines stated in NMED Permit Attachment 19 (NMED, 2009a) or any modified version of those requirements with NMED approval. Wells will be constructed using nominal 4-in. Schedule 80 PVC with 10 ft of 0.020-in. slotted screen. Well 600-G-138 was specifically designed to allow perched water to flow into the well screen at the bedrock surface and

	drain from the screen through a ¼-in. diameter weep hole to preclude the retention of any stagnant water during dry periods. For well completion purposes, well screens will be packed with 10/20 silica sand and the top of the sampling zone sealed with a bentonite plug. Although a sealed bottom plug was not required in well 600-G-138, it will be retained as an option for the PGW wells to isolate the perched water zone from the underlying aquifer. The annular space remaining above the bentonite seal will be backfilled with a mix of cement and 5% bentonite and lifted in stages so the heat generated during curing will not compromise the integrity of the PVC casing.
Well Development	NASA intends to use bailing and pumping to develop PGW wells during this investigation. Alternatively, a combination of different methods listed in Permit Attachment 19, Monitoring Well Construction Requirements, or methods otherwise approved by NMED may be used (NMED, 2009). The type of development performed will be influenced by the PGW recovery rate established for each individual well.
Groundwater Screening and Characterization Sampling	PGW characterization sampling will be performed following monitoring well installation, completion, and well development activities. Following monitoring well development and stabilization, PGW samples will be collected, managed, and shipped to a National Environmental Laboratory Accreditation Program certified laboratory for analysis. Groundwater quality parameters will be collected and recorded where feasible at the same time as each sampling event. The analytical methods will be determined from the list of previously identified 600 Area contaminants of concern (COCs). NASA will follow its established internal procedures for safely collecting quality PGW samples for analysis. Table 3 lists the COCs for the 600 Area and the analytical methods used for detection.
Tracer Test	Groundwater tracers are widely used to determine the direction and velocity of groundwater movement. A tracer test may be particularly applicable to this investigation due to the high porosity alluvium above the bedrock and relatively steep gradient of the bedrock surface. An appropriate fluorescent tracer will be chosen to support the investigation of PGW pathways and velocity. This tracer will be released directly from the most upgradient PGW well (potentially soil boring 600-PGW-1), or the next most proximal well with confirmed PGW (for example well 600-G-138). Monitoring for the tracer will be performed in receptor wells that include the other PGW wells screened at the bedrock surface (to track lateral movement through alluvium), and within selected monitoring wells screened in the regional aquifer below PGW (to monitor any potential vertical movement through fractured rock). A plan for the tracer test monitoring will be outlined based on the results of the AIWP fieldwork and included within the IR for NMED's approval prior to implementation.
Investigation-Derived Waste and Waste Characterization	This section provides a discussion of investigation-derived waste (IDW) in accordance with the WSTF Hazardous Waste Permit, Attachment 20, Section 20.2.13 (NMED, 2009). Potential IDW anticipated during this project include: • Unsaturated and saturated drill cuttings generated during soil boring drilling and logging process. • Contact waste including used sampling equipment, personal protective equipment, plastic sheeting, and other debris that has contacted soil or fluids.

	• Decontamination fluids (i.e., water and soap solutions used to wash and decontaminate equipment). • Groundwater produced during well development and sampling activities. **Waste Characterization, Management, and Disposal** <u>Drill Cuttings – unsaturated</u> No evidence of hazardous constituents exceeding regulatory limits was found in unsaturated drill cuttings (environmental media) during a previous investigation of the vadose zone at the 600 Area Closure (NASA, 2011). Analytical results from the previous investigation indicated that this type of environmental media did not meet the listing description of a listed hazardous waste incorporating the "contained-in" policy per 40 CFR Part 261 Subpart C, did not exhibit the characteristic of a hazardous waste per 40 CFR Part 261 Subpart D, and did not contain hazardous constituents at concentrations that exceeded the 40 CFR 268.40 Treatment Standard limits (NASA, 2011). Results from the previous investigation also indicated that this environmental media did not contain constituents at concentrations that exceeded New Mexico Soil Screening Levels (NMED, 2015) for industrial/ occupational soil. This media also did not meet the definition of New Mexico Special Waste. NASA requested and the NMED approved a "no longer contained in" determination (NLCID) for drill cuttings generated during the previous 600 Area Closure investigation, and NMED authorized IDW from the 600 Area Closure to be managed as non-hazardous waste (NMED, 2009b). Given the available data from the previous investigation (NASA, 2011) and prior NMED guidance (NMED, 2009b), unsaturated drill cuttings generated during this project will be managed as a solid waste (20.9 NMAC). NASA will collect and analyze samples of this environmental media to verify applicable standards are met. This data will be provided to the NMED with a request for land application of the unsaturated cuttings. If NMED approval for land application is not obtained, the waste will be disposed of at a Subtitle D landfill. In the event sampling results indicate applicable standards are not met, the waste will be managed as hazardous waste in accordance with WSTF waste management procedures that incorporate 40 CFR Part 262.34 (NASA, 2015a) and properly disposed of at a permitted RCRA Treatment, Storage, and Disposal Facility in accordance with all applicable regulations. <u>Drill Cuttings - saturated</u> Results from ongoing groundwater monitoring at and near the 600 Area Closure indicate that saturated cuttings (environmental media) extracted from zones with perched water or below the water table may contain hazardous constituents at concentrations exceeding regulatory limits. Specifically, this type of environmental media may meet the listing description of a listed hazardous waste incorporating the contained in policy per 40 CFR Part 261 Subpart C, carrying EPA Waste Codes F001 and F002 (Constituents of Concern: trichloroethylene, tetrachloroethylene, trichloromonofluoromethane, and 1,1,2-trichloro-1,2,2-trifluoroethane). Based on previous investigation results (NASA, 2011), there is no evidence to suggest that the environmental media will exhibit characteristics of a hazardous waste per 40 CFR Part

	261 Subpart D. Therefore, upon generation, this environmental media will be managed as hazardous waste carrying EPA Waste Codes F001 and F002 in accordance with WSTF waste management procedures that incorporate 40 CFR Part 262.34 (NASA, 2015a). NASA will perform sampling and analysis of the waste during or after generation, and if results are favorable, submit the results to NMED in conjunction with a NLCID and land application request. Based on interpretive EPA regulatory guidance (USEPA, 1998), NASA's request will also indicate that the environmental media does not exhibit the characteristics of a hazardous waste per 40 CFR Part 261 Subpart D, does not contain hazardous constituents at concentrations that exceed the 40 CFR Part 268.40 Treatment Standard limits, and the environmental media does not contain constituents at concentrations that exceed the New Mexico Soil Screening levels for Industrial/Occupational Soil (NMED, 2015). If NMED approval for land application is not obtained, the waste will be disposed of at a Subtitle D landfill. In the event sampling results indicate applicable standards for a NLCID are not met, the waste will be properly disposed of at a permitted RCRA Treatment, Storage, and Disposal Facility in accordance with all applicable regulations. <u>Contact Waste</u> Contact waste IDW generated during drilling activities that occur above the water table will be managed as solid waste (20.9 NMAC). All contact waste IDW generated during drilling and sampling activities at perched water zones or below the water table will be managed as listed hazardous waste carrying EPA Waste Codes F001 and F002. The waste will be managed in accordance with WSTF waste management procedures that incorporate 40 CFR Part 262.34 (NASA, 2015a). NASA may include this waste stream in the NLCID request, if appropriate, or properly dispose of this waste of at a permitted RCRA Treatment, Storage, and Disposal Facility in accordance with all applicable regulations. <u>Decontamination Fluids</u> Any decontamination fluid IDW generated from drilling activities above the water table will be managed as solid waste (20.9 NMAC). Decontamination fluid IDW generated from drilling and sampling activities at perched water zones or below the water table will be managed as listed hazardous waste carrying EPA Waste Codes F001 and F002. This waste will be managed in accordance with WSTF waste management procedures that incorporate 40 CFR Part 262.34 (NASA, 2015a). Decontamination fluids generated during the investigation will be treated at the WSTF Mid-plume Interception Treatment System. If that system is not capable of receiving the waste, it will be disposed of at a permitted RCRA Treatment, Storage, and Disposal Facility in accordance with all applicable regulations. <u>Groundwater</u> All groundwater IDW generated during well development and sampling activities will be managed as listed hazardous waste carrying EPA Waste Codes F001 and F002 in accordance with WSTF waste management procedures that incorporate 40 CFR Part 262.34 (NASA, 2015a). Potentially contaminated groundwater IDW generated during the investigation will be treated at the WSTF Mid-plume Interception Treatment System. If that system is not capable of receiving the waste, it will be disposed of at a permitted

	RCRA Treatment, Storage, and Disposal Facility in accordance with all applicable regulations.
Schedule	• NMED approval of PGW AIWP • Following NMED approval: o Complete procurement process for geophysical and drilling contractors. o Project preparation, staffing, and scheduling. o Geophysical survey and evaluation performed in March 2017 following 600 Area overflow lagoon evacuation and the Monsoon System season to maximize the quality of imaging – 60 days. o Soil boring installation, well installation, development, and initial sampling – 30 days. o Laboratory analysis and IR development – 60 days. o PGW IR submittal to NMED – 150 days following implementation of the geophysical field survey.
References	National Weather Service. (n.d.). *Reports to the Nation on Our Changing Planet – The North American Monsoon*. Retrieved from http://www.cpc.noaa.gov/products/outreach/Report-to-the-Nation-Monsoon_aug04.pdf NASA Johnson Space Center White Sands Test Facility, (2009, April 17). *NASA Response to NMED 03/19/09 Comments on the 600 Area Closure Investigation Work Plan HWB-NASA-08-007*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2010, August 30). *NASA White Sands Test Facility (WSTF) 600 Area Closure Investigation Report*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2011, March 30). *NASA White Sands Test Facility (WSTF) Revised 600 Area Closure Investigation Report*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2012a, September 13). *Response to NMED Disapproval - 600 Area Soil Vapor Extraction Pilot Test Investigation Report*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2012b, October 15). *Wastewater Lagoon Areas Closure Investigation Work Plan and Wastewater Lagoon Areas Historical Information Summary*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2013, August 6). *200 Area Investigations - Revised Phase I Status Report*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2015a, February 17). *White Sands Test Facility Standard Instruction – Waste Management*. Las Cruces, NM. NASA Johnson Space Center White Sands Test Facility. (2015b, June 29). *NASA WSTF 200 Area Phase II Investigation Report*. Las Cruces, NM.

	NMED Hazardous Waste Bureau. (2009a). *Hazardous Waste Permit EPA ID No. NM8800019434 to United States National Aeronautics and Space Administration for the White Sands Test Facility Located in Doña Ana County, New Mexico*. Santa Fe, NM. NMED Hazardous Waste Bureau (2009b, December 16). *Approval of "Contained-In" Determination Request NASA-JSC WSTF 600 Area Closure Investigation.* Santa Fe, NM. NMED Hazardous Waste Bureau. (2012, September 28). *Approval 600 Area Soil Vapor Extraction Pilot Test Investigation Report*. Santa Fe, NM. NMED Hazardous Waste Bureau. (2015, July). *Risk Assessment Guidance for Site Investigations and Remediation.* Santa Fe, NM. NMED Hazardous Waste Bureau. (2016, February 11). *Additional Work Plan Requirement to Evaluate Potential Source of 600 Area Contamination*. Santa Fe, NM. Solid Waste, New Mexico Environmental Improvement Board, 20.9 NMAC (08-02-07). United States Environmental Protection Agency (1998, August 21). *Effects of Land Disposal Restrictions Phase IV Treatment Standards on Manufactured Gas Plant Site Cleanups*. Retrieved from https://yosemite.epa.gov/osw/rcra.nsf/ea6e50dc6214725285256bf00063269d/83d803abfff0c617852568e3004683c1

.

