Department of Energy
Carlsbad Field Office
P. O. Box 3090
Carlsbad, New Mexico 88221

SEP 2 9 2011

Mr. John Kieling, Acting Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, New Mexico 87505-6303

Subject: Class 2 Permit Modification Request for the Waste Isolation Pilot Plant Hazardous Waste Facility Permit, Permit Number: NM4890139088-TSDF

Dear Mr. Kieling:

Enclosed is a Class 2 Permit Modification Request containing the following items:

- Item 1, Update Ventilation Language
- Item 2, Addition of a Shielded Container
- Item 3, Revise the WIPP Groundwater Detection Monitoring Program Plan

We certify under penalty of law that this document and the enclosure were prepared under our direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on our 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 our knowledge and belief, true, accurate, and complete. We are 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, please contact George T. Basabilvazo at (575) 234-7488.

Sincerely,

Original Signatures on File

Edward Ziemianski, Interim Manager
Carlsbad Field Office

M. F. Sharif, General Manager
Washington TRU Solutions LLC

Enclosure

cc: w/ enclosure

J. Edwards, EPA	*ED
J. Davis, NMED	ED
T. Hall, NMED	ED
C. Walker, Trinity Engineering	ED
CBFO M&RC	

*ED denotes electronic distribution

CBFO:OESH:GTB:ANC:11-1332:UFC 5487.00

Item 1

Class 2 Permit Modification Request

Update Ventilation Language

Waste Isolation Pilot Plant
Carlsbad, New Mexico

WIPP Permit Number - NM4890139088-TSDF

September 2011

Table of Contents

Transmittal Letter

Acronyms/Abbreviations/Units

CFR	Code of Federal Regulations
CH	contact-handled
HWDU	Hazardous Waste Disposal Unit
MSHA	Mine Safety and Health Administration
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
Permit	Hazardous Waste Facility Permit
PMR	Permit Modification Request
RH	remote-handled
scfm	standard cubic feet per minute
SOP	standard operating procedure
TRU	transuranic
VOC	volatile organic compound
WIPP	Waste Isolation Pilot Plant

Overview of the Permit Modification Request

This document contains one Class 2 Permit Modification Request (**PMR**) for the Waste Isolation Pilot Plant (**WIPP**) Hazardous Waste Facility Permit (**Permit**) Number NM4890139088-TSDF.

This PMR is being submitted by the U.S. Department of Energy Carlsbad Field Office and Washington TRU Solutions LLC, collectively referred to as the Permittees, in accordance with the WIPP Permit, Part 1, Condition 1.3.1 (20.4.1.900 New Mexico Administrative Code (**NMAC**) incorporating Title 40 Code of Federal Regulations (**CFR**) 270.42(b)). The modification provides for the following changes:

- Add definition of a filled room.
- Revise language to indicate when 35,000 standard cubic feet per minute (**scfm**) is required for worker entry into active rooms and when reporting is required.
- Change a related reporting requirement.

These changes do not reduce the ability of the Permittees to provide continued protection to human health and the environment**.**

The requested modification to the WIPP Permit is provided in this PMR. The proposed modification to the text of the WIPP Permit has been identified using red text and a double underline and a ~~strikeout~~ font for deleted information. All direct quotations are indicated by italicized text. The following information specifically addresses how compliance has been achieved with the WIPP Permit requirement, Permit Part 1, Condition 1.3.1. for submission of this Class 2 PMR.

1. 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(i)) requires the applicant to describe the exact change to be made to the permit conditions and supporting documents referenced by the Permit.

The Permittees are proposing the following changes in this PMR:

1. Add definition for a “filled room” in Condition 1.5.19.
2. Add clarifying language in Conditions 4.5.3.2, Attachment A2, Section A2-2a(3), Attachment O, Section O-1, Section O-2, Section O-3, Section O-3c(1), Section O-3c(2), and Section O-5a to indicate that 35,000 scfm is required for worker entry into any active CH TRU mixed waste room that is adjacent to a filled room or in room 7 of any panel.
3. Modify when reporting to the New Mexico Environment Department (NMED) is necessary if the ventilation requirements are not met. Delete text in O-3b(2) since it is redundant with the reporting requirements in O-5a and condition 4.6.4.3.

The Table of Changes (Appendix A) and proposed text changes in redline strikeout (Appendix B) of this PMR describe each change that is being proposed. Appendix A provides a detailed list of changes by Permit section.

2. 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(ii)), requires the applicant to identify that the modification is a Class 2 modification.

The Permittees are submitting this PMR as specified in Item A.4.b of Appendix I in 20.4.1.900 NMAC (incorporating 40 CFR 270.42) which states: "*Changes in the frequency of or procedures for monitoring, reporting, sampling or maintenance activities by the permittee: other changes.*" Therefore this modification request is a Class 2 under Item A.4.b.

3. 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(iii)), requires the applicant to explain why the modification is needed.

The basis for this PMR is to improve the protection of operating personnel by reducing the time the workers must be present in the exhaust air of panels to adjust ventilation regulators. Permit Attachment A4, Section A4-4 states that *"[t]he exhaust drift in the waste disposal area will normally not be used for personnel access."* This restriction minimizes the chance for exposure to emissions from the waste. This PMR proposes to use the active remote-handled (**RH**) transuranic (**TRU**) mixed waste disposal room to gain access to the ventilation louvers without requiring workers to travel the longer distances down the exhaust drift even if the ventilation flow rate in the RH TRU mixed waste disposal room is less than 35,000 scfm. Currently workers have to enter and travel within the ventilation exhaust areas to adjust ventilation. This PMR proposes to ameliorate this circumstance by minimizing the amount of time a worker must spend down-wind from the waste. This is accomplished by changing the restriction regarding access to rooms that contain TRU mixed waste. Specifically, this modification makes it acceptable for a worker to enter an RH TRU mixed waste room with less than 35,000 scfm as long as that room is not adjacent to a filled contact-handled (**CH**) TRU mixed waste room and RH TRU waste handling is not under way in the room. Using the RH TRU mixed waste room to access the ventilation control louvers shortens the travel path for workers and minimizes the amount of time that must be spent in the exhaust drift. This modification also clarifies that workers are not allowed into a CH TRU mixed waste room that is adjacent to a filled CH TRU mixed waste room or in Room 7 of any panel when CH TRU mixed waste is being disposed without a minimum airflow of 35,000 scfm. This proposed change is consistent with the exposure modeling and the administrative history of the Permit as discussed below. This change does not waive any ventilation requirements imposed by the Mine Safety and Health Administration (**MSHA**).

There are times when it is necessary to enter an active disposal room in order to establish normal ventilation. In such cases and in order to protect workers, reentry is accomplished in accordance with a standard operating procedure (**SOP**). According to the SOP the ventilation mode is shifted to "Filtration Mode" for thirty minutes prior to reentry to the underground. Also prior to reentry into the underground, filters at radiological station A are checked for radiological contamination. Then workers are allowed underground to establish that adequate air quality exists as defined by MSHA (30 CFR 57.5015) and the SOP including volatile organic compounds (**VOCs**) as appropriate. Once air quality has been determined to be acceptable the reentry team proceeds to the active panel area to inspect for abnormal conditions (i.e., fire, roof fall, or dropped/breached containers). Once the condition has been determined to be adequate, normal ventilation and entry to the underground may be established. This process is a systematic approach to prevent the inadvertent release of radioactive contamination and assures protection of human health and the environment.

Normally, the active panel inspection can be performed from the entry to the active room (i.e., from the intake drift at the room entrance). In order to assure such reentry activity can be performed after the Permit is modified, language is placed in Attachment O, Section O-3c(2) that specifically exempts entry for establishing normal ventilation (i.e., 35,000 scfm) from the requirement that ventilation be verified to be at 35,000 scfm prior to entering. The language requires that such entry be noted in the log book so that clear documentation of such events is kept in the Operating Record for the facility.

In addition, modification of the reporting requirements is proposed. Currently, there is a 7-day notification requirement whenever the ventilation requirements are not met. This is triggered after a monthly review of the ventilation records. The Permittees are proposing in place of the 7-day notification, which is usually reserved to situations which pose risk to human health or the environment, that instances where the ventilation requirements are not achieved be reported annually in the Mine Ventilation Rate Monitoring Annual Report. To this extent, the Permittees are proposing changes to the text in Permit Part 4, Condition 4.6.4.3 and Permit Attachment O, Sections O-3b(2) and O-5a. Currently required calculations, measurements and evaluations will remain the same. The changes will only be to the reporting mechanism, and frequency.

Source of the 35,000 scfm Ventilation Requirement in the Permit:

When the Permittees prepared their Permit Application in 1996, the NMED requested that several exposure scenarios be examined to evaluate the potential releases of VOCs and the effects on underground workers (WIPP RCRA Part B Permit Application, DOE/WIPP 91-005, Revision 6 Appendix D9, Attachment 1). These scenarios involved a roof fall in an open room (i.e., one being actively filled with CH TRU mixed waste) and a closed room (i.e., a CH TRU mixed waste room that was filled with drums of waste and had ventilation barriers in place). Two other scenarios evaluated “normal operations” to determine risk to workers actively placing waste in CH TRU mixed waste rooms when no roof fall occurs. In all four cases, the potentially exposed individual was an underground waste handler working in the active CH TRU mixed waste room. The four scenarios are shown in Figures 1 to 4 which are taken from the NMED’s written testimony submitted during the original Permit hearings in 1999 (NMED Direct Testimony Regarding Regulatory Process and Imposed Conditions” (HRM 98-04(P))). In all four cases, the NMED determined that the combination of the environmental performance standards (established through room-based limits) and the minimum ventilation of 35,000 scfm were sufficient to protect these workers. Hence, the Permit was issued with the condition that 35,000 scfm be maintained whenever workers are present in an active room (Permit Attachment O, multiple locations).

Applicability to RH TRU Mixed Waste Rooms:

At the time the Permit was issued in 1999, RH TRU waste was prohibited and RH TRU waste emplacements were not included in the NMED’s ventilation analysis. Rooms that are being filled with RH TRU waste represent one additional scenario as shown in Figure 5. As can be seen in Figure 5, the worker is unaffected by normal operations or a roof fall in the adjacent CH TRU mixed waste room and by any roof fall scenario in the adjacent filled room by virtue of the fact that the ventilation flow through the active CH TRU mixed waste room bypasses the active RH TRU mixed waste room. In other words, because RH TRU mixed waste rooms are upstream from CH TRU mixed waste rooms, the RH TRU mixed waste worker in an RH TRU mixed waste room is never in the CH TRU mixed waste room ventilation stream, and therefore would not be subject to the consequences of the roof-fall scenario.

Volatile Organic Compound emissions from RH TRU waste itself are negligible due to the low volume of RH TRU waste being emplaced. The Permit Part 4.1.12 restricts the volume of RH waste that can be placed in each panel. Based on the current Panel 7 volume limit in Part 4.1.1.2 this restriction equates to less than 104 canisters per disposal room. Furthermore, RH is emplaced in boreholes with shield plugs and is not subject to active ventilation similar to drums of waste on the floor of an active room. Therefore, this emplacement configuration restricts VOC emissions from RH TRU mixed waste into the active disposal room.

Appropriateness of the Proposed Changes:

The changes proposed in the PMR are based on the NMED record that indicates the concern for maintaining adequate ventilation is to protect workers from exposure to harmful concentrations of VOCs in the active CH TRU mixed waste room adjacent to a filled CH TRU mixed waste room or in Room 7 of any panel during normal operations and in the event of a roof fall. These harmful concentrations cannot occur in the RH TRU mixed waste rooms during normal operations or as the result of the roof fall. Therefore, the change specifically limits the condition to maintain 35,000 scfm to any active room that is adjacent to a filled disposal room when workers are present. A “filled room” is also defined so there is no confusion regarding this terminology. The change normally would apply to the room in a panel that is receiving CH TRU mixed waste and not to an RH TRU mixed waste disposal room. However, there may be circumstances when a room is filled with CH TRU mixed waste and there is remaining RH TRU mixed waste to be emplaced in the next room. Another situation exists with Room 7 in each panel when CH TRU mixed waste is being disposed. Since this is the first room filled there is no adjacent filled room. In such cases, the requirement for 35,000 scfm would apply to the RH TRU mixed waste room (i.e., the room adjacent to a filled disposal room) and to Room 7 of any panel when CH TRU mixed waste is being disposed.

Figure 6 shows the current and proposed worker pathways to adjust the ventilation regulators. Clearly, the pathway allowed by this proposed modification is significantly shorter and thereby reduces the time that a worker must be downstream of the emplaced waste.

4. 20.4.1.900 NMAC (incorporating 40 CFR 270.42 (b)(1)(iv)), requires the applicant to provide the applicable information required by 40 CFR 270.13 through 270.21, 270.62 and 270.63.

Regulatory citations in this modification reference 20.4.1.900 NMAC (incorporating 40 CFR §§270.13-15) revised March, 2009. Title 40 CFR §§270.16 through 270.22, 270.62, 270.63 and 270.66 are not applicable at WIPP. Consequently, they are not included. Title 40 CFR §270.23 is applicable to the WIPP Hazardous Waste Disposal Units (**HWDUs**). This modification does not impact the conditions associated with the HWDUs.

5. 20.4.1.900 NMAC (incorporating 40 CFR 270.11(d)(1) and 40 CFR 270.30(k)), requires that any person signing under paragraph a and b must certify the document in accordance with 20.4.1.900 NMAC.

The transmittal letter for this PMR contains the signed certification statement in accordance with Part 1, Condition 1.9 of the Permit.

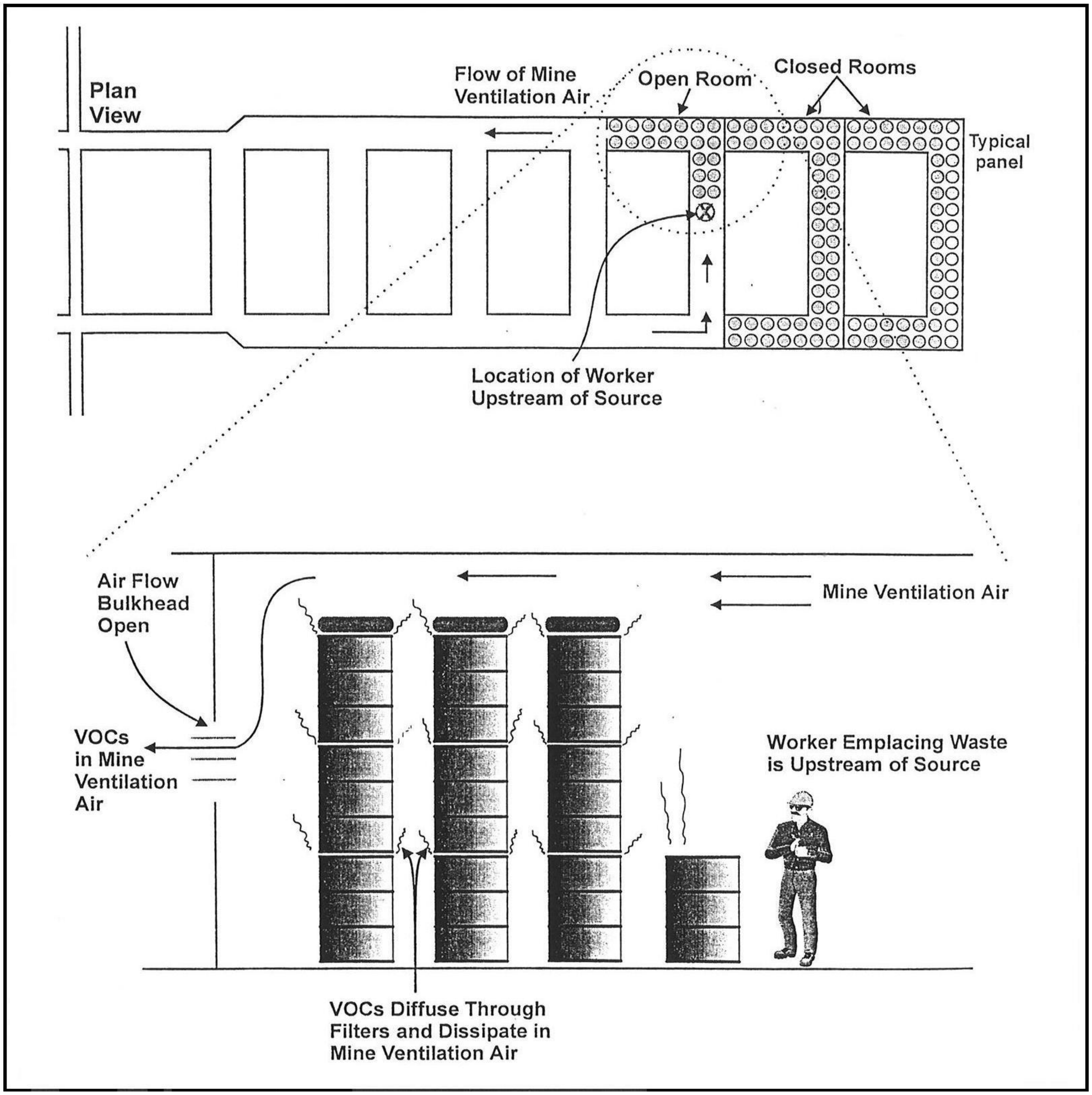

Figure 1
VOC Emissions from an Open Room, Open Panel under Normal Operation

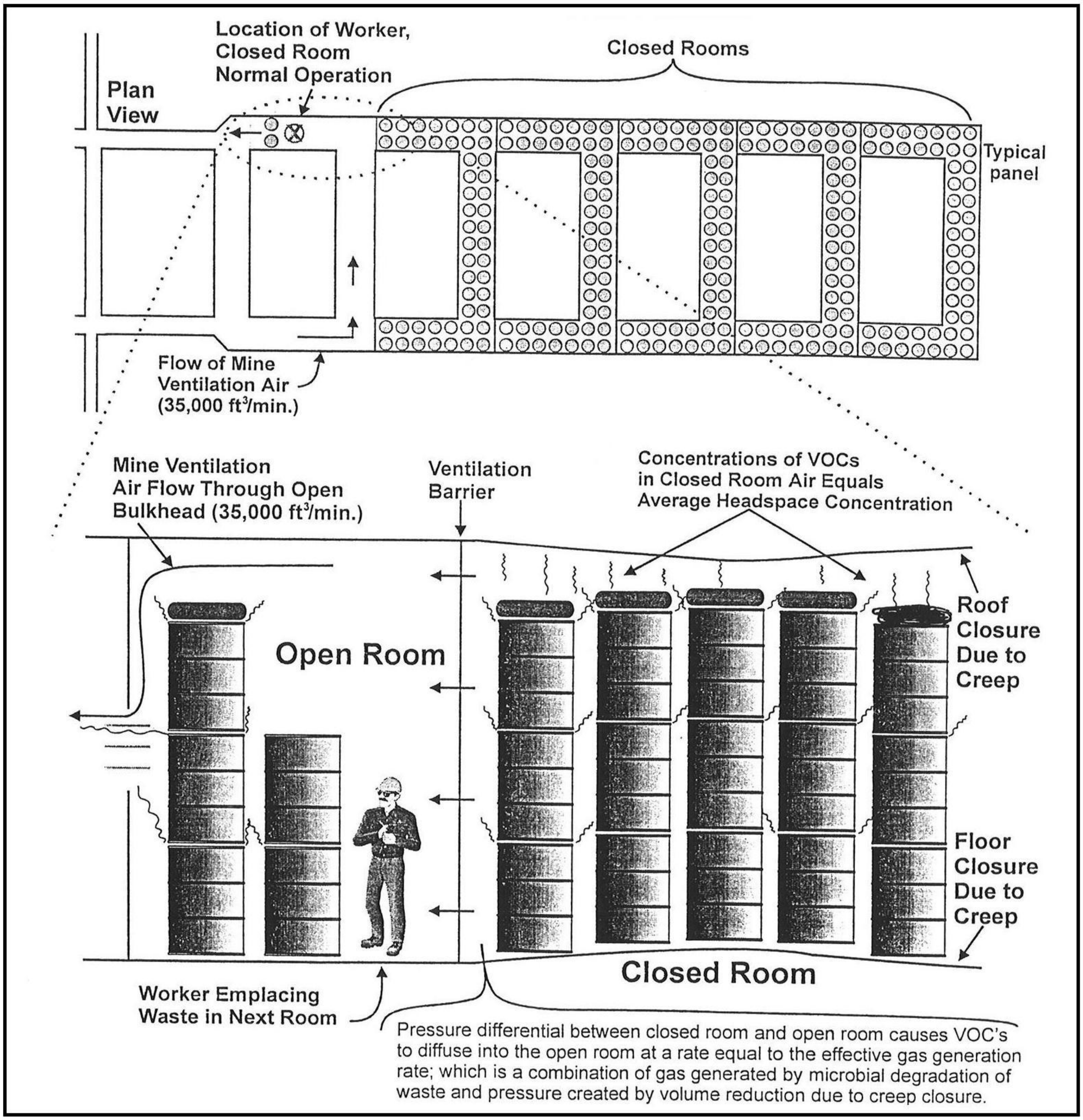

Figure 2
VOC Emissions from a Closed Room, Open Panel under Normal Operation

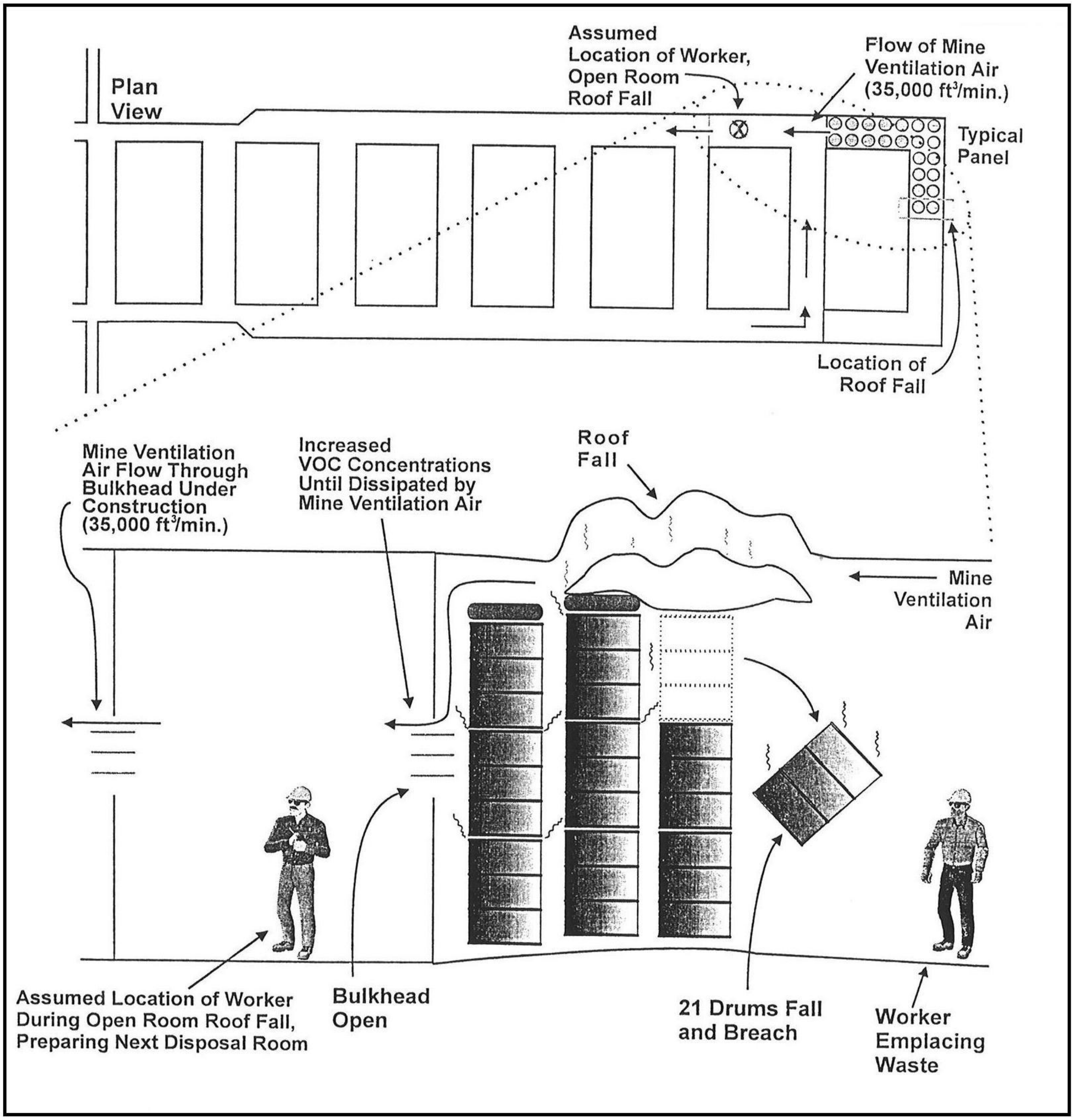

Figure 3
Roof Fall in an Open Room

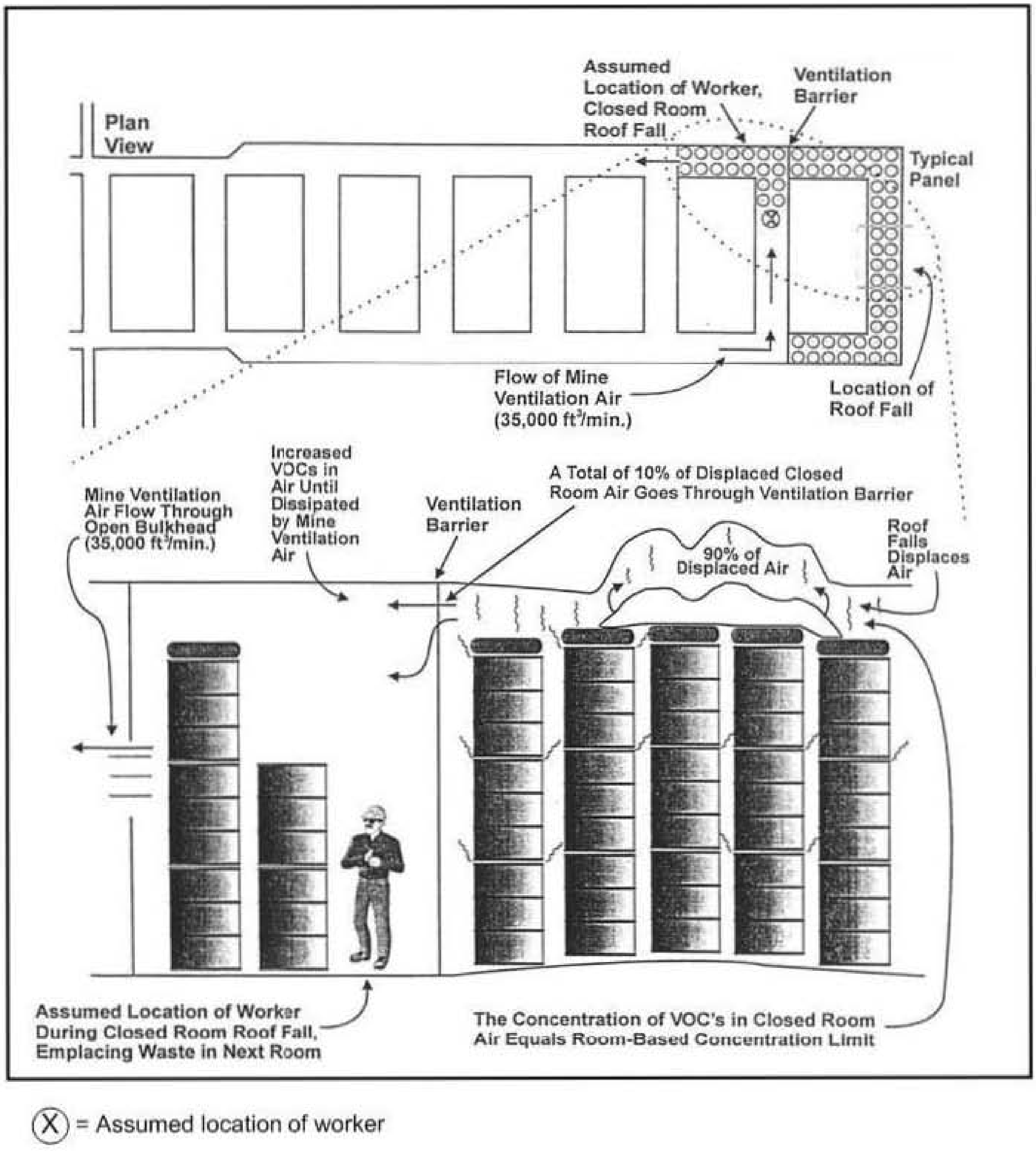

Figure 4
Roof Fall in Closed Room

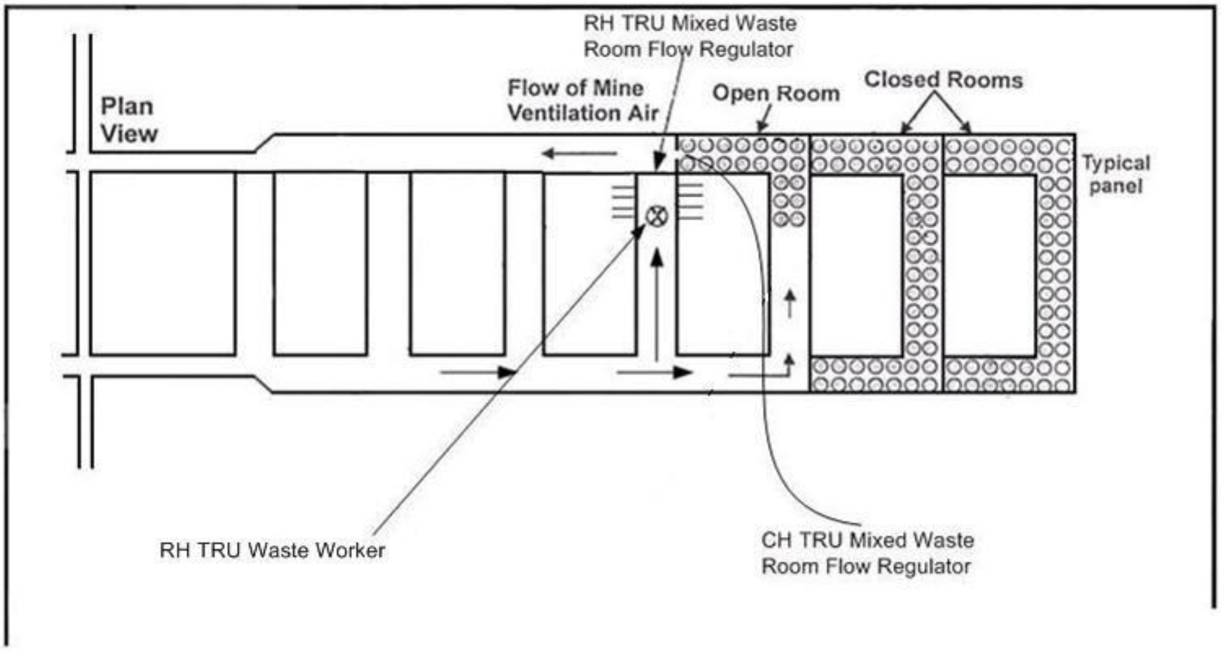

Figure 5
Location of Worker Emplacing RH-TRU Mixed Waste

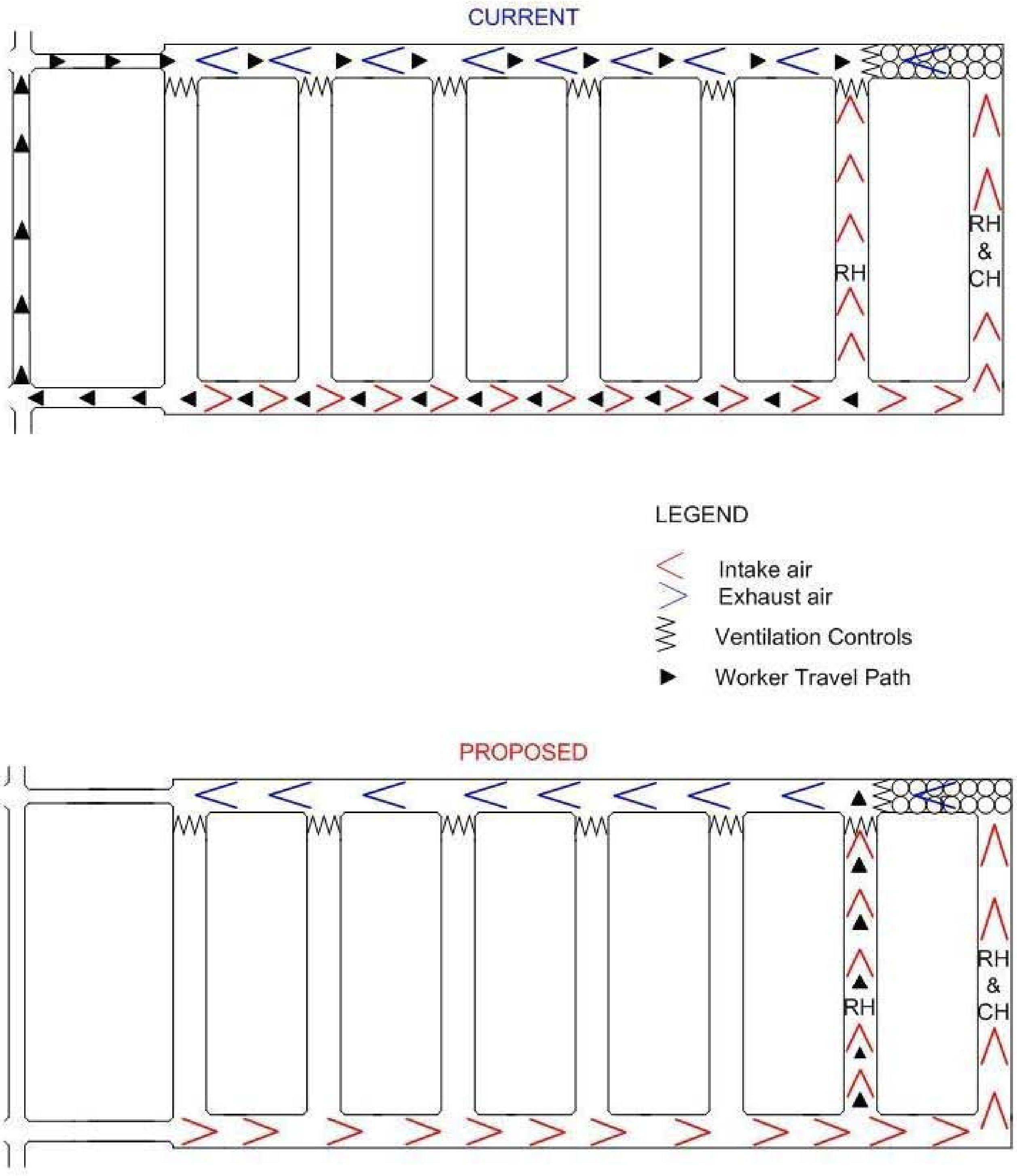

Figure 6
Current and Proposed Routes

Regulatory Crosswalk

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.13		Contents of Part A permit application	Attachment B Part A		✓
§270.14(b)(1)		General facility description	Attachment A		✓
§270.14(b)(2)	§264.13(a)	Chemical and physical analyses	Part 2.3.1 Attachment C		✓
§270.14(b)(3)	§264.13(b)	Development and implementation of waste analysis plan	Part 2.3.1.1 Attachment C		✓
	§264.13(c)	Off-site waste analysis requirements	Part 2.2.1 Attachment C		✓
§270.14(b)(5)	§264.15(a-d)	General inspection requirements	Part 2.7 Attachment E-1a		✓
	§264.174	Container inspections	Attachment E-1b(1)		✓
§270.23(a)(2)	§264.602	Miscellaneous units inspections	Attachment E-1b Attachment E-1b(1)		✓
§270.14(b)(6)		Request for waiver from preparedness and prevention requirements of Part 264 Subpart C	NA		✓
§270.14(b)(7)	264 Subpart D	Contingency plan requirements	Part 2.12 Attachment D		✓
	§264.51	Contingency plan design and implementation	Part 2.12.1 Attachment D		✓
	§264.52 (a) & (c-f)	Contingency plan content	Attachment D		✓
	§264.53	Contingency plan copies	Part 2.12.2 Attachment D		✓
	§264.54	Contingency plan amendment	Part 2.12.3 Attachment D		✓
	§264.55	Emergency coordinator	Part 2.12.4 Attachment D-4a(1)		✓
	§264.56	Emergency procedures	Attachment D-4		✓
§270.14(b)(8)		Description of procedures, structures or equipment for:	Attachment A Part 2.11		✓
§270.14(b)(8)(i)		Prevention of hazards in unloading operations (e.g., ramps and special forklifts)	Part 2.11		✓
§270.14(b)(8)(ii)		Runoff or flood prevention (e.g., berms, trenches, and dikes)	Attachment A1-1c(1) Part 2.11		✓
§270.14(b)(8)(iii)		Prevention of contamination of water supplies	Part 2.11		✓
§270.14(b)(8)(iv)		Mitigation of effects of equipment failure and power outages	Part 2.11		✓
§270.14(b)(8)(v)		Prevention of undue exposure of personnel (e.g., personal protective equipment)	Part 2.11		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	**Yes**	**No**
§270.14(b)(8)(vi) §270.23(a)(2)	§264.601	Prevention of releases to the atmosphere	Part 2.11 Part 4.4 Attachment D-4e Attachment G-1a		✓
	264 Subpart C	Preparedness and Prevention	Part 2.10		✓
	§264.31	Design and operation of facility	Part 2.1		✓
	§264.32	Required equipment	Part 2.10.1 Attachment D		✓
	§264.33	Testing and maintenance of equipment	Part 2.10.2 Attachment E-1a		✓
	§264.34	Access to communication/alarm system	Attachment E-1a Part 2.10.3		✓
	§264.35	Required aisle space	Part 2.10.4		✓
	§264.37	Arrangements with local authorities	Attachment D-4a(3)		✓
§270.14(b)(9)	§264.17(a-c)	Prevention of accidental ignition or reaction of ignitable, reactive, or incompatible wastes	Part 2.9		✓
§270.14(b)(10)		Traffic pattern, volume, and controls, for example: Identification of turn lanes Identification of traffic/stacking lanes, if appropriate Description of access road surface Description of access road load-bearing capacity Identification of traffic controls	Attachment A4		✓
§270.14(b) (11)(i) and (ii)	§264.18(a)	Seismic standard applicability and requirements	Attachment G2-2.2 Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(11)(iii-v)	§264.18(b)	100-year floodplain standard	Attachment A1-1c(1) Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b) (12)	§264.16(a-e)	Personnel training program	Part 2.8 Attachment F		✓
§270.14(b)(13)	264 Subpart G	Closure and post-closure plans	Part 6 & 7 Attachment G & H		✓
§270.14(b)(13)	§264.111	Closure performance standard	Attachment G-1a		✓
§270.14(b)(13)	§264.112(a), (b)	Written content of closure plan	Attachment G-1		✓
§270.14(b)(13)	§264.112(c)	Amendment of closure plan	Part 6.3 Attachment G-1d(4)		✓
§270.14(b)(13)	§264.112(d)	Notification of partial and final closure	Attachment G-2a		✓
§270.14(b)(13)	§264.112(e)	Removal of wastes and decontamination/dismantling of equipment	Attachment G-1e(2)		✓
§270.14(b)(13)	§264.113	Time allowed for closure	Part 6.5 Attachment G-1d		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.14(b)(13)	§264.114	Disposal/decontamination	Part 6.6 Attachment G-1e(2)		✓
§270.14(b)(13)	§264.115	Certification of closure	Part 6.7 Attachment G-2a		✓
§270.14(b)(13)	§264.116	Survey plat	Part 6.8 Attachment G-2b		✓
§270.14(b)(13)	§264.117	Post-closure care and use of property	Part 7.3 Attachment H-1a		✓
§270.14(b)(13)	§264.118	Post-closure plan; amendment of plan	Part 7.5 Attachment H-1a (1)		✓
§270.14(b)(13)	§264.178	Closure/containers	Part 6.9 Attachment A1-1h Attachment G-1		✓
§270.14(b)(13)	§264.601	Environmental performance standards-miscellaneous units	Attachment A-4 Attachment D-1 Attachment G-1a		✓
§270.14(b)(13)	§264.603	Post-closure care	Part 7.3 Attachment G-1a(3)		✓
§270.14(b)(14)	§264.119	Post-closure notices	Part 7.4 Attachment H-2		✓
§270.14(b)(15)	§264.142	Closure cost estimate	NA		✓
	§264.143	Financial assurance	NA		✓
§270.14(b)(16)	§264.144	Post-closure cost estimate	NA		✓
	§264.145	Post-closure care financial assurance	NA		✓
§270.14(b)(17)	§264.147	Liability insurance	NA		✓
§270.14(b)(18)	§264.149-150	Proof of financial coverage	NA		✓
§270.14(b)(19)(i), (vi), (vii), and (x)		Topographic map requirements Map scale and date Map orientation Legal boundaries Buildings Treatment, storage, and disposal operations Run-on/run-off control systems Fire control facilities	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(ii)	§264.18(b)	100-year floodplain	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(iii)		Surface waters	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.14(b)(19)(iv)		Surrounding land use	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(v)		Wind rose	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(viii)	§264.14(b)	Access controls	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(ix)		Injection and withdrawal wells	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(xi)		Drainage on flood control barriers	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(xii)		Location of operational units	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(20)		Other federal laws Wild and Scenic Rivers Act National Historic Preservation Act Endangered Species Act Coastal Zone Management Act Fish and Wildlife Coordination Act Executive Orders	Attachment B Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.15	§264 Subpart I	Containers	Part 3 Part 4.3 Attachment A1		✓
	§264.171	Condition of containers	Part 3.3 Attachment A1		✓
	§264.172	Compatibility of waste with containers	Part 3.4 Attachment A1		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	**Yes**	**No**
	§264.173	Management of containers	Part 3.5 Attachment A1		✓
	§264.174	Inspections	Part 3.7 Attachment E-1 Attachment A1-1e		✓
§270.15(a)	§264.175	Containment systems	Part 3.6 Attachment A1		✓
§270.15(c)	§264.176	Special requirements for ignitable or reactive waste	Attachment A1-1g Permit Part 2.1		✓
§270.15(d)	§264.177	Special requirements for incompatible wastes	Attachment A1-1g Permit Part 2.3.3.4		✓
	§264.178	Closure	Part 6 Attachment G		✓
§270.15(e)	§264.179	Air emission standards	Part 4.4.2 Attachment N		✓
§270.23	264 Subpart X	Miscellaneous units	Part 1.3.1 Attachment A2-1 Attachment G1.3.1		✓
§270.23(a)	§264.601	Detailed unit description	Part 4 Part 5 Attachment A2 Attachment L		✓
§270.23(b)	§264.601	Hydrologic, geologic, and meteorologic assessments	Part 4 Part 5 Attachment A2 Attachment L		✓
§270.23(c)	§264.601	Potential exposure pathways	Part 4 Attachment A2 Attachment N	✓	
§270.23(d)		Demonstration of treatment effectiveness	Part 4 Attachment A2 Attachment N		✓
	§264.602	Monitoring, analysis, inspection, response, reporting, and corrective action	Part 4 Part 5 Attachment A2 Attachment E-1 Attachment N Attachment L		✓
	§264.603	Post-closure care	Attachment H Attachment H1		✓
	264 Subpart E	Manifest system, record keeping, and reporting	Permit Part 1 Permit Part 2.13 & 2.14 Permit Part 4 Attachment C		✓
§270.30(j)(2)	§264.73(b)	Ground-water records	Part 1		✓
	264 Subpart F	Releases from solid waste management units	Part 5 & 7 Attachment G2 & L		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
	§264.90	Applicability	Part 5 Attachment L		✓
	§264.91	Required programs	Attachment L		✓
	§264.92	Ground-water protection standard	Attachment L		✓
	§264.93	Hazardous constituents	Attachment L		✓
	§264.94	Concentration limits	Part 5 Attachment L		✓
	§264.95	Point of compliance	Part 5 Attachment L		✓
	§264.96	Compliance period	Attachment L		✓
	§264.97	General ground-water monitoring requirements	Part 5 Attachment L		✓
	§264.98	Detection monitoring program	Part 5 Attachment L		✓
	§264.99	Compliance monitoring program	Part 5 Attachment L		✓
	§264.100	Corrective action program	Part 5 Attachment L		✓
	§264.101	Corrective action for solid waste management units	Part 8 Attachment L		✓
	264 Appendix IX	Ground-water Monitoring List	Part 5 Attachment L		✓

Appendix A
Table of Changes

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Table of Changes

Affected Permit Section	Explanation of Change	Page Number
- Part 1, Condition 1.5.19.	- Added definition for Filled Room	B-2
- Part 4, Condition 4.5.3.2.	- Deleted "active" - Deleted "the" - Added "an active" - Added "adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed"	B-2 B-2 B-2 B-2
- Part 4, Condition 4.6.4.3.	- Deleted "Notification" - Added "Evaluation" - Deleted "Whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section 4.5.3.2 have not been achieved, the" - Added "The" - Deleted "notify" replaced with "report to" - Deleted "writing within seven calendar days" - Added "the annual report specified in Permit Section 4.6.4.2 whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section 4.5.3.2 have not been achieved"	B-2 B-2 B-2 B-2 B-2 B-2
- Attachment A2, Section A2-2a(3)	- Added "active" - Added "that is adjacent to a filled room" - Deleted "where waste disposal is taking place" - Added "or in Room 7 of any panel when CH TRU mixed waste is being disposed" - Deleted "The" - Added "Filled" - Deleted "that are filled with waste" - Deleted "the" - Added "adjacent active" - Deleted " that are actively being filled" - Add "or in Room 7 of any panel when CH TRU mixed waste is being disposed."	B-3 B-3
- Attachment O, Section O-1	- Added "that is adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed."	B-3
- Attachment O, Section O-2	- Added "that are adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed."	B-4
- Attachment O, Section O-3	- Added "that are adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed."	B-4
- Attachment O, Section O-3b(2)	- Deleted "The Permittees will notify NMED within seven calendar days if either the minimum running annual average mine ventilation exhaust rate of 260,000 scfm or a minimum active room ventilation rate of 35,000 scfm when workers are present in the room are not achieved."	B-4
- Attachment O, Section O-3c(1)	- Added "the Minimum Airflow for an" - Added "that is Adjacent to a Filled Room" - Deleted "Minimum Airflow" - Added "in an active room that is adjacent to a	B-4 B-4 B-4 B-4

Affected Permit Section	Explanation of Change	Page Number
	filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed.” • Added “that” • Deleted “(s)”	B-4 B-4
• Attachment O, Section O-3c(2)	• Added “Entry to restricted access active disposal rooms for the purpose of establishing normal ventilation is allowed. Such entry shall also be documented on the log sheet including a reference to the SOP used for reentry.”	B-4
• Attachment O, Section O-5a	• Deleted “active room” • Added “for an active room that is adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed.” • Deleted “O-3b(2)” • Added “Permit Section 4.5.3.2” • Deleted “Whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in O-3b(2) have not been achieved, the” • Added “The” • Deleted “notify” • Added “report to” • Deleted “writing within seven calendar days” • Added “the annual report specified in Permit Section 4.6.4.2. whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section have not been achieved”	B-5 B-5 B-5 B-5 B-5 B-5 B-5 B-5

Appendix B
Proposed Revised Permit Text

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Proposed Revised Permit Text:

1.5.19. Filled Room

"Filled Room" means a room in an Underground Hazardous Waste Disposal Unit as described in Permit Part 4 that will no longer receive mixed waste for emplacement.

4.5.3.2. Ventilation

The Permittees shall maintain a minimum running annual average mine ventilation exhaust rate of 260,000 standard ft^3/min and a minimum ~~active~~ room ventilation rate of 35,000 standard ft^3/min when workers are present in ~~the~~ an active room adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed, as specified in Permit Attachment A2, Section A2-2a(3), "Subsurface Structures (Underground Ventilation System Description)" and as required by 20.4.1.500 NMAC (incorporating 40 CFR 264.601(c)).

4.6.4.3. ~~Notification~~ Evaluation Requirements

The Permittees shall calculate the running annual average mine ventilation exhaust rate on a monthly basis. In addition, the Permittees shall evaluate compliance with the minimum active room ventilation rate specified in Permit Section 4.5.3.2 on a monthly basis. ~~Whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section 4.5.3.2 have not been achieved, the~~ The Permittees shall ~~notify~~ report to the Secretary in ~~writing within seven calendar days~~the annual report specified in Permit Section 4.6.4.2 whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section 4.5.3.2 have not been achieved.

A2-2a(3) Subsurface Structures

Underground Ventilation System Description

At any given time during waste emplacement activities, there may be significant activities in multiple rooms in a panel. For example, one room may be receiving CH TRU mixed waste containers, another room may be receiving RH TRU mixed waste canisters, and the drilling of RH TRU mixed waste emplacement boreholes may be occurring in another room. The remaining rooms in a panel will either be completely filled with waste; be idle, awaiting waste handling operations; or being prepared for waste receipt. A minimum ventilation rate of 35,000 ft^3 (990 m^3) per minute will be maintained in each active room that is adjacent to a filled room ~~where waste disposal is taking place~~ when workers are present in the room or in

Room 7 of any panel when CH TRU mixed waste is being disposed. This quantity of air is required to support the numbers and types of diesel equipment that are expected to be in operation in the area, to support the underground personnel working in that area, and to exceed a minimum air velocity of 60 ft (18 m) per minute. The remainder of the air is needed in order to account for air leakage through inactive rooms.

Air will be routed into a panel from the intake side. Air is routed through the individual rooms within a panel using underground bulkheads and air regulators. Bulkheads are constructed by erecting framing of rectangular steel tubing and screwing galvanized sheet metal to the framing. Bulkhead members use telescoping extensions that are attached to framing and the salt which adjust to creep. Rubber or sheet metal attached to the bulkhead on one side and the salt on the other completes the seal of the ventilation. Where controlled airflow is required, a louver-style damper on a slide-gate (sliding panel) regulator is installed on the bulkhead. Personnel access is available through most bulkheads, and vehicular access is possible through selected bulkheads. Vehicle roll-up doors in the panel areas are not equipped with warning bells or strobe lights since these doors are to be used for limited periodic maintenance activities in the return air path. Flow is also controlled using brattice cloth barricades. These consist of chain link fence that is bolted to the salt and covered with brattice cloth; and are used in instances where the only flow control requirement is to block the air. A brattice cloth air barricade is shown in Figure A2-11. Ventilation will be maintained only in all active rooms within a panel until waste emplacement activities are completed and the panel-closure system is installed. The air will be routed simultaneously through all the active rooms within the panel. ~~The~~ Filled rooms ~~that are filled with waste~~ will be isolated from the ventilation system, while ~~the~~ adjacent active rooms ~~that are actively being filled~~or in Room 7 of any panel when CH TRU mixed waste is being disposed will receive a minimum of 35,000 SCFM of air when workers are present to assure worker safety. After all rooms within a panel are filled, the panel will be closed using a closure system described Permit Attachment G and Permit Attachment G1.

O-1 Definitions

Restricted Access: If the required ventilation rate in an active disposal room that is adjacent to a filled room or Room 7 of any panel when CH TRU mixed waste is being disposed cannot be achieved or cannot be supported due to operational needs, access is restricted by the use of barriers, signs and postings, or individuals stationed at the entrance to the active disposal room when ventilation rates are below 35,000 scfm.

O-2 Objective

The objective of this plan is to describe how the ventilation requirements in the Permit will be met. This plan achieves this objective and documents the process by which the Permittees demonstrate compliance with the ventilation requirements by:

- Maintaining an annual running average of 260,000 scfm through the underground repository

- Maintaining a minimum of 35,000 scfm of air through the active disposal rooms that are adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed when workers are present in the rooms

O-3 Design and Procedures

This section describes the four basic processes that make up the mine ventilation rate monitoring plan:

- Test and Balance, a periodic re-verification of the satisfactory performance of the entire underground ventilation system and associated components
- Monitoring and calculation of the Running Annual Average of the Total Mine Airflow to verify achievement of the 260,000 scfm minimum requirement
- Monitoring of active disposal room(s) that are adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed to ensure a minimum flow of 35,000 scfm whenever workers are present in the room

O-3b(2) Calculation of the Running Annual Average of Total Mine Airflow

The use of an average value of 730 hours per month in the monthly average calculation is reasonable, given that all the numbers involved are very large and that the final use of the monthly average flow is in an annual calculation. ~~The Permittees will notify NMED within seven calendar days if either the minimum running annual average mine ventilation exhaust rate of 260,000 scfm or a minimum active room ventilation rate of 35,000 scfm when workers are present in the room are not achieved.~~

O-3c(1) Verification of the Minimum Airflow for an Active Disposal Room that is Adjacent to a Filled Room ~~Minimum Airflow~~

Whenever workers are present in an active room that is adjacent to a filled room or in Room 7 of any panel when CH TRU mixed waste is being disposed, the Permittees shall verify the minimum airflow through that active disposal room~~(s)~~ of 35,000 scfm at the start of each shift, any time there is an operational mode change, or if there is a change in the ventilation system configuration.

O-3c(2) Measurement and Calculation of the Active Waste Disposal Room Airflow

The operator shall compare the recorded acfm value with the minimum acfm value provided at the top of the log sheet. The airflow shall be re-checked and recorded whenever there is an operational mode change or a change in ventilation system configuration. Once the ventilation rate has been recorded and verified to be at least the required minimum, personnel access to the room is unrestricted in accordance with normal underground operating procedures. If the required ventilation rate cannot be achieved, or cannot be supported due to operational needs, access to the room shall be restricted. Those periods when active disposal room access is restricted shall be documented on the log sheet for that active disposal room. Entry to restricted access active disposal rooms for the purpose of establishing normal ventilation is allowed. Such entry shall be documented on the log sheet including a reference to the SOP used for reentry.

O-5a Reporting

The Permittees shall submit an annual report to NMED presenting the results of the data and analysis of the Mine Ventilation Rate Monitoring Plan. In the years that the Test and Balance is performed, the Permittees will provide a summary of the results in the annual report.

The Permittees shall calculate the running annual average mine ventilation rate on a monthly basis and evaluate compliance with the minimum ~~active room~~ ventilation rate for an active room that is adjacent to a filled room or Room 7 of any panel when CH TRU mixed waste is being disposed specified in ~~O-3b(2)~~Permit Section 4.5.3.2 on a monthly basis. ~~Whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in O-3b(2) have not been achieved, the~~ The Permittees will ~~notify~~ report to the Secretary in ~~writing within seven calendar days~~ the annual report specified in Permit Section 4.6.4.2 whenever the evaluation of the mine ventilation monitoring program data identifies that the ventilation rates specified in Permit Section 4.5.3.2. have not been achieved.

Item 2

Class 2 Permit Modification Request

Addition of a Shielded Container

Waste Isolation Pilot Plant
Carlsbad, New Mexico

WIPP Permit Number - NM4890139088-TSDF

September 2011

Table of Contents

Acronyms/Abbreviations/Units

AK	Acceptable Knowledge
CFR	Code of Federal Regulations
CH	contact handled
DAC	Drum Age Criteria
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
ft	feet
gal	gallon
HWDU	Hazardous Waste Disposal Unit
L	Liter
lbs	pounds
m^3	cubic meters
mrem/h	millirem per hour
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
PMR	Permit Modification Request
RCRA	Resource Conservation and Recovery Act
RH	remote handled
TRU	transuranic
TSDF	Treatment, Storage and Disposal Facility
WHB	Waste Handling Building
WIPP	Waste Isolation Pilot Plant
WTS	Washington TRU Solutions LLC
WWIS	WIPP Waste Information System

Overview of the Permit Modification Request

This document contains one Class 2 Permit Modification Request (**PMR**) for the Waste Isolation Pilot Plant (**WIPP**) Hazardous Waste Facility Permit (**Permit**) Number NM4890139088-TSDF.

This PMR is being submitted by the U.S. Department of Energy (**DOE**) Carlsbad Field Office and Washington TRU Solutions LLC (**WTS**), collectively referred to as the Permittees, in accordance with the WIPP Permit, Part 1, Condition 1.3.1. (20.4.1.900 New Mexico Administrative Code (**NMAC**) incorporating Title 40 Code of Federal Regulations (**CFR**) §270.42(b)). The modification provides for the following changes:

- addition of a new gamma shielded container for managing remote-handled (**RH**) transuranic (**TRU**) mixed waste as contact handled (**CH**) TRU mixed waste since it meets the surface dose rate of CH TRU mixed waste,
- description of how the volume of RH TRU mixed waste which is disposed in gamma shielded containers will be tracked, and,
- related changes to waste handling descriptions.

The gamma shielded container will be used to package RH TRU mixed waste that is approved for shipment to the WIPP facility for disposal and meets the surface dose requirements, once packaged, of CH TRU mixed waste.

These changes do not reduce the ability of the Permittees to provide continued protection to human health and the environment.

The requested modification to the WIPP Permit and related supporting documents are provided in this PMR. The proposed modification to the text of the WIPP Permit has been identified using red text and a double underline and a ~~strikeout~~ font for deleted information. All direct quotations are indicated by italicized text. The following information specifically addresses how compliance has been achieved with the WIPP Permit Part 1, Condition 1.3.1. for submission of this Class 2 PMR.

1. 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(i)) requires the applicant to describe the exact change to be made to the permit conditions and supporting documents referenced by the Permit.

The Permittees are proposing to package a portion of the RH TRU mixed waste inventory in gamma shielded containers for emplacement at the WIPP facility. The use of the shielded containers will enable the DOE to reduce the time and personnel necessary for the packaging and management of specific RH TRU mixed waste that will meet the surface dose rate limitations for CH TRU mixed waste.

The Nuclear Regulatory Commission (**NRC**) has authorized the use of the HalfPACT transportation package for the shipment of shielded containers. The shielded containers comply with the U.S. Department of Transportation (**DOT**) Type 7A specifications.

The RH TRU mixed waste that will be packaged in shielded containers is included in the current inventory for disposal at the WIPP facility. Candidate RH TRU mixed waste streams for shipment and disposal in gamma shielded containers will be selected based on the requirement to keep the radiation surface dose rate at the external surface of the shielded container below 200 millirem per hour (**mrem/h**) in accordance with Permit Part 1, Condition 1.5.1. The characterization being performed on waste being shipped in shielded containers will be no different than the waste characterization that is now required for RH TRU mixed waste in the Permittees' Waste Analysis Plan.

RH TRU mixed waste emplaced at the WIPP facility in shielded containers will remain designated as RH TRU mixed waste in the WIPP Waste Information System (**WWIS**). The emplaced volume will be counted against the RH repository limit of 7,080 cubic meters (**m^3**) and RH TRU mixed waste volume limits specified in the Permit. The shielded container allows the Permittees to manage the shipment in a manner consistent with management of a CH TRU mixed waste shipment.

The shielded container is designed to hold an inner 30-gallon container. The cylindrical sidewall of the shielded container has approximately a 1-inch-thick lead shield sandwiched between two carbon steel shells. The external wall is approximately 1/8-inch thick, and the internal wall has a thickness of approximately 3/16-inch. The lid and the bottom of the shielded container are made of carbon steel and are approximately 3 inches thick. The empty weight of the shielded container is approximately 1,726 pounds. The shielded container and the inner 30-gallon container will be vented. The shielded container is shown in Figure 1.

The shielded containers will be assembled in a 3-pack configuration on a triangular pallet surrounded by radial and axial dunnage components. They will be transported as a single 3-pack configuration within the HalfPACT packaging.

Upon arrival at the WIPP facility, the shielded containers will be processed as CH TRU mixed waste using CH TRU mixed waste handling equipment and operating procedures. After receipt at the WIPP facility, the HalfPACT transportation container will be opened using existing lifting fixtures and equipment in the CH Bay portion of the Waste Handling Building. Once accessible after the HalfPACT lids have been removed, the top axial dunnage will be removed prior to removing the 3-pack assembly from the HalfPACT (see Figure 2). Next, the 3-pack assembly, the radial dunnage, the bottom slipsheet and the triangular pallet will be lifted from the HalfPACT using the installed guide tubes and placed on a facility pallet. The facility pallet will then be placed in storage or moved to the repository in the same manner as other CH TRU mixed waste. The 3-pack assembly will be placed singly on the floor using the slipsheet. The triangular pallet will be removed and not emplaced. The 3-pack will be placed in the interstitial spaces among the CH TRU mixed waste (see Figure 3). No waste assemblies will be placed on top of a 3-pack assembly of shielded containers because the narrower cross section of the 3-pack assembly of shielded containers may make the stack unstable. Emplacement of the 3-pack assembly of shielded containers will be performed using existing waste handling equipment and fixtures.

The Permittees will track waste components, packaging, transportation and emplacement information using the same method as other waste that is transported and emplaced at the WIPP facility. The shielded container waste will be reported as RH TRU mixed waste as the volume of waste in the inner waste container. Quantities of RH TRU waste that arrives in canisters is currently counted based on the volume of inner containers. Therefore, shielded containers and canisters will have a common volume reporting basis in the WWIS.

The Permittees have evaluated the Drum Age Criteria (**DAC**) for the shielded container packaging configuration (Drum Age Criteria Values for the Shielded Container, September 2011). A conservative packaging configuration was used in the evaluation (Appendix C). The evaluation indicates that existing 55-gallon DAC values bound the values for the shielded container.

The Permittees are proposing the following changes in this PMR:

1. Add a new container in Part 3, Condition, 3.3.18.; Part 4, Condition 4.3.1.8; Attachment A1, Section A1-1b(2); Section A1-1d(3); Section A1-1d(4); Table A1-2; Figure A1-37; Attachment A2, Section A2-2a(1); Section A2-2b, Table A2-1; Attachment A4, Section A4-3; Attachment C1, Section C1-1a, Section C1-1a(1), Table C1-8 and footnote; Attachment D, Section D-1d, Section D-1e(1); Attachment E, Section E-1b(1); Attachment G3, Section G3-4a; and Attachment H1, Introduction.

2. Revise Part 4, Table 4.1.1 to remove the container equivalent column since RH TRU mixed waste will be disposed of in both canisters and shielded containers making the calculation of container equivalents impossible. This is the same approach used for CH TRU mixed waste which can arrive in six different containers. Furthermore, this table is a volume based limitation and not a container limitation. Thus it is not necessary to have the number of equivalent containers since the volume is not being proposed for change.

3. Add a figure of the shielded container (Figure A1-37).

4. Add “Shielded Containers” to Attachment C1, Sections C1-1a and C1-1a (1) and revise Table C1-8 indicating that the 55-gallon drum DAC bounds the shielded container.

Appendix A, The Table of Changes, provides a detailed list of changes by Permit section. Proposed text changes are included in Appendix B of this PMR.

2. 20.4.1.900 NMAC (incorporating 40 CFR §270.42(b)(1)(ii)), requires the applicant to identify that the modification is a Class 2 modification.

- This PMR proposes to add a new container to the Permit. The Permittees have added other containers and shipping packages and these have been previously approved by the New Mexico Environment Department (**NMED**) as Class 2 modifications. These include the following:
- Direct loaded ten drum overpack (approved 11-25-2002)
- Direct loaded 85-gallon drums (approved 11-25-2002)
- Addition of 100-gallon drums (approved 11-25-2002)
- Addition of a standard large box 2 (**SLB2**) (approved 4-15-2011)
- Addition of a HalfPACT shipping package (approved 11-25-2002)
- Addition of a TRUPACT III shipping package (approved 4-15-2011)

Unlike the SLB2 and TRUPACT III, there is no need for specialized waste management equipment nor is there any increase in the proposed storage area in the Waste Handling Building for managing shielded containers. NMED processed and approved these containers and shipping packages as Class 2 PMRs. Therefore, this is a Class 2 as specified in 20.4.1.900 NMAC (incorporating 40 CFR, §270.42(b)), Appendix I, Item F.3.b which states: "*Storage of different wastes in containers,…. That do not require additional or different management practices from those authorized in the permit.*"

Although RH TRU mixed waste has been shipped to the WIPP facility previously, this waste has not been managed in the CH TRU waste management portion of the facility. Therefore, this classification is appropriate and will allow for public comment on this requested change.

3. 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(iii)), requires the applicant to explain why the modification is needed.

This PMR is necessary to add a shielded container as an acceptable waste container at the WIPP facility.

Shielded containers have been developed as one method to expedite the packaging and shipment of RH TRU mixed waste. Consequently, the Permittees seek approval to manage these containers under the WIPP facility Permit. Shielded containers are expected to reduce the time and personnel necessary for the packaging of RH TRU mixed waste at generator sites and the management of that waste at the WIPP facility. Only waste that meets the definitions of TRU mixed waste in Permit Part 1, Section 1.5.7 that can be packaged to meet the surface dose rate limitations for CH TRU mixed waste will be managed at the WIPP facility in shielded containers. The Permittees are proposing the use of shielded containers to reduce the time and personnel necessary for the packaging and management of specific RH TRU mixed waste that will meet the surface dose rate limitations for CH TRU mixed waste. The shielded container will be transported to the WIPP facility in the HalfPACT transportation package. The shielded containers will be managed and emplaced in the rooms of the repository as CH TRU mixed waste. The containers comply with DOT Type 7A specifications and they will have a surface dose rate of less than 200 mrem/h.

The RH TRU mixed waste that will be packaged in shielded containers is included in the inventory for the WIPP facility and will have undergone the required characterization as RH TRU mixed waste specified in the WIPP Waste Analysis Plan. No change in the permitted aboveground hazardous waste storage or underground disposal unit capacity is required. Candidate RH TRU mixed waste streams for shipment and disposal in shielded containers will be selected based on the requirement to keep the radiation surface dose rate at the external surface of the shielded containers below 200 mrem/h. The volume of waste emplaced in shielded containers will remain designated as RH TRU mixed waste in the WWIS and will be counted against the RH TRU mixed waste repository limit of 7,080 m^3.

Additional explanations of why the changes are needed is provided in Item 1 above.

4. 20.4.1.900 NMAC (incorporating 40 CFR §270.42 (b)(1)(iv)) requires the applicant to provide the applicable information required by 40 CFR §270.13 through §270.21, §270.62 and §270.63.

The attached regulatory crosswalk describes those portions of the WIPP Permit that are affected by this PMR. Where applicable, regulatory citations in this modification reference Title 20, Chapter 4, Part 1, NMAC, revised March 2009, incorporating the CFR, Title 40 (40 CFR Parts 264 and 270). 40 CFR §270.16 through §270.22, §270.62, §270.63 and §270.66 are not applicable at WIPP. Consequently, they are not listed in the regulatory crosswalk table. 40 CFR §270.23 is applicable to the WIPP Hazardous Waste Disposal Units (**HWDUs**). This modification does not impact the conditions associated with the HWDUs.

5. 20.4.1.900 NMAC (incorporating 40 CFR §270.11(d)(1) and 40 CFR §270.30(k)) require that any person signing under paragraph a and b must certify the document in accordance with 20.4.1.900 NMAC.

The transmittal letter for this PMR contains the signed certification statement in accordance with Permit Part 1, Condition 1.9. of the WIPP Permit.

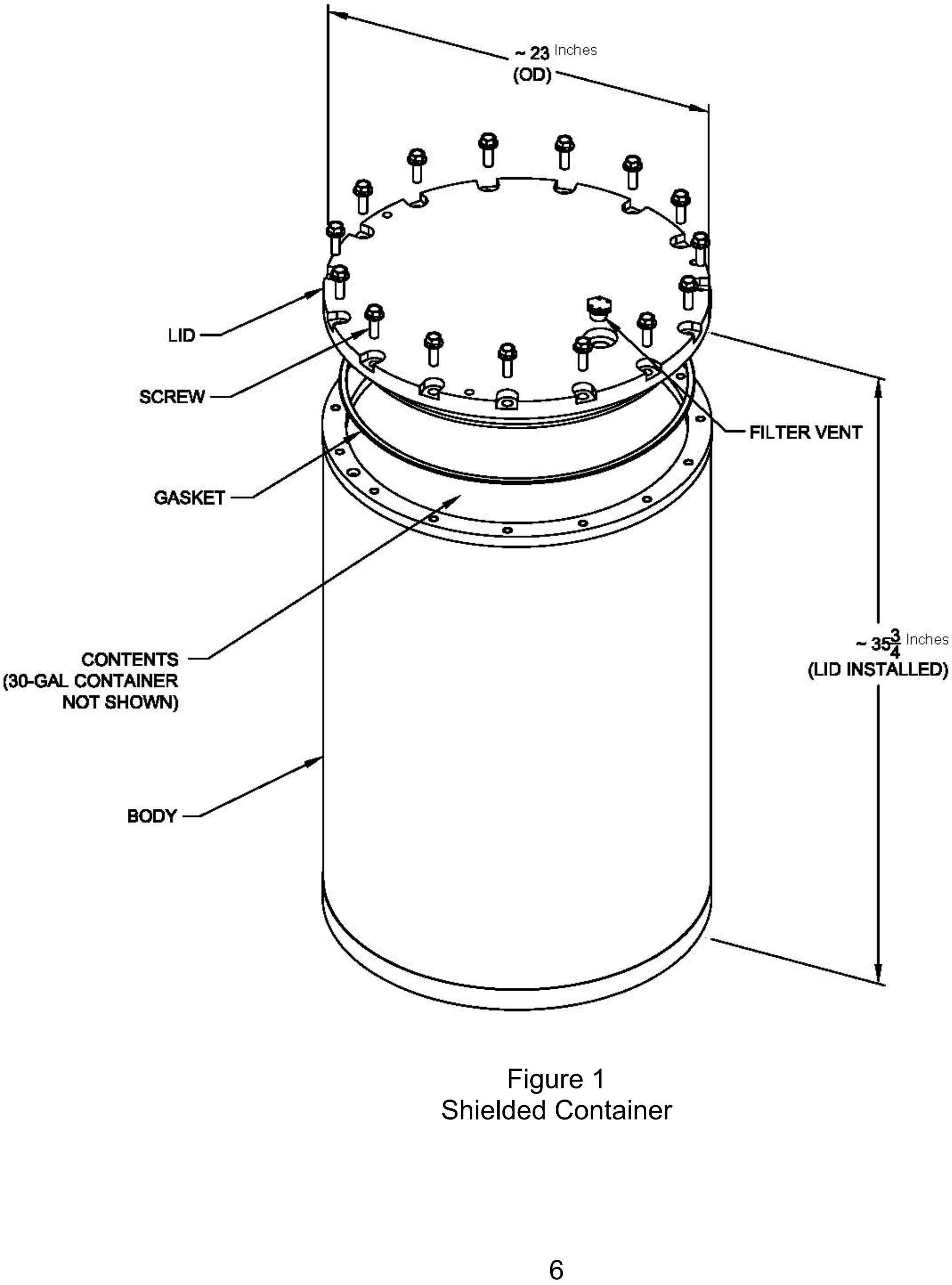

Figure 1
Shielded Container

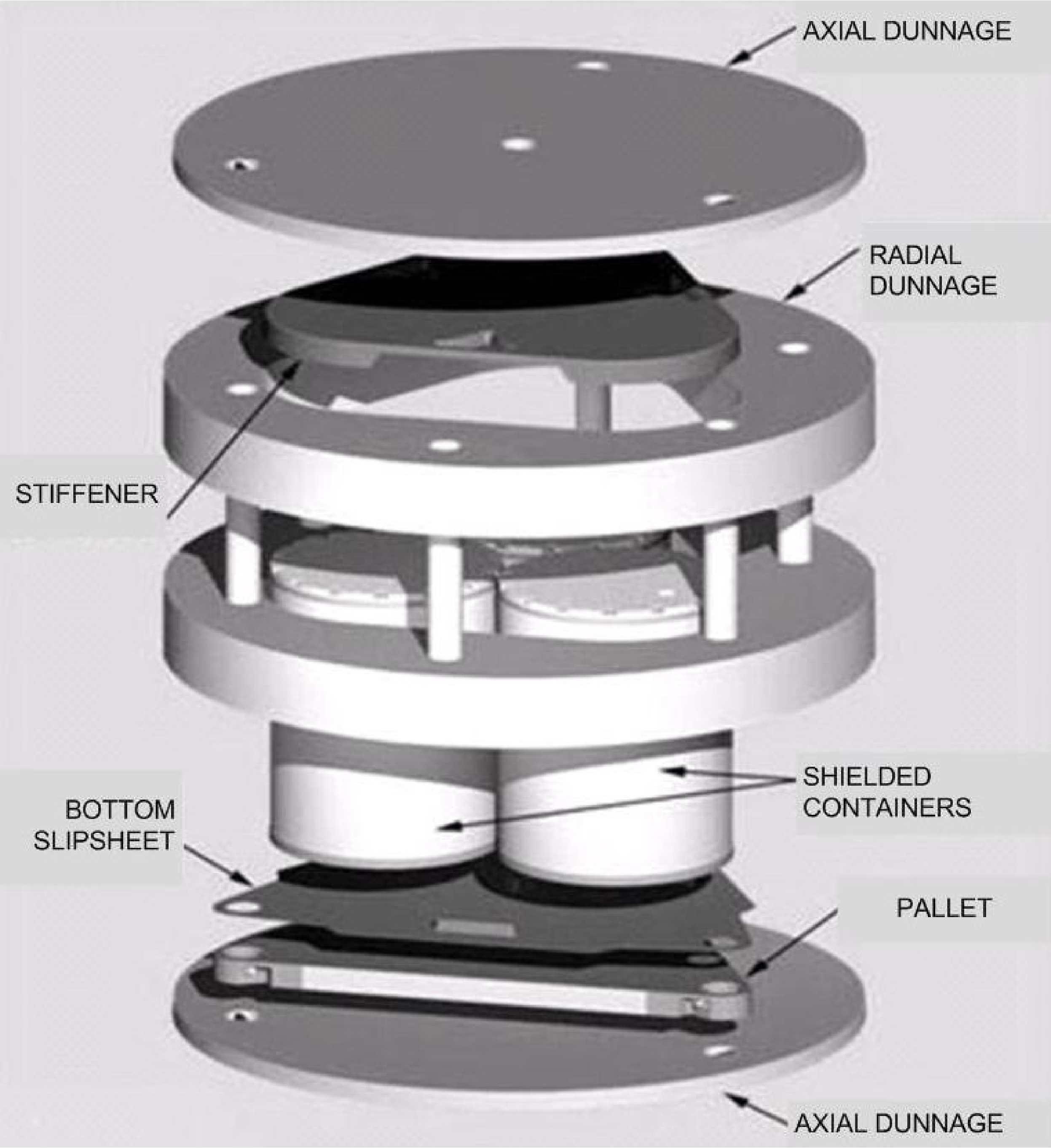

Figure 2
3-Pack Assembly of Shielded Containers with Axial and Radial Dunnage

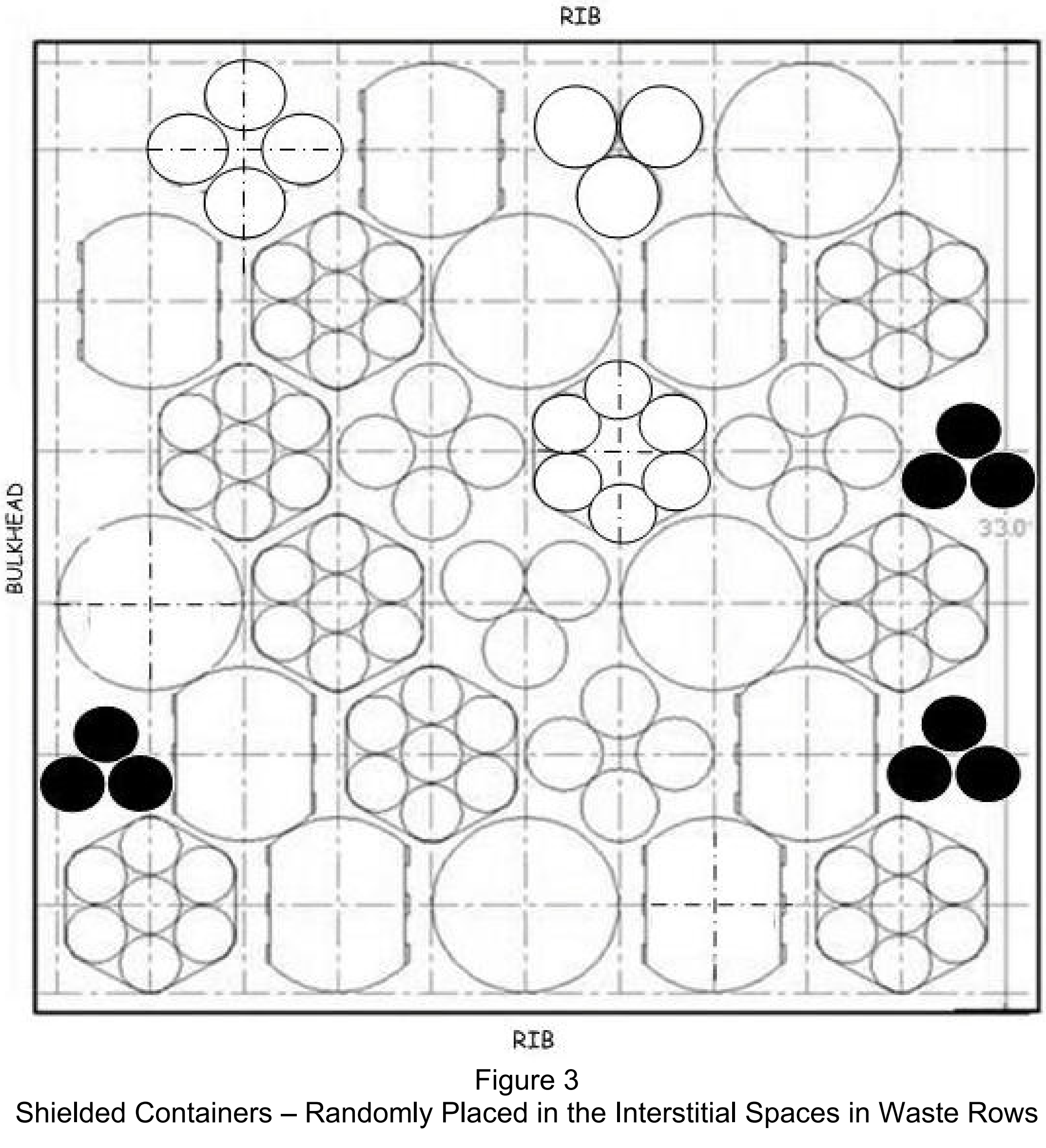

Figure 3
Shielded Containers – Randomly Placed in the Interstitial Spaces in Waste Rows

Regulatory Crosswalk

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the Permit or Permit Application	Yes	No
§270.13		Contents of Part A permit application	Attachment B, Part A		✓
§270.14(b)(1)		General facility description	Attachment A		✓
§270.14(b)(2)	§264.13(a)	Chemical and physical analyses	Attachment C		✓
§270.14(b)(3)	§264.13(b)	Development and implementation of waste analysis plan	Attachment C		✓
	§264.13(c)	Off-site waste analysis requirements	Attachment C		✓
§270.14(b)(4)	§264.14(a-c)	Security procedures and equipment	Part 2.6		✓
§270.14(b)(5)	§264.15(a-d)	General inspection requirements	Attachment E		✓
	§264.174	Container inspections	Attachment E	✓	
§270.23(a)(2)	§264.602	Miscellaneous units inspections	Attachment E		✓
§270.14(b)(6)		Request for waiver from preparedness and prevention requirements of Part 264 Subpart C	NA		
§270.14(b)(7)	264 Subpart D	Contingency plan requirements	Attachment D		✓
	§264.51	Contingency plan design and implementation	Attachment D		✓
	§264.52 (a) & (c-f)	Contingency plan content	Attachment D	✓	
	§264.53	Contingency plan copies	Attachment D		✓
	§264.54	Contingency plan amendment	Attachment D		✓
	§264.55	Emergency coordinator	Attachment D		✓
	§264.56	Emergency procedures	Attachment D		✓
§270.14(b)(8)		Description of procedures, structures or equipment for:	Part 2.10		✓
§270.14(b)(8) (i)		Prevention of hazards in unloading operations (e.g., ramps and special forklifts)	Part 2.10		✓
§270.14(b)(8) (ii)		Runoff or flood prevention (e.g., berms, trenches, and dikes)	Part 2.10		✓
§270.14(b)(8) (iii)		Prevention of contamination of water supplies	Part 2.10		✓
§270.14(b)(8) (iv)		Mitigation of effects of equipment failure and power outages	Part 2.10		✓
§270.14(b)(8) (v)		Prevention of undue exposure of personnel (e.g., personal protective equipment)	Part 2.10		✓
§270.14(b)(8) (vi) §270.23(a)(2)	§264.601	Prevention of releases to the atmosphere	Part Part 4 Attachment A2 Attachment N		✓
	264 Subpart C	Preparedness and Prevention	Part 2.10		✓
	§264.31	Design and operation of facility	Part 2.10		✓
	§264.32	Required equipment	Part 2.10 Attachment D		✓
	§264.33	Testing and maintenance of equipment	Attachment E		✓
	§264.34	Access to communication/alarm system	Part 2.10		✓
	§264.35	Required aisle space	Part 2.10		✓
	§264.37	Arrangements with local authorities	Attachment D		✓
§270.14(b)(9)	§264.17(a-c)	Prevention of accidental ignition or reaction of ignitable, reactive, or incompatible wastes	Part 2.10		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	**Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)**	**Description of Requirement**	**Added or Clarified Information**		
			Section of the Permit or Permit Application	**Yes**	**No**
§270.14(b) (10)		Traffic pattern, volume, and controls, for example: Identification of turn lanes Identification of traffic/stacking lanes, if appropriate Description of access road surface Description of access road load-bearing capacity Identification of traffic controls	Attachment A4	✓	
§270.14(b) (11)(i) and (ii)	§264.18(a)	Seismic standard applicability and requirements	Part B, Rev. 6 Chapter B		✓
§270.14(b) (11)(iii-v)	§264.18(b)	100-year floodplain standard	Part B, Rev. 6 Chapter B		✓
	§264.18(c)	Other location standards	Part B, Rev. 6 Chapter B		✓
§270.14(b) (12)	§264.16(a-e)	Personnel training program	Part 2 Attachment F		✓
§270.14(b) (13)	264 Subpart G	Closure and post-closure plans	Attachment G & H		✓
§270.14(b)(13)	§264.111	Closure performance standard	Attachment G		✓
§270.14(b)(13)	§264.112(a), (b)	Written content of closure plan	Attachment G		✓
§270.14(b)(13)	§264.112(c)	Amendment of closure plan	Attachment G		✓
§270.14(b)(13)	§264.112(d)	Notification of partial and final closure	Attachment G		✓
§270.14(b)(13)	§264.112(e)	Removal of wastes and decontamination/dismantling of equipment	Attachment G		✓
§270.14(b)(13)	§264.113	Time allowed for closure	Attachment G		✓
§270.14(b)(13)	§264.114	Disposal/decontamination	Attachment G		✓
§270.14(b)(13)	§264.115	Certification of closure	Attachment G		✓
§270.14(b)(13)	§264.116	Survey plat	Attachment G		✓
§270.14(b)(13)	§264.117	Post-closure care and use of property	Attachment H		✓
§270.14(b)(13)	§264.118	Post-closure plan; amendment of plan	Attachment H		✓
§270.14(b)(13)	§264.178	Closure/ containers	Attachment G		✓
§270.14(b)(13)	§264.601	Environmental performance standards-Miscellaneous units	Attachment G		✓
§270.14(b)(13)	§264.603	Post-closure care	Attachment G		✓
§270.14(b)(14)	§264.119	Post-closure notices	Attachment H		✓
§270.14(b)(15)	§264.142	Closure cost estimate	NA		✓
	§264.143	Financial assurance	NA		✓
§270.14(b)(16)	§264.144	Post-closure cost estimate	NA		✓
	§264.145	Post-closure care financial assurance	NA		✓
§270.14(b)(17)	§264.147	Liability insurance	NA		✓
§270.14(b)(18)	§264.149-150	Proof of financial coverage	NA		✓
§270.14(b)(19)(i), (vi), (vii), and (x)		Topographic map requirements Map scale and date Map orientation Legal boundaries Buildings Treatment, storage, and disposal operations Run-on/run-off control systems Fire control facilities	Attachment B Part A		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	**Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)**	**Description of Requirement**	**Added or Clarified Information**		
			Section of the Permit or Permit Application	**Yes**	**No**
§270.14(b)(19)(ii)	§264.18(b)	100-year floodplain	Attachment B Part A		✓
§270.14(b)(19)(iii)		Surface waters	Attachment B Part A		✓
§270.14(b)(19)(iv)		Surrounding Land use	Attachment B Part A		✓
§270.14(b)(19)(v)		Wind rose	Attachment B Part A		✓
§270.14(b)(19)(viii)	§264.14(b)	Access controls	Attachment B Part A		✓
§270.14(b)(19)(ix)		Injection and withdrawal wells	Attachment B Part A		✓
§270.14(b)(19)(xi)		Drainage on flood control barriers	Attachment B Part A		✓
§270.14(b)(19)(xii)		Location of operational units	Attachment B Part A		✓
§270.14(b)(20)		Other federal laws Wild and Scenic Rivers Act National Historic Preservation Act Endangered Species Act Coastal Zone Management Act Fish and Wildlife Coordination Act Executive Orders	Attachment B Part A		✓
§270.15	§264 Subpart I	Containers	Attachment A1	✓	
	§264.171	Condition of containers	Attachment A1		✓
	§264.172	Compatibility of waste with containers	Attachment A1		✓
	§264.173	Management of containers	Attachment A1	✓	
	§264.174	Inspections	Attachment E Attachment A1		✓
§270.15(a)	§264.175	Containment systems	Attachment A1		✓
§270.15(c)	§264.176	Special requirements for ignitable or reactive waste	Part 2		✓
§270..15(d)	§264.177	Special requirements for incompatible wastes	Part 2		✓
	§264.178	Closure	Attachment G		✓
§270.15(e)	§264.179	Air emission standards	Part 4 Attachment N		✓
§270.23	264 Subpart X	Miscellaneous units	Attachment A2	✓	
§270.23(a)	§264.601	Detailed unit description	Attachment A2		✓
§270.23(b)	§264.601	Hydrologic, geologic, and meteorologic assessments	Part 5 Attachment L		✓
§270.23(c)	§264.601	Potential exposure pathways	Part 4 Attachment A2 Attachment N		✓
§270.23(d)		Demonstration of treatment effectiveness	NA		✓
	§264.602	Monitoring, analysis, inspection, response, reporting, and corrective action	Part 2 Part 4 Part 5		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	**Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)**	**Description of Requirement**	**Added or Clarified Information**		
			Section of the Permit or Permit Application	**Yes**	**No**
			Attachment A2 Attachment N		
	§264.603	Post-closure care	Attachment H Attachment H1	✓	
	264 Subpart E	Manifest system, record keeping, and reporting	Part 2 Attachment C		✓

Appendix A
Table of Changes

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Table of Changes

Affected Permit Section	Explanation of Change	Page Number
Part 3, Condition 3.3.1.8.	Add "Section 3.3.1.8. Shielded Container" and "Each 30-gallon inner container has a gross internal volume of 4.0 ft^3 (0.11 m^3). This container will be used to emplace RH TRU mixed waste, but the shielding will allow it to be managed as CH TRU mixed waste. For the purpose of this Permit, shielded containers are managed and handled as CH TRU mixed waste containers, but will remain counted towards the volume of RH TRU mixed waste containers."	B-2
Part 4, Table 4.1.1.	Remove "container equivalent" column since the RH TRU mixed waste may now be disposed at the WIPP facility in containers other than canisters.	B-3
Part 4, Condition 4.3.1.8	Add Section "4.3.1.8 Shielded Container" and "Shielded containers are configured as a 3-pack."	B-4
Attachment A1, Section A1-1b(2)	Add "shielded containers which are received in HalfPACTs" Add "Shielded Container Remote-handled TRU mixed waste may be shipped to the WIPP facility in shielded containers arranged as 3-packs. A summary description of the shielded container is provided below. The shielded container meets the requirements for DOT specification 7A (Figure A1-37). Shielded containers consist of a 30-gallon inner container with a gross internal volume of 4.0 ft^3 (0.11 m^3). One or more filter vents will be installed in the shielded container lid to prevent the escape of radioactive particulates and to prevent internal pressurization. The shielded container is constructed with approximately one inch of lead shielding and will be used to emplace RH TRU mixed waste. The shielding will allow it to be managed as CH TRU mixed waste."	B-5
Attachment A1, Section A1-1d(3)	Add "that is not in a shielded container" Add "RH TRU mixed waste received in shielded containers will be handled as CH TRU mixed waste"	B-5
Attachment A1, Section A1-1d(4)	Add "A1-1d(4) Handling Waste in Shielded Containers Remote-handled TRU mixed waste shipped to the WIPP facility in shielded containers will be handled and emplaced as CH TRU mixed waste using the CH TRU mixed waste handling equipment described in this permit. Shielded containers with RH TRU mixed waste will arrive by tractor-trailer at the WIPP facility in sealed HalfPACTs at which time they will undergo security and radiological checks and shipping documentation reviews. Consistent with the handling of HalfPACT shipping packages in Section A1-1d(2), a forklift will remove the HalfPACT and transport it into the WHB and place the HalfPACT at either one of the two TRUDOCKs in the TRUDOCK Storage Area of the WHB Unit. An external survey of the HalfPACT inner vessel will be performed as the outer containment vessel lid is	B-5,B-6

Affected Permit Section	Explanation of Change	Page Number
	removed. The inner vessel lid or closure lid will be lifted under the VHS, and the contents will be surveyed during and after this process is complete. A description of the VHS and criteria that are applied if radiological contamination is detected are discussed in Section A1-1d(2). A HalfPACT may hold one 3-pack assembly of shielded containers. An overhead bridge crane will be used to remove the contents of the shielded container assembly and place them on a facility pallet. The containers will be visually inspected for physical damage (severe rusting, apparent structural defects, signs of pressurization, etc.) and leakage to ensure they are in good condition prior to storage. Waste containers will also be checked for external surface contamination. If a primary waste container is not in good condition, the Permittees will overpack the container, repair/patch the container in accordance with 49 CFR §173 and §178 (e.g., 49 CFR §173.28), or return the container to the generator. Once the shielded container assembly is on the facility pallet, the radial dunnage will be removed for return to the generator along with axial dunnage. For inventory control purposes, TRU mixed waste container identification numbers will be verified against the Uniform Hazardous Waste Manifest and the WWIS. Inconsistencies will be resolved as discussed in Section A1-1d(2). Up to two 3-pack assemblies of shielded containers will be placed on a facility pallet. The use of facility pallets will elevate the waste at least 6 in. (15 cm) from the floor surface. Pallets of waste will then be relocated to the CH Bay Storage Area of the WHB Unit for normal storage or will be transported to the conveyance loading room as described in Section A1-1d(2).”	
Attachment A1, Table A1-2	Revise Table A1-2 to add shielded containers.	B-7
Attachment A1, Figure A1-37	Add “Figure A1-37 Typical Shielded Container”	B-8
Attachment A2, Section A2-2a(1)	Add “two 3-packs of shielded containers” Delete “or”	B-9
Attachment A2, Section A2-2b	Add “and shielded containers” Delete “(e.g., TRUPACT IIs or HalfPACTs),” Add “one 3-pack of shielded containers” Add “or shielded containers”	B-9
Attachment A2, Table A2-1	Revise Table A2-1 to add shielded containers.	B-10
Attachment A4, Section A4-3	Add “one 3-pack of shielded containers,” Add “two 3-packs of shielded containers,”	B-11
Attachment C1, Section C1-1a	Add “and shielded containers”	B-12
Attachment C1, Section C1-1a(1)	Add “and shielded containers” Delete “and” Add “,and shielded containers”	B-12,B-13

Affected Permit Section	Explanation of Change	Page Number
Attachment C1, Table C1-8	Add “and shielded containers” Add “and shielded containers” to footnote [a]	B-14,B-15
Attachment D, Section D-1d	Add “RH TRU mixed waste may arrive in shielded containers with an internal capacity of 4.0 ft^3 (0.11 m^3). Shielded containers will be arranged as 3-packs.” .	B-16
Attachment D, Section D-1e(1)	Add “or shielded containers”	B-16
Attachment E, Section E-1b(1)	Delete “CH TRU mixed” Add “that will be managed as CH TRU mixed waste” Add “,” and delete “or” Add “or shielded containers as three (3) packs” Add “offsite waste that will be managed as” Add “Offsite waste that will be managed as”	B-17
Attachment G3, Section G3-4a	Add “TRU mixed waste including RH TRU mixed waste in shielded containers”	B-18
Attachment H1, Introduction	Add “Some RH TRU mixed waste may arrive in shielded containers as described in Permit Attachment A1.”	B-19

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Appendix B
Proposed Revised Permit Text

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Proposed Revised Permit Text:

3.3.1. Acceptable Storage Containers

The Permittees shall use containers that comply with the requirements for U.S. Department of Transportation shipping container regulations (49 CFR §173 - Shippers - General Requirements for Shipment and Packaging, and 49 CFR §178 - Specifications for Packaging) for storage of TRU mixed waste at WIPP. The Permittees are prohibited from storing TRU mixed waste in any container not specified in Permit Attachment A1, Section A1-1b, as set forth below:

3.3.1.8. Shielded Container

Each 30-gallon inner container has a gross internal volume of 4.0 ft^3 (0.11 m^3). This container will be used to emplace RH TRU mixed waste, but the shielding will allow it to be managed as CH TRU mixed waste. For the purpose of this Permit, shielded containers are managed and handled as CH TRU mixed waste containers, but will remain counted towards the volume of RH TRU mixed waste containers.

Table 4.1.1.

Table 4.1.1 - Underground HWDUs

Description[1]	Waste Type	Maximum Capacity[2]	~~Container Equivalent~~	Final Waste Volume
Panel 1	CH TRU	636,000ft^3 (18,000 m^3)		370,800 ft^3 (10,500 m^3)
Panel 2	CH TRU	636,000 ft^3 (18,000 m^3)		635,600 ft^3 (17,998 m^3)
Panel 3	CH TRU	662,150 ft^3 (18,750 m^3)		603,600 ft^3 (17,092 m^3)
Panel 4	CH TRU	662,150 ft^3 (18,750 m^3)		503,500 ft^3 (14,258 m^3)
	RH TRU	12,570 ft^3 (356 m^3)	~~400 RH TRU Canisters~~	6,200 ft^3 (176 m^3)
Panel 5	CH TRU	662,150 ft^3 (18,750 m^3)		
	RH TRU	15,720 ft^3 (445 m^3)	~~500 RH TRU Canisters~~	
Panel 6	CH TRU	662,150 ft^3 (18,750 m^3)		
	RH TRU	18,860 ft^3 (534 m^3)	~~600 RH TRU Canisters~~	
Panel 7	CH TRU	662,150 ft^3 (18,750 m^3)		
	RH TRU	22,950 ft^3 (650 m^3)	~~730 RH TRU Canisters~~	
Panel 8	CH TRU	662,150 ft^3 (18,750 m^3)		
	RH TRU	22,950 ft^3 (650 m^3)	~~730 RH TRU Canisters~~	
Total	**CH TRU**	**5,244,900 ft^3** **(148,500 m^3)**		
	RH TRU	**93,050 ft^3** **(2,635 m^3)**	~~**2960 RH TRU Canisters**~~	

[1] The area of each panel is approximately 124,150 ft^2 (11,533 m^2).

[2] "Maximum Capacity" is the maximum volume of TRU mixed waste that may be emplaced in each panel. The maximum repository capacity of "6.2 million cubic feet of transuranic waste" is specified in the WIPP Land Withdrawal Act (Pub. L. 102-579, as amended).

4.3. DISPOSAL CONTAINERS

4.3.1 Acceptable Disposal Containers

The Permittees shall use containers that comply with the requirements for U.S. Department of Transportation shipping container regulations (49 CFR §173 - Shippers - General Requirements for Shipment and Packaging, and 49 CFR §178 - Specifications for Packaging) for disposal of TRU mixed waste at WIPP. The Permittees are prohibited from disposing TRU mixed waste in any container not specified in Permit Attachment A1 (Container Storage), Section A1-1b, as set forth below:

4.3.1.8. Shielded Container

Shielded containers are configured as a 3-pack.

A1-1b(2) RH TRU Mixed Waste Containers

Remote-Handled (**RH**) TRU mixed waste containers include RH TRU Canisters, which are received at WIPP loaded singly in an RH-TRU 72-B cask, shielded containers which are received in HalfPACTs and 55-gallon drums, which are received in a CNS 10-160B cask.

Shielded Container

Remote-handled TRU mixed waste may be shipped to the WIPP facility in shielded containers arranged as 3-packs. A summary description of the shielded container is provided below. The shielded container meets the requirements for DOT specification 7A (Figure A1-37).

Shielded containers consist of a 30-gallon inner container with a gross internal volume of 4.0 ft^3 (0.11 m^3). One or more filter vents will be installed in the shielded container lid to prevent the escape of radioactive particulates and to prevent internal pressurization. The shielded container is constructed with approximately one inch of lead shielding and will be used to emplace RH TRU mixed waste. The shielding will allow it to be managed as CH TRU mixed waste.

A1-1d(3) RH TRU Mixed Waste Handling

The RH TRU mixed waste that is not in a shielded container will be received in the RH-TRU 72-B cask or CNS 10-160B cask loaded on a trailer, as illustrated in process flow diagrams in Figures A1-26 and A1-27, respectively. These are shown schematically in Figures A1-28 and A1-29. RH TRU mixed waste received in shielded containers will be handled as CH TRU mixed waste. Upon arrival at the gate, external radiological surveys, security checks, shipping documentation reviews are performed and the Uniform Hazardous Waste Manifest is signed. The generator's copy of the Uniform Hazardous Waste Manifest is returned to the generator. Should the results of the contamination survey exceed acceptable levels, the shipping cask and transport trailer remain outside the WHB in the Parking Area Unit, and the appropriate radiological boundaries (i.e., ropes, placards) are erected around the shipping cask and transport trailer. A determination will be made whether to return the cask to the originating site or to decontaminate the cask.

A1-1d(4) Handling Waste in Shielded Containers

Remote-handled TRU mixed waste shipped to the WIPP facility in shielded containers will be handled and emplaced as CH TRU mixed waste using the CH TRU mixed waste handling equipment described in this permit. Shielded containers with RH TRU mixed waste will arrive by tractor-trailer at the WIPP facility in sealed HalfPACTs at which time they will undergo security and radiological checks and shipping documentation reviews. Consistent with the handling of HalfPACT shipping packages in Section A1-1d(2), a forklift will remove the HalfPACT and transport it into the WHB and place the HalfPACT at either one of the two TRUDOCKs in the TRUDOCK Storage Area of the WHB Unit.

An external survey of the HalfPACT inner vessel will be performed as the outer containment vessel lid is removed. The inner vessel lid or closure lid will be lifted under the VHS, and the contents will be surveyed during and after this process is complete. A description of the VHS and criteria that are applied if radiological contamination is detected are discussed in Section A1-1d(2).

A HalfPACT may hold one 3-pack assembly of shielded containers. An overhead bridge crane will be used to remove the contents of the shielded container assembly and place them on a facility pallet. The containers will be visually inspected for physical damage (severe rusting, apparent structural defects, signs of pressurization, etc.) and leakage to ensure they are in good condition prior to storage. Waste containers will also be checked for external surface contamination. If a primary waste container is not in good condition, the Permittees will overpack the container, repair/patch the container in accordance with 49 CFR §173 and §178 (e.g., 49 CFR §173.28), or return the container to the generator.

Once the shielded container assembly is on the facility pallet, the radial dunnage will be removed for return to the generator along with axial dunnage. For inventory control purposes, TRU mixed waste container identification numbers will be verified against the Uniform Hazardous Waste Manifest and the WWIS. Inconsistencies will be resolved as discussed in Section A1-1d(2). Up to two 3-pack assemblies of shielded containers will be placed on a facility pallet. The use of facility pallets will elevate the waste at least 6 in. (15 cm) from the floor surface. Pallets of waste will then be relocated to the CH Bay Storage Area of the WHB Unit for normal storage or will be transported to the conveyance loading room as described in Section A1-1d(2).

Table A1-2
Waste Handling Equipment Capacities

CAPACITIES FOR EQUIPMENT	
CH Bay overhead bridge crane	12,000 lbs.
Surface forklifts	26,000 lbs. (CH Bay forklift) 70,000 lbs. (TRUPACT-III Handler forklift)
Facility Pallet	25,000 lbs.
Adjustable center-of-gravity lift fixture	10,000 lbs.
Facility Transfer Vehicle	30,000 lbs.
Yard Transfer Vehicle	60,000 lbs.
MAXIMUM GROSS WEIGHTS OF CONTAINERS	
Seven-pack of 55-gallon drums	7,000 lbs.
Four-pack of 85-gallon drums	4,500 lbs.
Three-pack of 100-gallon drums	3,000 lbs.
Ten-drum overpack	6,700 lbs.
Standard waste box	4,000 lbs.
Standard large box 2	10,500 lbs.
Shielded container	2,260 lbs.
MAXIMUM NET EMPTY WEIGHTS OF EQUIPMENT	
TRUPACT-II	13,140 lbs.
HalfPACT	10,500 lbs.
TRUPACT-III	43,600 lbs.
Adjustable center of gravity lift fixture	2,500 lbs.
Facility pallet	4,120 lbs.

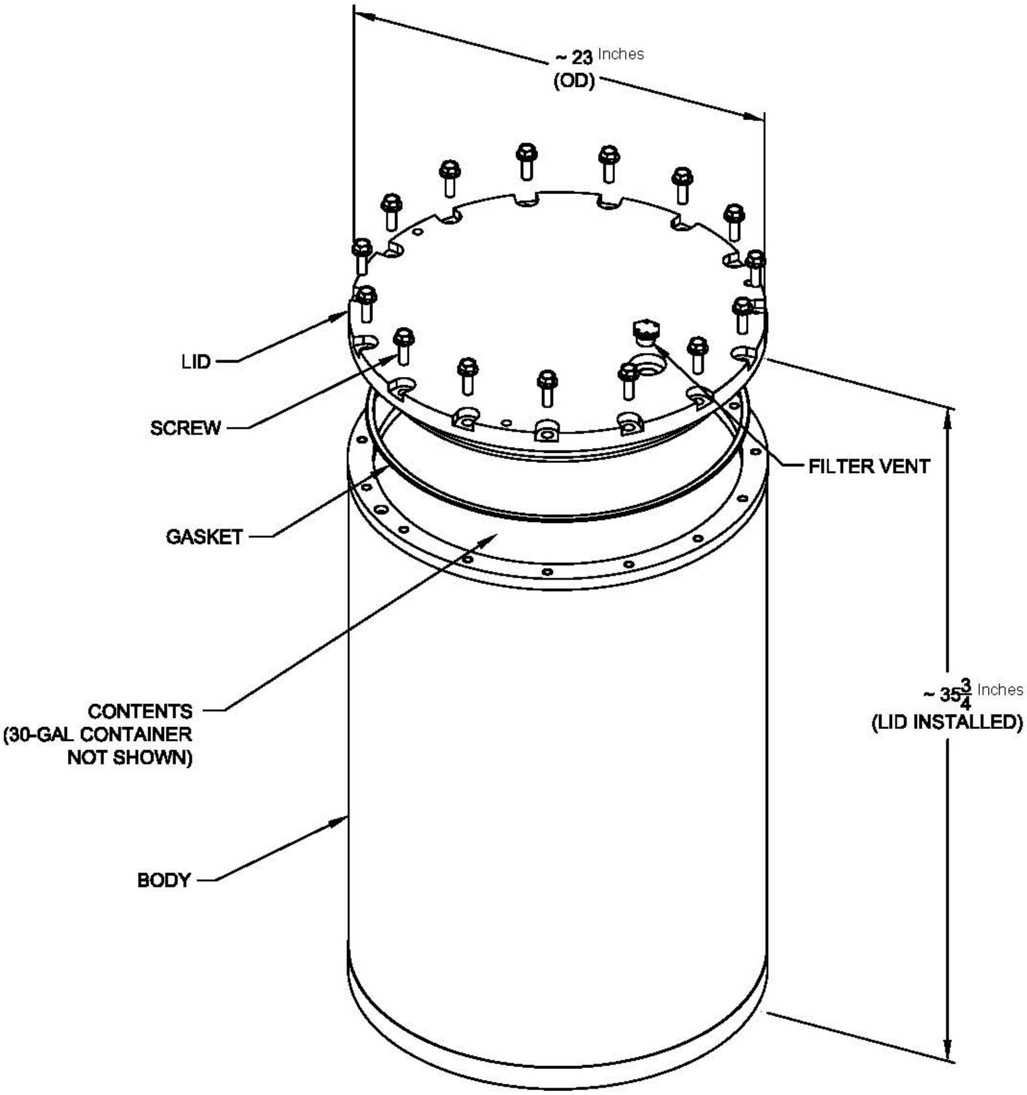

Figure A1-37
Typical Shielded Container

A2-2a(1) CH TRU Mixed Waste Handling Equipment

Facility Pallets

The facility pallet is a fabricated steel unit designed to support 7-packs, 3-packs, or 4-packs of drums, standard waste boxes (**SWBs**), ten-drum overpacks (**TDOPs**), or a standard large box 2 (**SLB2**), and has a rated load of 25,000 pounds (lbs.) (11,430 kilograms (kg)). The facility pallet will accommodate up to four 7-packs, four 3-packs, two 3-packs of shielded containers, ~~or~~ four 4-packs of drums, four SWBs (in two stacks of two units), two TDOPs, or one SLB2. Loads are secured to the facility pallet during transport to the emplacement area. Facility pallets are shown in Figure A2-3. Fork pockets in the side of the pallet allow the facility pallet to be lifted and transferred by forklift to prevent direct contact between TRU mixed waste containers and forklift tines. This arrangement reduces the potential for puncture accidents. WIPP facility operational documents define the operational load of the facility pallet to ensure that the rated load of a facility pallet is not exceeded.

A2-2b Geologic Repository Process Description

CH TRU Mixed Waste Emplacement

CH TRU mixed waste containers and shielded containers will arrive by tractor-trailer at the WIPP facility in sealed shipping containers ~~(e.g., TRUPACT-IIs or HalfPACTs),~~ at which time they will undergo security and radiological checks and shipping documentation reviews. The trailers carrying the shipping containers will be stored temporarily at the Parking Area Container Storage Unit (Parking Area Unit). A forklift will remove the Contact Handled Packages from the transport trailers and a forklift or Yard Transfer Vehicle will transport them into the Waste Handling Building Container Storage Unit for unloading of the waste containers. Each TRUPACT-II may hold up to two 7-packs, two 4-packs, two 3-packs, two SWBs, or one TDOP. Each HalfPACT may hold up to seven 55-gal (208 L) drums, one SWB, one 3-pack of shielded containers, or four 85-gal (322 L) drums. Each TRUPACT-III will hold one SLB2. An overhead bridge crane or Facility Transfer Vehicle with transfer table will be used to remove the waste containers from the Contact Handled Packaging and place them on a facility or containment pallet. Each facility pallet has two recessed pockets to accommodate two sets of 7-packs, two sets of 3-packs, two sets of 4-packs, two SWBs stacked two-high, two TDOPs, or one SLB2. Each stack of waste containers will be secured prior to transport underground (see Figure A2-3). A forklift or the facility transfer vehicle will transport the loaded facility pallet to the conveyance loading room adjacent to the Waste Shaft. The facility transfer vehicle will be driven onto the waste shaft conveyance deck, where the loaded facility pallet will be transferred to the waste shaft conveyance, and the facility transfer vehicle will be backed off. Containers of CH TRU mixed waste (55-gal (208 L) drums, SWBs, 85-gal (322 L) drums, 100-gal (379 L) drums, and TDOPs) or shielded containers can be handled individually, if needed, using the forklift and lifting attachments (i.e., drum handlers, parrot beaks).

Table A2-1
CH TRU Mixed Waste Handling Equipment Capacities

Capacities for Equipment	
Facility Pallet	25,000 lbs.
Facility Transfer Vehicle	26,000 lbs.
Underground transporter	28,000 lbs.
Underground forklift	12,000 lbs.
Maximum Gross Weights of Containers	
Seven-pack of 55-gallon drums	7,000 lbs.
Four-pack of 85-gallon drums	4,500 lbs.
Three-pack of 100-gallon drums	3,000 lbs.
Ten-drum overpack	6,700 lbs.
Standard waste box	4,000 lbs.
Standard large box 2	10,500 lbs.
Shielded container	2,260 lbs.
Maximum Net Empty Weights of Equipment	
TRUPACT-II	13,140 lbs.
HalfPACT	10,500 lbs.
TRUPACT-III	43,600 lbs.
Facility pallet	4,120 lbs.

A4-3 Waste Handling Building Traffic

The TRUPACT-II may hold up to two 55-gallon drum seven-packs, two 85-gallon drum four-packs, two 100-gallon drum three-packs, two standard waste boxes (SWB), or one ten-drum overpack (**TDOP**). A HalfPACT may hold seven 55-gallon drums, one SWB, one 3-pack of shielded containers, or four 85-gallon drums. The TRUPACT-III holds a single SLB2. A six-ton overhead bridge crane or Facility Transfer Vehicle with a transfer table will be used to remove the contents of the Contact Handled Package. Waste containers will be surveyed for radioactive contamination and decontaminated or returned to the Contact Handled Package as necessary.

Each facility pallet will accommodate four 55-gallon drum seven-packs, four SWBs, four 85-gallon drum four-packs, four 100-gallon drum three-packs, two 3-packs of shielded containers, two TDOPs, or an SLB2. Waste containers will be secured to the facility pallet prior to transfer. A forklift or facility transfer vehicle will transport the loaded facility pallet the air lock at the Waste Shaft (Figures A4-3, A4-3a, and A4-3b). The facility transfer vehicle will be driven onto the waste shaft conveyance deck, where the loaded facility pallet will be transferred to the waste shaft conveyance and downloaded for emplacement.

C1-1a Method Requirements

For those waste streams without an acceptable knowledge (**AK**) Sufficiency Determination approved by the U.S. Department of Energy (**DOE**), containers shall be randomly selected from waste streams designated as summary category S5000 (Debris waste) and shall be categorized under one of the sampling scenarios shown in Table C1-5 and depicted in Figure C1-1. If the container is categorized under Scenario 1, the applicable drum age criteria (**DAC**) from Table C1-6 must be met prior to headspace gas sampling. If the container is categorized under Scenario 2, the applicable Scenario 1 DAC from Table C1-6 must be met prior to venting the container and then the applicable Scenario 2 DAC from Table C1-7 must be met after venting the container. The DAC for Scenario 2 containers that contain filters or rigid liner vent holes other than those listed in Table C1-7 shall be determined using footnotes “a” and “b” in Table C1-7. Containers that have not met the Scenario 1 DAC at the time of venting must be categorized under Scenario 3. Containers categorized under Scenario 3 must be placed into one of the Packaging Configuration Groups listed in Table C1-8. If a specific packaging configuration cannot be determined based on the data collected during packaging and/or repackaging (Attachment C, Section C-3d(1)), a conservative default Packaging Configuration Group of 3 for 55-gallon drums and shielded containers, 6 for Standard Waste Boxes (**SWBs**) ten-drum overpacks (**TDOPs**), and standard larged box 2s (**SLB2s**), and 8 for 85-gallon and 100-gallon drums must be assigned, provided the drums do not contain pipe component packaging. If a container is designated as Packaging Configuration Group 4 (i.e., a pipe component), the headspace gas sample must be taken from the pipe component headspace. Drums, TDOPs, SLB2s, or SWBs that contain compacted 55-gallon drums containing a rigid liner may not be disposed of under any packaging configuration unless headspace gas sampling was performed before compaction in accordance with this waste analysis plan (**WAP**). The DAC for Scenario 3 containers that contain rigid liner vent holes that are undocumented during packaging, repackaging, and/or venting (Section C1-1a[4][ii]) shall be determined using the default conditions in footnote “b” in Table C1-9.The DAC for Scenario 3 containers that contain filters that are either undocumented or are other than those listed in Table C1-9 shall be determined using footnote ‘a’ in Table C1-9. Each of the Scenario 3 containers shall be sampled for headspace gas after waiting the DAC in Table C1-9 based on its packaging configuration (note: Packaging Configuration Groups 4, 5, 6, 7, and 8 are not summary category group dependent, and 85-gallon drum, 100-gallon drum, SWB, TDOP, and SLB2 requirements apply when the 85-gallon drum, 100-gallon drum, SWB, TDOP, or SLB2 is used for the direct loading of waste).

C1-1a(1) General Requirements

For all retrievably stored waste containers, the rigid liner vent hole diameter must be assumed to be 0.3 inches unless a different size is documented during drum venting or repackaging. For all retrievably stored waste containers, the filter hydrogen diffusivity must be assumed to be the most restrictive unless container-specific information clearly identifies a filter model and/or diffusivity characteristic that is less restrictive. For all retrievably stored waste containers that have not been repackaged, acceptable knowledge shall not be used to justify any packaging configuration less conservative than the default (i.e., Packaging Configuration Group 3 for 55-gallon drums and shielded containers, 6 for SWBs TDOPs, and SLB2s, and 8 for 85-gallon and 100-gallon drums). For information reporting purposes listed above, sites may report the default packaging configuration for retrievably stored waste without further verification.

Drum age criteria apply only to 55-gallon drums, 85-gallon drums, 100-gallon drums, SWBs, TDOPs, ~~and~~ SLB2s ,and shielded containers. Drum age criteria for all other container types must be established through permit modification prior to performing headspace gas sampling.

Table C1-8
Scenario 3 Packaging Configuration Groups

Packaging Configuration Group	Covered S5000 Packaging Configuration Groups
Packaging Configuration Group 1, 55-gal drums [a]	• No layers of confinement, filtered inner lid [b] • No inner bags, no liner bags (bounding case)
Packaging Configuration Group 2, 55-gal drums [a]	• 1 inner bag • 1 filtered inner bag • 1 liner bag • 1 filtered liner bag • 1 inner bag, 1 liner bag • 1 filtered inner bag, 1 filtered liner bag • 2 inner bags • 2 filtered inner bags • 2 inner bags, 1 liner bag • 2 filtered inner bags, 1 filtered liner bag • 3 inner bags • 3 filtered inner bags • 3 filtered inner bags, 1 filtered liner bag • 3 inner bags, 1 liner bag (bounding case)
Packaging Configuration Group 3, 55-gal drums and shielded containers [a]	• 2 liner bags • 2 filtered liner bags • 1 inner bag, 2 liner bags • 1 filtered inner bag, 2 filtered liner bags • 2 inner bags, 2 liner bags • 2 filtered inner bags, 2 filtered liner bags • 3 filtered inner bags, 2 filtered liner bags • 4 inner bags • 3 inner bags, 2 liner bags • 4 inner bags, 2 liner bags (bounding case)
Packaging Configuration Group 4, pipe components	• No layers of confinement inside a pipe component • 1 filtered inner bag, 1 filtered metal can inside a pipe component • 2 inner bags inside a pipe component • 2 filtered inner bags inside a pipe component • 2 filtered inner bags, 1 filtered metal can inside a pipe component • 2 inner bags, 1 filtered metal can inside a pipe component (bounding case)
Packaging Configuration Group 5, Standard Waste Box, Ten-Drum Overpack, or Standard Large Box 2 [a]	• No layers of confinement • 1 SWB liner bag (bounding case)
Packaging Configuration Group 6, Standard Waste Box, Ten-Drum Overpack, or Standard Large Box 2 [a]	• any combination of inner and/or liner bags that is less than or equal to 6 • 5 inner bags, 1 SWB liner bag (bounding case)
Packaging Configuration Group 7, 85-gal. drums and 100-gal. drums [a]	• No inner bags, no liner bags, no rigid liner, filtered inner lid (bounding case) [b] • No inner bags, no liner bags, no rigid liner

Packaging Configuration Group	Covered S5000 Packaging Configuration Groups
Packaging Configuration Group 8, 85-gal. drums and 100-gal. drums [a]	• 4 inner bags and 2 liner bags, no rigid liner, filtered inner lid (bounding case) [b]

[a] If a specific Packaging Configuration Groups cannot be determined based on the data collected during packaging and/or repackaging, a conservative default Packaging Configuration Group of 3 for 55-gallon drums and shielded containers, 6 for SWBs, TDOPs, and SLB2s, and 8 for 85-gallon and 100-gallon drums must be assigned provided the drums do not contain pipe component packaging. If pipe components are present as packaging in the drums, the pipe components must be sampled following the requirements for Packaging Configuration Group 4.

[b] A “filtered inner lid” is the inner lid on a double lid drum that contains a filter.

Definitions:

Liner Bags: One or more optional plastic bags that are used to control radiological contamination. Liner bags for drums have a thickness of approximately 11 mils. Liner bags are typically similar in size to the container. SWB liner bags have a thickness of approximately 14 mils. TDOPs and SLB2s use SWB liner bags.

Inner Bags: One or more optional plastic bags that are used to control radiological contamination. Inner bags have a thickness of approximately 5 mils and are typically smaller than liner bags.

D-1d Description of Containers

RH TRU mixed waste may arrive in shielded containers with an internal capacity of 4.0 ft^3 (0.11 m^3). Shielded containers will be arranged as 3-packs.

D-1e(1) CH Bay Operations

Once unloaded from the Contact-Handled Package, CH TRU mixed waste containers or shielded containers (7-packs of 55-gal drums, 3-packs of 100-gal drums, 4-packs of 85-gal drums, SWBs, TDOPs, ~~or~~ one SLB2) are placed on the facility pallet. The waste containers are stacked on the facility pallets (one- or two-high, depending on weight considerations). The use of facility pallets will elevate the waste at least 6 inches (in.) (15 centimeters [cm]) from the floor surface. Pallets of waste will then be stored in the CH bay. This storage area will be clearly marked to indicate the lateral limits of the storage area. This storage area will have a maximum capacity of thirteen facility pallets of waste during normal operations. These pallets will typically be in the CH Bay storage area for a period of up to five days.

E-1b(1) Container Inspection

Containers are used to manage TRU mixed waste at the WIPP facility. These containers are described in Permit Part 3. Off-site ~~CH TRU mixed~~ waste that will be managed as CH TRU mixed waste will arrive in 55-gallon drums arranged as seven (7)-packs, in Ten Drum Overpacks (**TDOP**), in 85-gallon drums arranged as four (4) packs, in 100-gallon drums arranged as three (3) packs, in standard waste boxes (**SWB**), ~~or~~ in standard large box 2s (**SLB2s**) or shielded containers as three (3) packs. The waste containers will be visually inspected to ensure that the waste containers are in good condition and that there are no signs that a release has occurred. This visual inspection shall not include the center drums of 7-packs and waste containers positioned such that visual observation is precluded due to the arrangement of waste assemblies on the facility pallets. If CH TRU mixed waste handling operations should stop for any reason with containers located on the TRUPACT-II Unloading Dock (**TRUDOCK** storage area of the WHB Unit) or in room 108 while still in the Contact-Handled Packages, primary waste container inspections could not be accomplished until the containers of waste are removed from the shipping containers.

As described in Permit Attachment A1, Section A1-1d(3), offsite waste that will be managed as RH TRU mixed waste will arrive in containers inside Nuclear Regulatory Commission (**NRC**)-certified casks designed to provide shielding and facilitate safe handling. Canisters, will be loaded singly into an RH-TRU 72-B cask. Drums will be loaded into a CNS 10-160B cask. The cask will be visually inspected upon arrival. Because RH TRU mixed waste is stored in the Parking Area Unit in sealed casks, there are no additional requirements for engineered secondary containment systems. Following removal of the canisters and drums, the interior of the cask will be inspected and surveyed for evidence of contamination that may have occurred during transport.

Offsite waste that will be managed as RH TRU mixed waste is handled and stored in the RH Complex of the WHB. The RH Complex includes the following: RH Bay, the Cask Unloading Room, the Hot Cell, the Transfer Cell, and the Facility Cask Loading Room. As RH TRU mixed waste is held in canisters within a canister rack the physical inspection of the drum or canister is not possible. Inspections of RH TRU mixed waste in these areas occurs remotely via closed-circuit cameras a minimum of once weekly when stored waste is present. Because RH TRU mixed waste is in sealed casks, there are no additional requirements for engineered secondary containment systems. However, the floors in the RH Complex (including the RH Bay, Facility Cask Loading Room and Cask Unloading Room) are coated concrete and during normal operations (i.e., when waste is present), the floor of the RH Complex is inspected visually or by using close-circuit cameras on a weekly basis to verify that it is in good condition and free of visible cracks and gaps.

G3-4a TRU Mixed Waste Processing

Tables G3-2 and G3-3 specify the various steps in the process of receiving and disposing containers of CH TRU mixed waste including RH TRU mixed waste in shielded containers and RH TRU mixed waste, respectively, where radiological surveys will be performed by the Permittees. WIPP Procedure WP 12-HP1100 provides the detailed description of methods and equipment used when performing surface contamination surveys, dose rate surveys, and large area wipes.

ATTACHMENT H1

ACTIVE INSTITUTIONAL CONTROLS DURING POST-CLOSURE

Introduction

Upon receipt of the necessary certifications and permits from the EPA and the New Mexico Environment Department, the Permittees will begin disposal of contact-handled (**CH**) and remote-handled (**RH**) TRU and TRU mixed waste in the WIPP. This waste emplacement and disposal phase will continue until the regulated capacity of the repository of 6,200,000 cubic feet (175,588 cubic meters) of TRU and TRU mixed waste has been reached, and as long as the Permittees comply with the requirements of the Permit. For the purposes of this Permit Attachment, this time period is assumed to be 25 years. The waste will be shipped from DOE facilities across the country in specially designed transportation containers certified by the Nuclear Regulatory Commission. The transportation routes from these facilities to the WIPP have been predetermined. The CH TRU mixed waste will be packaged in 55-gallon (208-liter), 85-gallon (322-liter), 100-gallon (379-liter) steel drums, standard waste boxes (**SWBs**), ten drum overpacks (**TDOPs**), and/or standard large box 2s (**SLB2s**). An SWB is a steel container having a free volume of 66.3 cubic feet (1.88 cubic meters). Figure H1-2 shows the general arrangement of a seven-pack of drums and an SWB as received in a Contact-Handled Package. RH TRU mixed waste inside a Remote-Handled Package is contained in one or more of the allowable containers described in Permit Attachment A1. Some RH TRU mixed waste may arrive in shielded containers as described in Permit Attachment A1.

Appendix C

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EVALUATION OF DRUM AGE CRITERIA FOR THE SHIELDED CONTAINER

September 2011
Revision 2

Prepared for:
Washington TRU Solutions, LLC
PO Box 2078
4021 National Parks Highway
Carlsbad, New Mexico 88221

Prepared by:
Shaw Environmental, Inc.
2440 Louisiana Blvd. NE
Suite 300
Albuquerque, New Mexico 87110

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Acronyms and Abbreviations

atm	atmosphere
DAC	drum age criterion
K	Kelvin
mol/s/mol fraction	mole/second/mole fraction
TRU	transuranic
VOC	volatile organic compound

1.0 Background and Purpose

Containers of transuranic (TRU) waste must meet a minimum age criterion before a volatile organic compound (VOC) gas sample collected from the waste container headspace is considered representative of the VOCs within the container. The drum age criterion (DAC) is the time required after container closure, or after container closure and container venting, before a headspace gas sample can be collected. The methodology described in "Determination of Drum Age Criteria and Prediction Factors Based on Packaging Configurations" (BWXT, 2000) is the basis for the packaging-specific DAC values for debris waste (summary category S5000) currently approved in the Hazardous Waste Facility Permit for the Waste Isolation Pilot Plant ("Permit") (NMED, current version).

The shielded container is a new waste container that has been proposed for disposal at the Waste Isolation Pilot Plant. The shielded container is a vented carbon steel and lead cylindrical assembly with a removable lid. It is approved for the shipment of TRU waste in the HalfPACT package. Up to three (3) shielded containers can be shipped within a HalfPACT package.

The shielded container is designed to carry one 30-gallon payload drum. A partially exploded view of the shielded container, including its 30-gallon payload drum, is provided in Figure 1. In addition to the 30-gallon payload drum, the shielded container may optionally contain a plastic mesh drum handling bag to facilitate installation of the 30-gallon payload drum within the shielded container. If used, the optional drum handling bag is left open.

The shielded container and 30-gallon drum must each be installed with a filter vent. TRU waste is placed into a vented 30-gallon drum, which is then loaded into the shielded container.

Packaging-specific DAC values were previously determined for a number of packaging configurations (BWXT, 2000, Shaw 2003). The DAC for each packaging configuration was determined using the computer program VDRUM that solved a series of differential equations describing the VOC transport phenomena within the waste container (BWXT, 2000 and Connolly et al, 1998). Model input parameters include the physical properties of VOCs, the initial concentration profile in the waste container, physical dimensions of each confinement layer (thickness, surface area, void volume), and the hydrogen diffusion characteristics of filter vents installed on the waste containers (BWXT, 2000 and Connolly et al, 1998). Model parameters and assumptions used in determining the DAC values have also been documented (Shaw 2003, BWXT, 2000 and Connolly et al, 1998).

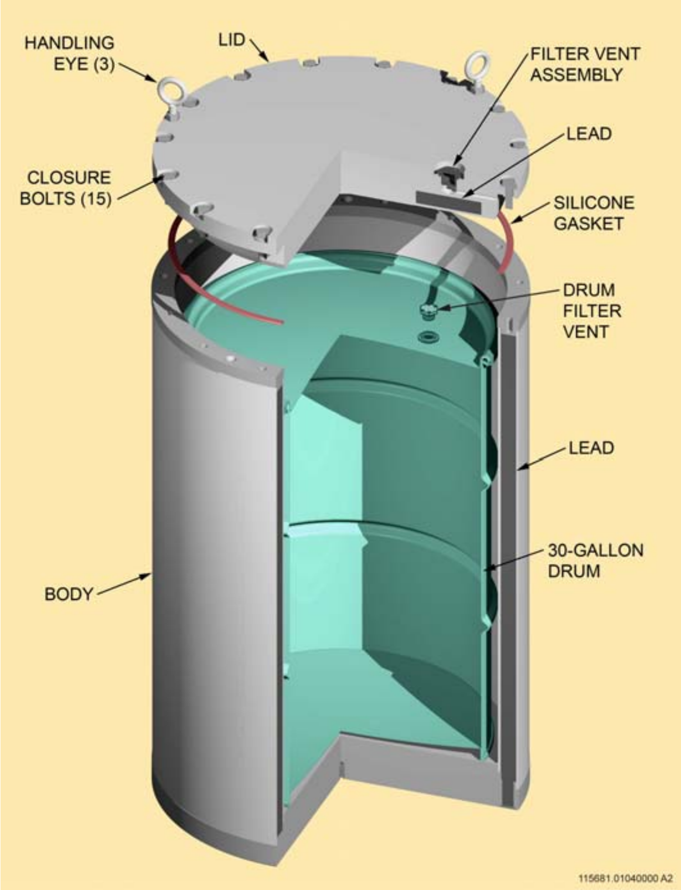


Figure 1
Shielded Container

The purpose of this report is to demonstrate that separate DAC values are not required for the shielded container or the 30-gallon drum (to allow for headspace sampling of stand-alone 30-gallon drum before being placed in the shielded container) because the existing 55-gallon drum default DAC values under Scenario 3, Packaging Configuration Group 3 (debris waste, summary category S5000) serve as reference upper bounds for the shielded container and 30-gallon drum packaging configurations, and therefore can be conservatively applied to the shielded container or 30-gallon drum. The inside volume of an empty shielded container is approximately 159 liters (Day, 2008) compared to 208 liters for an empty 55-gallon drum. As the waste will be loaded in a 30-gallon drum, a shielded container packaging configuration (and, by definition, the 30-gallon drum configuration) will hold less waste and has less available void volume than a typical 55-gallon drum loaded with debris waste. In addition, the shielded container packaging configurations will not use a rigid drum liner. Based on sensitivity studies (BWXT, 2000) these differences should result in lower DACs for the shielded container, and therefore the default 55-gallon drum DACs under Scenario 3, Packaging Configuration Group 3, should serve as conservative upper bounds. The next sections demonstrate that the DAC value for the shielded container (and the stand-alone 30-gallon drum) is indeed bounded by the existing 55-gallon drum packaging configuration DAC.

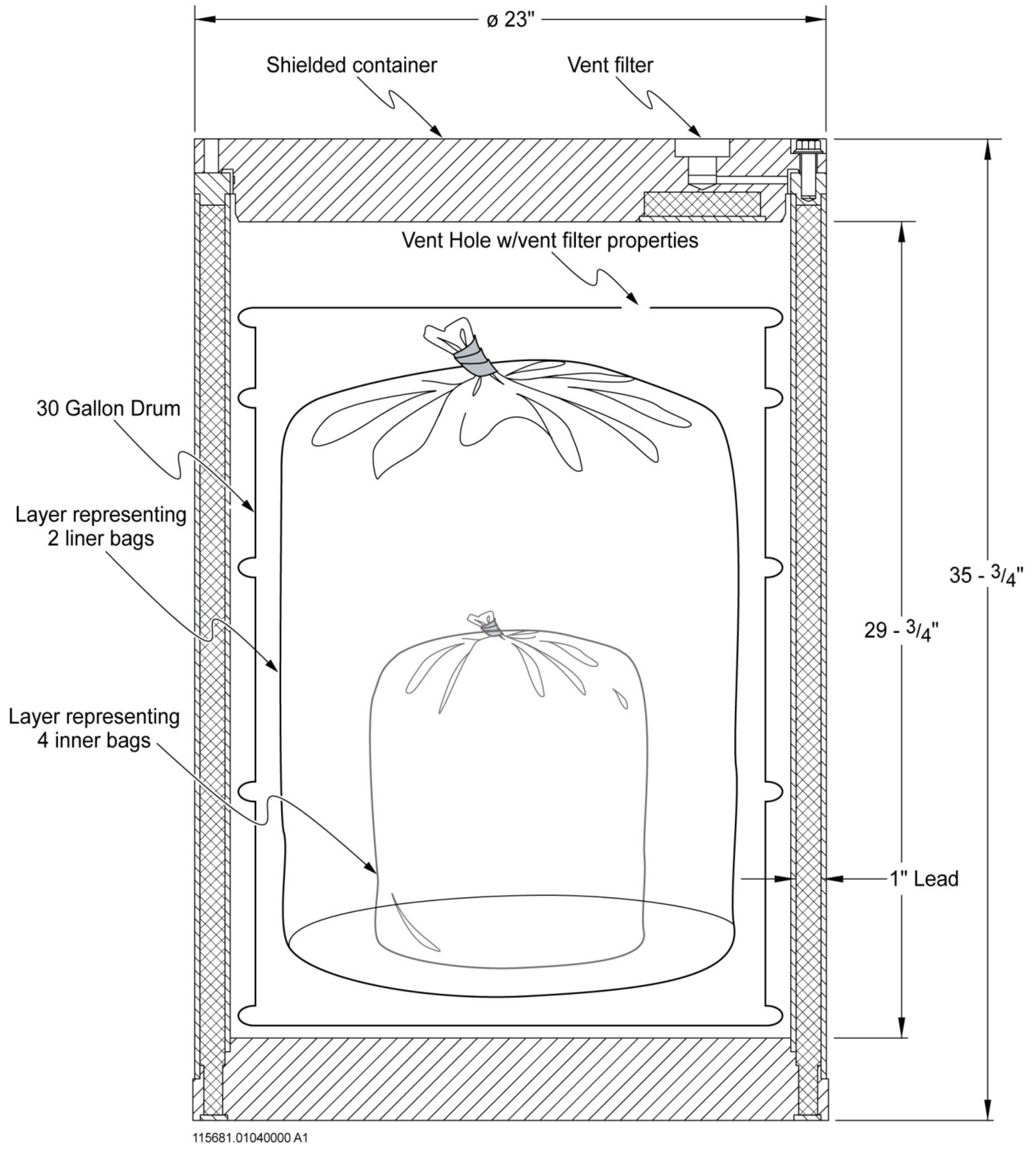
2.0 Methodology

All assumptions and parameters used in previous DAC calculations have been documented (Shaw 2003, BWXT, 2000). The VDRUM code was used to determine the DAC for a shielded container packaging configuration and 30-gallon drum configuration comparable to that of the 55-gallon drum. Parameter values specific to the shielded container DAC evaluation are discussed below and are listed in the input file included in Appendix A. Additional assumptions used in determining the DAC value for the shielded container are presented in this section.

A conservative inner packaging configuration was selected for the shielded container for this analysis. The packaging configuration consists of debris waste packaged in six plastic bags (i.e., four inner bags packaged in two liner bags). The drum handling bag (if used) is left open, but is conservatively modeled as a seventh bag layer (a third liner bag with a twist and tape closure) by the VDRUM code. Selection of this configuration is conservative as it will result in a longer DAC than the likely shielded container configuration with fewer bags. The bags are placed in a vented 30-gallon drum that is then placed inside a vented shielded container. There is no rigid drum liner in this packaging configuration. Both the 30-gallon drum and the shielded container are each assumed to be fitted with a filter vent with a hydrogen diffusivity characteristic of 1.85E-5 mole/second/mole fraction (mol/s/mol fraction). This filter is commonly used for new packaging configurations. The modeling of the shielded container packaging configuration is depicted in Figure 2. The calculated DAC for the shielded container configuration, as well as the DAC for the stand-alone 30-gallon drum, will be compared to the default Scenario 3, Packaging Configuration Group 3 DAC in Table C1-9 of the Permit (NMED, current version) for a 55-gallon drum with 4 inner bags, 2 liner bags, no rigid drum liner and a filter hydrogen diffusivity value of 3.7E-6 mol/s/mol fraction. The size and thickness of the bags is assumed to be the same as for the 55-gallon drum. Other parameter values are documented in Appendix A.

VOCs permeate across the inner and liner bags, diffuse out of the 30-gallon drum vent, into the shielded container headspace, and finally diffuse out through the shielded container filter vent.

In this and all previous DAC calculations (Shaw 2003, BWXT, 2000 and Connolly et al, 1998), it is conservatively assumed that the VOC concentration within the innermost confinement layer is constant due to thermodynamic equilibrium of the gas phase surrounding the VOC-contaminated waste matrix.



Note: Optional drum handling bag not shown.

Figure 2
VDRUM Model of Shielded Container Packaging Configuration

To model this configuration using VDRUM, the hydrogen diffusion value of the 30-gallon drum filter vent is expressed as an equivalent surface area of the opening in the lid. If the transport rate of a VOC across a filter vent and an opening are set equal to each other (BWXT, 2000), then an equivalent opening surface area can be defined in terms of the VOC diffusivity across the filter vent:

$$D_{VOC}^{*}\Delta y = \frac{D_{VOC}A_{d}c}{x_{d}}\Delta y \tag{1}$$

where

D^{*}_{VOC} = VOC diffusivity across filter vent, mole s^{-1}

D_{VOC} = VOC diffusivity in air, cm^2 s^{-1}

A_d = surface area of opening in confinement layer, cm^2

c = gas concentration, mole cm^{-3}

x_d = thickness of confinement layer at opening, cm

Δy = VOC mole fraction difference across confinement layer

Rearranging Equation (1) yields

$$A_{d} = \frac{D_{VOC}^{*}x_{d}}{D_{VOC}c} \tag{2}$$

From Shaw, 2003 the ratio of VOC diffusivity across a filter vent to that across air is assumed equivalent to the ratio of hydrogen across a filter vent to that of hydrogen in air:

$$\frac{D_{VOC}^{*}}{D_{VOC}} = \frac{D_{H_2}^{*}}{D_{H_2}} \tag{3}$$

where

D^{*}_{H2} = Hydrogen diffusivity across filter vent, mole s^{-1}

D_{H2} = Hydrogen diffusivity in air, cm^2 s^{-1}

Therefore, the equivalent surface area of an opening in a confinement layer can be expressed in terms of hydrogen diffusivity across the filter vent in the confinement layer

$$A_d = \frac{D^*_{H_2} x_d}{D_{H_2} c} \tag{4}$$

The ideal gas law estimates the gas concentration:

$$c = \frac{P_{atm}}{RT} \tag{5}$$

where

P_{atm} = pressure, atmosphere (atm)

T = temperature, Kelvin (K)

R = gas constant = 82.06 cm^3 atm/(g-mole) K

Hydrogen diffusivity is estimated using the Fuller, Schettler, and Giddings equation (Shaw, 2003):

$$D_{H_2} = \frac{0.00143 T^{1.75}}{P M^{0.5}_{H_2,air} \left[(\Sigma_v)^{1/3}_{H_2} + (\Sigma_v)^{1/3}_{air} \right]^2} \tag{6}$$

where

T = gas temperature, K

P = pressure, bar

$M_{H2,air}$ = 2 [1/M_{H2} + 1/M_{air}]$^{-1}$

M_i = molecular weight of component i, gram (gram-mole)$^{-1}$

$(\Sigma_v)_i$ = atomic diffusion volume of component i

where

M_{H2} = 2.016	$(\Sigma_v)_i$ = 6.12	
M_{air} = 28.97	$(\Sigma_v)_i$ = 19.7	(BWXT, 2000)

In the case of hydrogen-air system at T = 298.2 K and P = 1 atmosphere = 1.01325 bar, the diffusivity is:

$$D_{H2} = 0.758\ cm^2\ s^{-1}$$

Assuming an area thickness of 1.0 cm, the equivalent surface area for the 30-gallon drum filter vent of 1.85 x 10^{-5} mol/s/mol fraction diffusivity is the following:

$$A_d = \frac{1.85x10^{-5}(82.06)(298.2)}{0.758} = 0.597\ cm^2$$

3.0 Results

The DAC calculated using an established methodology (BWXT, 2000) for a representative shielded container packaging configuration (four inner bags packaged in two liner bags inside an optional drum handling bag inside a 30-gallon drum fitted with a 1.85E-5 mol/sec/mol fraction filter inside a shielded container fitted with a 1.85E-5 mol/sec/mol fraction filter) is documented in the output file included in Appendix A. The longest DAC is 16 days based on the VOC methyl isobutyl ketone. This DAC is equivalent to the Scenario 3, Packaging Configuration Group 3 DAC of 16 days in Table C1-9 of the Permit (NMED, current version) for a 55-gallon drum with 4 inner bags, 2 liner bags (bounding case), no rigid drum liner, and a filter hydrogen diffusivity value of 3.7E-6 mol/s/mol fraction. Thus, the analysis has demonstrated that separate DAC values are not required for the representative shielded container packaging configuration because the existing default 55-gallon drum DACs under Packaging Configuration Group 3 serve as upper bounds and should be used.

The DAC for directly sampling the headspace of the 30-gallon drum, prior to placing in a shielded container, was also evaluated. This DAC, calculated as 10 days, is also bounded by the Packaging Configuration Group 3 DAC of 16 days in Table C1-9 of the Permit (NMED, current version) for a 55-gallon drum. The input and output files for the 30-gallon drum configuration are also presented in Appendix A.

4.0 References

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Shaw, see Shaw Environmental and Infrastructure, Inc.

Shaw Environmental and Infrastructure, Inc. (Shaw), 2003, Determination of Drum Age Criteria Values for Ten-Drum Overpacks, 85-Gallon Drums, and 100-Gallon Drums, Revision 1, Shaw Environmental and Infrastructure, Inc, Albuquerque, New Mexico.

Appendix A
Input and Output Files Associated with the Shielded Container and 30-Gallon Drum DAC Value Determination

This appendix includes the input and output files for the shielded container and the 30-gallon drum that document the calculation of DAC values using the methodology described in BWXT (2000).

The computer program VDRUM used for deriving DAC values in BWXT (2000) employs input files of required data and reports the time for volatile organic compounds (VOCs) to reach at least 90 percent of their steady state concentrations. The input file for each packaging configuration includes the same data structure beginning with the input and output file names and the number of VOCs evaluated. Each VOC included in the analysis has two lines of input data, the initial concentrations in the layers of confinement and the physical and chemical properties. The physical characteristics, such as thickness and surface area, of each type of confinement layer are entered.

To determine the drum age criteria, the greatest time in days is selected from the VOCs (shown in bold in the output data listing). The data structures for the input and output files are shown in the following sections.

Input File Format

Line 1: Input file name, output file name, number of VOCs evaluated

Line 2: Name of VOC #1, $[IB]_0$, $[LB]_0$, $[LHS]_0$, $[DHS]_0$

Where:

$[IB]_0$ – Initial VOC concentration (ppmv) in inner bags
$[LB]_0$ – Initial VOC concentration (ppmv) in liner bags
$[LHS]_0$ – Initial VOC concentration (ppmv) in drum liner headspace
$[DHS]_0$ – Initial VOC concentration (ppmv) in drum headspace

Line 3: MW, ρ, D, T_c, P_c, D*, H, k, G (see Reference 1 for VOC-specific values)

Where:

MW – VOC molecular weight (g/gmol)
ρ – VOC permeability in polyethylene @ 25ºC, cm^3(STP) cm^{-1} sec^{-1} $(cmHg)^{-1}$
D – VOC diffusivity in air @ 25ºC, cm^2 s^{-1}
T_c – VOC critical temperature, K
P_c – VOC critical pressure, atm
D* – VOC diffusivity across filter vent, mol/s/mol fraction
H – VOC Henrys constant for polyethylene drum liner, (cm^3 polymer) atm/(cm^3 (STP) gas)
k – VOC mass transfer coefficient at drum liner surface, s^{-1}
G – VOC generate rate (always set to 0 (zero)).

Lines (2n, 2n+1): Information for n^{th} (last) VOC

Line (2n+2): $A_p(1)$, $A_d(1)$, V(1), $x_p(1)$, $x_d(1)$

Line (2n+3): $A_p(2)$, $A_d(2)$, V(2), $x_p(2)$, $x_d(2)$

Line (2n+4): $A_p(3)$, $A_d(3)$, V(3), $x_p(3)$, $x_d(3)$

Line (2n+5): $A_p(4)$, $A_d(4)$, V(4), $x_p(4)$, $x_d(4)$

Where:

A_p – permeable surface area, cm^2
A_d – diffusional cross-sectional area, cm^2
V – void volume inside layer of confinement, cm^3
x_p – layer thickness, cm
x_d – length of diffusional path length, cm
1 – inner bag
2 – drum liner bag
3 – drum liner headspace
4 – drum headspace

Line (2n+6): T, P, D_v*

Where:

T – gas temperature = 25°C
P – gas pressure = 76 cm Hg
D_v* – hydrogen diffusion characteristic across drum filter vent, mol/s/mol fraction

Output File Format

Line 1: Input file name

Lines 2, n+1: VOC, DAC, [DAC], [SS]

Where:

VOC – name of VOC
DAC – drum age criterion, days
[DAC] – VOC concentration at the time of the DAC value, ppmv
[SS] – VOC concentration at steady-state conditions, ppmv

Specific information about data input includes the following:

- The hydrogen release rate across the 30-gallon drum is defined by the hydrogen diffusivity of the filter vent. The DAC value was calculated for a diffusivity value of 1.85E-5 mol/s/mol fraction for the 30-gallon drum filter vent.

- T_c, P_c are required if $D = 0$ (i.e., when VOC diffusivity in air is not specified).
- T_c, P_c, D_v* are required if $D^* = 0$ (i.e., when VOC diffusivity across filter vent is not specified) and the drum is vented.
- If $D > 0$ and $D^* > 0$ (i.e., when diffusivities are specified), T_c and P_c can equal zero.
- No VOC gas generation is assumed; therefore, g equals zero.
- Only gas permeation across bags is considered, so $A_d = x_d = 0$ (for bags only).
- Although a rigid drum liner is not included in the packaging configuration, the VDRUM model includes a rigid drum liner layer in the input file and specification of A_p and x_p is required to estimate the volume of liner material. In order to nullify the effects of resistance to permeation of the non-existent rigid drum liner, x_p is set to a very small, non-zero value as shown in the input file, making the resistance to permeation of VOCs through this layer negligible.
- The shielded container packaging configuration parameter values are assumed to be the same as those for the corresponding 55-gallon drum (BWXT, 2000) values of bag thickness and surface area.
- The drum handling bag, though open at the top, is conservatively modeled as a third liner bag with twist and tape closure. The bag adds a thickness of 0.028 cm for 0.084 cm total. These values are shown in the corresponding input file.
- Assumptions for void volumes between the inner and liner bags and within the 30-gallon drum headspace are scaled by a factor of 30/55 from the corresponding 55-gallon drum void volumes previously used (BWXT, 2000). Thus, the void volume between inner and liner bags is 10,900 cm^3 (scaled from the 55-gallon drum value of 20,000 cm^3). The void volume in the 30-gallon drum headspace is 15,300 cm^3 (scaled from the 55-gallon drum value of 28,000 cm^3)
- The void volume between the 30-gallon drum and the shielded container is 37,284 cm^3 (Day, 2008).
- The release rate from the shielded container filter vent was set to a diffusivity of 1.85E-5 mol/s/mol fraction. Because VDRUM only allows entry of one filtered layer of confinement, the filter on the 30-gallon drum was accounted for by adjusting the parameter values for diffusion through the rigid drum liner layer hole to match the characteristics of the 30-gallon drum filter diffusion (the rigid drum liner layer is required in the VDRUM model). The modeled dimensions of the rigid drum liner hole are adjusted so the effective release rate equals the diffusivity value of 1.85E-5 mol/s/mol fraction 30-gallon drum filter vent. The 1.85E-5 mol/sec/mol fraction filter vent is modeled as a hole with an area of 0.597 cm^2 through a 1.0 cm thick layer.

Input File for Shielded Container DAC Evaluation

```
'shieldcontvdrum','shieldcontvdrum.out',12
'carbon tetrachloride',1000.,0.,0.,0.
153.82,193.e-10,0.0,556.4,45.0,0.,0.0217,6.e-5,0.
'methanol',1000.,0.,0.,0.
32.0,135.e-10,0.,513.2,78.5,0.,0.0272,2.4e-7,0.
'dichloromethane',1000.,0.,0.,0.
84.9,263.e-10,0.,510.,62.2,0.,0.0431,2.e-6,0.
'toluene',1000.,0.,0.,0.
92.1,669.e-10,0.0,591.8,40.5,0.,0.002857,7.e-6,0.
'trichloroethylene',1000.,0.,0.,0.
131.4,583.e-10,0.0,572.0,49.8,0.,0.00640,6.e-5,0.
'butanol',1000.,0.,0.,0.
74.1,300.e-10,0.,563.1,43.6,0.,0.02273,8.e-6,0.
'chloroform',1000.,0.,0.,0.
119.4,260.e-10,0.,536.4,53.0,0.,0.04545,8.e-6,0.
'1,1-dichloroethene',1000.,0.,0.,0.
96.9,110.e-10,0.,513.0,47.5,0.,0.09091,8.e-6,0.
'methyl ethyl ketone',1000.,0.,0.,0.
72.1,165.e-10,0.,536.8,41.5,0.,0.03704,8.e-6,0.
'methyl isobutyl ketone',1000.,0.,0.,0.
100.2,130.e-10,0.,571.0,32.3,0.,0.01724,8.e-6,0.
'1,1,2,2-tetrachloroethane',1000.,0.,0.,0.
167.9,2300.e-10,0.,661.2,57.6,0.,0.003846,8.e-6,0.
'chlorobenzene',1000.,0.,0.,0.
112.6,600.e-10,0.,632.4,44.6,0.,0.007692,8.e-6,0.
14000.,0.,0.,0.050,0.
14000.,0.,10900.,0.084,0.
12800.,0.597,15300.,0.00005,1.0
0.,0.,37284.,0.,0.
25.,76.,1.85e-5

c       shielded container, w/30-gal drum, each w/ filter vent, 4 inner bags, 2 liner bags
c          Drum handling bag modeled as a third twist and tape liner bag even though
c          bag is open at top. The bag adds a thickness of 0.028 cm for 0.084 cm total.
c       Value for volume within innermost bags not required.
c       Void volume between bags: 10,900 cm3 (scaled from 55-gal drum value of 20,000 cm3)
c       Bag thickness same as Scenario 3
c       Void volume in 30-gal drum headspace = 15,300 cm3 (scaled from 55-gal drum value of 28,000 cm3)
c       Void volume between 30-gal and shielded container: 37,284 cm3
c       No liner so no solubility for VOCs (thus, 30-gal drum as  "liner thickness" xp = 0.00005 cm)
c       Effective surface area across 30-gal drum  filter (assuming xd= 1.0 cm): Ad = 0.597 cm2
c       so effective H2 release rate equals 30-gal drum filter vent, D*(H2)=1.85e-5 mol/s/mol fraction
c       D*H2 = total H2 diff. char. across shielded container filter vent = 1.85e-5 mol/s/mol fr
c       VOC diff. char. estimated knowing D*H2, VOC Tc, VOC Pc
```

Output File for Shielded Container DAC Evaluation

```
shieldcontvdrum
carbon tetrachloride          14    399.5111    438.5642
methanol                      11    346.9043    379.4464
dichloromethane               11    403.0082    443.6181
toluene                       12    436.2250    480.7493
trichloroethylene             12    436.7753    477.0292
butanol                       12    412.6895    456.2111
chloroform                    12    406.4105    448.6669
1,1-dichloroethene            15    359.0007    392.9815
methyl ethyl ketone           14    389.6570    425.0542
methyl isobutyl ketone        16    380.5107    419.6800
1,1,2,2-tetrachloroethane     11    444.8763    493.8665
chlorobenzene                 12    431.7012    479.1213
```

Input File for 30-Gallon Drum DAC Evaluation

```
'30galdrum','30galdrum.out',12
'carbon tetrachloride',1000.,0.,0.,0.
153.82,193.e-10,0.0,556.4,45.0,0.,0.0217,6.e-5,0.
'methanol',1000.,0.,0.,0.
32.0,135.e-10,0.,513.2,78.5,0.,0.0272,2.4e-7,0.
'dichloromethane',1000.,0.,0.,0.
84.9,263.e-10,0.,510.,62.2,0.,0.0431,2.e-6,0.
'toluene',1000.,0.,0.,0.
92.1,669.e-10,0.0,591.8,40.5,0.,0.002857,7.e-6,0.
'trichloroethylene',1000.,0.,0.,0.
131.4,583.e-10,0.0,572.0,49.8,0.,0.00640,6.e-5,0.
'butanol',1000.,0.,0.,0.
74.1,300.e-10,0.,563.1,43.6,0.,0.02273,8.e-6,0.
'chloroform',1000.,0.,0.,0.
119.4,260.e-10,0.,536.4,53.0,0.,0.04545,8.e-6,0.
'1,1-dichloroethene',1000.,0.,0.,0.
96.9,110.e-10,0.,513.0,47.5,0.,0.09091,8.e-6,0.
'methyl ethyl ketone',1000.,0.,0.,0.
72.1,165.e-10,0.,536.8,41.5,0.,0.03704,8.e-6,0.
'methyl isobutyl ketone',1000.,0.,0.,0.
100.2,130.e-10,0.,571.0,32.3,0.,0.01724,8.e-6,0.
'1,1,2,2-tetrachloroethane',1000.,0.,0.,0.
167.9,2300.e-10,0.,661.2,57.6,0.,0.003846,8.e-6,0.
'chlorobenzene',1000.,0.,0.,0.
112.6,600.e-10,0.,632.4,44.6,0.,0.007692,8.e-6,0.
14000.,0.,0.,0.050,0.
14000.,0.,10900.,0.056,0.
12800.,150.,40000.,0.00005,1.4
0.,0.,15300.,0.,0.
25.,76.,185.e-7
c    30-gal drum w/ filter vent, 4 inner bags, 2 liner bags
c    Value for volume within innermost bags not required.
c    Void volume between bags: 10,900 cm3 (scaled from 55-gal drum value of 20,000 cm3)
c     Bag thickness same as Scenario 3
c     Void volume in 30-gal drum headspace = 15,300 cm3 (scaled from 55-gal drum value of 28,000 cm3)
c    No liner (estimated by Ad=150 cm2, xd=1.4 cm, xp=0.00005)
c    30-gal drum filter vent = 1.85e-5 mol/s/mol fr
c    VOC diff. char. estimated knowing D*H2, VOC Tc, VOC Pc
```

Output File for 30-Gallon Drum DAC Evaluation

```
30galdrum
carbon tetrachloride        7     756.5144     814.9987
methanol                    8     612.8073     663.1251
dichloromethane             5     762.1498     828.8836
toluene                     3     904.2119     935.8895
trichloroethylene           3     878.6143     924.7414
butanol                     5     809.4791     864.1644
chloroform                  5     769.9742     842.9145
1,1-dichloroethene          10    639.2377     696.2681
methyl ethyl ketone         7     704.3638     778.6090
methyl isobutyl ketone      9     696.7892     764.4190
1,1,2,2-tetrachloroethane   1     950.9211     976.5667
chlorobenzene               3     887.4651     930.9960
```

Item 3

Class 2 Permit Modification Request

Revise the WIPP Groundwater Detection Monitoring Program Plan

Waste Isolation Pilot Plant
Carlsbad, New Mexico

WIPP Permit Number - NM4890139088-TSDF

SEPTEMBER 2011

Table of Contents

Acronyms and Abbreviations

ASER	Annual Site Environmental Report
CBFO	Carlsbad Field Office
CFR	Code of Federal Regulations
DMP	Detection Monitoring Program
DOE	U.S. Department of Energy
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
HWDU	Hazardous Waste Disposal Unit
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
Permit	Hazardous Waste Facility Permit
PMR	Permit Modification Request
QAO	quality assurance objective
RCRA	Resource Conservation and Recovery Act
SOP	standard operating procedure
TOX	total organic halogen
TRU	transuranic
V and V	verification and validation
WIPP	Waste Isolation Pilot Plant
WLMP	Water Level Monitoring Program
WTS	Washington TRU Solutions LLC

Overview of the Permit Modification Request

This document contains one Class 2 permit modification request (**PMR**) to the Hazardous Waste Facility Permit (**Permit**) for the Waste Isolation Pilot Plant (**WIPP**) facility, Permit Number NM4890139088-TSDF.

This PMR is being submitted by the U.S. Department of Energy (**DOE**), Carlsbad Field Office (**CBFO**) and Washington TRU Solutions LLC (**WTS**), collectively referred to as the Permittees, in accordance with the Permit Part 1, Condition 1.3.1 (20.4.1.900 New Mexico Administrative Code (**NMAC**) incorporating Title 40 Code of Federal Regulations (**CFR**) §270.42(d)).

These changes do not reduce the ability of the Permittees to provide continued protection to human health and the environment.

The requested modification to the WIPP Permit and related supporting documents are provided in this PMR. The proposed modification to the text of the WIPP Permit has been identified using red text and a double underline and a ~~strikeout~~ font for deleted information. The following information specifically addresses how compliance has been achieved with the WIPP Permit Part 1, Condition 1.3.1. for submission of this Class 2 PMR.

1. **20.4.1.900 NMAC (incorporating 40 CFR §270.42(b)(1)(i)), requires the applicant to describe the exact change to be made to the permit conditions and supporting documents referenced by the Permit.**

This PMR proposes to make changes to the groundwater monitoring program as described in Permit Part 5 and Attachment L. The Table of Changes and redline/strikeout in Attachments A and B of this modification, respectively, and the discussion below describe the exact changes to be made to the Permit Conditions and supporting documents. These changes are being made in accordance with the Groundwater Permit Modification Work Plan approved by the NMED on August 5, 2011. The approved Groundwater Permit Modification Work Plan and the NMED approval letter are included in Attachment C to this PMR. The purpose of the Groundwater Permit Modification Work Plan is to address the content of the PMR and the process that the Permittees' will follow to prepare and submit the PMR. The Groundwater Permit Modification Work Plan tentative schedule includes discussing the Draft PMR with Stakeholders and the NMED. The Draft PMR was provided to Stakeholders and the NMED on August 15, 2011. The Draft PMR was then discussed with the Stakeholders and the NMED on August 30, 2011 at the Pre-submittal meeting in Albuquerque, NM.

The PMR includes, but is not limited to, the items in the Groundwater Permit Modifcation Work Plan described below. The elements of the Groundwater Permit Modification Work Plan are shown in **Bold** font below and the descriptions of the proposed changes are shown in *italized* text.

- **Revise sources of confusion and ambiguities.**

  *The Permit contains confusing references to the components of the groundwater monitoring plan and to the various elements of the program. The modification request proposes clarification by describing the program as the Groundwater Monitoring Program consisting of two components: the Detection Monitoring Program (**DMP**) and the Water Level Monitoring Program (**WLMP**). The DMP consists of six wells that are* *sampled, analyzed, and reported annually. The WLMP consists of over 40 wells that are measured monthly and reported semi-annually.*

- **Specifically identify which wells are used for density measurements.**

  A new table, Attachment L, Table L-4, was added to identify the Culebra wells used for obtaining density measurements.

  - **Specify frequency for density measurements and assessment.**

    Attachment L, Section L-4c(1) was revised to specify the frequency for density measurements as annually.

  - **Specify how density measurements are performed.**

    Attachment L, Section L-4c(1), last paragraph, now describes the means of how density measurements are performed.

- **Include a specific list of wells that must be monitored for water levels.**

  - **Exclude non-Culebra wells from those required for water level measurements.**

    A new table, Attachment L, Table L-4, lists the Culebra wells for water level monitoring. Non-Culebra wells have been excluded.

- **Remove all references to the non-Culebra sampling well identified as WQSP-6A.**

  This change was made when the Permit was renewed in 2010. Therefore, no change is being proposed.

- **Clarify the need for, and use of, written procedures for both field work and non-field work, including the procedure for developing a potentiometric surface map annually.**

  The sections listed below were revised to clarify the need for, and use of, written procedures (referred to as standard operating procedures or SOPs) for both field work and non-field work:

  > *Attachment L, Sections L-1, L-4c(1), L-4c(1)(i), L-4c(1)(ii), L-4c(2)(i), L-4c(2)(ii), L-4c(2)(iii), L-4c(2)(iv), L-4c(2)(v), L-4d(1), L-4d(2),L-7a(4),L-7c, L-7d, L-7e, L-7f, L-7g, L-7h, L-7i, and Table L-3.*

  In addition, the SOP descriptions were removed from the text, updated, and included as the new Table L-3. The procedure for developing a potentiometric surface map was added to Attachment L, Section L-5c.

- **Clarify the data quality objectives section and explain data quality objectives and quality assurance objectives and the difference between the quality assurance objectives for field work and laboratory analysis.**

*The data quality objectives (**DQOs**) and quality assurance objectives (**QAOs**) are clearly identified, revised, and separated into Attachment L, Sections L-7a(1), Data Quality Objectives, and new Section L-7a(2), Quality Assurance Objectives. These changes clearly define the DQOs for each Groundwater Monitoring Program component and clarify the associated QAOs.*

- **Remove specificity regarding departments and organizations and replace those terms with "the Permittees."**

  Attachment L, Section L-7, Project Organization and Responsibilities, has been deleted. References to departments, organizations, and titles referenced in Attachment L are eliminated or replaced with "Permittees."

  The sections that were revised are listed below:

  > *Attachment L, Sections L-4c(2)(i), L-4c(2)(ii), L-4c(2)(v), L-4c(3), L-5(a), L-5(b), and L-5(c).*

  *Updated the organization that performs data verification and validation (**V and V**) in Attachment L, Section L-4c(3).*

- **Add background values from the "Waste Isolation Pilot Plant Resource Conservation and Recovery Act Background Groundwater Quality Baseline Report" and Addendum 1, IT Corporation, July 2000, to be used for making statistical determinations of contamination.**

  This change was made when the Permit was renewed in 2010. Therefore, no change is being proposed.

- **Separate parameters from constituents so that general chemistry parameters (e.g., pH, calcium) are separated from the hazardous constituents.**

  This change was made when the Permit was renewed in 2010.

- **Clarify serial sampling requirements including the following:**

  - **Remove several field parameters that are not indicators of stabilization, such as chloride, divalent cations, alkalinity, total iron, and Eh.**

    This change was made in Attachment L, Section L-4c(2)(ii).

  - **Remove the bubbler line requirements.**

    This change was made in Attachment L, Section L-4c(2)(i).

  - **Restrict serial sampling for stabilization to no more than three well bore volumes.**

    This change was made in Attachment L, Section L-4c(2)(i) and L-4c(2)(ii).

- **Change the frequency of performing groundwater sampling and analysis to an annual basis rather than semi-annually.**

  - **Change the frequency of reporting to annually rather than semi-annually.**

    The modification includes clarification regarding when sampling data will be submitted. The Permittees are proposing annual sampling instead of semi-annual sampling based on 15 years of data that show little or no change in constituent concentrations. The Permittees are proposing a specific date that the report will be due to the NMED.

    A November 30 submittal will be in the form of an "Annual Culebra Groundwater Report" which includes the Annual Culebra Groundwater sampling results.

    See Part 5, Conditions 5.5.1, 5.10.2.1, 5.10.2.2, 5.10.2.3, Attachment L, Sections L-4a, L-4c(3), L-4e(4), L-5b, L-5c, Table L-2.

- **Change the frequency of reporting water level values to twice per year rather than monthly.**

    The details of the proposed changes with regard to WLMP reporting are as follows:

    - *Effective on the first reporting date after approval of the PMR, the Permittees will provide a groundwater level report to the NMED semi-annually according to the following schedule:*

        1. *By May 31 for groundwater level measurements taken between August 1 and January 31.*

        2. *By November 30 for groundwater level measurements taken between February 1 and July 31. The Permittees will combine the November water level data report with the November "Annual Culebra Groundwater Report."*

        3. *Each semi-annual report will include a hydrograph for each Culebra monitoring well. The hydrograph will show both uncorrected (as measured) and corrected (to equivalent freshwater) heads.*

        4. *Each semi-annual report will include a hydrograph for each Culebra monitoring well beginning with the 2005 sampling year and displaying at least five years of continuous measurement.*

        5. *In the November "Annual Culebra Groundwater Report," the Permittees will provide a Culebra Potentiometric Surface Map, corrected to equivalent freshwater heads.*

    See Part 5, Conditions 5.10.2.2, 5.10.2.3, Attachment L, Sections, L-4c(1), L-4c(1)(ii), L-5b,L-5c.

  - **Include enhanced interpretation in the form of annotated hydrographs.**

Attachment L, Section L-4c(1)(ii) was revised to stipulate that the semi-annual groundwater reports will include annotated hydrographs and trend analysis.

- **Include flow rate and direction determination in the annual detection monitoring report.**

  The Permittees have clarified that flow rate and direction determinations will be included in the "Annual Culebra Groundwater Report" required by Attachment L, Section L-5c. Only the downgradient wells could trigger actions leading to compliance monitoring. Based on transport modeling, the only wells that would likely intercept a contaminant plume are downgradient wells WQSP 4 to 6 from the WIPP shaft area. These wells are located between the shafts and the facility boundary such that detection would occur long before any contamination would reach the boundary. The Culebra water surface mapping method, employed by the Permittees to demonstrate flow rate and direction, will provide a periodic demonstration that the flow paths continue to be in the direction of these downgradient wells.

  - **Remove the "Annual Site Environmental Report" (ASER) as a means of reporting flow rate and direction.**

    The PMR proposes to remove the ASER as a Permit deliverable and report the relevant groundwater flow rate and direction in the "Annual Culebra Groundwater Report."

    The PMR proposes to remove requirements to report radionuclide analytical results annually to the NMED. These are not measured under the Permit and were previously provided as part of the ASER.

    See Part 5, Condition 5.10.2.3, Attachment L, Sections, L-4e(4), L-5b, L-5c.

- **Revise the statistical process for data analysis to be consistent with 20.4.1.500 NMAC (incorporating 40 CFR 264.97(h)).**

  The PMR clarifies how temporal and spatial analyses and statistical evaluations are performed.

  See Attachment L, Sections L-4e, L-4e(1), L-4e(2), L-4e(3).

- **Update figures, tables, and text with current information.**

  The PMR proposes to remove obsolete content throughout Part 5 and Attachment L. This includes conditions in the Permit that only applied to the initial baseline sampling and is no longer required. This language is proposed for deletion and past-tense statements are either completed or are made current. For example, in Section L-4e(4) added, "TRU mixed" to clarify the point in time when baseline measurements ceased.

- **Describe the methodology for generation of the Culebra Potentiometric Surface Map whereby the Permittees determine the groundwater flow rate and direction annually in accordance with 20.4.1.500 NMAC (incorporating 40 CFR 264.98(e)).**

In Attachment L, Section L-5c, Bullet #7 clarifies the methodology for groundwater surface elevations including how the potentiometric map is determined and drawn. The Permittees have proposed a procedure for generating the potentiometric map that is required by the Permit. This procedure is designed to reflect the most recent hydrological information regarding the Culebra and uses the most recent water level measurements and water densities. The Permittees propose that the potentiometric map be generated using the following steps:

- *Examine hydrographs to identify the month having the largest number of Culebra water levels available with the fewest wells affected by pumping or other anthropogenic events.*
- *Convert water levels from the subject month to equivalent freshwater heads using fluid densities appropriate to the date.*
- *Fit the trend surface through freshwater heads.*
- *Extrapolate the trend surface to the boundaries of the model domain used for the current Performance Assessment Baseline Calculations (PABCs) and define initial fixed-head boundary conditions based on the trend surface.*
- *Using the ensemble-average Culebra transmissivity field used for the current PABC, optimize the model boundary heads to improve the fit of the model to the freshwater heads at the wells using optimization software interactively with MODFLOW.*
- *Run MODFLOW with optimal boundary conditions fit.*
- *Contour MODFLOW head results on WIPP site.*
- *Compute the particle path and travel time from the Waste Handling Shaft to the LWA Boundary.*
- *Data analysis that will accompany the potentiometric surface map will include:*
    - *Measured versus modeled scatter plot diagram*
    - *Frequency of modeled head residuals*
    - *Modeled residual freshwater head at each well*
    - *Explanations for modeled misfit residuals greater than 16.4 feet (5 meters).*

Other Proposed Changes

The Groundwater Permit Modification Work Plan states, "The PMR will include, but will not necessarily be limited to the modifications…" Therefore, the Permittees propose these changes that are not specifically listed in the Groundwater Permit Modification Work Plan.

- Clarify the contents of the Operating Record versus what will be retained on file at the facility but not in the Operating Record.

The Permittees are clarifying which records are required to be in the Operating Record (20.4.1.501 NMAC, incorporating 40 CFR 264.73) versus those that will be kept on file at the facility.

- The Permittees are deleting the reference to Teflon and replacing it with “inert material.”

  See Attachment L, Sections in L-4c(2).

- The Permittees have added a clarification that the analytical laboratory may deviate from SW 846 and/or request sample containers, volumes, and holding times that are different than those listed in Table L-6 with prior approval by NMED.

  See Attachment L, Table L-6 Note

- The Permittees have combined the Request for Analysis and Chain of Custody example forms into one form.

  See Attachment L, Section L-4c(2)(iv), L-4c(2)(v) and Figure L-13.

- The Permittees are deleting the requirement for non-dedicated sample collection lines and referring the cleaning of other non-dedicated components to SOPs.

  See Attachment L, Section L-4c(2)(iii).

- The Permittees are proposing the removal of total organic halogen (TOX) as a parameter.

  See Part 5, Condition 5.4, Table 5.4.a, and Attachment L, Section L-4c(2)(iii), Table 6.

- The Permittees are proposing to change the baseline value for methylene chloride to five micrograms per liter (µg/L).

  See Part 5, Table 5.6.

- *The Permittees are making numerous editorial changes throughout Part 5 and Attachment L and deleting redundant text.*

The following are examples of Editorial changes that the Permittees are proposing to clarify Permit text and make the text consistent:

  - *Standardize the term “ground-water” and “ground water” to the term “groundwater.”*

  - *Eliminate “branching from the main sample line...” in Attachment L, Section L-4c(2)(iii) because it is redundant to text in Attachment L, Section L-4c(2)(i)*

- *Consolidated the terms "WIPP", "WIPP facility", "WIPP site", "WIPP area", "WIPP vicinity", and "WIPP region" in an attempt to make the useage consistent with the definition of the permitted facility in Permit Part 1, Section 1.5.3.*

2. 20.4.1.900 NMAC (incorporating 40 CFR §270.42(b)(1)(ii)), requires the applicant to identify that the modification is a Class 2 modification.

This is a Class 2 modification for the reasons listed below:

- "Changes in ground-water sampling or analysis procedures or monitoring schedule, with prior approval of the director…[1]1" pursuant to 20.4.1.900 NMAC (incorporating 40 CFR §270.42, Appendix I, C. Ground-water protection, Item 2). The NMED provided prior approval of the classification with the approval of the Groundwater Permit Modification Work Plan.

- "Changes in the indicator parameters, hazardous constituents, or concentration limits (including ACLs): b. as specified in the detection monitoring program…2" pursuant to 20.4.1.900 NMAC (incorporating 40 CFR §270.42, Appendix I, C. Ground-water protection, Item 5.b).

3. 20.4.1.900 NMAC (incorporating 40 CFR §270.42(b)(1)(iii)), requires the applicants to explain why the modification is needed.

This PMR is needed to comply with the Groundwater Permit Modification Work Plan, approved by the NMED on August 5, 2011. The following discussion provides a brief explanation of why the changes are required by the Groundwater Permit Modification Work Plan. The exact change that is being made is described in Item 1 above and the attached redline/strikeout text in Attachment B. The following discussion is formatted to follow the Groundwater Permit Modification Work Plan. The elements of the Work Plan are shown in **Bold** font below. Where applicable, the description of proposed changes is shown in *italized* text and the explanation of why the change is being made is shown in blue.

- **Revise sources of confusion and ambiguities.**

  *The Permit contains confusing references to the components of the groundwater monitoring plan and to the various elements of the program. The modification request proposes clarification by describing the program as the Groundwater Monitoring Program consisting of two components: the Detection Monitoring Program (**DMP**) and the Water Level Monitoring Program (**WLMP**). The DMP consists of six wells that are sampled, analyzed, and reported annually. The WLMP consists of over 40 wells that are measured monthly and reported semi-annually.*

  The first item in the Groundwater Permit Modification Work Plan deals with ambiguities and confusion in the Permit with regard to the implementation of groundwater monitoring at the WIPP facility. The Permittees identified several specific examples of these sources and listed them in the Groundwater Permit Modification Work Plan**.**

The first item in the Groundwater Permit Modification Work Plan deals with ambiguities and confusion in the Permit with regard to the implementation of groundwater detection monitoring requirements at the WIPP facility. Eliminating the sources of confusion and ambiguity is required to facilitate compliance with Permit and with Item 10.a. of the NMED stipulated Final Order NO. HWB-09-47. The Permittees identified specific examples of these sources and listed them in the Groundwater Permit Modification Work Plan. Ambiguities and confusing text dealt with areas such as groundwater well designation, water level measurement, procedures, data quality objectives, quality assurance objectives, and organizational responsibilities. However, before dealing with these specific sources, it is necessary to clarify the WIPP groundwater DMP and its program components to eliminate confusion with regard to what program components are used for compliance with various requirements.

Clarifying the program as the Groundwater Monitoring Program consisting of two components, the DMP and the WLMP, which eliminates confusion with regard to what program components are used to satisfy various requirements. Language in the Permit refers to the overall program and all wells as being the DMP. However, in other places, the DMP wells are limited to only the wells that are sampled and analyzed. In order to correct this, the Permittees are proposing language that defines the overall program as the Groundwater Monitoring Program with two components, the DMP and the WLMP. Each component has its own set of measurement wells and measurement activities and associated DQOs. The DMP consists of six wells that are sampled and analyzed annually to determine if contamination has been released from the disposal units. The WLMP consists of over 40 wells that are measured monthly and reported semi-annually to determine if assumptions regarding groundwater flow and direction remain valid.

- **Specifically identify which wells are used for density measurements.**

  A new table, Attachment L, Table L-4, was added to identify the Culebra wells used for obtaining density measurements.

  Density measurements are only relevant to Culebra water level determinations. Previously, the number of wells used was defined generally as those available for measurement. These wells included some that are too distant to have a meaningful impact on the facility water level determination and some that were completed in horizons other than the Culebra and had no impact on the water level mapping. The Permittees have optimized (McKenna 2004) the number and location of wells for making water level determinations and are proposing to establish these wells as a list in the Permit that can only be changed via a permit modification. The list eliminates non-Culebra wells from the measurement schedule since these measurements are not used to determine compliance with groundwater monitoring requirements of the Permit.

  In addition, language has been clarified to ensure that the water levels are measured monthly, that densities are measured annually, that acceptable methods are used for making measurements, and that new density data are used in correcting measured water levels to freshwater heads. This language ensures that semi-annual and annual data submittals are of acceptable quality and are presented in a consistent manner that makes comparison of results over time possible. The measurement methodology and the procedure for drawing the maps (discussed subsequently) also ensure consistency between the data reported to the NMED for Permit compliance and data reported to the Environmental Protection Agency (EPA).

This change is required to clarify specifically what wells are used to obtain density measurements.

- **Specify frequency for density measurements and assessment.**

  Attachment L, Section L-4c(1) was revised to specify the frequency for density measurements as annually.

  The language in the Permit does not reflect the original intent of the Groundwater Monitoring Program to evaluate density annually. The language has been clarified to require measurement and evaluation annually.

- **Specify how density measurements are performed.**

  Attachment L, Section L-4c(1), last paragraph, now describes the means of how density measurements are performed.

  This clarification is required to provide instructions on how density measurements can be consistently performed. Measurement will be made using a hydrometer for DMWs, mobile pressure transducer for redundant wells, and fixed transducers in other wells. Calculations are presented in Attachment L, Section L-4c(1).

- **Include a specific list of wells that must be monitored for water levels.**

  - **Exclude non-Culebra wells from those required for water level measurements.**

    A new table, Attachment L, Table L-4 lists all Culebra wells for water level monitoring, excluding non-Culebra wells.

    Some confusion exists in the Permit regarding which wells are to be sampled or measured. The Permittees have clarified this by providing a list of Culebra wells for both the DMP and the WLMP (new Attachment L, Table L-4). Non-Culebra wells have been excluded because they provide no data for detection monitoring.

- **Clarify the need for, and use of, written procedures for both field work and non-field work, including the procedure for developing a potentiometric surface map annually.**

  The sections listed below were revised to clarify the need for, and use of, written procedures for both field work and non-field work:

  > *Attachment L, Sections L-1, L-4c(1), L-4c(1)(i), L-4c(1)(ii), L-4c(2)(i), L-4c(2)(ii), L-4c(2)(iii), L-4c(2)(iv), L-4c(2)(v), L-4d(1), L-4d(2),L-7a(4),L-7c, L-7d, L-7e, L-7f, L-7g, L-7h, L-7i, and Table L-3.*

  In addition, the procedure descriptions were removed from the text, updated, and included as new Table L-3. The procedure for developing a potentiometric surface map was added to Attachment L, Section L-5c.

  Another source of confusion in the Permit has to do with procedures needed to conduct the Groundwater Monitoring Plan. The Permit lists specific procedures needed for field activities but is silent with regard to non-field procedures used to analyze and map groundwater data. Language regarding procedures is ambiguous. In order to eliminate this ambiguity, the Permittees are proposing a list of field and non-field procedures and a description of the process (procedure) for producing the annual potentiometric surface map.

This approach accomplishes three objectives. First, it satisfies the Resource Conservation and Recovery Act (**RCRA**) regulations that specify that certain groundwater activities be performed in accordance with procedures and that personnel be trained to those procedures and use them during monitoring activities. This table lists the minimum RCRA requirements that are to be included in procedures. Second, it removes the details of the procedures from the Permit, thereby giving the Permittees the flexibility to change procedures to accommodate administrative changes or changes in sampling or analytical methods without having to seek a permit modification. Preparing, using, and controlling SOPs is mandated at the WIPP facility by the DOE quality assurance requirements. Standard operating procedures may change frequently as the DOE requirements change. By listing specific SOPs by number and title in the Permit, the Permittees find themselves in a position where implementing changes, even administrative ones, may be delayed because of the need to modify the Permit first. In order to overcome this, the Permittees are proposing to list the specific items that must be included in facility SOPs, and committing to have the current version of the SOP on file for the NMED to examine at any time. In this way, the Permit controls the essential content of the SOP while the Permittees control the administration for the SOP. Third, it enhances the enforceability of the program by removing any question regarding which SOPs are in place and are being followed by the Permittees with regard to the Groundwater Monitoring Program.

- **Clarify the data quality objectives section and explain data quality objectives and quality assurance objectives and the difference between quality assurance objectives for field work and for laboratory analysis.**

  The DQOs and QAOs are clearly identified, revised, and separated into Attachment L, Sections L-7a(1), Data Quality Objectives, and new Section L-7a(2), Quality Assurance Objectives. These changes clearly define the DQOs for each Groundwater Monitoring Program component and clarifies the QAOs.

  The Permit confuses DQOs and QAOs and fails to distinguish between QAOs applicable to field measurements and those applicable to laboratory analysis. In addition, the clarification of the Groundwater Monitoring Program, consisting of two separate components, leads to the need to state a DQO for each component. While the program has been operating under a consistent set of QAOs, specifying them in the Permit ensures consistency for future Groundwater Monitoring Program activities. Furthermore, clearly stated QAOs and DQOs aligns the program with EPA Guidance which encourages this.

- **Remove specificity regarding departments and organizations and replace those terms with “the Permittees.”**

  Deleted entire section of former Permit, Attachment L, Section L-7, Project Organization and Responsibilities. Deleted all references to departments, organizations, and titles *referenced in former Attachment L, Section L-7 throughout Attachment L and eliminated or replaced with Permittees.*

The sections that were revised are listed below:

> *Attachment L, Sections L-4c(2)(i), L-4c(2)(ii), L-4c(2)(v), L-4c(3), L-5(a), L-5(b), and L-5(c).*

Changed organizational titles to the more generic “Permittees” where applicable in Attachment L.

When the Groundwater Program was initially placed in the Permit, it was based on an internal WIPP facility implementation plan which included specific organization and position names. As a result, there are numerous places in the Permit where unnecessary detail regarding position titles and organizations is provided. While this is important at the facility level as part of an implementation plan, it is not needed in the Permit, and creates an administrative burden to the extent that if the organizational names or functions change at the facility, a Permit modification is necessary. Therefore, in an effort to focus the Permit on the requirements and to leave the details for implementation to the Permittees internal programs and processes, changes such as this are being proposed.

Updated the organization that performs data V and V.

This change is necessary because previously the Permittees contracted data V & V to a subcontractor, the text reflected this activity. The Permittees now perform V & V in house and much of the language that applies to managing subcontractors does not apply. Instead, an SOP for V&V is listed in Attachment L, Table L-3 to ensure the proper V&V.

- **Clarify serial sampling requirements including the following:**

  - **Remove several field parameters that are not indicators of stabilization, such as chloride, divalent cations, alkalinity, total iron, and Eh.**

    See Attachment L, Section L-4c(2)(ii).

    Another area addressed by the Groundwater Permit Modification Work Plan regards serial sampling. The Permit requires the measurement of chloride divalent cations, alkalinity, total iron, Eh, pH, specific conductance, temperature, and specific gravity as parameters that may be used to determine field stabilization of Culebra groundwater prior to final sampling. After over 15 years of sampling experience, the Permittees have determined that certain changes are appropriate to facilitate sampling and to remove unneeded sampling activity. Specifically, the Permittees are proposing to change how field stabilization is determined prior to taking a final sample for analysis. Based on field experience with the DMP, the Permittees have identified that pH, specific conductance, temperature, and specific gravity are the most diagnostic indicators of groundwater condition and are easily measured in the field. Other parameters are significantly more difficult to measure and, in the case of iron, have little meaning with regard to the current well configuration because they are not iron cased wells. Furthermore, specific conductance does not require the sample be filtered.

- **Remove the bubbler line requirements.**

  See Attachment L, Section L-4c(2)(i).

  The bubbler line requirements are redundant to the water level probe. Bubbler technology is now obsolete.

- **Restrict serial sampling for stabilization to no more than three well bore volumes.**

  See Attachment L, Sections L-4c(2)(i) and L-4c(2ii).

  The Permittees are proposing to restrict the volume of water to be pumped from a well prior to sampling, to no more than three well bore volumes or when field parameters meet the stablility requirements in the Permit, whichever occurs first in order to be consistent with the EPA RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (EPA/530/SW-86/055, September 1986) and to avoid unnecessary pumping of groundwater.

- **Change the frequency of performing groundwater sampling and analysis to an annual basis rather than semi-annually.**

  As part of the Groundwater Permit Modification Work Plan, the Permittees have evaluated the frequency for groundwater sampling and reporting. The cumulative results, which can be found in the most recent data report, indicates that there has been no significant change in the nature of the Culebra groundwater and no indication of contamination leading to the conclusion that annual sampling will be adequate. Furthermore, there is no mechanism to transfer volatile organic compounds such as carbon tetrachloride from the air being exhausted from the repository to the Culebra groundwater. Therefore, increased levels of carbon tetrachloride in the WIPP underground will not impact the Culebra Groundwater. Reporting is proposed to be reduced to annually as well.

  - **Change the frequency of reporting to annually rather than semi-annually.**

    These changes are being made because the data shows limited variability in sampling events and no indication of contamination resulting from TRU waste management. Furthermore, many of the parameters are non-detects. Therefore, semi-annual reporting is not necessary.

- **Change the frequency of reporting water level values to twice per year rather than monthly.**

  Water level data shows minimal variability therefore, monthly reporting is not necessary and semi-annual reporting is adequate.

  - **Include enhanced interpretation in the form of annotated hydrographs.**

    Attachment L, Section L-4c(1)(ii) was revised to stipulate that the semi-annual groundwater reports will include annotated hydrographs and trend analysis.

The NMED has reported that the current format, while compliant with the Permit, is not as useful as a semi-annual report with hydrographs.

- **Include flow rate and direction determination in the annual detection monitoring report.**

  Because the Permittees are proposing to remove the ASER as described below as the vehicle for reporting flow rate and direction, the "Annual Culebra Groundwater Report" will now include this information. In addition, the Permittees are only reporting on downgradient wells because they are the only ones that can trigger actions leading to compliance monitoring. Based on transport modeling, the wells that would likely intercept a contaminant plume are WQSP 4 to 6. These wells are located between the shafts and the facility boundary such that detection would occur before any contamination would reach the boundary. The conceptual models now employed by the Permittees to demonstrate flow rate and direction will provide a periodic demonstration that the flow paths continue to be in the direction of these downgradient wells.

  The other wells are upgradient from the release point and could not be contaminated by releases from the repository, therefore using them to trigger compliance monitoring is not appropriate.

  - **Remove the "Annual Site Environmental Report " (ASER) as a means of reporting flow rate and direction.**

    Removed the ASER and replaced with the "Annual Culebra Groundwater Report."

    The requirement to submit the ASER is deleted since the ASER was previously the vehicle for submitting the water level sampling contour map. Now separate water level reports are proposed for submittal. Although the ASER is proposed for deletion from the Permit, it is still readily available to the NMED and interested Stakeholders. Copies may be obtained by calling the WIPP Information Center at (800) 336-9477 or by contacting the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

    Removed requirements to report radionuclide analytical results annually to the NMED as a consequence of deleting the requirement to submit the ASER. The requirement to report radionuclide data is also deleted.

    This information is not collected under the Permit and was available because it was contained in the ASER. With the deletion of the ASER as a deliverable, these data are proposed for deletion from the Permit.

- **Revise the statistical process for data analysis to be consistent with 20.4.1.500 NMAC (incorporating 40 CFR 264.97(h)).**

  Clarified how temporal and spatial analysis and statistical evaluations are performed.

  See Attachment L, Sections L-4e, L-4e(1), L-4e(2), L-4e(3).

  Another area addressed by the Groundwater Permit Modification Work Plan has to do with the removal of obsolete requirements from the Permit. Much of the statistical analysis portion of the permit is aimed at establishing the baseline statistics for ongoing comparisons to determine if a release has occurred. This information is no longer needed since the baseline has been established and has been incorporated into the Permit. The Permit was written with the assumption that there would be detectable constituents and that they can be represented as distributions making statistical analysis possible. In reality, no organic constituents have been detected so that the values are set at the minimum detection level for the analysis. This limits use of predictive statistics for comparisons. To compensate, the Permittees do comparisons to the baseline value to determine if the analytical result is “over or under” the baseline. Using this approach, most of the statistical discussion is not needed. Furthermore, by specifying that for constituents with distributions (such as metals), a statistical method will be used; the Permit accomplishes the goal of forcing a statistical analysis without the extensive detail in the text.

- **Update figures, tables and text with current information.**

  Removed obsolete content throughout Part 5 and Attachment L including conditions in the Permit that only applied to the initial baseline sampling and are no longer required. This language is proposed for deletion and past-tense statements are either completed or are made current.

  In addition, figures and tables are being revised to reflect current information and proposed Permit text is described in detail in Table 1.

Table 1

Description of Figure Changes in Attachment L and Explanation of why the Respective Changes were Made	
Figure L-1	No Change
Figure L-2	Deleted “Figure L-2” and replaced with a “New Figure L-2” which is more representative of facility boundries and the sixteen square mile Land Withdrawal Boundry.
Figure L-3	Revised L-3 due to the deletion of the “Unnamed Member” in the Rustler formation to “Los Medaños”. Also added a “~” to “Los Medaños” and “Gatuña”..
Figure L-4	Revised L-4 to show the scale changed from metric to feet for consistency and a cleaner version. Also added a “~” to “Gatuña”.
Figure L-5	Deleted “Figure L-5 Schematic North-South Cross Section Through the North Delaware Basin” and replaced with a new figure which represents the current presentation of the Potentiometric map generation methodology output and replaces Figures L-6 and L-9.
Figure L-6	Deleted “Figure-6 Culebra Freshwater Head Contour Surface” and replaced with new “Figure L-6 Detection Monitoring Well Locations”. The new Figure shows the current DMP wells.
Figure L-7	Deleted “Figure L-7 Total Dissolved Solids Distribution in the Culebra” because it does not match the current Geochemical conceptual model. Replaced with “Figure L-7 As-Built Configuration of Well WQSP-1”
Figure L-8	Deleted “Figure L-8 WQSP Monitor Well Locations “and replaced with a new “Figure L-8 As Built Configuration of Well WQSP-2” due to the depths not being correct in the original Permit.
Figure L-9	Deleted “Figure L-9 WIPP DMP Monitor Well Locations and Potentiometric Surface of the Culebra Near the WIPP Site as of 12/96 (adjusted to equivalent freshwater head)” and replaced with a new “Figure L-9 As-Built Configuration of Well WQSP-3” due to the depths not being correct in the original Permit.
Figure L-10	Deleted “Figure L-10 As-Built Configuration of Well WQSP-1” and replaced with a new “Figure L-10 As-Built Configuration of Well WQSP-4” due to the depths not being correct in the original Permit.
Figure L-11	Deleted “Figure L-11 As Built Configuration of Well WQSP-2” and replaced with a new “Figure L-11 As-Built Configuration of Well WQSP-5” due to the depths not being correct in the original Permit.
Figure L-12	Deleted “Figure L-12 As Built Configuration of Well WQSP-3” and replaced with a new “Figure L-12 As-Built Configuration of Well WQSP-6” due to the depths not being correct in the original Permit.
Figure L-13	Deleted “Figure L-13 As Built Configuration of Well WQSP-4” and replaced with a new “Figure L-13 Example Chain-of Custody/Request for Analysis Form” due to combining the COC and the RFA into one form.
Figure L-14	Deleted “Figure L-14 As Built Configuration of Well WQSP-5” and replaced with a new “Figure L-14 Groundwater Level Surveillance Wells (inset represents the groundwater surveillance wells in the WIPP Land Withdrawal Area). The new Figure L-14 is an update of L-18 which has been deleted.
Figure L-15	Deleted “Figure L-15 As Built Configuration of Well WQSP-6” and replaced with a new “Figure L-12 As-Built Configuration of Well WQSP-6” due to the depths not being correct in the original Permit.
Figure L-16	Deleted Figure L-16 Reserved due to it being blank and no Figure is attached.
Figure L-17a	Deleted, combined L-17a and L-17b to create Figure L-13.
Figure L-17b	Deleted, combined L-17a and L-17b to create Figure L-13.
Figure L-18	Deleted, the Figure has been updated and replaced in Figure L-14

- **Describe the methodology for generation of the Culebra Potentiometric Surface Map whereby the Permittees determine the groundwater flow rate and direction annually in accordance with 20.4.1.500 NMAC (incorporating 40 CFR 264.98(e)).**

  This methodology is being proposed to ensure development of consistent potentiometric surface maps.