Figures

Figure 1 **WSTF Location Map**

(SEE NEXT PAGE)

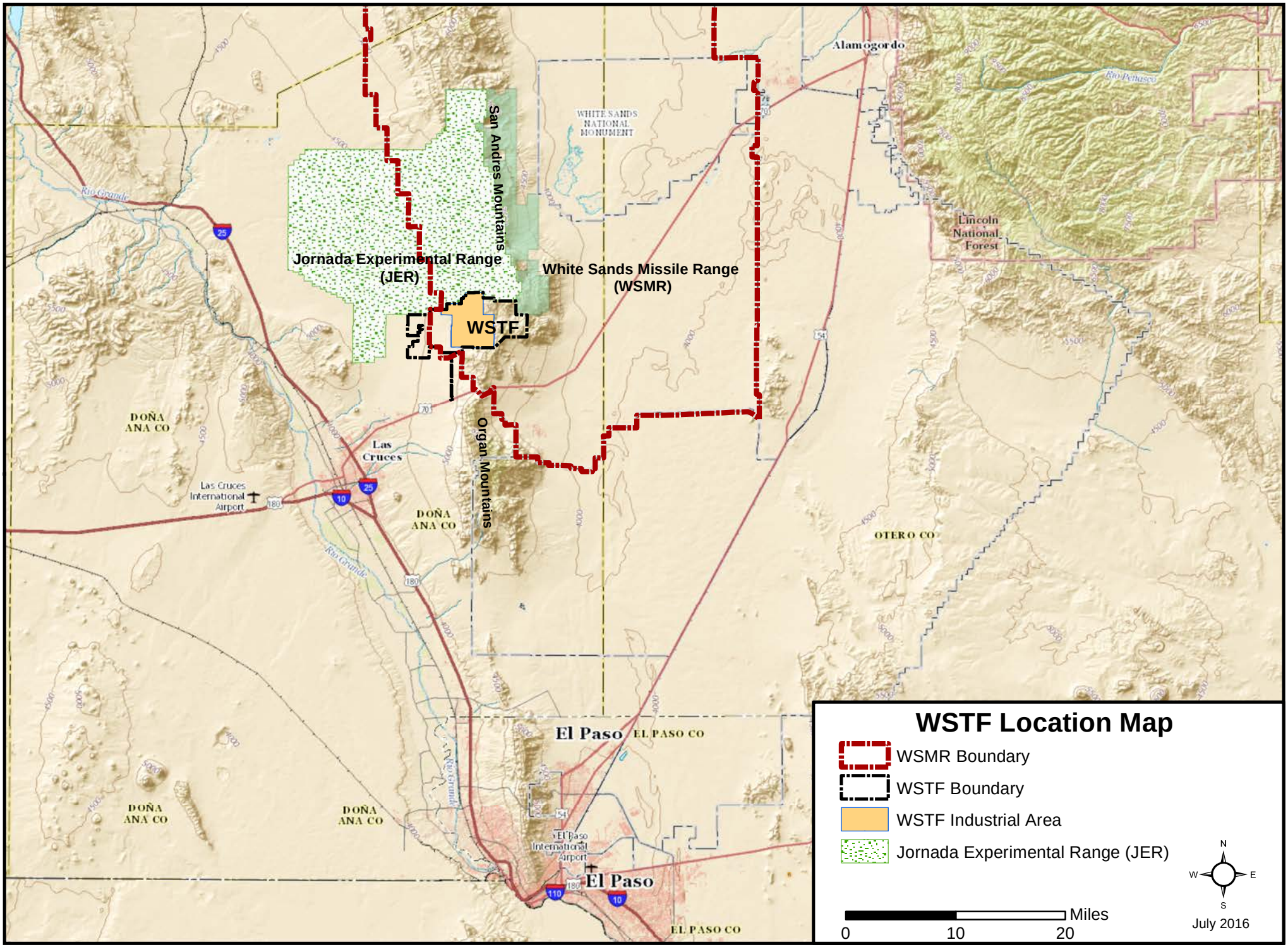

WSTF Location Map
WSMR Boundary
WSTF Boundary
WSTF Industrial Area
Jornada Experimental Range (JER)
Miles
0
10
20
N
W
E
S
July 2016
Jornada Experimental Range (JER)
San Andres Mountains
White Sands Missile Range (WSMR)
WSTF
Organ Mountains
WHITE SANDS NATIONAL MONUMENT
Alamogordo
Lincoln National Forest
Rio Pecuseo
Rio Grande
Las Cruces
Las Cruces International Airport
DOÑA ANA CO
OTERO CO
El Paso
EL PASO CO
El Paso International Airport
25
10
70
54
180
110

Figure 2 200 and 600 Area Lines of Cross-Section

(SEE NEXT PAGE)

200 and 600 Area Lines of Cross-Section

Lines of Cross-Section

Fault

Proposed Perched Groundwater Exploratory Borehole

Perched Groundwater Identified

Conventional Monitoring Well

Multiport Soil Vapor Monitoring

Existing Perched Groundwater Monitoring Well

Multiport Soil Vapor Groundwater Monitoring

Soil Vapor Test Well

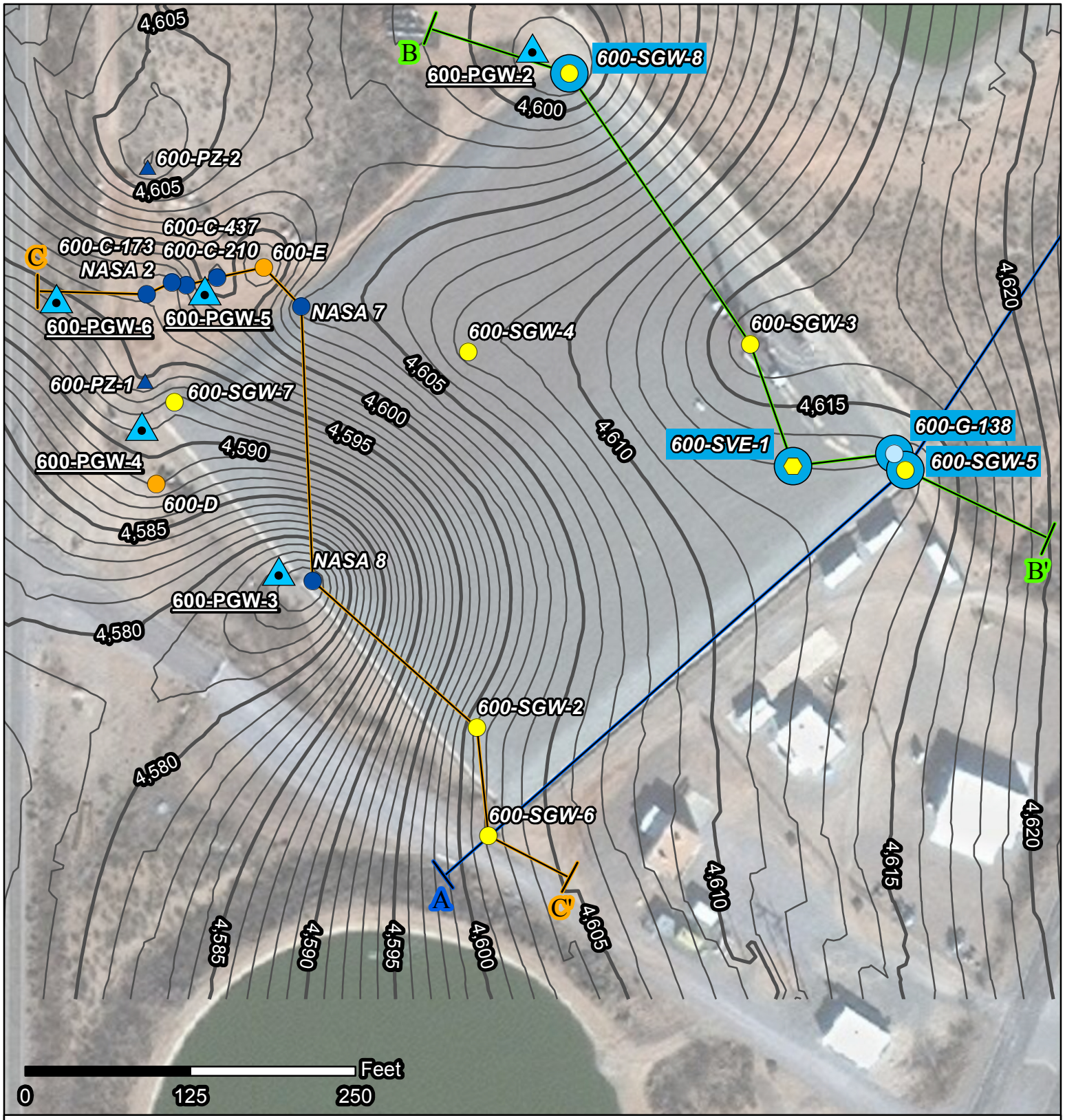
Westbay Multiport Well

N

0 250 500 1,000 1,500 Feet

Figure 3 **600 Area Closure Location Map**

(SEE NEXT PAGE)



600 Area Closure Showing Bedrock Elevation

1' Bedrock Contour

5' Bedrock Contour

Lines of Cross-Section
- A-A'
- B-B'
- C-C'

Perched Groundwater Identified

Proposed Perched Groundwater Exploratory Borehole

Conventional Monitoring Well

Multiport Soil Vapor Monitoring

Existing Perched Groundwater Monitoring Well

Piezometer

Soil Vapor Test Well

Westbay Multiport Well

N

Figure 4 Cross-Section A-A' Across 200 and 600 Areas

(SEE NEXT PAGE)

CROSS-SECTION A-A' ACROSS 200 AND 600 AREAS

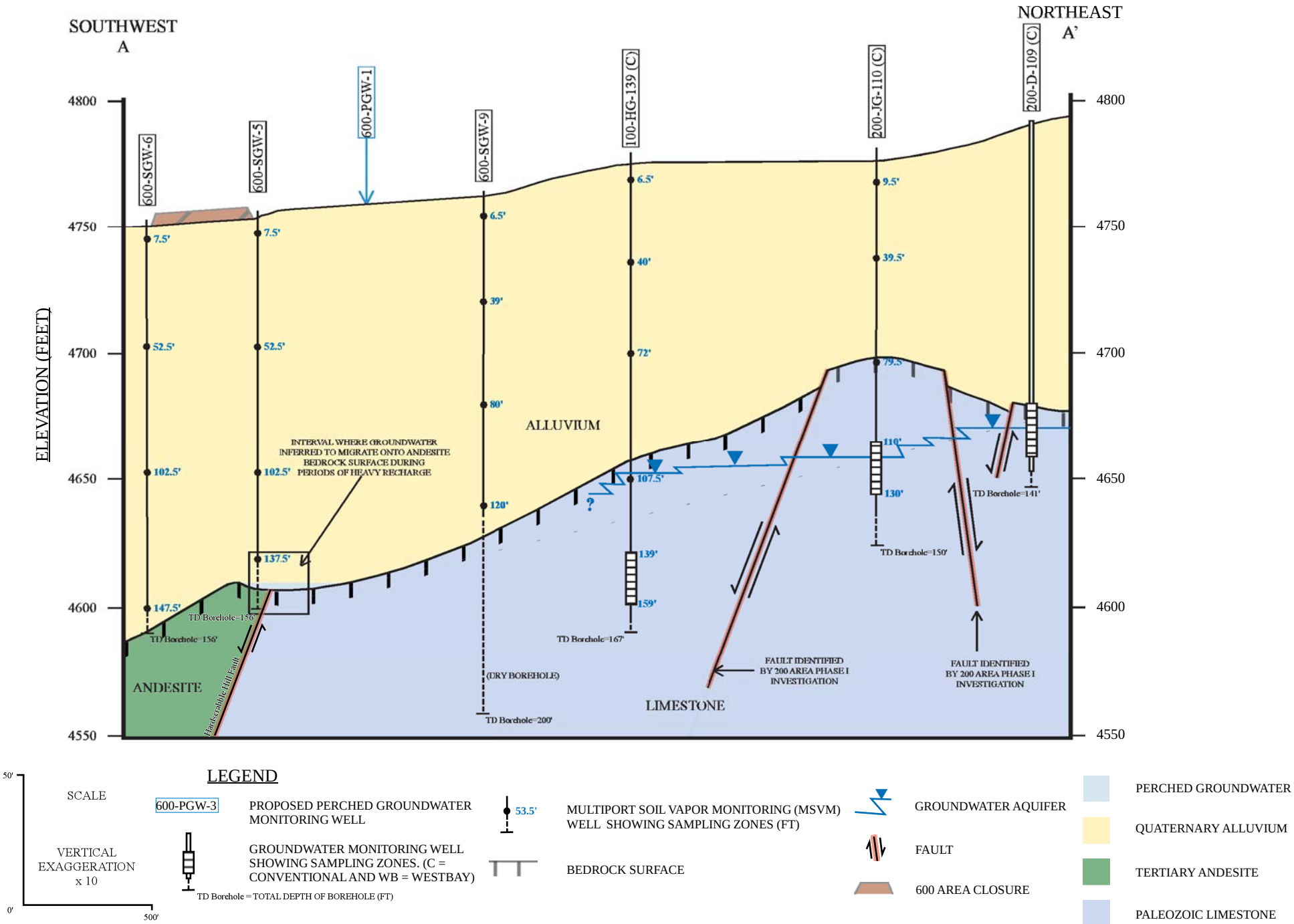
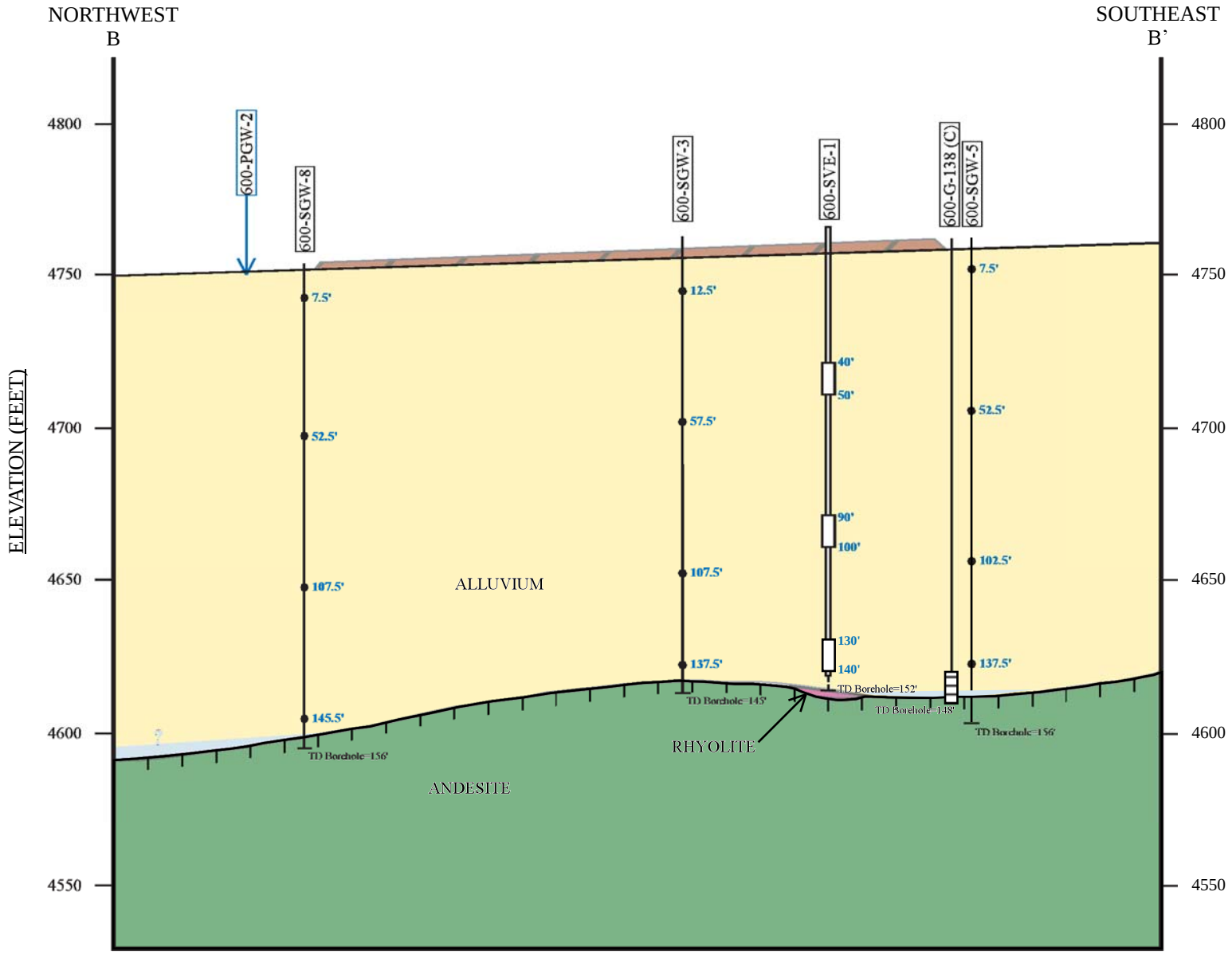