Other Proposed Changes

The Groundwater Permit Modification Work Plan recognizes that the Permittees may need to make other changes to the Groundwater Monitoring Plan in addition to those specifically identified in the Groundwater Permit Modification Work Plan. These “Other Changes” include the following:

- *The Permittees are moving records which are not required to be maintained in the Operating Record (20.4.1.501 NMAC, incorporating 40 CFR 264.73) to facility files.*

  This change is needed to ensure that the appropriate records are being maintained in the Operating Record.

- *The Permittees are proposing to change the sampling line from Teflon® to an inert material.*

  This change is being proposed because sampling line materials other than Teflon® are inert, less costly, and functionally equivalent.

- *The Permittees are clarifying that the analytical laboratory may request sample containers, volumes, and holding times that are different than those listed in Attachment L, Table L-6.*

  This change is required so that the samples are submitted in a manner that is compatible with the requirements of the analytical laboratory.

- *The Permittees are proposing to combine the Request for Analysis and Chain of Custody example forms into one form.*

  This change is being proposed to the form to minimize the administrative burden without loss of any required information. Using this form combines identifying the laboratory analytical request and chain of custody into one form.

- *The Permittees are deleting the requirement for non-dedicated sample collection lines and referring the cleaning of other non-dedicated components to SOPs.*

  This change is being proposed because the Permittees do not use non-dedicated sample collection lines and the cleaning process is specified in SOPs.

- *The Permittees are proposing the removal of TOX as an indicator parameter.*

The analytical results for TOX have resulted in low and variable concentrations in the DMP. The analysis is extremely difficult to perform on WIPP groundwater due to high chloride content. Deletion will reduce this analytical burden without reducing the effectiveness of the DMP. Halogenated organic compounds are analyzed using GC/MS and have not been detected.

- *The Permittees are proposing to change the baseline value for methylene chloride to five micrograms per liter (µg/L).*

  The value in the Permit of three micrograms per liter is not supported by the data collected as part of the baseline sampling program and appears to be in error. The proposed value is consistent with NMED screening levels for water and the minimum detection limit for this compound.

- *The Permittees are making numerous editorial changes throughout Part 5 and Attachment L and deleting redundant text.*

The following are examples of Editorial changes that the Permittees are proposing to clarify Permit text and make the text consistent:

  - Standardize the term “ground-water” and “ground water” to the term “groundwater.”
  - Eliminate “branching from the main sample line...” in Attachment L, Section L-4c(2)(iii) because it is redundant to text in Attachment L, Section L-4c(2)(i)
  - Consolidated the terms “WIPP”, “WIPP facility”, “WIPP site”, “WIPP area”, “WIPP vicinity”, and “WIPP region” in an attempt to make the useage consistent with the definition of the permitted facility in Permit Part 1, Section 1.5.3.

Such editorial changes are being made to make the Permit text consistent.

4. 20.4.1.900 NMAC (incorporating 40 CFR §270.42 (b)(1)(iv)), requires the applicant to provide the applicable information required by 40 CFR §§270.13 through 270.21, 270.62 and 270.63.

The attached regulatory crosswalk describes those portions of the Permit that are affected by this PMR. Where applicable, regulatory citations in this modification reference Title 20, Chapter 4, Part 1, NMAC, revised March 1, 2009, incorporating the CFR, Title 40 (40 CFR Parts 264 and 270). 40 CFR §§270.16 through 270.22, 270.62, 270.63 and 270.66 are not applicable at the WIPP. Consequently, they are not listed in the regulatory crosswalk table. 40 CFR §270.23 is applicable to the WIPP Hazardous Waste Disposal Units (**HWDUs**). This modification does not impact the conditions associated with the HWDUs.

5. 20.4.1.900 NMAC (incorporating 40 CFR §270.11(d)(1) and 40 CFR §270.30(k)), requires any person signing under paragraph a and b must certify the document in accordance with 20.4.1.900 NMAC.

The transmittal letter for this PMR contains the signed certification statement in accordance with Part 1, Condition 1.9 of the Permit.

Regulatory Crosswalk

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.13		Contents of Part A permit application	Attachment B Part A		✓
§270.14(b)(1)		General facility description	Attachment A		✓
§270.14(b)(2)	§264.13(a)	Chemical and physical analyses	Part 2.3.1 Attachment C		✓
§270.14(b)(3)	§264.13(b)	Development and implementation of waste analysis plan	Part 2.3.1.1 Attachment C		✓
	§264.13(c)	Off-site waste analysis requirements	Part 2.2.1 Attachment C		✓
§270.14(b)(5)	§264.15(a-d)	General inspection requirements	Part 2.7 Attachment E-1a		✓
	§264.174	Container inspections	Attachment E-1b(1)		✓
§270.23(a)(2)	§264.602	Miscellaneous units inspections	Attachment E-1b Attachment E-1b(1)		✓
§270.14(b)(6)		Request for waiver from preparedness and prevention requirements of Part 264 Subpart C	NA		✓
§270.14(b)(7)	264 Subpart D	Contingency plan requirements	Part 2.12 Attachment D		✓
	§264.51	Contingency plan design and implementation	Part 2.12.1 Attachment D		✓
	§264.52 (a) & (c-f)	Contingency plan content	Attachment D		✓
	§264.53	Contingency plan copies	Part 2.12.2 Attachment D		✓
	§264.54	Contingency plan amendment	Part 2.12.3 Attachment D		✓
	§264.55	Emergency coordinator	Part 2.12.4 Attachment D-4a(1)		✓
	§264.56	Emergency procedures	Attachment D-4		✓
§270.14(b)(8)		Description of procedures, structures or equipment for:	Attachment A Part 2.11		✓
§270.14(b)(8)(i)		Prevention of hazards in unloading operations (e.g., ramps and special forklifts)	Part 2.11		✓
§270.14(b)(8)(ii)		Runoff or flood prevention (e.g., berms, trenches, and dikes)	Attachment A1-1c(1) Part 2.11		✓
§270.14(b)(8)(iii)		Prevention of contamination of water supplies	Part 2.11		✓
§270.14(b)(8)(iv)		Mitigation of effects of equipment failure and power outages	Part 2.11		✓
§270.14(b)(8)(v)		Prevention of undue exposure of personnel (e.g., personal protective equipment)	Part 2.11		✓
§270.14(b)(8)(vi) §270.23(a)(2)	§264.601	Prevention of releases to the atmosphere	Part 2.11 Part 4.4 Attachment D-4e Attachment G-1a		✓
	264 Subpart C	Preparedness and Prevention	Part 2.10		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
	§264.31	Design and operation of facility	Part 2.1		✓
	§264.32	Required equipment	Part 2.10.1 Attachment D		✓
	§264.33	Testing and maintenance of equipment	Part 2.10.2 Attachment E-1a		✓
	§264.34	Access to communication/alarm system	Attachment E-1a Part 2.10.3		✓
	§264.35	Required aisle space	Part 2.10.4		✓
	§264.37	Arrangements with local authorities	Attachment D-4a(3)		✓
§270.14(b)(9)	§264.17(a-c)	Prevention of accidental ignition or reaction of ignitable, reactive, or incompatible wastes	Part 2.9		✓
§270.14(b)(10)		Traffic pattern, volume, and controls, for example: Identification of turn lanes Identification of traffic/stacking lanes, if appropriate Description of access road surface Description of access road load-bearing capacity Identification of traffic controls	Attachment A4		✓
§270.14(b) (11)(i) and (ii)	§264.18(a)	Seismic standard applicability and requirements	Attachment G2-2.2 Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(11)(iii-v)	§264.18(b)	100-year floodplain standard	Attachment A1-1c(1) Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(12)	§264.16(a-e)	Personnel training program	Part 2.8 Attachment F		✓
§270.14(b)(13)	264 Subpart G	Closure and post-closure plans	Part 6 & 7 Attachment G & H		✓
§270.14(b)(13)	§264.111	Closure performance standard	Attachment G-1a		✓
§270.14(b)(13)	§264.112(a), (b)	Written content of closure plan	Attachment G-1		✓
§270.14(b)(13)	§264.112(c)	Amendment of closure plan	Part 6.3 Attachment G-1d(4)		✓
§270.14(b)(13)	§264.112(d)	Notification of partial and final closure	Attachment G-2a		✓
§270.14(b)(13)	§264.112(e)	Removal of wastes and decontamination/dismantling of equipment	Attachment G-1e(2)		✓
§270.14(b)(13)	§264.113	Time allowed for closure	Part 6.5 Attachment G-1d		✓
§270.14(b)(13)	§264.114	Disposal/decontamination	Part 6.6 Attachment G-1e(2)		✓
§270.14(b)(13)	§264.115	Certification of closure	Part 6.7 Attachment G-2a		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.14(b)(13)	§264.116	Survey plat	Part 6.8 Attachment G-2b		✓
§270.14(b)(13)	§264.117	Post-closure care and use of property	Part 7.3 Attachment H-1a		✓
§270.14(b)(13)	§264.118	Post-closure plan; amendment of plan	Part 7.5 Attachment H-1a (1)		✓
§270.14(b)(13)	§264.178	Closure/containers	Part 6.9 Attachment A1-1h Attachment G-1		✓
§270.14(b)(13)	§264.601	Environmental performance standards-miscellaneous units	Attachment A-4 Attachment D-1 Attachment G-1a		✓
§270.14(b)(13)	§264.603	Post-closure care	Part 7.3 Attachment G-1a(3)		✓
§270.14(b)(14)	§264.119	Post-closure notices	Part 7.4 Attachment H-2		✓
§270.14(b)(15)	§264.142	Closure cost estimate	NA		✓
	§264.143	Financial assurance	NA		✓
§270.14(b)(16)	§264.144	Post-closure cost estimate	NA		✓
	§264.145	Post-closure care financial assurance	NA		✓
§270.14(b)(17)	§264.147	Liability insurance	NA		✓
§270.14(b)(18)	§264.149-150	Proof of financial coverage	NA		✓
§270.14(b)(19)(i), (vi), (vii), and (x)		Topographic map requirements Map scale and date Map orientation Legal boundaries Buildings Treatment, storage, and disposal operations Run-on/run-off control systems Fire control facilities	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(ii)	§264.18(b)	100-year floodplain	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(iii)		Surface waters	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(iv)		Surrounding land use	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.14(b)(19)(v)		Wind rose	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(viii)	§264.14(b)	Access controls	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(ix)		Injection and withdrawal wells	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(xi)		Drainage on flood control barriers	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(19)(xii)		Location of operational units	Attachment B2 Part A Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.14(b)(20)		Other federal laws Wild and Scenic Rivers Act National Historic Preservation Act Endangered Species Act Coastal Zone Management Act Fish and Wildlife Coordination Act Executive Orders	Attachment B Renewal App. Sep. 2009, 270.14 Contents of Part B: General Requirements		✓
§270.15	§264 Subpart I	Containers	Part 3 Part 4.3 Attachment A1		✓
	§264.171	Condition of containers	Part 3.3 Attachment A1		✓
	§264.172	Compatibility of waste with containers	Part 3.4 Attachment A1		✓
	§264.173	Management of containers	Part 3.5 Attachment A1		✓
	§264.174	Inspections	Part 3.7 Attachment E-1 Attachment A1-1e		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
§270.15(a)	§264.175	Containment systems	Part 3.6 Attachment A1		✓
§270.15(c)	§264.176	Special requirements for ignitable or reactive waste	Attachment A1-1g Permit Part 2.1		✓
§270.15(d)	§264.177	Special requirements for incompatible wastes	Attachment A1-1g Permit Part 2.3.3.4		✓
	§264.178	Closure	Part 6 Attachment G		✓
§270.15(e)	§264.179	Air emission standards	Part 4.4.2 Attachment N		✓
§270.23	264 Subpart X	Miscellaneous units	Part 1.3.1 Attachment A2-1 Attachment G1.3.1		✓
§270.23(a)	§264.601	Detailed unit description	Part 4 Part 5 Attachment A2 Attachment L	✓	
§270.23(b)	§264.601	Hydrologic, geologic, and meteorologic assessments	Part 4 Part 5 Attachment A2 Attachment L	✓	
§270.23(c)	§264.601	Potential exposure pathways	Part 4 Part 5 Attachment A2 Attachment N Attachment L	✓	
§270.23(d)		Demonstration of treatment effectiveness	Part 4 Attachment A2 Attachment N		✓
	§264.602	Monitoring, analysis, inspection, response, reporting, and corrective action	Part 4 Part 5 Attachment A2 Attachment E-1 Attachment N Attachment L	✓	
	§264.603	Post-closure care	Attachment H Attachment H1		✓
	264 Subpart E	Manifest system, record keeping, and reporting	Permit Part 1 Permit Part 2.13 & 2.14 Permit Part 4 Attachment C		✓
§270.30(j)(2)	§264.73(b)	Ground-water records	Part 1		✓
	264 Subpart F	Releases from solid waste management units	Part 5 & 7 Attachment G2 & L		✓
	§264.90	Applicability	Part 5 Attachment L		✓
	§264.91	Required programs	Attachment L		✓
	§264.92	Ground-water protection standard	Attachment L		✓
	§264.93	Hazardous constituents	Attachment L		✓

Regulatory Citation(s) 20.4.1.900 NMAC (incorporating 40 CFR Part 270)	Regulatory Citation(s) 20.4.1.500 NMAC (incorporating 40 CFR Part 264)	Description of Requirement	Added or Clarified Information		
			Section of the WIPP Permit Application	Yes	No
	§264.94	Concentration limits	Part 5 Attachment L		✓
	§264.95	Point of compliance	Part 5 Attachment L		✓
	§264.96	Compliance period	Attachment L		✓
	§264.97	General ground-water monitoring requirements	Part 5 Attachment L	✓	
	§264.98	Detection monitoring program	Part 5 Attachment L	✓	
	§264.99	Compliance monitoring program	Part 5 Attachment L		✓
	§264.100	Corrective action program	Part 5 Attachment L		✓
	§264.101	Corrective action for solid waste management units	Part 8 Attachment L		✓
	264 Appendix IX	Ground-water Monitoring List	Part 5 Attachment L		✓

Attachment A
Table of Changes

Table of Changes

Affected Permit Section	Explanation of Change
Global	Changed “ground-water” and “ground water” to “groundwater”
Part 5, Section 5.3.1.	Revised Figure L-8 to L-6
Part 5, Section 5.3.2.	Deleted “10" from “Figure L-10” and replace with “7” to read “Figure L-7"
Part 5, Section 5.3.2.	Deleted “16" from “Figure L-16” and replace with “12” to read “Figure L-12"
Part 5, Section 5.4., Table 5.4.a	Deleted “Total organic halogen (**TOH**)”
Part 5, Section 5.4., Table 5.4.a	Replaced “Density” with “Specific Gravity”
Part 5, Section 5.4., Table 5.4.a	Deleted “Iron (Total Fe)”
Part 5, Section 5.5.	Deleted “, including background ground-water quality samples, ”
Part 5, Section 5.5.1.	Deleted “semi” from “semiannually”
Part 5, Table 5.6	Replaced “3.00” with “5.00” for the Methylene chloride for WQSP wells 1 through 6
Part 5, Section 5.10.2.1.	Replaced “in compliance with the schedule on Table 5.10.2.1 below, and” with “in the Annual Groundwater Report by November 30 of each year”
Part 5, Section 5.10.2.1., Table 5.10.2.1	Deleted table
Part 5, Section 5.10.2.2.	Replaced “submitted within 30 calendar days after data are collected” with “reported semiannually by May 31 and November 30”
Part 5, Section 5.10.2.2.	Added “The November water level data report shall be combined with the Annual Groundwater Report specified in Permit Part 5.10.2.3.”
Part 5, Section 5.10.2.3.	Deleted “and Radionuclide Sampling” from heading
Part 5, Section 5.10.2.3.	Added “(to include annotated hydrographs)”
Part 5, Section 5.10.2.3.	Deleted “and the results of radionuclide specific analysis of groundwaters sampled from the DMWs”
Part 5, Section 5.10.2.3.	Replaced “Site Environmental” with “Culebra Groundwater”
Part 5, Section 5.10.2.3.	Replaced “by October 1” with “by November 30”
Attachment L, Global	Added “Amended Renewal Application” before Addendum L
Attachment L, Global	Deleted “, Amended Renewal Application” after section numbers
Attachment L, List of Abbreviations/Acronyms	Added “/UNITS” to title
Attachment L, List of Abbreviations/Acronyms	Deleted “ASER Annual Site Environmental Report”
Attachment L, List of Abbreviations/Acronyms	Deleted “AR/VR Approval/Variation Request”
Attachment L, List of Abbreviations/Acronyms	Replaced “CofC Chain of Custody” with “CofC/RFA chain of custody/request for analysis”
Attachment L, List of Abbreviations/Acronyms	Added “Dewey Lake Dewey Lake Redbeds Formation”
Attachment L, List of Abbreviations/Acronyms	Added “DMW Detection Monitoring Wells”
Attachment L, List of	Deleted “EM Environmental Monitoring”

Affected Permit Section	Explanation of Change
Abbreviations/Acronyms	
Attachment L, List of Abbreviations/Acronyms	Deleted “ES&H Environmental, Safety, and Health Department”
Attachment L, List of Abbreviations/Acronyms	Deleted “FEIS Final Environmental Impact Statement”
Attachment L, List of Abbreviations/Acronyms	Added “(s)” to “gram”
Attachment L, List of Abbreviations/Acronyms	Deleted “GWSP Groundwater Surveillance Program”
Attachment L, List of Abbreviations/Acronyms	Added “LCSD lab control sample duplicate”
Attachment L, List of Abbreviations/Acronyms	Deleted “LD limit of detection”
Attachment L, List of Abbreviations/Acronyms	Added “Los Medaños Los Medaños Member of the Rustler Formation”
Attachment L, List of Abbreviations/Acronyms	Added “Magenta Magenta Member of the Rustler”
Attachment L, List of Abbreviations/Acronyms	Added “molal moles per kilogram”
Attachment L, List of Abbreviations/Acronyms	Deleted “PRS Project Records Services”
Attachment L, List of Abbreviations/Acronyms	Added “QAO Quality Assurance Objective”
Attachment L, List of Abbreviations/Acronyms	Added “PABC Performance Assessment Baseline Calculation(s)”
Attachment L, List of Abbreviations/Acronyms	Deleted “RFA request for analysis”
Attachment L, List of Abbreviations/Acronyms	Deleted “RIDS Records Inventory and Disposition Schedule”
Attachment L, List of Abbreviations/Acronyms	Added “SAP Sampling and Analysis Plan”
Attachment L, List of Abbreviations/Acronyms	Deleted “STLB sample tracking book”
Attachment L, List of Abbreviations/Acronyms	Deleted “TOX total organic halogens”
Attachment L, List of Abbreviations/Acronyms	Deleted “TSS total suspended solids”
Attachment L, List of Abbreviations/Acronyms	Added “UTLV upper tolerance limit value”
Attachment L, List of Abbreviations/Acronyms	Deleted “WQSP Water Quality Sampling Program”
Attachment L, Section L-1	Replaced “is a geologic repository for the disposal of transuranic (**TRU**) waste” with “facility is subject to regulation under Title 20 of the New Mexico Administrative Code (**NMAC**), Chapter 4, Part 1, Subpart V (20.4.1.500 NMAC). As required by 20.4.500 NMAC (incorporating 40 CFR §264.601), the Permittees shall demonstrate that the environmental performance standards for a miscellaneous unit, which are applied to the hazardous waste disposal units

Affected Permit Section	Explanation of Change
	(**HWDUs**) in the underground, will be met”
Attachment L, Section L-1	Deleted “The disposal horizon is located 2,150 feet (ft) (655 meters [m]) below the land surface in the bedded salt of the Salado Formation (hereinafter referred to as the Salado). At WIPP, water-bearing units occur both above and below the disposal horizon. Ground-water monitoring of the uppermost aquifer below the facility is not proposed at WIPP because that water-bearing unit (the Bell Canyon Formation) is not considered a credible pathway for a release from the repository. This is because the repository horizon and water-bearing sandstones of the Bell Canyon Formation are separated by over 2000 ft (610 m) of very low-permeability evaporite sediments (Addendum L1, Amended Renewal Application (DOE, 2009)). No natural credible pathway has been established for contaminant transport to aquifers below the repository horizon, as there is no hydrologic communication between the repository and underlying aquifer. The U.S. Environmental Protection Agency (**EPA**) concluded in 1990 that natural vertical communication does not exist based on their review of numerous studies (EPA, 1990). Furthermore, drilling boreholes for ground-water monitoring through the Salado and the Castile Formation (hereinafter referred to as the Castile) into the Bell Canyon aquifer would compromise the isolation properties of the repository medium.”
Attachment L, Section L-1	Added “The WIPP facility is located in Eddy County in southeastern New Mexico (Figure L-1), within the Pecos Valley section of the southern Great Plains physiographic province. The facility is 26 miles (mi) (42 kilometers [km]) east of Carlsbad, New Mexico, in an area known as Los Medaños (the dunes). Los Medaños is a relatively flat, sparsely inhabited plateau with little water and limited land uses.”
Attachment L, Section L-1	Deleted “Disposal of TRU mixed waste in the WIPP facility is subject to regulation under 20.4.1.500 NMAC. As required by 20.4.1.500 NMAC (incorporating 40 CFR §264.601), the Permittees shall demonstrate that the environmental performance standards for a miscellaneous unit, which are applied to the hazardous waste disposal units (**HWDUs**) in the underground, will be met.”
Attachment L, Section L-1	Added “The WIPP facility (Figure L-2) consists of 16 sections of Federal land in Township 22 South, Range 31 East. The 16 sections of Federal land were withdrawn from the application of public land laws by the WIPP Land Withdrawal Act (**LWA**), Public Law 102-579. The WIPP LWA transferred the responsibility for the administration of the 16 sections from the Department of Interior, Bureau of Land Management, to the U.S. Department of Energy (**DOE**). This law specified that mining and drilling for purposes other than support of the WIPP project are prohibited within this 16 section area with the exception of Section 31. Oil and gas drilling activities are restricted in Section 31 from the surface down to 6,000 feet. The WIPP is a mined geologic repository for the disposal of transuranic (**TRU**) waste. The disposal horizon is located 2,150 feet (ft) (655 meters [m]) below the land surface in the bedded salt of the Salado Formation (**Salado**). At the WIPP facility, water-bearing units occur both above and below the disposal horizon. Groundwater monitoring of the uppermost aquifer below the facility is not required because the water-bearing unit (the Bell Canyon Formation (**Bell Canyon**)) is not considered a credible pathway for a release from the repository. This is because the repository horizon and water-bearing sandstones of the Bell Canyon are separated by over 2,000 ft (610 m) of very low-permeability evaporite sediments (Amended Renewal Application Addendum L1 (DOE, 2009)). No natural credible pathway has been established for contaminant transport to water-bearing zones below the repository horizon, as there is no hydrologic communication between the repository and underlying water-bearing zones. The U.S. Environmental Protection Agency (**EPA**) concluded in 1990 that natural vertical communication does not exist based on review of numerous studies (EPA, 1990). Furthermore, drilling boreholes for groundwater monitoring through the Salado and the Castile Formation (**Castile**)

Affected Permit Section	Explanation of Change
	into the Bell Canyon would compromise the isolation properties of the repository medium.”
Attachment L, Section L-1	Added “the”
Attachment L, Section L-1	Replaced “in the past has focused” with “facility focuses”
Attachment L, Section L-1	Replaced “member” with “Member (Culebra)”
Attachment L, Section L-1	Replaced “(hereinafter referred to as the Culebra)” with “(Rustler)”
Attachment L, Section L-1	Replaced “Modeling of ground-water movement in the Culebra, based on the concept of a ground-water basin” with “Groundwater movement in the Culebra, using results from the basin-scale groundwater model”
Attachment L, Section L-1	Deleted “The WIPP site is located in Eddy County in southeastern New Mexico (Figure L-1) within the Pecos Valley section of the southern Great Plains physiographic province (Powers et al., 1978). The site is 26 miles (mi) (42 kilometers [km]) east of Carlsbad, New Mexico in an area known as Los Medaños (the dunes). Los Medaños is a relatively flat, sparsely inhabited plateau with little water and limited land uses. The WIPP site (Figure L-2) consists of 16 sections of Federal land in Township 22 South, Range 31 East. The 16 sections of Federal land were withdrawn from the application of public land laws by the WIPP Land Withdrawal Act (**LWA**), Public Law 102-579. The WIPP LWA transferred the responsibility for the administration of the 16 sections from the Department of Interior, Bureau of Land Management, to the U.S. Department of Energy (**DOE**). This law specified that mining and drilling for purposes other than support of the WIPP project are prohibited within this 16 section area with the exception of Section 31. Oil and gas drilling activities are restricted in Section 31 from the surface down to 6,000 feet.”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Added “and rate determination”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Replaced “analytical” with “indicator”
Attachment L, Section L-1	Added “and hazardous constituents”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Deleted “, and establishes personnel responsibilities”
Attachment L, Section L-1	Replaced “sampling and analysis plan” with “DMP”
Attachment L, Section L-1	Replaced “field operating procedures, referenced throughout this plan.” with “the WIPP Standard Operating Procedures (**SOP**s) (see Table L-3), which are maintained in facility files and which comply with the applicable requirements of 20.4.1.500 NMAC (incorporating 40 CFR § 264.97 (d)).”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Added “Culebra” before “groundwater”
Attachment L, Section L-1	Added “and rate determination”
Attachment L, Section L-1	Deleted “These procedures prescribe proper field sampling techniques.”
Attachment L, Section L-1	Replaced “Samples” with “Data required by this plan”
Attachment L, Section L-1	Replaced “trained” with “qualified”

Affected Permit Section	Explanation of Change
Attachment L, Section L-1	Replaced "under the supervision and direction of qualified engineers, scientists, or other technical personnel." with "in accordance with SOPs (Table L-3)."
Attachment L, Section L-1a(1)	Replaced "site" with "facility"
Attachment L, Section L-1a(1)	Added "bounded to the north and east by the Capitan Reef"
Attachment L, Section L-1a(1)	Deleted "During the Permian period, which came to a close about 245 million years ago, ancient seas covered the basin. Their later evaporation resulted in the deposition of a thick sequence of evaporites. Addendum L1, Section L1-1 of the Amended Renewal Application (DOE, 2009) presents a detailed discussion of the regional geologic history."
Attachment L, Section L-1a(1)	Added "and Amended Renewal Application Addendum L1, Section L1-1 (DOE 2009) for more detail"
Attachment L, Section L-1a(1)	Deleted ", which formed through evaporation of the Permian Sea,"
Attachment L, Section L-1a(1)	Deleted "(hereinafter referred to as the Rustler)"
Attathment L, Section L-1a(1)	Changed "Rustler's" to "Rustler"
Attachment L, Section L-1a(1)	Added "Redbeds Formation (Dewey Lake)"
Attachment L, Section L-1a(1)	Deleted "^{1}" footnote indicator
Attachment L, Section L-1a(1)	Deleted "Formation (hereinafter referred to as the Bell Canyon)— "
Attachment L, Section L-1a(1)	Added "is"
Attachment L, Section L-1a(1)	Deleted footnote 1 " While there may be some uncertainty over the amount of vertical recharge occurring within the Rustler, the issue is only of significance to long-term performance calculations in which releases from the repository occur through the creation of a migration pathway resulting from drilling (inadvertently) in the WIPP area. The consequences of vertical recharge are bounded in the modeling by assuming that under future climate conditions (which are assumed to be cooler and wetter), the ground-water surface elevation (water table) raises near ground surface, at which time the water table tends to mimic topography."
Attachment L, Section L-1a(1)	Deleted "—"
Attachment L, Section L-1a(1)	Added "and"
Attachment L, Section L-1a(1)	Added "above"
Attachment L, Section L-1a(1)	Replaced "sequences" with "deposits"
Attachment L, Section L-1a(1)	Deleted "above"
Attachment L, Section L-1a(1)	Added "lithostatic"
Attachment L, Section L-1a(1)	Replaced "more than 2,000" with "approximately 2,200"
Attachment L, Section L-1a(1)	Replaced "13.8" with "14.9"
Attachment L, Section L-1a(1)	Replaced "moves" with "deforms"
Attachment L, Section L-1a(1)	Replaced "for millions of years" with "since deposition"
Attachment L, Section L-1a(1	Replaced "L-5" with L-4"
Attachment L, Section L-1a(2)(i)	Replaced "found" with "determined" Added "facility"
Attachment L, Section L-1a(2)(ii)	Added "naturally"
Attachment L, Section L-1a(2)(ii)	Deleted "As a comparison, the permeability of the Salado is roughly a thousand times less than that of a lower clay liner required of surface impoundments and

Affected Permit Section	Explanation of Change
	landfills, assuming similar thicknesses.”
Attachment L, Section L-1a(2)(iii)	Deleted “(specifically, the Culebra Member, hereafter referred to as the Culebra)”
Attachment L, Section L-1a(2)(iii)	Replaced “6" with “5” to read “L-5"
Attachment L, Section L-1a(2)(iii)	Deleted “The Culebra is hydrologically confined.”
Attachment L, Section L-1a(2)(iii)	Deleted “(Additional short-term pumping tests have been conducted in the Water Quality Sampling Program (**WQSP**) wells (see Addendum L1, Section L1-2a(3)(a)(ii) of the Amended Renewal Application (DOE, 2009)).”
Attachment L, Section L-1a(2)(iii)	Deleted “recently”
Attachment L, Section L-1a(2)(iii)	Replaced “The hydraulic tests are designed to yield pressure data for estimation of hydrologic characteristics” with “Pressure data are collected during hydraulic tests for estimation of hydrologic characteristics”
Attachment L, Section L-1a(2)(iii)	Replaced “for input to flow modeling” with “in calibration of flow models”
Attachment L, Section L-1a(2)(iii)	Replaced “six” with “ten”
Attachment L, Section L-1a(2)(iii)	Deleted “Over the site, Culebra transmissivity varies over three to four orders of magnitude. Figure D6-30 shows variation in transmissivity in the Culebra in the WIPP region.”
Attachment L, Section L-1a(2)(iii)	Replaced “^{3}” with “^{7}”
Attachment L, Section L-1a(2)(iii)	Replaced “^{9}” with “^{13}”
Attachment L, Section L-1a(2)(iii)	Replaced “P-18” with “SNL-15”
Attachment L, Section L-1a(2)(iii)	Added “(Roberts, 2007)”
Attachment L, Section L-1a(2)(iii)	Deleted “Qualitative correlations have been noted between transmissivity and several geologic features possibly related to open-fracture density, including (1) the distribution of overburden above the Culebra, (2) the distribution of halite in other members of the Rustler, (3) the dissolution of halite in the upper portion of the Salado, and (4) the distribution of gypsum fillings in fractures in the Culebra. Measured matrix porosities of the Culebra vary from 0.03 to 0.30. Fracture porosity values have not been measured directly, but interpreted values from tracer tests at the H-3, H-6, and H-11 hydropads vary from 5×10^{-4} to 3×10^{-3}. Data are insufficient to determine whether the average porosity of the matrix and fractures varies significantly on a regional scale.”
Attachment L, Section L-1a(2)(iii)	Deleted “Previous conceptual models of the Culebra (see Addendum L1 of the Amended Renewal Application (DOE, 2009)) have not been able to consistently relate the hydrogeochemical facies, radiogenic ages, and flow constraints (that is, transmissivity, boundary conditions, etc.) in the Culebra.” after “flow.”
Attachment L, Section L-1a(2)(iii)	Deleted “However”
Attachment L, Section L-1a(2)(iii)	Changed “the” to “The”
Attachment L, Section L-1a(2)(iii)	Deleted “new”
Attachment L, Section L-1a(2)(iii)	Deleted “could”
Attachment L, Section L-1a(2)(iii)	Added “s” to explain
Attachment L, Section L-1a(2)(iii)	Deleted “new”
Attachment L, Section L-1a(2)(iii)	Added “basin-scale”
Attachment L, Section L-1a(2)(iii)	Deleted “basin”
Attachment L, Section L-1a(2)(iii)	Deleted “This differs from previous interpretations, wherein no-flow was assumed between Rustler units.”

Affected Permit Section	Explanation of Change
Attachment L, Section L-1a(2)(iii)	Added “in the vicinity of the WIPP facility”
Attachment L, Section L-1a(2)(iii)	Added “toward Nash Draw”
Attachment L, Section L-1a(2)(iii)	Added “currently”
Attachment L, Section L-1a(2)(iii)	Replaced “to a more southerly direction.” with “in the Rustler from the vicinity of the WIPP facility towards the Balmorhea-Loving Trough to the south.”
Attachment L, Section L-1a(2)(iii)	Deleted “Four hydrogeochemical facies within the Culebra in the WIPP area (DOE, 1997) have been identified: • Zone A - saline (2-3 molal) NaCl brines, Mg/Ca ratio of 1.2 to 2; • Zone B - dilute (<0.1 molal) CaSO4 - rich ground water; • Zone C - variable composition (0.3-1.6 molal); Mg/Ca ratio 0.3 to 1.2; and • Zone D - high salinities (3-7 molal); K/Na weight ratios (0.2). Facies A ground-water flow is slow, has not changed over the last 14,000 years, and probably recharged more than 600,000 years ago. Vertical leakage occurs to Facies A, and both lateral and vertical ground-water flow rates are extremely low. Facies B occurs in an area with greater vertical fracturing in the Culebra, and therefore exhibits more vertical infiltration and more rapid lateral flow in the Culebra. Flow in Facies B is currently to the south (it may mix with Facies C water to the southeast) but was more toward the west during wetter climates; vertical infiltration from the Dewey Lake to the Culebra Facies B is assumed by the Permittees to have occurred during wetter climates in an area south of the WIPP site. Facies C water was not diluted to create Facies B water. Facies C occurs “in between” Facies A and B, and ground-water flow entered the Culebra prior to the climate change (to drier conditions) 14,000 years ago. Facies C ground-water flow is to the south at WIPP, where the Permittees theorized that it joins with a small amount of Facies A solute being transported from the east. Ground-water flow rate in Facies C is faster than in A but slower than in B, and the proposed recharge area from the Dewey Lake to the Culebra was to the northeast of the WIPP site. Facies C ground water infiltrated into the Dewey Lake and then interacted with anhydrite and halite along its path to the Culebra, wherein it mixed with smaller amounts of Facies A water. the Permittees concluded that the presence of anhydrite within Rustler units does not preclude slow downward infiltration (DOE, 1997).”
Attachment L, Section L-1a(2)(iii)	Added “Using data from 22 wells, Siegel, Robinson, and Myers (1991) originally defined four hydrochemical facies (A, B, C, and D) for Culebra groundwater based primarily on ionic strength and major constituents. With the data now available from 59 wells, Domski and Beauheim (2008) defined transitional A/C and B/C facies, as well as a new facies E for high-moles per kilogram (molal) Na-Mg Cl brines. • Zone B - Dilute (ionic strength ≤0.1 molal) CaSO$_4$-rich groundwater, from southern high-transmissivity area. Mg/Ca molar ratio 0.32 to 0.52. • Zone B/C - Ionic strength 0.18 to 0.29 molal, Mg/Ca molar ratio 0.4 to 0.6. • Zone C - Variable composition waters, ionic strength 0.3 to 1.0 molal, Mg/Ca molar ratio 0.4 to 1.1. • Zone A/C - Ionic strength 1.1 to 1.6 molal, Mg/Ca molar ratio 0.5 to 1.2. • Zone A - Ionic strength >1.66 molal, up to 5.3 molal, Mg/Ca molar ratio 1.2 to 2.4. • Zone D - Defined based on inferred contamination related to potash refining operations. Ionic strength 3 molal, K/Na weight ratios of ~0.2. • Zone E - Wells east of the mudstone-halite margins, ionic strength 6.4 to 8.6 molal, Mg/Ca molar ratio 4.1 to 6.6. The low-ionic-strength (≤0.1 molal) facies B waters contain more sulfate than chloride, and are found southwest and south of the WIPP site within and down

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	the Culebra hydraulic gradient from the southernmost closed catchment basins, mapped by Powers (2006), in the southwest arm of Nash Draw. These waters reflect relatively recent recharge through gypsum karst overlying the Culebra. However, with total dissolved solids (TDS) concentrations in excess of 3,000 mg/L, the facies B waters do not represent modern-day precipitation rapidly reaching the Culebra. They must have residence times in the Rustler sulfate units of thousands of years before reaching the Culebra. The higher-ionic-strength (0.3-1 molal) facies C brines have differing compositions, representing meteoric waters that have dissolved $CaSO_4$, overprinted with mixing and localized processes. Facies A brines (ionic strength 1.6–5.3 molal) are high in NaCl and are clustered along the extent of halite in the middle of the Tamarisk Member of the Rustler Formation. Facies A represents old waters (long flow paths) that have dissolved halite and/or connate brine, or a mixture of the two, from facies E. The facies D brines, as identified by Siegel, Robinson, and Myers (1991), are high-ionic-strength solutions found in western Nash Draw with high K/Na ratios representing waters contaminated with effluent from potash refining operations. Similar water is found at shallow depth (<36 ft (11 m)) in the upper Dewey Lake at SNL-1, just south of the Intrepid East tailings pile. The newly defined facies E waters are very high ionic strength (6.4-8.6 molal) NaCl brines with high Mg/Ca ratios. The facies E brines are found east of the WIPP site, where Rustler halite is present above and below the Culebra, and halite cements are present in the Culebra. They represent primitive brines present since deposition of the Culebra and immediately overlying strata.”
Attachment L, Section L-1a(2)(iii)	Changed “Facies” to “facies”
Attachment L, Section L-1a(2)(iii)	Added “basin-scale”
Attachment L, Section L-1a(2)(iii)	Deleted “basin”
Attachment L, Section L-1a(2)(iii)	Replaced “Ground-water levels in the Culebra in the WIPP region have been measured for several decades. Water-level rises have been observed in the WIPP region and are possibly related to recovery from impacts caused by shaft installation, response to potash effluent discharge, or are unexplained, as discussed below. The extent of water-level rise observed at a particular well depends on several factors, but the proximity of the observation point to the potential cause of the water-level rise appears to be a primary factor. In the vicinity of the WIPP site, water-level rises are believed to be caused by recovery from drainage into the shafts. Drainage into shafts has been reduced by a number of grouting programs over the years, most recently in 1993 around the Air Intake Shaft. Northwest of the site, in and near Nash Draw, water levels appear to fluctuate in response to effluent discharge from potash mines. Correlation of water-level fluctuation with potash mine discharge, however, cannot be proven definitively because sufficient data on the timing and volumes of discharge are not available. Water-level rises in the vicinity of the H-9 hydropad, about 6.5 miles south of the site, are thought to be caused by neither WIPP activities nor potash mining discharge. They remain unexplained. The Permittees continue to monitor ground-water levels throughout the region.” with “Groundwater levels in the Culebra in the region around the WIPP facility have been measured in numerous wells. Water-level rises have been observed in the WIPP region and are attributed to causes discussed in the Renewal Application Addendum L1, Section L1-2a(3)(a)(ii). The extent of water-level rise observed at a particular well depends on several factors, but the proximity of the observation point to the cause of the water-level change appears to be a primary factor. Hydrological investigations conducted from 2003 through 2007 provided new information, some of it confirming long-held assumptions and some offering new insight into the hydrological system around the WIPP site. A Culebra monitoring network optimization study was completed by McKenna (2004) and updated by Kuhlman (2010) to identify locations where new Culebra monitoring

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	wells would be of greatest value and to identify wells that could be removed from the network with little loss of information. As discussed in Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii), extensive hydrological testing has been performed in the new wells. This testing has involved both single well tests, which provide information on local transmissivity and heterogeneity, and long-term (19 to 32 days) pumping tests that have created observable responses in wells up to 5.9 mi (9.5 km) away.”
Attachment L, Section L-1a(2)(iii)	Replaced “unnamed lower member” with “Los Medaños Member”
Attachment L, Section L-1a(2)(iii)	Added “(**Los Medaños**)”
Attachment L, Section L-1a(2)(iii)	Changed “member” to “Member”
Attachment L, Section L-1a(2)(iii)	Added “(**Magenta**)”
Attachment L, Section L-1a(2)(iii)	Added”across” Deleted “over”
Attachment L, Section L-1a(2)(iii)	Added “basin-scale”
Attachment L, Section L-1a(2)(iii)	Deleted “basin”
Attachment L, Section L-1a(2)(iii)	Deleted “Recent simulations to enhance the conceptual understanding of the geohydrology of the Rustler can be found in Corbet and Knupp, 1996.”
Attachment L, Section L-1a(2)(iii)	Added “facility” in two places
Attachment L, Section L-1a(2)(iii)	Deleted “(shown, for example, as Well H-8 in Figure L-7). However, the Permittees identified the Culebra as potential aquifer in the Compliance Certification Application (DOE, 1996). Because of this, the Culebra will be the focus of future ground-water monitoring at WIPP as it is also the most transmissive continuous water-bearing zone at WIPP and is the most likely pathway for contaminant migration”
Attachment L, Section L-2	Added “The requirements of”
Attachment L, Section L-2	Replaced “applies” with “apply”
Attachment L, Section L-2	Added “the” and “facility”
Attachment L, Section L-3	Deleted “Ground-water” from section heading
Attachment L, Section L-3a	Deleted “The Permittees have established a RCRA “Ground-water Detection Monitoring Program (DMP) Plan” to define and protect ground-water resources at WIPP. One of the objectives of the WIPP DMP is to establish, by means of ground-water sampling and analysis, an accurate and representative ground-water database that is scientifically defensible and demonstrates regulatory compliance. In addition, the DMP will be used to determine background or existing conditions of ground-water quality and quantity, including ground-water surface elevation and direction of flow, around the WIPP facility area.”
Attachment L, Section L-3a	Added “DMP”
Attachment L, Section L-3a	Deleted “all”
Attachment L, Section L-3a	Added “applicable”
Attachment L, Section L-3a	Replaced “§§ 264.90 through 264.101” with “264 Subpart F”
Attachment L, Section L-3a	Deleted “all”
Attachment L, Section L-3a	Deleted “The ground-water quality data generated by monitoring activities will provide a comprehensive background database against which future”

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Attachment L, Section L-3a	Changed “analytical” to “Analytical”
Attachment L, Section L-3a	Replaced “can be compared” with “collected”
Attachment L, Section L-3a	Added “are compared to the baseline established in this Permit to determine whether or not a release has occurred”
Attachment L, Section L-3a	Deleted “Ground-water monitoring at WIPP has been historically conducted by several programs including the WIPP Site Characterization Program, the WIPP WQSP, and recently the WIPP Ground-water Surveillance Program (**GWSP**). Ground-water quality and ground-water surface elevation data have been collected by these programs for over 12 years at WIPP. Data from the WQSP wells (which are widely distributed across the area, see Figure L-8) will be used to continually define changes in the area’s potentiometric surface and ground-water flow directions. New monitoring wells included in the WIPP GWSP (WQSP wells 1-6a) were constructed to the specifications provided in the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (EPA, 1986) and constitute the RCRA ground-water monitoring network specified in this DMP as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101). These wells are being used to establish background ground-water quality, ground-water surface elevations and flow directions in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §§264.97(f) and (g) and 264.98(e)). Justification for the locations of these wells (3 upgradient and 4 downgradient) is presented below.”
Attachment L, Section L-3a	Added “There are two separate components of the Groundwater Monitoring Program, the Detection Monitoring Program (DMP) and the Water Level Monitoring Program (WLMP). The first component consists of a network of six Detection Monitoring Wells (DMWs). The DMWs (WQSP 1-6) were constructed to be consistent with the specifications provided in the Groundwater Monitoring Technical Enforcement Guidance Document and constitute the RCRA groundwater monitoring network specified in the DMP. The DMWs were used to establish background groundwater quality in accordance with 20.4.1.500 NMAC (incorporating 40 CFR § 264.97 and 264.98 (f)). The second component of the Groundwater Monitoring Program is the WLMP, which is used to determine the groundwater surface elevation and flow direction. Table L-4 is a list of the wells used in the WLMP as of January 1, 2011. The list of wells is subject to change due to plugging and abandonment and drilling of new wells.”
Attachment L, Section L-3b	Deleted “The WQSP wells 1 through 6 constitute the RCRA DMP for WIPP (Figure L-9 and Permit Attachment B, Figure B2-3) during detection monitoring as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101). This monitoring plan is a continuation of the current WIPP GWSP, and these wells will serve as the monitoring locations during background water-quality characterization and the RCRA DMP (Figure L-9 and Permit Attachment B, Figure B2-3).”
Attachment L, Section L-3b	Replaced “were” with “are”
Attachment L, Section L-3b	Added “(north)”
Attachment L, Section L-3b	Deleted “The locations of the three upgradient wells were selected to be representative of the flow vectors of ground water moving downgradient onto the WIPP site. Figure 34 of Davies, 1989, shows the simulation of direction and magnitude of ground-water flow. The upgradient wells were located based on the flow vectors resulting from this model simulation. The original WQSP observation wells, as well as those in the RCRA DMP, have been and will continue to be used as piezometer wells to support collection of ground-water surface elevation and ground-water flow modeling data to demonstrate regulatory compliance. Well location surveys for each of the seven wells were performed by the Permittees’ survey personnel using the State Plane Coordinates-North American Datum Model 27 method. Results of the surveys are on file with the New Mexico State Engineers Department along with the

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	associated extraction permits for each well.”
Attachment L, Section L-3b	Replace “were” with “are”
Attachment L, Section L-3b	Added “(south)”
Attachment L, Section L-3b	Deleted “in concert with the flow vectors shown by this model simulation” after “area”
Attachment L, Section L-3b	Added “to be located generally in the path of contaminants that might be released from the shaft area in the Culebra.”
Attachment L, Section L-3b	Deleted “based on the greatest velocity magnitude of ground-water flow leaving the shaft area as shown on Figure 34 of Davies, 1989, and upgradient of the WIPP LWA boundary”
Attachment L, Section L-3b	Added “Well”
Attachment L, Section L-3b	Deleted “around wells DOE-1 and H-11”
Attachment L, Section L-3b	Deleted “The Culebra has been selected for the focus of the DMP due to it being regionally extensive and exhibiting the most significant transmissivity of the water-bearing units at WIPP. The Culebra has been extensively studied during all past hydrologic characterization programs and found to be the most likely hydrologic pathway to the accessible environment or compliance point for any potential contamination.”
Attachment L, Section L-3b	Replaced “The RCRA ground-water monitoring network was not installed immediately downgradient of this plane. However, because the Underground HWDUs at WIPP are Subpart X units, and due to the relatively unique containment and transport aspects of the site, monitoring at the proposed locations will allow for detection of releases prior to release of these contaminants to the general public at the LWA boundary.” with “Wells WQSP-4, 5, and 6 are situated to demonstrate that during the operating life of the facility (including closure), release of contaminants to the general public will not occur.”
Attachment L, Section L-3b	Deleted “The DMP wells were located to intercept flow vectors downgradient away from the WIPP shafts area based on current density corrected potentiometric surfaces (Figure L-9). Based on natural contours of the potentiometric surface (Figure L-9) the selected well placement locations are downgradient of the general flow direction from the shaft area.”
Attachment L, Section L-3b	Added “suggests”
Attachment L, Section L-3b	Deleted “of contaminant migration throughout the Culebra to the Land Withdrawal Act boundary suggests”
Attachment L, Section L-3b	Added “from the Waste Handling Shaft to the LWA boundary”
Attachment L, Section L-3b	Added “.” After “years”
Attachment L, Section L-3b	Deleted “if, under worst case conditions,”
Attachment L, Section L-3b	Added “This assumes conditions where”
Attachment L, Section L-3b	Deleted “could”
Attachment L, Section L-3b	Added “(post closure) to the Culebra via the sealed shafts”
Attachment L, Section L-3b	Deleted “If contaminants were to migrate from the disposal facility, they would be detected by the DMP wells located midway between the shafts and LWA such that samples from wells could detect these contaminants long before they could reach the LWA boundary.”
Attachment L, Section L-3b	Added “for the Culebra”
Attachment L, Section L-3b	Deleted “s” on “suggests”

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Attachment L, Section L-3b	Deleted “Recent (December 1996)”
Attachment L, Section L-3b	Changed “potentiometric” to “Potentiometric”
Attachment L, Section L-3b	Added “. The wells used for measuring the potentiometric surface of the Culebra are measured monthly and listed in Table L-4.”
Attachment L, Section L-3b	Deleted “(Figure L-9). WQSP-4, WQSP-5, and WQSP-6 have been located downgradient of the waste emplacement areas according to present-day adjusted potentiometric surfaces. Potentiometric surfaces that have not been corrected for density differences and that contain transient relics of previous pumping-drawdown events do not reflect accurate natural ground-water flow directions and should not be used to assess the adequacy of ground-water monitoring locations. Previous potentiometric surface maps showing a potentiometric low and hydrologic gradient toward the area between WQSP-3 and WQSP-4 had not been adjusted to freshwater head equivalents, and had also been influenced by the long-term pumping at well H-19. Hence, some historic maps may not represent natural Culebra flow directions or gradients, and appropriateness of the RCRA monitoring network cannot be definitively evaluated using these data.”
Attachment L, Section L-3b(1)	Changed section heading from “DMP Well Construction Specification” to “Detection Monitoring Well Construction Specification”
Attachment L, Section L-3b(1)(i)	Deleted section heading
Attachment L, Section L-3b(1)(i)	Added “Diagrams of the six DMP wells are shown in Figures L-7 through L-12. Detailed descriptions of geology and construction methods may be found in DOE 1995.”
Attachment L, Section L-3b(1)(i)	Replaced “Well WQSP-1 was” with “The six WQSP Culebra wells were”
Attachment L, Section L-3b(1)(i)	Replaced “16” with “October 26”
Attachment L, Section L-3b(1)(i)	Replaced “, to a” with “. The”
Attachment L, Section L-3b(1)(i)	Replaced “737 ft (225 m) bgs” with “each well is shown in Table L-5”
Attachment L, Section L-3b(1)(i)	Replaced “borehole was” with “wells were”
Attachment L, Section L-3b(1)(i)	Deleted “extends 15 ft (5 m)”
Attachment L, Section L-3b(1)(i)	Replaced “unnamed lower member of the Rustler” with “Los Medaños as shown in Table L-5”
Attachment L, Section L-3b(1)(i)	Replaced “well was” with “wells were”
Attachment L, Section L-3b(1)(i)	Replaced “a depth of 693 ft (211 m) bgs using” with “the top of the Culebra using”
Attachment L, Section L-3b(1)(i)	Deleted “. The interval from 693 to 737 ft (225 to 211 m) bgs (the total depth) was drilled using air mist with a foaming agent as the drilling fluid. WQSP-1 was drilled to 695.6 ft (212 m) bgs using”
Attachment L, Section L-3b(1)(i)	Added “and”
Attachment L, Section L-3b(1)(i)	Replaced “and was” with “. The wells were then”
Attachment L, Section L-3b(1)(i)	Deleted “from 695.6 to 737 ft (212 to 225 m) bgs”
Attachment L, Section L-3b(1)(i)	Deleted “-“ after ‘in.”
Attachment L, Section L-3b(1)(i)	Added “to total depth”
Attachment L, Section L-3b(1)(i)	Added “See Table L-5 for the drilling and coring intervals for each well.”
Attachment L, Section L-3b(1)(i)	Replaced “WQSP-1 was” with “WQSP wells were”

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Attachment L, Section L-3b(1)(i)	Replaced space with "-"
Attachment L, Section L-3b(1)(i)	Replaced "WQSP-1 was" with "After reaming, wells were
Attachment L, Section L-3b(1)(i)	Replaced "737 ft (224.6 m) bgs" with "total depth"
Attachment L, Section L-3b(1)(i)	Replaced "from 702 to 727 ft (214 to 222 m) bgs" with "as shown in Table L-5"
Attachment L, Section L-3b(1)(i)	Deleted "from 640 to 651 ft (195 to 198 m) bgs"
Attachment L, Section L-3b(1)(i)	Replaced "from 651 to 737 ft (198 to 225 m) bgs." with "as indicated in Table L-5."
Attachment L, Section L-3b(1)(i)	Deleted "Based on core log results, the Culebra is located from 699 to 722 ft (213 to 220 m) bgs (see Figure L-10)."
Attachment L, Section L-3b(1)(ii)	Deleted section
Attachment L, Section L-3b(1)(iii)	Deleted section
Attachment L, Section L-3b(1)(iv)	Deleted section
Attachment L, Section L-3b(1)(v)	Deleted section
Attachment L, Section L-3b(1)(vi)	Deleted section
Attachment L, Section L-4a	Deleted "The seven RCRA monitoring wells have been sampled on a semiannual basis since their installation in 1995 to establish background ground-water quality in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98). This has included at least two full rounds of 20.4.1.500 NMAC (Incorporating 40 CFR §264) Appendix IX analysis for samples from each of the proposed RCRA detection monitoring wells. In addition, ground-water samples were collected from the DMP wells (from March 1997 until waste emplacement) at a frequency of four sample replicates collected semiannually from each well for the indicator parameters of pH, specific conductance (**SC**), total organic carbon (**TOC**), and total organic halogen (**TOX**) to further establish background ground-water quality until detection monitoring in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §264.98) becomes applicable. A total of four rounds of Appendix IX analysis will be conducted for samples from each well for use in background ground-water quality determinations. Detection monitoring will start when the Permittees emplace waste and continue through the post-closure phase as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.90[c]). During detection monitoring, one sample and one sample duplicate will be collected semiannually from each well in the RCRA detection monitoring network. As shown in Table L-2, the DMP will continue to collect ground-water quality samples for all seven wells on a semiannual basis during the life of the DMP. 20.4.1.500 NMAC (incorporating 40 CFR §264.97[g][2]) provides that an alternate sampling frequency to that provided in 20.4.1.500 NMAC (incorporating 40 CFR §264.98) may be proposed by the Permittees. Given the nature and rate of ground-water flow in the area surrounding WIPP, collecting and analyzing one sample semiannually will be protective of human health and the environment because any hazardous constituent leaving the underground disposal facility will not have the potential to migrate beyond the ground-water monitoring network in a one-year time frame. Ground-water flow characteristics are presented in detail in Addendum L1, Section L1-2a of the Amended Renewal Application (DOE, 2009)."
Attachment L, Section L-4a	Replaced "seven DMP wells" with "six DMWs"
Attachment L, Section L-4a	Replaced "DMP well" with "DMW"
Attachment L, Section L-4a	Added "annual"
Attachment L, Section L-4a	Replaced "other existing WQSP well sites" with "WLMP wells"

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Attachment L, Section L-4a	Replaced “to supplement the area water-level database and to help define regional changes in ground-water flow directions and gradients” with “when accessible”
Attachment L, Section L-4a	Replaced “RCRA DMP” with “DMW”
Attachment L, Section L-4a	Added “sampling”
Attachment L, Section L-4a	Deleted “If any change occurs which could affect the ability of the DMP to fulfill the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264 Subpart F), the Permittees shall promptly notify NMED in writing and apply for a permit modification, if appropriate.”
Attachment L, Section L-4b	Added “and Hazardous Constituents” to section heading
Attachment L, Section L-4b	Replaced “analytes of interest” with “parameters listed in Part 5, Table 5.4.a and hazardous constituents listed in Part 5, Table 5.4.b are”
Attachment L, Section L-4b	Replaced “to establish” with “as part of the DMP.”
Attachment L, Section L-4b	Deleted “background ground-water quality prior to emplacement of waste include all indicator parameters and all other parameters listed in 20.4.1.500 NMAC (incorporating 40 CFR §264) Appendix IX. Field measurements of pH, SC, temperature, chloride, Eh, total iron, and alkalinity are also measured during background sampling .” “The DMP was initiated upon waste emplacement, at which time the semiannual samples will be analyzed for the parameters listed in Table L-3. Parameters to be analyzed by the contract laboratory such as specific conductance, total dissolved solids, total suspended solids, density, pH, total organic carbon, and total organic halogens were included as indicator parameters because of their universal commonality to ground water. Parameters such as chloride, alkalinity, calcium, magnesium, and potassium were included as matrix-specific general indicator parameters. Calcium, magnesium, potassium, chloride, and iron may be deleted during detection monitoring, with prior approval of NMED. Organic and inorganic compounds on the right hand side of Table L-3 were chosen because they will occur in the waste to be disposed at the WIPP facility.”
Attachment L, Section L-4b	Replaced “parameters” with “hazardous constituents”
Attachment L, Section L-4b	Replaced “the tentatively identified compound (**TIC**) process specified in the Waste Analysis Plan, Permit Attachment C” with “changes to the list of hazardous waste numbers authorized for disposal at the WIPP facility.”
Attachment L, Section L-4b	Replaced "compounds” with “hazardous constituents”
Attachment L, Section L-4b	Replaced “DMP list” with “Part 5, Table 5.4.b”
Attachment L, Section L-4b	Added “(e.g., hazardous constituent not in 40 CFR §264 Appendix IX)”
Attachment L, Section L-4c	Replaced “well” with “DMW”
Attachment L, Section L-4c	Replaced “DMP analytical suite” with “parameters and hazardous constituents in Part 5, Tables 5.4.a and 5.4.b”
Attachment L, Section L-4c(1)	Replaced “is a subprogram of the DMP. The quality assurance activities of the WLMP are in strict accordance with WP 13-1, and the quality assurance implementing procedure specific to ground-water surface elevation monitoring is WIPP Procedure WP 02-EM1014[2]. Current versions of both WP 13-1 and WP 02-EM1014 are maintained in the WIPP Operating Record. with “activities are conducted in accordance with the WIPP facility SOPs listed in Table L-3. “
Attachment L, Section L-4c(1)	Deleted footnote 2 “[2]WP 02-EM1014 “Groundwater Level Measurements” is a technical procedure that specifies the steps followed by Environmental Monitoring (**EM**) personnel

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	for making manual ground-water level measurements in ground-water wells in the vicinity of the WIPP facility. The procedure provides general instructions including prerequisites, safety precautions, performance frequency, quality assurance, and records. Specific instructions are included for using the water level measurement electrical conductance probe and data management.”
Attachment L, Section L-4c(1)	Deleted “Ground-water surface elevation monitoring is in progress now and will continue through the post-closure care period specified in Permit Part 7. This section of the plan addresses the activities of the WLMP during the preoperational and operational phases of WIPP. Collection of ground-water surface elevation data is required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(f)). These data also provide: Data collection as required by the Environmental Monitoring Plan. A means to fulfill commitments made in the Final Environmental Impact Statement (**FEIS**). A means to comply with future ground-water inventory and monitoring regulations. Input for making land use decisions, (i.e., designing long-term active and passive institutional controls for the site). Assistance in understanding any changes to readings from the water-pressure transducers installed in each of the shafts to monitor water conditions behind the liners. An understanding of whether or not the horizontal and vertical gradients of flow are changing over time. The objective of the WLMP is to extend the documented record of ground-water surface elevation fluctuations in the Culebra and Magenta members of the Rustler in the vicinity of the WIPP facility and to meet the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264.97(f)). Ground-water surface elevation data will be collected from each well of the RCRA DMP. Ground-water surface elevation data will also be collected from other Culebra wells, as well as monitoring wells completed in other water-bearing zones overlying and underlying the WIPP repository horizon (see Figure L-18) when access to those zones is possible. This includes, but is not limited to, the Bell Canyon, the Forty-niner, the contact zone between the Rustler and Salado, and the Dewey Lake.”
Attachment L, Section L-4c(1)	Added “Groundwater surface elevation measurements will be taken monthly at each of the six DMWs and prior to the annual sampling event. Additionally,”
Attachment L, Section L-4c(1)	Changed “G” to “g” in “Groundwater”
Attachment L, Section L-4c(1)	Replaced “at least one accessible completed interval at each available well pad” with “the other Culebra wells as listed in Table L-4,”
Attachment L, Section L-4c(1)	Added “when accessible”
Attachment L, Section L-4c(1)	Deleted “At well pads with two or more wells completed in the same interval, quarterly measurements will be taken in the redundant wells (”
Attachment L, Section L-4c(1)	Changed “well to “Well”
Attachment L, Section L-4c(1)	Replaced “18” with “14” to read “L-14”
Attachment L, Section L-4c(1)	Deleted “)”
Attachment L, Section L-4c(1)	Deleted “Ground-water surface elevation measurements will be taken monthly at each of the seven DMP wells, as well as prior to each sampling event.”
Attachment L, Section L-4c(1)	Replaced “report” with “Annual Culebra Groundwater Report”
Attachment L, Section L-4c(1)	Replaced “may” with “will be evaluated to determine if they”
Attachment L, Section L-4c(1)	Replaced “DMP well” with “DMW”

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Attachment L, Section L-4c(1)	Added “c” to end of “Section L-5”
Attachment L, Section L-4c(1)	Added “the”
Attachment L, Section L-4c(1)	Added “facility”
Attachment L, Section L-4c(1)	Deleted “both vertically in well bores and areally from well to well”
Attachment L, Section L-4c(1)	Deleted “at WIPP”
Attachment L, Section L-4c(1)	Added “Culebra groundwater”
Attachment L, Section L-4c(1)	Replaced “bores” with “s listed in Table L-4”
Attachment L, Section L-4c(1)	Added “d” to “measure”
Attachment L, Section L-4c(1)	Deleted “When both of these parameters are known, equivalent freshwater heads will be calculated. The concept of freshwater head is discussed in Lusczynski (1961). A discussion explaining the calculation of freshwater heads from mid-formation depth at WIPP can be found in Haug, et al. (1987). Freshwater heads are useful in identifying hydraulic gradients in aquifers of variable density such as those existing at the WIPP site. Freshwater head at a given point is defined as the height of a column of freshwater that will balance the existing pressure at that point (Lusczynski, 1961).”
Attachment L, Section L-4c(1)	Replaced “ground-“ with “Culebra”
Attachment L, Section L-4c(1)	Replaced “g” with “γ”
Attachment L, Section L-4c(1)	Replaced “pressure” with “length of freshwater head”
Attachment L, Section L-4c(1)	Replaced “ρ” with “γ”
Attachment L, Section L-4c(1)	Added “ratio of borehole fluid density to density of fresh water”
Attachment L, Section L-4c(1)	Replaced “g” with “ρ”
Attachment L, Section L-4c(1)	Replaced “density (expressed as specific gravity).” With “specific gravity.”
Attachment L, Section L-4c(1)	Added “Density measurements are made annually. Density for the DMWs will be expressed as specific gravity as measured in the field during sampling events using a hydrometer. Freshwater head for other Culebra wells will be calculated as described above from fluid density measurements obtained using pressure transducers.
Attachment L, Section L-4c(1)(i)	Replaced “When using an electrical conductance probe, the depth to water will be determined by reading the appropriate measurement markings on the embossed measuring tape when the alarm is activated at the surface. WIPP Procedure WP 02-EM1014 specifies” with “An SOP will be used when making water-level measurements for this program. The SOP will specify”
Attachment L, Section L-4c(1)(i)	Added “, and provide general instructions including prerequisites, safety precautions, performance frequency, quality assurance, data management, and records”
Attachment L, Section L-4c(1)(i)	Deleted “A current revision of this procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(1)(ii)	Deleted “All”
Attachment L, Section L-4c(1)(ii)	Changed “incoming” to “Incoming”
Attachment L, Section L-4c(1)(ii)	Deleted “timely”
Attachment L, Section L-4c(1)(ii)	Replaced “to” with “that”
Attachment L, Section L-4c(1)(ii)	Replaced “assure” with “ensures”

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Attachment L, Section L-4c(1)(ii)	Replaced “i.e.” with “e.g.”
Attachment L, Section L-4c(1)(ii)	Replaced “guidelines outlined in WIPP Procedures WP 02-EM3001[3] and WP 02-EM1014[4]” with “applicable SOPs (see Table L-3)””
Attachment L, Section L-4c(1)(ii)	Deleted footnotes 3 and 4 “[3]WP 02-EM3001 “Administrative Processes for Environmental Monitoring Programs” is a management control procedure to provide the administrative guidance to be used by Environmental Monitoring (EM) personnel to maintain quality control (QC) associated with EM sampling activities and to assure that data acquired under the WIPP Environmental Monitoring Program are valid. The precautions and limitations portion of this procedure assure that only qualified personnel acquire samples under the EM program, that cross contamination of sampling equipment is prevented, and that sample hold times are not exceeded. The Performance portion of the procedure provides step-by-step instructions for Quality Assurance/Quality Control (QA/QC) implementation, the use of data sheets and sample tracking logbooks, sample tacking from collection to submittal, and actions to take if sample results indicate the potential for exceeding a regulatory limit. [4]WP 02-EM1014 “Groundwater Level Measurement”, is a technical procedure which lists the equipment required and the operational checks necessary to perform groundwater level measurements. This procedure as well as WP 02-EM3001 also provides information on performing validation and verification of laboratory data.”
Attachment L, Section L-4c(1)(ii)	Deleted “Current copies of these procedures are maintained within the WIPP Operating Record.”
Attachment L, Section L-4c(1)(ii)	Replaced “will” with “program”
Attachment L, Section L-4c(1)(ii)	Added “s” to “calculate”
Attachment L, Section L-4c(1)(ii)	Replaced “will also adjust” with “program adjusts”
Attachment L, Section L-4c(1)(ii)	Deleted “The data contained on the computerized work sheet will be translated into a database file. A printout will be made of the database file. The data each month will then be compiled into report format and transmitted to the appropriate agencies as requested by the Permittees.”
Attachment L, Section L-4c(1)(ii)	Replaced “all” with “the”
Attachment L, Section L-4c(1)(ii)	Added “in Table L-4”
Attachment L, Section L-4c(1)(ii)	Replaced “one month after data are collected” with “by May 31 and November 30”
Attachment L, Section L-4c(1)(ii)	Added “Semi-annual groundwater reports will also include annotated hydrographs and trend analysis.”
Attachment L, Section L-4c(1)(ii)	Deleted “A computerized database file will be maintained for all ground-water surface elevation data. Monthly and quarterly data will be appended into a yearly file. Upon verification that the yearly database is free of errors, it will be appended into the project database file. A printed copy of the current project database (through December of the preceding year) will be kept in the Environment, Safety and Health Department (**ES&H**) EM fire-resistant storage area.”
Attachment L, Section L-4c(2)(i)	Deleted “The water-bearing units at WIPP are highly variable in their ability to yield water to monitoring wells. The Culebra, the most transmissive hydrologic unit in the WIPP area, exhibits transmissivities that range many orders of magnitude across the site area and is the primary focus of the DMP.”
Attachment L, Section L-4c(2)(i)	Replaced “seven new DMP wells” with “six DMWs”
Attachment L, Section L-4c(2)(i)	Deleted “The wells used for ground-water quality sampling vary in yield, depth,

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	and pumping lift. These factors affect the duration of pumping as well as the equipment required at each well.”
Attachment L, Section L-4c(2)(i)	Replaced “DMP wells will be” with “DMWs are”
Attachment L, Section L-4c(2)(i)	Replaced “down hole” and “down-hole”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “are”
Attachment L, Section L-4c(2)(i)	Deleted “The electronic flow controller allows personnel collecting samples to control the rate of discharge during well purging to minimize the potential for loss of volatiles from the sample.”
Attachment L, Section L-4c(2)(i)	Replaced “a minimum of” with “no more than”
Attachment L, Section L-4c(2)(i)	Added “or until field parameters have stabilized, whichever occurs first.”
Attachment L, Section L-4c(2)(i)	Deleted “at a rate that will minimize the agitation of recharge water. This will be accomplished by monitoring formation pressure and matching the rate of discharge from the well as nearly as possible to the rate of recharge to the well. WIPP Procedure WP 02-EM1002[5] specifies the methods used for controlling flow rates and monitoring formation pressure. A current version of this document will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(2)(i)	Deleted footnote 5 “[5] WP 02-EM1002 “Electric Submersible Pump Monitoring System Installation and Operation” is a technical procedure that provides step-by-step instructions for acquiring ground-water samples using electric submersible pumps (ESPs). The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment, prerequisite actions which assure the correct installation and operation. The procedure details how to install the various subsystems such as the surface discharge and pressure monitoring system and the pressure monitoring bubbler and how to start up and shut down the ESP.”
Attachment L, Section L-4c(2)(i)	Replaced “requirements will be used” with “will be performed in accordance with an SOP”
Attachment L, Section L-4c(2)(i)	Replaced “DMP wells will be” with “DMWs are”
Attachment L, Section L-4c(2)(i)	Deleted “Details of well construction are presented in Section L-3b(1).”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”
Attachment L, Section L-4c(2)(i)	Deleted “will”
Attachment L, Section L-4c(2)(i)	Added “s” to “take”
Attachment L, Section L-4c(2)(i)	Deleted “Teflon®”
Attachment L, Section L-4c(2)(i)	Replaced “will also be” with “is”
Attachment L, Section L-4c(2)(i)	Added “The sampling line is manufactured from a chemically inert material.”
Attachment L, Section L-4c(2)(i)	Deleted “Flow through the pipe will be regulated on the surface by a flow control valve and/or variable speed drive controller.”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”
Attachment L, Section L-4c(2)(i)	Deleted “Teflon®”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”
Attachment L, Section L-4c(2)(i)	Deleted “Teflon®”
Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”

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Attachment L, Section L-4c(2)(i)	Replaced “will be” with “is”
Attachment L, Section L-4c(2)(i)	Deleted section on Pressure Monitoring Systems
Attachment L, Section L-4c(2)(i)	Deleted section on Sampling Overview
Attachment L, Section L-4c(2)(ii)	Added “’ SOP for serial sampling will provide criteria for determining when a final sample should be taken.”
Attachment L, Section L-4c(2)(ii)	Deleted “will consider a serial sample representative of undisturbed ground water when the majority of field indicator parameter measurements have stabilized within ±5 percent of the average of analytical results for the field indicator parameter from the background ground-water quality for each DMP well. Nonstabilization of one or two field indicator parameters attributable to matrix interferences, instrument drift, or other unforeseen reasons will not preclude the collection of final samples, provided the volume of purged water exceeds three well bore volumes.”
Attachment L, Section L-4c(2)(ii)	Added “Each DMW will be purged to no more than three well bore volumes, or until field parameters stabilize, whichever occurs first. Well stabilization occurs when the field-analyzed parameters are within ± 5% of three consecutive measurements. A well bore volume is defined as the volume of water from static water level to the bottom of the well sump. Serial samples will be analyzed in the mobile field laboratory for field indicator parameters.”
Attachment L, Section L-4c(2)(ii)	Deleted “report, in the operating record, any final samples collected when field indicator parameters were not stabilized, and will”
Attachment L, Section L-4c(2)(ii)	Added “and place that explanation in the WIPP Operating Record”
Attachment L, Section L-4c(2)(ii)	Replaced “Team Leader (see Section L-7)” with “Permittees”
Attachment L, Section L-4c(2)(ii)	Deleted “chloride, divalent cations (hardness), alkalinity, total iron,”
Attachment L, Section L-4c(2)(ii)	Deleted “Eh”
Attachment L, Section L-4c(2)(ii)	Deleted “Protocols for collection of serial samples are specified in WIPP Procedure WP 02-EM1006[6]. Analysis of serial samples are specified in WIPP Procedure WP 02-EM1005[7]. Current versions of these procedures will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(2)(ii)	Replaced “Eh” with “specific conductance”
Attachment L, Section L-4c(2)(ii)	Deleted footnotes 6 and 7 “[6]WP 02-EM1006 “Final Sample and Serial Sample Collection” is a technical procedure that provides step-by-step instructions for acquiring ground-water samples from the WQSP wells and from privately-owned wells in the vicinity of WIPP. The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment, and prerequisite actions which assure the data quality. The procedure addresses collection of samples from private wells, collection of serial ground-water samples, the collection of final samples for submittal to the laboratory, and data review by the monitoring task leader.” “[7]WP 02-EM1005 “Groundwater Serial Sample Analysis” is a technical procedure that provides step-by-step instructions for on site analysis of ground water to determine ground-water stability prior to the collection of final samples for analysis. The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment, prerequisite actions which assure data quality. The procedure addresses the field measurement of Eh, pH, temperature, specific gravity, specific conductance, alkalinity, chloride, divalent cation, and total iron as indicators of ground-water stability.”
Attachment L, Section L-4c(2)(ii)	Deleted “Teflon®”

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Attachment L, Section L-4c(2)(ii)	Deleted "The iron, divalent cation, chloride, alkalinity"
Attachment L, Section L-4c(2)(ii)	Changed "specific" to "Specific"
Attachment L, Section L-4c(2)(ii)	Deleted "Teflon®"
Attachment L, Section L-4c(2)(ii)	Added ", that are certified clean by the laboratory,"
Attachment L, Section L-4c(2)(ii)	Deleted "Teflon®"
Attachment L, Section L-4c(2)(ii)	Deleted "Serial sampling water collected for solute and specific conductance determinations will be filtered through a 0.45 micrometers (μm) membrane filter using a stainless steel, in-line filter holder."
Attachment L, Section L-4c(2)(ii)	Replaced "Filtered water will be used to rinse the sample bottle prior to serial sample collection." with "Serial samples collected in laboratory-certified clean containers do not require rinsing prior to sample collection."
Attachment L, Section L-4c(2)(ii)	Replaced "Eh" with "specific conductance"
Attachment L, Section L-4c(2)(ii)	Replaced "The filtered sample collected for solute analyses will be immediately analyzed for iron and alkalinity because these two solution parameters are extremely sensitive to changes in the ambient water-sample pressure and temperature. A sample and duplicate of filtered water will be collected and analyzed for solute parameters (alkalinity, chloride, divalent cations, and iron)." with "Samples collected will immediately be analyzed for pH and specific conductance (**SC**) as these parameters are most sensitive to changes in ambient temperature."
Attachment L, Section L-4c(2)(ii)	Replaced "Eh" with "specific conductance"
Attachment L, Section L-4c(2)(ii)	Deleted "Samples to be analyzed for chloride and divalent cations (after preservation with nitric acid and stored at 4°C) may be stored for one week prior to analysis with confidence that the analytical results will not be altered."
Attachment L, Section L-4c(2)(ii)	Replaced "WIPP Procedure WP 02-EM1006" with "Standard Operating Procedures (see Table L-3)"
Attachment L, Section L-4c(2)(ii)	Added "and analysis"
Attachment L, Section L-4c(2)(ii)	Deleted "WIPP Procedure WP 02-EM1005 defines the protocols for serial sample analysis. Current versions of these procedures will be maintained in the WIPP Operating Record. During the first two years of DMP well serial sampling, the first sample will be analyzed as soon as possible after the pump is turned on and daily thereafter for a period of four days or until the field indicator parameters (chloride, divalent cations, alkalinity, and iron) stabilize. pH and SC will be continually monitored by using a flow cell with ion-specific electrodes and a real-time readout. When detection monitoring begins, the serial sampling process may be modified and the decision to collect final samples would then be based on the number of well bore volumes purged and results of the analysis of chloride, temperature, specific gravity, pH, and SC. Removal of serial sampling from the DMP will be accomplished through a permit modification and a modification to this plan."
Attachment L, Section L-4c(2)(iii)	Replaced "4" with "6" to read "L-6"
Attachment L, Section L-4c(2)(iii)	Deleted "Non-dedicated sample collection lines from the well head to the sample collection area will be discarded after each use."
Attachment L, Section L-4c(2)(iii)	Added "in accordance with SOPs"
Attachment L, Section L-4c(2)(iii)	Deleted "with two gallons of fresh water, then rinsed with five gallons of 5 percent nitric acid solution and rinsed with five gallons of DI water"
Attachment L, Section L-4c(2)(iii)	Moved "blank" after "rinsate"
Attachment L, Section L-4c(2)(iii)	Replaced "decontamination" with "cleanliness"

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Attachment L, Section L-4c(2)(iii)	Deleted “Teflon®”
Attachment L, Section L-4c(2)(iii)	Deleted “branching from the main sample line”
Attachment L, Section L-4c(2)(iii)	Replaced “procedures, assure that” with “SOPs (see Table L-3) define how”
Attachment L, Section L-4c(2)(iii)	Deleted “. WIPP Procedure WP 02-EM1006 defines the requirements for collection of final samples”
Attachment L, Section L-4c(2)(iii)	Deleted “A current version of this procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(2)(iii)	Replaced “4" with “6” to read “L-6"
Attachment L, Section L-4c(2)(iii)	Deleted “Standard Operating Procedures [“ and “]”
Attachment L, Section L-4c(2)(iii)	Replaced “procedures” with “SOPs”
Attachment L, Section L-4c(2)(iii)	Deleted “contract”
Attachment L, Section L-4c(2)(iii)	Deleted “Before the final sample is taken, all plastic and glass containers will be rinsed with the pumped ground water, either filtered or unfiltered, dependent upon analysis protocol. When the rinsing procedure is completed the final sample will be collected.”
Attachment L, Section L-4c(2)(iii)	Replaced “contract” with “the analytical”
Attachment L, Section L-4c(2)(iii)	Replaced “general chemistry, radionuclides, metals, and selected VOCs that are specific to the waste anticipated to arrive at WIPP.” with “parameters and hazardous constituents specified in Part 5, Tables 5.4.a and 5.4.b.”
Attachment L, Section L-4c(2)(iii)	Deleted “Table L-3 presents the specific analytes for the DMP.”
Attachment L, Section L-4c(2)(iii)	Added “Project”
Attachment L, Section L-4c(2)(iii)	Replaced “as” with “when”
Attachment L, Section L-4c(2)(iii)	Deleted “by the Permittees or NMED”
Attachment L, Section L-4c(2)(iii)	Deleted “Resulting ”
Attachment L, Section L-4c(2)(iii)	Changed “wastes” to “Wastes”
Attachment L, Section L-4c(2)(iii)	Added “resulting from the sampling and field analysis of groundwater”
Attachment L, Section L-4c(2)(iii)	Replaced “Procedure WP 02-RC.01[8].” with “SOPs (see Table L-3).”
Attachment L, Section L-4c(2)(iii)	Deleted “A current version of this procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(2)(iii)	Deleted footnote 8 “[8]WP 02-RC.01 “Site-Generated, Non-Radioactive Hazardous Waste Management Plan” is a step-by-step procedure that defines site-generate non-radioactive hazardous waste (SGNRHW) and lists responsibilities of waste management organizations including the generator, waste handlers, sampling personnel, safety personnel, and compliance personnel. In addition, the procedure defines training requirements, container marking requirements, spill response, and list prohibitions. A Section of the procedure is focused on waste management practices including the management in satellite accumulation areas, the hazardous waste staging area for materials awaiting analysis, the establishment of accumulation times, and hazardous waste disposal.”
Attachment L, Section L-4c(2)(iv)	Deleted “with either high purity hydrochloric acid, nitric acid, or sulfuric acid (ULTREX or equivalent), depending upon the standard method of treatment required for the particular parameter suite or”
Attachment L, Section L-4c(2)(iv)	Replaced “contract” with “the analytical”

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Attachment L, Section L-4c(2)(iv)	Deleted “SOPs (see Table L-4)”
Attachment L, Section L-4c(2)(iv)	Replaced “contract” with “analytical”
Attachment L, Section L-4c(2)(iv)	Deleted “use procedures that”
Attachment L, Section L-4c(2)(iv)	Deleted “and”
Attachment L, Section L-4c(2)(iv)	Added “, and the shipping requirements”
Attachment L, Section L-4c(2)(iv)	Replaced “if” with “when”
Attachment L, Section L-4c(2)(iv)	Added “WIPP SOPs (see Table L-3) provide instructions to ensure proper sample preservation and shipping.”
Attachment L, Section L-4c(2)(iv)	Added “the”
Attachment L, Section L-4c(2)(iv)	Replaced “will use” with “facility uses”
Attachment L, Section L-4c(2)(iv)	Replaced “(CofC) Forms and” with “/”
Attachment L, Section L-4c(2)(iv)	Replaced “(RFA) Forms” with “(**CofC/RFA**) forms”
Attachment L, Section L-4c(2)(iv)	Replaced “parameters” with “analytes”
Attachment L, Section L-4c(2)(iv)	Replaced “Procedure WP 02-EM3001” with “SOPs (see Table L-3)”
Attachment L, Section L-4c(2)(iv)	Deleted “s” from “provides”
Attachment L, Section L-4c(2)(iv)	Deleted “A current revision of this procedure will be maintained within the WIPP Operating Record. Insulated shipping containers packaged with crushed ice or reusable ice packs will be used to keep the samples cool during transport to the contract laboratory. Holding times for specific analytical parameters require samples to be shipped by express air freight. The coolers will be packaged to meet Department of Transportation and International Air Transportation Association commercial carrier regulations.”
Attachment L, Section L-4c(2)(v)	Deleted “EM”
Attachment L, Section L-4c(2)(v)	Replaced “Procedure WP 02-EM3001” with “facility SOPs see (Table L-3)”
Attachment L, Section L-4c(2)(v)	Deleted “These procedures will be strictly followed throughout the course of each sample collection and analysis event. A current revision of this procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-4c(2)(v)	Deleted “will”
Attachment L, Section L-4c(2)(v)	Replaced “log books” with “data”
Attachment L, Section L-4c(2)(v)	Replaced “request for analysis/chain of custody (RFA and CofC” and “)” with “CofC/RFA”
Attachment L, Section L-4c(2)(v)	Replaced “The forms are briefly defined in the following subsections. with “An example form is shown in Figure L-13.”
Attachment L, Section L-4c(2)(v)	All sample documentation will be completed for each sample and reviewed by the Team Leader or his/her designee for completeness and accuracy.”
Attachment L, Section L-4c(2)(v)	Deleted “The Team Leader (see Section L-7) will assign the numbers prior to sample collection.”
Attachment L, Section L-4c(2)(v)	Deleted “permanent,”
Attachment L, Section L-4c(2)(v)	Replaced “The” with “For example,”
Attachment L, Section L-4c(2)(v)	Replaced “will be” with “that are”
Attachment L, Section L-4c(2)(v)	Deleted “that”

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Attachment L, Section L-4c(2)(v)	Changed subeading from “Sample Tracking Logbook” to “Sample Identification and Tracking”
Attachment L, Section L-4c(2)(v)	Deleted “A”
Attachment L, Section L-4c(2)(v)	Changed “sample” to “Sample”
Attachment L, Section L-4c(2)(v)	Replaced “logbook (STLB) form will be completed for each sample collected.” with “information will be completed for each sample collected.”
Attachment L, Section L-4c(2)(v)	Replaced “STLB will” with “sample tracking information”
Attachment L, Section L-4c(2)(v)	Added “s” to “include”
Attachment L, Section L-4c(2)(v)	Replaced “C of C” with “CofC/RFA form”
Attachment L, Section L-4c(2)(v)	Deleted “RFA No.;”
Attachment L, Section L-4c(2)(v)	Replaced “STLB” with “Sample tracking”
Attachment L, Section L-4c(2)(v)	Deleted “and checked by the Team Leader. When samples are shipped, the STLB will remain in the custody of the EM Section for sample tracking purposes.”
Attachment L, Section L-4c(2)(v)	Added “Sample tracking is monitored and documented with the CofC/RFA form and the shipping airbill. Both of these documents are included in the data packets. Receipt at the laboratory may be monitored, if necessary, via the shipper’s website tracking application. Samples are considered complete when a copy of the original CofC/RFA form is merged with the Field Lab copy of the same document.”
Attachment L, Section L-4c(2)(v)	Changed subeading from “Request for Analysis and Chain of Custody” to “Chain of Custody and Request for Analysis”
Attachment L, Section L-4c(2)(v)	Deleted “n” from “An”
Attachment L, Section L-4c(2)(v)	Replaced “RFA and CofC” with “CofC/RFA”
Attachment L, Section L-4c(2)(v)	Deleted “An example of the RFA and CofC form is presented in Figures L-17a and L-17b.”
Attachment L, Section L-4c(2)(v)	Replaced “RFA and CofC” with “CofC/RFA”
Attachment L, Section L-4c(2)(v)	Added “analytical”
Attachment L, Section L-4c(2)(v)	Replaced “RFA and CofC” with “CofC/RFA form”
Attachment L, Section L-4c(2)(v)	Replaced “RFA and CofC” with “CofC/RFA form”
Attachment L, Section L-4c(2)(v)	Replaced “Team Leader” with “Permittees”
Attachment L, Section L-4c(2)(v)	Replaced “RFA and CofC” with “CofC/RFA”
Attachment L, Section L-4c(2)(v)	Added “analytical”
Attachment L, Section L-4c(3)	Replaced “by a commercial laboratory.” with “using”
Attachment L, Section L-4c(3)	Changed “Methods” to “methods”
Attachment L, Section L-4c(3)	Deleted “will be specified in procurement documents and will be”
Attachment L, Section L-4c(3)	Added “In Part 5,”
Attachment L, Section L-4c(3)	Replaced “L-3” with “s 5.4.a and 5.4.b”
Attachment L, Section L-4c(3)	Added “and hazardous constituents”
Attachment L, Section L-4c(3)	Added “unless alternate methods or protocols are approved by the NMED”
Attachment L, Section L-4c(3)	Replaced “selected” with “analytical”

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Attachment L, Section L-4c(3)	Added “protocols such as”
Attachment L, Section L-4c(3)	Added “unless alternate methods or protocols are approved by the NMED”
Attachment L, Section L-4c(3)	Added “analytical”
Attachment L, Section L-4c(3)	Added “WIPP”
Attachment L, Section L-4c(3)	Changed “operating record” to Operating Record.”
Attachment L, Section L-4c(3)	Added “.” After “Record”
Attachment L, Section L-4c(3)	Deleted “and will be available for review upon request by NMED.”
Attachment L, Section L-4c(3)	Replaced “WIPP repository” with “Culebra groundwater”
Attachment L, Section L-4c(3)	Replaced “Once the initial qualification criteria, as specified above, have been met, the Permittees will select a laboratory based upon competitive bid. The selected laboratory will perform analytical work for the Permittees for a predetermined period of time, as specified in the contract between the Permittees and the selected laboratory. As this period of performance comes to an end, a new laboratory selection/competitive bid process will be initiated by the Permittees. The same or a different laboratory may be selected for the new contract period.” with “The laboratory will maintain documentation of sample handling and custody, analytical results, and internal quality control (QC) data. Additionally, the laboratory will analyze QC samples in accordance with this plan and its own internal QC program for indicators of analytical accuracy and precision. Data generated outside of laboratory acceptance limits will trigger an evaluation and, if appropriate, corrective action as directed by the Permittees. The laboratory will report the results of the environmental sample and QC sample analyses and any necessary corrective actions that were performed. In the event that more than one analytical laboratory is used (e.g., for different analyses), each one will have the responsibilities specified above.”
Attachment L, Section L-4c(3)	Replaced “The” with “A copy of the laboratory”
Attachment L, Section L-4c(3)	Deleted “for the laboratory currently under contract”
Attachment L, Section L-4c(3)	Deleted “in a file”
Attachment L, Section L-4c(3)	Replaced “the operating record by the Permittees.” with “WIPP facility files.”
Attachment L, Section L-4c(3)	Added “by January 31”
Attachment L, Section L-4c(3)	Replaced “on behalf of the Permittees by the Management and Operating Contractor (**MOC**) Environmental Monitoring (**EM**). Data validation results are documented on an Approval/Variation Request (**AR/VR**) form (Procedure WP 15-PC3041). If no discrepancies are found in the data, the AR/VR form will be signed and the approved box will be checked. If however, discrepancies are found, the AR/VR form will be signed and the disapproved or approved-on-condition box will be checked and the form will be returned to the team leader accompanied by an attached report discussing the data validation results, any anomalies, and resolutions. Copies of the data validation report will be distributed to the EM Manager, QA Manager, the Team Leader, and the Contract Administrator. Copies of the data validation report will be kept on file in the EM records section for review upon request by NMED.” with “and reported in the Annual Culebra Groundwater Report and will be maintained in the WIPP facility Operating Record.”
Attachment L, Section L-4d(1)	Changed section heading “Sampling Equipment Calibration Requirements” to “Sampling and Groundwater Elevation Monitoring Equipment Calibration”
Attachment L, Section L-4d(1)	Deleted “the WQSP and”

Affected Permit Section	Explanation of Change
Attachment L, Section L-4d(1)	Replaced “maintenance administrative procedures specified below” with “SOPs”
Attachment L, Section L-4d(1)	Replaced “EM Section” with “Permittees”
Attachment L, Section L-4d(1)	Replaced “, in accordance with written procedures. The EM Section will also be responsible” with “and”
Attachment L, Section L-4d(2)	Replaced “Procedure WP 10-AD3029[9] A current revision of this procedure will be maintained in the WIPP Operating Record.” with “facility SOPs (see Table L-3).”
Attachment L, Section L-4d(2)	Deleted footnote 9 “[9]WP 10-AD3029 “Calibration and Control of Monitoring and Data Collection Equipment” provides the step-by-step protocols for the establishment and maintenance of a master database of monitoring and data collection (**M&DC**) equipment, the recall process for equipment needing calibration, the performance of calibrations, the management of calibration results to determine the adequacy of recall frequencies, functional testing of M&DC equipment, and reporting including out-of-tolerance reporting and expired calibration reporting. In addition, the procedure provides step-by-step process for the storage of calibrated M&DC equipment and the use of rental equipment.”
Attachment L, Section L-4d(2)	Replaced “EM Section” with “Permittees”
Attachment L, Section L-4d(2)	Replaced “calibrating the needed” with “ensuring”
Attachment L, Section L-4d(2)	Added “is calibrated”
Attachment L, Section L-4d(2)	Replaced “written procedures” with “SOPs”
Attachment L, Section L-4d(2)	Replaced “EM Section” with “Permittees”
Attachment L, Section L-4d(2)	Re[;aced “current” with “copies of records of the most recent”
Attachment L, Section L-4d(2)	Deleted “records”
Attachment L, Section L-4e	Added “Analytical” to section heading
Attachment L, Section L-4e	Deleted “As required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98), data collected to establish background ground-water quality and” Added “Analytical data collected”
Attachment L, Section L-4e	Replaced “DMP.” with “Permittees”
Attachment L, Section L-4e	Deleted “Statistical analysis of DMP data will conform to EPA guidance “Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities (EPA, 1989)””
Attachment L, Section L-4e	Deleted “and “Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance” (EPA, 1992).”
Attachment L, Section L-4e(1)	Deleted “Environmental parameters vary with space and time. The effect of one or both of these two factors on the expected value of a point measurement will be statistically evaluated through spatial analysis and time series analysis. These methods often require extensive sampling efforts that may exceed the practical limits of the DMP sampling procedures. Spatial analysis may have limited use DMP during the operational period, although the effect of spatial auto-correlation on the interpretation of the data will be considered for each parameter. Spatial variability will be accounted for by the use of predetermined key sampling locations. Data analysis will be performed on a location-specific basis, or data from different locations will be combined only when the data are statistically homogeneous. Statistical homogeneity will be determined by evaluating mean values and variances from the residuals from the individual well data.

Affected Permit Section	Explanation of Change
	Time series analysis plays a more important role in data analysis for the DMP. Parameters will be reported as time series, either in tabular form or as time plots. For key time series parameters, these plots will be in the form of control charts on which control levels will be identified based on preoperational database, fixed standards, control location databases, or other standards for comparison. Where significant seasonal changes in the expected value of the parameter are identified in the preoperational database or in the control locations, corrections in the control levels which reflect the seasonal change will be made and documented.”
Attachment L, Section L-4e(1)	Added “Temporal and spatial analyses of the data were completed as part of establishing the water quality baseline (Crawley and Nagy, 1998; IT, 2000). As a result, the Permittees determined to evaluate changes relative to baseline on an individual location basis and to report the concentrations of constituents as a time series, either in tabular form or as time plots. No particular seasonal variations have been noted in the concentrations of groundwater samples collected during the spring and autumn; therefore, continuing temporal analysis is not required. The analytical results for constituents will be reported as time series, either in tabular form or as time plots or both, and compared to the 95th percentile values or reporting limits identified in Part 5, Table 5.6.”
Attachment L, Section L-4e(2)	Deleted “For data sets which include more than ten data points that are homogeneous in space and time (including seasonal homogeneity) and have less than ten percent missing data, a test for conformance to the normal distribution will be performed. The test for normality of the data will be performed in accordance with the methodologies presented in “Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance” (EPA, 1992). If normality is not met, the data will be log-transformed (or transformed using a suitable mathematical transformation, e.g., square root) and retested for normality. If the transformed data fit a normal distribution, the original data will be accepted as having lognormal or an otherwise mathematically-transformed normal distribution. If normality is still not found, two courses may be taken. One will be to continue to test the fit to standard families of distributions, such as the gamma, beta, and Weibull, with proper modifications to subsequent analyses based on these results. The other course will be to use nonparametric methods of data analysis. For data sets smaller than ten, but homogeneous and complete, the lognormal distribution will be assumed. Data sets with more than ten percent missing data will be analyzed using nonparametric methods. Nonhomogeneous data sets will be subdivided into homogeneous sets and each of these analyzed individually. Descriptive statistics will be calculated for each homogeneous data set. At a minimum, these include a central value and a range of variation. The central value is the arithmetic mean of the untransformed data if the data are not censored at either end. If the data are censored, either a trimmed mean or the median will be used as the central value (which may be within the censored range). If the data set is greater than ten and is uncensored, the standard deviation will be calculated and used as a basis for the reported range in variation. If these criteria are not met, the range between the 0.25 and 0.75 cartelist will be used.”
Attachment L, Section L-4e(2)	Added “Techniques were established to compare detection monitoring data generated during the baseline studies. A 95th upper tolerance limit value (UTLV) or 95th percentile was determined from those data sets where target analytes were measured at concentrations above the method detection limits. The UTLV is provided for normal or lognormal distributions and a 95th percentile confidence interval is provided for data sets that are nonparametric or have greater than 15 percent non-detects. For analytes with only a few detects (greater than 95 percent non-detects), an accurate 95th percentile cannot be

Affected Permit Section	Explanation of Change
	calculated. For these analytes, the maximum detected concentration is used as the baseline value. For the analytes that are non-detect in all the samples, the method reporting limit was used as the baseline value.”
Attachment L, Section L-4e(3)	Changed section heading from “Data Anomalies” to “Action Levels”
Attachment L, Section L-4e(3)	Deleted “Data anomalies include data points reported as being below the limit of detection (**LD**) or otherwise censored over a specific range of values, missing data points occurring randomly in the data set, and outliers that cannot be ascribed to a known source of variation. Whenever possible, sample values which are reported below detection limits will be incorporated into the database as sample values measured at one-half the detection limit for statistical analysis. When values are not available, alternative methods of analysis, as specified in previous sections, will be used. In particular, the use of nonparametric statistics will be required. Missing data points comprising less than 10 percent of the data set do not significantly affect data analyses. Results based on data in which more than 10 percent is missing will be identified as such at the time of reporting. Consideration of the potential effect of missing data shall be made when the majority of the data are missing from a discrete time span.”
Attachment L, Section L-4e(3) Attachment L, Section L-4e(3)	Replaced “Formal testing for outliers will only be done in accordance with EPA guidance. The” with “Using baseline distributions, actions levels were identified in accordance with methodologies described in the baseline documents. Action levels are based on the 95th percentile or reporting limits identified in the baseline. If the groundwater concentration of a constituent identified in Part 5, Table 5.6 is found to exceed an action level, a test for outliers is performed in accordance with the”
Attachment L, Section L-4e(3)	Deleted “Section 8.2 of the”
Attachment L, Section L-4e(3)	Replaced “1989” with “2009”
Attachment L, Section L-4e(3)	Deleted “will be used to check for outliers”
Attachment L, Section L-4e(3)	Deleted “If an outside source of variation is not identified to account for outliers in a data set, it will be included in the data set and all subsequent analyses. If the inclusion of such outliers is found to affect the final results of the analyses significantly, both results (with and without outliers) will be reported.”
Attachment L, Section L-4e(4)	Added “TRU mixed”
Attachment L, Section L-4e(4)	Added “hazardous”
Attachment L, Section L-4e(4)	Added “Part 5,”
Attachment L, Section L-4e(4)	Replaced “L-3” with “5.4.b”
Attachment L, Section L-4e(4)	Replaced “DMP ground-water” with “detection”
Attachment L, Section L-4e(4)	Added “during each of the ten background sampling events (with the exceptions of trans-1,2-dichloroethylene and vanadium that were added after TRU mixed waste disposal began)”
Attachment L, Section L-4e(4)	Deleted “If any background ground-water quality parameter or constituent has not been measured prior to waste receipt, measurements will be made for those parameters or constituents in hydraulically upgradient DMP ground-water monitoring wells for a sequence of four sampling events. Following completion of the four sampling events, the arithmetic mean and variance shall then be calculated by the field supervisor or designee for each well.”
Attachment L, Section L-4e(4)	Deleted “will then”
Attachment L, Section L-4e(4)	Replaced “background value against which statistical values” with “statistical baseline (Part 5, Table 5.6) that is used”

Affected Permit Section	Explanation of Change
Attachment L, Section L-4e(4)	Added “evaluating the significance of the results of”
Attachment L, Section L-4e(4)	Deleted “will be compared”
Attachment L, Section L-4e(4)	Added “. Time-trend control charts with associated screening values for each hazardous constituent are used for this evaluation”
Attachment L, Section L-4e(4)	Replaced “Statistical analysis and comparison will be accomplished using one of the five statistical tests specified in” with “The Permittees will compare the results from groundwater hazardous constituents of ongoing annual groundwater sample analysis to these baseline values in accordance with”
Attachment L, Section L-4e(4)	Replaced “98” with “97”
Attachment L, Section L-4e(4)	Added “(4)”
Attachment L, Section L-4e(4)	Deleted “, which may include Cochran’s Approximation to the Behrens-Fisher students’ t-test at the 0.01 level of significance (described in Appendix IV to 20.4.1.500 NMAC (incorporating 40 CFR §264)”
Attachment L, Section L-4e(4)	Replaced “a significant increase” with “that a constituent statistically exceeds the baseline”
Attachment L, Section L-4e(4)	Replaced “monitoring site” with “of the DMWs”
Attachment L, Section L-4e(4)	Added “)” after “CFR §264.98(f))”
Attachment L, Section L-4e(4)	Replaced “2” with “3”
Attachment L, Section L-4e(4)	Replaced “in” with “to”
Attachment L, Section L-4e(4)	Added “NMED in the”
Attachment L, Section L-4e(4)	Replaced “Site Environmental” with “Culebra Groundwater”
Attachment L, Section L-4e(4)	Deleted “(**ASER**)”
Attachment L, Section L-4e(4)	Replaced “and will be reported to NMED” with “by November 30”
Attachment L, Section L-4e(4)	Deleted “in October”
Attachment L, Section L-5a	Deleted “. Laboratory data reports will be forwarded to the Team Leader (see Section L-7) and NMED”
Attachment L, Section L-5a	Replaced “Analytical parameter” with “Parameter and hazardous constituent”
Attachment L, Section L-5a	Added “s” to result”
Attachment L, Section L-5a	Added “as specified in the Permit Part 5”
Attachment L, Section L-5b	Added “for hazardous constituents”
Attachment L, Section L-5b	Deleted “semi-“
Attachment L, Section L-5b	Replaced “Team Leader” with “Permitees”
Attachment L, Section L-5b	Replaced “Team Leader” with “Permitees”
Attachment L, Section L-5b	Replaced “ASER” with “Annual Culebra Groundwater Report”
Attachment L, Section L-5c	Changed section heading to “Semi-Annual Groundwater Surface Elevation Report “Annual Culebra Groundwater Report”
Attachment L, Section L-5c	Replaced “, and to the EM Manager and NMED in the ASER” with “in the Annual Culebra Groundwater Report”
Attachment L, Section L-5c	Replaced “ASER” with “report”
Attachment L, Section L-5c	Added “DMW and WLMP”
Attachment L, Section L-5c	Changed “Well” to “well”

Affected Permit Section	Explanation of Change
Attachment L, Section L-5c	Deleted “Any”
Attachment L, Section L-5c	Changed “pumping” to “Pumping”
Attachment L, Section L-5c	Added “related to”
Attachment L, Section L-5c	Deleted “activities”
Attachment L, Section L-5c	Added “that may have taken place since the last annual groundwater report”
Attachment L, Section L-5c	Added “ • A discussion of the origins of abnormal unexpected changes in the groundwater surface elevation, which is not attributable to site tests or natural stabilization of the site hydrologic system that exceeds 2 ft in a DMP well over the course of the period covered by the Annual Culebra Groundwater Report (this may indicate changes in recharge/discharge which would affect the assumptions regarding DMP well placement and constitute new information as specified in 20.4.1.900 NMAC (incorporating 40 CFR §270.41(a)(2)). • The results of the annual measurements of densities. • Annotated hydrographs. • Groundwater flow rate and direction. – Potentiometric surface map generated using the following steps: – Examine hydrographs to identify month having the largest number of Culebra water levels available with the fewest wells affected by pumping or other anthropogenic events. – Convert water levels from subject month to equivalent freshwater heads using fluid densities appropriate to the date. – Fit trend surface through freshwater heads. – Extrapolate the trend surface to the boundaries of the model domain used for the current Performance Assessment Baseline Calculations (PABC) and define initial fixed-head boundary conditions based on the trend surface. – Using the ensemble-average Culebra transmissivity field used for the current PABC, optimize the model boundary heads to improve the fit of the model to the freshwater heads at the wells using optimization software interactively with MODFLOW. – Run MODFLOW with optimal boundary conditions fit. – Contour MODFLOW head results on WIPP site. – Compute particle path and travel time from the Waste Handling Shaft to the LWA Boundary. – Data analysis that will accompany the potentiometric surface map will include: • Measured versus modeled scatter plot diagram • Frequency of modeled head residuals • Modeled residual freshwater head at each well • Explanations for modeled misfit residuals greater than 16.4 feet (5 meters). • Semi-annual groundwater surface elevation results will be reported as specified in Permit Part 5, Condition 5.10.2.2.”
Attachment L, Section L-5c	Deleted “● Radionuclide specific data collected during the previous year.”
Attachment L, Section L-5c	Replaced “ASER” with “Annual Culebra Groundwater Report”
Attachment L, Section L-5c	Added “facility”

Affected Permit Section	Explanation of Change
Attachment L, Section L-5c	Changed “operating record” to “Operating Record”
Attachment L, Section L-6	Replaced “ground-water surface elevation” with “water level”
Attachment L, Section L-6	Deleted “events”
Attachment L, Section L-6	Replaced “the form” with “either”
Attachment L, Section L-6	Replaced “in the EM section” with “at the Permittees facility or the Operating Record”
Attachment L, Section L-6	Replaced “records” with “files”
Attachment L, Section L-6	Added “”S” to “SAP”
Attachment L, Section L-6	Added “● Field Data Entry Sheets”
Attachment L, Section L-6	Deleted “● STLBs”
Attachment L, Section L-6	Added “CofC/”
Attachment L, Section L-6	Deleted “and CofC”
Attachment L, Section L-6	Deleted “s” on “forms”
Attachment L, Section L-6	Deleted “Contract”
Attachment L, Section L-6	Replaced “These and all raw analytical records generated in conjunction with ground-water sampling” with “Detection Monitoring Program monitoring, testing, and analytical data”
Attachment L, Section L-6	Replaced “ground-water surface elevation monitoring” with “WLMP data”
Attachment L, Section L-6	Replaced “stored in fire resistant cabinets” with “maintained in the WIPP facility Operating Record.”
Attachment L, Section L-6	Deleted “in the EM section according to the Records Inventory and Disposition Schedule (**RIDS**) and will be made available for inspection upon request. The following records will be transmitted to the Permittees’ Project Records Services (**PRS**) for long-term storage in accordance with the RIDS: • Instrument maintenance and calibration records • QC sample data • Control charts and calculation • Sample tracking and control documentation • Raw analytical results.”
Attachment L, Section L-7	Deleted section
Attachment L, Section L-7a	Deleted section
Attachment L, Section L-7b	Deleted section
Attachment L, Section L-7c	Deleted section
Attachment L, Section L-7d	Deleted section
Attachment L, Section L-7e	Deleted section
Attachment L, Section L-7f	Deleted section
Attachment L, Section L-8	Renumbered section from “L-8” to “L-7”
Attachment L, Section L-8	Deleted “Specific”
Attachment L, Section L-8	Deleted “requirements for WIPP are defined in WIPP document WP 13-1. A current revision of this document will be maintained in the WIPP Operating Record.”

Affected Permit Section	Explanation of Change
Attachment L, Section L-8	Changed “Requirements” to “requirements”
Attachment L, Section L-8a	Renumbered section from “L-8a” to “L-7a”
Attachment L, Section L-8a	Replaced “QA Program—Overview” with “Data Quality Objectives and Quality Assurance Objectives” in section heading
Attachment L, Section L-8a	Deleted “The QA program was developed to assure that integrity and quality will be maintained for all samples collected and that equipment and records will be maintained in accordance with EPA guidance. The QA Program identifies data quality objectives (**DQO**), processes for assuring sample quality, and processes for generating and maintaining quality records.”
Attachment L, Section L-8b	Renumbered section from “L-8b” to “L-7a(1)”
Attachment L, Section L-8b	Changed “DQOs” to “Data Quality Objectives” in section heading
Attachment L, Section L-8b	Added “Data Quality Objectives”
Attachment L, Section L-8b	Added parentheses around “DQOs”
Attachment L, Section L-8b	Replaced “will be” with “have been”
Attachment L, Section L-8b	Added “s” to “DQO”
Attachment L, Section L-8b	Added “DMP are shown in the following sections.”
Attachment L, Section L-8b	Deleted “project will be to collect accurate and defensible data of known quality that will be sufficient to assess the concentrations of constituents in the ground water underlying the WIPP area. The data generated thus far by the DMP has been used to establish background ground-water quality. For the purpose of this DMP, DQOs for measurement data will be specified in terms of accuracy, precision, completeness, representativeness, and comparability. Measurements of data quality in terms of accuracy and precision will be derived from the analysis of QC samples generated in the field and laboratory. Appropriate QC procedures will be used so that known and acceptable levels of accuracy and precision will be maintained for each data set. This section defines the acceptance criteria for each QC analysis performed. The following subsections define each DQO.”
Attachment L, Section L-8b	Added new sections “L-7a(1)(i) Detection Monitoring Program Collect accurate and defensible data of known quality that will be sufficient to assess the concentrations of constituents in the ground water underlying the WIPP facility. L-7a(1)(ii) Water Level Monitoring Program Collect accurate and defensible data of known quality that will be sufficient to assess the groundwater flow direction and rate at the WIPP facility. L-7a(2) Quality Assurance Objectives Quality Assurance Objectives (QAOs) for measurement data have been specified in terms of accuracy, precision, completeness, representativeness, and comparability.”
Attachment L, Section L-8b(1)	Renumbered section from “L-8a(1)” to “L-7a(2)(i)”
Attachment L, Section L-8b(1)	Replaced “samples” with “recoveries”
Attachment L, Section L-8b(1)(i)	Renumbered section from “L-8b(1)(i)” to “L-7a(2)(i)(A)”
Attachment L, Section L-8b(1)(i)	Added “specific conductance and” Added parentheses around “SC”
Attachment L, Section L-8b(1)(i)	Replaced “Eh” with “specific conductance”

Affected Permit Section	Explanation of Change
Attachment L, Section L-8b(1)(i)	Added “specific gravity”
Attachment L, Section L-8b(1)(i)	Deleted “check”
Attachment L, Section L-8b(1)(i)	Replaced “assure” with “ensure”
Attachment L, Section L-8b(1)(i)	Replaced “Procedure WP 10-AD3029” with “facility SOPs”
Attachment L, Section L-8b(1)(i)	Delete “s”
Attachment L, Section L-8b(1)(i)	Deleted “A current revision of this document or procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8b(1)(ii)	Renumbered section from “L-8b(1)(ii)” to “L-7a(2)(i)(B)”
Attachment L, Section L-8b(1)(ii)	Replaced “samples” with “recoveries”
Attachment L, Section L-8b(2)	Renumbered section from “L-8b(2)” to “L-7a(2)(ii)”
Attachment L, Section L-8b(2)(i)	Renumbered section from “L-8b(2)(i)” to “L-7a(2)(ii)(A)”
Attachment L, Section L-8b(2)(i)	Deleted “Precision of field measurements of water-quality parameters will meet or exceed required reporting levels.”
Attachment L, Section L-8b(2)(i)	Added “Specific conductance”
Attachment L, Section L-8b(2)(i)	Deleted “SC”
Attachment L, Section L-8b(2)(i)	Deleted “optionally Eh”
Attachment L, Section L-8b(2)(i)	Added “,” after “10%”
Attachment L, Section L-8b(2)(i)	Replaced “and” with “specific gravity to 0.01 by hydrometer,”
Attachment L, Section L-8b(2)(i)	Added “and SC”
Attachment L, Section L-8b(2)(i)	Added “Water-level measurement will be precise to ±0.01 ft. The precision of water density measurements, when measured in the field using down hole instrumentation, will be determined on a well-by-well basis and will result in no more than ±2 ft of error in the derived fresh-water head.”
Attachment L, Section L-8b(2)(ii)	Renumbered section from “L-8b(2)(ii)” to “L-7a(2)(ii)(B)”
Attachment L, Section L-8b(2)(ii)	Replaced “Precision of laboratory analyses will be assessed by performing the same analyses twice on LCSs with each analytical batch assessed at a minimum frequency of 1 in 20 ground-water samples for nonradiological parameters and 1 in 10 for radiological parameters. The laboratory will determine analytical precision control limits by performing replicate analyses of control samples. Precision measurements will be expressed as RPD.” with “Precision of laboratory analyses will be determined by analyzing a LCS and a lab control sample duplicate (LCSD) or by analyzing one of the field samples in duplicate depending on the requirements of the particular standard method. The precision is measured as the RPD of the recoveries for the spiked LCS/LCSD pair or the RPD of the duplicate sample analysis results.”
Attachment L, Section L-8b(3)	Renumbered section from “L-8b(3)” to “L-7a(2)(iii)”
Attachment L, Section L-8b(3)	Replaced “1991” with “1999”
Attachment L, Section L-8b(3)	Added “National”
Attachment L, Section L-8b(3)	Replaced “1988” with “2004”
Attachment L, Section L-8b(3)	Added “method”
Attachment L, Section L-8b(3)	Added “method”
Attachment L, Section L-8b(4)	Renumbered section from “L-8b(4)” to “L-7a(2)(iv)”
Attachment L, Section L-8b(4)	Added “during sample shipment or”

Affected Permit Section	Explanation of Change
Attachment L, Section L-8b(4)	Replaced “noncritical measurements (i.e., field measurements)” with “analysis of Part 5, Table 5.4.a parameters”
Attachment L, Section L-8b(4)	Replaced “for critical measurements (i.e., compliance data)” with “analysis of Part 5, Table 5.4.b hazardous constituents”
Attachment L, Section L-8b(4)	Added “for Part 5, Table 5.4.b hazardous constituents”
Attachment L, Section L-8b(4)	Replaced “WIPP EM Manager” with “Permittees”
Attachment L, Section L-8b(4)	Deleted “on behalf of the Permittees”
Attachment L, Section L-8b(5)	Renumbered section from “L-8b(5)” to “L-7a(2)(v)”
Attachment L, Section L-8b(5)	Added “For water levels and density, representativeness is a qualitative term that describes the extent to which a sampling design adequately reflects the environmental conditions of a site. The SOPs for measurement ensure that samples are representative of site conditions.”
Attachment L, Section L-8b(6)	Renumbered section from “L-8b(6)” to “L-7a(2)(vi)”
Attachment L, Section L-8b(6)	Added “and semivolatile organic compounds (**SVOC**s)”
Attachment L, Section L-8b(6)	Added “Culebra”
Attachment L, Section L-8b(6)	Changed “Ground-water” to “groundwater”
Attachment L, Section L-8c	Renumbered section from “L-8c” to “L-7b”
Attachment L, Section L-8c	Replaced “ground-water monitoring system was” with “approved”
Attachment L, Section L-8c	Deleted “ed” from “designed”
Attachment L, Section L-8c	Replaced “and will be maintained to meet specifications established in” with “for the DMP is specified in this Permit. Modifications to the DMP will be processed in accordance with”
Attachment L, Section L-8c	Replaced “500” with “900”
Attachment L, Section L-8c	Deleted “§”
Attachment L, Section L-8c	Replaced “264 Subpart F and 264.601 through 264.603”with “270.42”
Attachment L, Section L-8d	Renumbered section from “L-8d” to “L-7c”
Attachment L, Section L-8d	Deleted “Provisions and responsibilities for”
Attachment L, Section L-8d	Change “the” to “The”
Attachment L, Section L-8d	Added “the”
Attachment L, Section L-8d	Added “facility”
Attachment L, Section L-8d	Added “(see Table L-3)”
Attachment L, Section L-8d	Deleted “Any”
Attachment L, Section L-8d	Changed “activities” to “Activities”
Attachment L, Section L-8d	Replaced “ground-water monitoring” with “the DMP”
Attachment L, Section L-8d	Added “data quality”
Attachment L, Section L-8d	Deleted “documented and”
Attachment L, Section L-8d	Deleted “and the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264 Subpart F) Technical procedures, as specified elsewhere in this DMP, have been developed for each quality-affecting function performed for ground-water monitoring. The technical procedures unique to the DMP will be controlled by

Affected Permit Section	Explanation of Change
	the ES&H at WIPP. The procedures are sufficiently detailed and include, when applicable, quantitative or qualitative acceptance criteria. Procedures were prepared in accordance with requirements in WIPP document WP 13-1. A current revision of this document will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8e	Renumbered section from “L-8e” to “L-7d”
Attachment L, Section L-8e	Replaced “Document controls” with “Permittees”
Attachment L, Section L-8e	Replaced “procedures” with “WIPP facility SOPs”
Attachment L, Section L-8e	Added “adequately identified or”
Attachment L, Section L-8f	Deleted section
Attachment L, Section L-8g	Renumbered section from “L-8g” to “L-7e”
Attachment L, Section L-8g	Added “(see Table L-3)”
Attachment L, Section L-8g	Replaced “QA Department” with “Permittees”
Attachment L, Section L-8g	Added “WIPP facility SOPs.”
Attachment L, Section L-8g	Deleted “inspections and surveillance on the scope of work. EM section personnel will be responsible for performance checks as defined in applicable procedures and determined for the Permittees by MOC metrology laboratory personnel. Performance checks for the DMP will determine the acceptability of purchased items and assess degradation that occurs during use. A current revision of this document will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8h	Renumbered section from “L-8h” to “L-7f”
Attachment L, Section L-8h	Added “(see Table L-3)”
Attachment L, Section L-8h	Added “equipment”
Attachment L, Section L-8h	Replaced “Procedure WP 10-AD3029” with “facility SOPs (see Table L-3)”
Attachment L, Section L-8h	Deleted “A current revision of this document or procedure will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8i	Renumbered section from “L-8i” to “L-7g”
Attachment L, Section L-8i	Replaced “WIPP document” with “In accordance with”
Attachment L, Section L-8i	Deleted “specifies the system used at WIPP for ensuring that appropriate measures are established to control nonconforming conditions. Nonconforming conditions connected to the DMP will be identified in and controlled by documented procedures.” with “(see Table L-3),
Attachment L, Section L-8i	Changed “Equipment” to “equipment”
Attachment L, Section L-8i	Deleted “A current revision of this document will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8j	Renumbered section from “L-8j” to “L-7h”
Attachment L, Section L-8j	Added “the” Added “facility”
Attachment L, Section L-8j	Added “(see Table L-3)”
Attachment L, Section L-8j	Added “the” Added “facility”
Attachment L, Section L-8j	Deleted “A current revision of this document will be maintained in the WIPP Operating Record.”

Affected Permit Section	Explanation of Change
Attachment L, Section L-8k	Renumbered section from “L-8k” to “L-7i”
Attachment L, Section L-8k	Added “(see Table L-3)”
Attachment L, Section L-8k	Deleted “A current revision of this document will be maintained in the WIPP Operating Record.”
Attachment L, Section L-8k	Added “record”
Attachment L, Section L-8k	Replaced “EM RIDS” with “Environmental Monitoring Records Inventory and Disposition Schedule”
Attachment L, Section L-8k	Deleted “QA records will document the results of the DMP implementing procedures and will be sufficient to demonstrate that all quality-related aspects are valid. The records will be identifiable, legible, and retrievable.”
Attachment L, Section L-9	Renumbered section from “L-9” to “L-8”
Attachment L, Section L-9	Added “Crawley, M. and M. Nagy, 1998. “WIPP RCRA Background Groundwater Quality Baseline Report,” DOE/WIPP-98-2285.”
Attachment L, Section L-9	Added “Domski, P.S., and R.L. Beauheim. 2008. Evaluation of Culebra Brine Chemistry. AP-125. ERMS 549336. Carlsbad, NM: Sandia National Laboratories.(In development)
Attachment L, Section L-9	Deleted “Gilbert, R.O., 1987. Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, New York. Haug, A., V.A. Kelly, A.M. LaVenue, and J.F. Pickens, 1987. “Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report,” SAND86-7167, Sandia National Laboratories/New Mexico, Albuquerque, New Mexico.”
Attachment L, Section L-9	Added “IT Corporation, “2000 Addendum 1 Waste Isolation Pilot Plant RCRA Background Groundwater Quality Baseline Update Report.” Albuquerque, New Mexico.”
Attachment L, Section L-9	Added “Kuhlman, K.L. 2010. Analysis Report, AP-111 Revision 1, Culebra Water Level Monitoring Network Design. ERMS 554054. Carlsbad, NM: Sandia National Laboratories”
Attachment L, Section L-9	Deleted “Lusczynski, N.J., 1961. “Head and Flow of Ground Water of Variable Density,” Journal of Geophysical Research, Vol. 66, No. 12, pp. 4247–4256.”
Attachment L, Section L-9	Added “McKenna, S. A. 2004. Analysis Report: Culebra Water Level Monitoring Network Design. AP-111. ERMS 540477. Carlsbad, NM: Sandia National Laboratories.”
Attachment L, Section L-9	Deleted “Powers, D.W., S.J. Lambert, S.E. Shaffer, L.R. Hill, and W.D. Weart, eds., 1978. “Geologic Characterization Report for the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico,” SAND78-1596, Sandia National Laboratories/New Mexico, Albuquerque, New Mexico.”
Attachment L, Section L-9	Added “Powers, D. W. 2006. Analysis Report: Task 1B of AP-114; Identify Possible Area of Recharge to the Culebra West and South of WIPP (April 1). ERMS 543094. Carlsbad, NM: Sandia National Laboratories. Roberts, R. M. 2007. Analysis of Culebra Hydraulic Tests Performed Between June 2006 and September 2007. ERMS 547418. Carlsbad, NM: Sandia National Laboratories. Siegel, M.D., K. L. Robinson, and J. Myers. 1991. “Solute Relationships in Groundwaters from the Culebra Dolomite and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico,” SAND88-0196. U.S. Department of Energy (DOE), 1995. “Basic Data Report for WQSP-1 through WQSP-6A,” DOE/WIPP-95-2154.”
Attachment L, Section L-9	Deleted “U.S. Department of Energy (DOE), 1996. “United States Department

Affected Permit Section	Explanation of Change
	of Energy Waste Isolation Pilot Plant Compliance Certification Application," DOE/CAO-1996–2184, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, New Mexico. U.S. Department of Energy (DOE), 1997. Responses to EPA's Request in EPA's March 19, 1997 Letter on the WIPP CCA. May 14, 1997."
Attachment L, Section L-9	Replaced "1992" with "2009"
Attachment L, Section L-9	Replaced "Addendum to Interim Final Guidance" with "Unified Guidance"
Attachment L, Section L-9	Replaced "1991" with "1999"
Attachment L, Section L-9	Deleted "U.S. Environmental Protection Agency (EPA), 1989. "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities," U.S. Environmental Protection Agency, Washington, D.C."
Attachment L, Section L-9	Replaced "1988" with "2004"
Attachment L, Table L-1	Changed "Above" to "above"
Attachment L, Table L-1	Deleted "Coefficient"
Attachment L, Table L-1	Deleted "Specific capacity 0.029 to 0.04 ℓ/s/m"
Attachment L, Table L-1	Deleted Transmissivity and Permeability columns
Attachment L, Table L-1	Replaced "Unnamed lower member" with "Los Medaños"
Attachment L, Table L-1	Delete footnotes "3 and 4"
Attachment L, Table L-2	Changed "DMP monitoring wells" to "DMWs"
Attachment L, Table L-2	Changed "Semiannually" to "Annually"
Attachment L, Table L-2	Deleted "All other WIPP surveillance wells"
Attachment L, Table L-2	Deleted "On special request only"
Attachment L, Table L-2	Changed "DMP monitoring wells" to "DMWs"
Attachment L, Table L-2	Replaced "All other WIPP surveillance well sites" with "WLMP Wells (see Table L-4)"
Attachment L, Table L-2	Deleted "Redundant wells at all other WIPP surveillance well sites"
Attachment L, Table L-2	Deleted "Quarterly"
Attachment L, Table L-3	Deleted table
Attachment L, Tables	Inserted new Table L-3
Attachment L, Tables	Inserted new Table L-4
Attachment L, Tables	Inserted new Table L-5
Attachment L, Table L-4	Renumbered from "Table L-4" to "Table L-6"
Attachment L, Table L-4	Added "Note: Deviations from this table are allowed with prior approval by the NMED" to table
Attachment L, Table L-4	Deleted "TOX 3 250 ml Glass yes No H_2SO_4, pH<2 7 days^2" in row 1 of the table data
Attachment L, Table L-4	Added ")" after "(Total" in row 10 of the table data
Attachment L, Figure L-2	Updated figure
Attachment L, Figure L-3	Updated figure
Attachment L, Figure L-4	Updated figure

Affected Permit Section	Explanation of Change
Attachment L, Figure L-5	Deleted figure
Attachment L, Figures	Inserted new Figure L-5
Attachment L, Figure L-6	Deleted figure
Attachment L, Figure L-7	Deleted figure
Attachment L, Figure L-8	Renumbered figure from “L-8” to “L-6” and updated figure
Attachment L, Figure L-8	Replaced “WQSP” with “Detection”
Attachment L, Figure L-8	Added “ing” to “Monitor” in figure caption
Attachment L, Figure L-9	Deleted figure
Attachment L, Figure L-10	Renumbered figure from “L-10” to “L-7” and updated figure
Attachment L, Figure L-11	Renumbered figure from “L-11” to “L-8” and updated figure
Attachment L, Figure L-12	Renumbered figure from “L-12” to “L-9” and updated figure
Attachment L, Figure L-13	Renumbered figure from “L-13” to “L-10” and updated figure
Attachment L, Figure L-14	Renumbered figure from “L-14” to “L-11” and updated figure
Attachment L, Figure L-15	Renumbered figure from “L-15” to “L-12” and updated figure
Attachment L, Figure L-16	Deleted figure
Attachment L, Figure L-17a	Renumbered figure from “L-17a” to “L-13” and updated figure
Attachment L, Figure L-17a	Replaced “Record” with “Request for Analysis Form” in figure caption
Attachment L, Figure L-17b	Deleted figure
Attachment L, Figure L-18	Deleted figure
Attachment L, Figures	Inserted new Figure L-14

Attachment B
Proposed Revised Permit Text

5.1. DETECTION MONITORING PROGRAM

This Part specifies the requirements of the Detection Monitoring Program (**DMP**). The DMP shall establish background ~~ground water~~ groundwater quality and monitor indicator parameters and waste constituents that provide a reliable indication of the presence of hazardous constituents in the ~~ground water~~groundwater, as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98).

The DMP consists of six Detection Monitoring Wells (**DMWs**) located hydraulically upgradient and at the downgradient point of compliance of the WIPP Underground Hazardous Waste Disposal Units (**Underground HWDUs**). The DMWs are screened in the Culebra Member of the Rustler Formation.

A DMP is necessary to demonstrate compliance with the environmental performance standard for the Underground HWDUs, as specified in 20.4.1.500 NMAC (incorporating 40 CFR §264.601(a)). This environmental performance standard requires prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents in the ~~ground water~~ groundwater or subsurface environment.

5.3.1. Well Locations

The Permittees shall maintain the DMWs at the locations specified on the map in Figure L-~~8~~6 of Permit Attachment L (WIPP ~~Ground-water~~Groundwater Detection Monitoring Program Plan), as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(a) and §264.98(b)), and as specified in Table 5.3.1 below:

5.3.2. Well Maintenance

The Permittees shall maintain the DMWs specified in Table 5.3.1 and in Permit Attachment L, Section L-3b and Figures L-~~10~~7 through L-~~16~~12, and as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(c) and §264.98(b)).

5.3.3 Well Plugging and Abandoning

The Permittees may propose to plug and abandon a DMW by submitting a permit modification request to the Secretary in compliance with 20.4.1.900 NMAC (incorporating 40 CFR §270.42). The Permittees shall plug and abandon any DMW in a manner which eliminates physical hazards, prevents ~~ground water~~ groundwater contamination, conserves hydrostatic head, and prevents intermixing of subsurface water. The Permittees shall submit a report to the Secretary which summarizes and certifies DMW plugging and abandoning methods within 90 calendar days from the date a DMW is removed from the DMP.

5.4. DETECTION MONITORING PROGRAM PARAMETERS AND CONSTITUENTS

The Permittees shall conduct the DMP at the DMWs as specified in Table 5.3.1 for the indicator parameters listed in Table 5.4.a and the hazardous constituents listed in Table 5.4.b below and as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.98(a)):

Table 5.4.a – Indicator Parameters

pH	Specific conductance
Total organic carbon (**TOC**)	~~Total organic halogen (**TOH**)~~
Total dissolved solids (**TDS**)	Total suspended solids (**TSS**)
~~Density~~ Specific Gravity	Calcium
Magnesium	Potassium
Chloride	~~Iron (Total Fe)~~

5.5. SAMPLING AND ANALYSIS PROCEDURES

Except as provided in Permit Section 5.6, the Permittees shall use the following techniques and procedures to obtain and analyze DMP samples ~~including background ground-water quality samples~~, from the DMWs specified in Table 5.3.1, as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(d) and (e)):

5.5.1. Sample Collection Procedures

The Permittees shall collect one DMP sample and one DMP sample duplicate ~~semi~~annually from each DMW using the procedures specified in Permit Attachment L, Section L-4c, as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.97(g)(2), 264.98(d), and 264.601(a)).

5.6 BACKGROUND ~~GROUND-WATER~~ GROUNDWATER QUALITY

For those hazardous constituents listed in Table 5.4.b, and for all substances listed in 20.4.1.500 NMAC (incorporating 40 CFR §264 Appendix IX), the background ~~ground-water~~ groundwater quality values specified in Table 5.6 are established as specified in 20.4.1.500 NMAC (incorporating 40 CFR §§264.97(g) and 264.98(d)).

Table 5.6 – WQSP Well Background Values

Hazardous Constituent	WQSP-1	WQSP-2	WQSP-3	WQSP-4	WQSP-5	WQSP-6
Chloroform	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
1,2-dichloroethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Carbon tetrachloride	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Chlorobenzene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
1,1-dichloroethylene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
1,1-dichloroethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Methylene chloride	~~3.00~~5.00 µg/L	5.00~~3.00~~ µg/L	5.00~~3.00~~ µg/L	5.00~~3.00~~ µg/L	5.00~~3.00~~ µg/L	5.00~~3.00~~ µg/L
1,1,2,2-tetrachloroethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Toluene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
1,1,1-trichloroethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Cresols	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
1,4-dichlorobenzene	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
1,2-dichlorobenzene	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
trans-1,2-dichloroethylene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
2,4-dinitrophenol	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
2,4-dinitrotoluene	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Hexachloroethane	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Hexachlorobenzene	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Isobutanol	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Methyl ethyl ketone	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Pentachlorophenol	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Pyridine	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Tetrachloroethylene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
1,1,2-Trichloroethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Trichloroethylene	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Trichlorofluoromethane	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Xylenes	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L
Nitrobenzene	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L	5.00 µg/L
Vinyl chloride	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L	1.00 µg/L

Table 5.6 – WQSP Well Background Values						
Hazardous Constituent	**WQSP-1**	**WQSP-2**	**WQSP-3**	**WQSP-4**	**WQSP-5**	**WQSP-6**
Arsenic	0.10 mg/L	0.06 mg/L	0.21 mg/L	0.50 mg/L	0.50 mg/L	0.50 mg/L
Barium	1.00 mg/L	1.00 mg/L	1.00 mg/L	1.00 mg/L	1.00 mg/L	1.00 mg/L
Cadmium	0.20 mg/L	0.50 mg/L	0.50 mg/L	0.50 mg/L	0.05 mg/L	0.05 mg/L
Chromium	0.50 mg/L	0.50 mg/L	2.00 mg/L	2.00 mg/L	0.50 mg/L	0.50 mg/L
Lead	0.11 mg/L	0.17 mg/L	0.80 mg/L	0.53 mg/L	0.05 mg/L	0.15 mg/L
Mercury	.002 mg/L	.002 mg/L	.002 mg/L	.002 mg/L	.002 mg/L	.002 mg/L
Selenium	0.15 mg/L	0.15 mg/L	2.00 mg/L	2.00 mg/L	0.10 mg/L	0.10 mg/L
Silver	0.50 mg/L	0.50 mg/L	0.31 mg/L	0.52 mg/L	0.50 mg/L	0.50 mg/L
Antimony	0.33 mg/L	0.50 mg/L	1.00 mg/L	0.80 mg/L	0.07 mg/L	0.14 mg/L
Beryllium	0.02 mg/L	1.00 mg/L	0.10 mg/L	0.25 mg/L	0.02 mg/L	0.02 mg/L
Nickel	0.50 mg/L	0.50 mg/L	5.00 mg/L	5.00 mg/L	0.10 mg/L	0.50 mg/L
Thallium	1.00 mg/L	1.00 mg/L	5.80 mg/L	1.00 mg/L	0.21 mg/L	0.56 mg/L
Vanadium	0.10 mg/L	0.10 mg/L	5.00 mg/L	5.00 mg/L	2.70 mg/L	0.10 mg/L

5.7. ~~GROUND WATER~~ GROUNDWATER SURFACE ELEVATION DETERMINATION

5.7.1 DMP ~~Ground Water~~ Groundwater Surface Elevation Determination

The Permittees shall determine the ~~ground water~~ groundwater surface elevation at each DMW specified in Table 5.3.1 each time the ~~ground water~~ groundwater is sampled in compliance with Permit Sections 5.5.1 and 5.9.2, using the methods specified in Permit Attachment L, Section L-4c(1), and as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(f)).

5.7.2 Regional ~~Ground Water~~ Groundwater Surface Elevation Determination

The Permittees shall determine the ground-water surface elevation on a monthly basis for each well completed in the Culebra Member of the Rustler Formation in the WIPP ~~Ground Water~~ Groundwater Level Monitoring Program, as specified in Permit Attachment L, Section L-4c(1).

5.8 ~~GROUND WATER~~ GROUNDWATER FLOW DETERMINATION

The Permittees shall determine the ground-water flow rate and direction in the Culebra Member of the Rustler Formation at least annually, as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.98(e)). The Permittees shall use ~~ground water~~ groundwater surface elevation data specified in Permit Section 5.7 to determine ~~ground water~~ groundwater flow.

5.9.3 Data Evaluation

The Permittees shall determine whether there is statistically significant evidence of contamination for any hazardous constituent identified in Table 5.4.b each time the DMWs are sampled as specified in Permit Section 5.9.2. In determining whether statistically significant evidence of contamination exists, the Permittees shall compare the ~~ground water~~ groundwater quality at each DMW specified in Table 5.3.1 to the background ~~ground water~~ groundwater quality determined pursuant to Permit Section 5.6, in compliance with the statistical procedures specified in Permit Section 5.9.1, and as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.98(f)).

5.10.2.1. Data Evaluation Results

The Permittees shall submit to the Secretary the analytical results required by Permit Sections 5.5.1 and 5.9.2, and the results of the statistical analyses required by Permit Section 5.9.3, in the Annual Culebra Groundwater Report by November 30 of each year ~~in compliance with the schedule on Table 5.10.2.1 below, and~~ as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(j)):

~~**Table 5.10.2.1 - Analytical Results Submittal Schedule**~~	
~~**Samples to be collected during the preceding months of:**~~	~~**Results due to the NMED Secretary by:**~~
~~March - May~~	~~120calendar days after final sample is collected~~
~~September - November~~	~~120 calendar days after final sample is collected~~

5.10.2.2. Ground-Water Groundwater Surface Elevation Results

The Permittees shall submit to the Secretary ~~ground-water~~ groundwater surface elevation data specified in Permit Section 5.7. This submittal shall include both ~~ground-water~~groundwater surface elevations calculated from field measurements and fresh-water head elevations calculated as specified in Permit Attachment L, Section L-4c(1). Water level data shall be ~~submitted~~ reported semiannually by May 31 and November 30~~within 30 calendar days after data are collected~~. The November water level data report shall be combined with the Annual Culebra Groundwater Report specified in Permit Part 5.10.2.3.

5.10.2.3. ~~Ground-Water~~ Groundwater Flow ~~and Radionuclide Sampling~~ Results

The Permittees shall submit to the Secretary an evaluation of the ~~ground-water~~groundwater flow data (to include annotated hydrographs) specified in Permit Section 5.8 ~~and the results of radionuclide-specific analysis of groundwaters sampled from the DMWs~~ in the Annual Culebra Groundwater ~~Site Environmental~~ Report ~~by October 1~~ by November 30 of each calendar year.

5.10.3.2 Appendix IX Sampling

The Permittees shall immediately, but no later than one month, sample the ~~ground water~~ groundwater in all DMWs specified in Table 5.3.1 for which there was statistically significant evidence of contamination. The remaining DMWs shall be sampled within two months after statistically significant evidence of contamination is found in any DMW. All DMWs shall be sampled to determine the concentration of all substances identified in 20.4.1.500 NMAC (incorporating 40 CFR §264 Appendix IX), as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.98(g)(2)).

ATTACHMENT L

WIPP ~~GROUND-WATER~~GROUNDWATER DETECTION MONITORING PROGRAM PLAN

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ATTACHMENT L

WIPP ~~GROUND-WATER~~GROUNDWATER DETECTION MONITORING PROGRAM PLAN

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LIST OF ABBREVIATIONS/ACRONYMS/UNITS

~~ASER~~	~~Annual Site Environmental Report~~
~~AR/VR~~	~~Approval/Variation Request~~
Bell Canyon	Bell Canyon Formation
bgs	below ground surface
Castile	Castile Formation
cm	centimeter(s)
Culebra	Culebra Member of the Rustler Formation
CofC/RFA	~~Chain of Custody~~chain of custody/request for analysis
°C	degree(s) Celsius
%C	percent completeness
Dewey Lake	Dewey Lake Redbeds Formation
DI	deionized
DMP	Detection Monitoring Program
DMW	Detection Monitoring Well
DOE	U.S. Department of Energy
DQO	data quality objectives
~~EM~~	~~Environmental Monitoring~~
EPA	U.S. Environmental Protection Agency
~~ES&H~~	~~Environment, Safety, and Health Department~~
~~FEIS~~	~~Final Environmental Impact Statement~~
ft	foot (feet)
ft^2	square foot (square feet)
g/cm^3	gram(s) per cubic centimeter
~~GWSP~~	~~Groundwater Surveillance Program~~
HWDU	hazardous waste disposal unit(s)
km	kilometer(s)
km^2	square kilometer(s)
lb/in.^{2}	pound(s) per square inch
LCS	laboratory control samples
LCSD	lab control sample duplicate
~~LD~~	~~limit of detection~~
Los Medaños	Los Medaños Member of the Rustler Formation
LWA	Land Withdrawal Act
m	meter(s)
M&DC	monitoring and data collection
m^2	square meter(s)
Magenta	Magenta Member of the Rustler
mg/L	milligram(s) per liter
mi	mile(s)

mi^2	square mile(s)
molal	moles per kilogram
MOC	Management and Operating Contractor
MPa	megapascal(s)
mV	millivolt(s)
NIST	National Institute for Standards and Technology
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
~~PRS~~	~~Project Records Services~~
QA	Quality Assurance
QA/QC	quality assurance/quality control
QAO	Quality Assurance Objective
QC	quality control
PABC	Performance Assessment Baseline Calculation
RCRA	Resource Conservation and Recovery Act
~~RFA~~	~~request for analysis~~
~~RIDS~~	~~Records Inventory and Disposition Schedule~~
RPD	relative percent difference
Rustler	Rustler Formation
%R	percent recovery
Salado	Salado Formation
SAP	Sampling and Analysis Plans
SC	specific conductance
SOP	Standard Operating Procedure
~~STLB~~	~~sample tracking logbook~~
TDS	total dissolved solids
TOC	total organic carbon
~~TOX~~	~~total organic halogens~~
TRU	transuranic
TSDF	treatment, storage, and disposal facilities
~~TSS~~	~~total suspended solids~~
UTLV	upper tolerance limit value
VOC	volatile organic compound
WIPP	Waste Isolation Pilot Plant
WLMP	WIPP Groundwater Level Monitoring Program
~~WQSP~~	~~Water Quality Sampling Program~~
µg/L	microgram(s) per liter
µm	micrometers

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ATTACHMENT L

WIPP ~~GROUND-WATER~~GROUNDWATER DETECTION MONITORING PROGRAM PLAN

L-1 Introduction

The Waste Isolation Pilot Plant (**WIPP**) ~~is a geologic repository for the disposal of transuranic (**TRU**) waste~~ facility is subject to regulation under Title 20 of the New Mexico Administrative Code (**NMAC**), Chapter 4, Part 1, Subpart V (20.4.1.500 NMAC). As required by 20.4.500 NMAC (incorporating 40 CFR §264.601), the Permittees shall demonstrate that the environmental performance standards for a miscellaneous unit, which are applied to the hazardous waste disposal units (**HWDUs**) in the underground, will be met. ~~The disposal horizon is located 2,150 feet (ft) (655 meters [m]) below the land surface in the bedded salt of the Salado Formation (hereinafter referred to as the Salado). At WIPP, water-bearing units occur both above and below the disposal horizon. Ground-water monitoring of the uppermost aquifer below the facility is not proposed at WIPP because that water-bearing unit (the Bell Canyon Formation) is not considered a credible pathway for a release from the repository. This is because the repository horizon and water-bearing sandstones of the Bell Canyon Formation are separated by over 2000 ft (610 m) of very low-permeability evaporite sediments (Addendum L1, Amended Renewal Application (DOE, 2009)). No natural credible pathway has been established for contaminant transport to aquifers below the repository horizon, as there is no hydrologic communication between the repository and underlying aquifer. The U.S. Environmental Protection Agency (**EPA**) concluded in 1990 that natural vertical communication does not exist based on their review of numerous studies (EPA, 1990). Furthermore, drilling boreholes for ground-water monitoring through the Salado and the Castile Formation (hereinafter referred to as the Castile) into the Bell Canyon aquifer would compromise the isolation properties of the repository medium.~~

The WIPP facility is located in Eddy County in southeastern New Mexico (Figure L-1), within the Pecos Valley section of the southern Great Plains physiographic province. The facility is 26 miles (mi) (42 kilometers [km]) east of Carlsbad, New Mexico, in an area known as Los Medaños (the dunes). Los Medaños is a relatively flat, sparsely inhabited plateau with little water and limited land uses. ~~Disposal of TRU mixed waste in the WIPP facility is subject to regulation under 20.4.1.500 NMAC. As required by 20.4.1.500 NMAC (incorporating 40 CFR §264.601), the Permittees shall demonstrate that the environmental performance standards for a miscellaneous unit, which are applied to the hazardous waste disposal units (**HWDUs**) in the underground, will be met.~~

The WIPP facility (Figure L-2) consists of 16 sections of Federal land in Township 22 South, Range 31 East. The 16 sections of Federal land were withdrawn from the application of public land laws by the WIPP Land Withdrawal Act (**LWA**), Public Law 102-579. The WIPP LWA transferred the responsibility for the administration of the 16 sections from the Department of Interior, Bureau of Land Management, to the U.S. Department of Energy (**DOE**). This law specified that mining and drilling for purposes other than support of the WIPP project are prohibited within this 16 section area with the exception of Section 31. Oil and gas drilling activities are restricted in Section 31 from the surface down to 6,000 feet.

The WIPP facility includes a mined geologic repository for the disposal of transuranic (**TRU**) waste. The disposal horizon is located 2,150 feet (ft) (655 meters [m]) below the land surface in the bedded salt of the Salado Formation (**Salado**). At the WIPP facility, water-bearing units occur both above and below the disposal horizon. Groundwater monitoring of the uppermost aquifer below the facility is not required because the water-bearing unit (the Bell Canyon Formation (**Bell Canyon**)) is not considered a credible pathway for a release from the repository. This is because the repository horizon and water-bearing sandstones of the Bell Canyon are separated by over 2,000 ft (610 m) of very low-permeability evaporite sediments (Amended Renewal Application Addendum L1 (DOE, 2009)). No natural credible pathway has been established for contaminant transport to water-bearing zones below the repository horizon, as there is no hydrologic communication between the repository and underlying water-bearing zones. The U.S. Environmental Protection Agency (**EPA**) concluded in 1990 that natural vertical communication does not exist based on review of numerous studies (EPA, 1990). Furthermore, drilling boreholes for groundwater monitoring through the Salado and the Castile Formation (**Castile**) into the Bell Canyon would compromise the isolation properties of the repository medium.

~~Ground-water~~Groundwater monitoring at the WIPP facility ~~in the past has focused~~ focuses on the Culebra ~~member~~ Member (**Culebra**) of the Rustler Formation (**Rustler**) ~~(hereinafter referred to as the Culebra)~~ because it represents the most significant hydrologic contaminant migration pathway to the accessible environment. The Culebra is the most significant water-bearing unit lying above the repository. ~~Modeling of ground-water movement in the Culebra, based on the concept of a ground-water basin~~Groundwater movement in the Culebra, using results from the basin-scale groundwater model, is discussed in detail in Amended Renewal Application Addendum L1, Section L1-2a~~, Amended Renewal Application~~ (DOE, 2009).

~~The WIPP site is located in Eddy County in southeastern New Mexico (Figure L-1) within the Pecos Valley section of the southern Great Plains physiographic province (Powers et al., 1978). The site is 26 miles (mi) (42 kilometers [km]) east of Carlsbad, New Mexico in an area known as Los Medaños (the dunes). Los Medaños is a relatively flat, sparsely inhabited plateau with little water and limited land uses.~~

~~The WIPP site (Figure L-2) consists of 16 sections of Federal land in Township 22 South, Range 31 East. The 16 sections of Federal land were withdrawn from the application of public land laws by the WIPP Land Withdrawal Act (**LWA**), Public Law 102-579. The WIPP LWA transferred the responsibility for the administration of the 16 sections from the Department of Interior, Bureau of Land Management, to the U.S. Department of Energy (**DOE**). This law specified that mining and drilling for purposes other than support of the WIPP project are prohibited within this 16 section area with the exception of Section 31. Oil and gas drilling activities are restricted in Section 31 from the surface down to 6,000 feet.~~

This monitoring plan addresses requirements for sample collection, Culebra ~~ground-water~~groundwater surface elevation monitoring, Culebra ~~ground-water~~groundwater flow direction and rate determination, data management, and reporting of Culebra ~~ground-water~~groundwater monitoring data. It also identifies indicator ~~analytical~~ parameters and hazardous constituents selected to assess Culebra ~~ground-water~~groundwater quality~~, and establishes personnel responsibilities~~ for the WIPP ~~ground-water~~groundwater detection monitoring program (**DMP**). Because quality assurance is an integral component of the ~~ground-water~~groundwater sampling, analysis, and reporting process, quality assurance/quality control (**QA/QC**) elements and associated data acceptance criteria are included in this plan.

Instructions for performing field activities that will be conducted in conjunction with this DMP ~~sampling and analysis plan~~ are provided in the WIPP Standard Operating Procedures (**SOPs**) (see Table L-3), which are maintained in facility files and which comply with the applicable requirements of 20.4.1.500 NMAC (incorporating 40 CFR § 264.97 (d)). ~~field operating procedures, referenced throughout this plan.~~ Procedures are required for each aspect of the Culebra ~~ground-water~~groundwater sampling process, including Culebra ~~ground-water~~groundwater surface elevation measurement, Culebra ~~ground-water~~groundwater flow direction and rate determination, sampling equipment installation and operation, field water-quality measurements, and sample collection. ~~These procedures prescribe proper field sampling techniques.~~ Data required by this plan ~~Samples~~ will be collected by ~~trained~~ qualified personnel in accordance with SOPs (Table L-3). ~~under the supervision and direction of qualified engineers, scientists, or other technical personnel.~~

L-1a Geologic and Hydrologic Characteristics

L-1a(1) Geology

The WIPP ~~site~~ facility is situated within the Delaware Basin bounded to the north and east by the Capitan Reef, which is part of the larger Permian Basin, located in the south-central region of North America. ~~During the Permian period, which came to a close about 245 million years ago, ancient seas covered the basin. Their later evaporation resulted in the deposition of a thick sequence of evaporites. Addendum L1, Section L1-1 of the Amended Renewal Application (DOE, 2009) presents a detailed discussion of the regional geologic history.~~ Three major evaporite-bearing formations were deposited in the Delaware Basin (see Figures L-3 and L-4 and Amended Renewal Application Addendum L1, Section L1-1 (DOE, 2009) for more detail):

- The Castile~~, which formed through evaporation of the Permian Sea,~~ consists of interbedded anhydrites and halite. Its upper boundary is at a depth of about 2,825 ft (861 m) below ground surface (**bgs**), and its thickness at the WIPP facility is 1,250 ft (381 m).

- The repository is located in the Salado, which overlies the Castile and resulted from prolonged desiccation that produced predominantly halite, with some carbonates, anhydrites, and clay seams. Its upper boundary is at a depth of about 850 ft (259 m) bgs, and it is about 2,000 ft (610 m) thick in the repository area.

- The Rustler Formation ~~(hereinafter referred to as the Rustler)~~ was deposited in a lagoonal environment during a major freshening of the basin and consists of carbonates, anhydrites, and halites. Its beds consist of clay and anhydrite and contain small amounts of brine. The Rustler~~’s~~ upper boundary is about 500 ft (152 m) bgs, and it ranges up to 350 ft (107 m) in thickness in the repository area.

These evaporite-bearing formations lie between two other formations significant to the geology and hydrology of the WIPP ~~site~~facility. The Dewey Lake Redbeds Formation (**Dewey Lake**) overlying the Rustler is dominated by nonmarine sediments and consists almost entirely of mudstone, claystone, siltstone, and interbedded sandstone (see Amended Renewal Application Addendum L1, Section L1-1c(6) ~~of the Amended Renewal Application~~ (DOE, 2009)). This formation forms a 500-ft- (152-m) thick barrier of fine-grained sediments that retard the downward percolation of water into the evaporite units below.[1] The Bell Canyon ~~Formation~~

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[1] ~~While there may be some uncertainty over the amount of vertical recharge occurring within the Rustler, the issue is only of significance to long-term performance calculations in which releases from the repository occur through the creation of a migration pathway resulting from drilling (inadvertently) in the WIPP area. The consequences of vertical recharge are bounded in the modeling~~

~~(hereinafter referred to as the Bell Canyon)—~~ is the first water-bearing unit below the repository (see Amended Renewal Application Addendum L1, Section L1-1c(2) ~~of the Amended Renewal Application~~ (DOE, 2009))~~—~~ and is confined above by the thick evaporite ~~sequences~~ deposits of the Castile~~ above~~. It consists of 1,200 ft (366 m) of interbedded sandstone, shale, and siltstone.

The Salado was selected to host the WIPP repository for several reasons. First, it is regionally extensive, underlying an area of more than 36,000 square mi (mi^2) (93,240 square kilometers [km^2]). Second, its permeability is extremely low. Third, salt behaves mechanically in a plastic manner under pressure (the lithostatic pressure at the disposal horizon is approximately 2,200 ~~more than 2,000~~ pounds per square inch [lb/in.^{2}] or ~~13.8~~14.9 megapascals [MPa]) and eventually ~~moves~~ deforms to fill any opening (referred to as creep). Fourth, any fluid remaining in small fractures or openings is saturated with salt, is incapable of further salt dissolution, and has probably remained in place ~~for millions of years~~since deposition. Finally, the Salado lies between the Rustler and the Castile (Figure L-4~~5~~), which contain very low permeability layers that help confine and isolate waste within and keep water outside of the WIPP repository (see Amended Renewal Application Addendum L1, Section L1-1c(5) and L1-1c(3) ~~of the Amended Renewal Application~~ (DOE, 2009)).

L-1a(2) ~~Ground-water~~Groundwater Hydrology

The general hydrogeology of the area surrounding the WIPP facility is described in this section starting with the first geologic unit below the Salado. Addendum L1, Section L1-2a of the Amended Renewal Application (DOE, 2009) provides more detailed discussions of the local and regional hydrogeology. Relevant hydrological parameters for the various rock units above the Salado at WIPP are summarized in Table L-1.

L-1a(2)(i) The Castile

The Castile is a basin-filling evaporite sequence of sediments surrounded by the Capitan Reef. The Castile represents a major regional ~~ground-water~~groundwater aquitard that effectively prevents upward migration of water from the underlying Bell Canyon. Fluid present in the Castile is very restricted because evaporites do not readily maintain pore space, solution channels, or open fractures at depth. Drill-stem tests conducted in the Castile during construction of the WIPP facility ~~found~~ determined its permeability to be lower than detection limits; however, the hydraulic conductivity has been conservatively estimated to be less than 10^{-8} ft (3×10^{-9} m) per day. A description of the Castile brine reservoirs outside the WIPP facility area is provided in Addendum L1, Section L1-2a(2)(b) of the Amended Renewal Application (DOE, 2009).

L-1a(2)(ii) The Salado

The Salado is an evaporite sequence that filled the remainder of the Delaware Basin and lapped extensively over the Capitan Reef and the back-reef sediments beyond. The Salado consists of approximately 2,000 ft (610 m) of bedded halite, with interbeds or seams of anhydrite, clay, and polyhalite. It acts hydrologically as a regional confining bed. The porosity of the Salado is very low and naturally interconnected pores are probably nonexistent in halite at the depth of the disposal horizon. Fluids associated with the Salado occur mainly as very small fluid inclusions in

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~~by assuming that under future climate conditions (which are assumed to be cooler and wetter), the ground-water surface elevation (water table) raises near ground surface, at which time the water table tends to mimic topography.~~

the halite crystals and also occur between crystal boundaries (interstitial fluid) of the massive crystalline salt formation; fluids also occur in clay seams and anhydrite beds. Permeabilities measured from the surface in the area of the WIPP facility range from 0.01 to 25 microdarcies. The most reliable value, 0.3 microdarcy, was obtained from well DOE-2. The results of permeability testing at the disposal horizon are within the range of 0.001 to 0.01 microdarcy. ~~As a comparison, the permeability of the Salado is roughly a thousand times less than that of a lower clay liner required of surface impoundments and landfills, assuming similar thicknesses.~~

L-1a(2)(iii) The Rustler

The Rustler has been the subject of extensive characterization activities because it contains the most transmissive hydrologic units overlying the Salado ~~(specifically, the Culebra Member, hereafter referred to as the Culebra)~~. Within the Rustler, five members have been identified. Of these, the Culebra is the most transmissive and has been the focus of most of the Rustler hydrologic studies.

The Culebra is the first continuous water-bearing zone above the Salado and is up to approximately 30 ft (9 m) thick. Water in the Culebra is usually present in fractures and is confined by overlying gypsum or anhydrite and underlying clay and anhydrite beds. The hydraulic gradient within the Culebra in the area of the WIPP facility is approximately 20 ft per mi (3.8 m per km) and becomes much flatter south and southwest of the site (Figure L-~~6~~5). Culebra transmissivities in the Nash Draw range up to 1,250 square ft (ft^2) (116 square m [m^2]) per day; closer to the WIPP facility, they are as low as 0.007 to 74 ft^2 (0.00065 to 7.0 m^2) per day. ~~The Culebra is hydrologically confined.~~

The two primary types of field tests that are being used to characterize the flow and transport characteristics of the Culebra are hydraulic tests and tracer tests.

The hydraulic tests consist of pump, injection, and slug testing of wells across the study area (see Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)). The most detailed hydraulic test data exist for the WIPP hydropads (e.g., H-19). The hydropads generally comprise a network of three or more wells located within a few tens of meters of each other. Long-term pumping tests have been conducted at hydropads H-3, H-11, and H-19 and at well WIPP-13 (see Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)). These pumping tests provided transient pressure data both at the hydropad and over a much larger area. Tests often included use of automated data-acquisition systems, providing high-resolution (in both space and time) data sets. In addition to long-term pumping tests, slug tests and short-term pumping tests have been conducted at individual wells to provide pressure data that can be used to interpret the transmissivity at that well (see Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)). ~~(Additional short-term pumping tests have been conducted in the Water Quality Sampling Program (**WQSP**) wells (see Addendum L1, Section L1-2a(3)(a)(ii) of the Amended Renewal Application (DOE, 2009)).~~ Detailed cross-hole hydraulic testing has ~~recently~~ been conducted at the H-19 hydropad (see Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)).

~~The hydraulic tests are designed to yield pressure data for estimation of hydrologic characteristics~~ Pressure data are collected during hydraulic tests for estimation of hydrologic characteristics such as transmissivity, permeability, and storativity. The pressure data from long-term pumping tests and the interpreted transmissivity values for individual wells are used ~~for~~

~~input to flow modeling~~in calibration of flow models. Some of the hydraulic test data and interpretations are also important for the interpretation of transport characteristics. For instance, the permeability values interpreted from the hydraulic tests at a given hydropad are needed for interpretations of tracer test data at that hydropad.

There is strong evidence that the permeability of the Culebra varies spatially and varies sufficiently that it cannot be characterized with a uniform value or range over the region of interest to WIPP. The transmissivity of the Culebra varies spatially over ~~six~~ ten orders of magnitude from east to west in the vicinity of WIPP. ~~Over the site, Culebra transmissivity varies over three to four orders of magnitude. Figure D6-30 shows variation in transmissivity in the Culebra in the WIPP region.~~ Transmissivities have been calculated at 1 × $10^{-\cancel{3}7}$ square feet per day (1 × $10^{-\cancel{9}13}$ square meters per second) at well ~~P-18~~SNL-15 east of the WIPP site to 1 × 10^{3} square feet per day (1 × 10^{-3} square meters per second) at well H-7 in Nash Draw (see Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)).

Transmissivity variations in the Culebra are believed to be controlled by the relative abundance of open fractures rather than by primary (that is, depositional) features of the unit (Roberts, 2007). Lateral variations in depositional environments were small within the mapped region, and primary features of the Culebra show little map-scale spatial variability, according to Holt and Powers, 1988. Direct measurements of the density of open fractures are not available from core samples because of incomplete recovery and fracturing during drilling, but observation of the relatively unfractured exposures in the WIPP shafts suggests that the density of open fractures in the Culebra decreases to the east. ~~Qualitative correlations have been noted between transmissivity and several geologic features possibly related to open-fracture density, including (1) the distribution of overburden above the Culebra, (2) the distribution of halite in other members of the Rustler, (3) the dissolution of halite in the upper portion of the Salado, and (4) the distribution of gypsum fillings in fractures in the Culebra.~~

~~Measured matrix porosities of the Culebra vary from 0.03 to 0.30. Fracture porosity values have not been measured directly, but interpreted values from tracer tests at the H-3, H-6, and H-11 hydropads vary from 5 ×~~ ~~10^{-4}~~ ~~to 3 ×~~ ~~10^{-3}~~~~. Data are insufficient to determine whether the average porosity of the matrix and fractures varies significantly on a regional scale.~~

Geochemical and radioisotope characteristics of the Culebra have been studied. There is considerable variation in ~~ground-water~~groundwater geochemistry in the Culebra. The variation has been described in terms of different hydrogeochemical facies that can be mapped in the Culebra. A halite-rich hydrogeochemical facies exists in the region of the WIPP site and to the east, approximately corresponding to the regions in which halite exists in units above and below the Culebra, and in which a large portion of the Culebra fractures are gypsum filled. An anhydrite-rich hydrogeochemical facies exists west and south of the WIPP site, where there is relatively less halite in adjacent strata and where there are fewer gypsum-filled fractures. Radiogenic isotopic signatures suggest that the age of the ~~ground water~~groundwater in the Culebra is on the order of 10,000 years or more (see Amended Renewal Application Addendum L1 ~~of the Amended Renewal Application~~ (DOE, 2009)).

The radiogenic ages of the Culebra ~~ground water~~groundwater and the geochemical differences provide information potentially relevant to the ~~ground-water~~groundwater flow directions and ~~ground-water~~groundwater interaction with other units and are important constraints on conceptual models of ~~ground-water~~groundwater flow. ~~Previous conceptual models of the Culebra (see Addendum L1 of the Amended Renewal Application (DOE, 2009)) have not been~~

~~able to consistently relate the hydrogeochemical facies, radiogenic ages, and flow constraints (that is, transmissivity, boundary conditions, etc.) in the Culebra.~~

~~However, t~~The Permittees have proposed a ~~new~~ conceptualization of ~~ground-water~~groundwater flow that ~~could~~ explains observed geochemical facies and ~~ground-water~~groundwater flow patterns. The ~~new~~ conceptualization, referred to as the basin-scale ~~ground-water~~groundwater ~~basin~~ model, offers a three dimensional approach to treatment of Supra-Salado rock units, and assumes vertical leakage (albeit very slow) between rock units of the Rustler exists (where hydraulic head is present).

Flow in the Culebra is considered transient. ~~This differs from previous interpretations, wherein no-flow was assumed between Rustler units.~~ The model assumes that the ~~ground-water~~groundwater system is dynamic and is responding to the drying of climate that has occurred since the late Pleistocene period. The Permittees assumed that recharge rates during the late Pleistocene period were sufficient to maintain the water table near land surface, but has since dropped significantly. Therefore, the impact of local topography on ~~ground-water~~groundwater flow was greater during wetter periods, with discharge from the Rustler in the vicinity of the WIPP facility to the west toward Nash Draw; flow is currently dominated by more regional topographic effects during drier times, with flow in the Rustler from the vicinity of the WIPP facility towards the Balmorhea-Loving Trough to the south. ~~to a more southerly direction.~~

~~Four hydrogeochemical facies within the Culebra in the WIPP area (DOE, 1997) have been identified:~~

- ~~Zone A - saline (2-3 molal) NaCl brines, Mg/Ca ratio of 1.2 to 2;~~
- ~~Zone B - dilute (<0.1 molal) CaSO4 - rich ground water;~~
- ~~Zone C - variable composition (0.3-1.6 molal); Mg/Ca ratio 0.3 to 1.2; and~~
- ~~Zone D - high salinities (3-7 molal); K/Na weight ratios (0.2).~~

~~Facies A ground-water flow is slow, has not changed over the last 14,000 years, and probably recharged more than 600,000 years ago. Vertical leakage occurs to Facies A, and both lateral and vertical ground-water flow rates are extremely low. Facies B occurs in an area with greater vertical fracturing in the Culebra, and therefore exhibits more vertical infiltration and more rapid lateral flow in the Culebra. Flow in Facies B is currently to the south (it may mix with Facies C water to the southeast) but was more toward the west during wetter climates; vertical infiltration from the Dewey Lake to the Culebra Facies B is assumed by the Permittees to have occurred during wetter climates in an area south of the WIPP site. Facies C water was not diluted to create Facies B water. Facies C occurs "in between" Facies A and B, and ground-water flow entered the Culebra prior to the climate change (to drier conditions) 14,000 years ago. Facies C ground-water flow is to the south at WIPP, where the Permittees theorized that it joins with a small amount of Facies A solute being transported from the east. Ground-water flow rate in Facies C is faster than in A but slower than in B, and the proposed recharge area from the Dewey Lake to the Culebra was to the northeast of the WIPP site. Facies C ground water infiltrated into the Dewey Lake and then interacted with anhydrite and halite along its path to the Culebra, wherein it mixed with smaller amounts of Facies A water. the Permittees concluded that the presence of anhydrite within Rustler units does not preclude slow downward infiltration (DOE, 1997).~~

Using data from 22 wells, Siegel, Robinson, and Myers (1991) originally defined four hydrochemical facies (A, B, C, and D) for Culebra groundwater based primarily on ionic strength and major constituents. With the data now available from 59 wells, Domski and Beauheim

(2008) defined transitional A/C and B/C facies, as well as a new facies E for high-moles per kilogram (molal) Na-Mg Cl brines.

- Zone B - Dilute (ionic strength ≤0.1 molal) $CaSO_4$-rich groundwater, from southern high-transmissivity area. Mg/Ca molar ratio 0.32 to 0.52.
- Zone B/C - Ionic strength 0.18 to 0.29 molal, Mg/Ca molar ratio 0.4 to 0.6.
- Zone C - Variable composition waters, ionic strength 0.3 to 1.0 molal, Mg/Ca molar ratio 0.4 to 1.1.
- Zone A/C - Ionic strength 1.1 to 1.6 molal, Mg/Ca molar ratio 0.5 to 1.2.
- Zone A - Ionic strength >1.66 molal, up to 5.3 molal, Mg/Ca molar ratio 1.2 to 2.4.
- Zone D - Defined based on inferred contamination related to potash refining operations. Ionic strength 3 molal, K/Na weight ratios of ~0.2.
- Zone E - Wells east of the mudstone-halite margins, ionic strength 6.4 to 8.6 molal, Mg/Ca molar ratio 4.1 to 6.6.

The low-ionic-strength (≤0.1 molal) facies B waters contain more sulfate than chloride, and are found southwest and south of the WIPP site within and down the Culebra hydraulic gradient from the southernmost closed catchment basins, mapped by Powers (2006), in the southwest arm of Nash Draw. These waters reflect relatively recent recharge through gypsum karst overlying the Culebra. However, with total dissolved solids (**TDS**) concentrations in excess of 3,000 mg/L, the facies B waters do not represent modern-day precipitation rapidly reaching the Culebra. They must have residence times in the Rustler sulfate units of thousands of years before reaching the Culebra.

The higher-ionic-strength (0.3-1 molal) facies C brines have differing compositions, representing meteoric waters that have dissolved $CaSO_4$, overprinted with mixing and localized processes. Facies A brines (ionic strength 1.6-5.3 molal) are high in NaCl and are clustered along the extent of halite in the middle of the Tamarisk Member of the Rustler Formation. Facies A represents old waters (long flow paths) that have dissolved halite and/or connate brine, or a mixture of the two from facies E. The facies D brines, as identified by Siegel, Robinson, and Myers (1991), are high-ionic-strength solutions found in western Nash Draw with high K/Na ratios representing waters contaminated with effluent from potash refining operations. Similar water is found at shallow depth (<36 ft (11 m)) in the upper Dewey Lake at SNL-1, just south of the Intrepid East tailings pile. The newly defined facies E waters are very high ionic strength (6.4-8.6 molal) NaCl brines with high Mg/Ca ratios. The facies E brines are found east of the WIPP site, where Rustler halite is present above and below the Culebra, and halite cements are present in the Culebra. They represent primitive brines present since deposition of the Culebra and immediately overlying strata.

Previously, the Permittees and others believed the geochemistry of Culebra ~~ground water~~groundwater was inconsistent with flow directions. This was based on the premise that ~~F~~facies C water must transform to facies B water (e.g. become "fresher"), which is inconsistent with the observed flow direction. It is now believed that the observed geochemistry and flow directions can be explained with different recharge areas and Culebra travel paths (Amended Renewal Application Addendum L1 ~~of the Amended Renewal Application~~ (DOE, 2009)).

Head distribution in the Culebra (see Amended Renewal Application Addendum L1 ~~of the Amended Renewal Application~~ (DOE, 2009)) is consistent with basin-scale ~~ground-water~~groundwater ~~basin~~ modeling results indicating that the generalized ~~ground-water~~groundwater flow direction in the Culebra is currently north to south. However, the fractured nature of the Culebra, coupled with variable fluid densities, can cause localized flow patterns to differ from general flow patterns.

~~Ground-water levels in the Culebra in the WIPP region have been measured for several decades. Water-level rises have been observed in the WIPP region and are possibly related to recovery from impacts caused by shaft installation, response to potash effluent discharge, or are unexplained, as discussed below. The extent of water-level rise observed at a particular well depends on several factors, but the proximity of the observation point to the potential cause of the water-level rise appears to be a primary factor.~~

~~In the vicinity of the WIPP site, water-level rises are believed to be caused by recovery from drainage into the shafts. Drainage into shafts has been reduced by a number of grouting programs over the years, most recently in 1993 around the Air Intake Shaft. Northwest of the site, in and near Nash Draw, water levels appear to fluctuate in response to effluent discharge from potash mines. Correlation of water-level fluctuation with potash mine discharge, however, cannot be proven definitively because sufficient data on the timing and volumes of discharge are not available. Water-level rises in the vicinity of the H-9 hydropad, about 6.5 miles south of the site, are thought to be caused by neither WIPP activities nor potash mining discharge. They remain unexplained. The Permittees continue to monitor ground-water levels throughout the region.~~

Groundwater levels in the Culebra in the region around the WIPP facility have been measured in numerous wells. Water-level rises have been observed and are attributed to causes discussed in the Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) (DOE, 2009). The extent of water-level rise observed at a particular well depends on several factors, but the proximity of the observation point to the cause of the water-level change appears to be a primary factor.

Hydrological investigations conducted from 2003 through 2007 provided new information, some of it confirming long-held assumptions and some offering new insight into the hydrological system around the WIPP site. A Culebra monitoring network optimization study was completed by McKenna (2004) and updated by Kuhlman (2010) to identify locations where new Culebra monitoring wells would be of greatest value and to identify wells that could be removed from the network with little loss of information.

As discussed in Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) (DOE, 2009), extensive hydrological testing has been performed in the new wells. This testing has involved both single well tests, which provide information on local transmissivity and heterogeneity, and long-term (19 to 32 days) pumping tests that have created observable responses in wells up to 5.9 mi (9.5 km) away.

Inferences about vertical flow directions in the Culebra have been made from well data collected by the Permittees. Beauheim (1987) reported flow directions towards the Culebra from both the underlying Los Medaños~~unnamed lower member~~ Member (**Los Medaños**) of the Rustler and the overlying Magenta ~~member~~ Member (**Magenta**) of the Rustler (**Magenta**) ~~over~~ across the WIPP site, indicating that the Culebra acts as a drain for the units around it. This is consistent with results of basin-scale ~~ground-water~~groundwater ~~basin~~ modeling. ~~Recent simulations to~~

~~enhance the conceptual understanding of the geohydrology of the Rustler can be found in Corbet and Knupp, 1996.~~

Use of water from the Culebra in the WIPP facility area is quite limited because of its varying yields and high salinity. The Culebra is not used for water supply in the immediate WIPP ~~site~~ facility vicinity. Its nearest use is approximately 7 mi (11 km) southwest of the WIPP facility, where salinity is low enough to allow its use for livestock watering ~~(shown, for example, as Well H-8 in Figure L-7). However, the Permittees identified the Culebra as potential aquifer in the Compliance Certification Application (DOE, 1996). Because of this, the Culebra will be the focus of future ground-water monitoring at WIPP as it is also the most transmissive continuous water-bearing zone at WIPP and is the most likely pathway for contaminant migration~~.

L-2 General Regulatory Requirements

Because geologic repositories such as the WIPP facility are defined under the Resource Conservation and Recovery Act (**RCRA**) as land disposal facilities and as miscellaneous units, the ~~ground-water~~groundwater monitoring requirements of 20.4.1.500 NMAC (incorporating 40 CFR §§264.600 through 264.603) shall be addressed. The requirements of 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101) ~~applies~~ apply to miscellaneous unit treatment, storage, and disposal facilities (**TSDF**) only if ~~ground-water~~groundwater monitoring is needed to satisfy 20.4.1.500 NMAC (incorporating 40 CFR §§264.601 through 264.603) environmental performance standards.

The New Mexico Environment Department (**NMED**) has concluded that ~~ground-water~~groundwater monitoring in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §264 Subpart F) at the WIPP facility is necessary to meet the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §§264.601 through 264.603).

L-3 WIPP ~~Ground-water~~ Detection Monitoring Program (DMP)—Overview

L-3a Scope

~~The Permittees have established a RCRA "Ground-water Detection Monitoring Program (DMP) Plan" to define and protect ground-water resources at WIPP. One of the objectives of the WIPP DMP is to establish, by means of ground-water sampling and analysis, an accurate and representative ground-water database that is scientifically defensible and demonstrates regulatory compliance. In addition, the DMP will be used to determine background or existing conditions of ground-water quality and quantity, including ground-water surface elevation and direction of flow, around the WIPP facility area.~~

This DMP plan governs ~~all ground-water~~groundwater sampling events conducted to meet the applicable requirements of 20.4.1.500 NMAC (incorporating 40 CFR 264~~§§~~ Subpart F ~~264.90 through 264.101~~), and ensures that ~~all~~ such data are gathered in accordance with these and other applicable requirements. ~~The ground-water quality data generated by monitoring activities will provide a comprehensive background database against which future a~~Analytical results collected ~~can be compared~~ during the DMP are compared to the baseline established in this Permit to determine whether or not a release has occurred.

~~Ground-water monitoring at WIPP has been historically conducted by several programs including the WIPP Site Characterization Program, the WIPP WQSP, and recently the WIPP Ground-water Surveillance Program (**GWSP**). Ground-water quality and ground-water surface~~

~~elevation data have been collected by these programs for over 12 years at WIPP. Data from the WQSP wells (which are widely distributed across the area, see Figure L-8) will be used to continually define changes in the area's potentiometric surface and ground-water flow directions. New monitoring wells included in the WIPP GWSP (WQSP wells 1-6a) were constructed to the specifications provided in the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (EPA, 1986) and constitute the RCRA ground-water monitoring network specified in this DMP as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101). These wells are being used to establish background ground-water quality, ground-water surface elevations and flow directions in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §§264.97(f) and (g) and 264.98(e)). Justification for the locations of these wells (3 upgradient and 4 downgradient) is presented below.~~

There are two separate components of the Groundwater Monitoring Program, the Detection Monitoring Program (DMP) and the Water Level Monitoring Program (WLMP). The first component consists of a network of six Detection Monitoring Wells (DMWs). The DMWs (WQSP 1-6) were constructed to be consistent with the specifications provided in the Groundwater Monitoring Technical Enforcement Guidance Document and constitute the RCRA groundwater monitoring network specified in the DMP. The DMWs were used to establish background groundwater quality in accordance with 20.4.1.500 NMAC (incorporating 40 CFR § 264.97 and 264.98 (f)). The second component of the Groundwater Monitoring Program is the WLMP, which is used to determine the groundwater surface elevation and flow direction. Table L-4 is a list of the wells used in the WLMP as of January 1, 2011. The list of wells is subject to change due to plugging and abandonment and drilling of new wells.

L-3b Current WIPP DMP

~~The WQSP wells 1 through 6 constitute the RCRA DMP for WIPP (Figure L-9 and Permit Attachment B, Figure B2-3) during detection monitoring as required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101). This monitoring plan is a continuation of the current WIPP GWSP, and these wells will serve as the monitoring locations during background water-quality characterization and the RCRA DMP (Figure L-9 and Permit Attachment B, Figure B2-3).~~

Wells WQSP-1, WQSP-2, and WQSP-3 ~~were~~ are located directly upgradient (north) of the WIPP shaft area. ~~The locations of the three upgradient wells were selected to be representative of the flow vectors of ground water moving downgradient onto the WIPP site. Figure 34 of Davies, 1989, shows the simulation of direction and magnitude of ground-water flow. The upgradient wells were located based on the flow vectors resulting from this model simulation. The original WQSP observation wells, as well as those in the RCRA DMP, have been and will continue to be used as piezometer wells to support collection of ground-water surface elevation and ground-water flow modeling data to demonstrate regulatory compliance. Well location surveys for each of the seven wells were performed by the Permittees' survey personnel using the State Plane Coordinates-North American Datum Model 27 method. Results of the surveys are on file with the New Mexico State Engineers Department along with the associated extraction permits for each well.~~

WQSP-4, WQSP-5, and WQSP-6 ~~were~~ are located downgradient (south) of the WIPP shaft area ~~in concert with the flow vectors shown by this model simulation~~. All three Culebra downgradient wells (WQSP-4, 5, and 6) were sited to be located generally in the path of contaminants that might be released from the shaft area in the Culebra.~~based on the greatest velocity magnitude of ground-water flow leaving the shaft area as shown on Figure 34 of~~

~~Davies, 1989, and upgradient of the WIPP LWA boundary.~~ Well WQSP-4 was also specifically located to monitor the zone of higher transmissivity~~ around wells DOE-1 and H-11~~, which may represent faster flow path away from the WIPP shaft area to the LWA boundary (Amended Renewal Application Addendum L1, Section L1-2a(3)(a)(ii) ~~of the Amended Renewal Application~~ (DOE, 2009)).

~~The Culebra has been selected for the focus of the DMP due to it being regionally extensive and exhibiting the most significant transmissivity of the water-bearing units at WIPP. The Culebra has been extensively studied during all past hydrologic characterization programs and found to be the most likely hydrologic pathway to the accessible environment or compliance point for any potential contamination.~~

The compliance point is defined in 20.4.1.500 NMAC (incorporating 40 CFR §264.95) as the vertical plane immediately downgradient of the hazardous waste management unit area (i.e., at the downgradient footprint of the WIPP repository). Permit Part 5 specifies the point of compliance as “the vertical surface located at the hydraulically downgradient limit of the Underground HWDUs that extends to the Culebra Member of the Rustler Formation.”~~ The RCRA ground-water monitoring network was not installed immediately downgradient of this plane. However, because the Underground HWDUs at WIPP are Subpart X units, and due to the relatively unique containment and transport aspects of the site, monitoring at the proposed locations will allow for detection of releases prior to release of these contaminants to the general public at the LWA boundary.~~ Wells WQSP-4, 5, and 6 are situated to demonstrate that during the operating life of the facility (including closure), release of contaminants to the general public will not occur.

~~The DMP wells were located to intercept flow vectors downgradient away from the WIPP shafts area based on current density corrected potentiometric surfaces (Figure L-9). Based on natural contours of the potentiometric surface (Figure L-9) the selected well placement locations are downgradient of the general flow direction from the shaft area.~~ Transport modeling suggests ~~of contaminant migration throughout the Culebra to the Land Withdrawal Act boundary suggests~~ that travel times from the Waste Handling Shaft to the LWA boundary could be on the order of thousands of years.~~ if, under worst case conditions,~~ This assumes conditions where hazardous constituents ~~could~~ migrate from the sealed repository (post closure) to the Culebra via the sealed shafts. ~~If contaminants were to migrate from the disposal facility, they would be detected by the DMP wells located midway between the shafts and LWA such that samples from wells could detect these contaminants long before they could reach the LWA boundary.~~

Potentiometric surfaces and ~~ground-water~~groundwater flow directions defined for the Culebra prior to large-scale pumping in the WIPP facility area and the excavation of WIPP shafts suggest~~s~~ that flow was generally to the south-southeast from the waste disposal and shaft areas (Mercer, 1983; Davies, 1989). ~~Recent (December 1996) p~~Potentiometric surface maps of the Culebra adjusted for density differences show very similar characteristics. The wells used for measuring the potentiometric surface of the Culebra are measured monthly and listed in Table L-4. ~~(Figure L-9). WQSP-4, WQSP-5, and WQSP-6 have been located downgradient of the waste emplacement areas according to present-day adjusted potentiometric surfaces.~~

~~Potentiometric surfaces that have not been corrected for density differences and that contain transient relics of previous pumping-drawdown events do not reflect accurate natural ground-water flow directions and should not be used to assess the adequacy of ground-water monitoring locations. Previous potentiometric surface maps showing a potentiometric low and hydrologic gradient toward the area between WQSP-3 and WQSP-4 had not been adjusted to~~

~~freshwater head equivalents, and had also been influenced by the long-term pumping at well H-19. Hence, some historic maps may not represent natural Culebra flow directions or gradients, and appropriateness of the RCRA monitoring network cannot be definitively evaluated using these data.~~

L-3b(1) Detection Monitoring ~~P~~ Well Construction Specification

~~L-3b(1)(i) WQSP-1~~

Diagrams of the six DMP wells are shown in Figures L-7 through L-12. Detailed descriptions of geology and construction methods may be found in DOE 1995.

The six WQSP Culebra wells ~~Well WQSP-1 was~~ were drilled between September 13 and ~~16~~October 26, 1994~~, to a~~. The total depth of ~~737 ft (225 m) bgs~~each well is shown in Table L-5. The ~~borehole was~~wells were drilled through the Culebra and ~~extends 15 ft (5 m)~~ into the ~~unnamed lower member of the Rustler~~Los Medaños as shown in Table L-5. The wells ~~was~~ were drilled to ~~a depth of 693 ft (211 m) bgs using~~the top of the Culebra using compressed air as the drilling fluid~~. The interval from 693 to 737 ft (225 to 211 m) bgs (the total depth) was drilled using air mist with a foaming agent as the drilling fluid. WQSP-1 was drilled to 695.6 ft (212 m) bgs using~~ and a 9⅞-in. drill bit. The wells were then ~~and was~~ cored ~~from 695.6 to 737 ft (212 to 225 m) bgs~~ using a 5¼-in. core bit to cut 4-in.- (0.1-m) diameter core to total depth. See Table L-5 for the drilling and coring intervals for each well. After coring, ~~WQSP-1~~ WQSP wells were ~~was~~ reamed to 9⅞-in. (0.3 m) in diameter to total depth. ~~WQSP-1 was~~After reaming, wells were cased from the surface to ~~737 ft (224.6 m) bgs~~total depth with 5-in. (0.1-m) (0.28-in. [0.7-centimeter (cm)] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval ~~from 702 to 727 ft (214 to 222 m) bgs~~as shown in Table L-5. The annulus between the borehole wall and the casing/screen is packed with sand ~~from 640 to 651 ft (195 to 198 m) bgs~~ and with 8/16 Brady gravel ~~from 651 to 737 ft (198 to 225 m) bgs.~~ as indicated in Table L-5. ~~Based on core log results, the Culebra is located from 699 to 722 ft (213 to 220 m) bgs (see Figure L-10).~~

~~L-3b(1)(ii) WQSP-2~~

~~Well WQSP-2 was drilled between September 6 and 12, 1994, to a total depth of 846 ft (257.9 m) bgs. The borehole was drilled through the Culebra and extends 12.3 ft (3.7 m) into the unnamed lower member of the Rustler. The well was drilled to a depth of 800 ft (244 m) bgs with a 9⅞-in. drill bit using compressed air as the drilling fluid. The interval from 800 to 846 ft (244 to 258 m) bgs (the total depth) was drilled with a 5¼-in. core bit to cut 4-in.- (0.1-m) diameter core using air mist with a foaming agent as the drilling fluid. After coring, WQSP-2 was reamed to 9⅞ in. (0.3 m) in diameter to total depth. WQSP-2 was cased from the surface to 846 ft (258 m) bgs with 5-in. (0.1-m) (0.28-in. [0.7-cm] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval from 811 to 836 ft (247 to 255 m) bgs. The annulus between the borehole wall and the casing/screen is packed with sand from 790 to 793 ft (241 to 242 m) bgs and with 8/16 Brady gravel from 793 to 846 ft (242 to 258 m) bgs. Based on core log results, the Culebra is located from 810.1 to 833.7 ft (247 to 254 m) bgs (see Figure L-11).~~

~~L-3b(1)(iii) WQSP-3~~

~~Well WQSP-3 was drilled between October 21 and 26, 1994, to a total depth of 880 ft (268 m) bgs. The borehole was drilled through the Culebra and extends 10 ft (3.1 m) into the unnamed~~

~~lower member of the Rustler. The well was drilled to a depth of 880 ft (268 m) bgs using compressed air as the drilling fluid. The borehole was cleaned using air mist with a foaming agent. WQSP-3 was drilled to 833 ft (254 m) bgs using a 9⅞-in. drill bit and was cored from 833 to 879 ft (254 to 268 m) bgs using a 5¼-in. core bit to cut 4-in.- (0.1-m) diameter core. After coring, WQSP-3 was reamed to 9⅞ in. (0.3 m) in diameter to total depth of 880 ft (268 m) bgs. WQSP-3 was cased from the surface to 880 ft (268 m) bgs with 5-in. (0.1-m) (0.28-in. [0.7-cm] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval from 844 to 869 ft (257 to 265 m) bgs. The annulus between the borehole wall and the casing/screen is packed with sand from 827 to 830 ft (252 to 253 m) bgs and with 8/16 Brady gravel from 830 to 880 ft (253 to 268 m) bgs. Based on core log results, the Culebra is located from 844 to 870 ft (257 to 265 m) bgs (see Figure L-12).~~

~~L-3b(1)(iv) WQSP-4~~

~~Well WQSP-4 was drilled between October 5 and 10, 1994, to a total depth of 800 ft (244 m) bgs. The borehole was drilled through the Culebra and extends 9.2 ft (2.8 m) into the unnamed lower member of the Rustler. The well was drilled to a depth of 740 ft (226 m) bgs with a 9⅞-in. drill bit using compressed air as the drilling fluid. The interval from 740.5 to 798 ft (225.7 to 243 m) bgs was cored with a 5¼-in. (0.13-m) core bit to cut 4-in.- (0.1-m) diameter core using air mist with a foaming agent as the drilling fluid. After coring, WQSP-4 was reamed to 9⅞ in. (0.3 m) in diameter to total depth of 800 ft (244 m) bgs. WQSP-4 was cased from the surface to 800 ft (244 m) bgs with 5-in. (0.1-m) (0.28-in. [0.7-cm] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval from 764 to 789 ft (233 to 241 m) bgs. The annulus between the borehole wall and the casing/screen is packed with sand from 752 to 755 ft (229 to 230 m) bgs and with 8/16 Brady gravel from 755 to 800 ft (230 to 244 m) bgs. Based on core log results, the Culebra is located from 766 to 790.8 ft (233 to 241 m) bgs (see Figure L-13).~~

~~L-3b(1)(v) WQSP-5~~

~~Well WQSP-5 was drilled between October 12 and 19, 1994, to a total depth of 681 ft (208 m) bgs. The borehole was drilled through the Culebra and extends into the unnamed lower member of the Rustler. The well was drilled to a depth of 676 ft (206 m) bgs using compressed air as the drilling fluid. The borehole was cleaned using air mist with a foaming agent. WQSP-5 was drilled to 648 ft (198 m) bgs using a 9⅞-in. drill bit and was cored from 648 to 676 ft (198 to 206 m) bgs using a 5¼-in. core bit to cut 4-in.- (0.1-m) diameter core. After coring, WQSP-5 was reamed to 9⅞ in. (0.3 m) in diameter to total depth of 681 ft (208 m) bgs. WQSP-5 was cased from the surface to 681 ft (208 m) bgs with 5-in. (0.1-m) (0.28-in. [0.7-cm] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval from 646 to 671 ft (197 to 205 m) bgs. The annulus between the borehole wall and the casing/screen is packed with sand from 623 to 626 ft (190 to 191 m) bgs and with 8/16 Brady gravel from 626 to 681 ft (191 to 208 m) bgs. Based on core log results, the Culebra is located from 648 to 674.4 ft (198 to 205.6 m) bgs (see Figure L-14).~~

~~L-3b(1)(vi) WQSP-6~~

~~Well WQSP-6 was drilled between September 26 and October 3, 1994, to a total depth of 616.6 ft (187.9 m) bgs. The borehole was drilled through the Culebra and extends 9.7 ft (3 m) into the unnamed lower member of the Rustler. The well was drilled to a depth of 367 ft (112 m) bgs using compressed air as the drilling fluid. The interval from 367 to 616 ft (112 to 188 m) bgs (the total depth) was drilled using brine as the drilling fluid. WQSP-6 was drilled to 568 ft (173 m) 4-~~

~~in.- (0.1-m) ft bgs using a 9⅞-in. drill bit and was cored from 568 to 616 ft (173 to 188 m) bgs using a 5¼-in. core bit to cut 4-in.- (0.1-m) diameter core. After coring, WQSP-6 was reamed to 9⅞ in. (0.3 m) in diameter to total depth of 616.6 ft (188 m) bgs. WQSP-6 was cased from the surface to 616.6 ft (188 m) bgs with 5-in. (0.1-m) (0.28-in. [0.7-cm] wall) blank fiberglass casing with in-line 5-in.- (0.1-m) diameter fiberglass 0.02-in. (0.1-cm) slotted screen across the Culebra interval from 581 to 606 ft (177 to 185 m) bgs. The annulus between the borehole wall and the casing/screen is packed with sand from 567 to 570 ft (173 to 173.7 m) bgs and with 8/16 Brady gravel from 570 to 616.6 ft (174 to 188 m) bgs. Based on core log results, the Culebra is located from 582 to 606.9 ft (177 to 185 m) bgs (see Figure L-15).~~

L-4 Monitoring Program Description

The WIPP DMP has been designed to meet the ~~ground-water~~groundwater monitoring requirements of 20.4.1.500 NMAC (incorporating 40 CFR §§264.90 through 264.101). The following sections of the monitoring plan specify the components of the DMP.