Figure 5 Cross-Section B-B' Across 600 Area Closure (Northeast)

(SEE NEXT PAGE)

CROSS-SECTION B-B' ACROSS 600 AREA CLOSURE (NORTHEAST)



LEGEND

SCALE

VERTICAL EXAGGERATION x 2

50' 0' 100'

600-PGW-3 PROPOSED PERCHED GROUNDWATER MONITORING WELL

GROUNDWATER MONITORING WELL SHOWING SAMPLING ZONES. (C = CONVENTIONAL AND WB = WESTBAY)

TD Borehole = TOTAL DEPTH OF BOREHOLE (FT)

53.5' MULTIPORT SOIL VAPOR MONITORING (MSVM) WELL SHOWING SAMPLING ZONES (FT)

BEDROCK SURFACE

130' 140' SOIL VAPOR EXTRACTION (SVE) WELL SHOWING SCREEN DEPTHS (FT)

GROUNDWATER AQUIFER

600 AREA CLOSURE

PERCHED GROUNDWATER

QUATERNARY ALLUVIUM

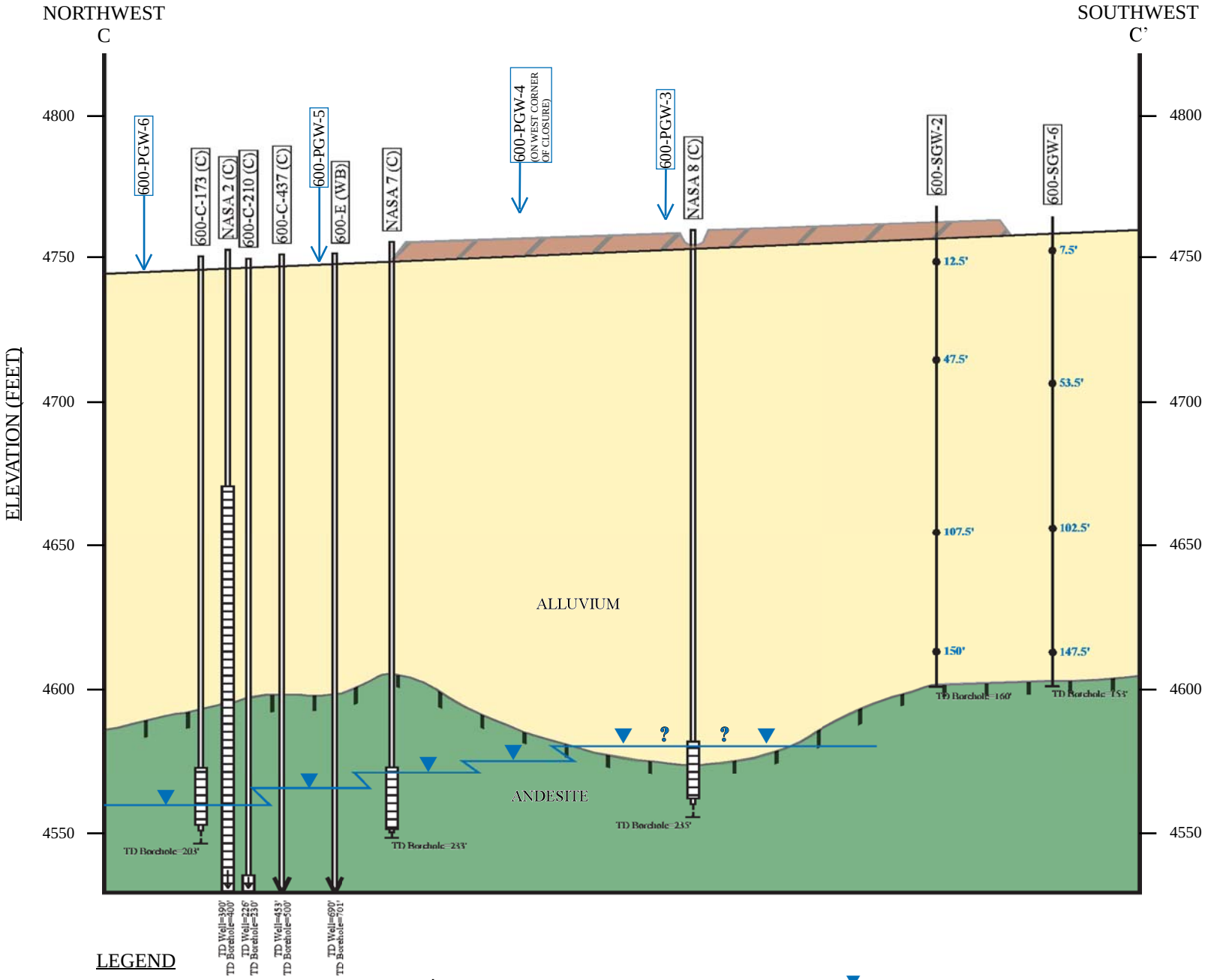
TERTIARY RHYOLITE

TERTIARY ANDESITE

Figure 6 Cross-Section C-C' Across 600 Area Closure (Southwest)

(SEE NEXT PAGE)

CROSS-SECTION C-C' ACROSS 600 AREA CLOSURE (SOUTHWEST)



LEGEND

SCALE

50'

0'

100'

VERTICAL EXAGGERATION x 2

600-PGW-3 PROPOSED PERCHED GROUNDWATER MONITORING WELL

GROUNDWATER MONITORING WELL SHOWING SAMPLING ZONES. (C = CONVENTIONAL AND WB = WESTBAY)

TD Borehole = TOTAL DEPTH OF BOREHOLE (FT)

53.5' MULTIPORT SOIL VAPOR MONITORING (MSVM) WELL SHOWING SAMPLING ZONES (FT)

BEDROCK SURFACE

130' 140' SOIL VAPOR EXTRACTION (SVE) WELL SHOWING SCREEN DEPTHS (FT)

GROUNDWATER AQUIFER

600 AREA CLOSURE

PERCHED GROUNDWATER

QUATERNARY ALLUVIUM

TERTIARY RHYOLITE

TERTIARY ANDESITE

Figure 7 Completion Diagram for Well 600-G-138

(SEE NEXT PAGE)

WELL COMPLETION DIAGRAM

Perched Groundwater Monitoring

JSC - White Sands Test Facility
Las Cruces, New Mexico, USA

Well ID: **600-G-138**

Site ID: **NASA-WSTF, Doña Ana County, NM**

Township and Range: **SW 1/4, NW 1/4, SW 1/4, Sec. 2, T21S, R3E**
NM State Plane Coordinates (NAD 83): **549126.20' N 1528671.29' E**
Elevation (Brass Cap): **4759.43'**
Elevation (Top of Casing): **4761.41'**
Drilling Contractor: **WDC Exploration & Wells**
Driller: **T. Valentine**
Total Depth of Borehole (bgs): **148' (45.11 m)**
Borehole Diameter: **9 5/8" Stratex Casing Air Advance = 12"**
Depth to Bedrock (bgs): **146' (44.50 m); andesite**
Depth to Groundwater: **142.45' (43.42 m; measured 10/1/2011 bgs)**
Total Depth Surface Casing (bgs): **N/A**
Diameter and Type Surface Casing: **9 5/8" Drive Casing (removed as well was installed)**

Date(s) Well Installed: **10/1/2011**
Date(s) Well Developed: **10/19/2001**
Field Representative(s): **John Roland**
Total Depth Well Casing (bgs): **148' (45.11 m)**
Type of Casing: **Schedule 80 PVC**
Diameter Well Casing: **Nominal 4" (4.5" OD)**
Groundwater Screened Zone (bgs): **137.5'-147.5' (41.91-44.96 m)**
Comments: **The well measures groundwater perched on the bedrock surface, not the regional groundwater within bedrock.**

Explanation:

Surface Casing
N/A

Conventional Casing
4.5" OD Schedule 80 PVC

Conventional Screen
4.5" OD Schedule 80 PVC
0.020"

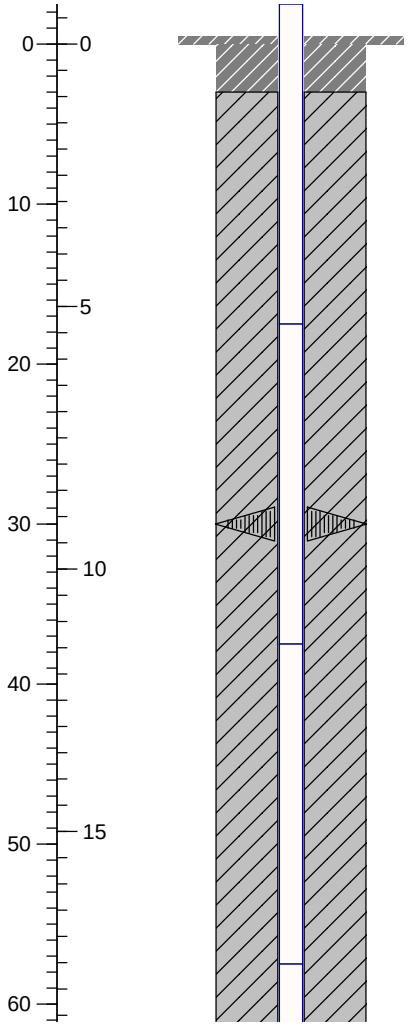
Conventional End Cap
4.5" OD Schedule 80 PVC

Bolted Steel Centralizers
Cage Type

Water Table

Cement
Cement (5% Bentonite)
Bentonite Seal
10/20 Sand/ Bentonite Mix
Slough
1/8 Gravel
8/20-16/40 Sand Mix
4/8 Sand
6/9 Sand
8/12 Sand
8/20 Sand
10/20 Sand
16/40 Sand
20/40 Sand
30/70 Sand

Feet/Meters



Well Descriptions
All depths listed are bgs (unless noted)

Conventional Well Stick-Up = ~3' (0.91 m)

This well monitors perched (above the bedrock) groundwater under the 600 Area Closure.