L-4a Monitoring Frequency

~~The seven RCRA monitoring wells have been sampled on a semiannual basis since their installation in 1995 to establish background ground-water quality in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98). This has included at least two full rounds of 20.4.1.500 NMAC (Incorporating 40 CFR §264) Appendix IX analysis for samples from each of the proposed RCRA detection monitoring wells. In addition, ground-water samples were collected from the DMP wells (from March 1997 until waste emplacement) at a frequency of four sample replicates collected semiannually from each well for the indicator parameters of pH, specific conductance (**SC**), total organic carbon (**TOC**), and total organic halogen (**TOX**) to further establish background ground-water quality until detection monitoring in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §264.98) becomes applicable. A total of four rounds of Appendix IX analysis will be conducted for samples from each well for use in background ground-water quality determinations.~~

~~Detection monitoring will start when the Permittees emplace waste and continue through the post-closure phase as required by 20.4.1.500 NMAC (incorporating 40 CFR §264.90[c]). During detection monitoring, one sample and one sample duplicate will be collected semiannually from each well in the RCRA detection monitoring network. As shown in Table L-2, the DMP will continue to collect ground-water quality samples for all seven wells on a semiannual basis during the life of the DMP. 20.4.1.500 NMAC (incorporating 40 CFR §264.97[g][2]) provides that an alternate sampling frequency to that provided in 20.4.1.500 NMAC (incorporating 40 CFR §264.98) may be proposed by the Permittees. Given the nature and rate of ground-water flow in the area surrounding WIPP, collecting and analyzing one sample semiannually will be protective of human health and the environment because any hazardous constituent leaving the underground disposal facility will not have the potential to migrate beyond the ground-water monitoring network in a one-year time frame. Ground-water flow characteristics are presented in detail in Addendum L1, Section L1-2a of the Amended Renewal Application (DOE, 2009).~~

~~Ground-water~~Groundwater surface elevations will be monitored in each of the ~~seven~~ six ~~DMP~~ DMWs ~~wells~~ on a monthly basis. The ~~ground-water~~groundwater surface elevation in each ~~DMP~~ DMW ~~well~~ will also be measured prior to each annual sampling event. ~~Ground-water~~Groundwater surface elevation measurements in the ~~other~~ WLMP wells ~~existing WQSP well sites~~ will also be monitored on a monthly basis when accessible ~~to supplement the area water-level database and to help define regional changes in ground-water flow directions and~~

~~gradients~~. The characteristics of the ~~RCRA DMP~~DMW (sampling frequency, location) will be evaluated if significant changes are observed in the ~~ground-water~~groundwater flow direction or gradient. ~~If any change occurs which could affect the ability of the DMP to fulfill the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264 Subpart F), the Permittees shall promptly notify NMED in writing and apply for a permit modification, if appropriate.~~

L-4b Analytical Parameters and Hazardous Constituents

The parameters listed in Part 5, Table 5.4.a and hazardous constituents listed in Part 5, Table 5.4.b ~~analytes of interest~~ are measured ~~to establish~~ as part of the DMP. ~~background ground-water quality prior to emplacement of waste include all indicator parameters and all other parameters listed in 20.4.1.500 NMAC (incorporating 40 CFR §264) Appendix IX. Field measurements of pH, SC, temperature, chloride, Eh, total iron, and alkalinity are also measured during background sampling .~~

~~The DMP was initiated upon waste emplacement, at which time the semiannual samples will be analyzed for the parameters listed in Table L-3. Parameters to be analyzed by the contract laboratory such as specific conductance, total dissolved solids, total suspended solids, density, pH, total organic carbon, and total organic halogens were included as indicator parameters because of their universal commonality to ground water. Parameters such as chloride, alkalinity, calcium, magnesium, and potassium were included as matrix-specific general indicator parameters. Calcium, magnesium, potassium, chloride, and iron may be deleted during detection monitoring, with prior approval of NMED. Organic and inorganic compounds on the right hand side of Table L-3 were chosen because they will occur in the waste to be disposed at the WIPP facility.~~ Additional ~~parameters~~ hazardous constituents may be identified through changes to the list of hazardous waste numbers authorized for disposal at the WIPP facility. ~~the tentatively identified compound (**TIC**) process specified in the Waste Analysis Plan, Permit Attachment C.~~ If ~~compounds~~ hazardous constituents are identified, these will be added to ~~the DMP list~~Part 5, Table 5.4.b, unless the Permittees provide justification for their omission (e.g.,hazardous constituent not in 40 CFR §264 Appendix IX), and this omission is approved by NMED.

L-4c ~~Ground-water~~Groundwater Surface Elevation Measurement, Sample Collection and Laboratory Analysis

~~Ground-water~~Groundwater surface elevations will be measured in each ~~well~~DMW prior to ~~ground-water~~groundwater sample collection. ~~Ground water~~Groundwater will be extracted using serial and final sampling methods. Serial samples will be collected until ~~ground-water~~groundwater field indicator parameters stabilize, after which the final sample for complete analysis will be collected. Final samples will then be analyzed for the ~~DMP analytical suite~~ parameters and constituents in Part 5, Tables 5.4.a and 5.4.b.

L-4c(1) ~~Ground-water~~Groundwater Surface Elevation Monitoring Methodology

The WIPP ~~ground-water~~groundwater level monitoring program (**WLMP**) activities are conducted in accordance with the WIPP facility SOPs listed in Table L-3. ~~is a subprogram of the DMP. The quality assurance activities of the WLMP are in strict accordance with WP 13-1, and the quality assurance implementing procedure specific to ground-water surface elevation monitoring is~~

~~WIPP Procedure WP 02-EM1014~~[2]~~. Current versions of both WP 13-1 and WP 02-EM1014 are maintained in the WIPP Operating Record.~~

~~Ground-water surface elevation monitoring is in progress now and will continue through the post-closure care period specified in Permit Part 7. This section of the plan addresses the activities of the WLMP during the preoperational and operational phases of WIPP.~~

~~Collection of ground-water surface elevation data is required by 20.4.1.500 NMAC (incorporating 40 CFR §264.97(f)). These data also provide:~~

- ~~Data collection as required by the Environmental Monitoring Plan.~~
- ~~A means to fulfill commitments made in the Final Environmental Impact Statement (**FEIS**).~~
- ~~A means to comply with future ground-water inventory and monitoring regulations.~~
- ~~Input for making land use decisions, (i.e., designing long-term active and passive institutional controls for the site).~~
- ~~Assistance in understanding any changes to readings from the water-pressure transducers installed in each of the shafts to monitor water conditions behind the liners.~~
- ~~An understanding of whether or not the horizontal and vertical gradients of flow are changing over time.~~

~~The objective of the WLMP is to extend the documented record of ground-water surface elevation fluctuations in the Culebra and Magenta members of the Rustler in the vicinity of the WIPP facility and to meet the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264.97(f)). Ground-water surface elevation data will be collected from each well of the RCRA DMP. Ground-water surface elevation data will also be collected from other Culebra wells, as well as monitoring wells completed in other water-bearing zones overlying and underlying the WIPP repository horizon (see Figure L-18) when access to those zones is possible. This includes, but is not limited to, the Bell Canyon, the Forty-niner, the contact zone between the Rustler and Salado, and the Dewey Lake.~~

Groundwater surface elevation measurements will be taken monthly at each of the six DMWs and prior to the annual sampling event. Additionally, ~~Ground-water~~groundwater surface elevation measurements will be taken monthly in the other Culebra wells as listed in Table L-4, ~~at least one accessible completed interval at each available well pad~~when accessible. ~~At well pads with two or more wells completed in the same interval, quarterly measurements will be taken in the redundant wells (w~~Well locations are shown in Figure L-~~18~~14~~)~~. ~~Ground-water surface elevation measurements will be taken monthly at each of the seven DMP wells, as well as prior to each sampling event.~~ If a cumulative ~~ground-water~~groundwater surface elevation change of more than 2 feet is detected in any DMP well over the course of one year which is not

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[2] ~~WP 02-EM1014 “Groundwater Level Measurements” is a technical procedure that specifies the steps followed by Environmental Monitoring (**EM**) personnel for making manual ground-water level measurements in ground-water wells in the vicinity of the WIPP facility. The procedure provides general instructions including prerequisites, safety precautions, performance frequency, quality assurance, and records. Specific instructions are included for using the water level measurement electrical conductance probe and data management.~~

attributable to site tests or natural stabilization of the site hydrologic system, the Permittees will notify NMED in writing and discuss the origin of the changes in the ~~report~~ Annual Culebra Groundwater Report specified in Permit Part 5. Abnormal, unexplained changes in ~~ground-water~~groundwater surface elevation ~~may~~ will be evaluated to determine if they indicate changes in site recharge/discharge which could affect the assumptions regarding ~~DMP~~ DMW ~~well~~ placement and constitute new information as specified in 20.4.1.900 NMAC (incorporating 40 CFR §270.41(a)(2)).

~~Ground-water~~Groundwater surface elevation monitoring will continue through the post-closure care period specified in Permit Part 7. The Permittees may temporarily increase the frequency of monitoring to effectively document naturally occurring or artificial perturbations that may be imposed on the hydrologic systems at any point in time. This will be conducted in selected key wells by increasing the frequency of the manual ~~ground-water~~groundwater surface elevation measurements or by monitoring water pressures with the aid of electronic pressure transducers and remote data-logging systems. The Permittees will include such additional data in the reports specified in Section L-5c.

Interpretation of ~~ground-water~~groundwater surface elevation measurements and corresponding fluctuations over time is complicated at the WIPP facility by spatial variation in fluid density ~~both vertically in well bores and areally from well to well~~. To monitor the hydraulic gradients of the hydrologic flow systems ~~at WIPP~~ accurately, actual ~~ground-water~~groundwater surface elevation measurements will be monitored at the frequencies specified in Table L-2, and the Culebra groundwater densities of the fluids in the wells listed in Table L-4 ~~bores~~ will be measured annually. ~~When both of these parameters are known, equivalent freshwater heads will be calculated. The concept of freshwater head is discussed in Lusczynski (1961).~~

~~A discussion explaining the calculation of freshwater heads from mid-formation depth at WIPP can be found in Haug, et al. (1987). Freshwater heads are useful in identifying hydraulic gradients in aquifers of variable density such as those existing at the WIPP site. Freshwater head at a given point is defined as the height of a column of freshwater that will balance the existing pressure at that point (Lusczynski, 1961).~~

Measured Culebra ~~ground-~~water surface elevation data can be converted to equivalent freshwater head from knowledge of the density of the borehole fluid, using the following formula.

p = ρ~~g~~γh

where

p = freshwater head (~~pressure~~length of freshwater head)

γ~~ρ~~ = average specific gravity of the borehole fluid (unitless ratio of borehole fluid density to density of fresh water)

ρ~~g~~ = freshwater density (mass/volume)

h = fluid column height above the datum (length)

If the freshwater density is assumed to be 1.000 gram per cubic centimeter (g/cm^3), then the equivalent freshwater head is equal to the fluid column height times the average borehole fluid specific gravity. ~~density (expressed as specific gravity).~~

Density measurements are made annually. Density for the DMWs will be expressed as specific gravity as measured in the field during sampling events using a hydrometer. Freshwater head for other Culebra wells will be calculated as described above from fluid density measurements obtained using pressure transducers.

L-4c(1)(i) Field Methods and Data Collection Requirements

To obtain an accurate ~~ground-water~~groundwater surface elevation measurement, a calibrated water-level measuring device will be lowered into a test well and the depth to water recorded from a known reference point. ~~When using an electrical conductance probe, the depth to water will be determined by reading the appropriate measurement markings on the embossed measuring tape when the alarm is activated at the surface. WIPP Procedure WP 02-EM1014~~ An SOP will be used when making water-level measurements for this program. The SOP will specify ~~specifies~~ the methods to be used in obtaining groundwater-level measurements, and provide general instructions including prerequisites, safety precautions, performance frequency, quality assurance, data management, and records. ~~A current revision of this procedure will be maintained in the WIPP Operating Record.~~

L-4c(1)(ii) ~~Ground-water~~Groundwater Surface Elevation Records and Document Control

~~All i~~Incoming data will be processed in a ~~timely~~ manner ~~to~~ that ~~assure~~ensures data integrity. The data management process for ~~ground-water~~groundwater surface elevation measurements will begin with completion of the field data sheets. Date, time, tape measurement, equipment identification number, calibration due date, initial of the field personnel, and equipment/comments will be recorded on the field data sheets. If, for some unexpected reason, a measurement is not possible (~~i.e.~~e.g., a test is under way that blocks entry to the well bore), then a notation as to why the measurement was not taken will be recorded in the comment column. Personnel will also use the comment column to report any security observations (i.e., well lock missing).

Data recorded on the field data sheets and submitted by field personnel will be subject to ~~guidelines outlined in~~ applicable SOPs ~~WIPP Procedures WP 02-EM3001~~[3] ~~and WP 02-EM1014~~[4] (see Table L-3). ~~Current copies of these procedures are maintained within the WIPP Operating Record.~~ These procedures specify the processes for administering and managing such data. The data will be entered onto a computerized work sheet. The work sheet program ~~will~~ calculates ~~ground-water~~groundwater surface elevation in both feet and meters relative to the top of the casing and also relative to mean sea level. The work sheet ~~will also adjust~~program adjusts ~~ground-water~~groundwater surface elevations to equivalent freshwater heads.

A check print will be made of the work sheet printout. The check print will be used to verify that data taken in the field was properly reported on the database printout. A minimum of 10 percent

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[3] ~~WP 02-EM3001 "Administrative Processes for Environmental Monitoring Programs" is a management control procedure to provide the administrative guidance to be used by Environmental Monitoring (EM) personnel to maintain quality control (QC) associated with EM sampling activities and to assure that data acquired under the WIPP Environmental Monitoring Program are valid. The precautions and limitations portion of this procedure assure that only qualified personnel acquire samples under the EM program, that cross contamination of sampling equipment is prevented, and that sample hold times are not exceeded. The Performance portion of the procedure provides step-by-step instructions for Quality Assurance/Quality Control (QA/QC) implementation, the use of data sheets and sample tracking logbooks, sample tacking from collection to submittal, and actions to take if sample results indicate the potential for exceeding a regulatory limit.~~

[4] ~~WP 02-EM1014 "Groundwater Level Measurement", is a technical procedure which lists the equipment required and the operational checks necessary to perform groundwater level measurements. This procedure as well as WP 02-EM3001 also provides information on performing validation and verification of laboratory data.~~

of the spreadsheet calculations will be randomly verified on the check print to ensure that calculations are being performed correctly. If errors are found, the work sheet will be corrected. ~~The data contained on the computerized work sheet will be translated into a database file. A printout will be made of the database file. The data each month will then be compiled into report format and transmitted to the appropriate agencies as requested by the Permittees. Ground-water~~Groundwater surface elevation data and equivalent freshwater heads for ~~all~~ the Culebra wells in Table L-4 will be transmitted to NMED ~~one month~~ by May 31 and November 30 ~~after data are collected~~. Semi-annual groundwater reports will also include annotated hydrographs and trend analysis.

~~A computerized database file will be maintained for all ground-water surface elevation data. Monthly and quarterly data will be appended into a yearly file. Upon verification that the yearly database is free of errors, it will be appended into the project database file. A printed copy of the current project database (through December of the preceding year) will be kept in the Environment, Safety and Health Department (**ES&H**) EM fire-resistant storage area.~~

L-4c(2) ~~Ground-water~~Groundwater Sampling

L-4c(2)(i) ~~Ground-water~~Groundwater Pumping and Sampling Systems

~~The water-bearing units at WIPP are highly variable in their ability to yield water to monitoring wells. The Culebra, the most transmissive hydrologic unit in the WIPP area, exhibits transmissivities that range many orders of magnitude across the site area and is the primary focus of the DMP.~~

The ~~ground-water~~groundwater pumping and sampling systems used to collect a ~~ground-water~~groundwater sample from the ~~seven~~ six ~~new DMP~~ DMWs ~~wells~~ will provide continuous and adequate production of water so that a representative ~~ground-water~~groundwater sample can be obtained. ~~The wells used for ground-water quality sampling vary in yield, depth, and pumping lift. These factors affect the duration of pumping as well as the equipment required at each well.~~

The type of pumping and sampling system to be used in a well depends primarily on the aquifer characteristics of the Culebra and well construction. The ~~DMP wells~~DMWs are ~~will be~~ individually equipped with dedicated submersible pumping assemblies. Each well has a specific type of submersible pump, matched to the ability of the well to yield water during pumping. The down-~~-~~hole submersible pumps are ~~will be~~ controlled by a variable electronic flow controller to match the production capacity of the formation at each well.

~~The electronic flow controller allows personnel collecting samples to control the rate of discharge during well purging to minimize the potential for loss of volatiles from the sample.~~ As recommended in the "RCRA Ground-Water Monitoring Technical Enforcement Guidance Document" (EPA, 1986) the wells will be purged ~~a minimum of~~no more than three well bore volumes or until field parameters have stabilized, whichever occurs first. ~~at a rate that will minimize the agitation of recharge water. This will be accomplished by monitoring formation pressure and matching the rate of discharge from the well as nearly as possible to the rate of recharge to the well. WIPP Procedure WP 02-EM1002~~[5] ~~specifies the methods used for~~

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[5] ~~WP 02-EM1002 "Electric Submersible Pump Monitoring System Installation and Operation" is a technical procedure that provides step-by-step instructions for acquiring ground-water samples using electric submersible pumps (ESPs). The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment,~~

~~controlling flow rates and monitoring formation pressure. A current version of this document will be maintained in the WIPP Operating Record.~~ Well purging will be performed in accordance with an SOP ~~requirements will be used~~ in conjunction with serial sampling to determine when the ~~ground-water~~groundwater chemistry stabilizes and is therefore representative of undisturbed ~~ground water~~groundwater.

The ~~DMP wells~~DMWs are ~~will be~~ cased and screened through the production interval with materials that do not yield contamination to the aquifer or allow the production interval to collapse under stress (high epoxy fiberglass). ~~Details of well construction are presented in Section L-3b(1).~~ An electric, submersible pump installation without the use of a packer is ~~will be~~ used in this instance. The largest amount of discharge from the submersible pump ~~will~~ takes place from a discharge pipe. In addition to this main discharge pipe a dedicated ~~Teflon®-~~sample line, running parallel to the discharge pipe, is ~~will also be~~ used. The sampling line is manufactured from a chemically inert material. ~~Flow through the pipe will be regulated on the surface by a flow control valve and/or variable speed drive controller.~~ Cumulative flow ~~will be~~is measured using a totalizing flow meter. Flow from the discharge pipe ~~will be~~is routed to a discharge tank for disposal.

The dedicated ~~Teflon®-~~sampling line ~~will be~~is used to collect the water sample that will undergo analysis. By using a dedicated ~~Teflon®-~~sample line, the water will not be contaminated by the metal discharge pipe. The sample line will branch from the main discharge pipe a few inches above the pump. Flow from the sample line will be routed into the sample collection area. Flow through the sample collection line ~~will be~~is regulated by a flow-control valve. The sample line ~~will be~~is insulated at the surface to minimize temperature fluctuations.

~~Pressure Monitoring Systems~~

~~The DMP wells do not require the installation of a packer because sample biases due to well construction deficiencies are not present. However, pressures will be monitored using down hole automatic air line bubblers in the formation to maintain the water level above the pump intake. Pressure transducers may be used in line with bubblers to provide continual electronic monitoring through data acquisition systems. WIPP Procedure WP 02-EM1002 provides instructions for monitoring formation pressure using automatic airline bubblers in conjunction with pressure transducers and data acquisition systems. A current version of this document will be maintained in the WIPP Operating Record.~~

~~The mobile field laboratory provides a work place for conducting field sampling and analyses. The laboratory will be positioned near the wellhead, will be climate controlled, and will contain the necessary equipment, reagents, glassware, and deionized water for conducting the various field analyses.~~

~~Sampling Overview~~

~~Two types of water samples will be collected: serial samples and final samples. Serial samples will be taken at regular intervals and analyzed in the mobile field laboratory for various physical and chemical parameters (called field indicator parameters). The serial sample data will be used~~

~~prerequisite actions which assure the correct installation and operation. The procedure details how to install the various subsystems such as the surface discharge and pressure monitoring system and the pressure monitoring bubbler and how to start up and shut down the ESP.~~

~~to determine whether the sample is representative of undisturbed ground water as a direct function of the stabilization of field indicator parameters and the volume of the water being pumped from the well. Interpretation of the serial sampling data will enable the Team Leader (see Section L-7) to determine when conditions representative of undisturbed ground water are attained in the pumped ground water.~~

~~Final samples will be collected when the serially sampled field indicator parameters have stabilized and are therefore representative of undisturbed ground water.~~

L-4c(2)(ii) Serial Samples

Serial sampling is the collection of sequential samples for the purpose of determining when the ~~ground-water~~groundwater chemistry stabilizes and is therefore representative of undisturbed ~~ground water~~groundwater. The Permittees' SOP for serial sampling will provide criteria for determining when a final sample should be taken. ~~will consider a serial sample representative of undisturbed ground water when the majority of field indicator parameter measurements have stabilized within ±5 percent of the average of analytical results for the field indicator parameter from the background ground-water quality for each DMP well. Nonstabilization of one or two field indicator parameters attributable to matrix interferences, instrument drift, or other unforeseen reasons will not preclude the collection of final samples, provided the volume of purged water exceeds three well bore volumes.~~ Each DMW will be purged to no more than three well bore volumes, or until field parameters stabilize, whichever occurs first. Well stabilization occurs when the field-analyzed parameters are within ± 5% of three consecutive measurements. A well bore volume is defined as the volume of water from static water level to the bottom of the well sump. Serial samples will be analyzed in the mobile field laboratory for field indicator parameters. The Permittees will ~~report, in the operating record, any final samples collected when field indicator parameters were not stabilized, and will~~ provide an explanation of why the sample was collected when field indicator parameters were not stabilized and place that explanation in the WIPP facility Operating Record.

Serial samples will be collected and analyzed to detect and monitor the chemical variation of the ~~ground water~~groundwater as a function of the volume of water pumped. Once serial sampling begins, the frequency at which serial samples are collected and analyzed will be left to the discretion of the ~~Team Leader (see Section L-7)~~Permittees, but will be performed a minimum of three times during a sampling round.

The Permittees will use appropriate field methods to identify stabilization of the following field indicator parameters: ~~chloride, divalent cations (hardness), alkalinity, total iron,~~ pH, ~~Eh,~~ temperature, specific conductance, and specific gravity.

~~Protocols for collection of serial samples are specified in WIPP Procedure WP 02-EM1006~~[6]~~.~~ ~~Analysis of serial samples are specified in WIPP Procedure WP 02-EM1005~~[7]~~. Current versions of these procedures will be maintained in the WIPP Operating Record.~~

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[6] ~~WP 02-EM1006 "Final Sample and Serial Sample Collection" is a technical procedure that provides step-by-step instructions for acquiring ground-water samples from the WQSP wells and from privately-owned wells in the vicinity of WIPP. The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment, and prerequisite actions which assure the data quality. The procedure addresses collection of samples from private wells, collection of serial ground-water samples, the collection of final samples for submittal to the laboratory, and data review by the monitoring task leader.~~

The three field indicator parameters of temperature, ~~Eh~~specific conductance, and pH will be determined by either an “in-line” technique, using a self-contained flow cell, or an “off-line” technique, in which the samples will be collected from a ~~Teflon~~®sample line at atmospheric pressure. ~~The iron, divalent cation, chloride, alkalinity, s~~Specific conductance~~,~~ and specific gravity samples will be collected from the ~~Teflon~~®-sample line at atmospheric pressure. Because of the lack of sophisticated weights and measures equipment available for field density assessments, field density evaluations will be expressed in terms of specific gravity, which is a unitless measure. Density is expressed as unit weight per unit volume.

New polyethylene containers, that are certified clean by the laboratory, will be used to collect the serial samples from the ~~Teflon~~®-sample line. ~~Serial sampling water collected for solute and specific conductance determinations will be filtered through a 0.45 micrometers (µm) membrane filter using a stainless-steel, in-line filter holder.~~

Serial samples collected in laboratory-certified clean containers do not require rinsing prior to sample collection. ~~Filtered water will be used to rinse the sample bottle prior to serial sample collection.~~ Unfiltered ~~ground water~~groundwater will be used when determining temperature, pH, ~~Eh~~specific conductance, and specific gravity. Sample bottles will be properly identified and labeled.

Samples collected will immediately be analyzed for pH and specific conductance (**SC**) as these parameters are most sensitive to changes in ambient temperature.~~The filtered sample collected for solute analyses will be immediately analyzed for iron and alkalinity because these two solution parameters are extremely sensitive to changes in the ambient water-sample pressure and temperature. A sample and duplicate of filtered water will be collected and analyzed for solute parameters (alkalinity, chloride, divalent cations, and iron).~~ Temperature, pH, and ~~Eh~~specific conductance, when not measured in a flow cell, will be measured at the approximate time of serial sample collection. These samples will be collected from the unfiltered sample line.

~~Samples to be analyzed for chloride and divalent cations (after preservation with nitric acid and stored at 4°C) may be stored for one week prior to analysis with confidence that the analytical results will not be altered.~~

Upon completion of the collection of the last serial sample suite, the serial sample bottles accrued throughout the duration of the pumping of the well will be discarded. No serial sample bottles will be reused for sampling purposes of any sort. However, serial samples may be stored for a period of time depending upon the need. ~~WIPP Procedure WP 02-EM1006~~Standard Operating Procedures (see Table L-3) define~~s~~ the protocols for the collection of final and serial samples and analysis. ~~WIPP Procedure WP 02-EM1005 defines the protocols for serial sample analysis. Current versions of these procedures will be maintained in the WIPP Operating Record.~~

~~During the first two years of DMP well serial sampling, the first sample will be analyzed as soon as possible after the pump is turned on and daily thereafter for a period of four days or until the~~

~~[7] WP 02-EM1005 “Groundwater Serial Sample Analysis” is a technical procedure that provides step-by-step instructions for on site analysis of ground water to determine ground-water stability prior tot he collection of final samples for analysis. The procedure addresses the equipment in general, lists precautions and limitations which assure that only qualified individuals operate the equipment, prerequisite actions which assure data quality. The procedure addresses the field measurement of Eh, pH, temperature, specific gravity, specific conductance, alkalinity, chloride, divalent cation, and total iron as indicators of ground-water stability.~~

~~field indicator parameters (chloride, divalent cations, alkalinity, and iron) stabilize. Eh, pH, and SC will be continually monitored by using a flow cell with ion-specific electrodes and a real-time readout. When detection monitoring begins, the serial sampling process may be modified and the decision to collect final samples would then be based on the number of well bore volumes purged and results of the analysis of chloride, temperature, specific gravity, pH, Eh, and SC. Removal of serial sampling from the DMP will be accomplished through a permit modification and a modification to this plan.~~

L-4c(2)(iii) Final Samples

The final sample will be collected once the measured field indicator parameters have stabilized (refer to Section L-4(c)(2)(ii)). A serial sample will also be collected and analyzed for each day of final sampling to ensure that samples collected for laboratory analysis are still representative of stable conditions. Sample preservation, handling, and transportation methods will maintain the integrity and representativeness of the final samples.

Prior to collecting the final samples, the collection team shall consider the analyses to be performed so that proper shipping or storage containers can be assembled. Table L-~~4~~6 presents the sample containers, volumes, and holding times for laboratory samples collected as part of the DMP.

The monitoring system will use dedicated pumping systems and sample collection lines from the sampled formation to the well head. ~~Non-dedicated sample collection lines from the well head to the sample collection area will be discarded after each use.~~

Sample integrity will be ensured through appropriate decontamination procedures. Laboratory glassware will be washed after each use with a solution of nonphosphorus detergent and deionized (**DI**) water and rinsed in DI water. Sample containers will be new, certified clean containers that will be discarded after one use. ~~Ground-water~~Groundwater surface elevation measurement devices will be rinsed with fresh water after each use. Non-dedicated sample collection manifold assemblies will be rinsed in accordance with SOPs ~~with two gallons of fresh water, then rinsed with five gallons of 5 percent nitric acid solution and rinsed with five gallons of DI water~~ after each use. The exposed ends will be capped off during storage. Prior to the next use of the sampling manifold, it will be rinsed a second time with DI water and a ~~blank~~ rinsate blank sample will be collected to verify ~~decontamination~~cleanliness.

Water samples will be collected at atmospheric pressure using either the filtered or unfiltered ~~Teflon®~~ sampling lines~~ branching from the main sample line~~. Detailed protocols, in the form of ~~procedures~~SOPs (see Table L-3) define how~~, assure that~~ final samples will be collected in a consistent and repeatable fashion~~. WIPP Procedure WP 02-EM1006 defines the requirements for collection of final samples~~ for analyses. ~~A current version of this procedure will be maintained in the WIPP Operating Record.~~

Final samples will be collected in the appropriate type of container for the specific analysis to be performed. The samples will be collected in new and unused glass and plastic containers (refer to Table L-~~4~~6). For each parameter analyzed, a sufficient volume of sample will be collected to satisfy the volume requirements of the analytical laboratory (as specified by laboratory ~~Standard Operating Procedures [~~SOPs~~]~~). This includes an additional volume of sample water necessary for maintaining quality control standards. All final samples will be treated, handled, and preserved as required for the specific type of analysis to be performed. Details about sample containers, preservation, and volumes required for individual types of analyses are found in the applicable ~~procedures~~ SOPs generated, approved, and maintained by the ~~contract~~ analytical laboratory.

~~Before the final sample is taken, all plastic and glass containers will be rinsed with the pumped ground water, either filtered or unfiltered, dependent upon analysis protocol. When the rinsing procedure is completed the final sample will be collected.~~

Final samples will be sent to the analytical ~~contract~~ laboratories and analyzed for parameters and hazardous constituents specified in Part 5, Tables 5.4.a and 5.4.b. ~~general chemistry, radionuclides, metals, and selected VOCs that are specific to the waste anticipated to arrive at WIPP. Table L-3 presents the specific analytes for the DMP.~~

Duplicates of the final sample will be provided to WIPP Project oversight agencies ~~as~~ when requested ~~by the Permittees or NMED~~.

~~Resulting w~~Wastes resulting from the sampling and field analysis of groundwater are disposed of in accordance with the WIPP SOPs (see Table L-3). ~~Procedure WP 02-RC.01~~[8]~~. A current version of this procedure will be maintained in the WIPP Operating Record.~~

L-4c(2)(iv) Sample Preservation, Tracking, Packaging, and Transportation

Many of the chemical constituents measured by the DMP are not chemically stable and require preservation and special handling techniques. Samples requiring acidification will be treated ~~with either high purity hydrochloric acid, nitric acid, or sulfuric acid (ULTREX or equivalent), depending upon the standard method of treatment required for the particular parameter suite or~~ as requested by the ~~contract~~ analytical laboratory ~~SOPs (see Table L-4)~~.

The ~~contract~~ analytical laboratory receiving the samples will ~~use procedures that~~ prescribe the type and amount of preservative, the container material type, ~~and~~ the required sample volumes that shall be collected, and the shipping requirements. This information will be recorded on the Final Sample Checklist for use by field personnel when final samples are being collected. The Permittees will follow the EPA "RCRA Ground-Water Monitoring Technical Enforcement Guidance Document," Table 4-1 (EPA, 1986), ~~if~~ when laboratory SOPs do not specify sample container, volume, or preservation requirements. WIPP SOPs (see Table L-3) provide instructions to ensure proper sample preservation and shipping.

The sample tracking system at the WIPP facility ~~will use~~uses uniquely numbered chain of custody ~~(**CofC**) Forms and~~ / request for analysis ~~(**RFA**) Forms~~ **(CofC/RFA)** forms. The primary consideration for storage or transportation is that samples shall be analyzed within the prescribed holding times for the analytes ~~parameters~~ of interest. WIPP ~~Procedure WP 02-EM3001~~SOPs (see Table L-3) provide~~s~~ instructions to ensure proper sample tracking protocol. ~~A current revision of this procedure will be maintained within the WIPP Operating Record.~~

~~Insulated shipping containers packaged with crushed ice or reusable ice packs will be used to keep the samples cool during transport to the contract laboratory. Holding times for specific~~

~~[8] WP 02-RC.01 "Site-Generated, Non-Radioactive Hazardous Waste Management Plan" is a step-by-step procedure that defines site-generate non-radioactive hazardous waste (SGNRHW) and lists responsibilities of waste management organizations including the generator, waste handlers, sampling personnel, safety personnel, and compliance personnel. In addition, the procedure defines training requirements, container marking requirements, spill response, and list prohibitions. A Section of the procedure is focused on waste management practices including the management in satellite accumulation areas, the hazardous waste staging area for materials awaiting analysis, the establishment of accumulation times, and hazardous waste disposal.~~

~~analytical parameters require samples to be shipped by express air freight. The coolers will be packaged to meet Department of Transportation and International Air Transportation Association commercial carrier regulations.~~

L-4c(2)(v) Sample Documentation and Custody

To ensure the integrity of samples from the time of collection through reporting date, sample collection, handling, and custody shall be documented. Sample custody and documentation procedures for ~~EM~~ sampling and analysis activities are detailed in WIPP facility ~~Procedure WP 02-EM3001~~SOPs (see Table L-3). ~~These procedures will be strictly followed throughout the course of each sample collection and analysis event. A current revision of this procedure will be maintained in the WIPP Operating Record.~~

Standardized forms used to document samples ~~will~~ include sample identification numbers, sample labels, custody tape, the sample tracking ~~log books~~data, and the ~~request for analysis/chain of custody (RFA and CofC~~CofC/RFA~~)~~ form. An example form is shown in Figure L-13. ~~The forms are briefly defined in the following subsections.~~

~~All sample documentation will be completed for each sample and reviewed by the Team Leader or his/her designee for completeness and accuracy.~~

Sample Numbers and Labels

A unique sample identification number will be assigned to each sample sent to the laboratory for analysis. ~~The Team Leader (see Section L-7) will assign the numbers prior to sample collection.~~ The sample identification numbers will be used to track the sample from the time of collection through data reporting. Every sample container sent to the laboratory for analysis will be identified with a label affixed to it. Sample label information will be completed in ~~permanent,~~ indelible ink and will contain the following information: sample identification number with sample matrix type; sample location; analysis requested; time and date of collection; preservative(s), if any; and the sampler's name or initials.

Custody Seals

Custody seals will be used to detect unauthorized sample tampering from collection through analysis. ~~The~~ For example, custody seals ~~will be~~that are adhesive-backed strips ~~that~~ are destroyed when removed or when the container is opened. The seal will be dated, initialed, and affixed to the sample container in such a manner that it is necessary to break the seal to open the container. Seals will be affixed to sample containers in the field immediately after collection. Upon receipt at the laboratory, the laboratory custodian will inspect the seal for integrity; a broken seal will invalidate the sample.

Sample Identification and Tracking ~~Logbook~~

~~A s~~Sample tracking ~~logbook (**STLB**)~~ information will be completed for each sample collected. ~~form will be completed for each sample collected.~~ The sample tracking information~~STLB will~~ includes the following information: ~~C of C~~ CofC/RFA form number; ~~RFA No.;~~ date sample(s) were sent to the lab; laboratory name; acknowledgment of receipt or comments; well name and round number. Sample codes will indicate the well location; the geologic formation where the water was collected from, the sampling round number; and the sample number. The code is broken down as follows:

WQ6[1]C[2]R2[3]N1[4]

[1] Well identification (e.g., WQSP-6 in this case)
[2] Geologic formation (e.g., the Culebra in this case)
[3] Sample round no. (Round 2)
[4] Sample no. (N1)

To distinguish duplicate samples from other samples, a “D” is added as the last digit to signify a duplicate. ~~STLB~~ Sample tracking information will be completed in the field by the sampling team. ~~and checked by the Team Leader. When samples are shipped, the STLB will remain in the custody of the EM Section for sample tracking purposes.~~

Sample tracking is monitored and documented with the CofC/RFA form and the shipping airbill. Both of these documents are included in the data packets. Receipt at the analytical laboratory may be monitored, if necessary, via the shipper’s website tracking application. Samples are considered complete when a copy of the original CofC/RFA form is merged with the Field Lab copy of the same document.

~~Request for Analysis and~~ Chain of Custody and Request for Analysis

A~~n~~ ~~RFA and CofC~~CofC/RFA form will be completed during or immediately following sample collection and will accompany the sample through analysis and disposal.~~ An example of the RFA and CofC form is presented in Figures L-17a and L-17b.~~ The ~~RFA and CofC~~CofC/RFA form will be signed and dated each time the sample custody is transferred. A sample will be considered to be in a person’s custody if: the sample is in his/her physical possession; the sample is in his/her unobstructed view; and/or the sample is placed, by the last person in possession of it, in a secured area with restricted access. During shipment, the carrier’s air bill number serves as custody verification. Upon receipt of the samples at the analytical laboratory, the laboratory sample custodian acknowledges possession of the samples by signing and dating the ~~RFA and CofC~~CofC/RFA form. The completed original (top page) of the ~~RFA and CofC~~CofC/RFA form will be returned to the ~~Team Leader~~Permittees with the laboratory analytical report and becomes part of the permanent record of the sampling event. The ~~RFA and CofC~~CofC/RFA form also contains specific instructions to the analytical laboratory for sample analysis, potential hazards, and disposal instructions.

L-4c(3) Laboratory Analysis

Analysis of samples will be performed ~~by~~ using ~~a commercial laboratory. M~~methods ~~will be specified in procurement documents and will be~~ selected to be consistent with EPA recommended procedures in SW 846 (EPA, 1996). Additional detail on analytical techniques and methods will be given in laboratory SOPs. In Part 5, Tables 5.4.a and 5.4.b ~~L-3~~ presents the analytical parameters and hazardous constituents for the WIPP DMP.

The Permittees will establish the criteria for laboratory selection, including the stipulation that the laboratory follow the procedures specified in SW 846 and that the laboratory follow EPA protocols unless alternate methods or protocols are approved by the NMED. The analytical ~~selected~~ laboratory shall demonstrate, through laboratory SOPs, that it will follow appropriate EPA SW 846 requirements and the requirements specified by the EPA protocols unless alternate methods or protocols are approved by the NMED.~~.~~ The analytical laboratory shall also provide documentation to the Permittees describing the sensitivity of laboratory instrumentation. This documentation will be retained in the WIPP facility ~~o~~Operating ~~r~~Record. ~~and will be~~

~~available for review upon request by NMED.~~ Instrumentation sensitivity needs to be considered because of regulatory requirements governing constituent concentrations in ~~ground water~~groundwater and the complexity of brines associated with the ~~WIPP repository~~Culebra groundwater.

~~Once the initial qualification criteria, as specified above, have been met, the Permittees will select a laboratory based upon competitive bid. The selected laboratory will perform analytical work for the Permittees for a predetermined period of time, as specified in the contract between the Permittees and the selected laboratory. As this period of performance comes to an end, a new laboratory selection/competitive bid process will be initiated by the Permittees. The same or a different laboratory may be selected for the new contract period.~~ The laboratory will maintain documentation of sample handling and custody, analytical results, and internal quality control (**QC**) data. Additionally, the laboratory will analyze QC samples in accordance with this plan and its own internal QC program for indicators of analytical accuracy and precision. Data generated outside of laboratory acceptance limits will trigger an evaluation and, if appropriate, corrective action as directed by the Permittees. The laboratory will report the results of the environmental sample and QC sample analyses and any necessary corrective actions that were performed. In the event that more than one analytical laboratory is used (e.g., for different analyses), each one will have the responsibilities specified above. ~~The~~ A copy of the laboratory SOPs ~~for the laboratory currently under contract~~ will be maintained ~~in a file~~ in WIPP facility files.~~the operating record by the Permittees.~~ The Permittees will provide NMED with an initial set of applicable laboratory SOPs for information purposes, and provide NMED with any updated SOPs on an annual basis by January 31.

Data validation will be performed ~~on behalf of the Permittees by the Management and Operating Contractor (**MOC**) Environmental Monitoring (**EM**). Data validation results are~~ and reported in the Annual Culebra Groundwater Report and will be maintained in the WIPP facility Operating Record. ~~documented on an Approval/Variation Request (**AR/VR**) form (Procedure WP 15-PC3041). If no discrepancies are found in the data, the AR/VR form will be signed and the approved box will be checked. If however, discrepancies are found, the AR/VR form will be signed and the disapproved or approved-on-condition box will be checked and the form will be returned to the team leader accompanied by an attached report discussing the data validation results, any anomalies, and resolutions. Copies of the data validation report will be distributed to the EM Manager, QA Manager, the Team Leader, and the Contract Administrator. Copies of the data validation report will be kept on file in the EM records section for review upon request by NMED.~~

L-4d Calibration

L-4d(1) Sampling and Groundwater Elevation Monitoring Equipment Calibration ~~Requirements~~

The equipment used to collect data for ~~the WQSP and~~ this DMP will be calibrated in accordance with SOPs~~maintenance administrative procedures specified below~~. The Permittees ~~EM Section~~ will be responsible for calibrating needed equipment on schedule~~, in accordance with written procedures. The EM Section will also be responsible~~ and for maintaining current calibration records for each piece of equipment.

L-4d(2) ~~Ground-water~~Groundwater Surface Elevation Monitoring Equipment Calibration Requirements

The equipment used in taking ~~ground-water~~groundwater surface elevation measurements will be maintained in accordance with WIPP facility SOPs (see Table L-3). ~~Procedure WP 10-AD3029~~[9] ~~A current revision of this procedure will be maintained in the WIPP Operating Record.~~ The ~~EM Section~~Permittees will be responsible for ensuring ~~calibrating the needed~~ equipment is calibrated on schedule in accordance with ~~written procedures~~SOPs. The ~~EM Section~~Permittees will also be responsible for maintaining copies of records of the most recent ~~current~~ calibration ~~records~~ for each piece of equipment.

L-4e Statistical Analysis of Laboratory Analytical Data

~~As required by 20.4.1.500 NMAC (incorporating 40 CFR §§264.97 and 264.98), data collected to establish background ground-water quality and~~Analytical data collected as part of the DMP will be evaluated using appropriate statistical techniques. The following specifies the statistical analysis to be performed by the Permittees~~DMP. Statistical analysis of DMP data will conform to EPA guidance "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities" (EPA, 1989) and "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance" (EPA, 1992).~~

L-4e(1) Temporal and Spatial Analysis

~~Environmental parameters vary with space and time. The effect of one or both of these two factors on the expected value of a point measurement will be statistically evaluated through spatial analysis and time series analysis. These methods often require extensive sampling efforts that may exceed the practical limits of the DMP sampling procedures.~~

~~Spatial analysis may have limited use DMP during the operational period, although the effect of spatial auto-correlation on the interpretation of the data will be considered for each parameter. Spatial variability will be accounted for by the use of predetermined key sampling locations. Data analysis will be performed on a location-specific basis, or data from different locations will be combined only when the data are statistically homogeneous. Statistical homogeneity will be determined by evaluating mean values and variances from the residuals from the individual well data.~~

~~Time series analysis plays a more important role in data analysis for the DMP. Parameters will be reported as time series, either in tabular form or as time plots. For key time series parameters, these plots will be in the form of control charts on which control levels will be identified based on preoperational database, fixed standards, control location databases, or other standards for comparison. Where significant seasonal changes in the expected value of the parameter are identified in the preoperational database or in the control locations, corrections in the control levels which reflect the seasonal change will be made and documented.~~

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[9] ~~WP 10-AD3029 "Calibration and Control of Monitoring and Data Collection Equipment" provides the step-by-step protocols for the establishment and maintenance of a master database of monitoring and data collection (**M&DC**) equipment, the recall process for equipment needing calibration, the performance of calibrations, the management of calibration results to determine the adequacy of recall frequencies, functional testing of M&DC equipment, and reporting including out-of-tolerance reporting and expired calibration reporting. In addition, the procedure provides step-by-step process for the storage of calibrated M&DC equipment and the use of rental equipment.~~

Temporal and spatial analyses of the data were completed as part of establishing the water quality baseline (Crawley and Nagy, 1998; IT, 2000). As a result, the Permittees determined to evaluate changes relative to baseline on an individual location basis and to report the concentrations of constituents as a time series, either in tabular form or as time plots. No particular seasonal variations have been noted in the concentrations of groundwater samples collected during the spring and autumn; therefore, continuing temporal analysis is not required.

The analytical results for constituents will be reported as time series, either in tabular form or as time plots or both, and compared to the 95th percentile values or reporting limits identified in Part 5, Table 5.6.

L-4e(2) Distributions and Descriptive Statistics

~~For data sets which include more than ten data points that are homogeneous in space and time (including seasonal homogeneity) and have less than ten percent missing data, a test for conformance to the normal distribution will be performed. The test for normality of the data will be performed in accordance with the methodologies presented in “Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance” (EPA, 1992).~~

~~If normality is not met, the data will be log-transformed (or transformed using a suitable mathematical transformation, e.g., square root) and retested for normality. If the transformed data fit a normal distribution, the original data will be accepted as having lognormal or an otherwise mathematically-transformed normal distribution. If normality is still not found, two courses may be taken. One will be to continue to test the fit to standard families of distributions, such as the gamma, beta, and Weibull, with proper modifications to subsequent analyses based on these results. The other course will be to use nonparametric methods of data analysis.~~

~~For data sets smaller than ten, but homogeneous and complete, the lognormal distribution will be assumed. Data sets with more than ten percent missing data will be analyzed using nonparametric methods. Nonhomogeneous data sets will be subdivided into homogeneous sets and each of these analyzed individually.~~

~~Descriptive statistics will be calculated for each homogeneous data set. At a minimum, these include a central value and a range of variation. The central value is the arithmetic mean of the untransformed data if the data are not censored at either end. If the data are censored, either a trimmed mean or the median will be used as the central value (which may be within the censored range). If the data set is greater than ten and is uncensored, the standard deviation will be calculated and used as a basis for the reported range in variation. If these criteria are not met, the range between the 0.25 and 0.75 cartelist will be used.~~

Techniques were established to compare detection monitoring data generated during the baseline studies. A 95th upper tolerance limit value (**UTLV**) or 95th percentile was determined from those data sets where target analytes were measured at concentrations above the method detection limits. The UTLV is provided for normal or lognormal distributions and a 95th percentile confidence interval is provided for data sets that are nonparametric or have greater than 15 percent non-detects. For analytes with only a few detects (greater than 95 percent non-detects), an accurate 95th percentile cannot be calculated. For these analytes, the maximum detected concentration is used as the baseline value. For the analytes that are non-detect in all the samples, the method reporting limit was used as the baseline value.

L-4e(3) Action Levels~~Data Anomalies~~

~~Data anomalies include data points reported as being below the limit of detection (**LD**) or otherwise censored over a specific range of values, missing data points occurring randomly in the data set, and outliers that cannot be ascribed to a known source of variation.~~

~~Whenever possible, sample values which are reported below detection limits will be incorporated into the database as sample values measured at one-half the detection limit for statistical analysis. When values are not available, alternative methods of analysis, as specified in previous sections, will be used. In particular, the use of nonparametric statistics will be required.~~

~~Missing data points comprising less than 10 percent of the data set do not significantly affect data analyses. Results based on data in which more than 10 percent is missing will be identified as such at the time of reporting. Consideration of the potential effect of missing data shall be made when the majority of the data are missing from a discrete time span.~~

Using baseline distributions, actions levels were identified in accordance with methodologies described in the baseline documents. Action levels are based on the 95th percentile or reporting limits identified in the baseline. If the groundwater concentration of a constituent identified in Part 5, Table 5.6 is found to exceed an action level, a test for outliers is performed in accordance with the ~~Formal testing for outliers will only be done in accordance with EPA guidance. The~~ methodologies specified in ~~Section 8.2 of the~~ “Statistical Analysis of Ground-~~W~~water Monitoring Data at RCRA Facilities” (EPA, ~~1989~~2009)~~ will be used to check for outliers~~.

~~If an outside source of variation is not identified to account for outliers in a data set, it will be included in the data set and all subsequent analyses. If the inclusion of such outliers is found to affect the final results of the analyses significantly, both results (with and without outliers) will be reported.~~

L-4e(4) Comparisons and Reporting

Prior to TRU mixed waste receipt, measurements were made of each background ~~ground-water~~groundwater quality hazardous constituent specified in Part 5, Table ~~L-3~~5.4.b at every ~~DMP ground-water~~detection monitoring well during each of the ten background sampling events (with the exceptions of trans-1,2-dichloroethylene and vanadium that were added after TRU mixed waste disposal began). ~~If any background ground-water quality parameter or constituent has not been measured prior to waste receipt, measurements will be made for those parameters or constituents in hydraulically upgradient DMP ground-water monitoring wells for a sequence of four sampling events. Following completion of the four sampling events, the arithmetic mean and variance shall then be calculated by the field supervisor or designee for each well.~~ These measurements ~~will then~~ serve as a ~~background value~~ statistical baseline (Part 5, Table 5.6) ~~against which~~ that is ~~statistical values~~ used for evaluating the significance of the results of subsequent sampling events during detection monitoring~~ will be compared~~. Time-trend control charts with associated screening values for each hazardous constituent are used for this evaluation. ~~Statistical analysis and comparison will be accomplished using one of the five statistical tests specified in~~ The Permittees will compare the results from groundwater hazardous constituents of ongoing annual groundwater sample analysis to these baseline values in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §264.~~98~~97(h)(4))~~, which may include Cochran’s Approximation to the Behrens-Fisher students’ t-test at the 0.01 level of significance (described in Appendix IV to 20.4.1.500 NMAC (incorporating 40 CFR §264)~~. If the comparisons show that a constituent statistically exceeds the baseline ~~a significant increase~~ at any ~~monitoring site~~of the DMWs (as defined in 20.4.1.500 NMAC (incorporating 40 CFR §264.98(f))), the well shall be resampled and an analysis performed as soon as possible, in accordance with 20.4.1.500 NMAC (incorporating 40 CFR §264.98(g)(~~2~~3)). The results of the statistical comparison will be reported annually to ~~in~~ the NMED in the Annual Culebra ~~Site Environmental~~ Groundwater Report ~~(**ASER**)~~ by November 30, ~~and will be reported to NMED~~ as required under 20.4.1.500 NMAC (incorporating 40 CFR §264.98(g))~~ in October~~.

L-5 Reporting

L-5a Laboratory Data Reports

Laboratory data will be provided in electronic and hard copy reports to the Permittees~~.~~ ~~Laboratory data reports will be forwarded to the Team Leader (see Section L-7) and NMED~~ and will contain the following information for each analytical report:

- A brief narrative summarizing laboratory analyses performed, date of issue, deviations from the analytical method, technical problems affecting data quality, laboratory quality checks, corrective actions (if any), and the project manager's signature approving issuance of the data report.

- Header information for each analytical data summary sheet including: sample number and corresponding laboratory identification number; sample matrix; date of collection, receipt, preparation and analysis; and analyst's name.

- Parameter and hazardous constituent~~Analytical parameter~~, analytical results, reporting units, reporting limit, analytical method used.

- Results of QC sample analyses for all concurrently analyzed QC samples.

All analytical results will be provided to NMED as specified in the Permit Part 5.

L-5b Statistical Analysis and Reporting of Results

Analytical results for hazardous constituents from ~~semi-~~annual ~~ground-water~~groundwater sampling activities will be compared and interpreted by the ~~Team Leader~~Permittees through generation of statistical analyses as specified in Section L-4e. The ~~Team Leader~~Permittees will perform statistical analyses; the results will be included in the Annual Culebra Groundwater Report ~~ASER~~ in summary form, and will also be provided to NMED as specified in Permit Part 5.

L-5c Semi-Annual Groundwater Surface Elevation Report and Annual Culebra ~~Site Environmental~~Groundwater Report

Data collected from this DMP will be reported to NMED as specified in Permit Part 5 in the Annual Culebra Groundwater Report~~, and to the EM Manager and NMED in the ASER~~. The ~~ASER~~ report will include all applicable information that may affect the comparison of background ~~ground-water~~groundwater quality and ~~ground-water~~groundwater surface elevation data through time. This information will include but is not limited to:

- DMW and WLMP ~~W~~well configuration changes that may have occurred from the time of the last measurement (i.e., plug installation and removal, packer removal and reinstallation, or both; and the type and quantity of fluids that may have been introduced into the test wells).

- ~~Any p~~Pumping activities that may have taken place since publication of the last annual report (i.e., related to ~~ground-water~~groundwater quality sampling, hydraulic testing, and shaft installation or grouting~~ activities~~) that may have taken place since the last annual groundwater report.

- A discussion of the origins of abnormal unexpected changes in the groundwater surface elevation, which is not attributable to site tests or natural stabilization of the site hydrologic system that exceeds 2 ft in a DMP well over the course of the period covered by the Annual Culebra Groundwater Report (this may indicate changes in recharge/discharge which would affect the assumptions regarding DMP well placement and constitute new information as specified in 20.4.1.900 NMAC (incorporating 40 CFR §270.41(a)(2)).

- The results of the annual measurements of densities.

- Annotated hydrographs.

- Groundwater flow rate and direction.

- Potentiometric surface map generated using the following steps:

    - Examine hydrographs to identify month having the largest number of Culebra water levels available with the fewest wells affected by pumping or other anthropogenic events.

    - Convert water levels from subject month to equivalent freshwater heads using fluid densities appropriate to the date.

    - Fit trend surface through freshwater heads.

    - Extrapolate the trend surface to the boundaries of the model domain used for the current Performance Assessment Baseline Calculations (**PABCs**) and define initial fixed-head boundary conditions based on the trend surface.

    - Using the ensemble-average Culebra transmissivity field used for the current PABC, optimize the model boundary heads to improve the fit of the model to the freshwater heads at the wells using optimization software interactively with MODFLOW.

    - Run MODFLOW with optimal boundary conditions fit.

    - Contour MODFLOW head results on WIPP site.

    - Compute particle path and travel time from the Waste Handling Shaft to the LWA Boundary.

    - Data analysis that will accompany the potentiometric surface map will include:

    - Measured versus modeled scatter plot diagram
    - Frequency of modeled head residuals
    - Modeled residual freshwater head at each well
    - Explanations for modeled misfit residuals greater than 16.4 feet (5 meters).
- Semi-annual groundwater surface elevation results will be reported as specified in Permit Part 5, Condition 5.10.2.2.
- ~~Radionuclide-specific data collected during the previous year.~~

The DMP data used in generating the ~~ASER~~ Annual Culebra Groundwater Report will be maintained as part of the WIPP facility ~~o~~Operating ~~r~~Record and will be provided to NMED for review as specified in the permit.

L-6 Records Management

Records generated during ~~ground-water~~groundwater sampling and water level ~~ground-water surface elevation~~ monitoring ~~events~~ will be maintained in either ~~the form~~ project files ~~in the EM section~~at the Permitees facility or the Operating Record. Project ~~records~~ files will include, but are not limited to:

- Sampling and Analysis Plans (**SAPs**)
- SOPs
- Field Data Entry Sheets
- ~~STLBs~~
- CofC/RFA ~~and CofC~~ forms
- ~~Contract~~ Analytical Laboratory Data Reports
- Variance Logs and Nonconformance Reports
- Corrective Action Reports.

~~These and all raw analytical records~~ Detection Monitoring Program monitoring, testing, and analytical data ~~generated in conjunction with ground-water sampling~~ and ~~ground-water surface elevation~~ WLMP data~~monitoring~~ will be ~~stored in fire resistant cabinets~~maintained in the WIPP facility Operating Record. ~~in the EM section according to the Records Inventory and Disposition Schedule (**RIDS**) and will be made available for inspection upon request. The following records will be transmitted to the Permittees' Project Records Services (**PRS**) for long-term storage in accordance with the RIDS:~~

- ~~Instrument maintenance and calibration records~~
- ~~QC sample data~~
- ~~Control charts and calculation~~
- ~~Sample tracking and control documentation~~
- ~~Raw analytical results.~~

~~L-7 Project Organization and Responsibilities~~

~~L-7a Environmental Monitoring Manager~~

~~The EM Manager will be responsible for the overall design and implementation of the DMP. The EM Manager will develop and approve specific procedures all DMP activities, and will review and approve programmatic reports. The EM Manager will provide oversight of appropriate levels of cooperation and consultation between the EM Section and the State of New Mexico regarding environmental monitoring and will revise the QA section of the DMP, if necessary, and submit revisions as permit modifications as specified in 20.4.1.900 NMAC (incorporating 40 CFR §270.42).~~

~~The EM Manager and staff will be responsible for achieving and maintaining quality in the DMP. All DMP data will be reviewed and approved by the EM Manager, or designee, prior to release.~~

~~The EM Manager will establish minimum qualification criteria and training requirements for all DMP personnel. The EM Manager will assure that position descriptions for assigned DMP personnel are adequately prepared. The EM Manager and/or Team Leader will assure that training is performed on an individual basis to maintain an acceptable level of proficiency by all new or temporary DMP staff and by all permanent GWSP staff. The EM Manager will assure that documents detailing all staff training are current and properly filed. Copies of training records will be on file for the Permittees in the MOC Technical Training Section.~~

~~The EM Manager will appoint a DMP Team Leader and Field Team, and assign the following responsibilities specified below.~~

~~L-7b Team Leader~~

~~The Team Leader will coordinate and oversee field sampling activities, ensuring that sampling and associated procedures will be followed and that QA/QC and safety guidelines will be met. The Team Leader will direct the DMP per written approved procedures, and initiate the review of programmatic plans and procedures. The Team Leader will review and evaluate sample data, prepare and review programmatic reports, and assure that appropriate samples will be collected and analyzed. The Team Leader will assure that adequate technical support is provided to the Quality Assurance (**QA**) Department, when required during audits of vendor facilities. Any nonconformances or project changes will be immediately communicated to the Team Leader.~~

~~L-7c Field Team~~

~~The field team members will consist of one or more scientists, engineers, or technicians, who will be responsible for sample collection, handling, shipping, and preparation and maintenance of appropriate data sheets, and completion of sample tracking documentation under the direction of the Team Leader, in accordance with this DMP and associated field procedures. The field team will inspect, maintain, and ensure proper calibration of equipment prior to use at each site, while ensuring that site health and safety requirements will be met at all times. The field team will communicate any nonconformances, malfunctions, or project changes to the Team Leader immediately.~~

~~L-7d Safety Manager~~

~~The Safety Manager will be responsible for ensuring that the necessary requirements for the health and safety of personnel associated with sampling and analysis activities are met. The cognizant manager will be responsible for ensuring that field team members operate in a safe manner and personnel have appropriate training. The Safety Manager will ensure that periodic~~

~~health and safety assessments are conducted and that the cognizant manager will initiate corrective actions where deficiencies are identified.~~

~~L-7e Analytical Laboratory Management~~

~~Sample collection containers supplied by the laboratory will be certified as clean by either the laboratory or their supplier. The Permittees will supply containers for radiological samples. The analytical laboratory will be responsible for performing analyses in accordance with this DMP Plan and regulatory requirements. The laboratory will maintain documentation of sample handling and custody, analytical results, and internal QC data. Additionally, the laboratory will analyze QC samples in accordance with this plan and its own internal QC program for indicators of analytical accuracy and precision. Data generated outside laboratory acceptance limits will trigger an investigation and, if appropriate, corrective action, as directed by the EM Manager. The laboratory will report the results of the environmental sample and QC sample analyses and any necessary corrective actions that were performed. In the event that more than one analytical laboratory is used (e.g., for different analyses), each one will have the responsibilities specified above.~~

~~L-7f Quality Assurance (QA) Manager~~

~~The QA Manager will provide independent oversight of the DMP, via the assigned cognizant QA engineer, to verify that quality objectives are defined and achieved. The QA Manager will ensure objective, independent assessments of the DMP quality performance and the quality performance of the contract analytical laboratory. The QA Manager has been delegated authority on behalf of the Permittees by the MOC General Manager and will have access to work areas, identify quality problems, initiate or recommend corrective actions, verify implementation of corrective actions, and ensure that work will be controlled or stopped until adequate disposition of an unsatisfactory condition has been implemented.~~

L-7~~8~~ Quality Assurance Requirements

~~Specific~~ Quality Assurance (**QA**) ~~requirements for WIPP are defined in WIPP document WP 13-1. A current revision of this document will be maintained in the WIPP Operating Record.~~ ~~R~~requirements specific to the DMP are presented in this section.

L-~~8a~~7a ~~QA Program—Overview~~ Data Quality Objectives and Quality Assurance Objectives

~~The QA program was developed to assure that integrity and quality will be maintained for all samples collected and that equipment and records will be maintained in accordance with EPA guidance. The QA Program identifies data quality objectives (**DQO**), processes for assuring sample quality, and processes for generating and maintaining quality records.~~

L-~~8b~~7a(1) Data Quality Objectives

Data Quality Objectives (**DQOs**) are qualitative and quantitative statements that specify the quality of data required to support project decisions. DQOs have been ~~will be~~ established to ensure that the data collected will be of a sufficient and known quality for their intended uses. The overall DQOs for this DMP are shown in the following sections. ~~project will be to collect accurate and defensible data of known quality that will be sufficient to assess the concentrations of constituents in the ground water underlying the WIPP area. The data generated thus far by the DMP has been used to establish background ground-water quality. For the purpose of this~~

~~DMP, DQOs for measurement data will be specified in terms of accuracy, precision, completeness, representativeness, and comparability. Measurements of data quality in terms of accuracy and precision will be derived from the analysis of QC samples generated in the field and laboratory. Appropriate QC procedures will be used so that known and acceptable levels of accuracy and precision will be maintained for each data set. This section defines the acceptance criteria for each QC analysis performed. The following subsections define each DQO.~~

L-7a(1)(i) Detection Monitoring Program

Collect accurate and defensible data of known quality that will be sufficient to assess the concentrations of constituents in the groundwater underlying the WIPP facility.

L-7a(1)(ii) Water Level Monitoring Program

Collect accurate and defensible data of known quality that will be sufficient to assess the groundwater flow direction and rate at the WIPP facility.

L-7a(2) Quality Assurance Objectives

Quality Assurance Objectives (**QAOs**) for measurement data have been specified in terms of accuracy, precision, completeness, representativeness, and comparability.

L-~~8b~~7a(~~1~~2)(i) Accuracy

Accuracy is the closeness of agreement between a measurement and an accepted reference value. When applied to a set of observed values, accuracy is a combination of a random component and a common systematic error (bias) component. Measurements for accuracy will include analysis of calibration standards, laboratory control samples, matrix spike samples, and surrogate spike recoveries~~samples~~. The bias component of accuracy is expressed as percent recovery (%R). Percent recovery is expressed as follows:

$$\%R = \frac{(measured\ sample\ concentration)}{true\ concentration} \times 100$$

L-~~8b~~7a(~~1~~2)(i)(A) Accuracy Objectives for Field Measurements

Field measurements will include pH, Specific Conductance (**SC**), temperature, ~~Eh~~, specific gravity and static ~~ground-water~~groundwater surface elevation. Field measurement accuracy will be determined using calibration ~~check~~ standards. Thermometers used for field measurements will be calibrated to the National Institute for Standards and Technology (**NIST**) traceable standard on an annual basis to ~~assure~~ensure accuracy. Accuracy of ~~ground-water~~groundwater surface elevation measurements will be checked before each measurement period by verifying calibration of the device within the specified schedule. WIPP document WP 13-1 outlines the basic requirements for field equipment use and calibration. WIPP facility SOPs ~~Procedure WP 10-AD3029~~ contain~~s~~ instructions that outline protocols for maintaining current calibration of ~~ground-water~~groundwater surface elevation measurement instrumentation. ~~A current revision of this document or procedure will be maintained in the WIPP Operating Record.~~

L-~~8b~~7a(~~1~~2)(i~~i~~)(B) Accuracy Objectives for Laboratory Measurements

Analytical system accuracy will be quantified using the following laboratory accuracy QC checks: calibration standards, laboratory control samples (**LCS**), laboratory blanks, matrix and surrogate spike recoveries ~~samples~~. Single LCSs and matrix spike and surrogate spike sample analyses will be expressed as %R. Laboratory analytical accuracy is parameter dependent and will be prescribed in the laboratory SOP.

L-~~8b~~7a(2)(ii) Precision

Precision is the agreement among a set of replicate measurements without assumption or knowledge of the true value. Precision data will be derived from duplicate field and laboratory measurements. Precision will be expressed as relative percent difference (**RPD**), which is calculated as follows:

$$RPD = \frac{\left|(measured\ value\ sample\ 1 - measured\ value\ sample\ 2)\right|}{average\ of\ \ measured\ samples\ 1+2} \times 100$$

L-~~8b~~7a(2)(ii)(A) Precision Objectives for Field Measurements

~~Precision of field measurements of water-quality parameters will meet or exceed required reporting levels.~~ Specific conductance ~~SC~~, pH, temperature, and ~~optionally Eh~~ will be measured during well purging and after sampling. SC measurements will be precise to ±10%, pH to 0.10 standard unit, specific gravity to 0.01 by hydrometer, ~~and~~ temperature to 0.10 degrees Celsius (°C), and SC~~Eh~~ to 10 millivolts (mV). Water-level measurement will be precise to ±0.01 ft. The precision of water density measurements, when measured in the field using down hole instrumentation, will be determined on a well-by-well basis and will result in no more than ±2 ft of error in the derived fresh-water head.

L-~~8b~~7a(2)(ii)(B) Precision Objectives for Laboratory Measurements

~~Precision of laboratory analyses will be assessed by performing the same analyses twice on LCSs with each analytical batch assessed at a minimum frequency of 1 in 20 ground-water samples for nonradiological parameters and 1 in 10 for radiological parameters. The laboratory will determine analytical precision control limits by performing replicate analyses of control samples. Precision measurements will be expressed as RPD.~~ Precision of laboratory analyses will be determined by analyzing a LCS and a lab control sample duplicate (**LCSD**) or by analyzing one of the field samples in duplicate depending on the requirements of the particular standard method. The precision is measured as the RPD of the recoveries for the spiked LCS/LCSD pair or the RPD of the duplicate sample analysis results. Laboratory analytical precision is also parameter dependent and will be prescribed in laboratory SOPs.

L-~~8b~~7a(~~3~~2)(iii) Contamination

In addition to measurements of precision and bias, QC checks for contamination will be performed. QC samples including trip blanks, field blanks, and method blanks will be analyzed to assess and document contamination attributable to sample collection equipment, sample handling and shipping, and laboratory reagents and glassware. Trip blanks will be used to assess volatile organic compound (**VOC**) sample contamination during shipment and handling and will be collected and analyzed at a frequency of 1 sample per sample shipment. Field blanks will be used to assess field sample collection methods and will be collected and analyzed at a minimum frequency of one sample per 20 samples (five percent of the samples collected).

Method blanks will be used to assess contamination resulting from the analytical process and will be analyzed at a minimum frequency of one sample per 20 samples, or five percent of the samples collected. Evaluation of sample blanks will be performed following U.S. EPA "National Functional Guidelines for Organic Data Review" (EPA, ~~1991~~1999) and "National Functional Guidelines for Evaluating Inorganics Analyses" (EPA, ~~1988~~2004). Only method blanks will be analyzed via wet chemistry methods. The criteria for evaluating method blanks will be established as follows: If method blank results exceed method reporting limits, then that value will become the detection limit for the sample batch. Detection of analytes of interest in method blank samples may be used to disqualify some samples, requiring resampling and additional analyses on a case-by-case basis.

L-~~8b~~7a(~~4~~2)(iv) Completeness

Completeness is a measure of the amount of usable valid data resulting from a data collection activity, given the sample design and analysis. Completeness may be affected by unexpected conditions that may occur during the data collection process.

Occurrences that reduce the amount of data collected include sample container breakage during sample shipment or in the laboratory and data generated while the laboratory was operating outside prescribed QC limits. All attempts will be made to minimize data loss and to recover lost data whenever possible. The completeness objective for analysis of Part 5, Table 5.4.a parameters ~~noncritical measurements (i.e., field measurements)~~ will be 90 percent and 100 percent analysis of Part 5, Table 5.4.b hazardous constituents~~for critical measurements (i.e., compliance data)~~. If the completeness objective for Part 5, Table 5.4.b hazardous constituents is not met, the ~~WIPP EM Manager~~Permittees will determine ~~on behalf of the Permittees~~ the need for resampling on a case-by-case basis. Numerical expression of the completeness (**%C**) of data is as follows:

$$\%C = \frac{number\ of\ accepted\ samples}{total\ number\ of\ samples\ collected} \times 100$$

L-~~8b~~7a(~~5~~2)(v) Representativeness

Representativeness is the degree to which sample analyses accurately and precisely represent the media they are intended to represent. Data representativeness for this DMP will be accomplished through implementing approved sampling procedures and the use of validated analytical methods. Sampling procedures will be designed to minimize factors affecting the integrity of the samples. ~~Ground-water~~Groundwater samples will only be collected after well purging criteria have been met. The analytical methods selected will be those that will most accurately and precisely represent the true concentration of analytes of interest.

For water levels and density, representativeness is a qualitative term that describes the extent to which a sampling design adequately reflects the environmental conditions of a site. The SOPs for measurement ensure that samples are representative of site conditions.

L-~~8b~~7a(~~6~~2)(vi) Comparability

Comparability is the extent to which one data set can be compared to another. Comparability will be achieved through reporting data in consistent units and collection and analysis of samples using consistent methodology. Aqueous samples will consistently be reported in units of measures dictated by the analytical method. Units of measure include:

- Milligrams per liter (mg/L) for alkalinity, inorganic compounds and metals
- Micrograms per liter (µg/L) for VOCs and semivolatile organic compounds (**SVOC**s).

Culebra ~~Ground-water~~groundwater surface elevation measurements will be expressed as equivalent freshwater elevation in feet above mean sea level.

L-~~8c~~7b Design Control

The approved ~~ground-water monitoring system was~~ design~~ed~~ for the DMP is specified in this Permit. Modifications to the DMP will be processed in accordance with ~~and will be maintained to meet specifications established in~~ 20.4.1.~~500~~ 900 NMAC (incorporating 40 CFR §§~~264 Subpart F~~270.42 ~~and 264.601 through 264.603~~).

L-~~8d~~7c Instructions, Procedures, and Drawings

~~Provisions and responsibilities for t~~The preparation and use of instructions and procedures at the WIPP facility are outlined in WIPP document WP 13-1 (see Table L-3). ~~Any a~~Activities performed for the DMP ~~ground-water monitoring~~ that may affect ~~ground water~~groundwater data quality will be performed in accordance with ~~documented and~~ approved procedures which comply with the Permit ~~and the requirements of 20.4.1.500 NMAC (incorporating 40 CFR §264 Subpart F~~).

~~Technical procedures, as specified elsewhere in this DMP, have been developed for each quality-affecting function performed for ground-water monitoring. The technical procedures unique to the DMP will be controlled by the ES&H at WIPP. The procedures are sufficiently detailed and include, when applicable, quantitative or qualitative acceptance criteria.~~

~~Procedures were prepared in accordance with requirements in WIPP document WP 13-1. A current revision of this document will be maintained in the WIPP Operating Record.~~

L-~~8e~~7d Document Control

Permittees ~~Document controls~~ will ensure that the latest approved versions of ~~procedures~~ WIPP facility SOPs will be used in performing ~~ground-water~~groundwater monitoring functions and that obsolete materials will be adequately identified or removed from work areas.

~~L-8f Control of Work Processes~~

~~Process control requirements, defined in WIPP document WP 13-1 are met, and will continue to be met, for this DMP. A current revision of this document will be maintained in the WIPP Operating Record.~~

L-~~8g~~7e Inspection and Surveillance

Inspection and surveillance activities will be conducted as outlined in WIPP document WP 13-1 (see Table L-3). The ~~QA Department~~Permittees will be responsible for performing the applicable WIPP facility SOPs. ~~inspections and surveillance on the scope of work. EM section personnel will be responsible for performance checks as defined in applicable procedures and determined for the Permittees by MOC metrology laboratory personnel. Performance checks for the DMP will determine the acceptability of purchased items and assess degradation that occurs during use. A current revision of this document will be maintained in the WIPP Operating Record.~~

L-~~8h~~7f Control of Monitoring and Data Collection Equipment

WIPP document WP 13-1 (see Table L-3) outlines the basic requirements for control and calibrating monitoring and data collection (**M&DC**) equipment. M&DC equipment shall be properly controlled, calibrated, and maintained according to WIPP facility SOPs (see Table L-3) ~~Procedure WP 10-AD3029~~ to ensure continued accuracy of ~~ground-water~~groundwater monitoring data. Results of calibrations, maintenance, and repair will be documented. Calibration records will identify the reference standard and the relationship to national standards or nationally accepted measurement systems. Records will be maintained to track uses of M&DC equipment. If M&DC equipment is found to be out of tolerance, the equipment will be tagged and it will not be used until corrections are made. ~~A current revision of this document or procedure will be maintained in the WIPP Operating Record.~~

L-~~8i~~7g Control of Nonconforming Conditions

In accordance with ~~WIPP document~~ WP 13-1 (see Table L-3), ~~specifies the system used at WIPP for ensuring that appropriate measures are established to control nonconforming conditions. Nonconforming conditions connected to the DMP will be identified in and controlled by documented procedures. E~~equipment that does not conform to specified requirements will be controlled to prevent use. The disposition of defective items will be documented on records traceable to the affected items. Prior to final disposition, faulty items will be tagged and segregated. Repaired equipment will be subject to the original acceptance inspections and tests prior to use. ~~A current revision of this document will be maintained in the WIPP Operating Record.~~

L-~~8j~~7h Corrective Action

Requirements for the development and implementation of a system to determine, document, and initiate appropriate corrective actions after encountering conditions adverse to quality at the WIPP facility are outlined in WIPP document WP 13-1 (see Table L-3). Conditions adverse to acceptable quality will be documented and reported in accordance with corrective action procedures and corrected as soon as practical. Immediate action will be taken to control work performed under conditions adverse to acceptable quality and its results to prevent quality degradation. ~~A current revision of this document will be maintained in the WIPP Operating Record.~~

L-~~8k~~7i Quality Assurance Records

WIPP document WP 13-1 (see Table L-3) outlines the policy that will be used at the WIPP facility regarding identification, preparation, collection, storage, maintenance, disposition, and permanent storage of QA records. ~~A current revision of this document will be maintained in the WIPP Operating Record.~~

Records to be generated in the DMP will be specified by procedure. QA and RCRA operating records will be identified. This will be the basis for the labeling of records as “QA” or “RCRA operating record” on the Environmental Monitoring Records Inventory and Disposition Schedule~~EM RIDS~~.

~~QA records will document the results of the DMP implementing procedures and will be sufficient to demonstrate that all quality-related aspects are valid. The records will be identifiable, legible, and retrievable.~~

L-~~9~~8 References

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TABLES

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Table L-1
Hydrological Parameters for Rock Units a~~A~~bove the Salado at WIPP

Unit		Hydraulic Conductivity	Storage ~~Coefficient~~	~~Transmissivity~~	~~Permeability~~	Thickness	Hydraulic Gradient
Santa Rosa		2 × 10^{-8} to 2 × 10^{-6} m/s (1) (2)	~~Specific capacity 0.029 to 0.041 ℓ/s/m~~	~~6 × 10^{-7} to 6 × 10^{-5} m^2/s (3)~~	~~10^{-10} m^2~~	0 to 91 m	0.001 (5)
Dewey Lake		10^{-8} m/s	Specific storage 1 × 10^{-5} (1/m) (2)	~~2.8 × 10^{-6} to 2.8 × 10^{-4} m^2/s (4)~~	~~5.01 × 10^{-17} m^2~~	152 m	0.001 (5)
Rustler	Forty-niner	1 × 10^{-13} to 1 × 10^{-11} m/s (anhydrite) 1 × 10^{-9} m/s (mudstone) (2)	Specific storage 1 × 10^{-5} (1/m) (2)	~~8 × 10^{-8} to 8 × 10^{-9} m^2/s~~	~~0 m^2~~	13 to 23 m	NA (6)
	Magenta	1 × 10$^{-8.5}$ to 1 × 10$^{-6.5}$ m/s (2)	Specific storage 1 × 10^{-5} (1/m) (2)	~~4 × 10^{-4} to 1 × 10^{-9} m^2/s~~	~~6.31 × 10^{-14} m^2~~	7 to 8.5 m	3 to 6
	Tamarisk	1 × 10^{-13} to 1 × 10^{-11} m/s (anhydrite) 1 × 10^{-9} m/s (mudstone) (2)	Specific storage 1 × 10^{-5} (1/m) (2)	~~<2.7 × 10^{-11} m^2/s~~	~~0 m^2~~	26 to 56 m	NA (6)
	Culebra	1 × 10$^{-7.5}$ to 1 × 10$^{-5.5}$ m/s (2)	Specific storage 1 × 10^{-5} (1/m) (2)	~~1 × 10^{-3} to 1 × 10^{-129} m^2/s~~	~~2.1 × 10^{-14} m^2~~	4 to 11.6 m	0.003 to 0.007 (5)
	~~Unnamed lower member~~Los Medaños	6 × 10^{-15} to 1 × 10^{-13} m/s 1.5 × 10^{-11} to 1.2 × 10^{-11} m/s (basal interval)	Specific storage 1 × 10^{-5} (1/m) (2)	~~2.9 × 10^{-10} to 2.2 × 10^{-13} m^2/s~~ ~~2.9 × 10^{-10} to 2.4 × 10^{-10} m^2/s (basal interval)~~	~~0 m^2~~	29 to 38 m	NA (6)

Matrix characteristics relevant to fluid flow include values used in this table such as permeability, hydraulic conductivity, gradient, etc.)

Table Notes:

(1) The Santa Rosa Formation is not present in the western portion of the WIPP site. It was combined with the Dewey Lake Red Beds in three-dimensional regional groundwater flow modeling (Corbet and Knupp, 1996), and the range of values entered here are those used in that study for the Dewey Lake/Triassic hydrostratigraphic unit.

(2) Values or ranges of values given for these entries are the values used in three-dimensional regional groundwater flow modeling (Corbet and Knupp, 1996). Values are estimated based on literature values for similar rock types, adjusted to be consistent with site-specific data where available. Ranges of values include spatial variation over the WIPP site and differences in values used in different simulations to test model sensitivity to the parameter.

~~(3) The range of values given here for transmissivity of the Santa Rosa is estimated for the center of the site. Transmissivity is the product of the thickness of the productive interval times its hydraulic conductivity. Thickness of the Santa Rosa is estimated to be 30 meters at the center of the WIPP site, and the range of derived transmissivities are based on the range of hydraulic conductivity values used by Corbet and Knupp (1996) for the combined Dewey Lake/Triassic unit.~~

~~(4) The range of values given here by transmissivity of the Dewey Lake is estimated for the center of the site. Transmissivity is the product of the thickness of the productive interval times its hydraulic conductivity. Thickness of the Dewey Lake is estimated to be 140 meters at the center of the WIPP site, and the range of derived transmissivities are based on the range of hydraulic conductivity values used by Corbet and Knupp (1996) for the combined Dewey Lake/Triassic unit.~~

(5) Hydraulic gradient is a dimensionless term describing change in the elevation of hydraulic head divided by change in horizontal distance. Values given in these entries are determined from potentiometric surfaces. The range of values given for the Culebra reflects the highest and lowest gradients observed within the WIPP site boundary. Values for the Dewey Lake and Santa Rosa are assumed to be the same as the gradient determined from the water table. Note that the Santa Rosa Formation is absent or above the water table in most of the controlled area, and that the concept of a horizontal hydraulic gradient is not meaningful for these regions.

(6) Flow in units of very low hydraulic conductivity is slow, and primarily vertical. The concept of a horizontal hydraulic gradient is not applicable.

Sources: Beauheim, 1986; Domenico and Schwartz, 1990; Domski, Upton, and Beauheim, 1996; Earlough, 1977.

Table L-2

WIPP ~~Ground-water~~Groundwater Detection Monitoring Program Sample Collection and ~~Ground-water~~Groundwater Surface Elevation Measurement Frequency

Installation	Frequency
~~Ground-water~~Groundwater Quality Sampling	
~~DMP monitoring wells~~DMWs	~~Semia~~Annually
~~All other WIPP surveillance wells~~	~~On special request only~~
~~Ground-water~~Groundwater Surface Elevation Monitoring	
~~DMP monitoring wells~~DMWs	Monthly and prior to sampling events
WLMP Wells (see Table L-4) ~~All other WIPP surveillance well sites~~	Monthly
~~Redundant wells at all other WIPP surveillance well sites~~	~~Quarterly~~

~~Table L-3~~
~~Analytical Parameter List for the WIPP Detection Monitoring Program~~

~~Background Ground-water Quality~~	~~Operational Detection Monitoring Ground-water Quality~~
~~Indicator Parameters~~ ~~pH, SC, TOC, TOH, TDS, TSS, density~~ ~~Parameters Listed in~~ ~~20.4.1.500 NMAC (incorporating 40 CFR §264) Appendix IX, Calcium, Magnesium, Potassium~~ ~~Field Analyses~~ ~~pH, SC, temperature, chloride, Eh, alkalinity, total Fe, specific gravity~~	~~Indicator Parameters~~ ~~pH, SC, TOC, TOH, TDS, TSS, density~~ ~~Hazardous Constituents~~ ~~Organic~~ ~~Chloroform~~ ~~1,2-dichloroethane~~ ~~Carbon tetrachloride~~ ~~Chlorobenzene~~ ~~1,1-dichloroethylene~~ ~~1,1-dichloroethane~~ ~~Methylene chloride~~ ~~1,1,2,2-tetrachloroethane~~ ~~Toluene~~ ~~1,1,1-trichloroethane~~ ~~Cresols~~ ~~1,4-dichlorobenzene~~ ~~1,2-dichlorobenzene~~ ~~trans-1,2-dichloroethylene~~ ~~2,4-dinitrophenol~~ ~~2,4-dinitrotoluene~~ ~~Hexachloroethane~~ ~~Hexachlorobenzene~~ ~~Isobutanol~~ ~~Methyl ethyl ketone~~ ~~Pentachlorophenol~~ ~~Pyridine~~ ~~Tetrachloroethylene~~ ~~1,1,2 Trichloroethane~~ ~~Trichloroethylene~~ ~~Trichlorofluoromethane~~ ~~Xylenes~~ ~~Nitrobenzene~~ ~~Vinyl Chloride~~ ~~Metals~~ ~~Arsenic~~ ~~Barium~~ ~~Cadmium~~ ~~Chromium~~ ~~Lead~~ ~~Mercury~~ ~~Selenium~~ ~~Silver~~ ~~Antimony~~ ~~Calcium~~ ~~Beryllium~~ ~~Magnesium~~ ~~Nickel~~ ~~Potassium~~ ~~Thallium~~ ~~Vanadium~~ ~~Field Analyses~~ ~~pH, SC, temperature, chloride, Eh, alkalinity, total Fe, specific gravity~~

~~Note: Because of the lack of sophisticated weights and measures equipment available for field density assessment, field density evaluations are expressed in terms of specific gravity, which is a unitless measure.~~

Table L-3
Standard Operating Procedures Applicable to the DMP

Number	**Title/Description**
WP 02-EM1005	Groundwater Serial Sample Analysis: This procedure provides general instructions necessary to perform field analyses of serial samples in support of the DMP. Serial samples are collected and analyzed at the field laboratory for field indicators. Serial sample results help determine if pumped groundwater is representative of undisturbed groundwater within the formation.
WP 02-EM1006	Final and Serial Sample Collection: This procedure describes the steps for collecting groundwater samples from the DMWs near the WIPP facility. Serial samples are collected and analyzed at the Field Laboratory until stabilization of the field parameters occurs. Final samples for Resource Conservation and Recovery Act (RCRA) analyses are collected and analyzed by a contract laboratory.
WP 02-EM1014	Groundwater Level Measurement: This document describes the method used for groundwater level measurements in support of groundwater monitoring at the WIPP facility using a portable electronic water-level probe.
WP 02-EM1021	Pressure Density Survey: This procedure defines the field methodology used to determine the average density of fluid standing in the well bores of groundwater-level monitoring wells. The data derived from the survey are used to calculate equivalent freshwater heads at non-detection monitoring wells. Because most pressure densities are obtained by Sandia National Laboratories via pressure transducers installed in wells, this procedure is used to obtain pressure densities at wells not equipped with fixed transducers.
WP 02-EM1026	Water Level Data Handling and Reporting: This procedure provides instructions on handling water level data. Data are collected and recorded on field forms in accordance with WP 02-EM1014. This procedure is initiated when wells in the water surveillance program have been measured for a given month.
WP 02-EM3001	Administrative Processes for Environmental Monitoring and Hydrology Programs: This procedure provides the administrative guidance environmental monitoring personnel use to maintain quality control associated with environmental monitoring sampling and reporting activities. This administrative procedure does not pertain to volatile organic compound (VOC) monitoring, with the exception of Section 5.0 which pertains to the regulatory reporting review process.
WP 02-EM3003	Data Validation and Verification of RCRA Constituents: This procedure provides instructions on performing verification and validation of laboratory data containing the analytical results of groundwater monitoring samples. This procedure is applied only to the non-radiological analyses results for compliance data associated with the detection monitoring samples. The data reviewed for this procedure includes general chemistry parameters and RCRA constituents.
WP-02-RC.01	Hazardous and Universal Waste Management Plan: This plan describes the responsibilities and handling requirements for hazardous and universal wastes generated at the WIPP facility. It is meant to ensure that these wastes are properly handled, accumulated, and transported to an approved Treatment, Storage, Disposal Facility (TSDF) in accordance with applicable state and federal regulations, U.S. Department of Energy (DOE) Orders, and Washington TRU Solutions LLC (WTS) policies and procedures. This plan implements applicable sections of 20.4.1.100-1102 New Mexico Administrative Code (NMAC), *Hazardous Waste Management* (incorporating 40 *Code of Federal Regulations* [CFR] Parts 260-268 and 273).
WP 10-AD3029	Calibration and Control of Monitoring and Data Collection Equipment: This procedure provides direction for the control and calibration of Monitoring and Data Collection (M&DC) equipment at the WIPP facility, and ensures traceability to NIST (National Institute of Standards and Technology) standards, international standards, or intrinsic standards. This procedure also establishes requirements and responsibilities for identifying recall equipment, and for obtaining calibration services for WIPP facility M&DC equipment.
WP 13-1	Washington TRU Solutions LLC Quality Assurance Program Description: This document establishes the minimum quality requirements for Management and Operating Contractor (**MOC**) personnel and guidance for the development and implementation of QA programs by MOC organizations.

Table L-4
January 2011 Culebra WLMP

WELL ID	WELL ID	WELL ID
AEC-7	H-17	SNL-15
C-2737	H-19 pad*	SNL-16
ERDA-9	I-461	SNL-17
H-02b2	SNL-01	SNL-18
H-03b2	SNL-02	SNL-19
H-04bR	SNL-03	WQSP-1
H-05b	SNL-05	WQSP-2
H-06bR	SNL-06	WQSP-3
H-07b1	SNL-08	WQSP-4
H-9bR	SNL-09	WQSP-5
H-10c	SNL-10	WQSP-6
H-11b4	SNL-12	WIPP-11
H-12	SNL-13	WIPP-13
H-15R	SNL-14	WIPP-19
H-16		

*H-19b0 monthly

Table L-5
Details of Construction for the Six Culebra Detection Monitoring Wells

NAME (Figure)	DATE DRILLED	TOTAL DEPTH feet (meters) bgs	DEPTH INTO LOS MEDAÑOS feet (meters)	DRILLING DEPTHS feet (meters) bgs		CASING feet (meters) bgs		PACKING feet (meters) bgs		CULEBRA INTERVAL feet (meters) bgs
				WITH AIR	CORING	DEPTH FOR 5 in. CASING	INTERVAL FOR SLOTTED SCREEN	SAND PACK INTERVAL	BRADY GRAVEL PACK INTERVAL	
WQSP-1 Figure L-7	September 13 and 16, 1994	737 (225)	15 (5)	693 (211)	695.6 to 737 (211 to 224.6)	737 (224.6)	702 to 727 (214 to 222)	640 to 651 (195 to 198)	651 to 737 (198 to 224.6)	699 to 722 (213 to 221)
WQSP-2 Figure L-8	September 6 and 12, 1994	846 (257.9)	12.3 (3.7)	800 (244)	800 to 846 (244 to 258)	846 (258)	811 to 836 (247 to 255)	790 to 793 (241 to 242)	793 to 846 (242 to 258)	810.1 to 833.7 (247 to 254)
WQSP-3 Figure L-9	October 21 and 26, 1994	880 (268)	10 (3.1)	880 (268)	833 to 879 (254 to 268)	880 (268)	844 to 869 (257 to 265)	827 to 830 (252 to 253)	830 to 880 (253 to 268)	844 to 870 (257 to 265)
WQSP-4 Figure L-10	October 5 and 10, 1994,	800 (244)	9.2 (2.8)	740 (226)	740.5 to 798 (225.7 to 243)	800 (244)	764 to 789 (233 to 241)	752 to 755 (229 to 230)	755 to 800 (230 to 244)	766 to 790.8 (233 to 241)
WQSP-5 Figure L-11	October 12 and 19, 1994,	681 (208)	2.0(0.61)	676 (206)	648 to 676 (198 to 206)	681 (208)	646 to 671 (197 to 205)	623 to 626 (190 to 191)	626 to 681 (191 to 208)	648 to 674.4 (198 to 205.6)
WQSP-6 Figure L-12	September 26 and October 3, 1994	616.6 (187.9)	9.7 (3)	367 (112)	367 to 616 (112 to 188)	616.6 (188)	581 to 606 (177 to 185)	567 to 570 (173 to 173.7)	570 to 616.6 (174 to 188)	582 to 606.9 (177 to 185)

Table L-46
Analytical Parameter and Sample Requirements

(10) PARAMETERS	(12) NO. OF BOTTLES	(13) VOLUME	(14) TYPE	(15) ACID WASH	(16) SAMPLE FILTER	(17) PRESERVATIVE	(18) HOLDING TIME
Indicator[1] Parameters:							
- pH	-	25 ml[2]	Glass	Field determined	No?	Field determined	None
- SC	-	100 ml[2]	Glass	Field determined	No	Field determined	None
- TOC	4	15 ml[2]	Glass	yes	No	HCl	28 days[2]
- ~~TOX~~	~~3~~	~~250 ml~~	~~Glass~~	~~yes~~	~~No~~	~~H_2SO_4, pH<2~~	~~7 days~~[2]
General Chemistry	1	1 Liter	Plastic	Yes	No	HNO_3,4pH<2	not specified in DMP
Phenolics	1	1 Liter	Amber Glass	Yes	No	H_2SO_4, pH<2	not specified in DMP
Metals/Cations	2	1 Liter	Plastic	Yes	No	HNO_3, pH<2	6 months[2,3]
VOC	4	40 ml	Glass	No	No	HCL, ph<2	14 days[2]
VOC (Purgable)	2	40 ml	Glass	No	No	HCL, ph<2	14 days[2]
VOC (Non-Purgable)	2	40 ml	Glass	No	No	HCL, ph<2	14 days[2]
BN/As	1	½ Gallon	Amber Glass	Yes	No	None	
TCLP	1	1 Liter	Plastic	Yes	No	HNO_3, pH<2	7 days[2]
Cyanide (Total)	1	1 Liter	Plastic	Yes	No	NaOH, pH>12	14 days[2]
Sulfide	1	250 ml	Amber Glass	Yes	No	NaOH + Zn Acetate	28 days[2]
Radionuclides	1	1 Gallon	Plastic Cube	Yes	Yes	HNO_3, pH<2	6 months[2]

1 = RCRA Detection Monitoring Analytes

2 = As specified in Table 4-1 of the RCRA TEGD

3 = Reduced holding time of 1 week for WIPP-specific Divalent cation 2 samples noted in the GMD

Note: Unless otherwise indicated, data are from DOE Procedure WP 02-EM1006 methods and are provided as information only.

Note: Deviations from this table are allowed with prior approval by the NMED.

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FIGURES

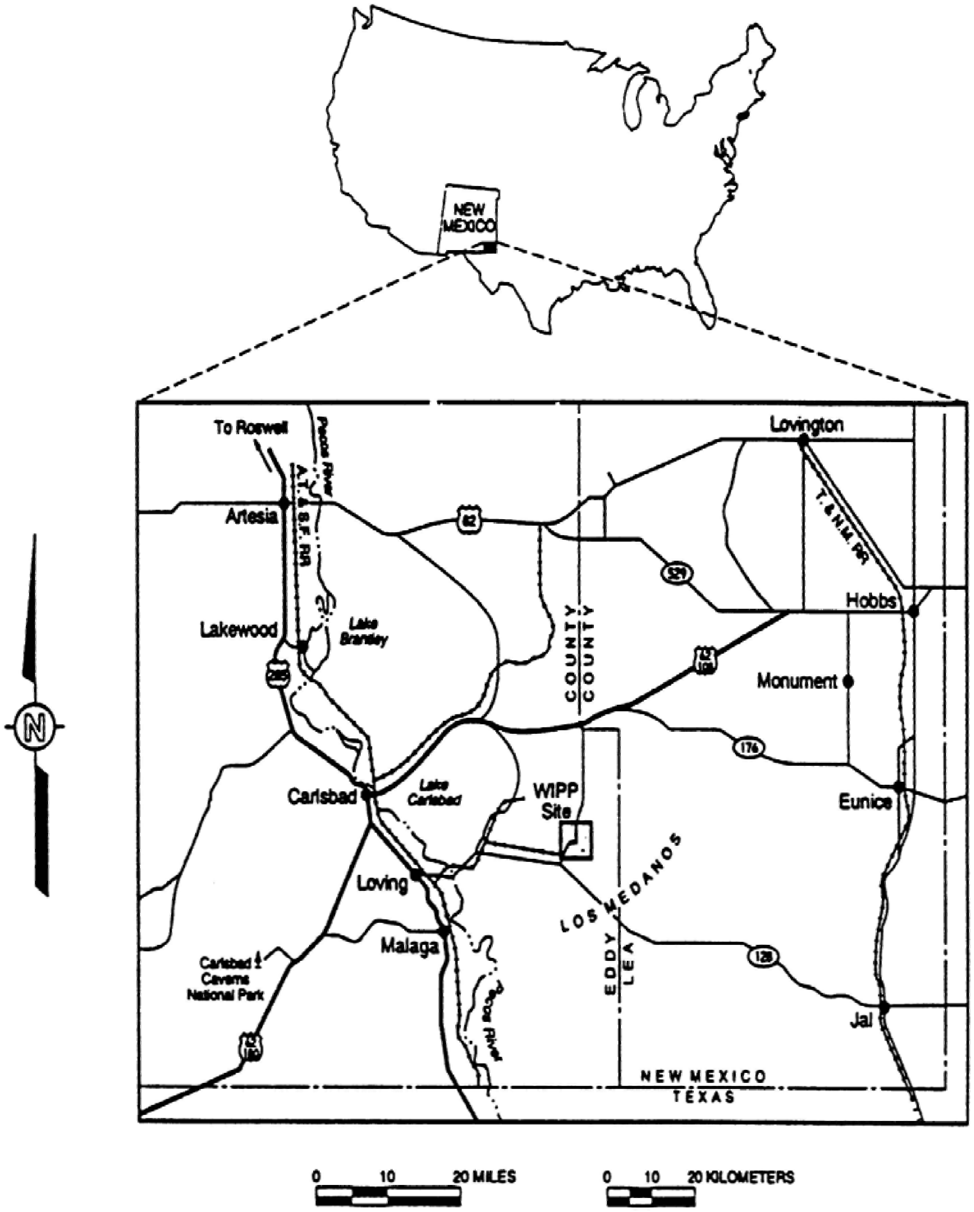
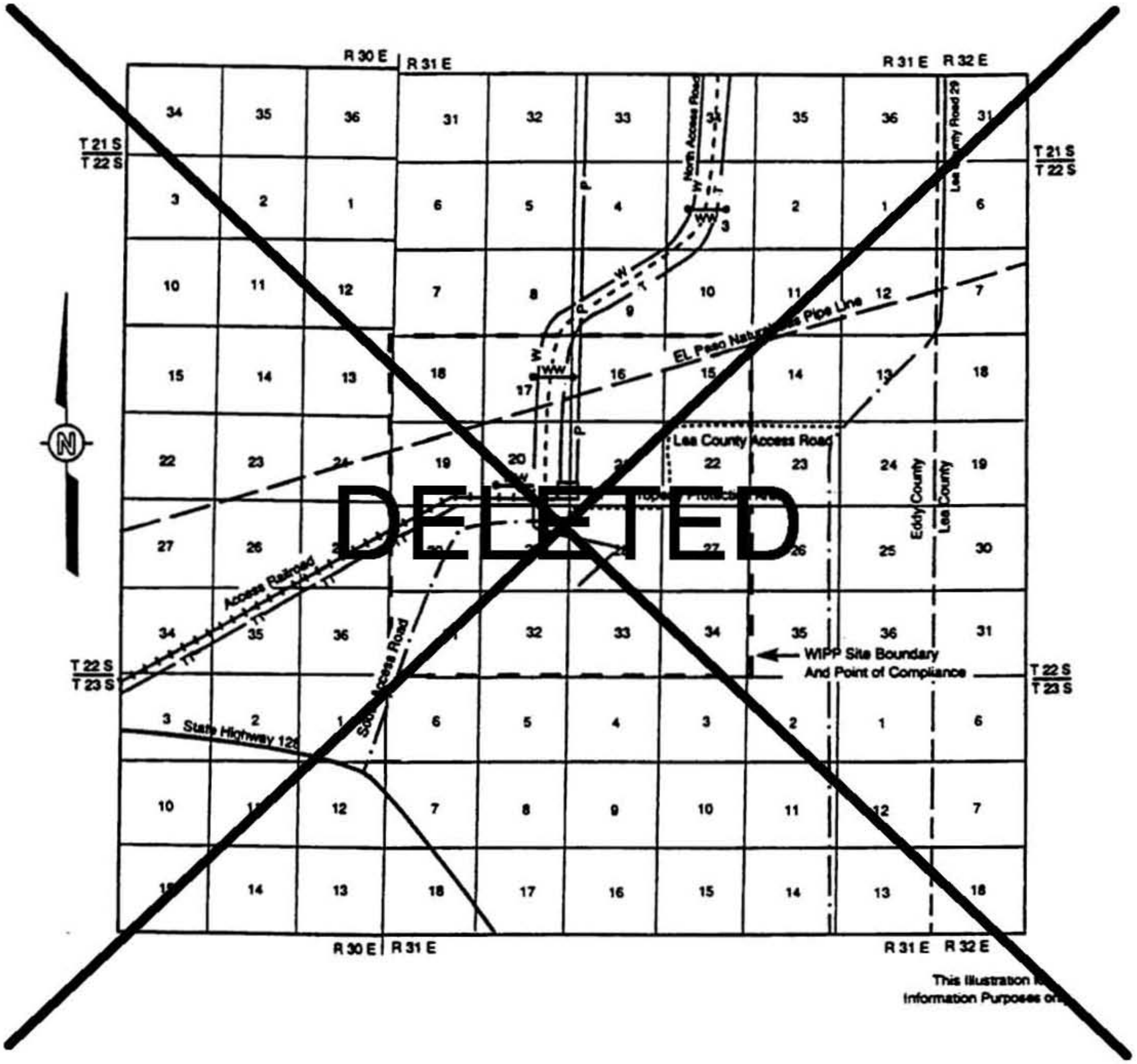


Figure L-1
General Location of the WIPP Facility



~~Figure L-2~~
~~WIPP Facility Boundaries Showing 16-Square-Mile Land Withdrawal Boundary~~

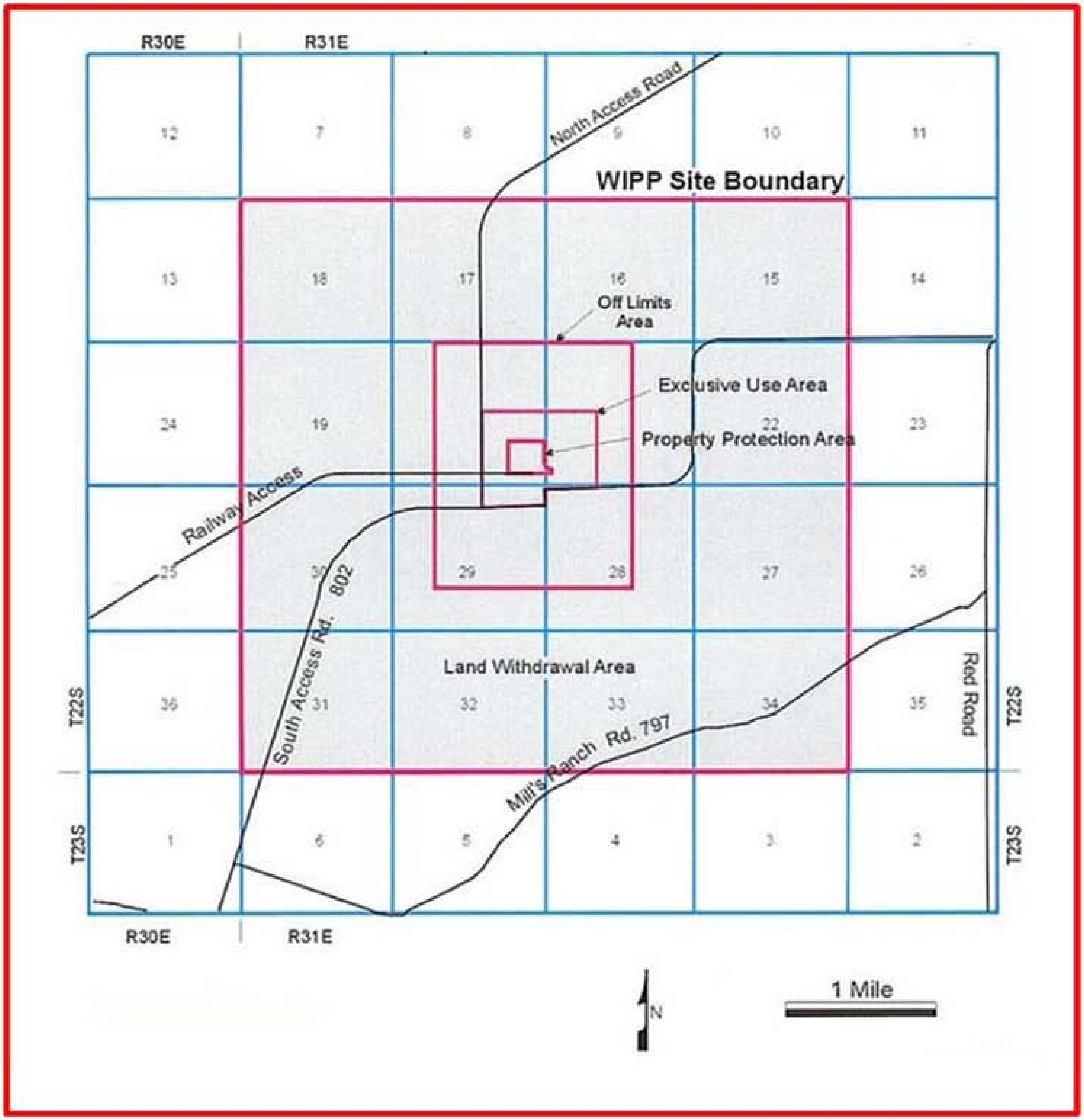


Figure L-2
WIPP Facility Boundaries Showing 17-square-Mile Land Withdrawal Boundary

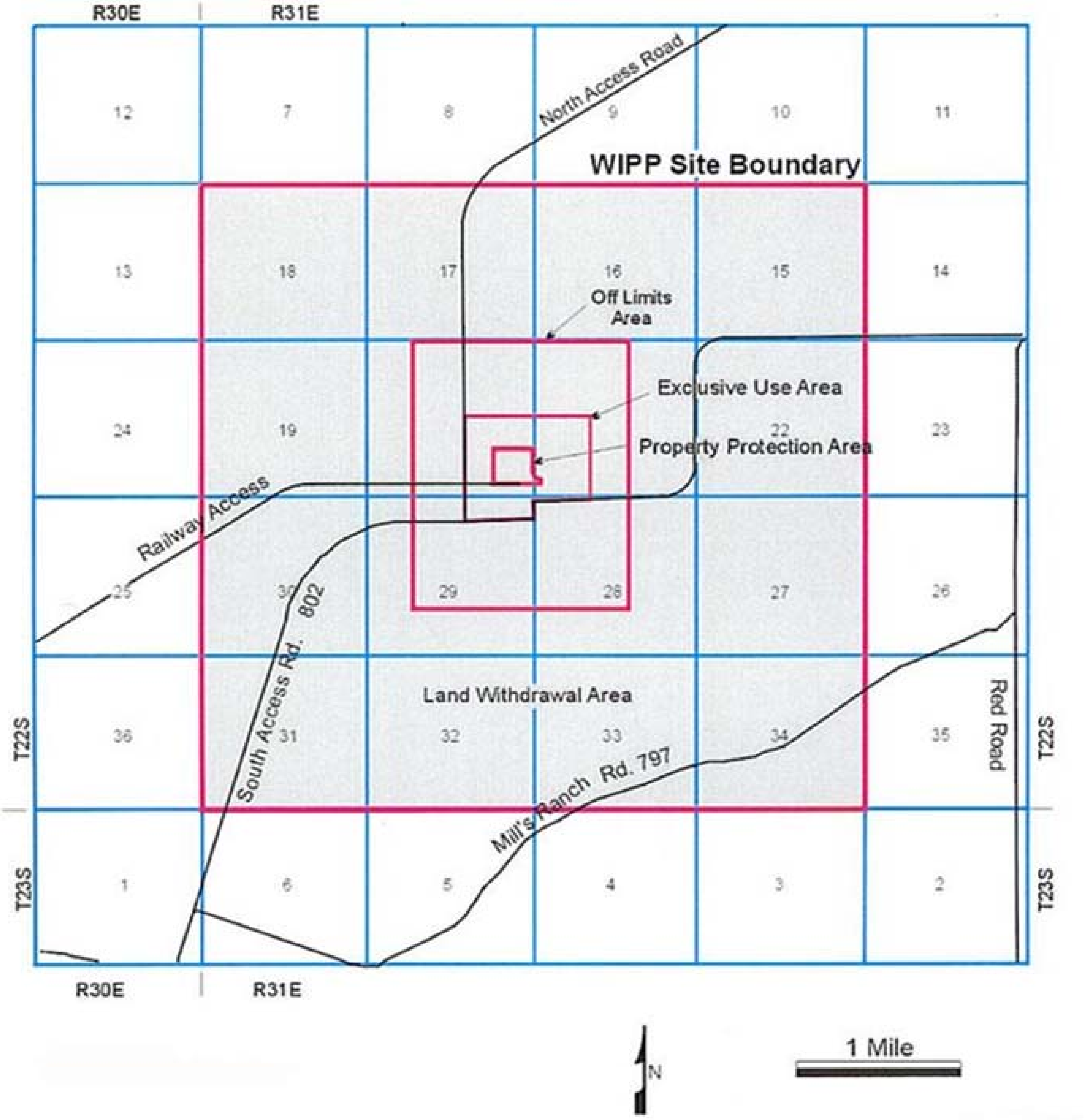


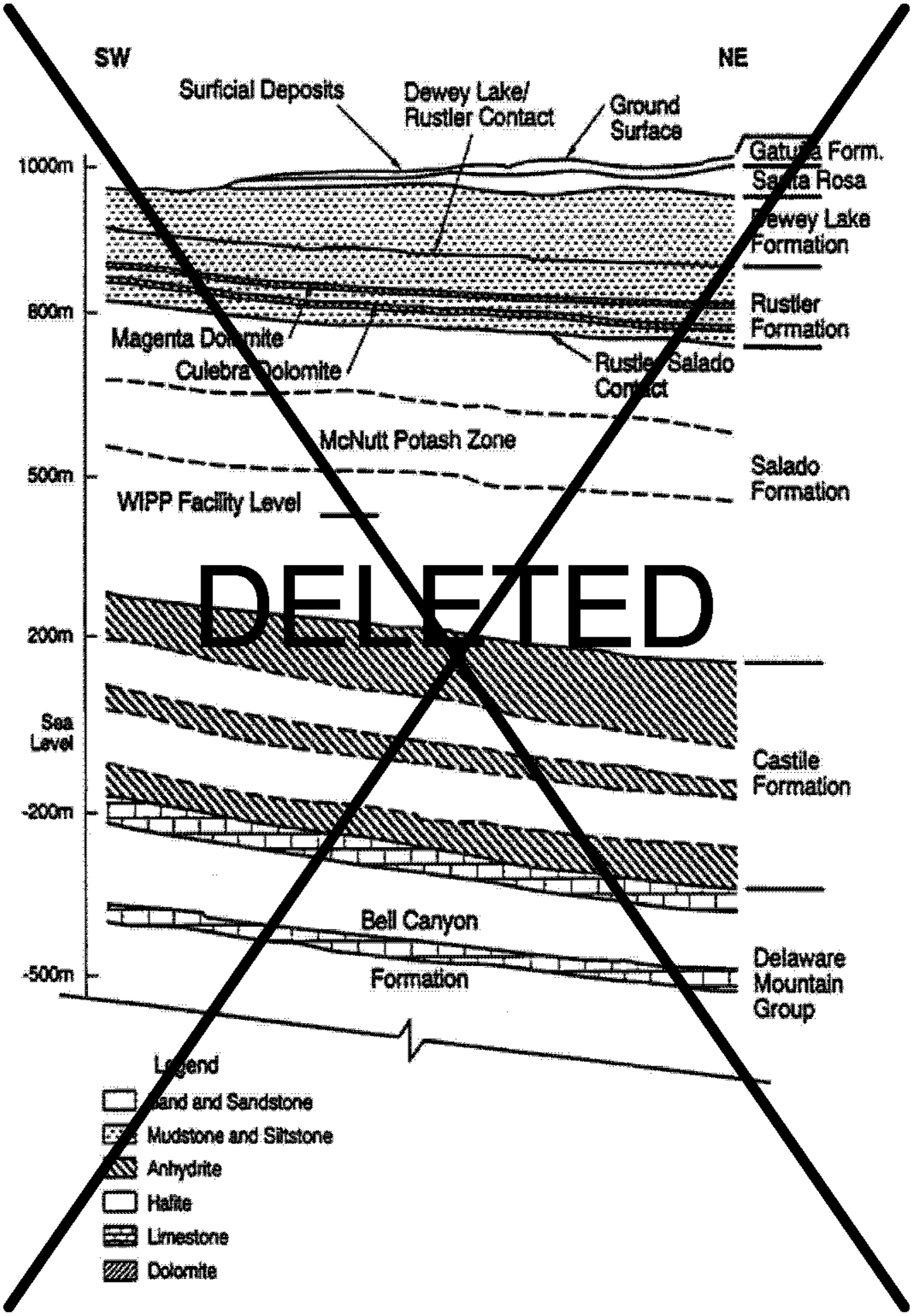
Figure L-2
WIPP Facility Boundaries Showing 17-square-Mile Land Withdrawal Boundary

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATERNARY	PLEISTOCENE		MESCALERO CALICHE	
			GATUÑA	
TERTIARY	MID-PLIOCENE		OGALLALA	
TRIASSIC		DOCKUM	SANTA ROSA	
PERMIAN	**OCHOAN**		**DEWEY LAKE**	
			RUSTLER	Forty-niner
				Magenta
				Tamarisk
				Culebra
				~~Unnamed~~Los Medaños
			SALADO	Upper
				McNutt Potash
				Lower
			CASTILE	
	GUADALUPIAN	**DELAWARE MOUNTAIN**	**BELL CANYON**	
			CHERRY CANYON	
			BRUSHY CANYON	

Figure L-3
Site Geologic Column

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATERNARY	PLEISTOCENE		MESCALERO CALICHE	
			GATUÑA	
TERTIARY	MID-PLIOCENE		OGALLALA	
TRIASSIC		DOCKUM	SANTA ROSA	
PERMIAN	**OCHOAN**		**DEWEY LAKE**	
			RUSTLER	Forty-niner
				Magenta
				Tamarisk
				Culebra
				Los Medaños
			SALADO	Upper
				McNutt Potash
				Lower
			CASTILE	
	GUADALUPIAN	**DELAWARE MOUNTAIN**	**BELL CANYON**	
			CHERRY CANYON	
			BRUSHY CANYON	

Figure L-3
Site Geologic Column



~~Figure L-4~~
~~Generalized Statigraphic Cross Section Above Bell Canyon Formation at WIPP SIte~~

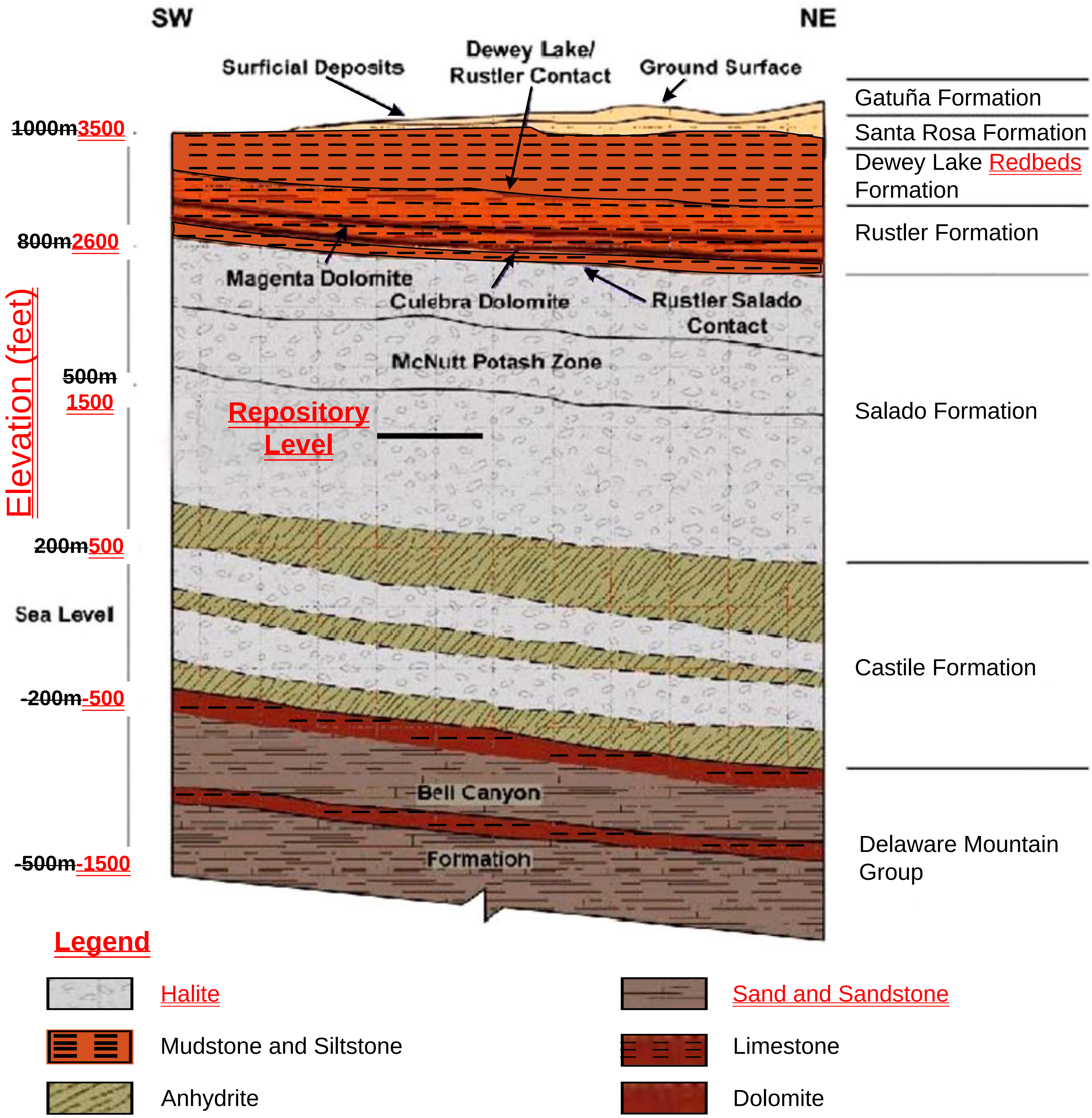


Figure L-4

Generalized Stratigraphic Cross Section Above Bell Canyon Formation at WIPP Site

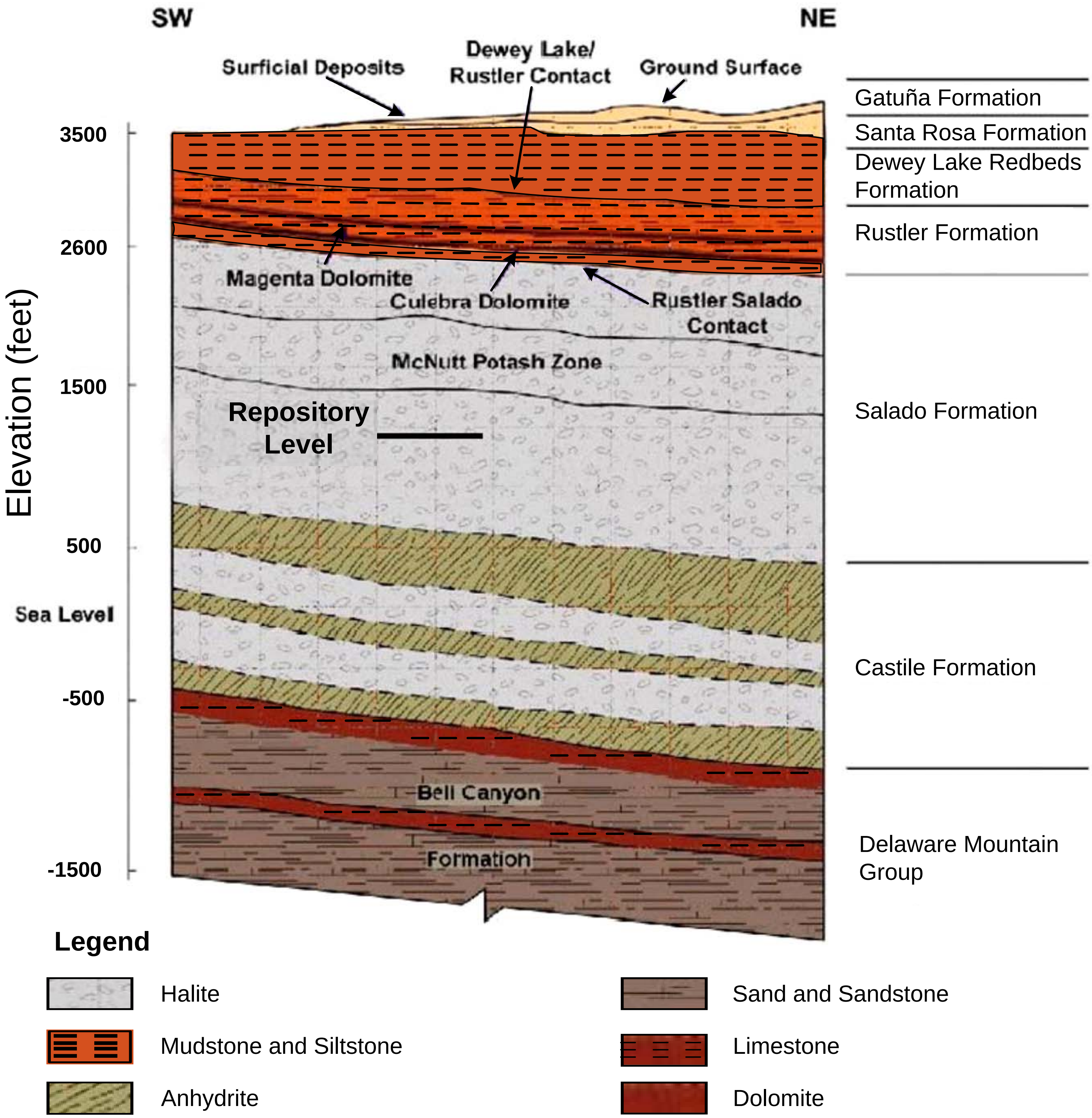
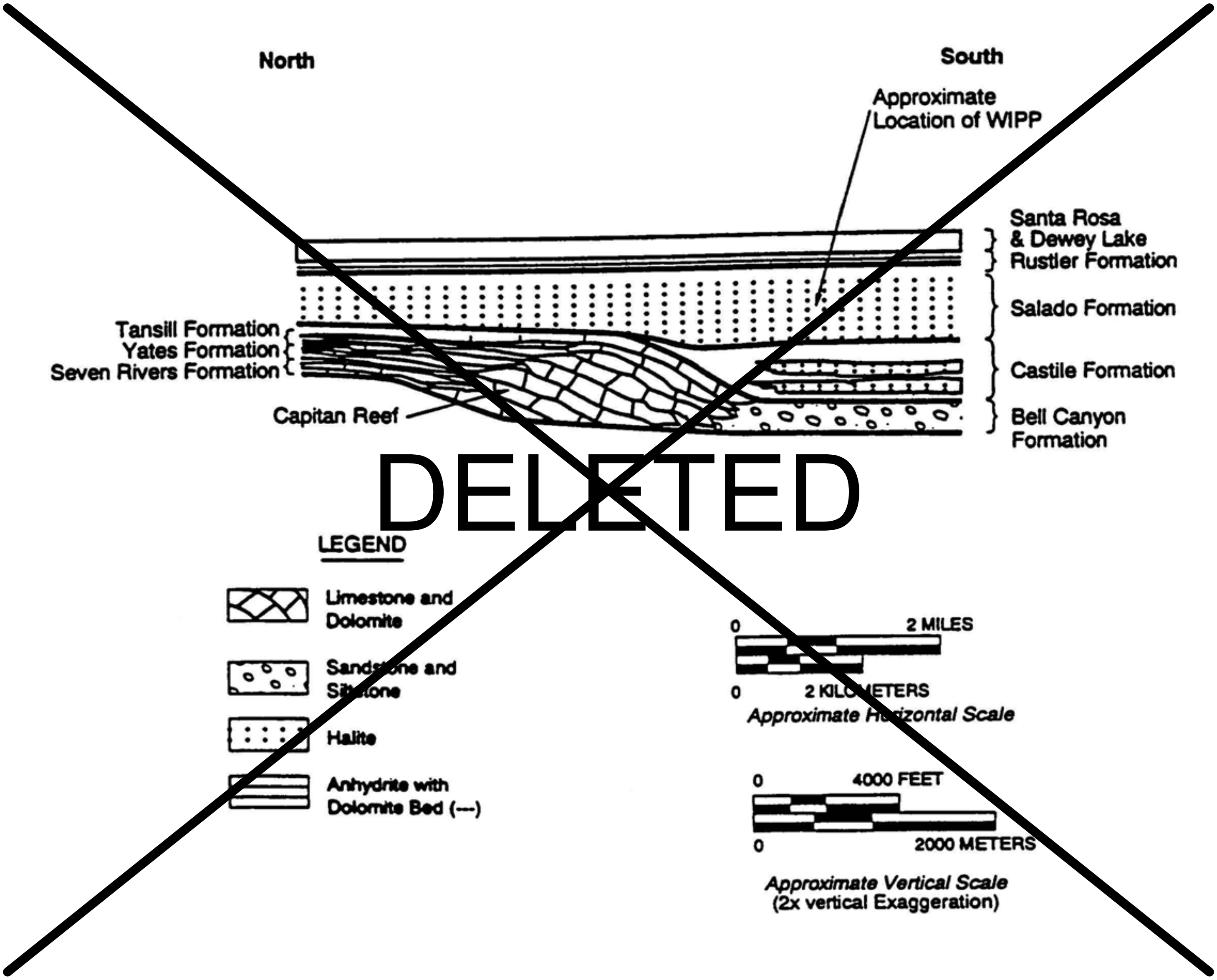


Figure L-4
Generalized Stratigraphic Cross Section Above Bell Canyon Formation at WIPP Site



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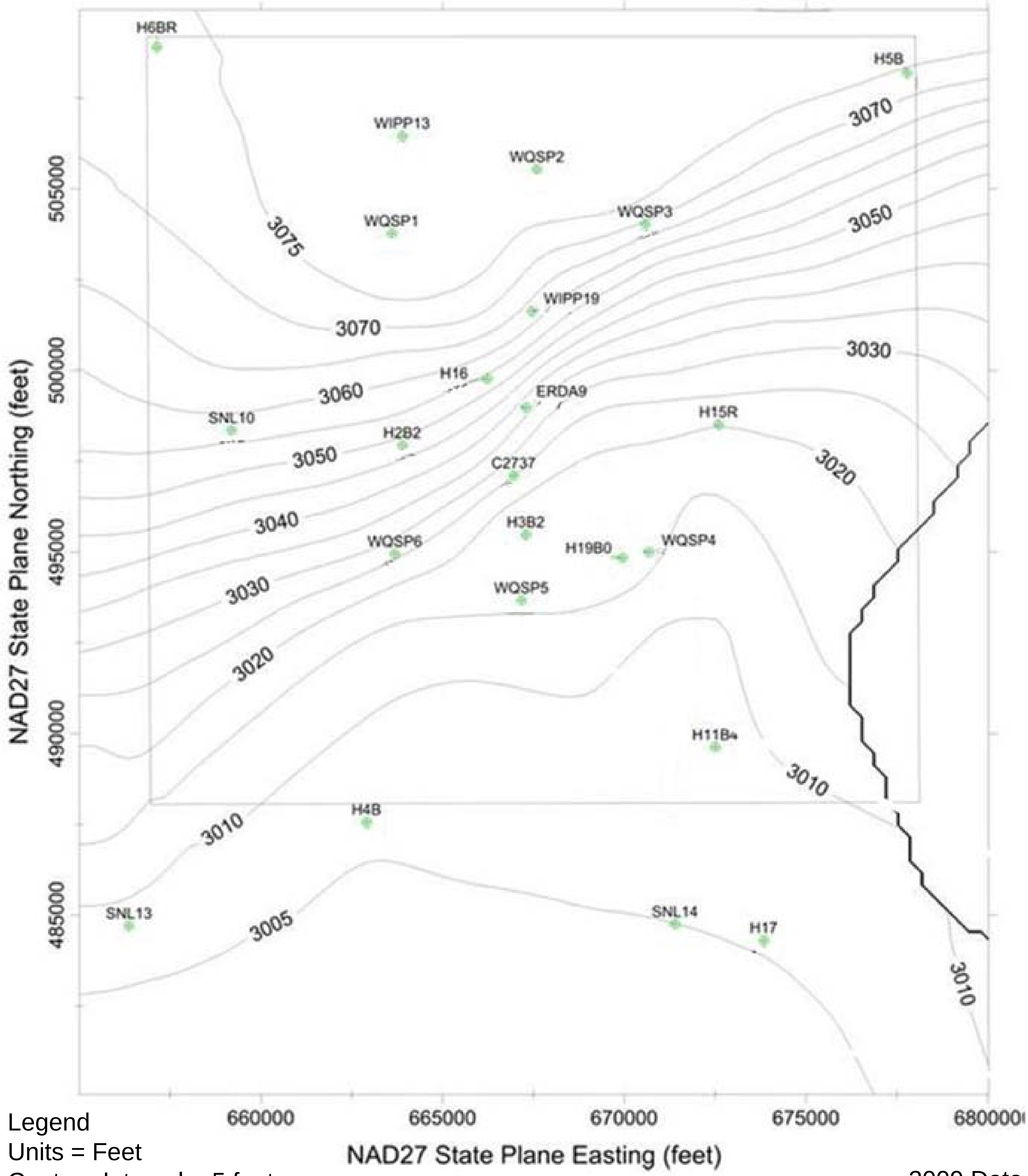
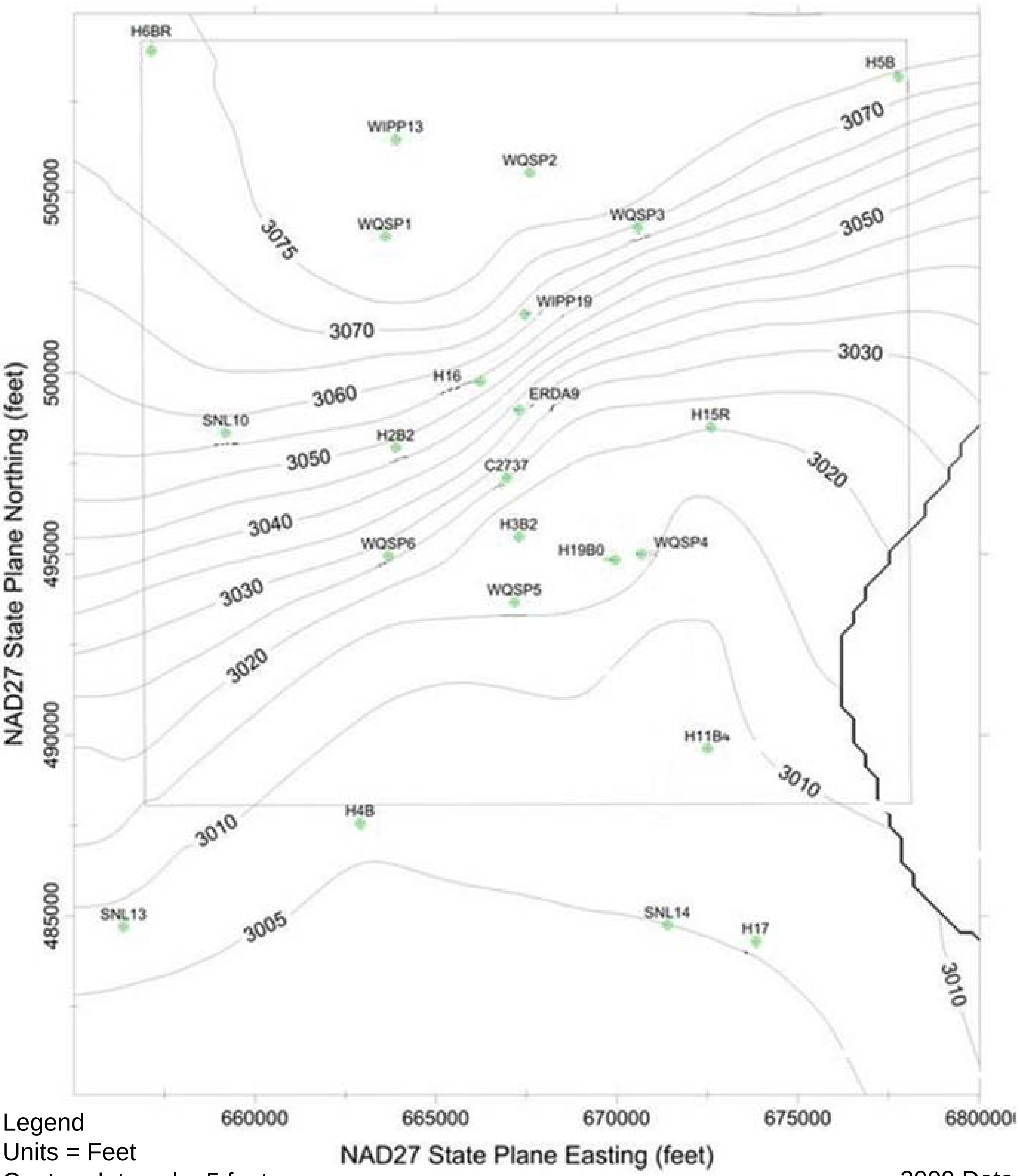
~~Figure L-5~~
~~Schematic North-South Cross Section Through the North Delaware Basin~~



Legend
Units = Feet
Contour Interval = 5 feet

2009 Data

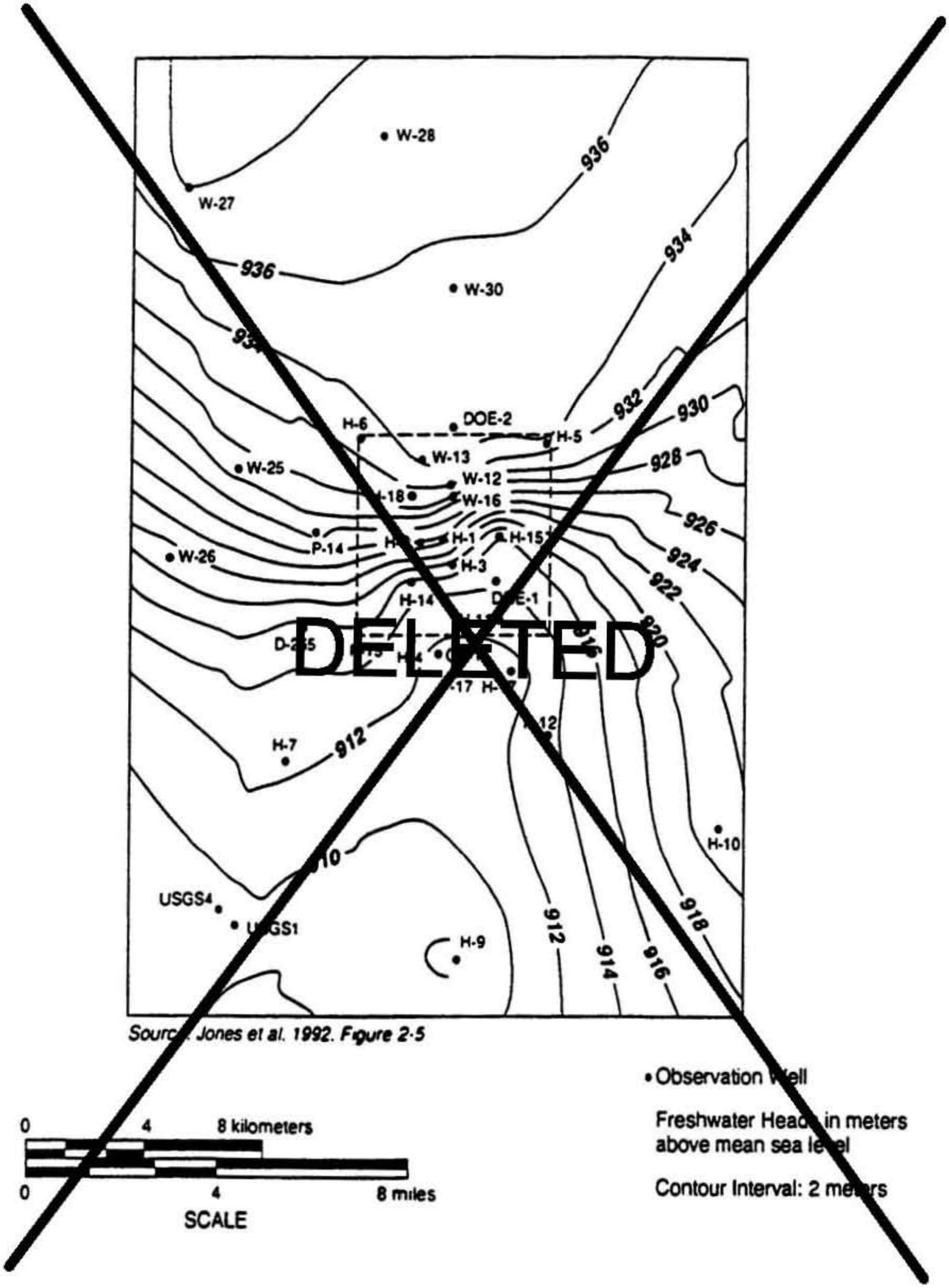
Figure L-5
Culebra Freshwater-Head Potentiometric Surface



Legend
Units = Feet
Contour Interval = 5 feet

2009 Data

Figure L-5
Culebra Freshwater-Head Potentiometric Surface



Source: Jones et al. 1992. Figure 2-5

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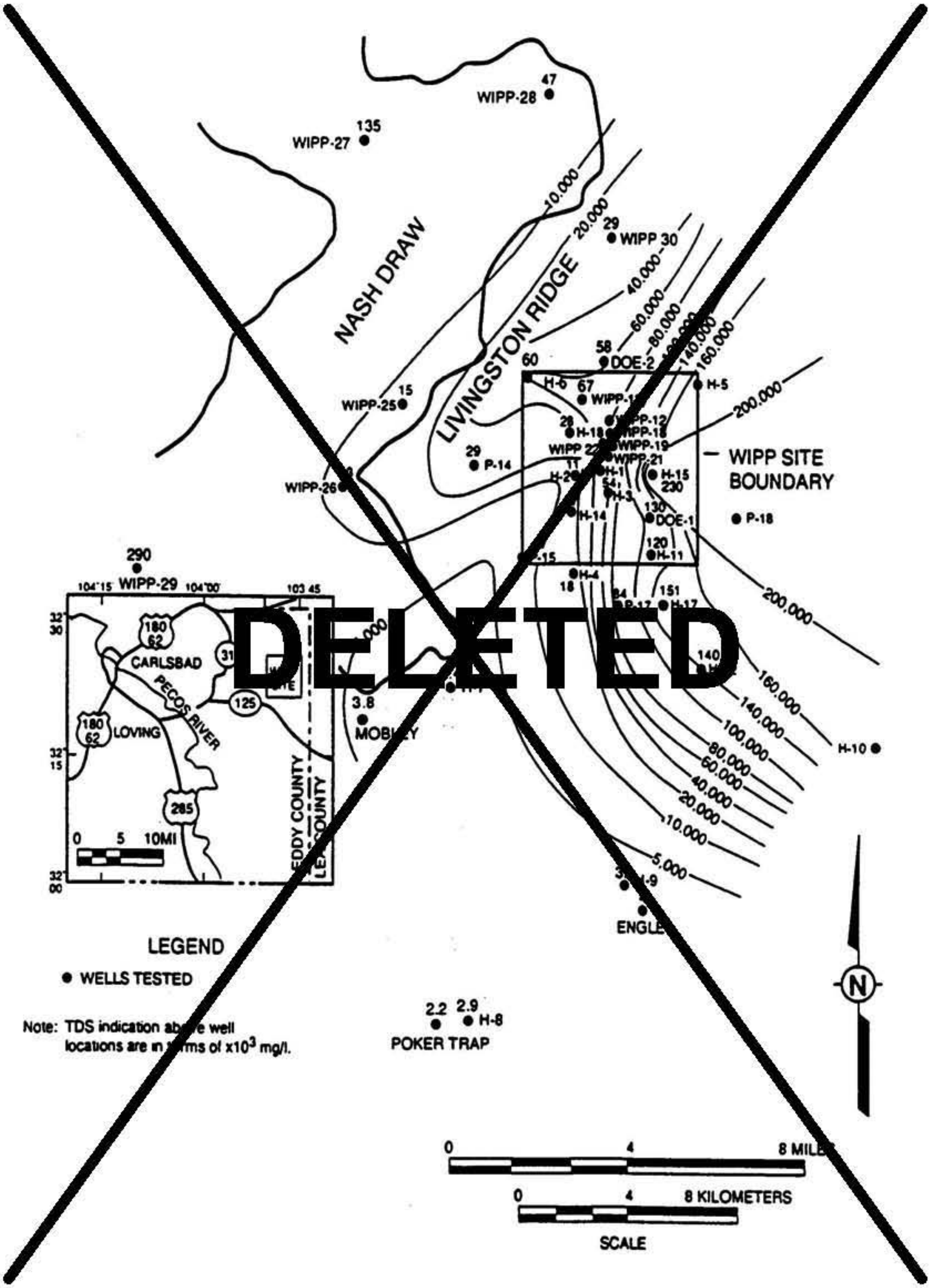
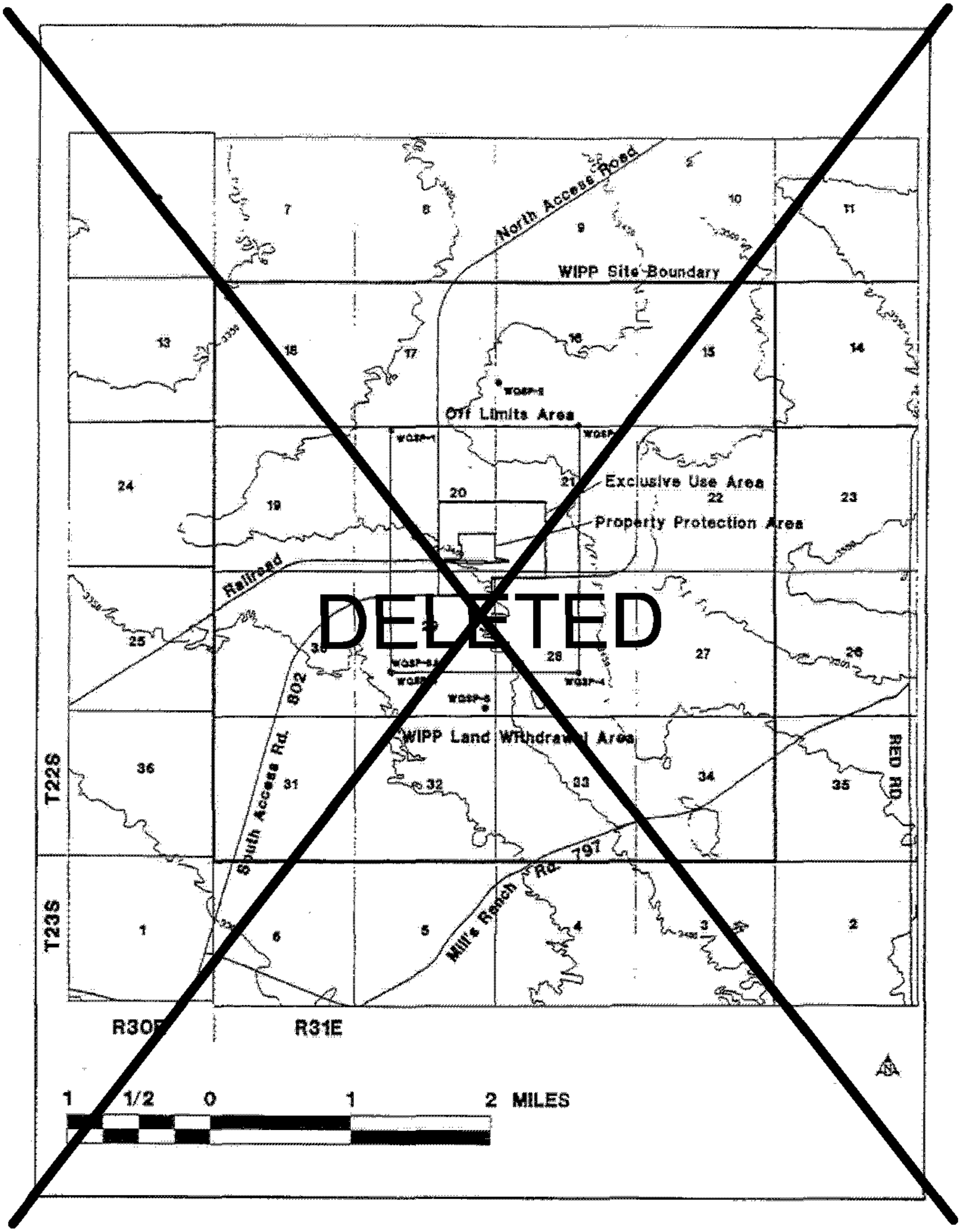
~~Figure L-6~~
~~Culebra Freshwater-Head Contour Surface~~



~~Figure L-7~~
~~Total Dissolved Solids Distribution in the Culebra~~



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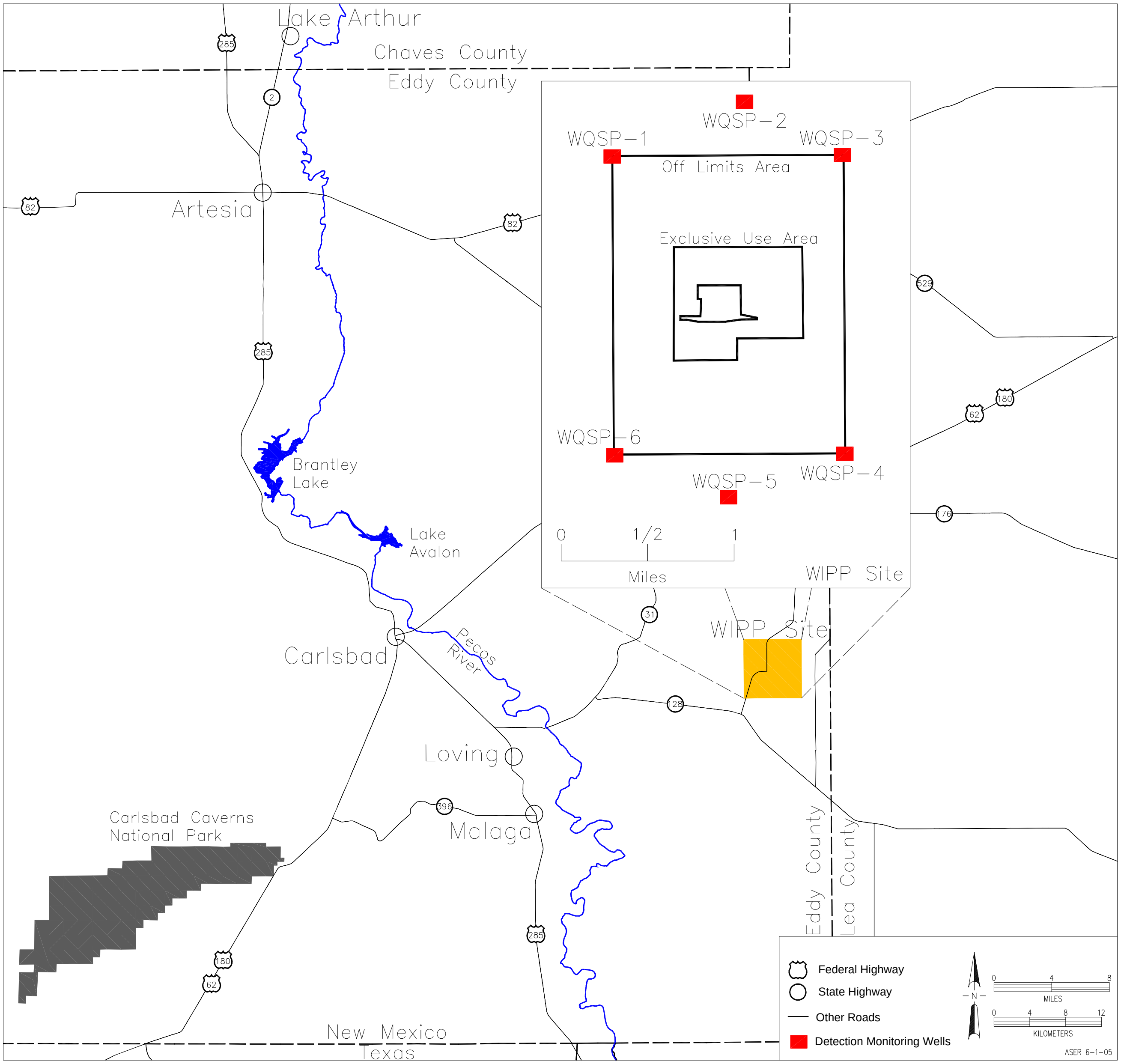
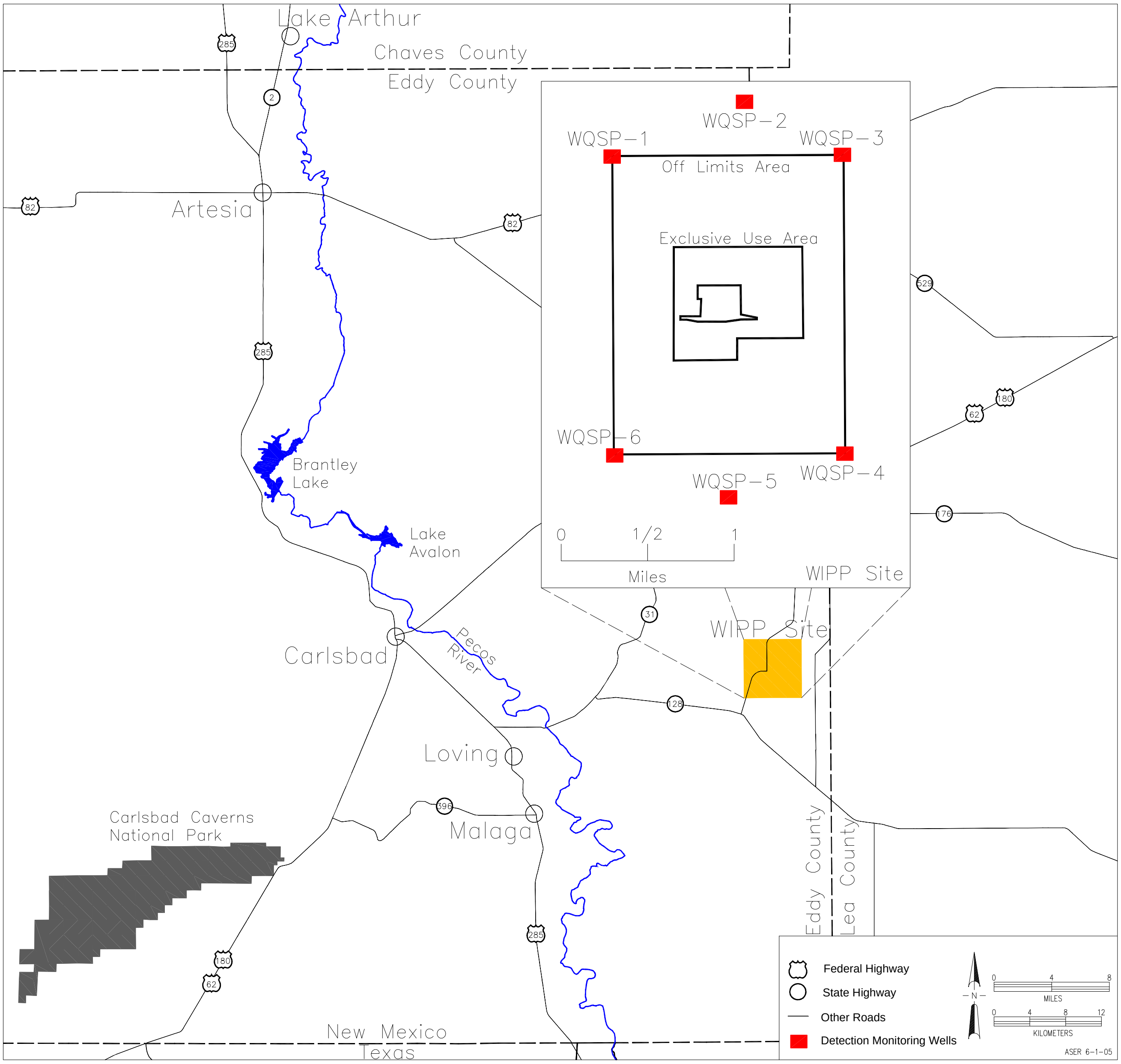
~~Figure L-8~~
~~WQSP Monitor Well Locations~~



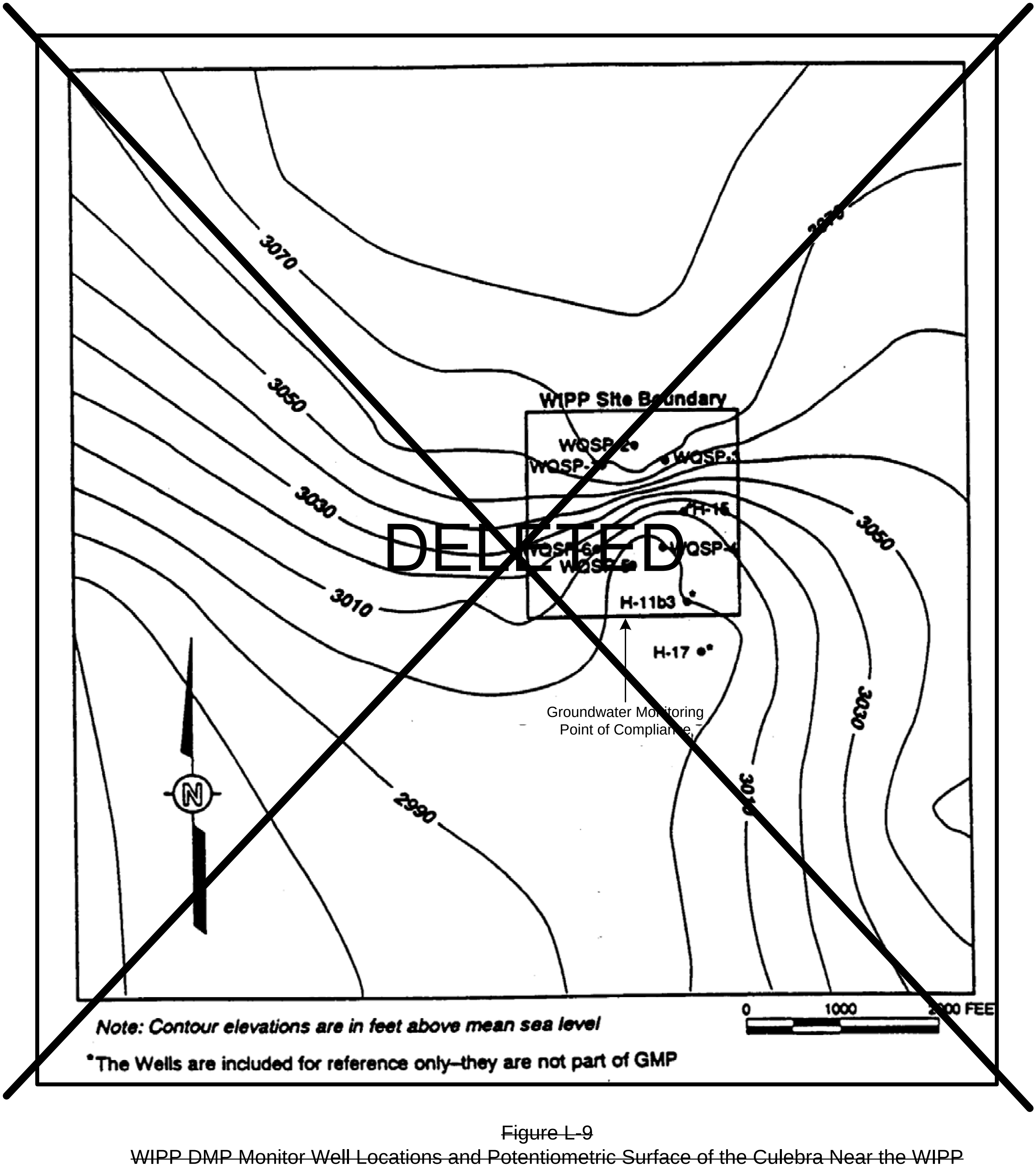
NOTE: Point of compliance is defined in Part 5.3.1.

Figure L-~~8~~6
~~WQSP~~ Detection Monitoring Well Locations



NOTE: Point of compliance is defined in Part 5.3.1.

Figure 6
WQSP Detection Monitoring Well Locations

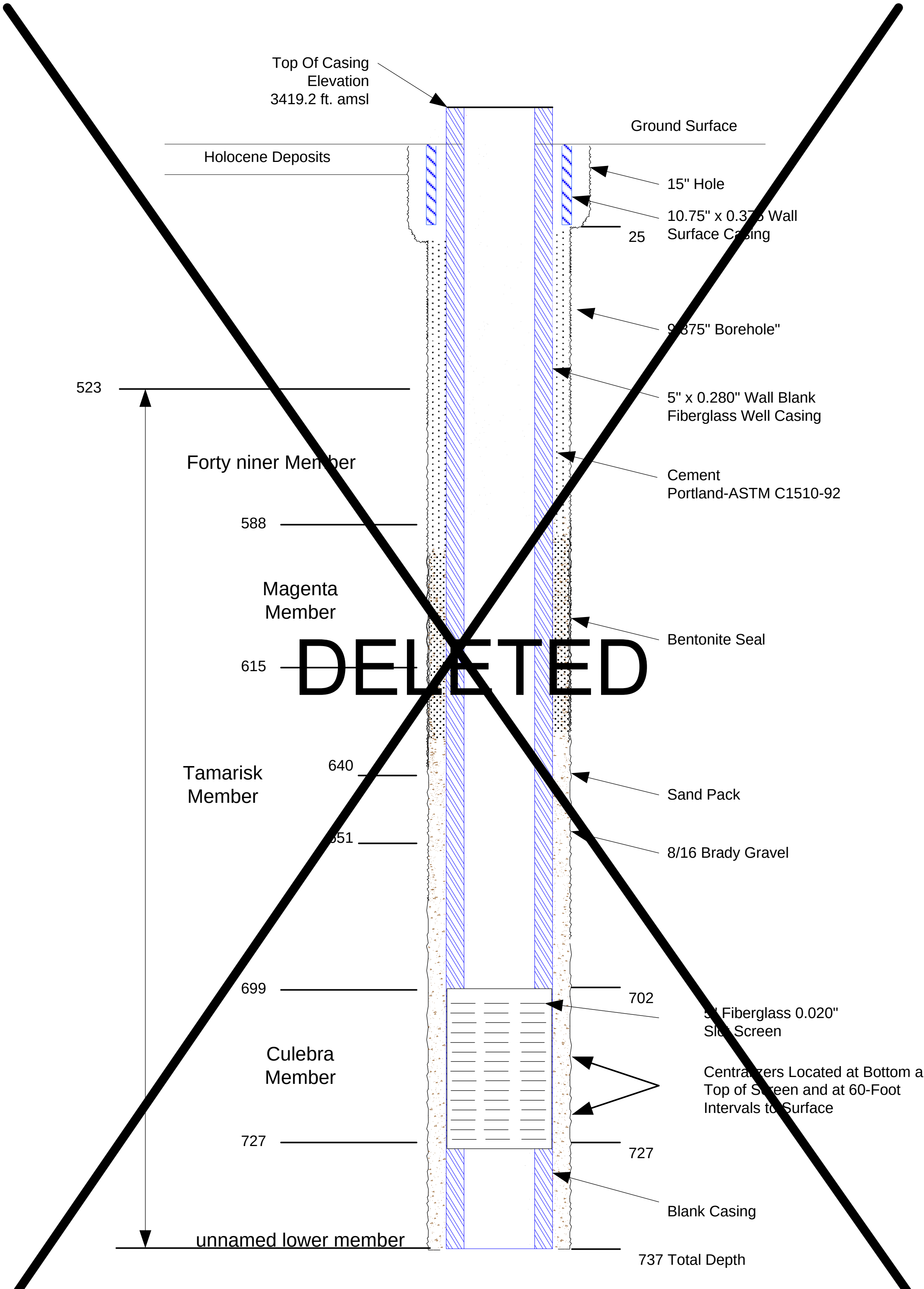


Note: Contour elevations are in feet above mean sea level

*The Wells are included for reference only–they are not part of GMP

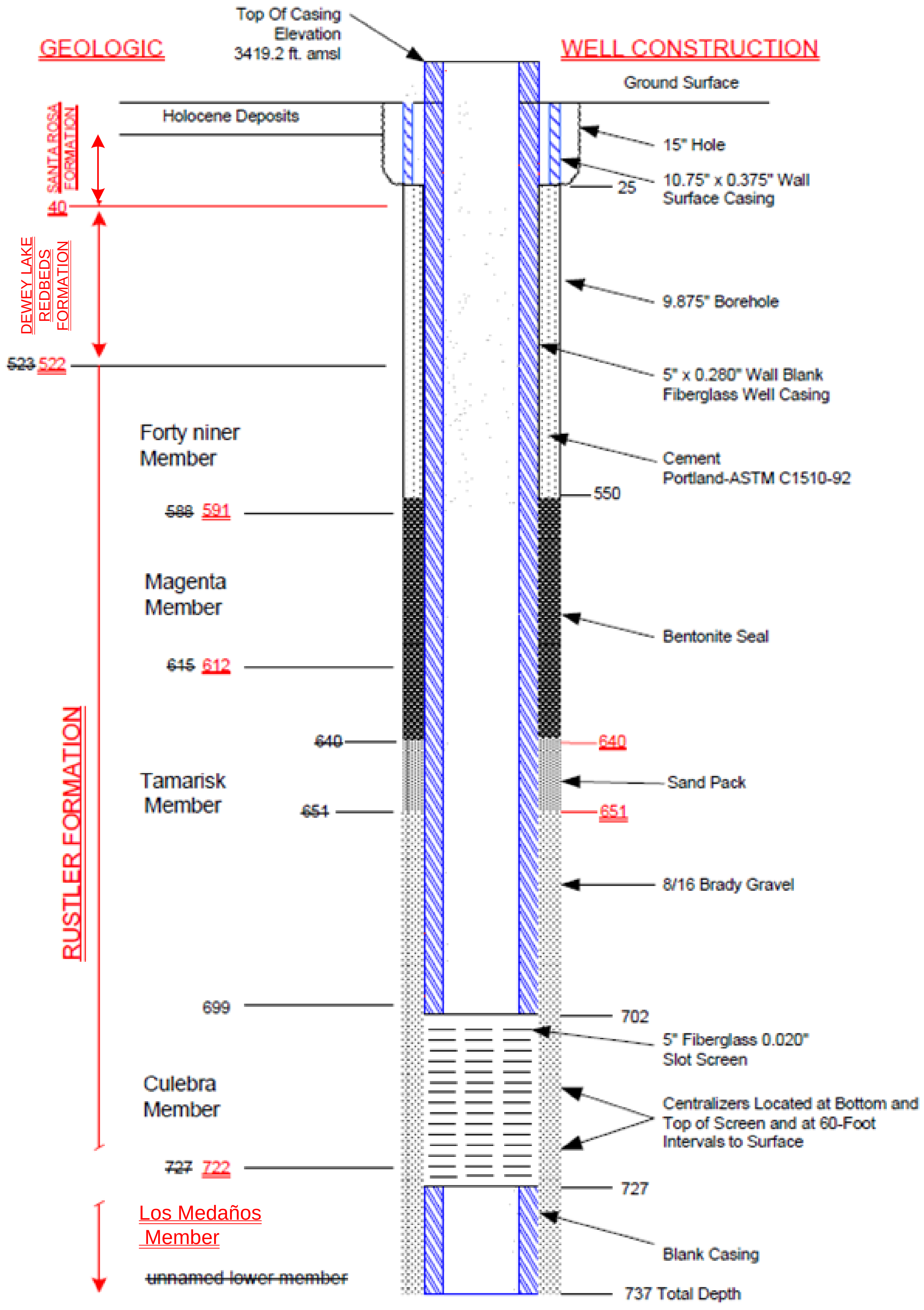
~~Figure L-9~~

~~WIPP DMP Monitor Well Locations and Potentiometric Surface of the Culebra Near the WIPP Site as of 12/96 (adjusted to equivalent freshwater head)~~



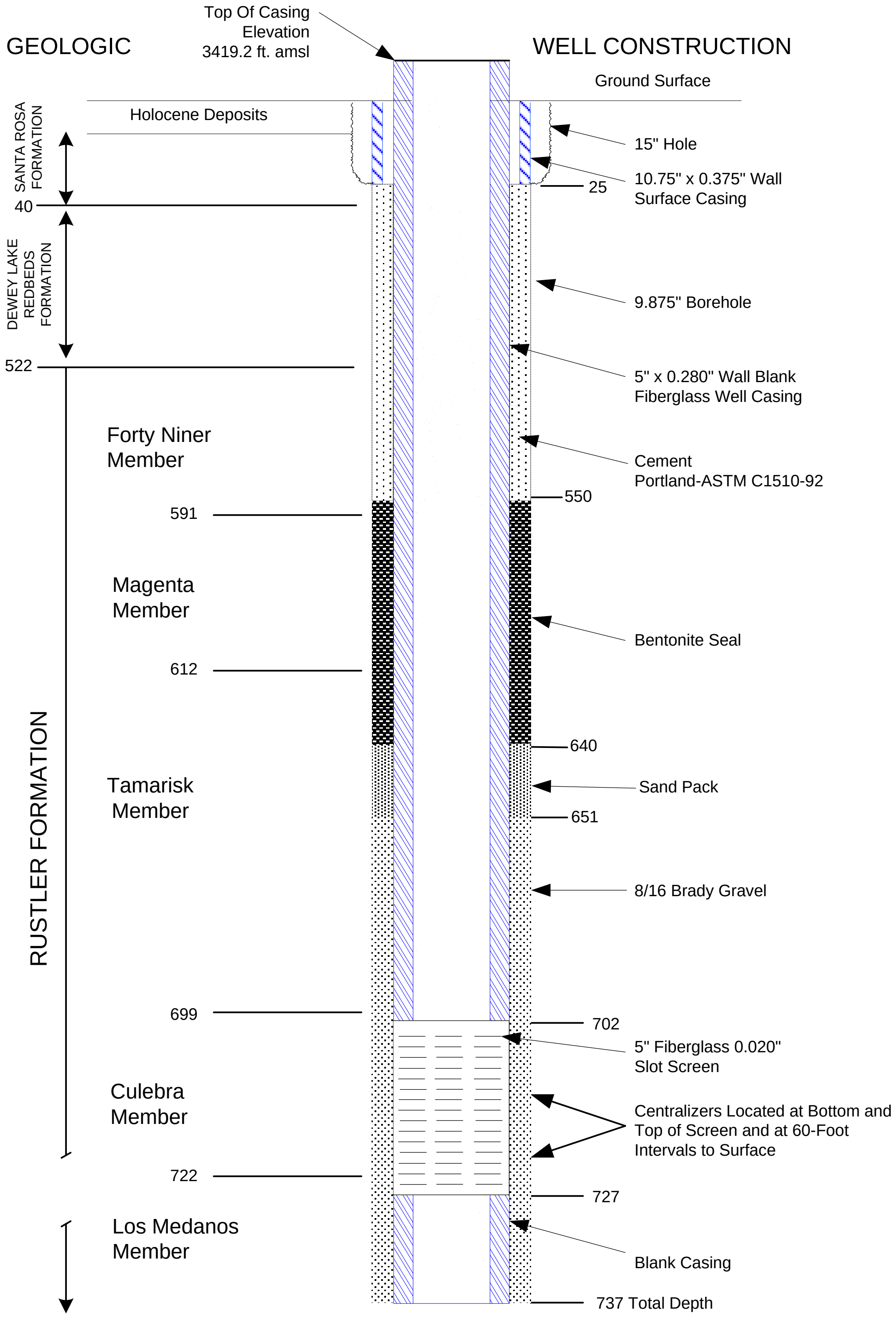
Note: Depths in feet bgs approximate
Not to Scale

~~Figure L-10~~
~~As-Built Configuration of Well WQSP-1~~



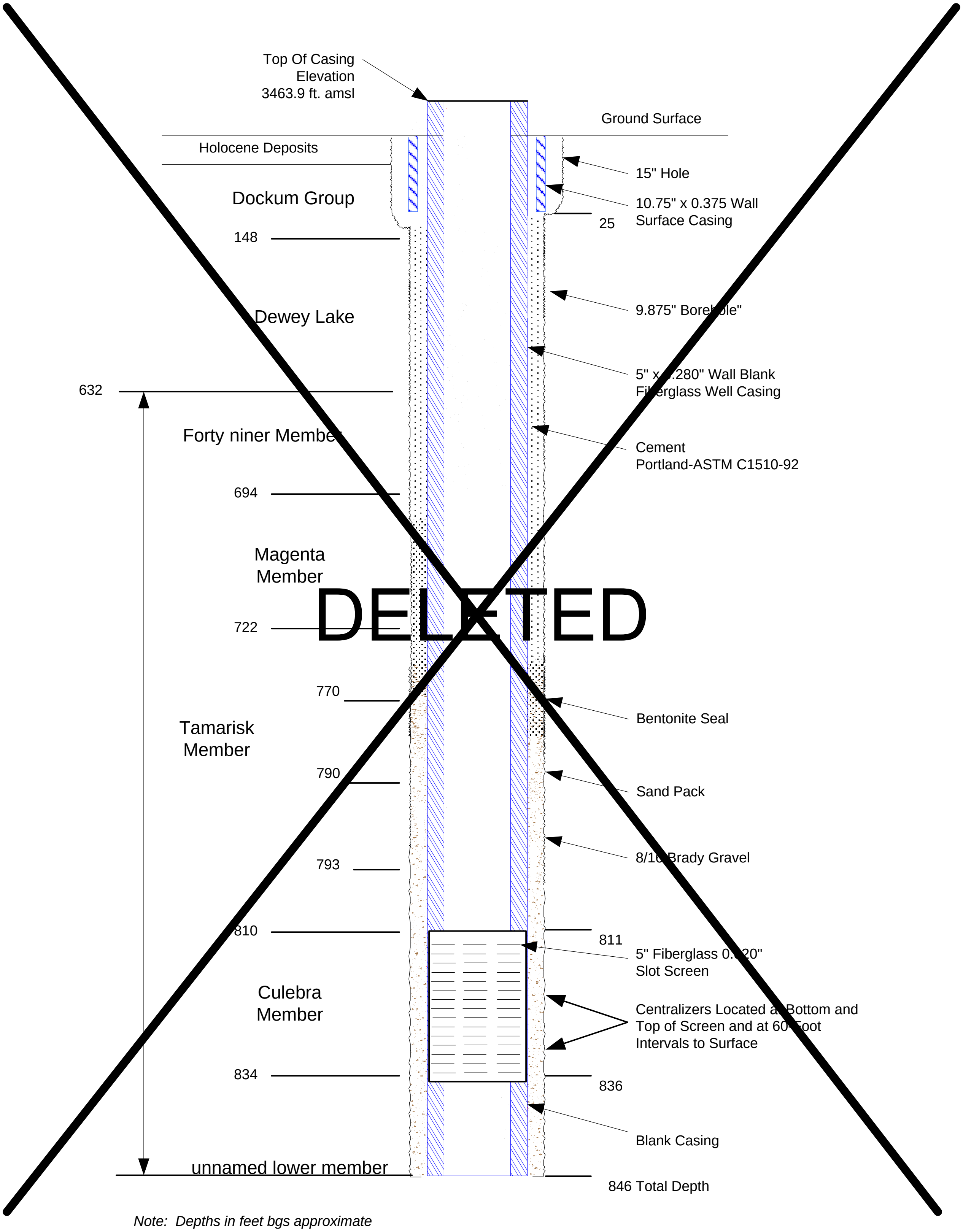
Note: Depths in feet bgs approximate
Not to Scale

Figure L-~~10~~7
As-Built Configuration of Well WQSP-1



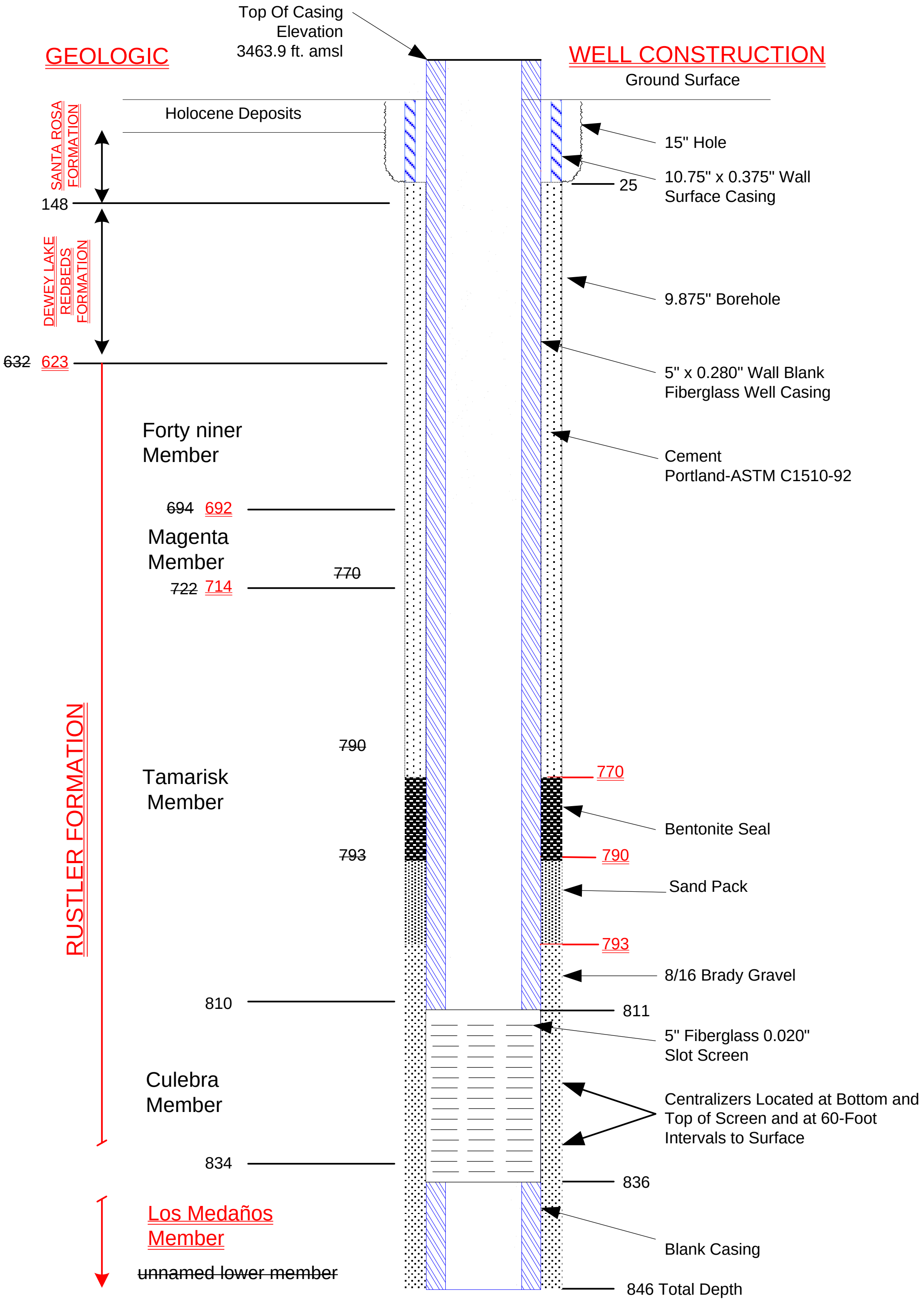
Note: Depths in feet bgs approximate
Not to Scale

Figure L-7
As-Built Configuration of Well WQSP-1



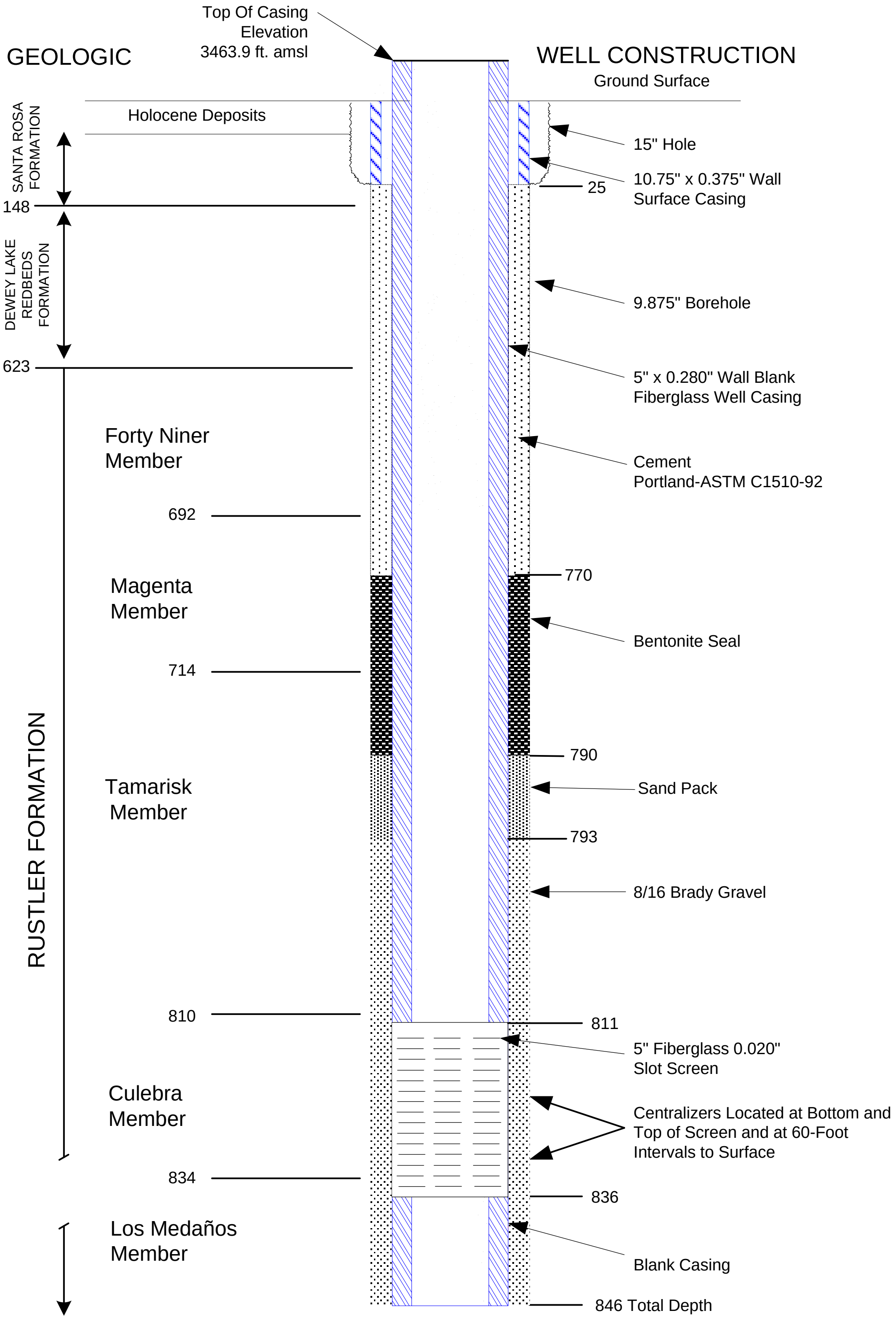
Note: Depths in feet bgs approximate
Not to Scale

~~Figure L-11~~
~~As-Built Configuration of Well WQSP-2~~



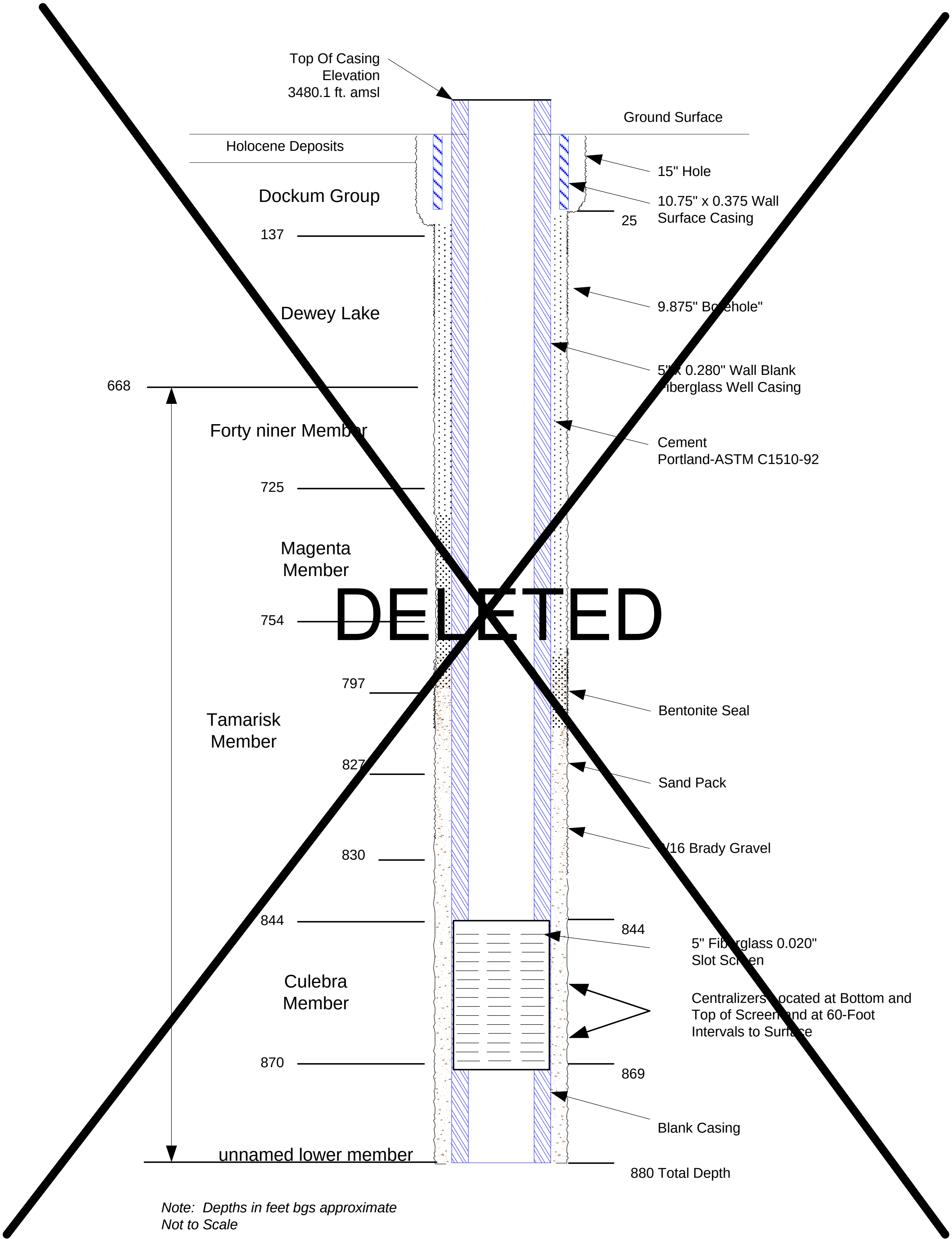
Note: Depths in feet bgs approximate
Not to Scale

Figure L-~~11~~8
As-Built Configuration of Well WQSP-2



Note: Depths in feet bgs approximate
Not to Scale

Figure L-8
As-Built Configuration of Well WQSP-2



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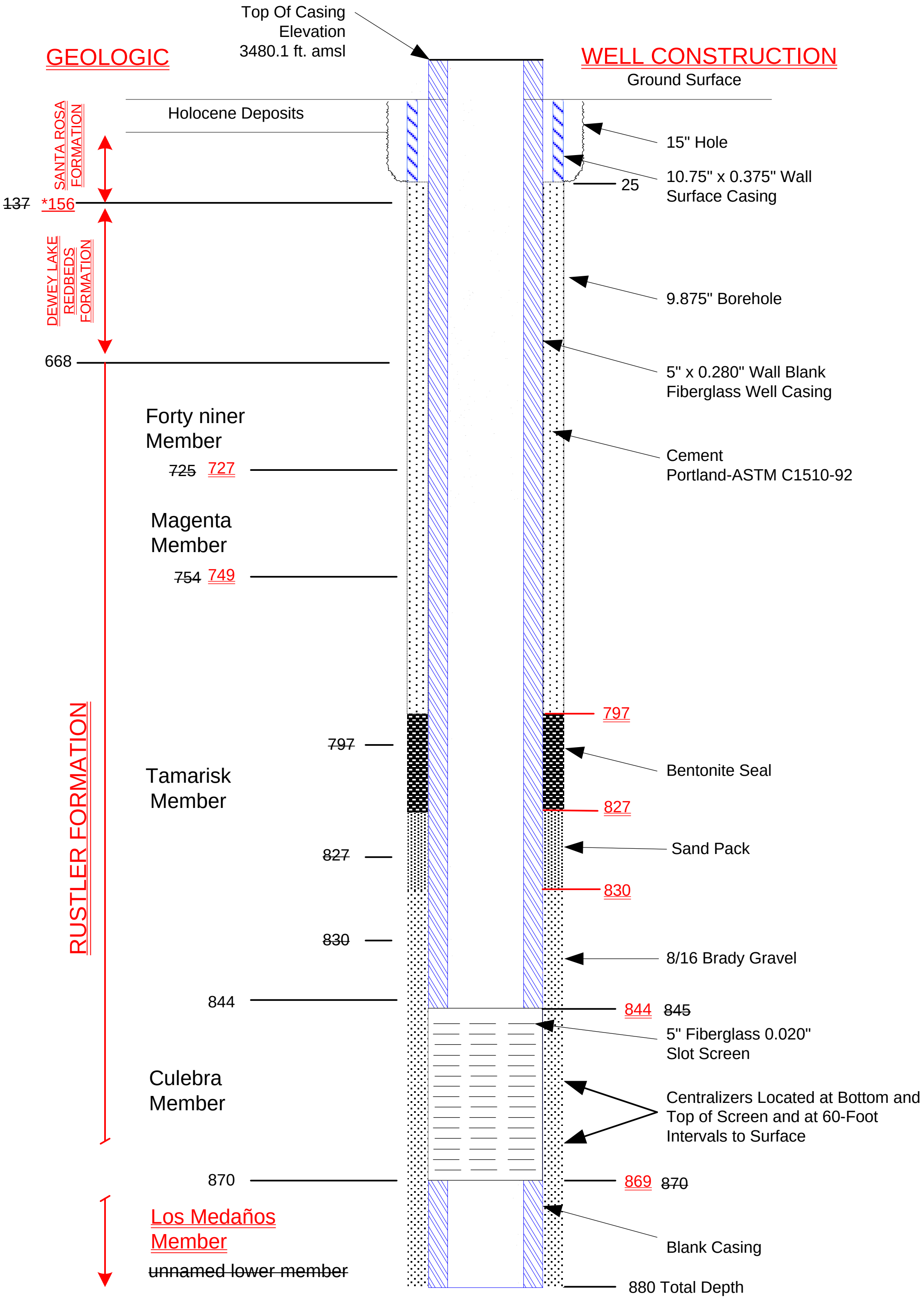
Note: Depths in feet bgs approximate
Not to Scale

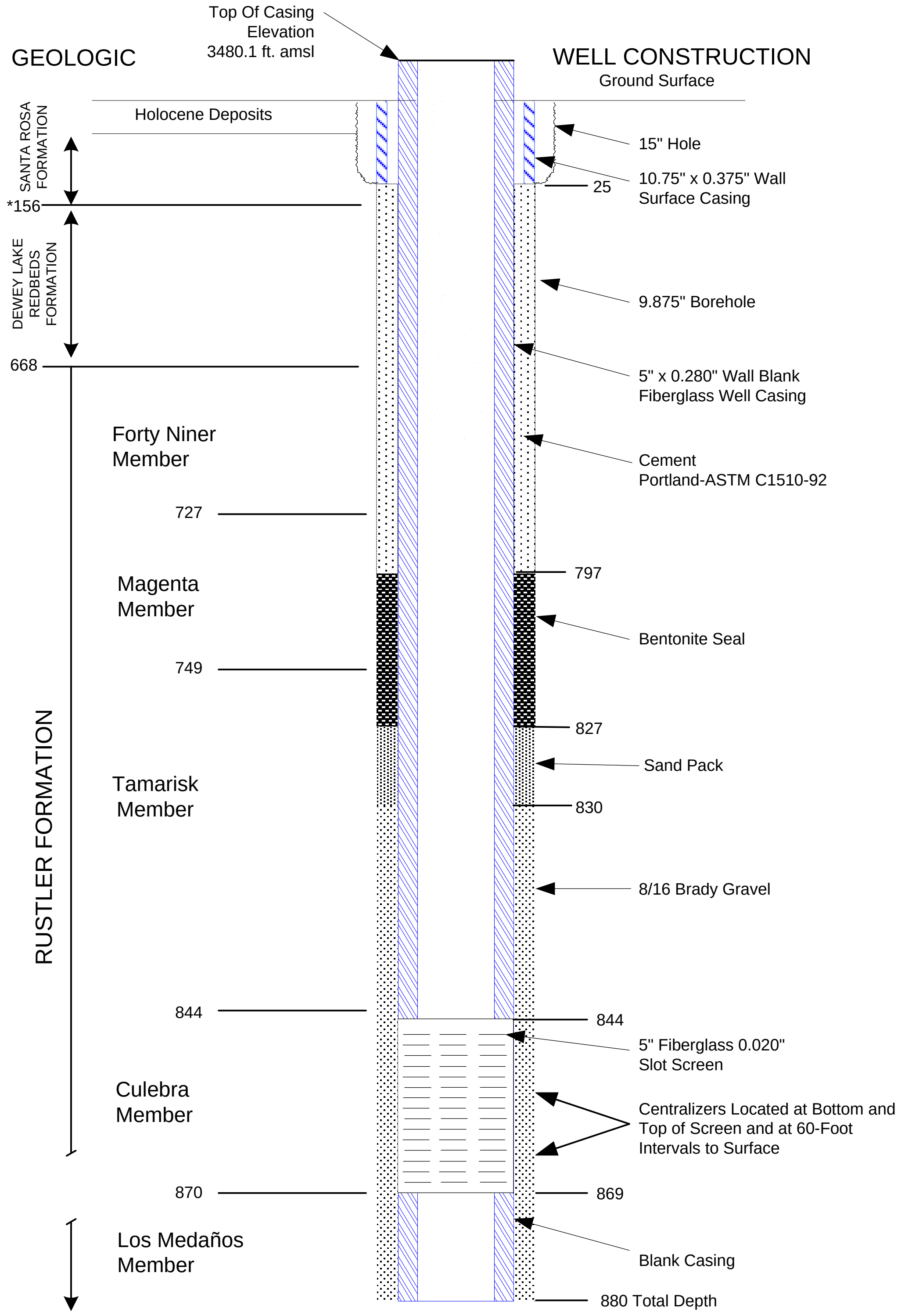
~~Figure L-12~~
~~As-Built Configuration of Well WQSP-3~~