Well completed with 6" x 6' steel well protector with locking cap, ~4' x 4' concrete well pad, and barrier posts above ground surface.

Steel bolt-on centralizer ~30' (9.14 m)

Annular/Borehole Descriptions
All depths listed are bgs

Top of Cement = 0'

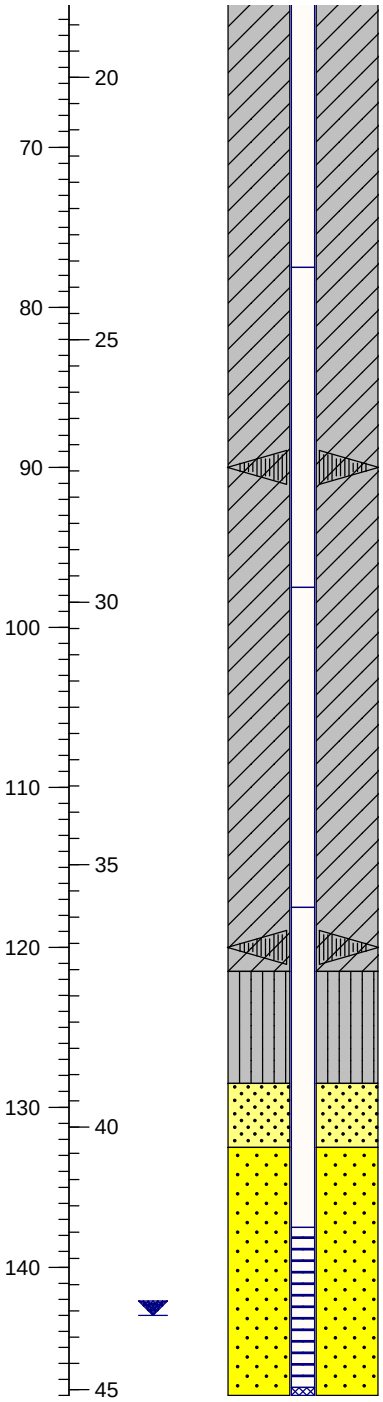
Top of Cement (Portland Type I/II with 5% bentonite) = 3' (0.91 m)

Casing Explanation:

- Surface Casing — **9 5/8" Drive Casing (removed as well was installed)**
- Conventional Casing — **4.5" OD Schedule 80 PVC**
- Conventional Screen — **4.5" OD Schedule 80 PVC 0.020"**
- Conventional End Cap — **4.5" OD Schedule 80 PVC**
- **Bolted Steel Centralizers Cage Type**
- Water Table

Cement	1/8 Gravel	8/20 Sand
Cement (5% Bentonite)	8/20-16/40 Sand Mix	10/20 Sand
Bentonite Seal	4/8 Sand	16/40 Sand
10/20 Sand/ Bentonite Mix	6/9 Sand	20/40 Sand
Slough	8/12 Sand	30/70 Sand

Feet/Meters



Well Descriptions
All depths listed are bgs (unless noted)

Steel bolt-on centralizer ~90' (27.43 m)

Steel bolt-on centralizer ~120' (36.57 m)

Top of Nominal 4" (4.5" OD) Schedule 80 PVC 0.020"-Slot Screen = 137.5' (41.91 m)

*Groundwater During Drilling (First Occurrence) = 142.45' (43.42 m; measured 10/1/2011 bgs)

Water Table = 143' (43.58 m; measured 10/25/2011 bgs at first sampling)

Bottom of Nominal 4" (4.5" OD) Schedule 80 PVC 0.020"-Slot Screen = 147.5' (44.96 m)

PVC cap contains a 1/4" diameter weep hole (to accommodate dry periods)

Nominal 4" (4.5" OD) Schedule 80 PVC Casing TD = 148' (45.11 m)

Annular/Borehole Descriptions
All depths listed are bgs

Top of Bentonite = 121.5' (37.03 m)

Top of 16/40 Sand = 128.5' (39.16 m)

*Groundwater was not present during drilling, but seeped in overnight.

Top of 10/20 Sand = 132.5' (40.38 m)

12" Borehole TD = 148' (45.11 m) drilled with 9 5/8" Stratex Casing Advance Air Rotary method

Tables

Table 1 600 Area Closure Bedrock Data Points

Well ID	Date Installed	Well Type	Brass Cap Elevation (ft)[1]	TD Borehole (ft)	Bedrock Depth (ft)	Rec Rev*	Lithology	Bedrock Elevation (ft)	Drilling Method/ Perched Water at Bedrock	Decision Basis (Bedrock Calls)[2]
100-D-176	05/20/97	Conventional Monitoring Well	4750.52	210	176	Yes	Andesite	**4574.52**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, rock chips
600-C-173	02/25/87	Conventional Monitoring Well	4746.1	202.6	150	Yes	Andesite	**4596.1**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-C210	06/16/87	Conventional Monitoring Well	4746.26	230	148	Yes	Andesite	**4598.26**	Mud/ air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-C-437	02/08/88	Conventional Monitoring Well	4747.12	500	145	Yes	Andesite	**4602.12**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-D	06/15/95	Westbay Multiport Well	4749.54	880	160	Yes	Andesite	**4589.54**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, geophysical logs, rock chip samples
600-E	10/10/97	Westbay Multiport Well	4748.13	701	152	Yes	Andesite	**4596.13**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, geophysical logs, rock chip samples
600-G-138	10/01/11	Perched Monitoring Well	4759.57	148	146	Yes	Andesite	**4613.57**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
600-PZ-1	04/21/89	Piezometer	4747.55	300	152	Yes	Andesite	**4595.55**	Air-foam rotary to bedrock - N/A	Field notebook, lithologic logs
600-PZ-2	04/28/89	Piezometer	4744.56	442	137	Yes	Andesite	**4607.56**	Air-foam rotary to bedrock - N/A	Field notebook, lithologic logs
600-SGW-2	02/01/10	Multiport Soil Vapor Monitoring	4761.6	160	160	Yes	Andesite	**4601.6**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-3	01/18/10	Multiport Soil Vapor Monitoring	4759.32	145	142	Yes	Andesite	**4617.32**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-4	01/25/10	Multiport Soil Vapor Monitoring	4755.97	155	147	Yes	Andesite	**4608.97**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-5	12/23/09	Multiport Soil Vapor Monitoring	4760.04	156	148	Yes	Andesite	**4612.04**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
600-SGW-6	01/11/10	Multiport Soil Vapor Monitoring	4758.39	156	156	Yes	Andesite	**4602.39**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-7	12/09/09	Multiport Soil Vapor Monitoring	4748.98	158.5	158	Yes	Andesite	**4590.98**	ARCH - dry	Field notebook, lithologic logs, rock chip samples

Table 1 600 Area Closure Bedrock Data Points

Well ID	Date Installed	Well Type	Brass Cap Elevation (ft)[1]	TD Borehole (ft)	Bedrock Depth (ft)	Rec Rev*	Lithology	Bedrock Elevation (ft)	Drilling Method/ Perched Water at Bedrock	Decision Basis (Bedrock Calls)[2]
600-SGW-8	12/16/09	Multiport Soil Vapor Monitoring	4750.34	156	153	Yes	Andesite	**4597.34**	ARCH - perched water recorded (3 - 4 ft)	Field notebook, lithologic logs, rock chip samples
600-SVE-1	10/06/11	Soil Vapor Test Well	4761.94	152	149	Yes	Rhyolitic Tuff	**4612.94**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
BLM-3-182	02/10/87	Conventional Monitoring Well	4745.99	213.5	162	Yes	Andesite	**4583.99**	Mud/ air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 2	07/13/84	Conventional Well	4745.9	400	150	Yes	Andesite	**4595.9**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 4	03/07/85	Conventional Monitoring Well	4772.51	175	125	Yes	Limestone	**4647.51**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 7	04/05/85	Conventional Monitoring Well	4750.19	233	145	Yes	Andesite	**4605.19**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 8	04/05/85	Conventional Monitoring Well	4753.52	235	180	Yes	Andesite	**4573.52**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs

* Rec Rev (records reviewed) indicates all available information for all wells reviewed.
Notes:
[1] Brass cap elevation re-measured in March, 2016.
[2] Decision basis elements re-evaluated in February – April, 2016

Table 2 Proposed Perched Groundwater Soil Borings Depths

Soil Boring ID*	Soil Boring Method	Diameter (in.)	Anticipated Bedrock Depth (ft)	Anticipated Soil Boring Depth (ft)	Anticipated Lithology	Rationale
600-PGW-1	Air rotary casing hammer	9”	145’	147’	Andesite	Upgradient source area; relative bedrock low
600-PGW-2	Air rotary casing hammer	9”	153’	155’	Andesite	Adjacent to perched water observed in 600-SGW-8; relative bedrock low
600-PGW-3	Air rotary casing hammer	9”	173’	175’	Andesite	Important location adjacent to well NASA 8; inferred to be a bedrock low
600-PGW-4	Air rotary casing hammer	9”	170’	172’	Andesite	Adjacent to 600 Area Closure; relative bedrock low
600-PGW-5	Air rotary casing hammer	9”	150’	152’	Andesite	Potential downgradient flow pathway; relative bedrock low
600-PGW-6	Air rotary casing hammer	9”	158’	160’	Andesite	Potential downgradient flow pathway; relative bedrock low

Notes:
* = Proposed soil boring locations will be re-evaluated based on results of the geophysical survey and require subsequent NMED approval prior to installation.

Table 3 Preliminary List of COCs for the 600 Area Perched Groundwater

Constituent	Sample Type	Lab Analytical Method
Chloride	ANION	300.0
Cyanide	CYANIDE	8012
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (HpCDD)	DIOXINS/FURANS	8290
Heptachlorodibenzo-p-dioxins (HpCDD), Total	DIOXINS/FURANS	8290
Octachlorodibenzofuran (OCDF)	DIOXINS/FURANS	8290
Octachlorodibenzo-p-dioxin (OCDD)	DIOXINS/FURANS	8290
Hydrazine	HYDRAZINE	8315
Monomethylhydrazine (MMH)	HYDRAZINE	8315
Unsymmetrical Dimethylhydrazine (UDMH)	HYDRAZINE	8315
Aluminum	METALS	6010, 7470
Antimony	METALS	6010, 7470
Arsenic	METALS	6010, 7470
Barium	METALS	6010, 7470
Beryllium	METALS	6010, 7470
Boron	METALS	6010, 7470
Cadmium	METALS	6010, 7470
Calcium	METALS	6010, 7470
Chromium (Total)	METALS	6010, 7470
Chromium (VI)	METALS	6010, 7470
Cobalt	METALS	6010, 7470
Copper	METALS	6010, 7470
Lead	METALS	6010, 7470
Mercury	METALS	6010, 7470
Molybdenum	METALS	6010, 7470
Nickel	METALS	6010, 7470
Selenium	METALS	6010, 7470
Silver	METALS	6010, 7470
Strontium	METALS	6010, 7470
Thallium	METALS	6010, 7470
Tin	METALS	6010, 7470
Vanadium	METALS	6010, 7470
Zinc	METALS	6010, 7470
Bromacil	BROMACIL	8321B
N-Nitrosodimethylamine	NITROSAMINES	607
Nitrate	NITROGEN	353.2
Nitrite	NITROGEN	353.2
Perchlorate	PERCHLORATE	6850
Bis(2-ethylhexyl) Phthalate	SVOA	8270
Di-n-butyl Phthalate	SVOA	8270
1,1,1-Trichloroethane	VOA	8260

Table 3 Preliminary List of COCs for the 600 Area Perched Groundwater

Constituent	Sample Type	Lab Analytical Method
1,1,2-Trichloroethane	VOA	8260
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	VOA	8260
1,1-Dichloroethene	VOA	8260
1,2-Dichloro-1,1,2-trifluoroethane (Freon 123a)	VOA	8260
1,2-Dichloroethane	VOA	8260
2,2-Dichloro-1,1,1-trifluoroethane (Freon 123)	VOA	8260
2-Butanone (Methyl Ethyl Ketone)	VOA	8260
2-Propanol	VOA	8260
Acetone	VOA	8260
Benzene	VOA	8260
Bromodichloromethane	VOA	8260
Bromoform	VOA	8260
Chlorobenzene	VOA	8260
Chloroform	VOA	8260
Chloromethane	VOA	8260
Dibromochloromethane	VOA	8260
Dichlorofluoromethane (Freon 21)	VOA	8260
Methyl tert-Butyl Ether	VOA	8260
Methylene Chloride	VOA	8260
m-Xylene & p-Xylene	VOA	8260
Tetrachloroethene (PCE)	VOA	8260
Toluene	VOA	8260
Trichloroethene (TCE)	VOA	8260
Trichlorofluoromethane (Freon 11)	VOA	8260

Appendix A Consultation Report

GEOPHYSICAL REVIEW OF DATA, CONCLUSIONS, AND RECOMMENDATIONS FOR NASA WHITE SANDS TEST FACILITY 600 AREA

Marianne Karplus, Ph.D.
Assistant Professor of Geological Sciences
University of Texas at El Paso
500 W. University Ave.
El Paso, TX 79968-0555
mkarplus@utep.edu
office: 915-747-5413
cell: 915-234-8882

Prepared for Navarro Research and Engineering, Inc.