Note: Depths in feet bgs approximate
Not to Scale

**from DOE/WIPP-95-2154*

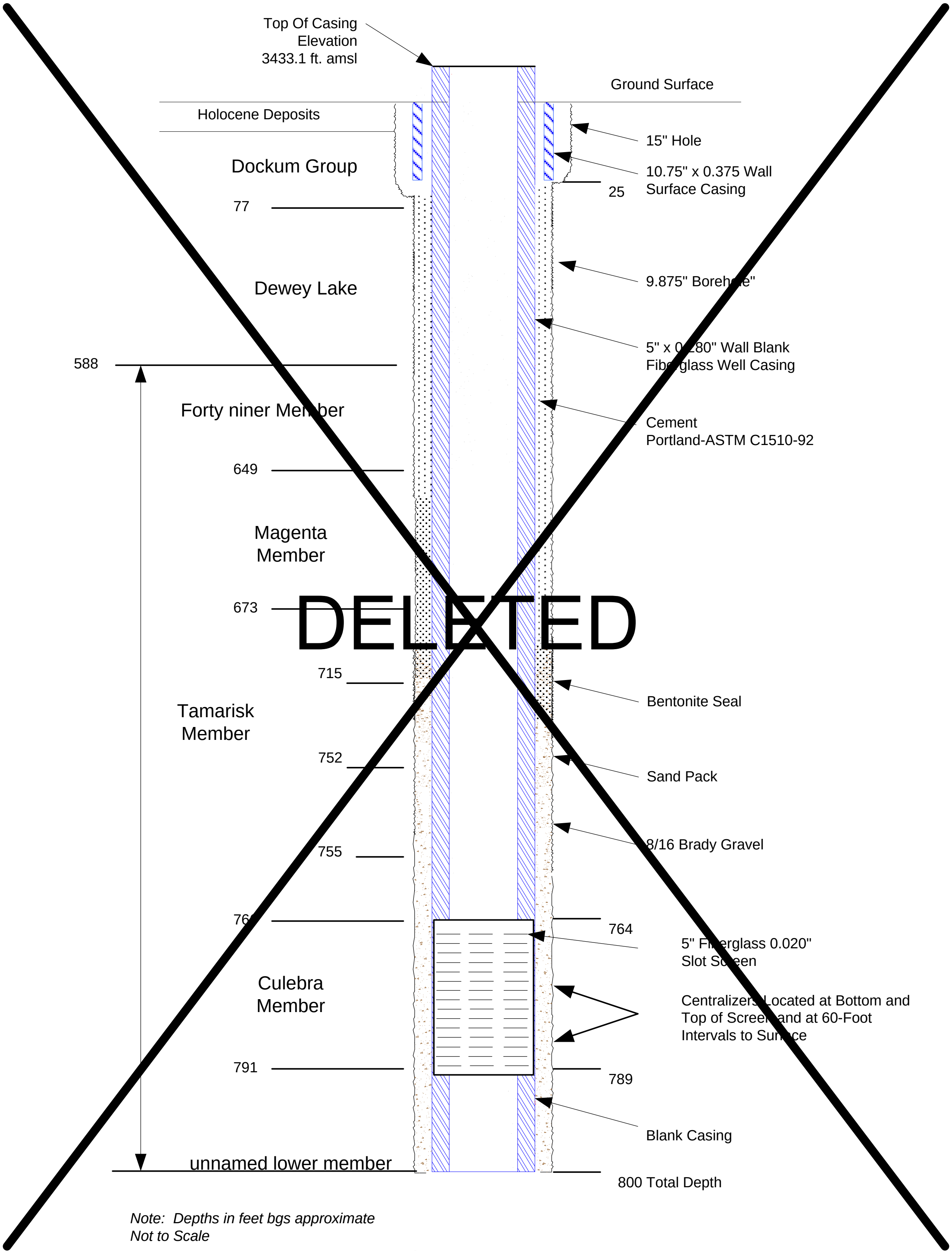
Figure L-~~12~~9
As-Built Configuration of Well WQSP-3



Note: Depths in feet bgs approximate
Not to Scale

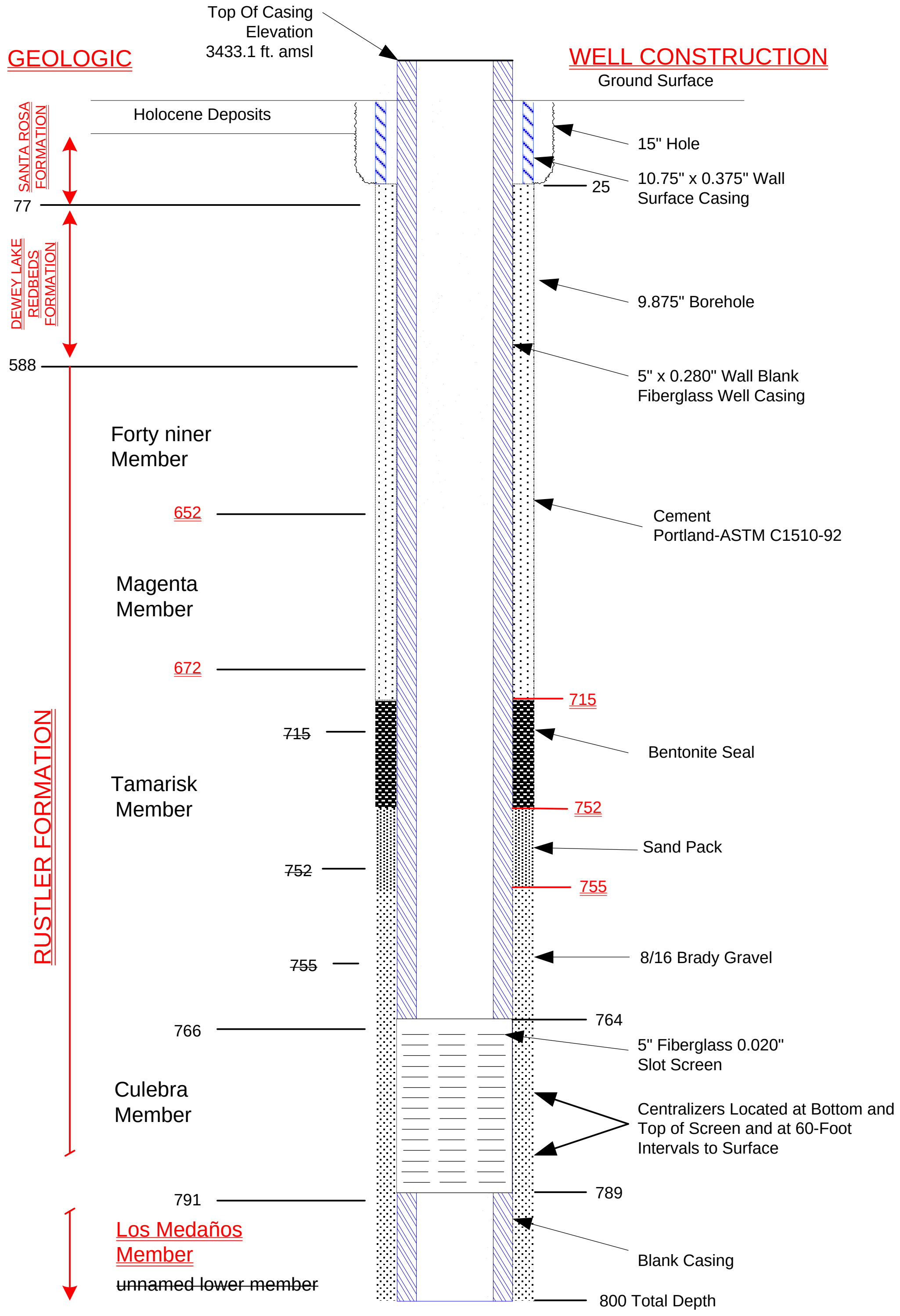
**from DOE/WIPP-95-2154*

Figure L-9
As-Built Configuration of Well WQSP-3



Note: Depths in feet bgs approximate
Not to Scale

~~Figure L-13~~
~~As-Built Configuration of Well WQSP-4~~



Note: Depths in feet bgs approximate
Not to Scale

Figure L-~~13~~10
As-Built Configuration of Well WQSP-4

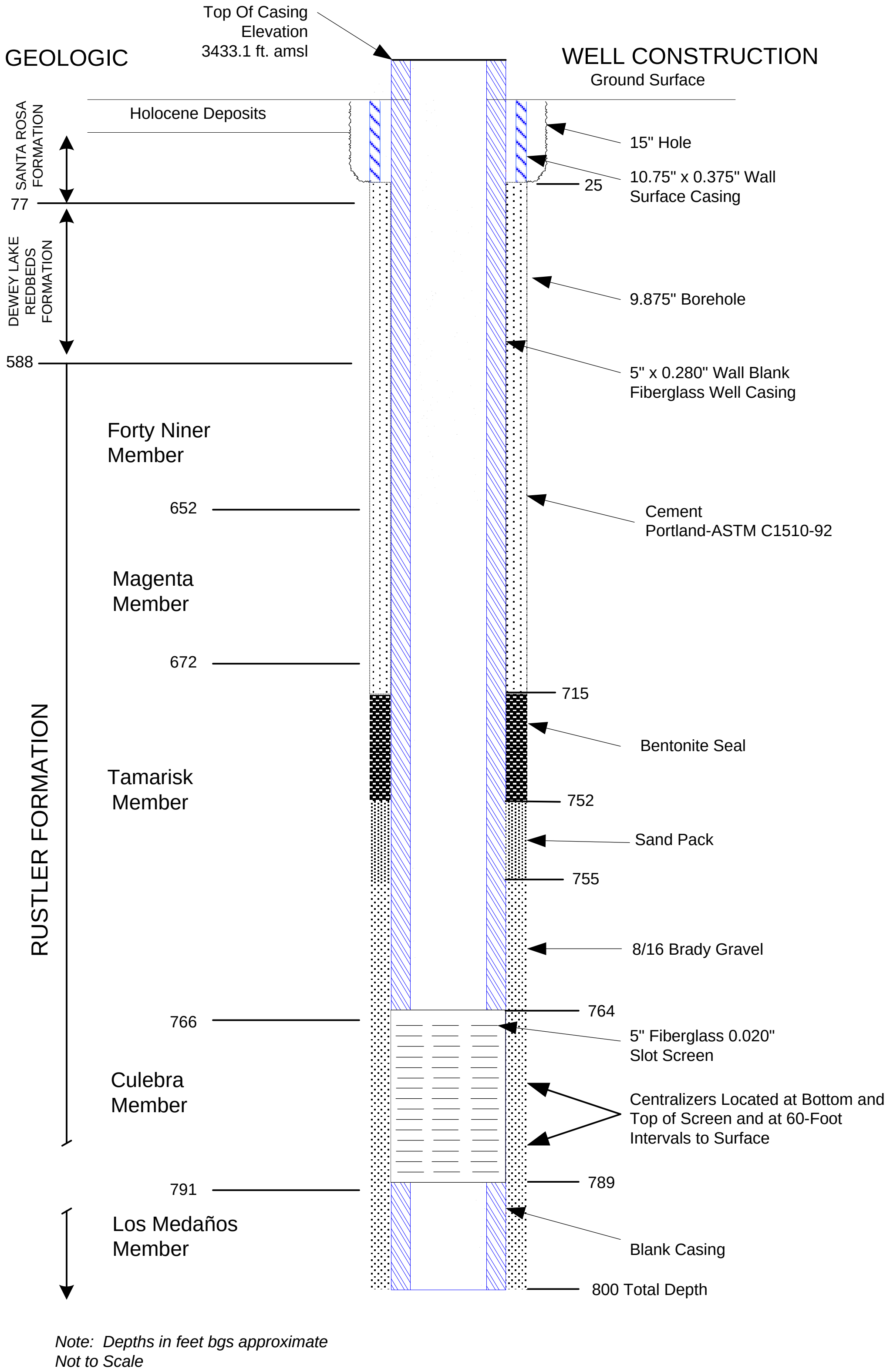
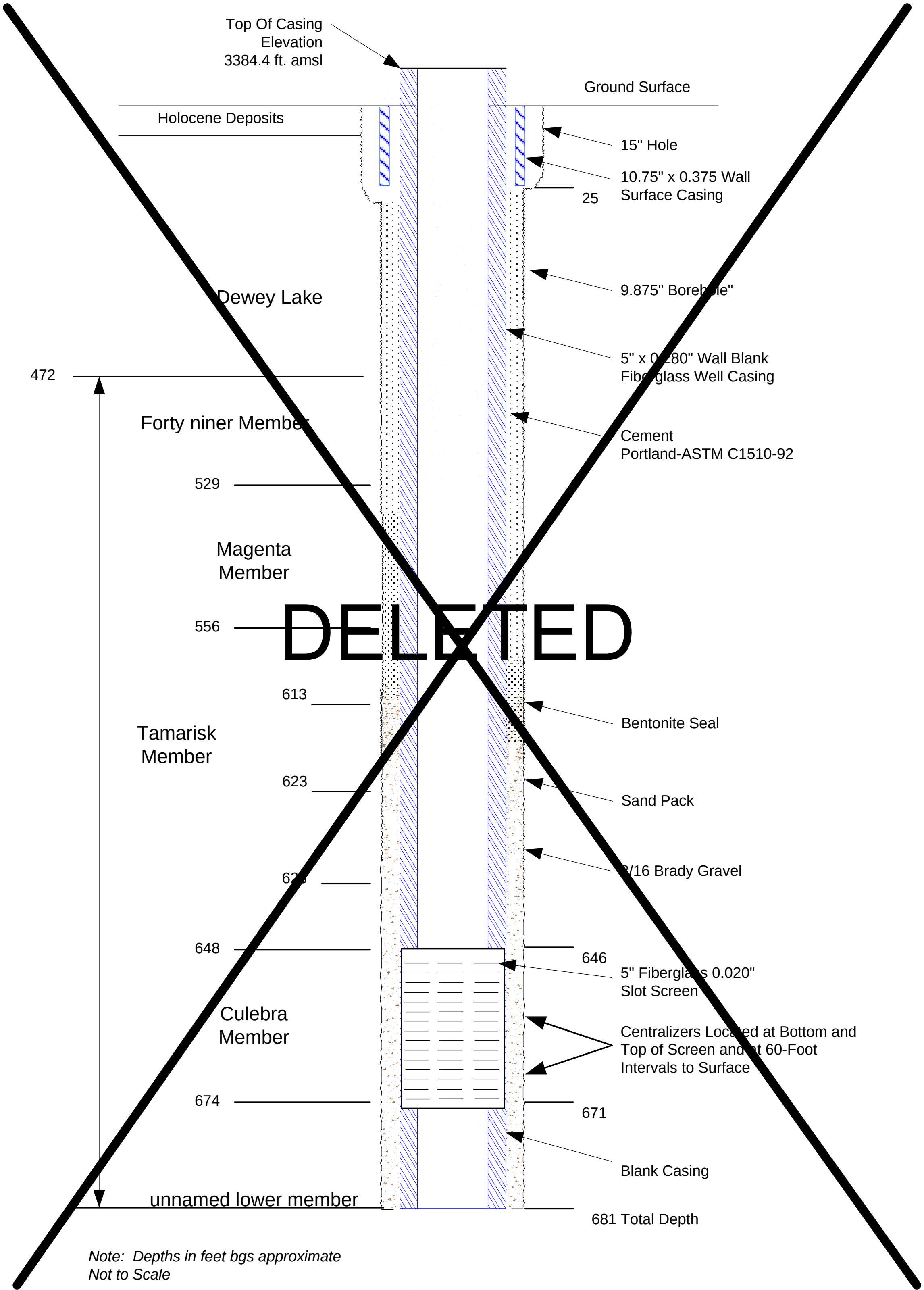
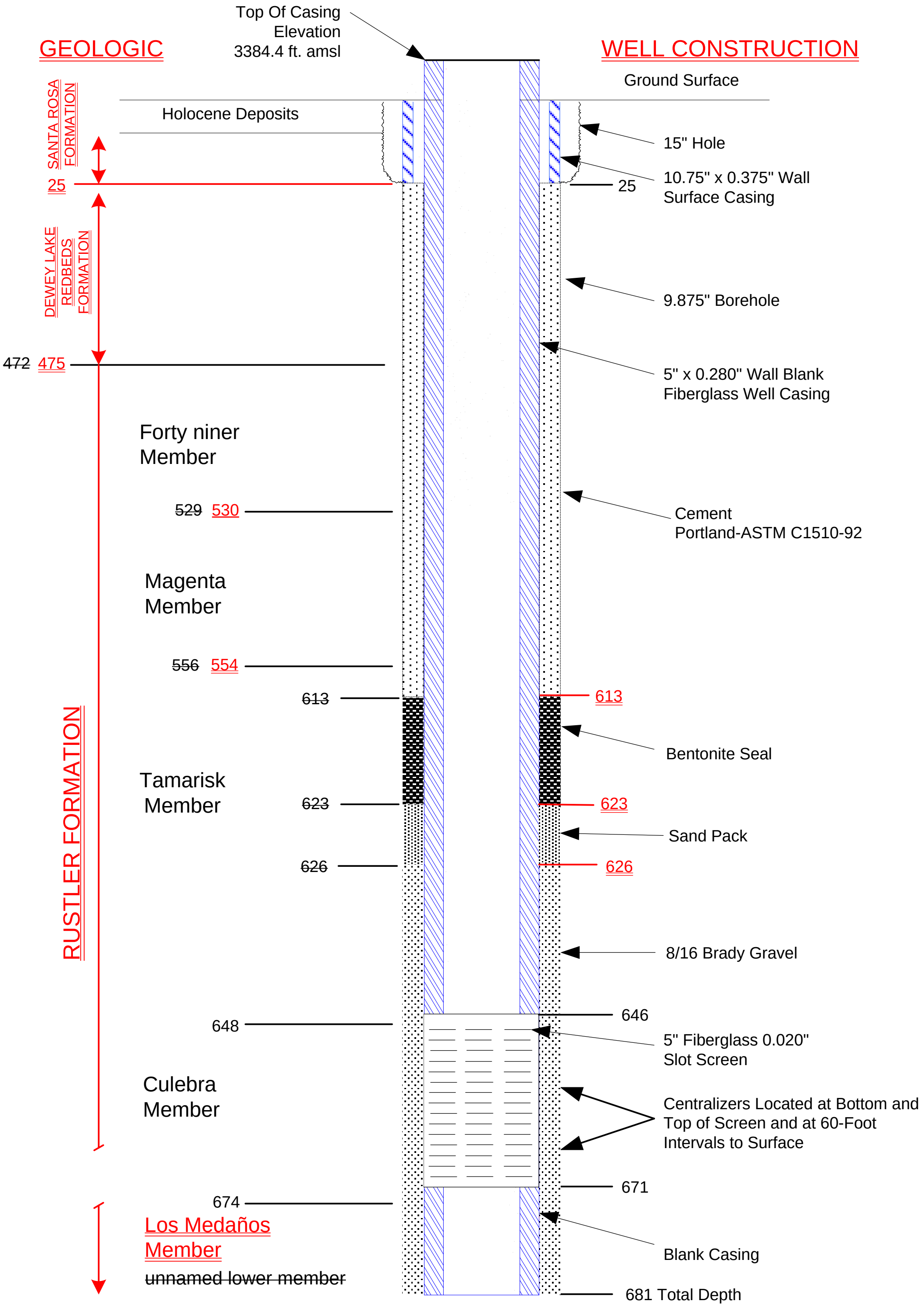


Figure L-10
As-Built Configuration of Well WQSP-4



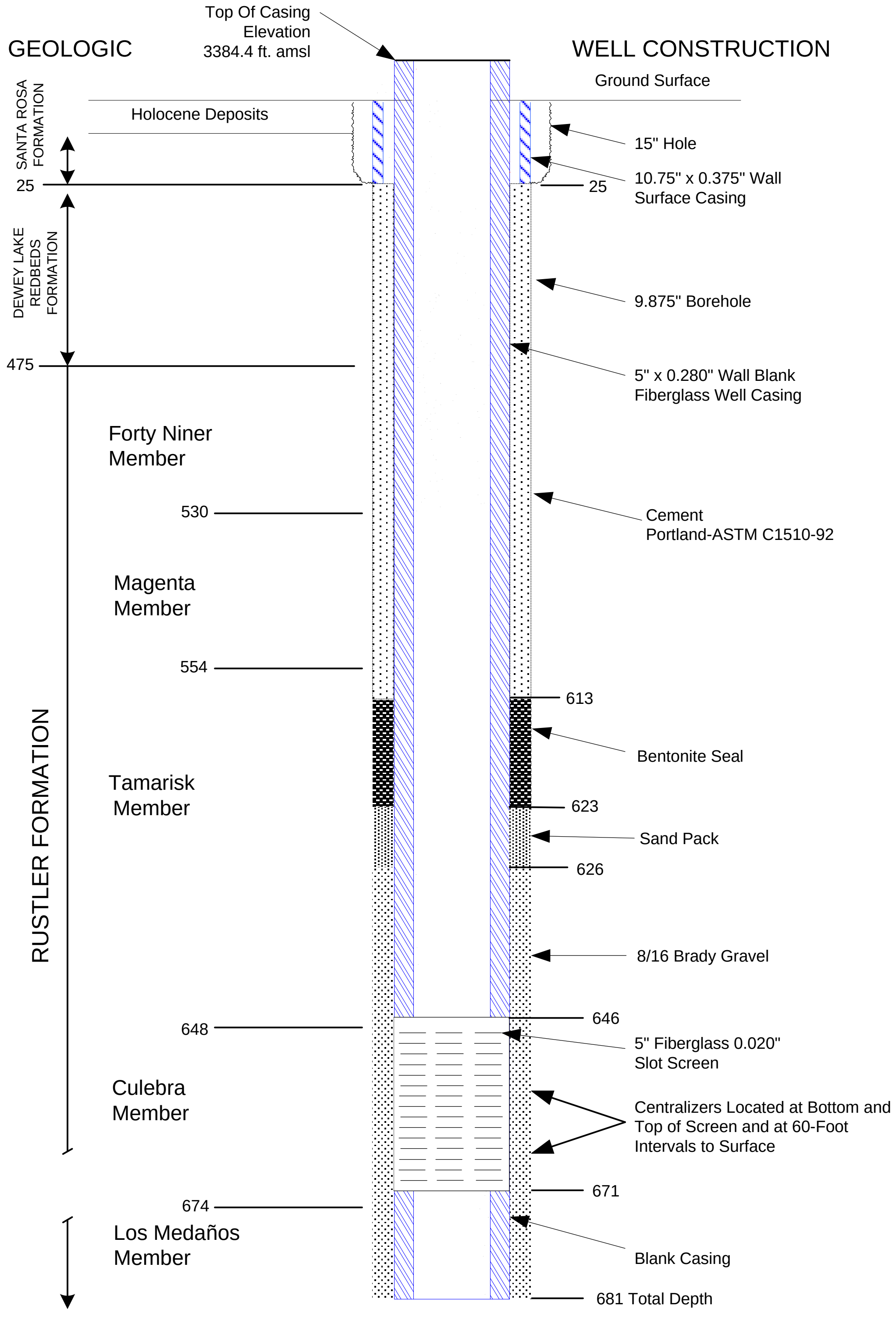
Note: Depths in feet bgs approximate
Not to Scale

~~Figure L-14~~
~~As-Built Configuration of Well WQSP-5~~



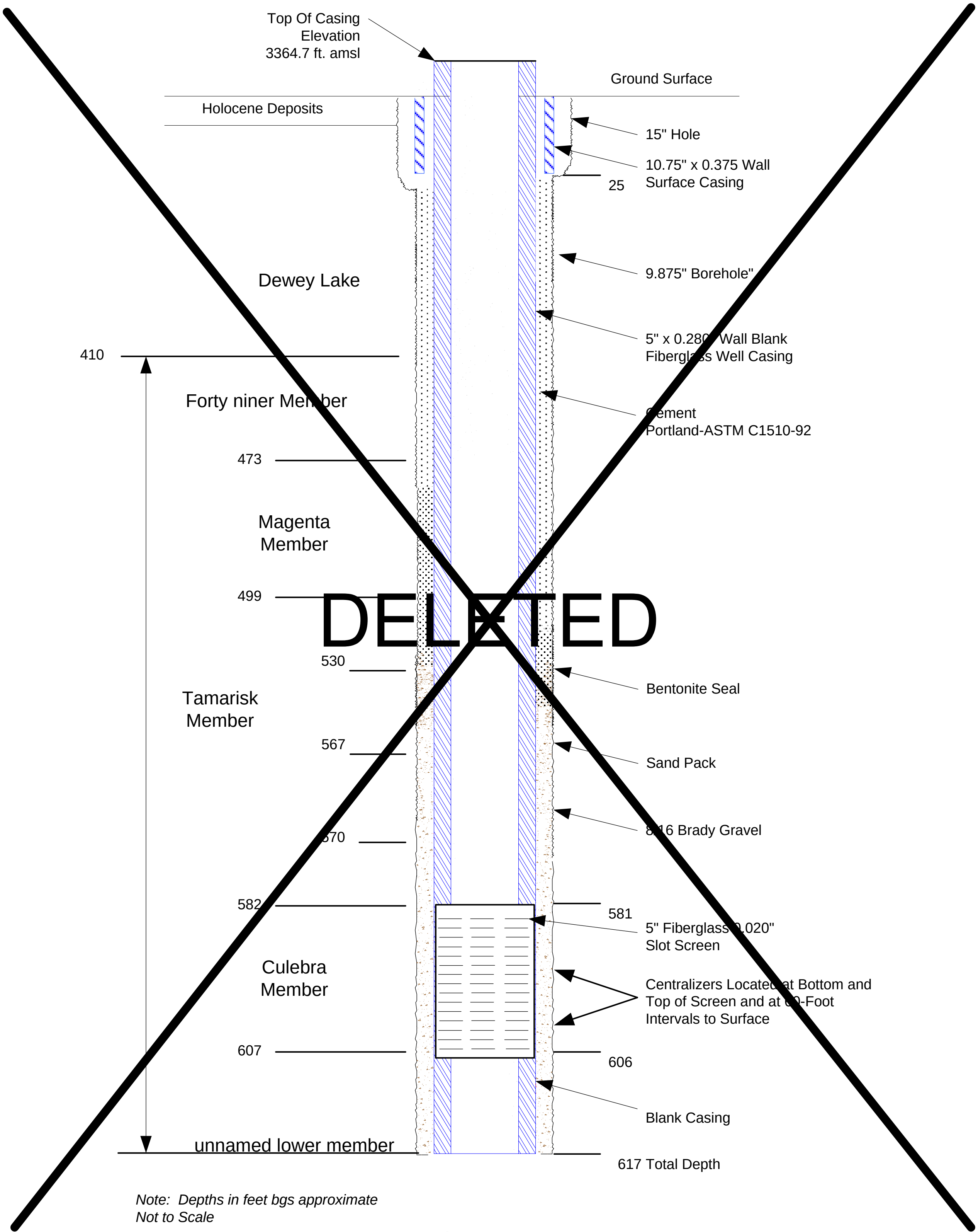
Note: Depths in feet bgs approximate
Not to Scale

Figure L-~~14~~11
As-Built Configuration of Well WQSP-5



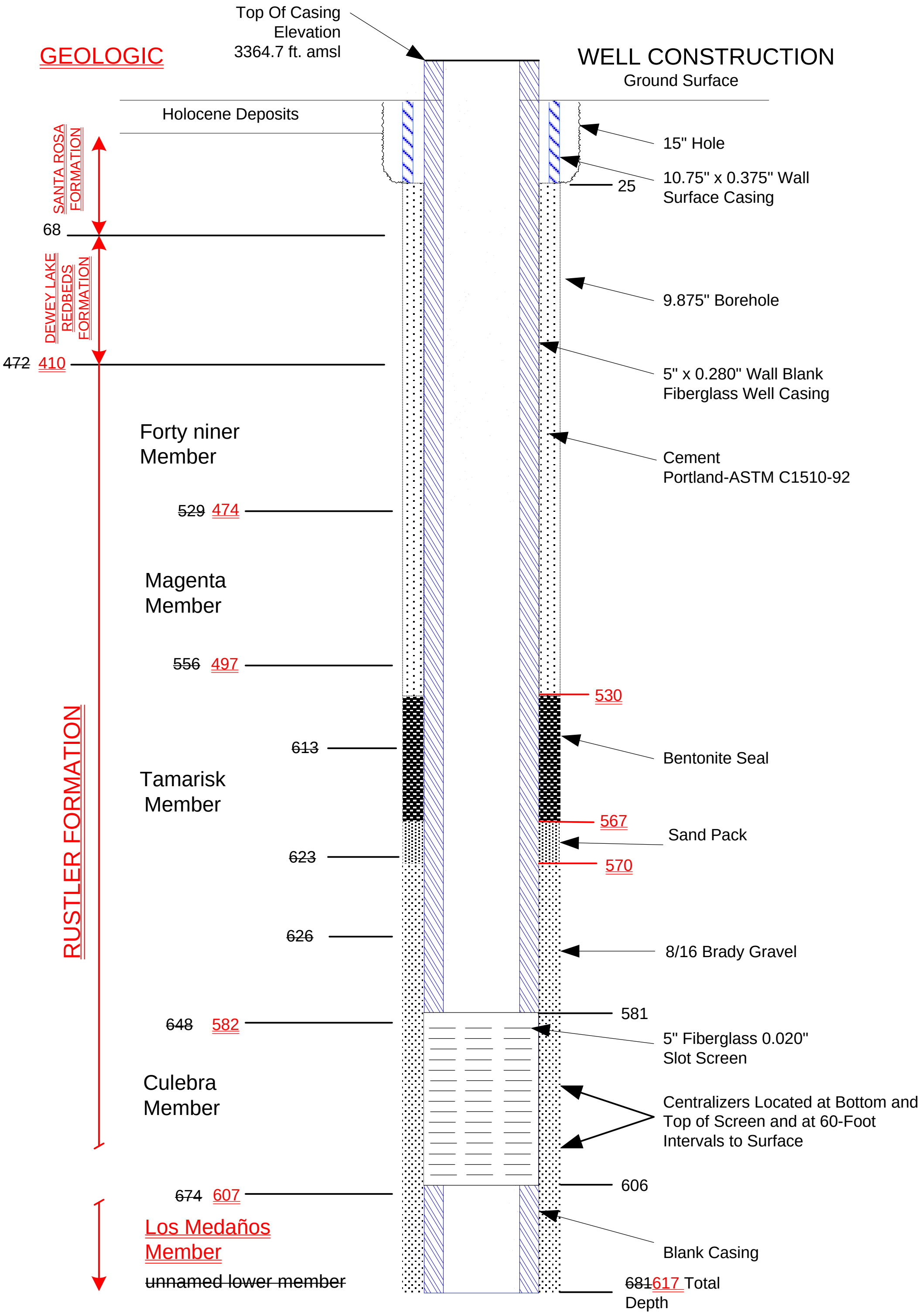
Note: Depths in feet bgs approximate
Not to Scale

Figure L-11
As-Built Configuration of Well WQSP-5



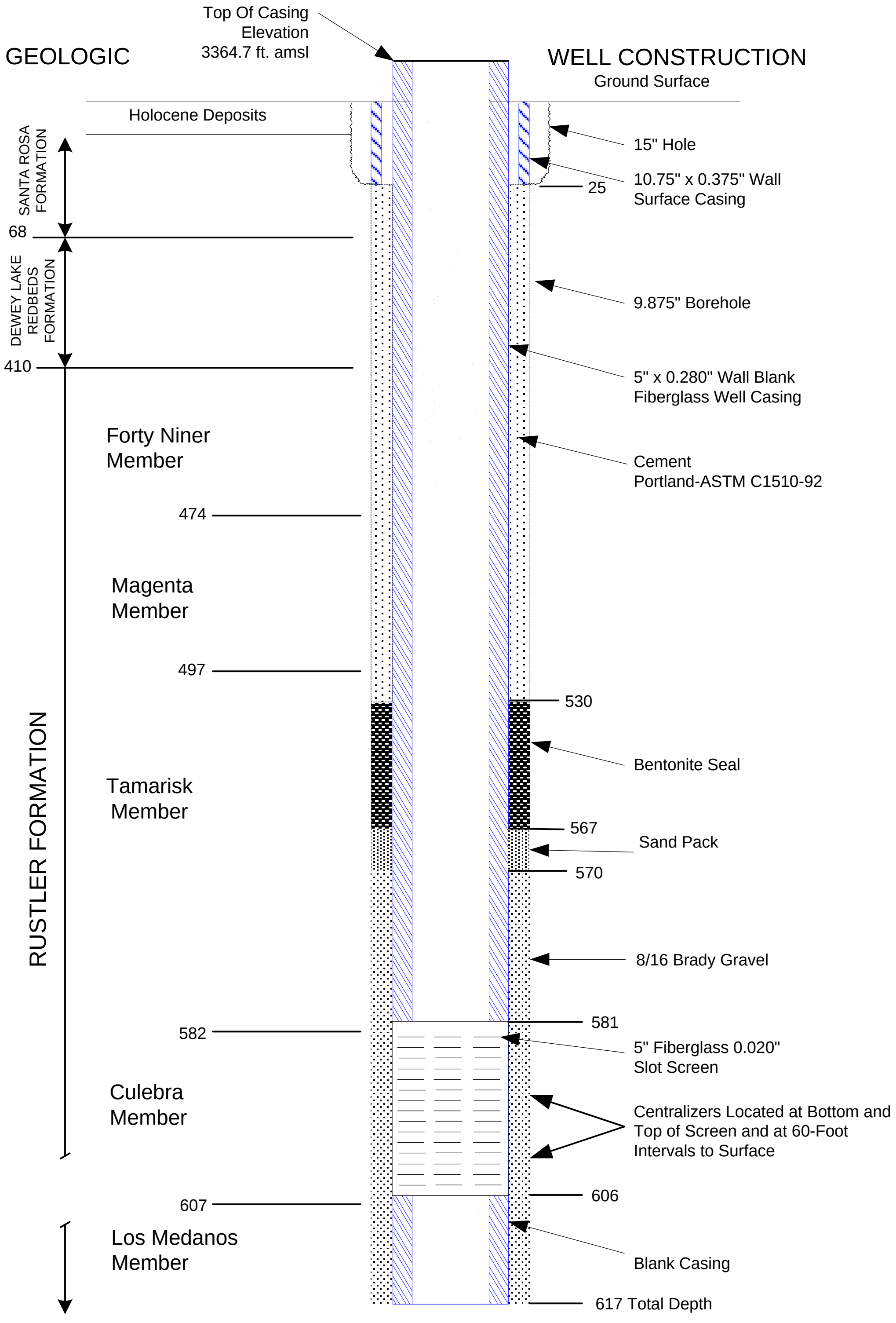
Note: Depths in feet bgs approximate
Not to Scale

~~Figure L-15~~
~~As-Built Configuration of Well WQSP-6~~



Note: Depths in feet bgs approximate
Not to Scale

Figure L-~~15~~12
As-Built Configuration of Well WQSP-6



Note: Depths in feet bgs approximate
Not to Scale

Figure L-12
As-Built Configuration of Well WQSP-6

~~Figure L-16~~
~~Reserved~~

Chain of Custody Record

{MOC Name and Address}

C of C Control No. ______

RFA Control No. ______

SAMPLING PROGRAM ______ LAB DESTINATION ______

SAMPLE TEAM MEMBERS ______ CARRIER/WAYBILL NO. ______

Sample Number	Sample Location and Description	Date and Time Collected	Sample Type	Container Type	Condition on Receipt (Name and Date)	Disposal Record No.

DELETED

Special Instructions ______

Possible Sample Hazards: ______

Signatures: (Name, Company, Date and Time: ______

1. Relinquished By: ______
   Received By: ______
2. Relinquished By: ______
   Received By: ______
3. Relinquished By: ______
   Received By: ______
4. Relinquished By: ______
   Received By: ______

WHITE - Original, to accompany samples YELLOW- Field Copy PINK- OTHER

~~Figure L-17a~~

~~Example Chain-of-Custody Record~~

REQUEST FOR ANALYSIS

{MOC Name and Address}______
______
______
______

R/A Control ______
C/C Control No. ______
Date Sample Shipped ______
Lab Destination ______
Laboratory Contact ______
Send Lab Report To______
______
______
Date Report Required ______
Project Contact ______
Project Contact Phone No. ______

VOC Monitoring Program______

Purchase Order No.______

DELETED

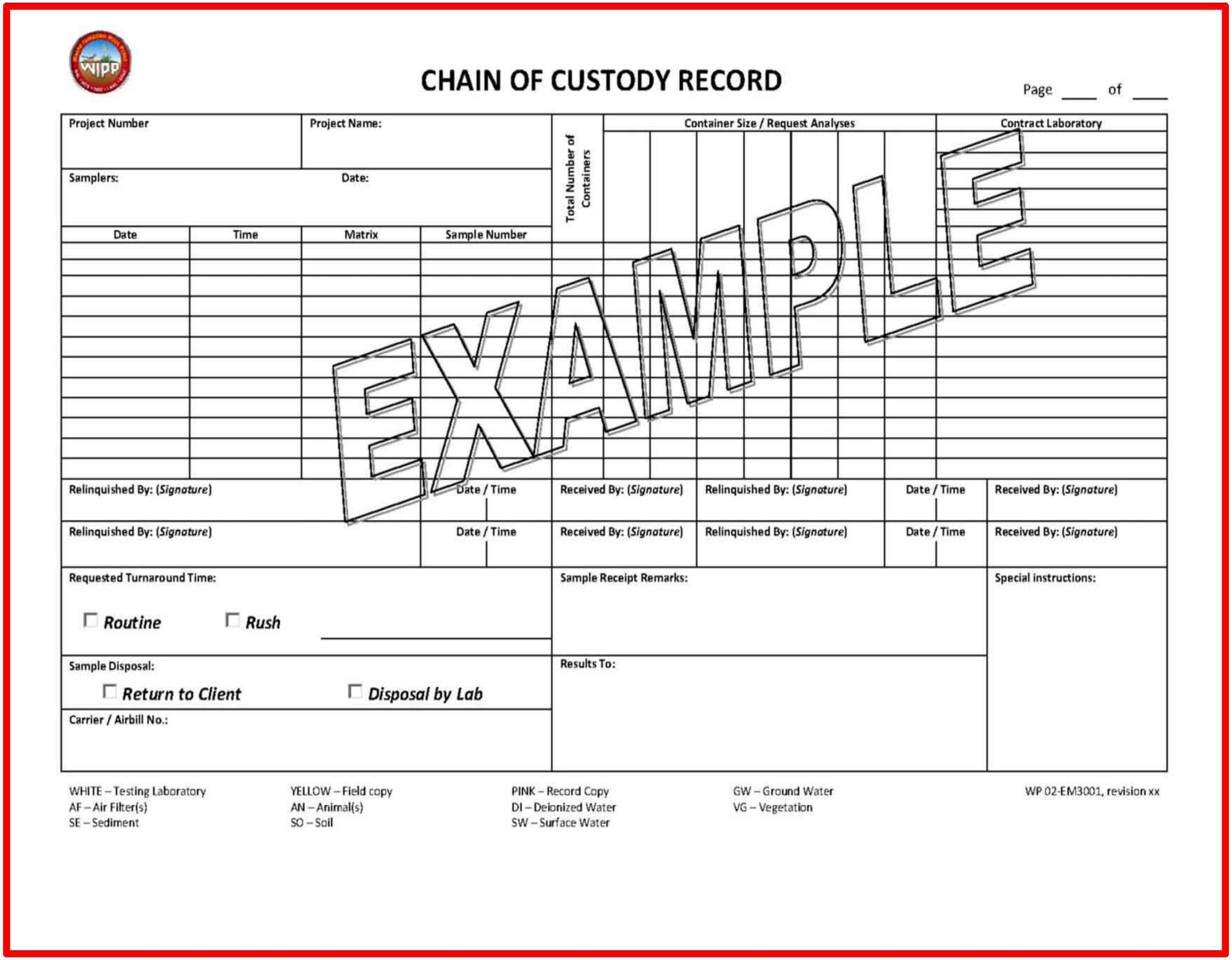
Serial No.	Sample No.	C-of-C No.	Sample Type	Sample Pressure	Preservative	Contract-Specific Testing	Special Instructions

TURNAROUND TIME REQUIRED: (Rush must be approved by appropriate Manager) NORMAL______ RUSH____(Subject to rush surcharge)
POSSIBLE HAZARD IDENTIFICATION: (Please indicate if sample(s) are hazardous materials and/or contain high levels of hazardous substances.)
NONHAZARD______FLAMMABLE______SKIN IRRITANT______HIGHLY TOXIC______BIOLOGICAL______OTHER

SAMPLE DISPOSAL (Please indicate disposition of sample following analysis.) RETURN TO CLIENT______DISPOSAL BY LAB______ (Please Specify)

FOR LAB USE ONLY
RECEIVED BY ______ DATE/TIME ______

~~Figure L-17b~~
~~Example Request for Analysis~~



EXAMPLE

CHAIN OF CUSTODY RECORD

Page ____ of ____

Project Number	Project Name:	Total Number of Containers	Container Size / Request Analyses	Contract Laboratory
Samplers:	Date:			

Date	Time	Matrix	Sample Number

Relinquished By: (*Signature*) | Date / Time | Received By: (*Signature*) | Relinquished By: (*Signature*) | Date / Time | Received By: (*Signature*)

Relinquished By: (*Signature*) | Date / Time | Received By: (*Signature*) | Relinquished By: (*Signature*) | Date / Time | Received By: (*Signature*)

Requested Turnaround Time:

☐ ***Routine*** ☐ ***Rush*** ____________

Sample Receipt Remarks:

Special instructions:

Sample Disposal:

☐ ***Return to Client*** ☐ ***Disposal by Lab***

Results To:

Carrier / Airbill No.:

WHITE – Testing Laboratory
AF – Air Filter(s)
SE – Sediment

YELLOW – Field copy
AN – Animal(s)
SO – Soil

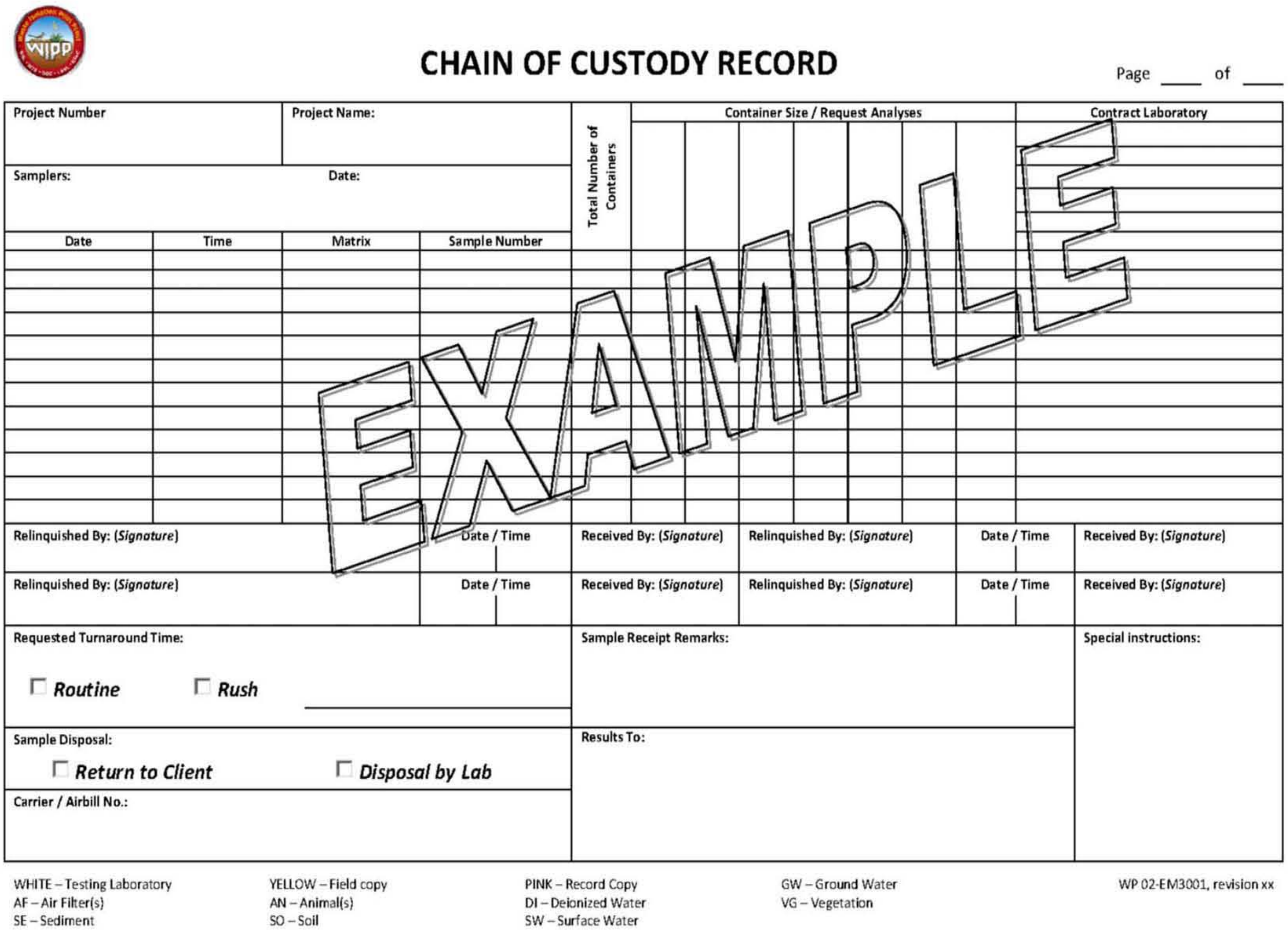
PINK – Record Copy
DI – Deionized Water
SW – Surface Water

GW – Ground Water
VG – Vegetation

WP 02-EM3001, revision xx

Figure L-~~17a~~13

Example Chain-of-Custody/Request for Analysis Form~~Record~~



CHAIN OF CUSTODY RECORD

Page ____ of ____

Project Number

Project Name:

Samplers:

Date:

Container Size / Request Analyses

Contract Laboratory

Date	Time	Matrix	Sample Number	Total Number of Containers								Contract Laboratory

Relinquished By: (*Signature*)	**Date / Time**	**Received By: (*Signature*)**	**Relinquished By: (*Signature*)**	**Date / Time**	**Received By: (*Signature*)**
Relinquished By: (*Signature*)	**Date / Time**	**Received By: (*Signature*)**	**Relinquished By: (*Signature*)**	**Date / Time**	**Received By: (*Signature*)**

Requested Turnaround Time:

☐ ***Routine*** ☐ ***Rush*** ____________

Sample Receipt Remarks:

Special instructions:

Sample Disposal:

☐ ***Return to Client*** ☐ ***Disposal by Lab***

Results To:

Carrier / Airbill No.:

WHITE – Testing Laboratory
AF – Air Filter(s)
SE – Sediment

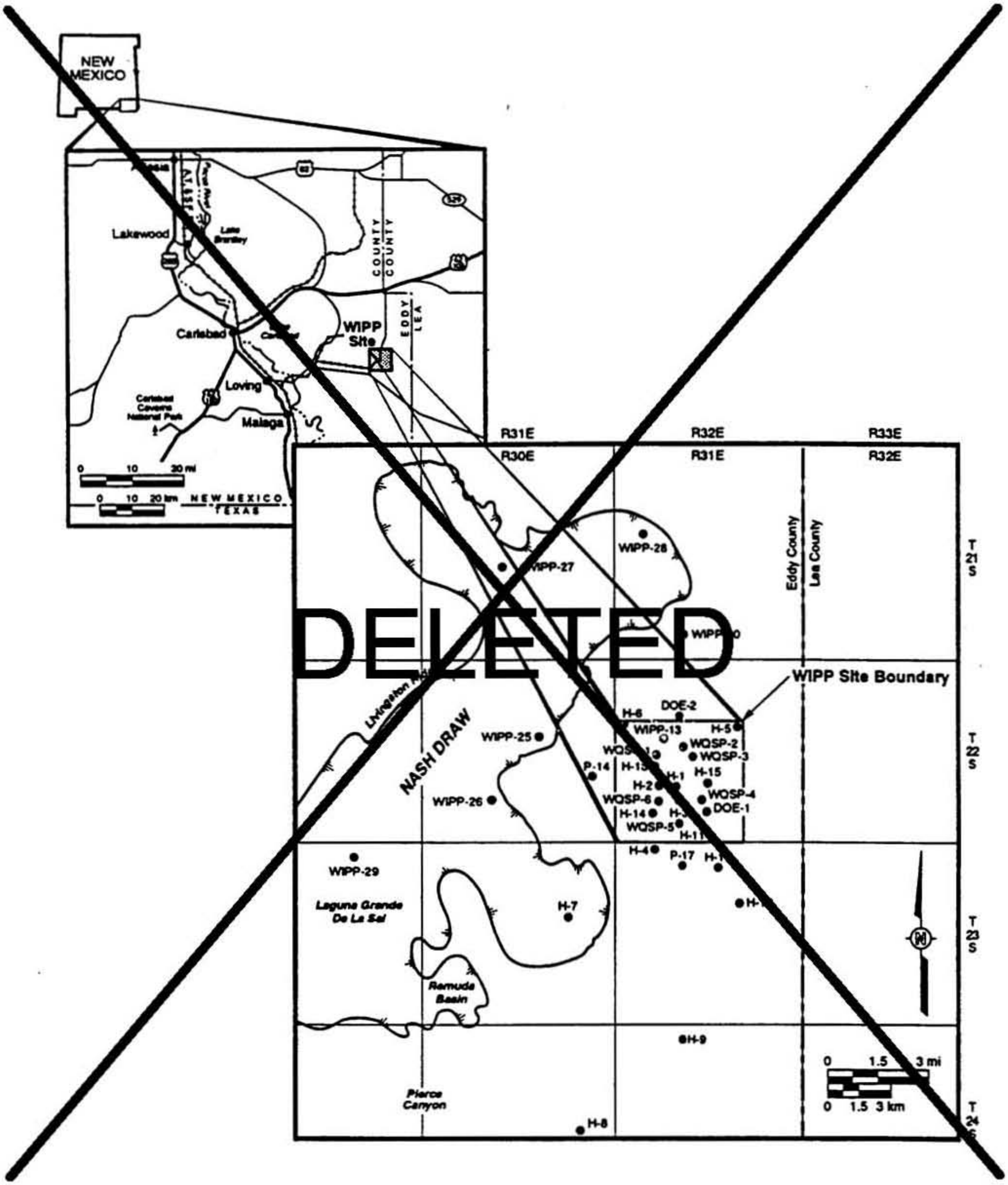
YELLOW – Field copy
AN – Animal(s)
SO – Soil

PINK – Record Copy
DI – Deionized Water
SW – Surface Water

GW – Ground Water
VG – Vegetation

WP 02-EM3001, revision xx

Figure L-13
Example Chain-of-Custody/Request for Analysis Form



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~~Figure L-18~~

~~Ground-water Surface Elevation Monitoring Locations~~

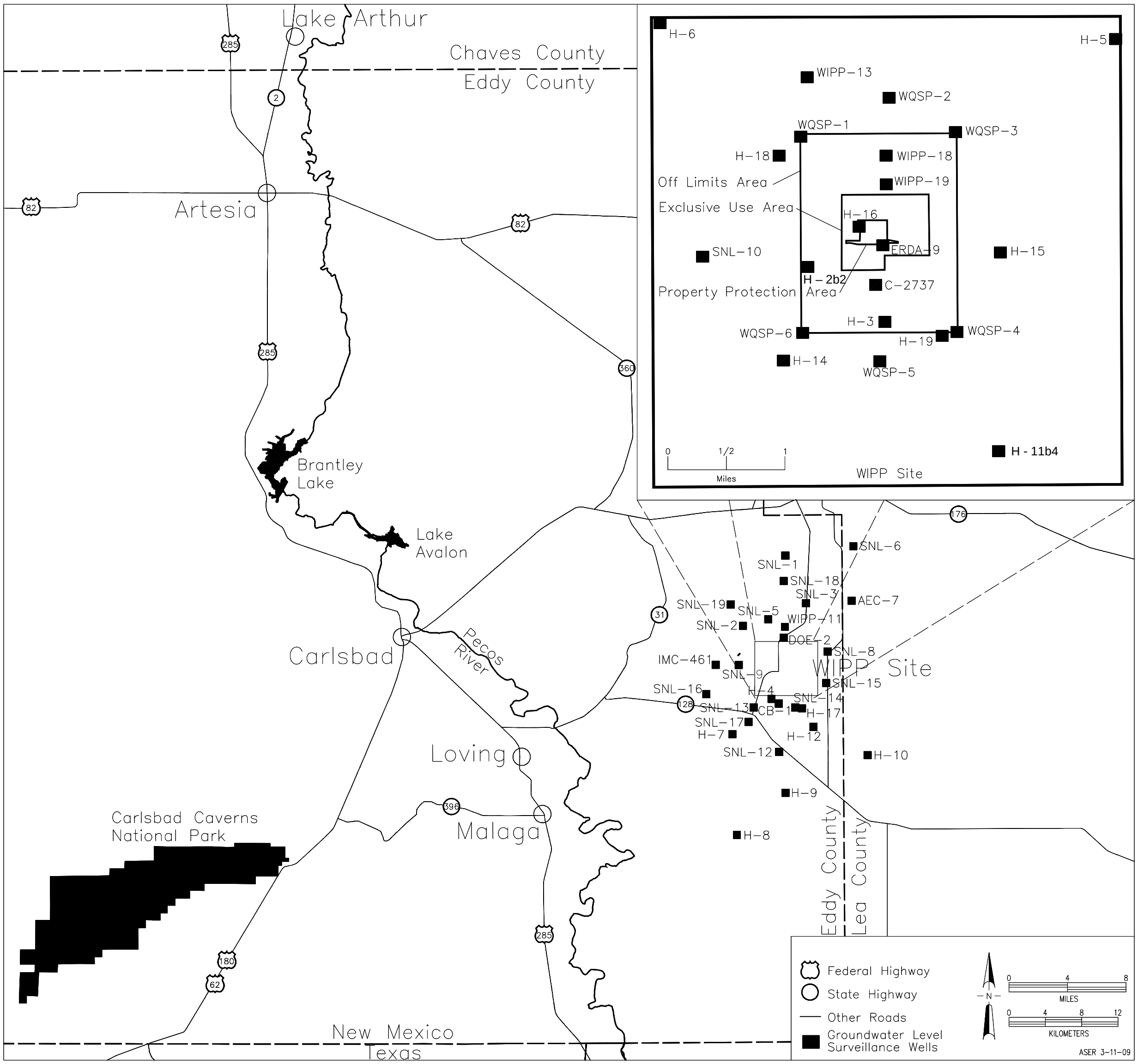


Figure L-14

Groundwater Level Surveillance Wells

(inset represents the groundwater surveillance wells in WIPP Land Withdrawal Area)

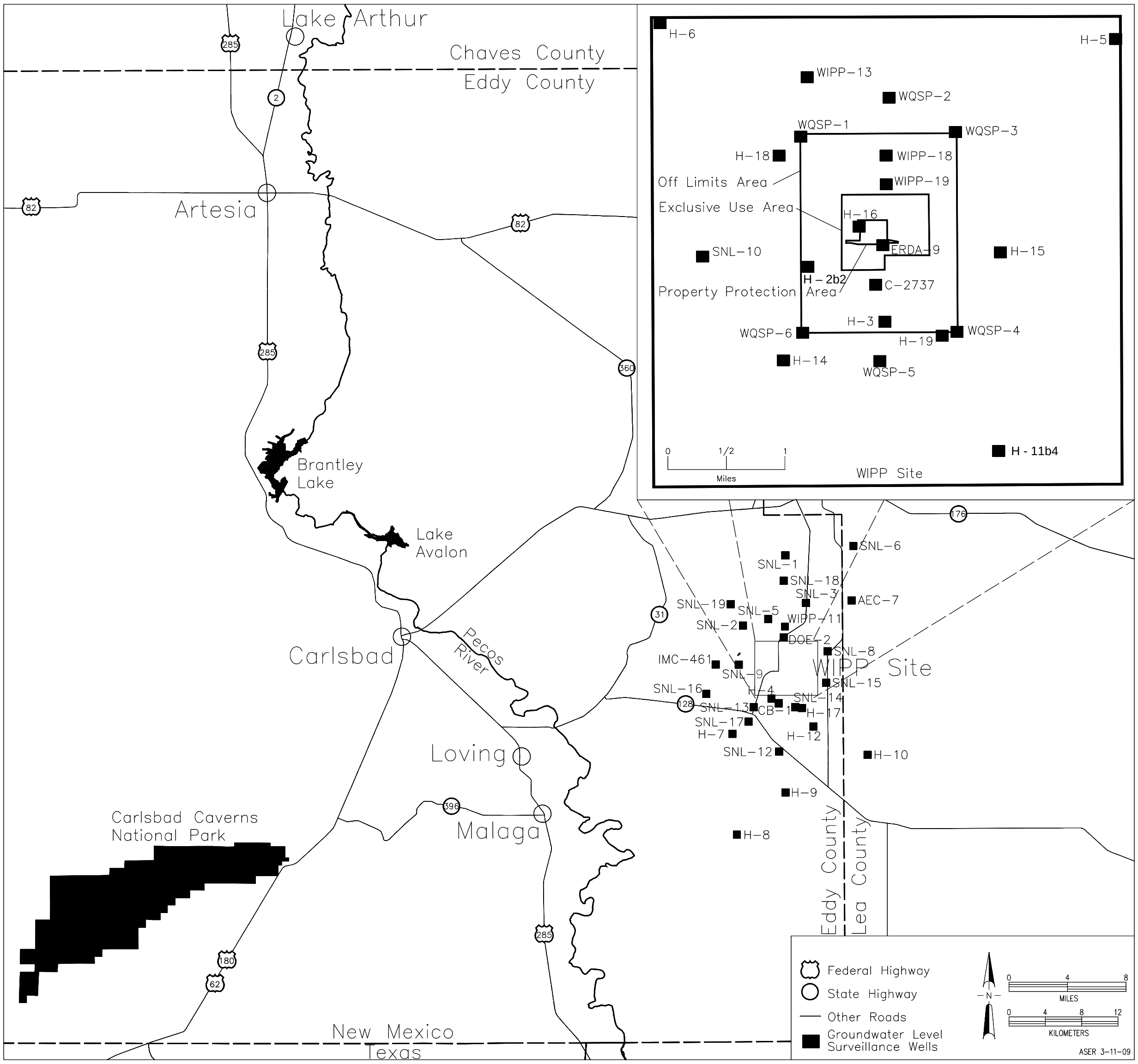


Figure L-14
Groundwater Level Surveillance Wells
(inset represents the groundwater surveillance wells in WIPP Land Withdrawal Area)

Attachment C

Groundwater Work Plan and Groundwater Work Plan Approval and References

GROUNDWATER PERMIT MODIFICATION WORK PLAN

1. OVERVIEW

Pursuant to the New Mexico Environment Department (**NMED**) Stipulated Final Order No. HWB-09-47 (**Order**), the United States Department of Energy and Washington TRU Solutions, LLC, hereinafter referred to as the Permittees, are submitting this document to comply with Item 10.a. of the Order. This item requires the Permittees to describe the proposed contents of a Class 2 Permit Modification Request (**PMR**) to include, but not be limited to, revising all alleged sources of confusion and ambiguities in Module V, Groundwater Detection Monitoring, and Attachment L, WIPP Groundwater Detection Monitoring Program Plan, and incorporating proposed mapping methodology for generating a Culebra Potentiometric Surface Map.

This work plan addresses the content of the PMR and the process that the Permittees will follow to prepare and submit the PMR. At a minimum, the PMR will be submitted pursuant to Item 10.b. of the Order and Waste Isolation Pilot Plant Hazardous Waste Permit (**Permit**) Condition I.B.1 and address the following requirements:

- It will contain the exact changes to be made to the Permit conditions and supporting documents per 20.4.1.900 New Mexico Administrative Code (**NMAC**) (incorporating 40 Code of Federal Regulations (**CFR**) 270.42(b)(1)(i)).
- It will identify that it is a Class 2 modification per 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(ii)).
- It will explain why the modification is needed per 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(iii)).
- It will provide a regulatory crosswalk to the appropriate sections of the regulations per 20.4.1.900 NMAC (incorporating 40 CFR 270.42(b)(1)(iv)).
- It will contain a signed certification statement per 20.4.1.900 NMAC (incorporating 40 CFR 270.11(d)(1) and 40 CFR 270.30(k)).

2. PROPOSED PERMIT REVISIONS

The PMR will include, but will not necessarily be limited to the modifications listed below.

- Revise sources of confusion and ambiguities.
  - Specifically identify which wells are used for density measurements.
    - Specify the frequency for density measurements and assessment.
    - Specify how density measurements are performed.

  - Include a specific list of wells that must be monitored for water levels.
    - Exclude non-Culebra wells from those required for water level measurements.
  - Remove all references to the non-Culebra sampling wells identified as WQSP-6A.
  - Clarify the need for, and use of, written procedures for both field work and non-field work including the procedure for developing a potentiometric surface map annually.
  - Clarify the data quality objectives section and explain data quality objectives and quality assurance objectives and the difference between quality assurance objectives for field work and for laboratory analysis.
  - Remove specificity regarding departments and organizations and replace those terms with "the Permittees."

- Add background values from the Waste Isolation Pilot Plant Resource Conservation and Recovery Act Background Groundwater Quality Baseline Report and Addendum 1, IT Corporation, July 2000 to be used for making statistical determinations of contamination.

- Separate parameters from constituents so that general chemistry parameters (e.g., pH, calcium) are separated from the hazardous constituents.

- Clarify serial sampling requirements including the following:
  - Remove several field parameters that are not indicators of stabilization, such as chloride, divalent cations, alkalinity, total iron, and Eh.
  - Remove the bubbler line requirements.
  - Restrict serial sampling for stabilization to no more than three well bore volumes.

- Change the frequency of performing groundwater sampling and analysis to an annual basis rather than semi-annually.
  - Change the frequency of reporting to annually rather than semi-annually.

- Change the frequency of reporting water level values to twice per year rather than monthly.
  - Include enhanced interpretation in the form of annotated hydrographs.

- Include flow rate and direction determination in the annual detection monitoring report.
  - Remove the Annual Site Environmental Report as a means of reporting flow rate and direction.

- Revise the statistical process for data analysis to be consistent with 20.4.1.500 NMAC (incorporating 40 CFR 264.97(h)).
- Update figures, tables and text with current information.
- Describe the methodology (see Attachment A) for generation of the Culebra Potentiometric Surface Map whereby the Permittees determine the groundwater flow rate and direction annually in accordance with 20.4.1.500 NMAC (incorporating 40 CFR 264.98(e)).

3. DISCUSS DRAFT PMR AND MAPPING METHODOLOGY WITH STAKEHOLDERS AND NMED

The Permittees will conduct a pre-submittal stakeholder information meeting to obtain feedback from stakeholders prior to finalizing the PMR. Stakeholders will be given 10 days to review the draft prior to the meeting.

4. REVISE DRAFT PMR AND METHODOLOGY TO INCORPORATE NMED AND STAKEHOLDER INPUT

To the extent possible, the Permittees will address stakeholder comments in the PMR.

5. SUBMIT PMR TO NMED

Within 60 days from the NMED approval of the work plan, the Permittees shall submit a Class 2 Permit Modification Request.

Tentative Schedule

Day 0	NMED Approves Work Plan
Day 30	Develop Draft PMR
Day 40	Complete WIPP Internal Reviews
Day 41	Submit Draft PMR to Stakeholders
Day 50	Discuss Draft PMR with Stakeholders and NMED
Day 55	Revise PMR to Incorporate NMED and Stakeholder Input
Day 59	Complete Final Review PMR
Day 60	Submit PMR to NMED

Attachment A:
Methodology for Generating the Culebra Potentiometric Surface Map

The Potentiometric surface map for a given calendar year shall be generated using the following steps:

1. Examine hydrographs to identify month having the largest number of Culebra water levels available with the fewest wells affected by pumping or other anthropogenic events.

2. Convert water levels from subject month to equivalent freshwater heads using fluid densities appropriate to the date.

3. Fit trend surface through freshwater heads.

4. Extrapolate the trend surface to the boundaries of the model domain used for the current Performance Baseline Calculations (PABC) and define initial fixed-head boundary conditions based on the trend surface.

5. Using the ensemble-average Culebra transmissivity field used for the current PABC, optimize the model boundary heads to improve the fit of the model to the freshwater heads at the wells using optimization software interactively with MODFLOW.

6. Run MODFLOW with optimal boundary conditions fit.

7. Contour MODFLOW head results on WIPP site.

8. Compute particle path and travel time from the waste handling shaft to the Land Withdrawal Boundary.

9. Data analysis that will accompany the potentiometric surface map will include

    - Measured versus modeled scatter plot
    - Frequency of modeled head residuals
    - Modeled residual freshwater head at each well
    - Explanations for modeled misfit residuals greater than 5 meters (16.4 feet)

NEW MEXICO
ENVIRONMENT DEPARTMENT

Hazardous Waste Bureau

2905 Rodeo Park Drive East, Building 1
Santa Fe, New Mexico 87505-6303
Phone (505) 476-6000 Fax (505) 476-6030
www.nmenv.state.nm.us

SUSANA MARTINEZ
Governor

JOHN A. SANCHEZ
Lieutenant Governor

DAVE MARTIN
Secretary

RAJ SOLOMON, P.E.
Deputy Secretary

CERTIFIED MAIL - RETURN RECEIPT REQUESTED

August 5, 2011

Edward Ziemianski, Acting Manager
Carlsbad Field Office
Department of Energy
P.O. Box 3090
Carlsbad, New Mexico 88221-3090

Farok Sharif
Washington TRU Solutions LLC
P.O. Box 2078
Carlsbad, New Mexico 88221-5608

RE: NOTICE OF APPROVAL
GROUNDWATER PERMIT MODIFICATION WORK PLAN
WASTE ISOLATION PILOT PLANT
EPA I.D. NUMBER NM4890139088

Dear Messrs. Ziemianski and Sharif:

On December 21, 2009, the New Mexico Environment Department (**NMED**) received from the United States Department of Energy Carlsbad Field Office and Washington TRU Solutions (collectively, the **Permittees**) the document entitled *Groundwater Permit Modification Work Plan* (hereafter, the **Plan**). NMED has reviewed the Plan and hereby issues this Notice of Approval.

In accordance with paragraph 10.b of Stipulated Final Order (**SFO**) number HWB 09-47, dated December 1, 2009, the Permittees must submit a Class 2 Permit Modification Request (**PMR**) within 60 days from NMED's approval. Therefore the PMR must be submitted no later than October 4, 2011.

If you have any questions regarding this matter, please contact me at (505) 476-6035 or Tim Hall at (505) 476-6049.

Sincerely,

John E. Kieling
Acting Bureau Chief
Hazardous Waste Bureau

JEK/th

cc: Tim Hall, NMED HWB
George Basabilvaso, DOE CBFO
Thomas Kesterson, DOE OB
Julia Marple, DOE OB
File: Red WIPP '11

554054

Analysis Report
AP-111 Revision 1

Culebra Water Level Monitoring Network Design

(AP-111: Analysis Plan for Optimization and Minimization of the Culebra Monitoring Network for the WIPP)

Task Number 1.4.2.3
Report Date: August 4, 2010

Author: Date: 8/4/10
Kristopher L. Kuhlman
Repository Performance Department (6712)

Technical Review: Mario Chavez for Date: 8/6/10
Sean A. McKenna
National Security Applications Department (6311)

QA Review: Mario Chavez Date: 8/6/10
Mario J. Chavez
Carlsbad Programs Group (6710)

Management Review Date: 8/4/2010
Christi D. Leigh
Manager, Repository Performance Department (6712)

WIPP:1.4.2.3:TD:QA-L:RECERT:540476

Acknowledgements

Thanks to David Hart and Sean McKenna for their previous work on the calibration of the transmissivity fields, utilized as inputs in Section 4 of this analysis. Thanks to Rick Beauheim for his comments and guidance on early drafts of this report.

Table of Contents

List of Figures

List of Tables

Executive Summary

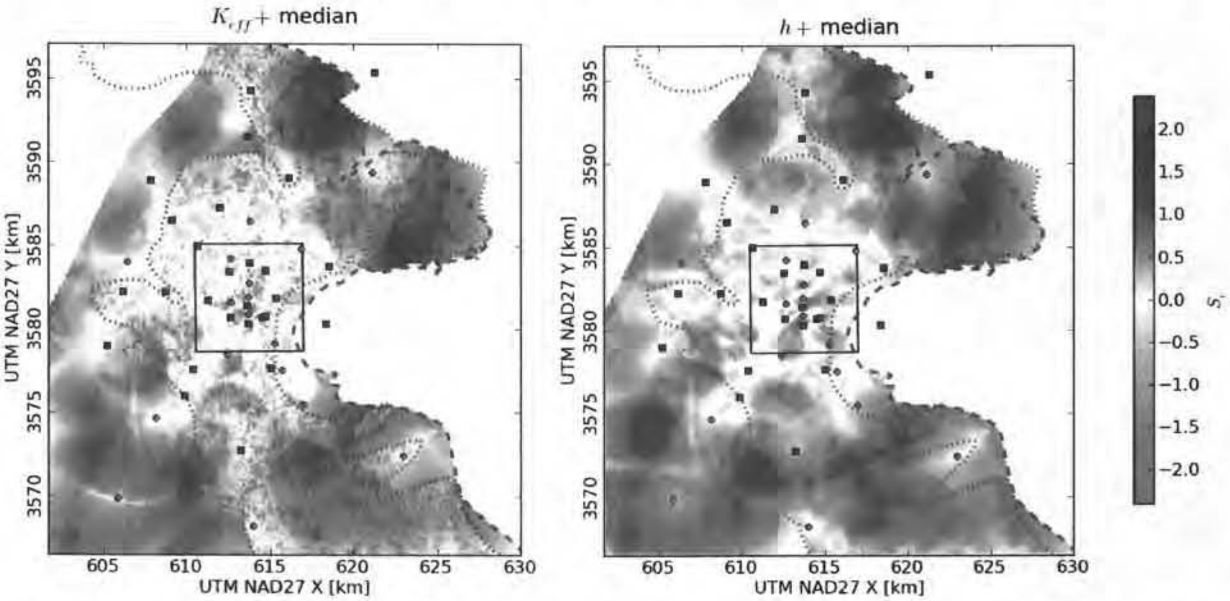
This analysis report presents the methods, data, and results of calculations done in support of Culebra head and hydraulic gradient monitoring network design and optimization. The three metrics used include:

1. freshwater head kriging variance reduction,
2. triangle geometry shape quality maximization, and
3. identification of areas where there is a high statistical correlation between model-predicted travel times and either
   a. model input effective hydraulic conductivity (K_{eff}) or
   b. heads (h)

These three different and largely independent approaches to monitoring network design are discussed individually in detail (Sections 2, 3 and 4) and are combined (Section 5) for two different types of results,

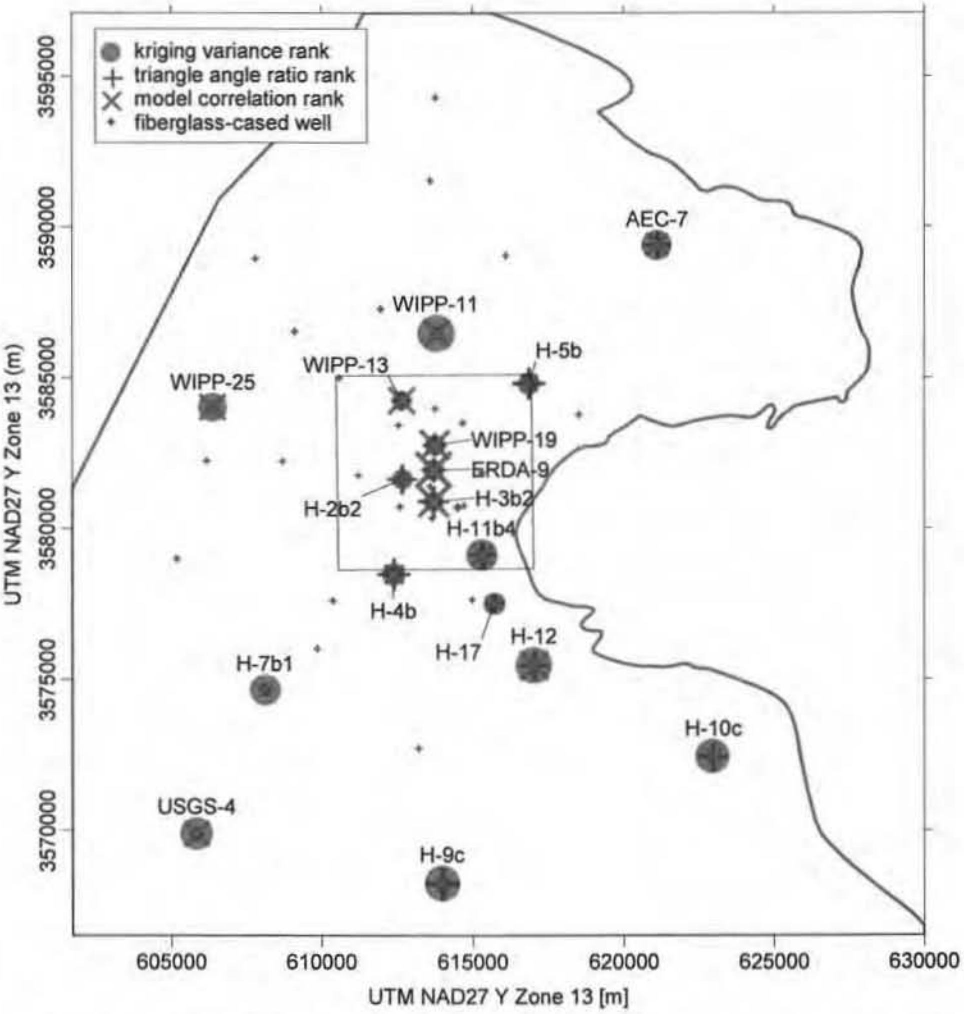
1. ranking of possible locations for new wells, and
2. ranking the importance of maintaining existing locations.

The combinations of the three metrics for the suitability of a location for a new monitoring location are shown in the following two figures (discussed more fully in the Section 5).



In these two figures, red and orange areas are poor locations for a new well, while dark blue and purple areas are good locations for a new well. The left figure includes metrics 1, 2, and 3a (from the top bulleted list), while the right fiure includes metrics 1, 2, and 3b. While the two figures are different in some details, they both show that the areas between monitoring locations that are distant from the WIPP LWB (interior black square) rank highly overall (dark blue). Areas roughly consisting of 'spokes" radiating away from the WIPP LWB – between closely spaced monitoring wells – rank poorly overall (yellow and orange).

Using the same three metrics for ranking the existing steel-cased wells (assuming fiberglass-cased wells will have a long life), the results are combined in the following figure (discussed more fully in Section 5).



In this figure, the size of the different symbols is related to the relative importance of each of the steel-cased wells, ranked via the three metrics. Many wells are important to one or two metrics and unimportant to another (e.g., closely-spaced wells inside the WIPP LWB perform poorly in the kriging variance reduction, but might be in important areas for the model input/output correlation). Overall, wells H-12, H-10c, and AEC-7 have relatively high ranks in all three metrics. These wells are somewhat isolated and therefore are individually important in their contributions to the success of the overall monitoring network.

1.0 Introduction

This analysis report presents the methods, data, and results of calculations done in support of Culebra head and hydraulic gradient monitoring network design and optimization. Three different and largely independent approaches to monitoring network design are examined. These approaches include optimal locations for additional monitoring wells and identification of wells in the current monitoring network that could be removed with minimal effect on meeting the monitoring objectives. The three different sets of results are then combined into a final set of maps indicating potential areas for the installation of new monitoring wells. Additionally, several wells in the existing network could be removed with minimal effect on the ability of the monitoring network to predict heads at unmonitored locations and to detect changes in the hydraulic gradient. The three approaches used here are similar to approaches used in the 2004 ground water monitoring network design calculations, and this allows for direct comparison of some results with those obtained five years ago.

1.1. Background

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico and has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth at Title 40 of the Code of Federal Regulations, Parts 191 and 194. The DOE demonstrates compliance with the containment requirements in the regulations by means of a performance assessment (PA), which estimates releases from the repository for the regulatory period of 10,000 years after closure.

Groundwater monitoring and modeling activities at the WIPP are an integral part of the DOE's broader requirements to demonstrate that WIPP operations are performed in a manner that ensures protection of the environment, the health and safety of workers and the public, proper characterization of the disposal system, and compliance of the WIPP with applicable regulations. Continued compliance with regulations must be demonstrated every five years during the operational phase of the WIPP. The monitoring requirements apply not only for the current operational phase (~35 years), but extend through the post-closure phase of the facility to meet applicable regulations. Because of these long-term requirements, DOE's Carlsbad Field Office (CBFO) has developed the WIPP Groundwater Protection Program Plan (DOE, 2009) that describes: relevant regulatory (EPA and New Mexico Environment Department) drivers; the current groundwater-monitoring network and how it has evolved over time; current groundwater program elements; strategies for maintaining compliance; methods for implementing the strategies; and roles and responsibilities of monitoring program participants.

This analysis report is a revision of McKenna (2004), which identified wells that could be removed from the existing network as well as looked at potential locations to expand the monitoring network. Since 2004, the number of monitoring wells available for analysis have increased by 40%, from 30 to 42. Now after the SNL-series fiberglass-cased wells have been constructed, this report is re-evaluating the well network based on the new information obtained from these new wells and the updated Culebra PA flow model, completed for the compliance recertification application (CRA) 2009 performance assessment baseline calculation (PABC).

1.2. Purpose

The purpose of these calculations is primarily to determine which of the remaining steel-cased wells can be plugged and abandoned (P&Aed) without degrading the monitoring network. A secondary goal is to identify optimal locations for any new Culebra monitoring wells. The calculations herein will be focused on meeting the goals of:

1. The monitoring network must allow the determination of the direction and rate of groundwater flow across the WIPP site. This is both an NMED and an EPA requirement (NMAC, 2000 incorporating 40 CFR Part 194 §264.98(e) (U.S. EPA, 1996));
2. The monitoring network must provide data needed to infer causes of changes in water levels that might be observed. This is an EPA requirement, 40 CFR Part 194, Subpart C §194.42 (U.S. EPA, 1996); and
3. The monitoring network must provide spatially distributed head data adequate to allow both defensible boundary conditions to be inferred for Culebra flow models and defensible calibration of those models (PA requirements).

The degree to which these objectives can be reduced to quantitative measures is evaluated as part of the work reported in this analysis report.

The minimized and optimized monitoring network will be created using available information including existing wells and up to date understanding of the hydrology of the Culebra. The optimization and minimization process takes the following factors into consideration:

1. Existing locations of fiberglass-cased wells
2. Existing well locations that are not needed
3. Culebra hydraulic property variations and geologic boundaries

1.3. Outline

This report documents the data, methods, and summary results of the work completed under Analysis Plan 111 (Kuhlman, 2008). The analysis has four main components, which look at the network optimization from the perspective of:

1. **kriging**: considers the spatial clustering of observation points and the geostatistical structure of the data via the variogram (see Section 2.0);
2. **local gradient estimators**: Delaunay triangles that consider the geometric quality of the well network and the observed gradient across the well network (see Section 3.0);
3. **flow model correlation**: uses the structure embodied in the calibrated flow model regarding formation heterogeneity and geologic processes (see Section 4.0);
4. combining the results of the three above methods into one result (see Section 5.0)

1.4. Calculation domain

The spatial domain used for the different calculations in support of monitoring network design is the same as the model domain used in the two-dimensional (2D) Culebra groundwater flow model (Hart et al., 2008; 2009). This model domain is aligned with the Universal Transverse Mercator (UTM) coordinate system and is 30.7 km long by 28.4 km wide (872 km^2 total, 587 km^2 active). The corners of the Culebra numerical groundwater model domain are listed in Table 1-1. Relative to the CRA 2004 calculations, the eastern extent of the model domain has moved from 624000 m to 630000 m UTM 1927 North American datum (NAD27) meters, as explained in (Hart et al., (2008), §2.1). These coordinates define the center of 100 m × 100 m model cells at the four corners of the model domain. All monitoring calculations that produce results on a spatial grid employ the same grid as used for the 2D Culebra flow model (see e.g., Kuhlman, 2010b), unless otherwise noted.

Table 1-1. Culebra flow model domain UTM NAD27 Zone 13 coordinates

Model domain corner	X [m]	Y [m]
Northeast	630000	3597100
Northwest	601700	3597100
Southeast	630000	3566500
Southwest	601700	3566500

The WIPP land-withdrawal boundary (LWB) encloses 16 township and range sections (approximately 41 km^2) near the center of the MODFLOW model domain. The boundary of the WIPP site is defined by the corners of the 16 sections, which have the UTM coordinates given in Table 1-2. For the calculations described in this report, the coordinates given in Table 1-1 and Table 1-2 are used to delineate areas, across which we average different measures of effectiveness for the monitoring network.

Table 1-2. The WIPP LWB UTM NAD27 Zone 13 coordinates

WIPP boundary corner	X [m]	Y [m]
Northeast	616941	3585109
Northwest	610495	3585068
Southeast	617015	3578681
Southwest	610567	3578623

1.5. Observed Data

The approaches developed in this report can be applied to any set of nearly-simultaneous undisturbed head measurements (i.e., a "snapshot" in time of the hydraulic head in the Culebra). The wells used here are shown in Figure 1-1 and the data observed at these wells are listed in Table 1-3 (freshwater head data from (Johnson, 2009)). The majority of the calculated freshwater head values correspond to those used in the calibration of the CRA-2009 PABC transmissivity fields (Hart et al., 2009) with four exceptions and one note:

1. A representative 2004 value from AEC-7 was used (this well was left out of the flow model calibration due to known configuration problems in 2007). Freshwater heads at AEC-7 have been very stable historically (1988 through 2004), and are now representative of previous trends after well reconfiguration. Over 15 years (12/1988 through 3/2004) there were 172 head measurements with a standard deviation of only 0.56 m;

2. Freshwater heads from March 2007 were used at the H-19 wellpad, to include the six redundant wells (H-19b{2,3,4,5,6,7}), which are only monitored quarterly. These wells are only included in the variogram modeling, to better constrain head variation at short distance scales (see discussion about optimal well networks for estimating variograms in Warrick & Myers (1984) or Conwell, et al. (1997)). The central H-19b0 well is used as

the sole H-19b well in the rest of the analyses discussed in this report. The coordinates of the H-19b wells reflect their computed UTM *x*, *y* locations at the Culebra (229 m below ground surface (bgs)), accounting for observed deviations from vertical completion (Meigs et al., 2000). H-19b0 freshwater heads are within 2 cm between the March and May 2007 observation times.

3. SNL-6 and SNL-15 have not recovered since being drilled in 2005, and will likely take hundreds of years to recover to "static" conditions. These wells use land-surface elevations in place of water levels in the model calibration (>1000 m above mean sea level (AMSL)); they are not used in situations where a representative head value is needed (e.g., variogram modeling and gradient estimation), but their locations are included otherwise (e.g., kriging and network geometry optimization).
4. WIPP-30 is not included in the network optimization, since this well was plugged and abandoned in May 2007.
5. WIPP-25 is used both here and in the CRA-2009 PABC Culebra flow modeling exercise, although this well was P&Aed in 2009.

In addition to the calculated May 2007 freshwater heads, calibration results from the most recent iteration of the Culebra PA T-fields (Hart et al., 2009) are also used. These results include the simulated head values, calibrated transmissivity and anisotropy values, and particle travel times from C-2737 to the WIPP LWB for each of the 100 model realizations. These results are used in the third sensitivity-based approach.

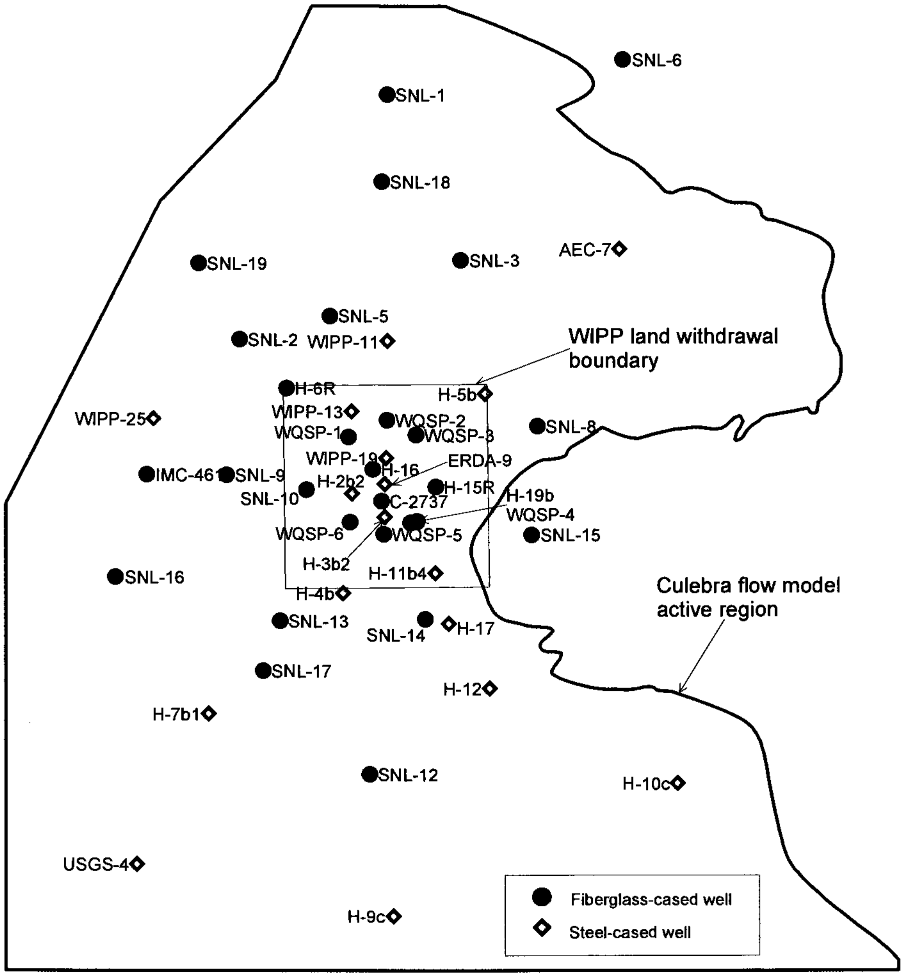


Figure 1-1. Locations of monitoring wells used in this study

Table 1-3. Freshwater Heads from May 2007 used in analysis (Johnson, 2009)

	Well	UTM NAD27 *x* Zone 13[m]	UTM NAD27 *y* Zone 13 [m]	Freshwater Head [m AMSL]
1	AEC-7(1)	621126	3589381	933.03
2	C-2737	613598.0	3581400.9	921.23
3	ERDA-9	613696.1	3581944.3	924.88
4	H-2b2	612662.5	3581639.7	929.62
5	H-3b2	613693.6	3580899.6	918.68
6	H-4b	612376.0	3578478.5	916.34
7	H-5b	616866.0	3584807.0	939.12
8	H-6b	610598.6	3584986.9	936.44
9	H-7b1	608122.8	3574646.4	914.58
10	H-9c	613971.1	3568237.2	912.80
11	H-10c	622976.3	3572444.3	922.02
12	H-11b4	615297.3	3579123.5	917.09
13	H-12	617022.0	3575460.5	916.53
14	H-15	615310.0	3581855.2	920.32
15	H-17	615717.0	3577507.8	916.24
16	H-19b0(2)	614515.2	3580718.9	918.82
17	H-19b2(2)	614516.2	3580693.8	918.64
18	H-19b3(2)	614526.1	3580719.6	918.57
19	H-19b4(2)	614494.6	3580727.6	918.77
20	H-19b5(2)	614502.3	3580713.6	918.60
21	H-19b6(2)	614518.0	3580738.5	918.58
22	H-19b7(2)	614516.0	3580706.7	918.54
23	IMC-461	606182.6	3582246.4	928.95
24	SNL-1	613781.4	3594299.0	941.86
25	SNL-2	609113.1	3586529.1	937.65
26	SNL-3	616103.0	3589046.9	939.81
27	SNL-5	611970.2	3587284.7	938.59
28	SNL-6(3)	621244.6	3595390.0	856.00
29	SNL-8	618522.8	3583783.3	929.94
30	SNL-9	608704.8	3582237.7	932.05
31	SNL-10	611229.3	3581764.8	931.54
32	SNL-12	613223.4	3572727.4	915.24
33	SNL-13	610394.3	3577599.8	918.19
34	SNL-14	614989.7	3577652.0	916.33
35	SNL-15(3)	618353.2	3580336.4	865.65
36	SNL-16	605191.8	3578999.7	918.68
37	SNL-17	609863.2	3576016.1	916.78
38	SNL-18	613605.8	3591528.6	939.87
39	SNL-19	607813.5	3588947.4	937.58
49	USGS-4	605841.0	3569887.0	911.11
41	WIPP-11	613788.2	3586474.0	940.65
42	WIPP-13	612645.0	3584241.7	939.78
43	WIPP-19	613738.8	3582773.5	933.66
44	WIPP-25	606385.7	3584022.8	937.57
45	WQSP-1	612559.4	3583430.3	938.28
46	WQSP-2	613770.4	3583972.2	939.87
47	WQSP-3	614685.5	3583506.8	936.43
48	WQSP-4	614724.5	3580762.8	919.50
49	WQSP-5	613666.5	3580353.6	918.18
50	WQSP-6	612602.3	3580737.9	921.96

1. representative water level from 2004
2. H-19 wells from March 2007
3. not used in variogram estimation

1.6. Run Control

Nearly all the calculations done for this analysis report were completed on a Dell Precision 690 workstation, equipped with two quad-core 2.66-GHz Intel Xeon chips (X5355). The work was done on this system running the Microsoft Windows XP (service pack 2) operating system. Two of the scripts were run on the PA Pentium 4 Linux cluster (`alice.sandia.gov`); these scripts checked the Culebra MODFLOW model results out of CVS (only accessible from Linux) and performed the binary-to-ASCII conversion on the model-produced heads before creating a zip archive of the files for transfer to Windows. The input files, scripts, and outputs are contained within the `analysis` directory on the CD-ROM associated with this analysis report; the contents of the CD are listed in Section 8.1.

Each section has a run control subsection describing the software and scripts that were used to perform the analysis in that section. All scripts created for this analysis report are listed in Section 8.0 with syntax highlighting and line numbers. Table 1-4 lists the software used throughout this report, all software is either commercial off the shelf (COTS), or it is qualified for use with WIPP PA.

Table 1-4. Summary of software used

Software	Version	Type	Use
Golden Software Surfer	9.9	COTS	Map plotting / Variograms
Microsoft Office Excel	2007 (SP1)	COTS	Plotting / Regression
R	2.10	COTS	Statistical Script Interpreter
Enthought Python (EPD)	6.1	COTS	Script Interpreter / Plotting
GSLIB program KT3D	2.0 (1996)	Qualified	Kriging
The Mathworks MATLAB	R2009b	COTS	Script Interpreter / Plotting
Gnu Bash	3.00.15	COTS	Script Interpreter (Linux)
Windows XP `cmd.exe`	5.1.2600	COTS	Script Interpreter (Windows)

Scripts for Python, R, Bash, and MATLAB are ASCII and are listed in Section 8.0, while Surfer and Excel input files are binary and therefore are included on the CD (see listing of contents of CD in Section 8.1).

1.7. Notation

Throughout this analysis report the following conventions are used:

1. file names and directory paths are listed in the `Courier New` monospaced font;
2. source code excerpts are listed in the `Lucida Console` monospaced font;
3. program functions and classes are listed as code excerpts with trailing parentheses for clarity;
4. units are given in metric, specified in square brackets (unless used as an adjective);
5. scalar variables are in italic font; and
6. vector variables are in bold font.

2.0 Geostatistical Variance Reduction

Geostatistics is the modeling and prediction of spatially-correlated information and it has been used extensively over the past 30 years in areas including ore reserve estimation, contaminant mapping in soils and groundwater, and modeling spatial variability of physical properties of aquifers and petroleum reservoirs. Kriging is the geostatistical algorithm used for spatial estimation; compared to other spatial interpolation algorithms (e.g., inverse distance or linear interpolation), kriging uniquely estimates both a value and its variance at unsampled locations.

Previous studies (Rouhani, 1985) have used kriging variance as a measure of the ability of a groundwater monitoring network to predict hydraulic heads at locations where no wells exist. Groundwater monitoring network design can be optimized to either minimize average kriging variance across the domain or to minimize the maximum predicted kriging variance. The estimation variance can also be used as a metric to justify removing wells from an existing network such that the overall kriging variance has a minimal increase. As an example, (Tuckfield et al., 2001) used the kriging variance of contaminants in a plume to determine the redundancy of groundwater contaminant monitoring wells and targeted those wells with the highest redundancy for removal from the network.

Kriging variance is a direct function of the spatial distribution of observations and the variogram (which is fitted to observed data). Kriging variance is only indirectly a function of the observed values; this is a major advantage of using kriging in monitoring network optimization. Therefore, changes in the kriging variance from the addition or removal of a well can be estimated prior to adding or removing that well with a standard kriging calculation.

The geostatistical analysis presented here utilizes ordinary kriging of the residual freshwater heads, after removing a linear trend. The freshwater heads in the Culebra across the model domain have a clear trend (i.e., the regional north-south gradient, see Figure 2-1). Although it is possible to krige values while simultaneously estimating a trend (i.e., universal kriging), this approach is not used here. Universal kriging does obviate the need to first estimate the linear trend for the kriging, but model-fitting to the observed variogram is made more complex, requiring a non-linear optimization or iterative refinement between variogram fitting and kriging with a trend (Armstrong, 1984; Goovaerts, 1998).