Abstract

This report discusses and evaluates possible geophysical methods that could better constrain the depth to andesite bedrock beneath the 600 Area Hazardous Waste Management Unit (HWMU) at the National Aeronautics and Space Administration's (NASA) White Sands Test Facility (WSTF). The 600 Area is a 400 by 400 foot area that is a historic hazardous waste impoundment sealed by an impermeable cap and managed by the WSTF. Wells drilled into the 600 Area have yielded lithologies, depth to bedrock (with some uncertainty), depth to water table (with some uncertainty), and locations of contaminated perched water. A better map of the top of bedrock surface (135-180 feet deep) is desired to better model locations and flow pathways of perched water (presumably along topographic lows and downward sloping surfaces in the basement). Material above the basement includes a series of Quaternary to Tertiary heterogeneous alluvial fan deposits and the impermeable cap.

The imaging detail desired for this area (modeling and imaging of changes of less than 10 feet in bedrock depth at 135-180 feet depth) present significant challenges for geophysical imaging. Seismic refraction and reflection methods may be able to resolve these changes using changes in seismic velocity and reflectivity if data quality is good, sources include high enough frequency content, and seismometers can be deployed across the top of the 600 Area cap. Resistivity surveys may be able to resolve it if they are suitably dense and able to survey across the 600 Area cap.

I. Introduction

The National Aeronautics and Space Administration's (NASA) White Sands Test Facility (WSTF), located ~20 miles northeast of Las Cruces, NM, includes several, monitored technical areas (Figure 1). This report focuses on one of these areas, Area 600 Hazardous Waste Management Unit (HWMU), which was built in 1964 as two adjacent surface impoundments. The purpose of this report is to review previous geological, hydrological, and geophysical data collected in the vicinity of the 600 Area and to make recommendations regarding geophysical methods that might resolve the uncertainties regarding the top of bedrock topography underlying the 600 Area. Numerous wells have been drilled in this area and some geophysical data has been collected (Figures 1-2, Table 1).

Each of the two 600 Area impoundments measures 350 feet long by 150 feet wide by three feet deep, with long axes oriented to the northeast. This area received liquid wastes from various sources from 1964 to 1986. These wastes included saltwater backwash from the WSTF water softening plant, hazardous waste from the 200 Area Clean Room and Chemistry Laboratory Tanks, and process waste from the White Sands Missile Range's High Energy Laser System Test Facility. Hazardous chemicals in these wastes include tetrachloroethene (TCE), perchloroethene (PCE), and Freons 11, 21, 113. Area 600 was capped in 1988-1989 with a single, impermeable 400 by 400 foot cap. The composition of the cap is two feet of low-permeability clay followed by a plastic liner, then six inches of pit sand, and then seven inches of ¾ inch top rock.

The understanding of the flow patterns of contaminated water (perched water and groundwater) is very important for managing and mitigating plumes of hazardous materials. In this report, we present recommendations for possible geophysical methods that may resolve some of the uncertainties in the bedrock surface beneath the 600 Area and discuss details and limitations of those methods.

2. Regional and local geology

NASA White Sands Test Facility is located within the Basin and Range physiographic province on the eastern side of the Jornada del Muerto basin, on the western flank of the southern San Andres - Caballo Mountains. There are three major faults crossing north-northwest of the WSTF, two of which form the eastern normal boundary fault for the Jornada basin. This boundary fault has around 7900 ft of displacement and brings Paleozoic limestone against Tertiary volcanics (Maciejewski, 1996).

In the early Paleozoic, present-day southern New Mexico was near the passive margin of western North America, but located at the southern tip of a stable cratonic arch (Dickinson, 1981). In late Cambrian to early Devonian time, seas transgressed east-northeast across present-day southern New Mexico depositing marine sediments unconformably on eroded Precambrian and Cambrian rocks of southern New Mexico (Seager, 1981). During the Tertiary, subduction of the Farallon slab

brought both contractional deformation (Laramide orogeny) and arc volcanism. Laramide thrusting and compression has been mapped north of the WSTF at the Bear Peak fold-and-thrust belt. Rifting in the Rio Grande Rift began about 30 Ma and continues to the present day. In the WSTF region, there is a complex series of normal faults and grabens (Keller et al., 1990).

The 600 Area is northwest of the 100 Area, near the entrance of WSTF. The bedrock beneath the 600 Area consists of tertiary andesite and is between 137-180 feet in depth (according to previously collected well data, Figures 1-4, Table 1). The bedrock dips to the northwest and has an elevation from 4573 ft to 4613 ft. The bedrock is overlain by unconsolidated material, course-to-fine-grained sediments deposited in alluvial fans and shed from the San Andreas Mountains to the east. The San Andreas mountains are composed of tertiary andesite and rhyolite as well as Paleozoic limestone. The alluvial fans are vertically and laterally heterogeneous. Some of them may include large blocks of andesite, rhyolite, or limestone.

The detailed topography of the bedrock below the 600 Area is uncertain. Some of the historic well logs have large uncertainties associated with the depth to bedrock. The large blocks of rock that may be at the base of the fans cause contribute to the uncertainty. The 600 Area also includes several crossing faults that appear to offset the bedrock (Maciejewski, 1996). Furthermore, the Hardscrabble Hill fault is located just east of the 600 Area. Another major fault, the Western Boundary Fault Zone 2, is located just west of the 600 Area (Maciejewski, 1996).

The hydrology of this area includes a potentiometric surface below the top of bedrock (based on well data) and controlled by fracture patterns. The inferred direction of flow is from the northeast to the southwest. Perched water on top of the bedrock containing contaminants has been observed in several wells drilled through the northern and northeastern 600 Area. In order to determine the migration pathways of the perched water, the top of the bedrock needs to be accurately quantified (Figure 3). The perched water appears to be present in topographic lows and migrating down slope (Figure 4-5). The perched water may be partially sourced from the sewage lagoons adjacent to the 600 Area, based on the presence of nitrates/ nitrites in the perched water.

3. Previous geophysical studies

Multiple regional geophysical studies have been published or conducted near WSTF. Regional seismic refraction profiles demonstrated that the crust is 28 to 30 km thick (Sinno et al., 1986). P-wave velocity studies (Harder et al., 1986) and gravity studies (Daggett et al., 1986; Gilmer et al., 1986) have suggested that Jornada Quaternary basin fill may reach as much as 3500 feet in thickness, and Cenozoic fill may reach as much as 10,000 feet in thickness. Over 42 miles of seismic lines have been acquired in the WSTF site, and a bedrock elevation map was interpreted from those data (e.g., Miller & Maciejewski, 1995).

A number of previous resistivity profiles have been collected in WSTF (Figures 6-7), including one adjacent to the 600 Area overflow wastewater lagoon (Rucker et al., 2012, Line M, Figure 8). The data showed very high near-surface conductivities, which made modeling and interpreting the deeper structure impossible. The area of high conductivity likely correspond to leaking from the wastewater lagoon. The resistivity data from other lines without near-surface water (and corresponding high conductivities) did resolve the top of bedrock surface (e.g., Line C, Figure 7).

4. Geophysical recommendations

Based on well data, the top of bedrock surface beneath the 400 by 400 foot 600 Area is believed to range between 137-180 feet in depth (from well data). The magnitude of the top of bedrock surface depth changes is thus typically less than 43 feet. Individual bedrock depressions where perched water has been observed and WSTF wishes to map in more detail sometimes are associated with depth changes of fewer than 10 feet. Resolving those depressions at 137-180 feet depth with geophysics is a challenging problem. We present some techniques that may contribute to solving that problem below.

A. Seismic refraction

Seismic refraction involves setting up a number of seismometers and recording propagating refracted waves from a manmade 'shot' (explosion, seismic gun, accelerated weight drop, etc.). Picking the travel times of the refracted arrivals from the shot to each of the receivers and comparison with the distance travelled allows the calculation of velocities beneath the area.

Previous high resolution seismic refraction surveys have been successful at distinguishing relatively fine-scale changes in basement topography. I am not sure which seismic sources and receivers (if any) could be used on top of the 600 Area closure seal. If sources and instruments cannot be placed on top of the seal, this will make the high resolution imaging of the basement even more difficult. Given more time, I could calculate some synthetic refraction data and evaluate the resolution limits in more detail.

B. Seismic reflection

Seismic reflection involves setting up a number of seismometers and recording propagating reflected waves from a manmade 'shot'. Reflections can be used to calculate wave speeds from source to receiver through the subsurface. They can also be used to create an image of subsurface reflectivity (dependent on impedance contrast of subsurface lithologies). Seismic reflection profiles are able to provide images of the subsurface when there are sufficient contrasts in acoustic impedance (for a detailed discussion, see Sheriff & Geldart, 1995), which is expected to be the case for the top of andesite bedrock surface (Miller & Maciejewski, 1995). However, when synthetic seismograms were calculated

from the 600-D well log, the andesite had only a few boundaries with reflection coefficient as high as 0.1. Those may correspond to localized fracturing or volcanic flow boundaries. It may be possible – but likely difficult - to distinguish a large boulder sitting on the bedrock surface from the bedrock surface.

Reflection seismology can typically image the bedrock depth when it is greater than $\lambda/2$. A typical dominant frequency for a seismic reflection survey is ~50 Hz. Assuming an average velocity of 3,400 ft/ sec (1036 m/s) for the upper layer of alluvium beneath the 600 Area, the λ would be 68 feet (20.7 meters), which corresponds to a minimum depth of resolution of 34 feet for the bedrock surface. Since the bedrock beneath the 600 Area is at 135-150 feet, the top of the bedrock surface should be resolvable using seismic reflection techniques.

The vertical resolution limit of seismic reflection data is typically considered to by ~$\lambda/4$, which in this case is ~17 feet. However, sometimes you can still detect layers down to $\lambda/32$, which in this case is just over 2 feet. The horizontal resolution is typically $\lambda/4$ (~17 feet). Given that we are searching for depth changes on the order of fewer than 10 feet and horizontal changes over 10s of feet, imaging the depressions in the bedrock surface may be possible with seismic reflection, but it would be difficult.

Complicating this analysis is the question of which seismic sources and receivers (if any) could be used on top of the 600 Area closure seal. Given more time, I could calculate some synthetic reflection data and evaluate the resolution limits in more detail.

C. Seismic ambient noise studies

There have been efforts recently to extract reflected body waves from passive recordings of ambient noise (e.g., Draganov et al., 2009). While these have not been very successful at viewing velocity changes at the top of the basement so far, there is a possibility that these could be successful with advances in instrumentation, larger numbers of instruments, and/ or improved data processing techniques. Deploying nodal seismometers (e.g., UTEP has a 48-node Fairfield Z-Land system) in 2-D profiles or a 3-D arrangement of seismometers across the top of the 600 Area may allow some improvement in the resolution of the top basement. This method is inexpensive, as no manmade sources are required, but also has a lower chance of success due to the use of newer (less well-developed) techniques and the fact that the noise has a lower frequency than a manmade source leading to decreased ability to resolve fine scale changes in bedrock topography.

D. Electrical resistivity

As with the seismic methods detailed above, imaging changes of 10 feet or less in the top of basement at 137-180 feet depth will be very challenging with

electrical resistivity data. Rucker et al. (2012) did interpret changes of 20-40 feet in bedrock depth in their resistivity profiles, so this method may allow better resolution of the top of bedrock surface than is currently known. Any resistivity surveys of the 600 Area would have a higher likelihood of success if the surveys are carried out >3-6 months after the wastewater lagoons are drained. Surveys will be required across the 600 Area cap in order to determine the detailed bedrock structure. It's possible that the impermeable cap may prevent imaging of the top of bedrock. However, if the material above the seal is dry, modeling conductivity of the basement should be possible.

5. Geophysical recommendations probability of success

Resolving 10 foot changes in bedrock depth at 135-180 feet depth is a difficult imaging problem. Dense geometries of geophysical surveys directly above or on either side of the 600 Area are necessary to resolve such fine-scale changes, and even then it may not be feasible. I would rank the relative probabilities of success of the four methods as follows: 1) seismic refraction, 2) seismic reflection, 3) electrical resistivity, 4) seismic ambient noise studies.

6. Supporting information useful to improving geophysical interpretations

The existing borehole data will be very useful for better assessing the likelihood of success of the above-mentioned methods. The borehole data can be used to compute synthetic seismograms, which allow further testing of the likelihood of success of the seismic and resistivity methods. The borehole data will also be extremely helpful for constraining velocity and reflectivity models and testing hypotheses about the depth to bedrock, including whether the bedrock depth interpreted from some of the older wells was correct.

The previously acquired resistivity and regional seismic data may help with larger scale constraints of the regional structure and allow improved evaluation of any new models.

7. Conclusion

The purpose of this study is to assess whether geophysical methods may be helpful for constraining the depth to bedrock surface beneath the 600 Area at the NASA WSTF. The 600 Area is a 400 foot by 400 foot Hazardous Waste Management Unit. A map of the depth of bedrock beneath the unit is desired to better understand possible locations and pathways for perched water (which has been observed in wells drilling several topographic lows in the basement surface). Based on well data, the top of basement is believed to range from ~135-180 feet in depth, with topography amplitude changes of 10 feet or less from the bottom of the lows to the nearby topographic highs.

Dense geophysical surveys directly over the 600 Area may be helpful at remotely constraining the bedrock topography. In particular, active-source seismic reflection and refraction methods and electrical resistivity are the most likely methods to improve the map of bedrock depths. Recording seismic ambient noise may also be able to help with this problem, but the method is relatively new and has not been used for such fine-scale, shallow imaging (and the wavelengths recorded are likely not to be small enough to see fine-scale changes in bedrock topography).

All of the field acquisitions detailed in this report could be carried out using UTEP Department of Geological Sciences equipment and expertise. If desired, I can provide more details of some example geometries and types of equipment that could be used for these experiments.

8. References

Daggett,P.H., G.R. Keller, P. Morgan, and C.-L. Wen, 1986, Structure of the southern Rio Grande rift from gravity interpretation, Journal of Geophysical Research, v. 91.

Draganov, D., X. Campman, J. Thornbecke, A. Verdel, and K. Wapenaar, 2009, Reflection images from ambient seismic noise, Geophysics, 74 (5).

Dickinson, W.R., 1981, Plate tectonic evolution of the southern Cordillera, Arizona Geo. Soc. Digest, 14, 113-135, 1981

Geoff Giles and Navarro Research and Engineering, personal communication, June 16, 2016.

Gilmer, A.L., R.A. Maudlin, and G.R. Keller, 1986, A gravity study of the Jornada del Muerto and Palomas basins, New Mexico Geological Survey guidebook, 37th Field Conference, Truth or Consequences, pp. 131-134.

Harder, S., G.R. Keller, P. Morgan, and C. Wen, 1986, Cenozoic fill thickness estimates from P-wave delays in the Jornada del Muerto and Palomas Basins, New Mexico Geological Survey Guidebook, 37th Field Conference, Truth or Consequences, pp. 135-138.

Keller, G.R., P. Morgan, W.R. Seager, 1990, Crustal structure, gravity anomalies, and heat flow in the southern Rio Grande Rift and their relationship to extensional tectonics, Tectonophysics, 174, 21-37.

Maciejewski, T.J., 1996, Integrated geophysical interpretation of bedrock geology, San Andres Mountains, New Mexico, Master's Thesis, University of Texas at El Paso, 123 pp. December 1996.

Miller, K.C. and T. Maciejewski, 1995, Evaluation of seismic data for the NASA Johnson Space Center, White Sands Test Facility, Final Report.

Parsekian, A. D., K. Singha, B. J. Minsley, W. S. Holbrook, and L. Slater (2015), Multiscale geophysical imaging of the critical zone, Rev. Geophys., 53, doi:10.1002/2014RG000465.

Picozzi, M., S. Parolai, D. Bindi, and A. Strollo (2009), Characterization of shallow geology by high-frequency seismic noise tomography, Geophys. J. Int., 176, 164–174, doi:10.1111/j.1365-246X.2008.03966.x.

Reynolds, C.B. and Associates, 1988, Shallow seismic reflection investigation at the NASA-Johnson Space Center White Sands Test Facility, Final Report.

Rucker, D., C. Baldyga, G. Noonan, B. Cubbage, 2012, Geophysical characterization of the National Aeronautics and Space Administration's White Sands Test Facility: 200 Area and adjacent portions of the 100, 600, and 800 areas, Report prepared for Navarro Research and Engineering, Inc.

Seager, R.W., 1981, Geology of the Organ Mountains and Southern San Andreas Mountains, New Mexico, New Mexico Bureau of Mines and Mineral Resources, Memoir 36, 97 pp.

Sheriff, R.E., and L.P. Geldart, 1995, Exploration Seismology, Cambridge University Press, Cambridge, 592 pp.

Sinno, Y.A., P.H. Daggett, G.R. Keller, P. Morgan, and S.H. Harder, 1986, Crustal structure of the Rio Grande Rift determined from seismic refraction profiling,, Journal of Geophysical Research, v. 91, pp. 6143-6156.

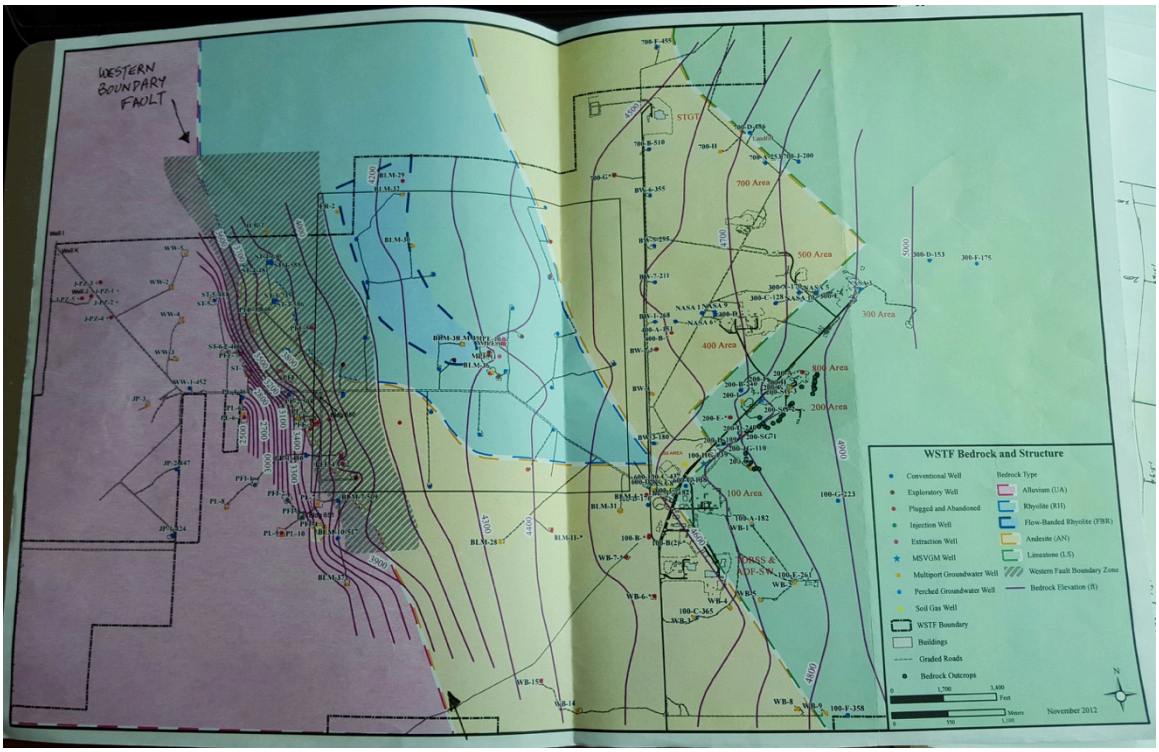


Figure 1. White Sands Test Facility geologic and structural map. Lithologies, bedrock contours, locations of Hazardous Waste Management Units, and locations of wells are shown (Giles et al., pers. comm.).

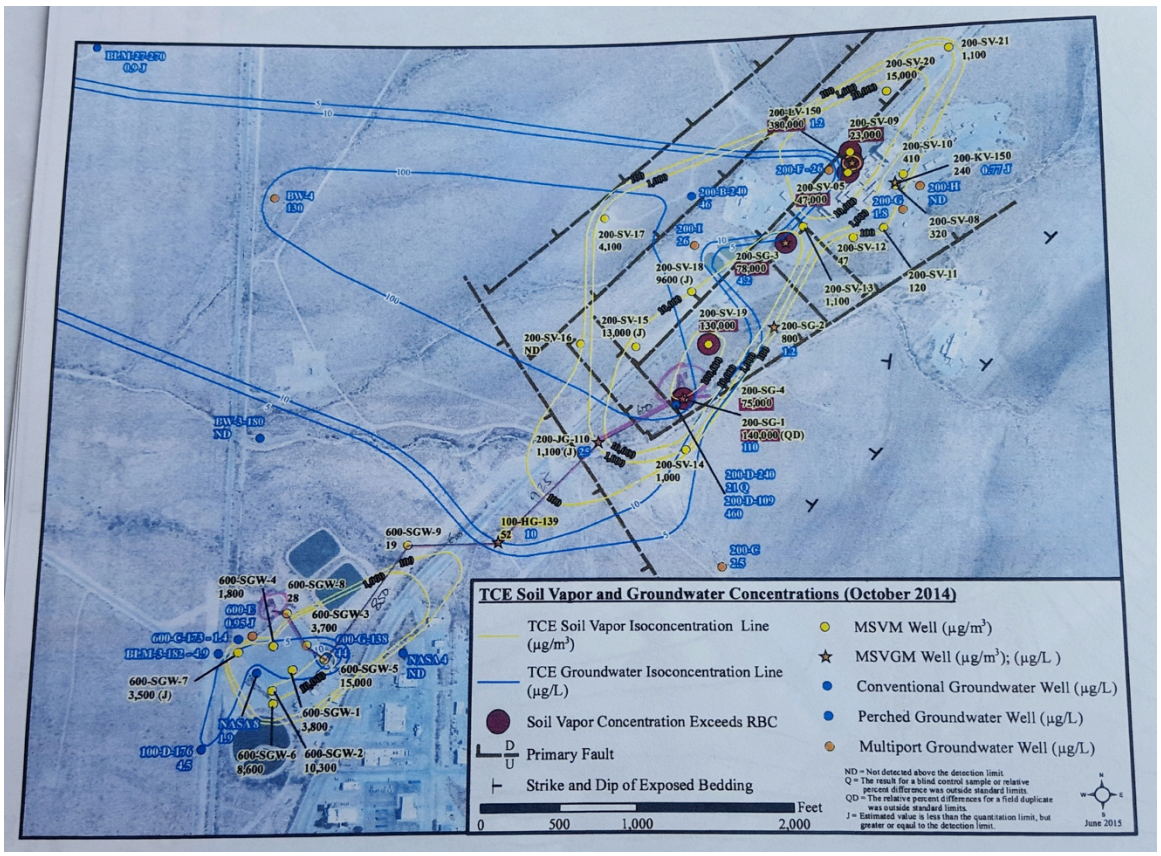


Figure 2. White Sands Test Facility TCE soil vapor and groundwater concentrations (Giles et al., pers. comm.).

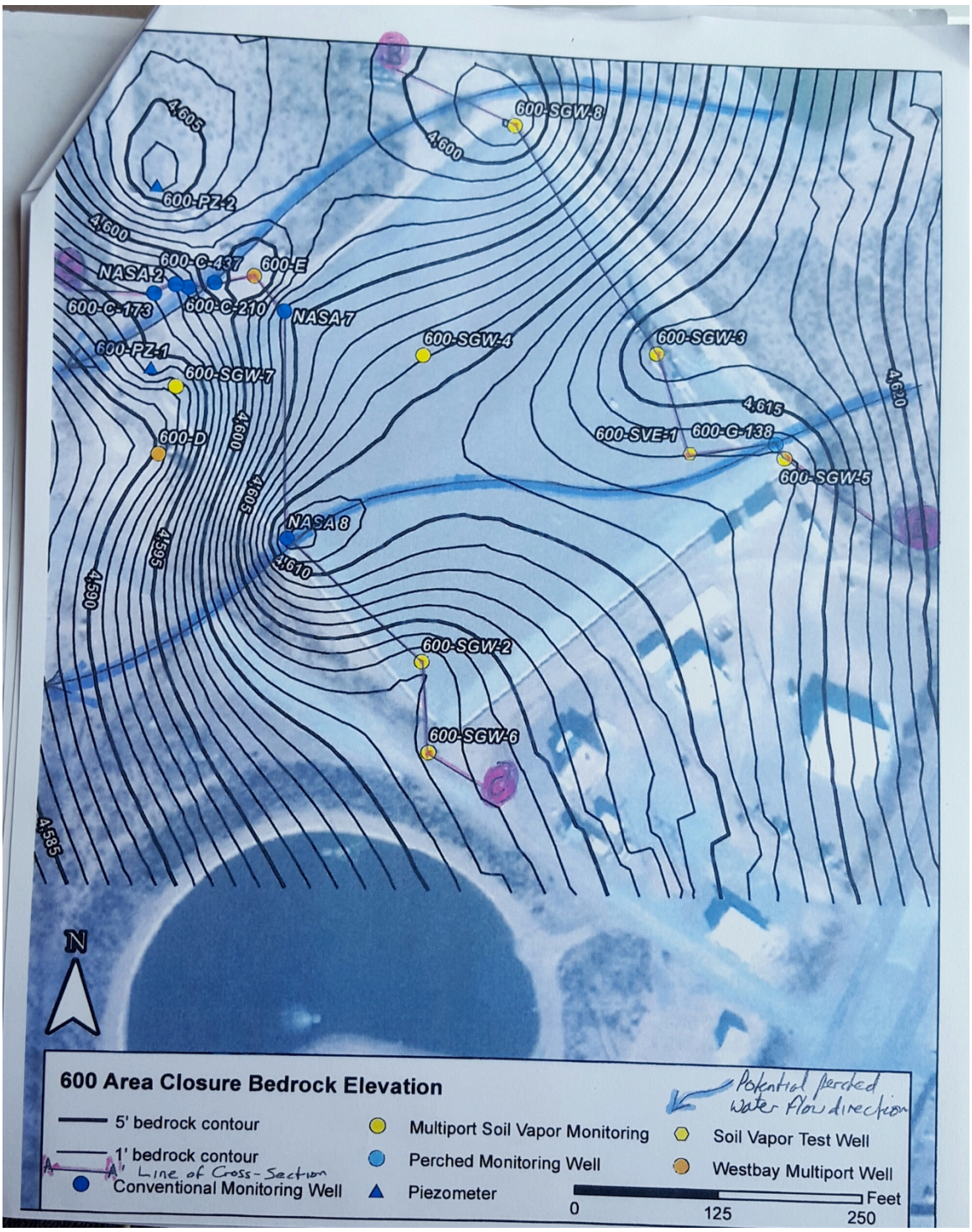


Figure 3. 600 Area closure bedrock elevation contour map (from wells, which are also shown). Blue lines indicate potential directions of perched water flow. (Giles et al., pers. comm.)

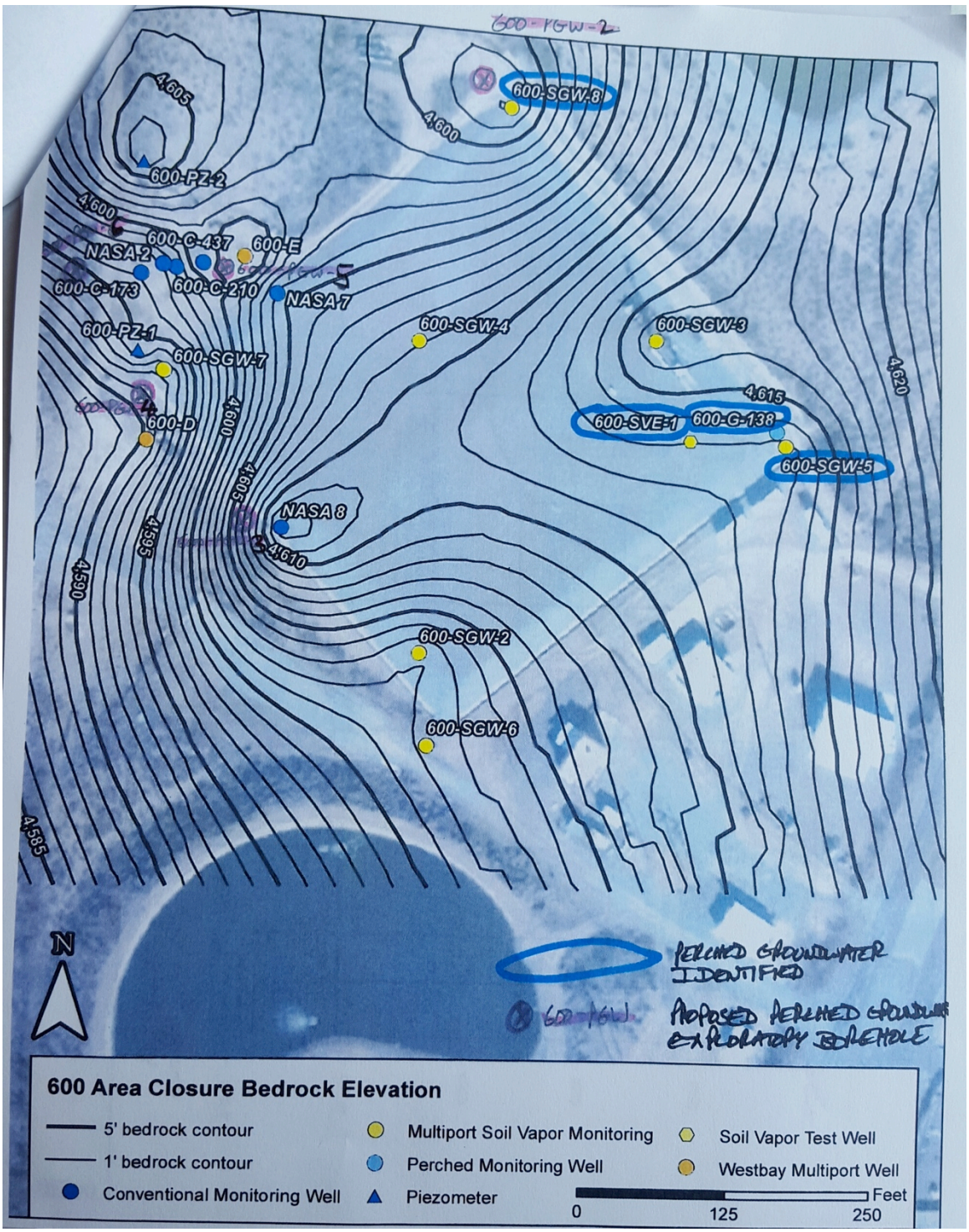


Figure 4. 600 Area closure bedrock elevation contour map (from wells, which are also shown). Blue circled wells indicate where perched water has been observed. (Giles et al., pers. comm.)

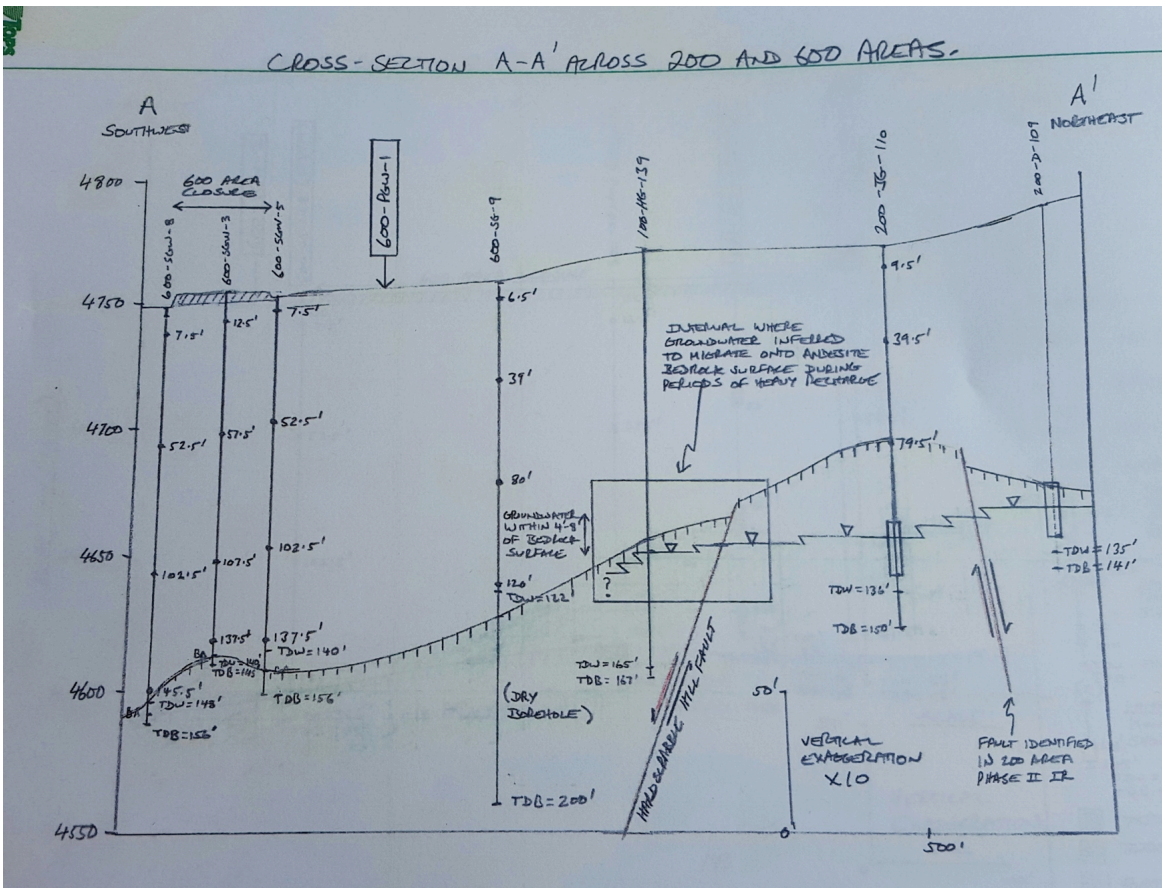


Figure 5a. Cross section along A-A' across the 200 and 600 Areas (see map in Figure 3 for cross section location). (Giles et al., pers. comm.)

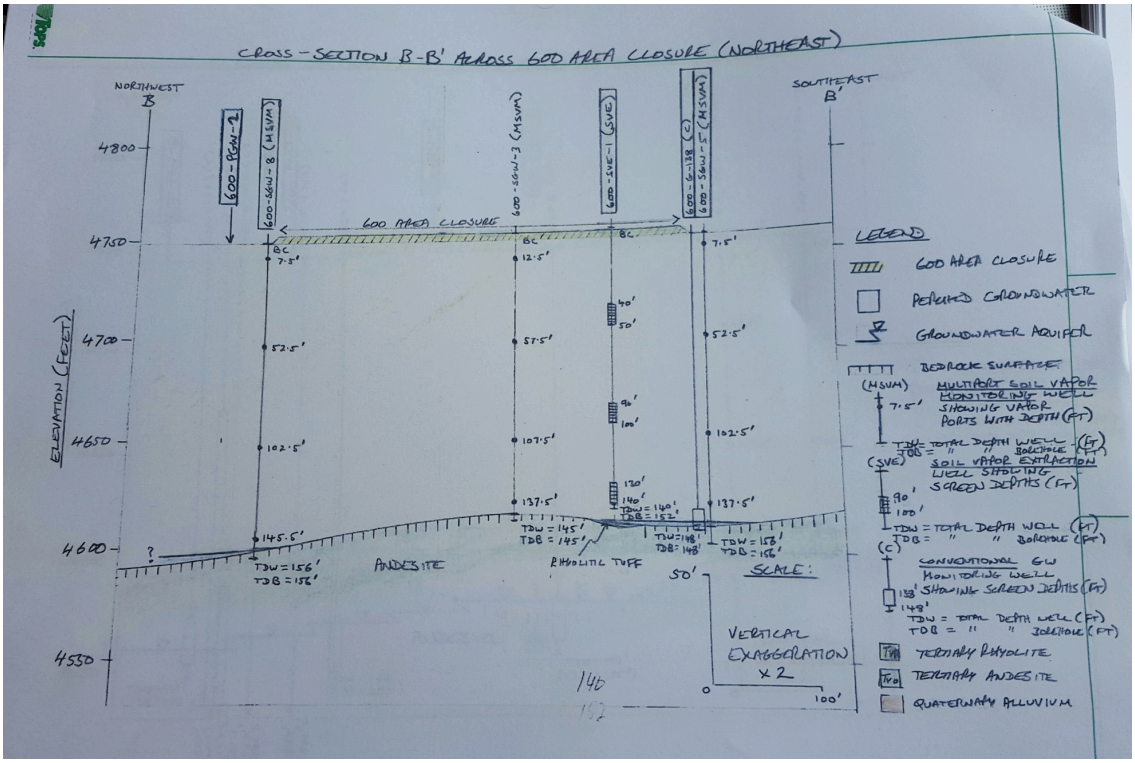


Figure 5b. Cross section along A-A' across the 200 and 600 Areas (see map in Figure 3 for cross section location). (Giles et al., pers. comm.)

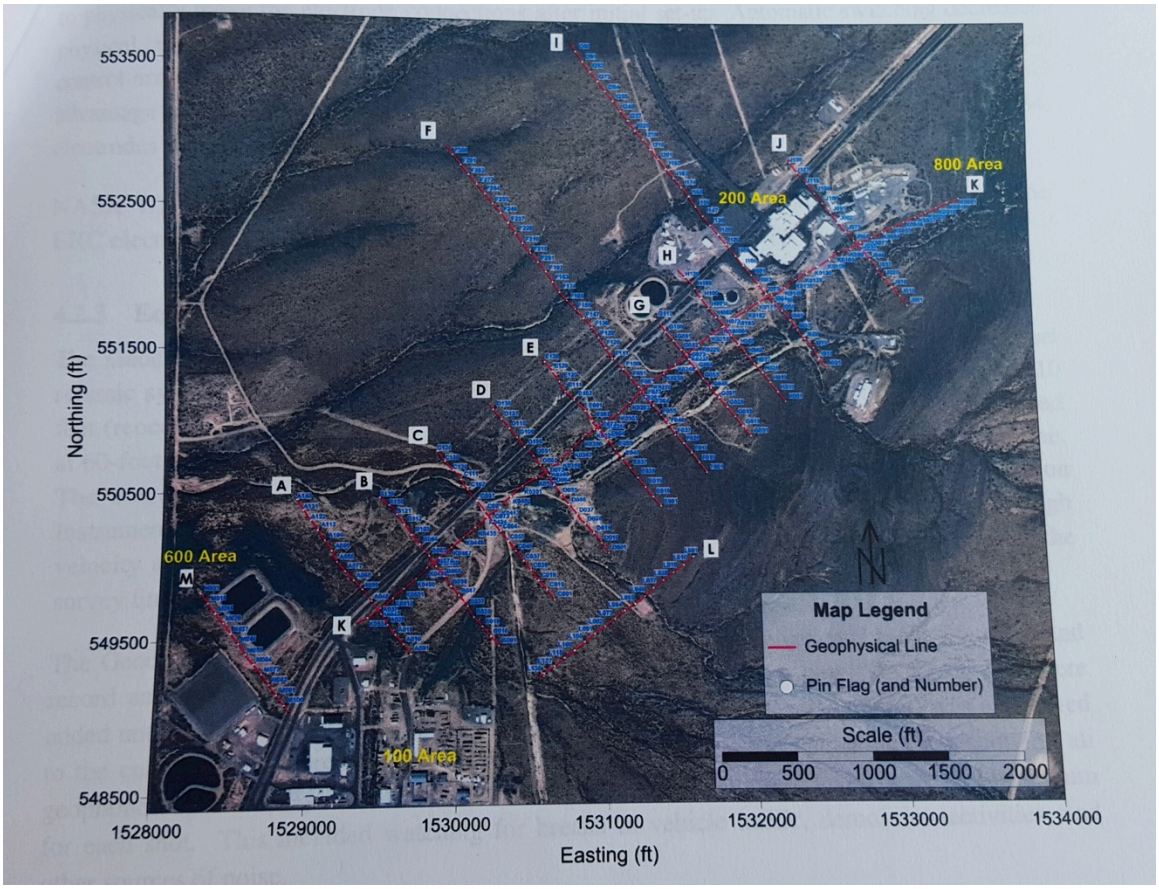


Figure 6. Locations of previous electrical resistivity surveys (Rucker et al., 2012).

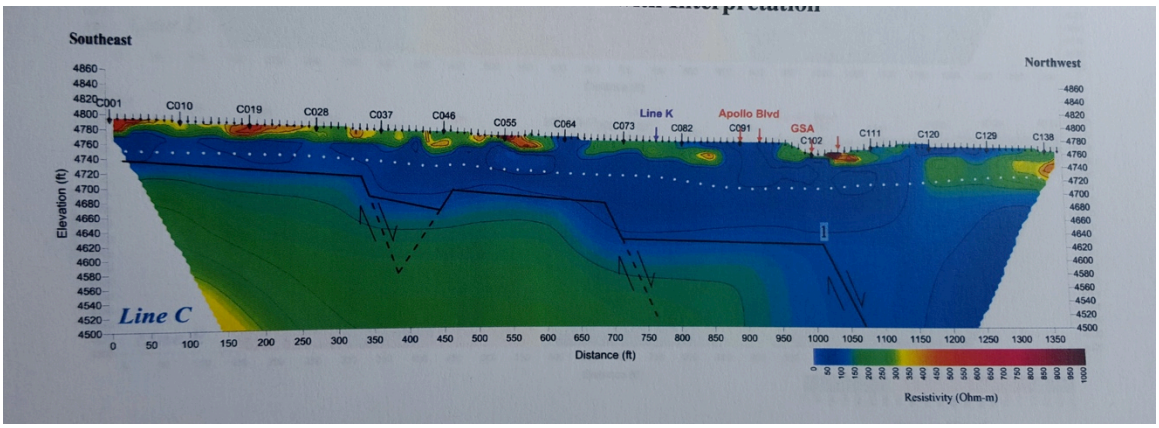


Figure 7. Line C resistivity profile, which was successful at interpreting details of the basin topography. (Rucker et al., 2012)

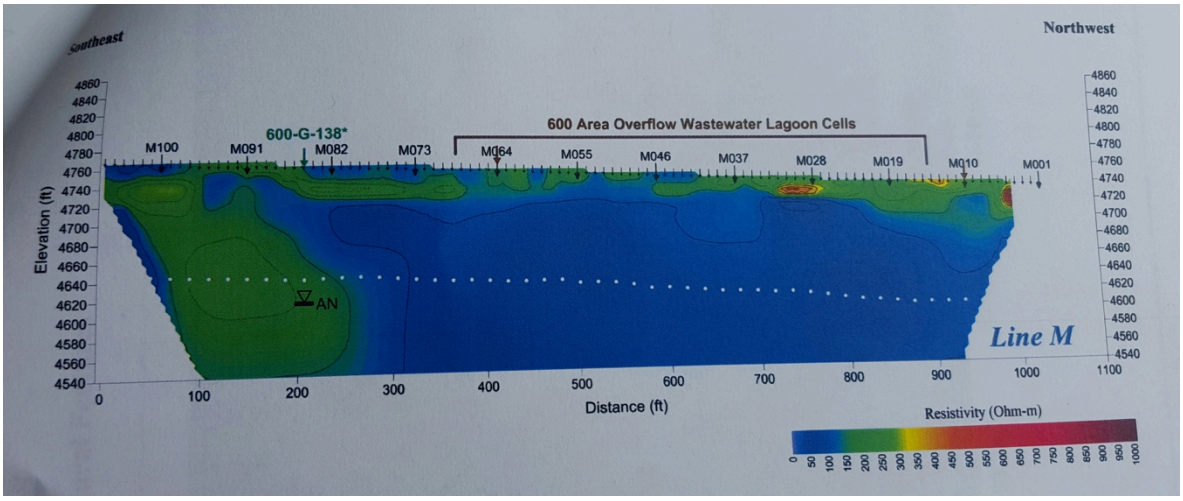


Figure 8. Line M resistivity profile, which was not successful at interpreting details of the basin topography, perhaps due to near-surface water from the wastewater lagoons. (Rucker et al., 2012)

Table 1. Bedrock data from previously drilled wells (Giles et al., pers. comm., next 2 pages)

Table 1 Bedrock Data Points (Updated 5/3/16)

Well ID	Date Installed	Well Type	Brass Cap Elevation	TD Borehole	Bedrock Depth	Rec Rev	Lithology	Bedrock Elevation	Drilling Method/ Perched Water at Bedrock	Decision Basis (Bedrock Calls)
100-D-176	05/20/97	Conventional Monitoring Well	4750.52	210	176	Yes	Andesite	**4574.52**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, rock chips
600-C-173	02/25/87	Conventional Monitoring Well	4746.1	202.6	150	Yes	Andesite	**4596.1**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-C210	06/16/87	Conventional Monitoring Well	4746.26	230	148	Yes	Andesite	**4598.26**	Mud/ air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-C-437	02/08/88	Conventional Monitoring Well	4747.12	500	145	Yes	Andesite	**4602.12**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs
600-D	06/15/95	Westbay Multiport Well	4749.54	880	160	Yes	Andesite	**4589.54**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, geophysical logs, rock chip samples
600-E	10/10/97	Westbay Multiport Well	4748.13	701	152	Yes	Andesite	**4596.13**	Mud rotary drilling to bedrock - N/A	Field notebook, lithologic logs, geophysical logs, rock chip samples
600-G-138	10/01/11	Perched Monitoring Well	4759.57	148	146	Yes	Andesite	**4613.57**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
600-PZ-1	04/21/89	Piezometer	4747.55	300	152	Yes	Andesite	**4595.55**	Air-foam rotary to bedrock - N/A	Field notebook, lithologic logs
600-PZ-2	04/28/89	Piezometer	4744.56	442	137	Yes	Andesite	**4607.56**	Air-foam rotary to bedrock - N/A	Field notebook, lithologic logs
600-SGW-2	02/01/10	Multiport Soil Vapor Monitoring	4761.6	160	160	Yes	Andesite	**4601.6**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-3	01/18/10	Multiport Soil Vapor Monitoring	4759.32	145	142	Yes	Andesite	**4617.32**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-4	01/25/10	Multiport Soil Vapor Monitoring	4755.97	155	147	Yes	Andesite	**4608.97**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-5	12/23/09	Multiport Soil Vapor Monitoring	4760.04	156	148	Yes	Andesite	**4612.04**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
600-SGW-6	01/11/10	Multiport Soil Vapor Monitoring	4758.39	156	156	Yes	Andesite	**4602.39**	ARCH - dry	Field notebook, lithologic logs, rock chip samples
600-SGW-7	12/09/09	Multiport Soil Vapor Monitoring	4748.98	158.5	158	Yes	Andesite	**4590.98**	ARCH - dry	Field notebook, lithologic logs, rock chip samples

Table 1 Bedrock Data Points (Updated 5/3/16)

Well ID	Date Installed	Well Type	Brass Cap Elevation	TD Borehole	Bedrock Depth	Rec Rev	Lithology	Bedrock Elevation	Drilling Method/ Perched Water at Bedrock	Decision Basis (Bedrock Calls)
600-SGW-8	12/16/09	Multiport Soil Vapor Monitoring	4750.34	156	153	Yes	Andesite	**4597.34**	ARCH - perched water recorded (3 - 4 ft)	Field notebook, lithologic logs, rock chip samples
600-SVE-1	10/06/11	Soil Vapor Test Well	4761.94	152	149	Yes	Rhyolitic Tuff	**4612.94**	ARCH - perched water recorded (2 - 3 ft)	Field notebook, lithologic logs, rock chip samples
BLM-3-182	02/10/87	Conventional Monitoring Well	4745.99	213.5	162	Yes	Andesite	**4583.99**	Mud/ air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 2	07/13/84	Conventional Well	4745.9	400	150	Yes	Andesite	**4595.9**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 4	03/07/85	Conventional Monitoring Well	4772.51	175	125	Yes	Limestone	**4647.51**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 7	04/05/85	Conventional Monitoring Well	4750.19	233	145	Yes	Andesite	**4605.19**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs
NASA 8	04/05/85	Conventional Monitoring Well	4753.52	235	180	Yes	Andesite	**4573.52**	Air-foam rotary drilling to bedrock - N/A	Field notebook, lithologic logs