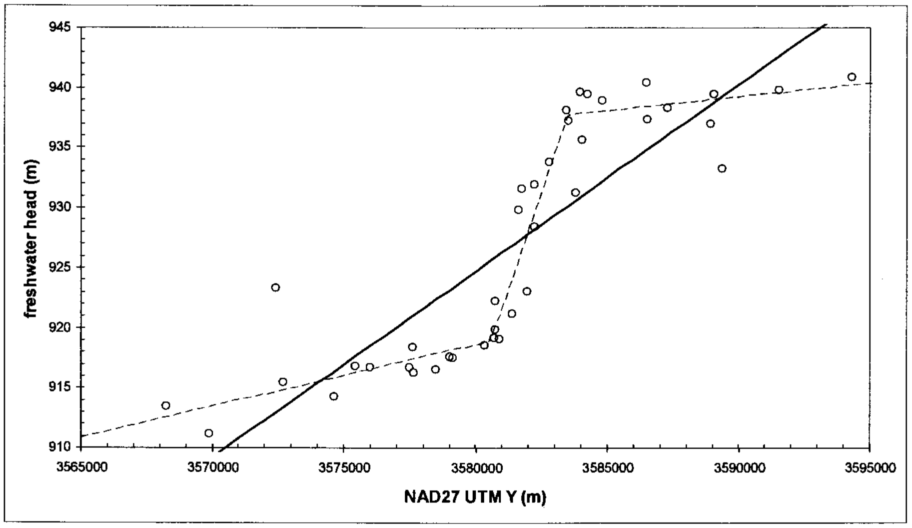


Figure 2-1.Projection of freshwater heads (circles), piecewise linear trend (blue dashed line), and best-fit linear trend (red line) onto *y*-head plane at *x*-midpoint of MODFLOW model domain.

2.1. *Trend Fitting and Residual Calculations*

The residuals associated with the head observations from May 2007 are used for the geostatistical variance reduction analysis. A best-fit linear surface through these heads was calculated using the COTS statistical software R. The equation for the best-fit plane through May 2007 freshwater heads is

$$h(x,y) = Ax + By + C\,. \tag{1}$$

The results of fitting this equation to the data in Table 1-3 are $A = -9.0\times10^{-5}$, $B = 1.5\times10^{-3}$ and $C = -4.6\times10^{3}$ m (see Table 2-1 for more significant digits and fit statistics). The *y* component (*B*) of the gradient is approximately an order of magnitude larger than the *x* component (*A*). Both *B* and *C* have *t* statistic values indicating significance ($|t|>2$), but *A* does not (see Table 2-1); the east-west component of the regional gradient cannot be estimated accurately from the given data. This same linear fit resulted in coefficients of $A = 1.98\times10^{-4}$, $B = 1.62\times10^{-3}$ and $C = -5007.74$ in the 2004 version of this analysis. The *y*-component of the gradient (*B*) has not changed much, but the *x*-component (*A*) and the additive constant (*C*) have changed. Overall, the resulting gradient vectors are quite similar (see Figure 2-2), considering the large number of wells that have changed between the two studies.

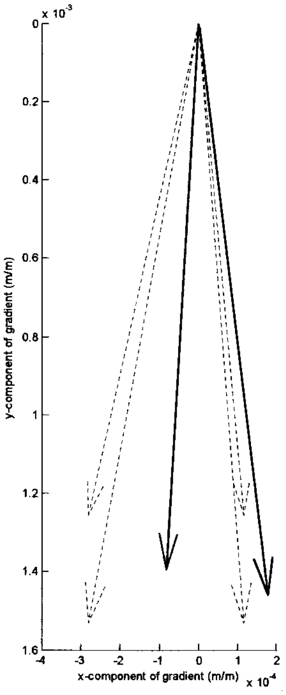


Figure 2-2. Comparison of gradient vectors corresponding to best-fit planes through 2003 (black) and 2007 (red) data. Red dotted lines correspond to estimated gradient ± gradient standard error.

Figure 2-3 illustrates several plots related to the fit of Equation (1) to freshwater heads. The upper-left plot shows the residual (measured – trend) as a function of the trend. The outliers from the moving-average residual trend are H-10c, WQSP-2 and WIPP-13 (see red line and labeled points in the upper left plot in Figure 2-3). The upper-right normal quantile plot (Q-Q) shows that aside from the extreme values, the residuals are ordered approximately normally (plotting quantiles, rather than values makes this plot non-parametric). The lower-left scale-location plot shows magnitude of residuals against the trend value, illustrating that the steep gradient across the WIPP site (920-935 m elevation) is where residuals are largest on average. The lower-right leverage plot shows the relative effects that removing a well has on the predicted surface, plotted against residuals. The wells with the most leverage and the largest residuals are wells at the extremities of the domain, including H-10c, H-9c and AEC-7.

Table 2-1. Fit statistics for linear surface (Equation 1) through freshwater head data (Table 1-3)

```
(Intercept)             x             y
-4.563833e+03 -9.023153e-05  1.548563e-03

Residuals:
   Min     1Q Median     3Q    Max
-7.361 -4.833 -0.459  3.901  9.911

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.564e+03  5.594e+02  -8.158 5.83e-10 ***
x           -9.023e-05  2.231e-04  -0.405    0.688
y            1.549e-03  1.537e-04  10.077 2.06e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.392 on 39 degrees of freedom
Multiple R-squared: 0.7226,     Adjusted R-squared: 0.7083
F-statistic: 50.79 on 2 and 39 DF,  p-value: 1.386e-11
```

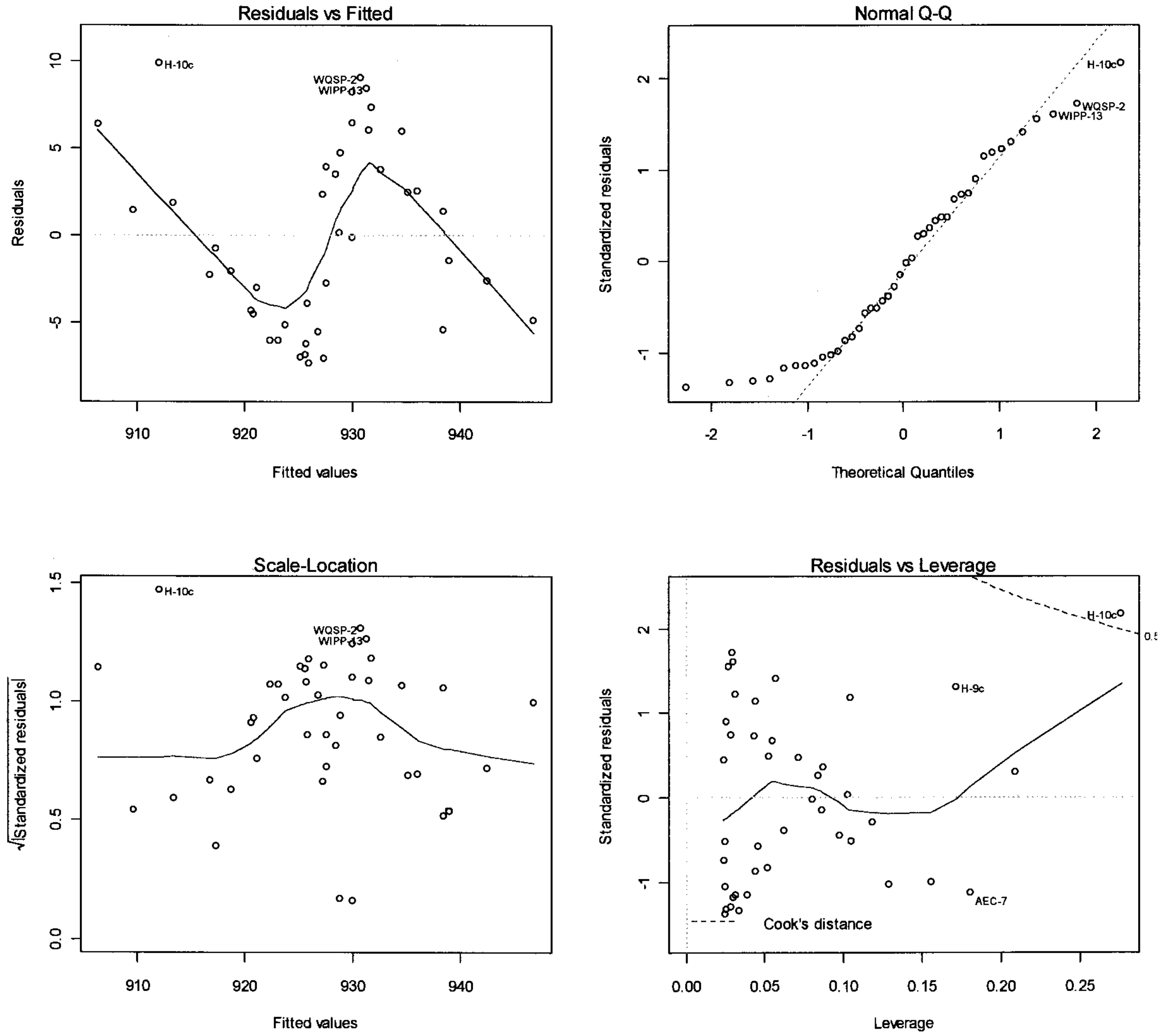


Figure 2-3. Statistics of linear surface (Equation 1) fit to May 2007 freshwater heads

With these parameter values, Equation 1 fits the May 2007 heads with R^2=0.7083 (see penultimate row of Table 2-1). This best-fit plane has a hydraulic gradient of 1.55×10^{-3} and a flow direction 3 degrees east of south, but the exact angle is poorly defined. The residuals between the estimated and measured heads are used as the input data for the geostatistical analysis. In the 2004 version of this analysis, R^2=0.6, the gradient magnitude and angle were computed to be 1.64×10^{-3} and 7 degrees east of south (see Figure 2-2 for comparison).

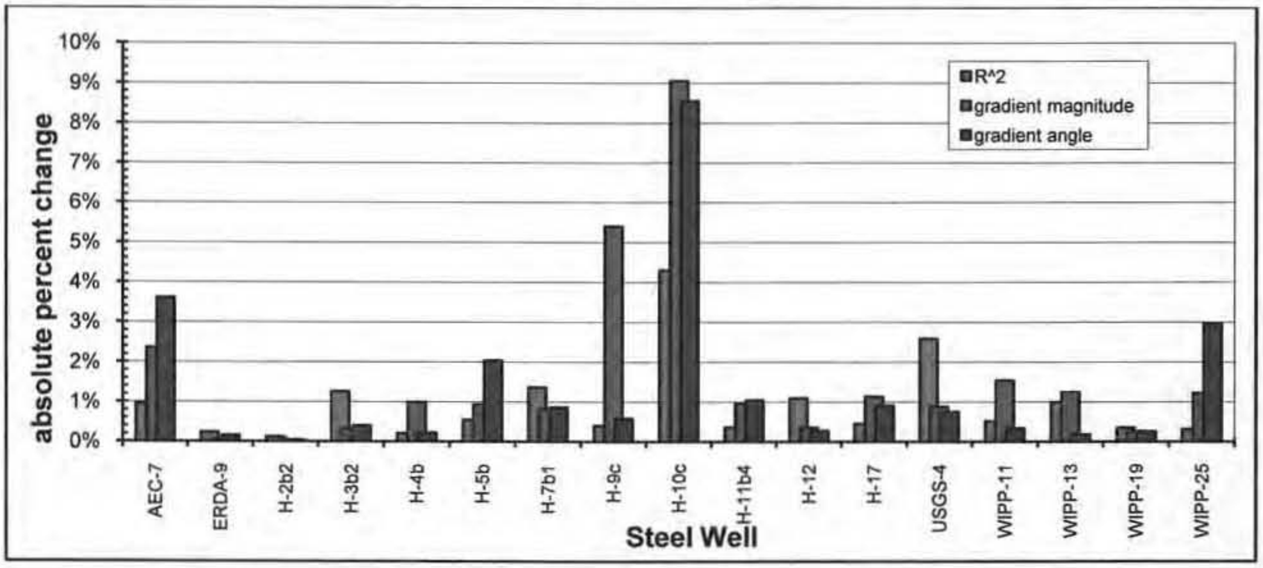


Figure 2-4. Effects of removing a steel-cased well on parameters related to the estimated linear trend.

Adding or removing a single data point from the dataset (Table 2-2) has two potential effects on the results of kriging. First, the best-fit trend surface can change (see "residuals vs. leverage" plot in Figure 2-3 and Figure 2-4), especially if the point being added or removed is at the extremities of the domain (e.g., wells AEC-7, H-9c, and H-10c). Second, the experimental variogram computed from the residuals can change (see next section).

Figure 2-4 shows the results of removing each steel-cased well individually, and fitting Equation (1) using least-squares to the resulting smaller dataset. As was shown in the "residuals vs. leverage" plot in Figure 2-3, H-10c, H-9c, and AEC-7 have a large effect on the R^2 measure of the fit quality. The blue and green bars in Figure 2-4 illustrate the change on the magnitude and angle of the gradient due to removing a single steel-cased well. H-9c has a large effect on the magnitude but not the angle of the gradient; it is located in the south-central portion of the domain. In contrast, WIPP-25 and AEC-7 have larger effects on the angle than the magnitude of the gradient; these wells are on the east and west extremities of the MODFLOW domain, respectively.

Table 2-2. May 2007 freshwater head (FWH) data and residual. The residuals in the right column are calculated as measured – modeled head, sorted by residual magnitude.

	Well	Observed FWH [m]	Residual [m]
1	H-3b2	918.68	-7.36
2	H-19b6	918.58	-7.14
3	H-19b7	918.54	-7.13
4	H-19b3	918.57	-7.12
5	H-19b5	918.6	-7.08
6	H-15	920.32	-7.05
7	WQSP-5	918.18	-7.02
8	H-19b2	918.64	-7.01
9	H-19b4	918.77	-6.93
10	H-19b0	918.82	-6.87
11	WQSP-4	919.5	-6.24
12	H-4b	916.34	-6.07
13	H-11b4	917.09	-6.06
14	C-2737	921.23	-5.60
15	AEC-7	933.03	-5.47
16	SNL-16	918.68	-5.19
17	SNL-1	941.86	-4.92
18	SNL-14	916.33	-4.56
19	H-17	916.24	-4.37
20	WQSP-6	921.96	-3.93
21	SNL-13	918.19	-3.04
22	ERDA-9	924.88	-2.78
23	SNL-18	939.87	-2.64
24	H-7b1	914.58	-2.28
25	SNL-17	916.78	-2.04
26	SNL-19	937.58	-1.45
27	H-12	916.53	-0.79
28	SNL-8	929.94	-0.13
29	IMC-461	928.95	0.15
30	SNL-3	939.81	1.37
31	USGS-4	911.11	1.41
32	SNL-12	915.24	1.81
33	H-2b2	929.62	2.34
34	SNL-2	937.65	2.48
35	SNL-5	938.59	2.51
36	SNL-9	932.05	3.49
37	H-6b	936.44	3.79
38	SNL-10	931.54	3.94
39	WIPP-19	933.66	4.72
40	WIPP-11	940.65	5.99
41	WIPP-25	937.57	6.03
42	H-9c	912.8	6.39
43	WQSP-3	936.43	6.44
44	H-5b	939.12	7.31
45	WQSP-1	938.28	8.22
46	WIPP-13	939.78	8.47
47	WQSP-2	939.87	9.08
48	H-10c	922.02	9.91

2.2. *Variogram Estimation and Modeling*

The experimental variogram is calculated and modeled using Surfer. Introductions to variogram modeling and geostatistics in general are found in many places in the geostatistics literature; e.g., (Isaaks and Srivastava, 1989; American Society of Civil Engineers, 1990; Kitanidis, 1997). The experimental variogram is calculated in Surfer as

$$\hat{\gamma}(\boldsymbol{h}) = \frac{1}{2N(\boldsymbol{h})} \sum_{i=1}^{N(\boldsymbol{h})} [z(\mathbf{u}_i) - z(\mathbf{u}_i + \boldsymbol{h})]^2 , \tag{2}$$

where $\boldsymbol{h}$ is the lag spacing vector [m] (most generally $\boldsymbol{h}$ is a vector, but later it will assumed to be a scalar distance), $z(\mathbf{u}_i)$ are the residual freshwater head values at $\mathbf{u}_i$, $\mathbf{u}_i$ is a vector of spatial coordinates (x,y) for the sample locations of each residual value, and $N(\boldsymbol{h})$ is the number of pairs of data points separated by $\boldsymbol{h}$ (within a given tolerance of $\boldsymbol{h}$). The values of the experimental variogram $\hat{\gamma}$, are plotted as a function of $|\boldsymbol{h}|$ and a variogram model (a mathematical function) is fit to these data. Valid variogram models ensure a positive-definite covariance matrix in the kriging equations.

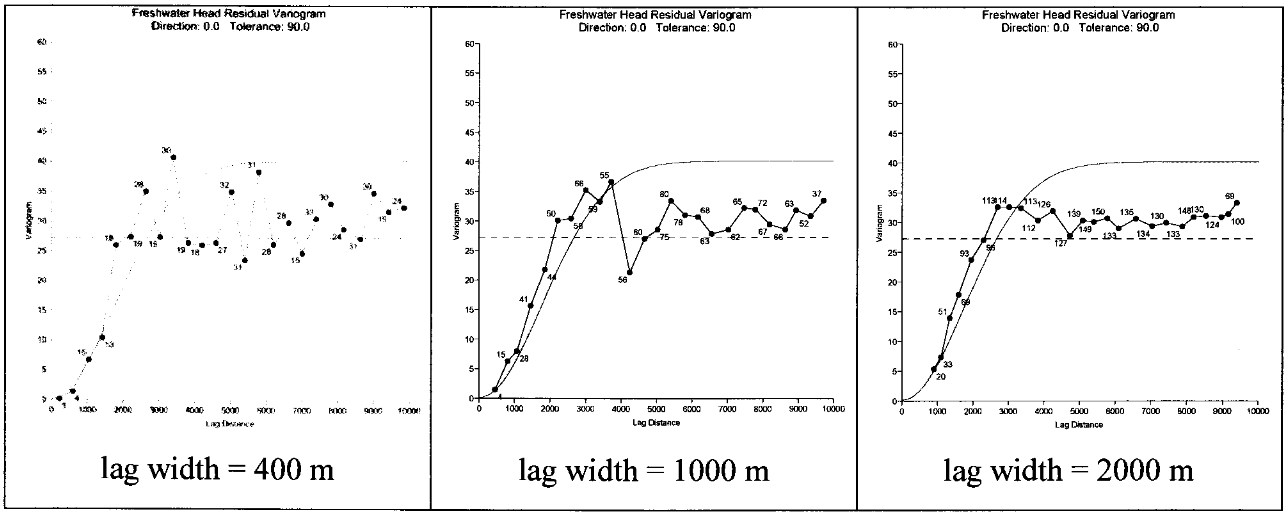
In the current analysis, the infinitely differentiable Gaussian variogram model is chosen to fit the experimental variogram. Since freshwater hydraulic head and residuals computed from it are assumed to be smoothly varying properties (with well-defined first and second spatial derivatives), a variogram that is at least second-order smooth is appropriate. The Gaussian variogram model, as implemented in the kriging program KT3D in GSLIB (Deutsch and Journel, 1998) is

$$\gamma(\boldsymbol{h}) = C\left\{1 - \exp\left[-\left(\frac{3\boldsymbol{h}}{a}\right)^2\right]\right\} \tag{3}$$

where C is the sill [m^2] and a is the range [m]. The variogram modeling is performed using Surfer, which models the Gaussian variogram model without the factor 3 in the exponential. The Gaussian model fit to the experimental variogram, computed from the residual heads, is shown in Figure 2-5. This model has a nugget value of 0.1 m^2, a sill of 40 m^2 and an effective range of 7500 m (the 2004 report had a nugget of 13.0 m^2, a sill of 45.2 m^2, and an effective range of 9000 m). The numbers of data pairs used in the calculation of each point in the experimental variogram are also shown. The calculation of the experimental variogram was done by considering combinations of pairs of data points in all directions. By not considering direction, only distance, the variogram is an omnidirectional calculation using h, where h is the length of the vector $\boldsymbol{h}$. An omnidirectional variogram was also used in the 2004 version of this analysis.

Although a small number of pairs (<30) exist for many of the shorter lag spacing in Figure 2-5, it is felt this variogram is still valid and representative. The only short-lag observation pairs are the redundant wells on the H-19 wellpad. These wells were included in the variogram analysis to get some approximation of the short-lag behavior of freshwater head residual, coupled with the knowledge that the freshwater head residual is a smooth function (i.e., the reason the differentiable Gaussian variogram was used in the first place). The model variogram used in 2004 had a much larger nugget value than the current model does (13 m^2 – compared to 0.1 m^2), but the 2004 model did not use the redundant H-19 wells, which solely contribute to the short-lag experimental variogram.

Although it is possible to calculate directionally dependent variograms, this was not done. The steep north-south hydraulic head gradient observed in the Culebra across the WIPP site is coincident with the densest clustering of observation wells (see steep segment in the center of Figure 2-1). This produces a greater east-west correlation between data compared to correlation in the north-south direction (across the steep gradient) for the entire domain. Since most of the domain where kriging is being used to estimate values is outside the LWB, an anisotropic model would be misrepresentative of this apparent anisotropy, although it may fit the observed data. Although kriging effectively handles clustered data during the estimation process, the effects which data clustering can have on the variogram modeling process must be considered by the analyst.



lag width = 400 m

lag width = 1000 m

lag width = 2000 m

Figure 2-5. Experimental variograms (points) and best-fit Gaussian model variogram (lines) for three different lag widths. NB: there is a factor-of-three difference in definition of variograms between Surfer and GSLIB (multiply lag by 3.0).

It is possible to fit different models or models with different parameters to the same data, but it is felt that the choice of variogram model and parameters given here sufficiently represents the data and corroborates with the presumed knowledge of the system. If a different type of surface were fit to the data, the residuals would have a different structure and therefore a different variogram as well.

Following up on results of the trend surface sensitivity to removing a steel-cased well (see Section 2.1), the experimental variogram is re-computed for each well removed and shown in Figure 2-6. The exact values of the experimental variograms are not important, just the qualitative observation that the relative variability between the different experimental variograms is small. Both the change in the best-fit surface, and the subsequent changes in the variogram of head residuals, due to removing (or adding) a single observation will diminish as the dataset becomes larger. For the current dataset of over 40 monitoring points, the variogram is virtually unchanged upon removal of a steel well, re-calculation of the trend surface (see Figure 2-4) and residuals and model variogram calculation (see Figure 2-6).

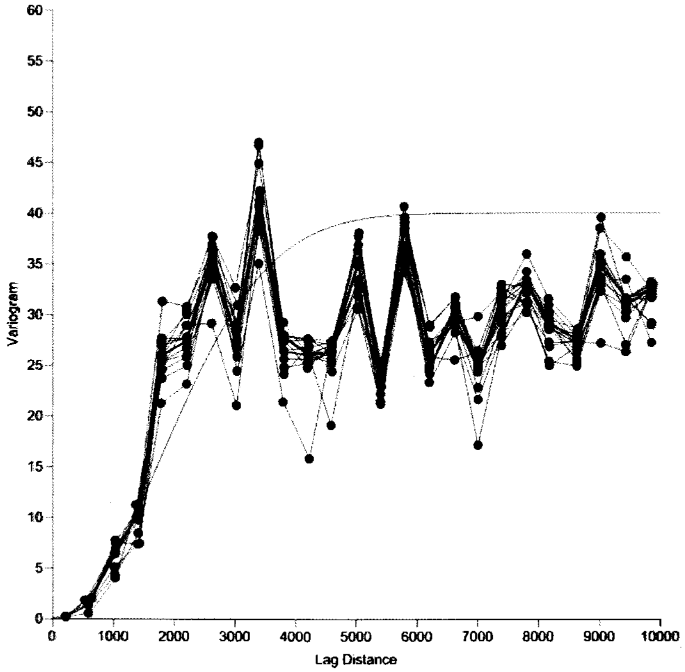


Figure 2-6. Experimental variograms after removing a steel-cased well (variogram for all wells shown in red). Residuals are re-computed based on the best-fit linear trend for each new set of wells and the variogram is re-computed for each new set of residuals.

2.3. *Ordinary Kriging*

Kriging is a geostatistical algorithm for estimating a property at unsampled locations. The kriging equations are formulated to provide an unbiased, minimum variance estimate of the property from a linear combination of the surrounding measured data. Kriging additionally provides a measure of the uncertainty associated with each estimate. The uncertainty measure is known as the kriging variance or the estimation variance. Details on the many variants of the kriging algorithm and its application can be found in the literature, e.g., (Deutsch and Journel, 1998; Goovaerts, 1998). For this work, we use ordinary kriging (OK) and the details of the OK algorithm are presented briefly.

Consider the problem of estimating the value of a continuous attribute, *z*, (e.g. head residual) at an unsampled location **u**. The information available consists of measurements of *z* at *n* locations $\mathbf{u}_\alpha$, $z(\mathbf{u}_\alpha)$, $\alpha = 1,2, ..., n$. Kriging is a form of generalized least-squares regression and therefore all univariate kriging estimates are variants of the general linear regression estimate $z^*(\mathbf{u})$ defined as

$$z^*(\mathbf{u}) - m(\mathbf{u}) = \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})\left[z(\mathbf{u}_\alpha) - m(\mathbf{u}_\alpha)\right] \quad (4)$$

where $\lambda_\alpha(\mathbf{u})$ is the dimensionless weight indicating the contribution of $z(\mathbf{u}_\alpha)$ - $m(\mathbf{u}_\alpha)$ to the estimate of z^* (*z* at unsampled locations), and $m(\mathbf{u})$ is the trend or mean component of the spatially varying attribute [m].

The most common kriging estimator is OK, which estimates the unsampled value $z^*(\mathbf{u})$ as a linear combination of neighboring observations

$$z^{*}_{OK}(\mathbf{u}) = \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u}) z(\mathbf{u}_\alpha) \tag{5}$$

OK weights λ_α are determined so as to minimize the error or estimation variance $\sigma^2(\mathbf{u}) = \text{Var}\{z^*(\mathbf{u}) - z(\mathbf{u})\}$ under the constraint of unbiasedness of the estimate. These weights are obtained by solving a system of linear equations, which is known as the ordinary kriging system of equations. Solution of the kriging system requires that covariance, Cov($\boldsymbol{u}_\alpha$,$\boldsymbol{u}_\beta$), between any two locations be calculated. Covariance is derived from the variogram model under an assumption of second-order stationarity. The unbiasedness of the OK estimator is ensured by constraining the weights to sum to one, which requires the definition of the Lagrange parameter $\mu(\mathbf{u})$ within the system of equations (Bazaraa et al., 1993),

$$\begin{cases} \sum_{\beta=1}^{n(\mathbf{u})} \lambda_\beta(\mathbf{u}) \gamma(\mathbf{u}_\alpha - \mathbf{u}_\beta) - \mu(\mathbf{u}) = \gamma(\mathbf{u}_\alpha - \mathbf{u}) \qquad \alpha = 1,\ldots,n(\mathbf{u}) \\ \sum_{\beta=1}^{n(\mathbf{u})} \lambda_\beta(\mathbf{u}) = 1. \end{cases} \tag{6}$$

The kriging variance is also derived from the set of weights and the Lagrange parameter determined through solution of (6) and it is given as:

$$\sigma^2_{OK}(\mathbf{u}) = \text{Cov}(\mathbf{u},\mathbf{u}) - \sum_{\alpha=1}^{N} \lambda_\alpha \text{Cov}(\mathbf{u},\mathbf{u}_\alpha) - \mu \tag{7}$$

The covariance [m^2] used to calculate the ordinary kriging variance is derived from the model variogram. The covariance between two points separated by zero lag, Cov(**u**,**u**) = Cov(0) is equal to the variance of the data set. It is important to note that the OK variance is not a direct function of the specific data values, other than how those data values define the experimental variogram of the residuals (see discussion associated with Figure 2-6), to which the model variogram is fit.

2.4. Estimation Variance Calculations

The program KT3D (Deutsch and Journel, 1998) is used with the model variogram determined above (estimated and plotted using Surfer) to calculate both the estimated residuals and variance at all locations. The full calculation domain is 87188 100-m × 100-m cells, with 36213 of those cells (41 percent) inactive, lying either beyond the no-flow boundary on the west or the composite H2/M2 – H3/M3 Rustler halite margins on the east. Those inactive cells are not included in the calculations of estimation variance. For the calculations done herein, the average estimation variance both within the flow domain and within the WIPP site are calculated for different monitoring well configurations.

The map of estimation variance for the May 2007 monitoring network defined in Table 2-2 is shown in Figure 2-7. The effect of the monitoring network configuration on the resulting estimates of variance is obvious. The lowest estimation variance values (blue) occur at the well locations and the highest values (red) occur at locations that are beyond the distance of the variogram range (7500 m) away from existing wells. The minimum possible value of the kriging variance is the value of the nugget in the variogram model (0.1 m^2). The maximum kriging variance in these calculations is approximately 46.4 m^2. In the following analysis, the actual values of the kriging variance are not significant, it is only the relative changes in the kriging variance due to the addition, or subtraction, of wells to or from the monitoring network that are of interest.

The full monitoring network of 48 wells and the model variogram calculated from the head residuals at those wells produce an average estimation variance within the flow domain of 29.1 m^2 and an average estimation variance within the land withdrawal boundary of 7.0 m^2. From Figure 2-7 it is obvious that there are many locations outside of the WIPP site where the addition of a well would have large impact on the estimation variance. Within the WIPP site, the estimation variance is already relatively low at nearly all locations. In fact, given the small distances between some wells relative to the range of the variogram, it is possible to remove some of the existing wells within the WIPP site boundary with only minimal increase in the estimation variance.

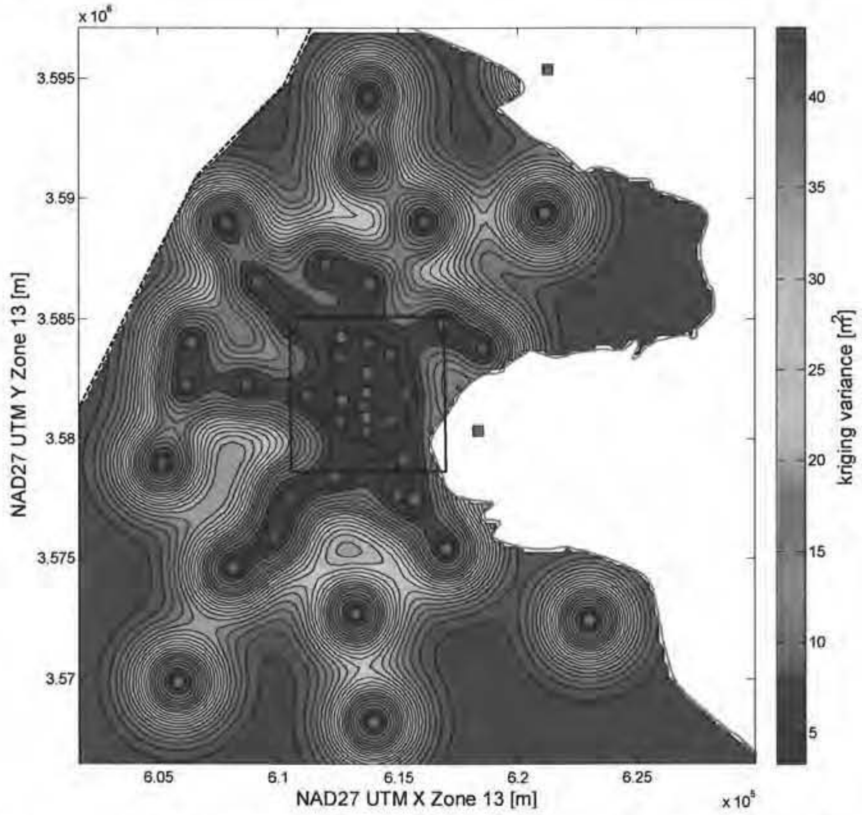


Figure 2-7. Kriging estimation variance for freshwater head residuals. Steel-cased wells are red circles, fiberglass wells are green squares, WIPP LWB is solid black line.

2.4.1. Add one new well

Any proposed new well locations can be added to the current well network and the estimation variance can be recalculated including the additional point. This approach takes advantage of the fact that the estimation variance does not depend on the data values, only on their spatial configuration. This approach does require the assumption that the model variogram does not change significantly with the addition of new locations (analogous to the qualitative sensitivity study illustrated in Figure 2-4 and Figure 2-6 for the case of removing one well).

Figure 2-8 and Figure 2-9 show the relative effects an additional observation point has on the model-domain-wide mean and median of the kriging variance, computed as

$$\Delta\sigma_{+1}^2 = -\frac{\langle\sigma_{+1}^2\rangle - \langle\sigma_{base}^2\rangle}{\langle\sigma_{base}^2\rangle} \tag{8}$$

where σ_{+1}^2 is the kriging variance for the case with one additional well, σ_{base}^2 is the variance for the base case with the 2007 well network and $\langle x\rangle$ is the averaging operator (in this case averaged over the model domain). Steel-cased wells are red circles, fiberglass-cased wells are green squares. The contours in these figures illustrate the decrease in the domain-wide average variance, not the distribution of the variance due to any one distribution of wells. While the mean and median largely show the same trends, the median values are larger and their distribution is less sensitive to a few extreme high or low values, which can skew the mean. Areas with a small average decrease (i.e., inside and near the LWB) indicate an additional observation at these locations would not significantly improve the estimation variance, averaged over the entire domain. The highest values (i.e., the red 'bulls-eye' areas in Figure 2-8 and Figure 2-9) are located midway between wells along the periphery of the monitoring well network.

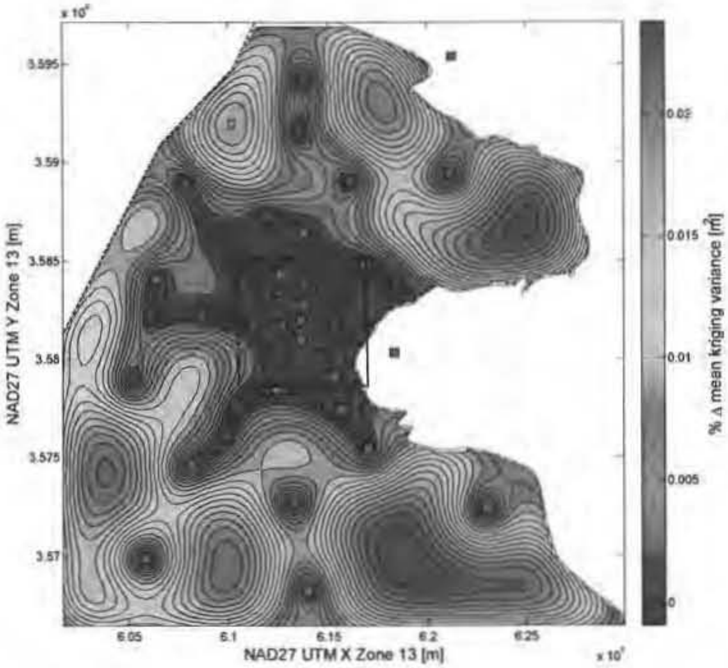


Figure 2-8. Percent decrease in mean kriging variance over model domain due to one additional well

Figure 2-8 and Figure 2-9 account for edge effects near the boundaries of the domain. Areas of high kriging variance (i.e., the red regions in Figure 2-7) mostly correspond to the areas where the largest mean change in variance occurs upon the addition of a new observation point. In the corners of the model domain (especially the southeast corner), the increase is not so large, indicating that much of the effects of a new observation point at this location would be "wasted" outside the model domain.

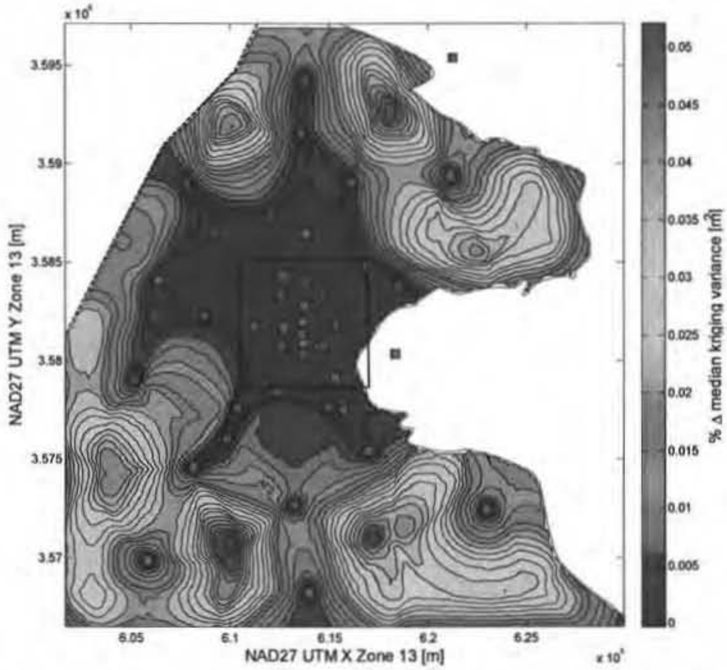


Figure 2-9. Percent decrease in median kriging variance over model domain due to one additional well

Figure 2-10 shows the fractional change in the standard deviation of the kriging variance due to the addition of one more observation location. The standard deviation of the values in the kriging variance field is computed across the entire matrix of values corresponding to adding one additional observation location, without regard to spatial distribution of values. A negative value (blue) indicates the additional location will "smooth out" the kriging variance field (lowering its standard deviation), while a positive number (red) indicates the kriging variance field becomes more variable; a heavy black line indicates the zero-change contour. The positive (red) regions are located in areas distant to the WIPP LWB, and indicate where an additional well would "extend" the current network. The negative regions (blue) are located closer to the WIPP LWB, and indicate where an additional well would "fill in a gap" in the current network.

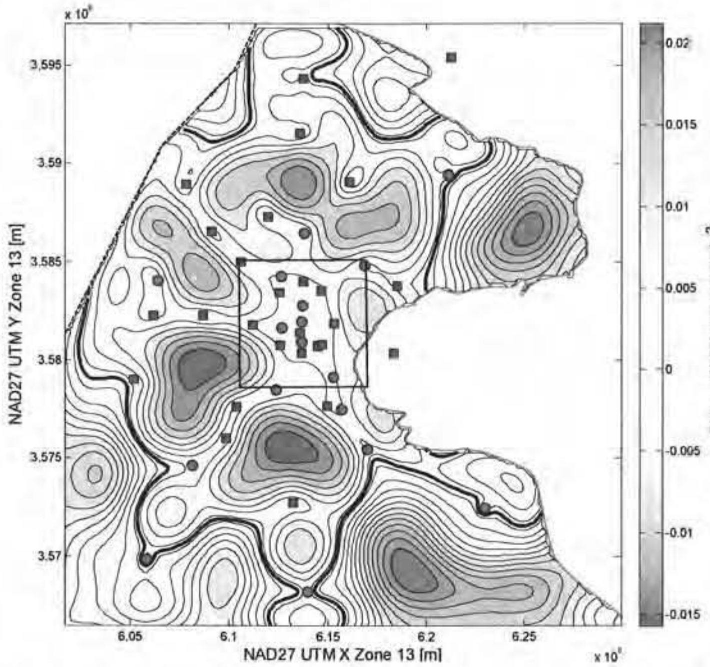


Figure 2-10. Percent change in standard deviation of kriging variance over model domain due to one additional well; heavy black line is zero contour.

Similar calculations were also done with the WIPP LWB as the area of interest, excluding a small area in the southeast corner of the LWB that is constant head in the Culebra MODFLOW model. The region that affects the results within the WIPP LWB is confined to the center of the model domain. The edge effects are clearly evident for the case of averaging over the WIPP LWB, only the LWB and a 3.5-km region surrounding the LWB are shown in Figure 2-11 through Figure 2-13.

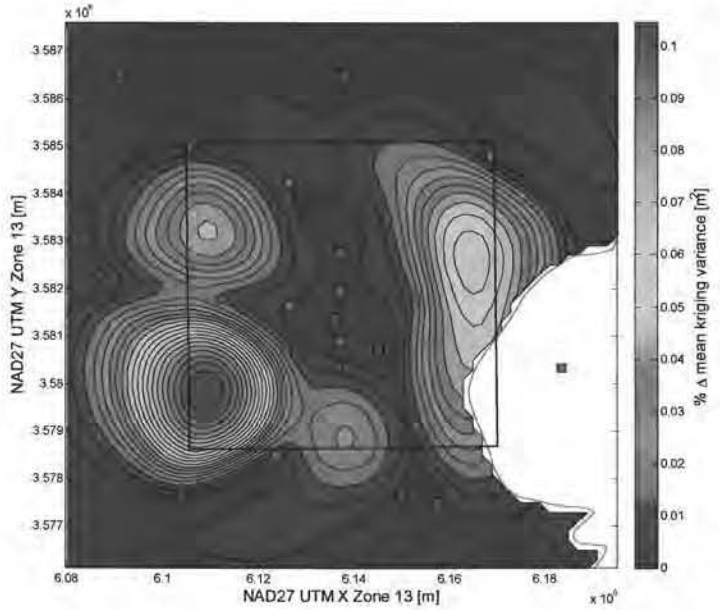


Figure 2-11. Change in mean kriging variance over WIPP LWB due to one additional well

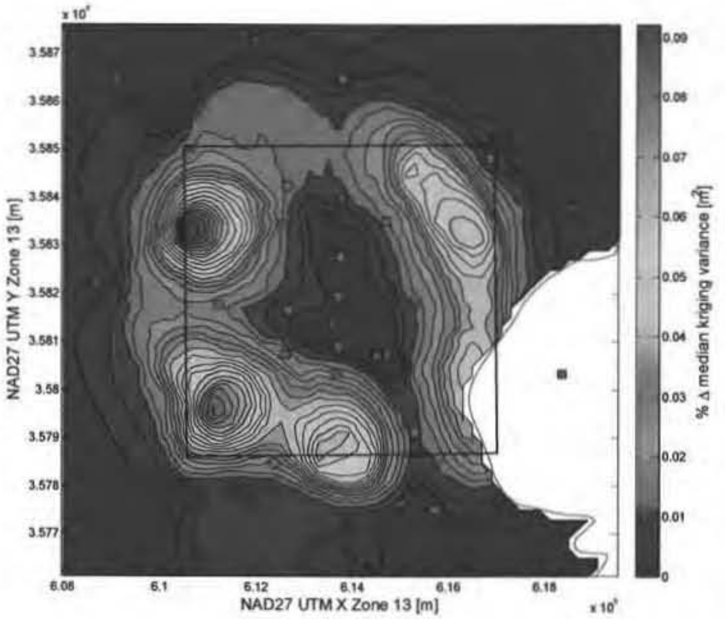


Figure 2-12. Change in median kriging variance over WIPP LWB due to one additional well

Figure 2-11, Figure 2-12, and Figure 2-13 indicate the southwest corner of the LWB is the location that would maximally benefit from an additional monitoring location. The northeast corner is next in relative importance for a new location. Figure 2-12 indicates that the northwest corner would have the largest effect on the median kriging variance across the WIPP LWB. All three figures indicate that the areas along the periphery of the LWB, where there are no existing wells would be good locations for reducing uncertainty through an additional observation point, because a large number of wells already exist in the center of the WIPP LWB.

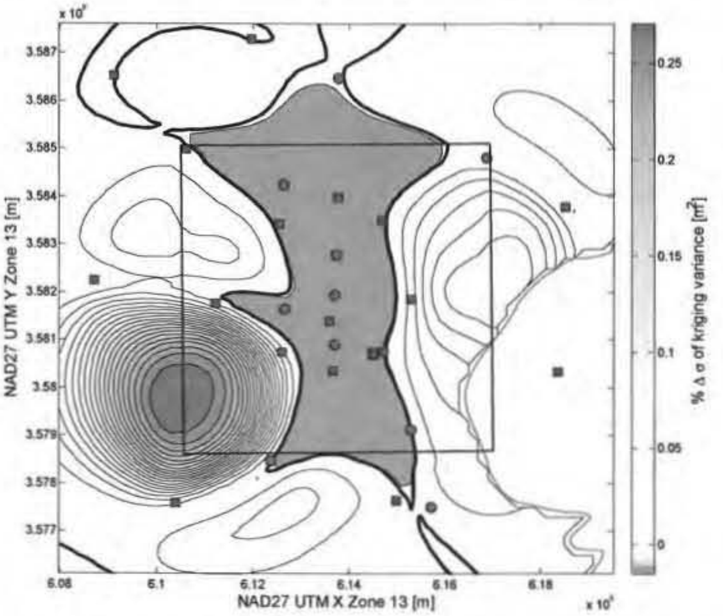


Figure 2-13. Change in standard deviation of kriging variance over WIPP LWB due to one additional well

2.4.2. Remove one steel well

The same approach for determining the variance reduction due to the addition of a new monitoring well can also be used to compute the potential increase in the estimation variance from the removal of an existing well. In this case, it is possible to recalculate the variogram model from the remaining wells after any number of wells are removed; however, to make the process more efficient, the same variogram is used for all calculations done herein. This approach assumes that the variogram does not change significantly with the loss of any one of the wells (see discussion associated with Figure 2-6).

Each existing steel-cased well is removed and the average estimation variances across the flow domain and the WIPP site are recalculated. Those wells that cause the smallest increase in average estimation variance are the ones that could be removed with a minimal impact on the ability of the monitoring network to provide accurate predictions of heads at locations without monitoring wells. The results of these calculations are shown in Table 2-3.

Table 2-3 shows the change in the average estimation variance within the flow domain as well as within the WIPP site area as calculated for the less-by-one networks associated with removing steel-cased wells. Removal of fiberglass-cased wells is not considered, since they are expected to have a long useful life. Table 2-4 shows the same results only averaged over the WIPP LWB when steel-cased wells are removed from the network. Removal of wells that result in the largest increases in the estimation variance are the wells that are most important with respect to the ability of the network to predict heads. Therefore, if the goal is to predict heads across the entire domain, the wells that create the largest increases in estimation variance when removed are generally those located distant from other wells: H-10c, USGS-4, H-9c, AEC-7, H-11b4, and WIPP-11. Small decreases in the estimation variance can also occur with the removal of a well (e.g., ERDA-9, H-3b2, H-2b2, and WIPP-19). These decreases are due to the configuration of the current wells creating negative kriging weights in the solution of kriging equations (see positive values in mean and median columns of Table 2-3 and Table 2-4). These decreases are always less than two-tenths of one percent of the original variance and are considered as insignificant near-zero changes in this work.

Table 2-3. Results of estimation variance changes over the entire model domain for the removal of one steel-cased well from the network. A large integer rank indicates an important well, while a small rank is associated with wells with little impact on the entire model domain.

	|Δ standard deviation|		Δ mean		Δ median		avg rank
ERDA-9	0.48%	2	0.19%	1	0.13%	2	1.67
H-3b2	0.49%	3	0.19%	2	0.13%	1	2.00
H-2b2	0.52%	4	0.18%	3	0.13%	2	3.00
WIPP-19	0.75%	5	0.09%	4	0.13%	2	3.67
H-17	1.36%	9	-0.24%	5	0.02%	6	6.67
H-12	0.46%	1	-1.78%	10	-3.13%	11	7.33
H-4b	1.46%	10	-0.36%	6	-0.13%	7	7.67
WIPP-25	1.04%	7	-1.10%	8	-1.49%	9	8.00
WIPP-13	2.00%	13	-0.70%	7	0.07%	5	8.33
H-7b1	1.22%	8	-2.13%	11	-2.54%	10	9.67
H-5b	2.51%	15	-1.26%	9	-1.09%	8	10.67
WIPP-11	0.80%	6	-3.26%	14	-3.52%	13	11.00
H-11b4	1.67%	11	-2.62%	13	-3.47%	12	12.00
AEC-7	2.15%	14	-2.52%	12	-3.86%	14	13.33
H-9c	1.88%	12	-3.97%	15	-7.20%	16	14.33
USGS-4	2.59%	16	-4.39%	16	-6.98%	15	15.67
H-10c	3.90%	17	-4.88%	17	-7.80%	17	17.00

The five wells that could be removed from the network and create the smallest increase in the mean or median estimation variance are those wells in close proximity to other existing wells. These include: ERDA-9, H-2b2, H-3b2, H-17, and WIPP-19 (see Table 2-3 and Figure 2-14). The change in the standard deviation of the kriging variance is shown in Figure 2-14.

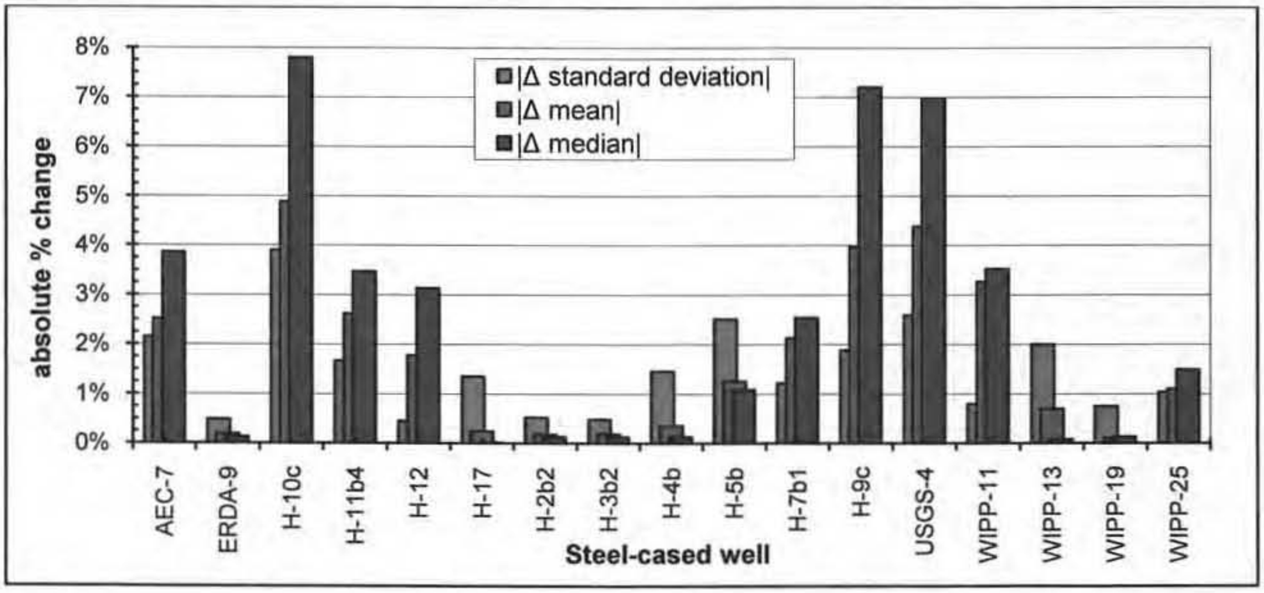


Figure 2-14. Change in estimation variance averaged across entire model domain (data from Table 2-3)

The wells on the other end of the spectrum, which would have the largest effect on the mean or median estimation variance, include wells on the periphery of the domain (i.e., large bars in Figure 2-14).

Table 2-4. Results of estimation variance changes over WIPP Land Withdrawal Boundary for removal of one well from the network. A high rank indicates importance while a low rank indicates little impact on the area within the LWB.

	$\lvert\Delta$ standard deviation$\rvert$		Δ mean		Δ median		avg rank
H-10c	0.0001%	1	0.00001%	1	0%	1	1.00
AEC-7	0.0001%	2	-0.0001%	2	0%	1	1.67
USGS-4	0.01%	3	-0.02%	3	0%	1	2.33
H-9c	0.48%	7	-0.09%	4	-0.02%	5	5.33
WIPP-11	0.23%	4	-0.72%	5	-0.65%	8	5.67
WIPP-25	0.84%	8	-0.89%	6	-0.01%	4	6.00
H-3b2	0.33%	6	-1.32%	7	-0.51%	7	6.67
ERDA-9	0.87%	9	-1.37%	8	-0.42%	6	7.67
H-2b2	1.07%	10	-1.88%	9	-0.90%	9	9.33
WIPP-13	0.27%	5	-2.83%	10	-5.67%	16	10.33
WIPP-19	1.65%	11	-2.85%	11	-4.31%	11	11.00
H-7b1	24.04%	14	-7.51%	13	-1.57%	10	12.33
H-11b4	11.87%	12	-7.35%	12	-5.64%	14	12.67
H-12	12.88%	13	-7.70%	14	-5.66%	15	14.00
H-4b	28.12%	15	-11.73%	16	-4.65%	12	14.33
H-17	29.34%	16	-11.57%	15	-4.75%	13	14.67
H-5b	47.64%	17	-19.15%	17	-6.72%	17	17.00

The removal of wells far from the WIPP site creates the largest increases in the estimation variance averaged over the flow domain, but the removal of many of these steel-cased wells has little or no effect on the estimation variance averaged across the WIPP site. These wells, AEC-7, H-9c, H-10c, USGS-4, and WIPP-25 are too far away from the WIPP site to directly impact the mean or median estimation variance inside the LWB. The most important monitoring wells, those that create the largest variance mean or median increase upon removal, for predicting heads within the WIPP site are: H-5b, H-4b, H-11b4, H-12, and H-17. All these wells are located near the LWB (H-12 being the furthest away from the LWB). Some of the wells have very large effects on the standard deviation of the kriging variance within the site, but the trends also follow those for the mean and median kriging variance.

Figure 2-15 summarizes the results in Table 2-3 and Table 2-4 graphically, indicating where the wells with high or low rank are located geographically.

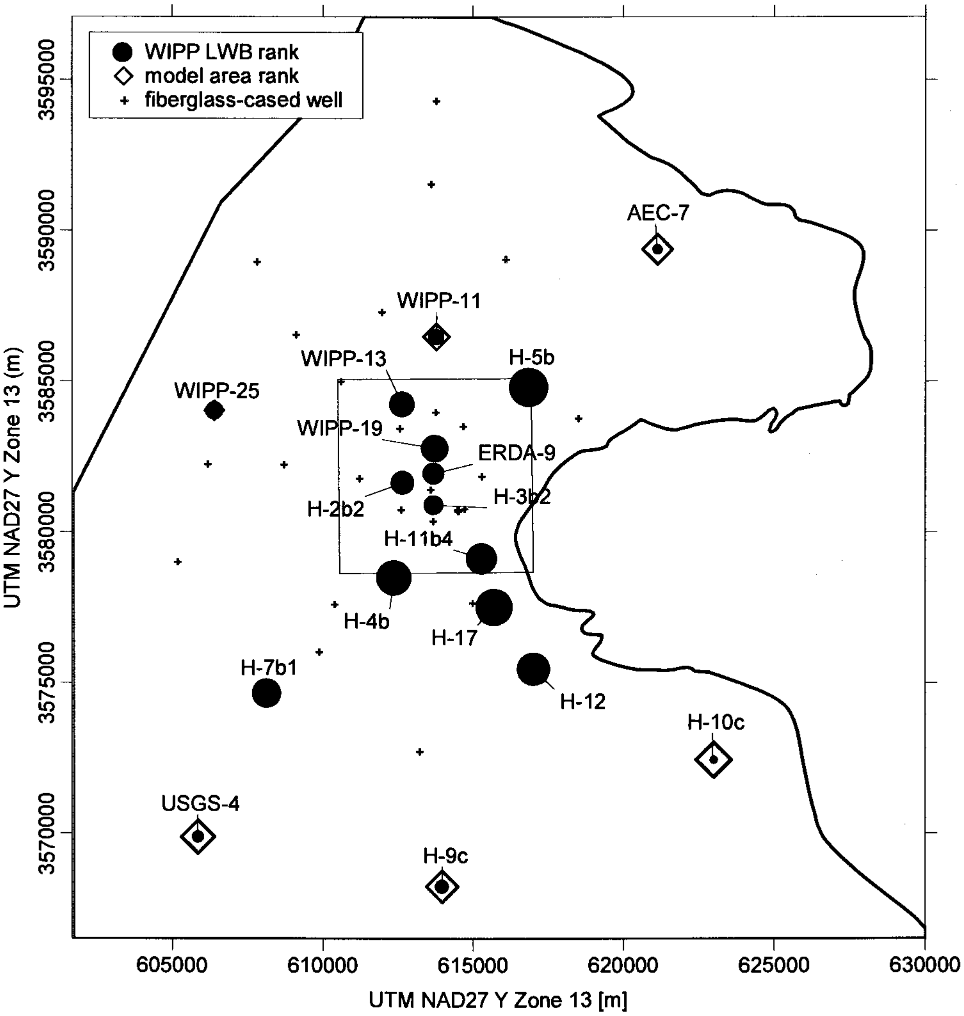


Figure 2-15. Steel-cased wells ranked by effect of removal on kriging variance; symbol sizes are proportional to overall rank (and therefore importance), data in Table 2-3 and Table 2-4. MODFLOW active model domain delineated in green, WIPP LWB is black square.

The wells that create the smallest increases in estimation variance upon removal for both the WIPP site and the flow domain are: ERDA-9, H-2b2, and H-3b2. Any one of these three wells could be removed with minimal effect on the ability of the network to predict heads across both the domain and the WIPP site. These calculations are for removal of a single well.

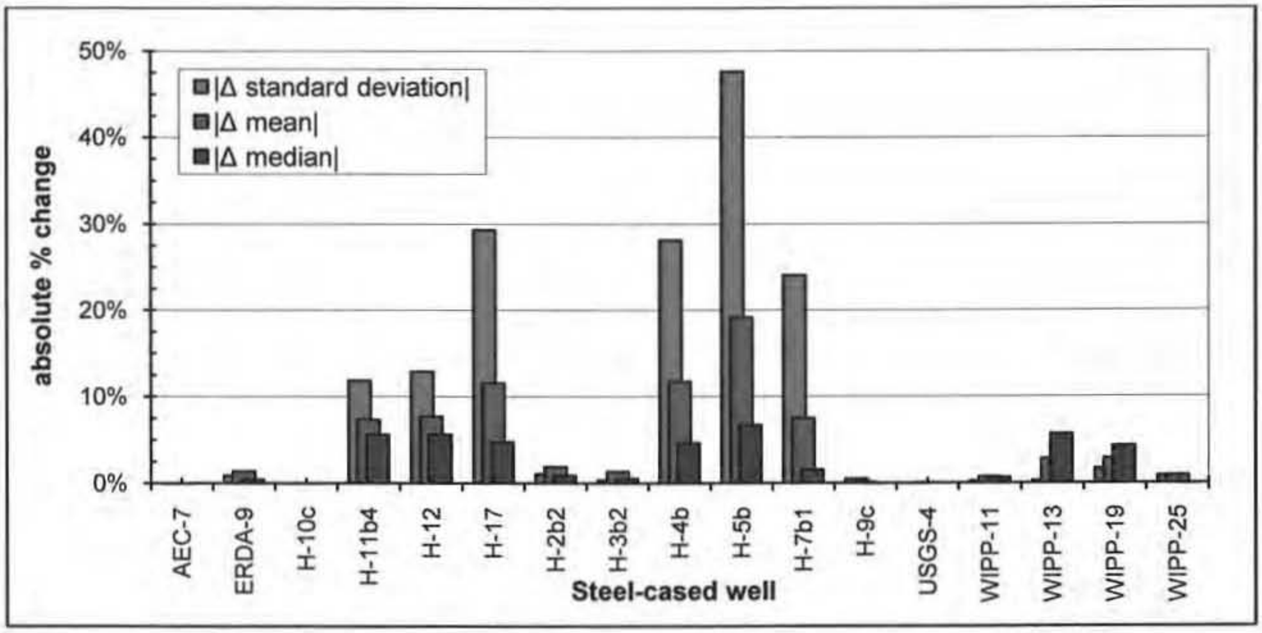


Figure 2-16. Change in estimation variance averaged across WIPP LWB, data in Table 2-4

2.4.3. Remove Two Steel Wells

Based on expectations that the following steel wells will soon need to be replaced or P&Aed: WIPP-25, WIPP-13, H-12 and H-7b1; the analysis of the previous section is carried out removing each of these wells, then additionally removing each of the remaining steel-cased wells one at a time.

Table 2-5 shows the percent change in the kriging variance averaged across the entire model domain computed as (changed - base)/base for combinations of steel-cased wells being removed. The 4×17 image shows the same results in the table. This shows that removing AEC-7 and H-9c, along with any of the three wells represented as columns, makes a large relative change across the entire model domain. This is to be expected, as both of these wells are far away from other wells; removing two wells a large distance from each other affects the largest potential area. Conversely, the column corresponding to WIPP-13 leads to the smallest relative changes (some even being slightly positive), indicating the kriging area of influence for this well has a large amount of overlap with those from other wells, since this well is located in the north-central portion of the WIPP LWB.

Table 2-5. Change in mean kriging variance across model domain upon removal of two steel-cased wells; integer values indicate rank within each column

		H-12		H-7b1		WIPP-13		WIPP-25	
1	AEC-7	-4.15%	15	-4.17%	15	-2.49%	14	-3.70%	14
2	ERDA-9	-1.52%	3	-1.53%	3	0.11%	2	-1.09%	2
3	H-10c	-4.18%	16	-1.73%	8	-2.51%	15	-3.72%	15
4	H-11b4	-1.78%	8	-3.27%	14	-0.09%	5	-1.29%	6
5	H-12			-1.76%	9	-1.61%	11	-2.81%	11
6	H-17	-1.51%	1	-1.52%	1	-0.10%	6	-1.30%	7
7	H-2b2	-1.53%	5	-1.55%	5	0.09%	3	-1.10%	4
8	H-3b2	-1.51%	2	-1.53%	2	0.12%	1	-1.08%	1
9	H-4b	-2.09%	9	-2.10%	10	-0.46%	7	-1.65%	8
10	H-5b	-2.41%	11	-2.43%	12	-0.78%	9	-1.98%	10
11	H-7b1	-3.27%	13			-1.62%	12	-2.84%	12
12	H-9c	-3.95%	14	-4.19%	16	-2.29%	13	-3.51%	13
13	USGS-4	-2.31%	10	-2.33%	11	-2.56%	16	-3.78%	16
14	WIPP-11	-1.61%	7	-1.62%	7	-0.70%	8	-1.88%	9
15	WIPP-13	-1.53%	4	-1.55%	4			-1.18%	5
16	WIPP-19	-2.81%	12	-2.84%	13	-1.18%	10	-1.10%	3
17	WIPP-25	-1.58%	6	-1.60%	6	-0.05%	4		

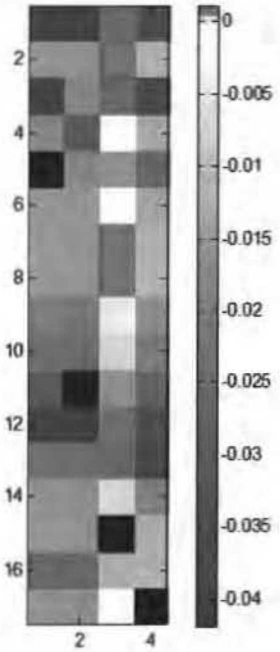
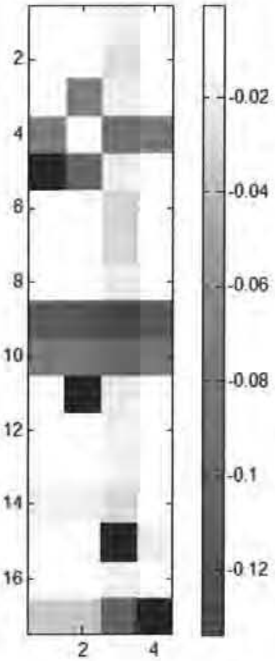


Table 2-6 gives the same statistics as in Table 2-5, but the results are averaged over the area within the WIPP LWB only (rather than the entire model domain). The conclusions from this analysis are different, since WIPP-13 is now the column which on average is darkest blue, (rather than lightest in Table 2-5). Wells H-4b and H-5b are the two "row" wells which have the largest negative change across the four columns. These wells are located on or near the WIPP LWB, similar to how AEC-7 and H-9c from the analysis in the previous paragraph, are located along the periphery of the model domain.

Table 2-6. Change in mean kriging variance across WIPP LWB upon removal of two steel-cased wells; integer values indicate rank within each column

		H-12		H-7b1		WIPP-13		WIPP-25	
1	AEC-7	-0.03%	3	-0.09%	2	-1.95%	2	0.00%	2
2	ERDA-9	-0.69%	8	-0.76%	7	-2.65%	9	-0.67%	8
3	H-10c	-0.03%	1	-7.45%	13	-1.95%	1	0.00%	1
4	H-11b4	-7.70%	14	-0.12%	4	-9.32%	13	-7.36%	14
5	H-12			-10.50%	15	-1.97%	6	-0.03%	5
6	H-17	-0.08%	5	-0.14%	5	-3.07%	12	-1.13%	12
7	H-2b2	-1.05%	11	-1.12%	10	-2.99%	11	-1.03%	11
8	H-3b2	-0.30%	7	-0.37%	6	-2.22%	8	-0.28%	7
9	H-4b	-11.49%	16	-11.64%	16	-13.40%	16	-11.46%	16
10	H-5b	-7.71%	15	-7.78%	14	-9.66%	14	-7.69%	15
11	H-7b1	-0.12%	6			-2.04%	7	-0.10%	6
12	H-9c	-0.03%	2	-0.09%	1	-1.95%	4	0.00%	4
13	USGS-4	-0.75%	9	-0.81%	8	-1.95%	3	0.00%	3
14	WIPP-11	-1.97%	12	-2.04%	11	-2.83%	10	-0.72%	9
15	WIPP-13	-0.92%	10	-0.98%	9			-1.95%	13
16	WIPP-19	-0.03%	4	-0.10%	3	-1.95%	5	-0.89%	10
17	WIPP-25	-3.35%	13	-3.41%	12	-10.32%	15		



In Figure 2-17 and Figure 2-18 the overall rank (between all 64 combinations of two steel-cased wells, rather than 16 steel-cased wells individually) is plotted against the distance between the two wells comprising the pair as a measure of the impact of removing a pair of wells. The overall rank is computed as an average of the results of three metrics (mean, median and standard deviation of the change in the kriging variance).

Figure 2-17 shows a weak positive correlation (R^2=0.35 fit through all points) between the relative impact of removing a pair of steel wells and the distance between those wells, when the impact is averaged over the entire model domain. A high rank indicates a higher impact to the kriging variance averaged over the model domain; a low rank indicates low impact. Wells which are separated by large distances tend to have the largest cumulative effect. The different symbols in the figure show that individual wells (these four symbols correspond to the wells represented as columns in Table 2-5) tend to also follow this trend

Figure 2-18 shows the same results, only averaging the impact over the area encompassed by the WIPP LWB. Here the correlation is even weaker, and also negative. Wells that are closer together have a larger relative impact when they are removed. WIPP-13 (black triangles) is only associated with higher rank pairs (>32), but in general all the individual wells follow the weak overall trend.

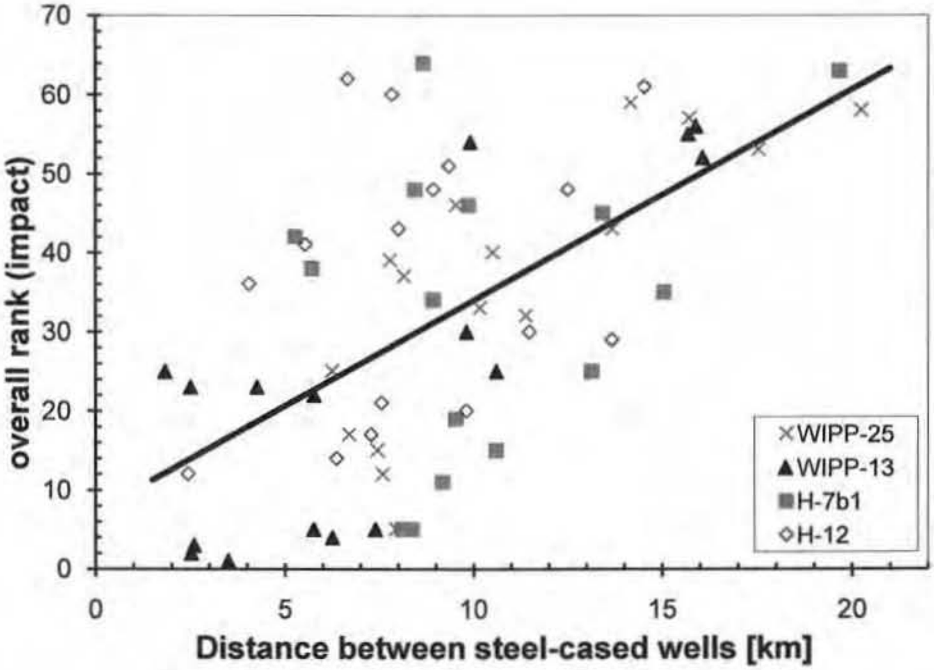


Figure 2-17. Rank and distance between wells for removal of pairs of steel-cased wells, averaging effects across the entire model domain (R^2=0.35 for linear fit). High numerical rank indicates a large impact on the model-wide kriging variance.

WIPP-25, H-12, and H-7b1 are all located outside the WIPP LWB. WIPP-13 is inside the WIPP LWB, and all pairs of wells including WIPP-13 have high rank in Figure 2-18. The smallest linear dimension across the WIPP LWB is 6.4 km (east-west or north-south), while the largest linear dimension of the WIPP LWB would be a diagonal across the site 9.09 km. Pairs of wells with distances larger than these values must include at least one well outside the LWB, possibly both. The pairs of wells with very large separations are pairs of wells where both wells are distant from the WIPP site. Removing these wells would obviously have little direct impact on the region inside the WIPP LWB.

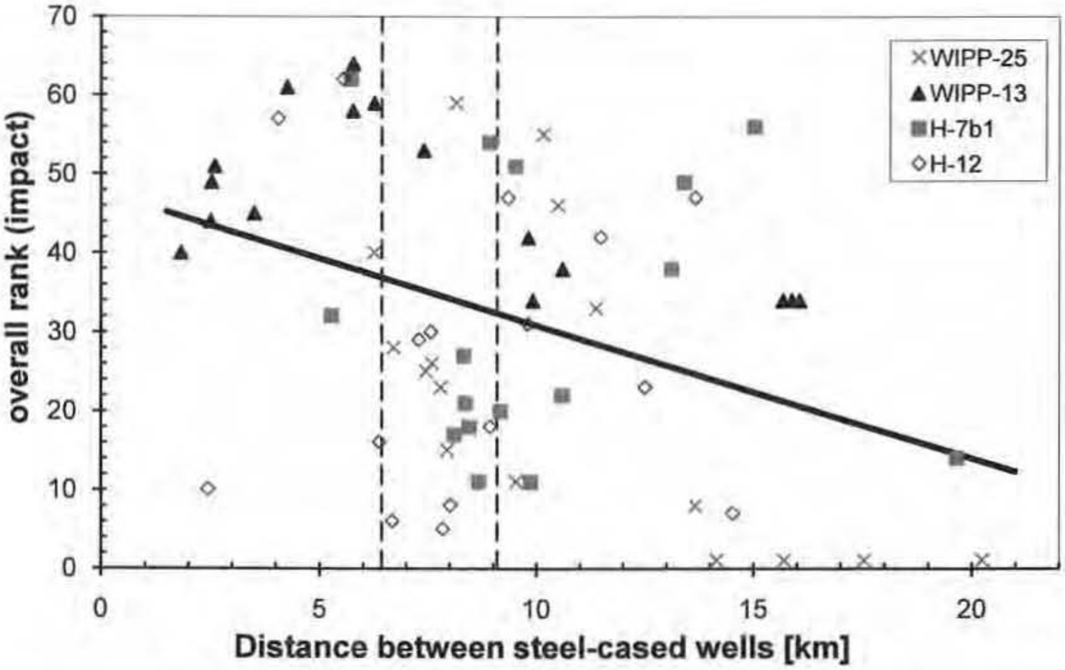


Figure 2-18. Rank and distance between pairs of steel-cased wells, considering WIPP LWB (R^2=0.14 for linear fit). Vertical dashed lines represent the min (6.4 km) and max (9.1 km) distances across the LWB. High numerical rank indicates a large impact on the kriging variance inside the WIPP LWB.

This analysis supports the idea that removing two distant steel-cased wells from the network has the largest impact on the kriging variance, averaged over the entire model domain. The relationship that inter-well distance plays in the removing of two wells, when only considering the area within the LWB is more complex and less conclusive. Apparently, there is a negative correlation between distance and importance, but likely because wells with large inter-well separations are likely distant to the WIPP LWB as well.

All the well-removal scenarios in this section have the assumption that the variogram does not change upon removal of the selected wells. In situations where we are only removing one well, this is a very good assumption (see discussion associated with Figure 2-6); removing two or more wells still should not violate the assumption that their removal would not change the variogram.

2.5. *Kriging Variance Reduction Summary*

It is relatively simple to calculate the decrease or increase in the kriging estimation variance over a specified area from the addition or removal of one or more monitoring wells. The maximum reduction in estimation variance, or increase in the ability to predict heads, can be achieved by placing a new monitoring well in any location of the flow domain that is far away from an existing well or the model boundary. There are a large number of locations in the domain where a new well could be placed to meet this condition. At this point in the analysis, a maximal reduction in variance from a new well can be considered as a necessary input, but not sufficient condition for locating a new well.

Removal of wells from the existing monitoring network was also examined using the kriging estimation variance. The impact of well removal was evaluated by calculating the increase in estimation variance for both the entire flow domain and the area within the WIPP LWB. These calculations were done for the removal of a single well from a base case of 42 wells and the results are only valid for the removal of the one specified well. These results also safely assume that the variogram is constant across all monitoring network configurations (see Figure 2-6). These calculations were completed again for removal of combinations of multiple wells when those combinations of interest are defined. Wells that are most important to the existing monitoring network that should not be removed are listed above and are, generally, those wells most distant from any existing wells. Wells that have the smallest influence on the ability of the current network to predict heads at unmeasured locations across the entire flow domain as well as within the WIPP site are also listed above. If more than one well is to be removed, the combinations of wells should be selected from this list.

2.6. Kriging Variance Reduction Run Control Summary

The kriging variance reduction analysis performed in this section is described here in terms of files, programs, and scripts used. The required files are located on the CD and are described in sufficient detail to allow recreation of the results given in the text.

2.6.1. Linear trend fit and variogram calculations

The linear trend fitting to the computed freshwater head values (see Section 2.1, Table 2-1, and Figure 2-3) was computed in the COTS statistical software R. The script `plot_linear_fit_summary.R` (Section 8.2.1) uses the built-in linear model function `lm()` to produce a linear fit, then standard statistics are produced by summarizing this fit (see see Table 2-1 produced by `summary()` in line 15 of script) and standard diagnostic plots (see Figure 2-3) are created by plotting this fit (see lines 16 and 17 of script).

The sensitivity of the experimental variogram to removal of a single steel-cased well was investigated (see Figure 2-4 and Figure 2-6) using the Python script `remove_one_variogram_effects.py` (Section 8.2.2). This script loaded the well data (lines 4 through 35) and performed a least-squares fit of a linear surface (see Equation 1) through the data (e.g., see Menke (1984), Chapter 3), looping through the data to remove one steel-cased well at a time, re-computing the fit (lines 37 to 58). An ASCII text file was output (see line 24 for the filename) with summary statistics relating to each network-minus-one fit corresponding to the lines of the output file. This csv file was imported into MS-Excel, resulting in the plot of relative percent change in the slope and direction of the best-fit linear surface due to removing each steel-cased well, as shown in Figure 2-4 (see file `trend_surface_remove_one_results.xls` on the CD in the `report/figures/02_kriging` directory).

This same Python script also wrote a set of data files corresponding to the main dataset less a single steel-cased well for variogram analysis. These data files were imported into Surfer for experimental variogram plotting to create Figure 2-6; see the CD in directory `report/figures/02_kriging` for the data files and resulting Surfer file `perturbation_spread_of_variograms.srf` used to plot this figure. In the same directory on the CD, the Surfer file used to generate the final experimental variogram plot in Figure 2-5 can be found (`may2007_variogram_modela.srf`).

2.6.2. Kriging variance reduction calculation

The kriging variance minimization (see Section 2.4) consisted of a main Python script, `krig_plus_one.py` (Section 8.2.3), which drives the kriging process for different inputs and summarizes the outputs. This main script uses two subsidiary scripts `shared_data.py` (Section 8.2.4) and `kt3d_driver.bat` (Section 8.2.5) to perform its duties.

2.6.2.1. Kriging add one

The `krig_plus_one.py` script is explained here. Most of the first half of the file (lines 18 to 130) is the definition of the function `krig()`, which is called with arguments related to where to put an additional data point. Lines 28 through 53 are the input file for KT3D saved as a string having key parameters in the input file substituted with variables passed to the function (e.g., see pattern `%(varname)d` on lines 38 and 39). The data file used as input to KT3D is written on lines 56 to 61, potentially with an additional point appended to the end of the file. The DOS batch file `kt3d_driver.bat` is called to run `kt3d.exe` on lines 65 to 73. The kriging variance output created by running KT3D is read on lines 75 to 78, while certain subsets of the variance arrays are selected on lines 87 and 88. Lines 91 through 130 are located inside a threading `with` lock block, since they are writing summary results to a global variable (there are potentially more than one thread running at a time and the lock is to prevent two threads attempting to write at the same time and corrupting the data). Lines 95 through 115 are related to model-domain wide statistics, while lines 117 through 130 are related to the same statistics but only computed over the WIPP LWB.

The actual program flow begins at line 139, with the reading and preparation of various data from disk (lines 139 to 207). The last portion of the script (inside the `if __name__ == "__main__"` conditional on line 214) is only executed if the script is called from the command line. This portion is not executed if the script is imported (as is done in the `krig_remove_one_steel.py` and `krig_remove_two_steel.py` scripts). This final section sets up the arrays for saving the results (lines 216 to 218), calls `krig()` with the original unmodified dataset for comparison (line 220), and loops over all locations on a grid, adding one point at a time to the analysis (lines 229 through 242). Finally, the results of the entire analysis are saved to disk (lines 251 through 260 – these results are on the CD in the `analysis/kriging/kriging_add_well/output` directory); these matrices of results are used to plot the color figures in Section 2.4.1 using the MATLAB script `krig_add_one_plotting.m` one the CD in the `report/figure/02_kriging/` directory (since this MATLAB script was not used for analysis (only creation of color contour maps from ASCII data files), it is not listed in Section 8.2).

At lines 171 through 175, ASCII matrices are imported that indicate whether a given model cell is inside the active portion of the MODFLOW model domain. These matrices are written by the MATLAB script `generate_model_cell_masks.m` (Section 8.2.6), which uses the built-in function `inpolygon()` to determine which cells are inside the irregular polygon defining the MODFLOW active model area.

The `krig_plus_one.py` script is threaded because each call to KT3D takes roughly 10 to 15 seconds and there are tens of thousands of locations in the model domain where a point can be added; since the results of adding each point are done individually, the problem lends itself well to parallelization (i.e., a speedup of over four times using eight processors).

2.6.2.2. Kriging remove wells

As already stated, the scripts that run KT3D for the analysis of removing a well from the network import the majority of their functionality from the `krig_plus_one.py` script described in the previous section. The scripts for removing one (Section 8.2.7) and two wells (Section 8.2.8) are quite similar, and are described here. Each script reads in the relevant well and model domain data, the in the remove-one well case each steel well is individually removed from the network and the `krig()` function defined in the import `krig_plus_one.py` script are called to do run KT3D and summarize the results (lines 34 to 49). The results are written to ASCII files (see lines 44 through 49) for summarizing into Table 2-3, Table 2-4, Figure 2-14, and Figure 2-16. The source of the tables and bar-chart figures is saved in the spreadsheet `remove_one_well_results2_2010.xls` on the CD in the `analysis/kriging/kriging_remove_steel/` directory.

The map in Figure 2-15, showing the relative importance of removing steel-cased wells from the network with respect to the entire domain and the WIPP LWB, was created in Surfer from the tabular results. The Surfer file (`remove_one_steel_well.srf`) is included on the CD in the `report/figure/02_kriging/` directory.

In the remove-two-wells case, a list of four “most likely to be removed” steel-cased wells are used as the first well, then the remaining steel-cased wells are each additionally removed, similarly calling the imported `krig()` function to run kt3d and summarize the results (lines 38 to 68). Similarly, these results are written to files for summary in Table 2-5 and Table 2-6.

The source of the scatter plots in Figure 2-17 and Figure 2-18 and the tables of data is the spreadsheet `remove_two_well_results3.xls`, located on the CD in the `report/figure/02_kriging/` directory.

3.0 Local Gradient Estimation with Triangulation

The methodology used for local gradient estimation in the previous revision of this analysis report (McKenna, 2004) and in the associated follow-up paper (McKenna and Wahi, 2006) involved the use of "three-point estimators" to assess the ability to estimate head gradients in a 2D aquifer. The analysis presented here is instead in terms of a simpler approach using non-overlapping Delaunay triangles (a small subset of the triangles included in the three-point estimators).

Although three-point estimators have been used several places in the literature to estimate a regional gradient value from observed data; see e.g., (Cole and Silliman, 1996; Conwell et al., 1997; Silliman and Frost, 1998; Silliman and Mantz, 2000; McKenna and Wahi, 2006), few practicing hydrologists take this approach to estimating the gradients when presented with 2D head data. It is a more common approach to contour observed heads (i.e., potentials), estimating gradients from equipotential contours. While there are numerous techniques for creating contour maps from point measurements (e.g., kriging, inverse distance, splines), linear interpolation could be considered the most basic and easily understood approach. Often a geologist will sketch in the results of linear interpolation between data as a first step to hand contouring depth or thickness data, and then they will modify these results with their own professional judgment. In two dimensions, three points define both a triangle and a piecewise-constant estimate of the gradient across that triangle. A group of more than three points defines a network of triangles (bounded by their convex hull) and a piecewise-constant estimate of the gradient across the area inside the convex hull.

Linear interpolation is used for the local gradient-based estimation, since linear interpolation is a straightforward method that is easy to visualize and understand, and triangulation is readily implemented using available tools in the COTS software MATLAB (i.e., the built-in functions `delaunay()` and `voroni()`).

3.1. Delaunay Triangulation

In the three-point estimator approach of (McKenna, 2004), all possible combinations of three points were constructed into triangles to assess the quality of the network (with a fraction of the triangles discarded based on selection criteria). Many thousand overlapping triangles made visualization of results difficult (see Figure 3-1). For 30 wells, there are 4060 possible three-well combinations and for 40 wells there are 9880 possible combinations. In the current approach, the much smaller subset of non-overlapping triangles produced by Delaunay triangulation is used.

Since the triangles will not overlap, the gradients estimated with this technique are as local as possible with the given set of points. When using overlapping triangles, the selection of one gradient estimate over another (when two triangles cover the same area) may become complex, or some sort of averaging must be done to produce a useful result.

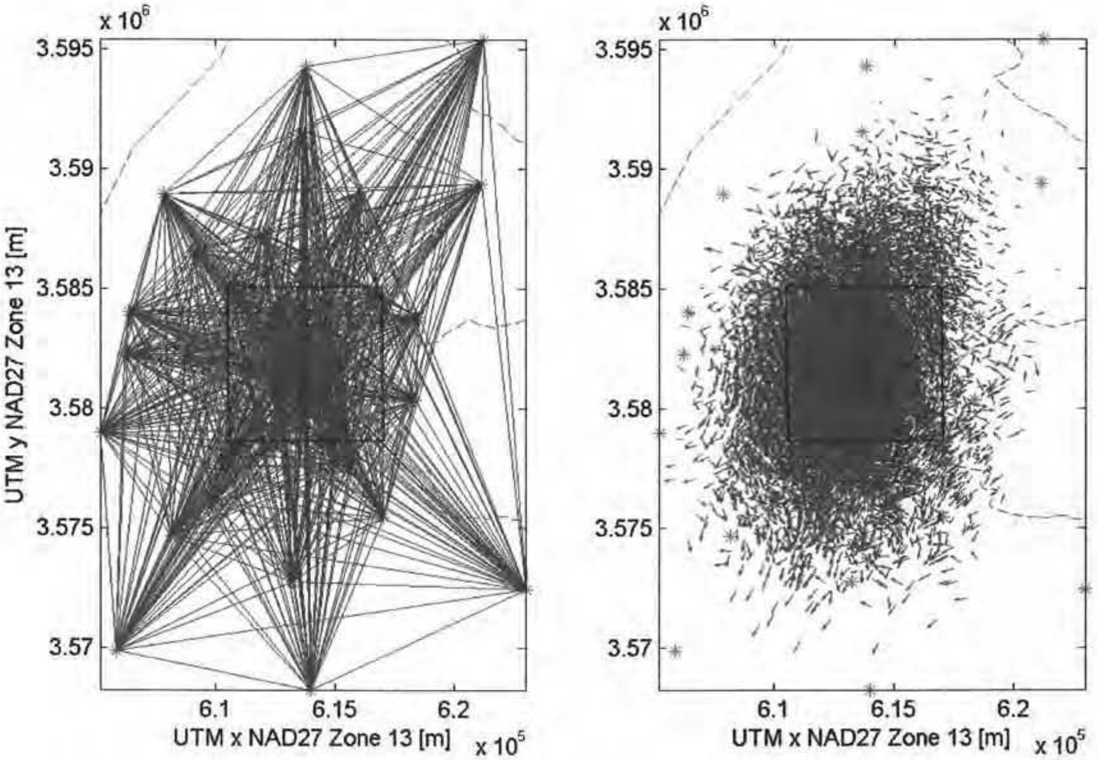


Figure 3-1. All possible triangles (left) and corresponding gradient vectors (right) for May 2007 Culebra monitoring network (as was used in the three-point estimator approach from first revision of this report). Vectors are $\log_{10}$ length scaled; tails of vectors are anchored at the center of their triangle.

Given a 2D set of data points, Delaunay triangulation produces a set of triangles, where each triangle bounds a point and its natural neighbors (see Figure 3-2a). Delaunay triangles are directly related to Voronoi polygons, which are the unique polygons circumscribing the area closer to a given observation well than any other well (see Figure 3-2b).

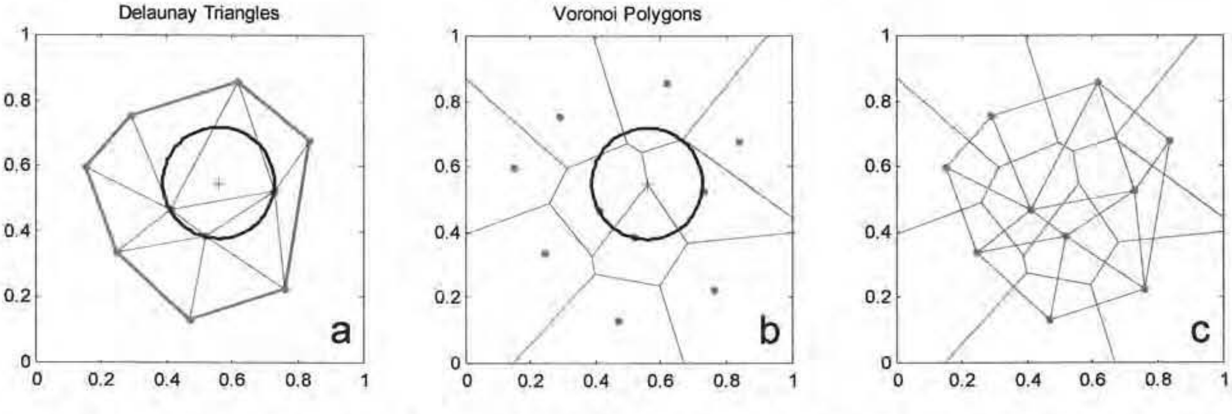


Figure 3-2. Delaunay triangles and Voronoi polygons for 10 randomly located points (red symbols). Black circle with green center used to illustrate the relationship between triangles (a) and polygons (b). Red lines indicate the convex hull, (c) shows both sets of polygons together.

Some properties of these unique triangles and polygons are:

- Delaunay triangles uniquely tessellate the area within a convex hull enclosing the data (except in certain symmetric cases);
- Voronoi polygons fill the entire plane; the polygons corresponding to the data on the convex hull have infinite area;
- Vertices of Voronoi polygons correspond to the centers of circles that uniquely go through the three neighboring points (see Figure 3-2b);
- In a square grid of points, Delaunay triangles become right isosceles triangles (two equal angles and sides) and Voronoi polygons become squares (see Figure 3-3).
- In a triangular grid of points, Delaunay triangles become equilateral and Voronoi polygons become regular hexagons (see Figure 3-4).

Three points are the minimum required to estimate direction and magnitude of a gradient from 2D point observations; Delaunay triangles therefore define piecewise-constant gradient over the area enclosed by the convex hull surrounding all points. Delaunay triangles, when assigned z values at the vertices (i.e., heads), become a triangular irregular network (TIN); these are often used in engineering to approximate irregular surfaces.

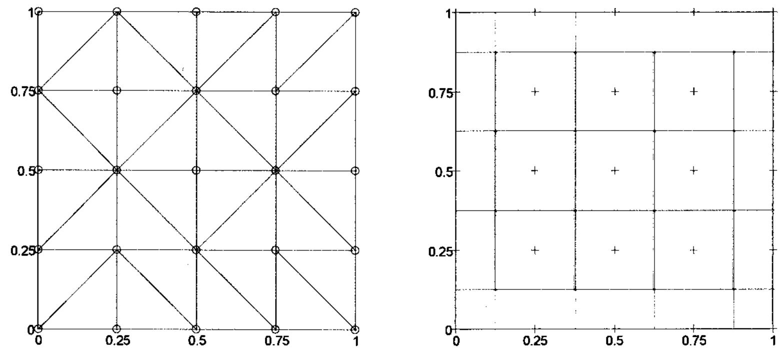


Figure 3-3. Delaunay triangles and Voronoi polygons for symmetric square grid; note ambiguity in triangles

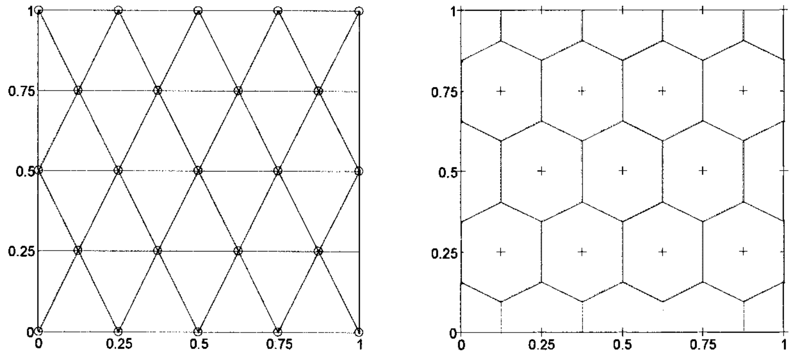


Figure 3-4. Delaunay triangles and Voronoi polygons for symmetric triangular mesh

The regular grids of points in Figure 3-3 and Figure 3-4 illustrate the shapes of triangles that arise under these ideal conditions (compared to the random arrangement of points in Figure 3-2, and seen in the following Culebra monitoring network analysis).

Voronoi polygons are not used in this analysis, but they are included in this introductory discussion because it is clear that they are unique for a given set of points and there is a unique mapping from Voronoi polygons to Delaunay triangles, therefore it is illustrated how the Delaunay triangles are also unique. The non-unique case corresponds to the extreme symmetry shown in Figure 3-3; squares can equivalently be cut into triangles along either diagonal. This will not affect the results of this analysis, since the Culebra monitoring wells are not located on a symmetric rectangular grid.

3.2. Triangle Shape Metric

To rank the quality of the shape of triangles, the ratio of the minimum and maximum of the interior angles is assessed; this value is believed to capture the quality of a triangle for the purposes of gradient estimation from three data points. The lengths of the sides of the triangles can be related to the size of the angles through the law of sines,

$$\frac{a}{b}=\frac{\sin(A)}{\sin(B)}, \qquad (9)$$

where *a* and *b* are the shortest and longest sides of the triangle (i.e., the min/max length ratio), and *A* and *B* are the corresponding largest and smallest angles of the triangle – angle *A* opens up to side *a* (i.e., the ratio of the sines of the min/max angles).

In the case illustrated in Figure 3-3, the triangles have angle ratios of 0.5 (one 90° and two 45° degree angles). Figure 3-4 illustrates triangles with an angle ratio of 1 (three 60° angles); this is the maximum ratio. Using the angle ratio as the metric, therefore the "best" triangle is an isosceles one. Likewise, triangles with one dimension or angle much smaller than the others will have a very small angle ratio, approaching zero in the limit as the three points become collinear. Triangles with large aspect ratios (proportional to the inverse of the angle ratio) tend to produce worse estimates of the gradient, based on an assumed unbiased normal distribution of errors associated with observing heads in a well (McKenna and Wahi, 2006).

Figure 3-5 shows the distribution of triangle size, interior angle ratio and the magnitude of the gradient computed from observed May 2007 freshwater heads. In Figure 3-5a, the logarithm of area is used to color-code the triangles that make up the 2007 Culebra monitoring network. Some very elongate triangles have small areas, considering how distant the wells are that make up their corners (e.g., the blue triangle along the west-central edge of the area, comprising wells WIPP-25, IMC-461, and SNL-16). Figure 3-5b shows the distribution of the angle ratio, for the 2007 Culebra network; the dark red triangles are nearly isosceles, while the dark blue triangles have one large obtuse angle. Figure 3-5c shows the logarithm of the head gradient magnitude, computed from the three corner wells. Aside from the two anomalously high gradient areas associated with SNL-6 and SNL-15 (east-central and north-east areas), there is an east-west yellow band across the middle of the model area, with blues north and south of it, representing the observed higher freshwater head gradient across the center of the LWB (e.g., see Figure 2-1).

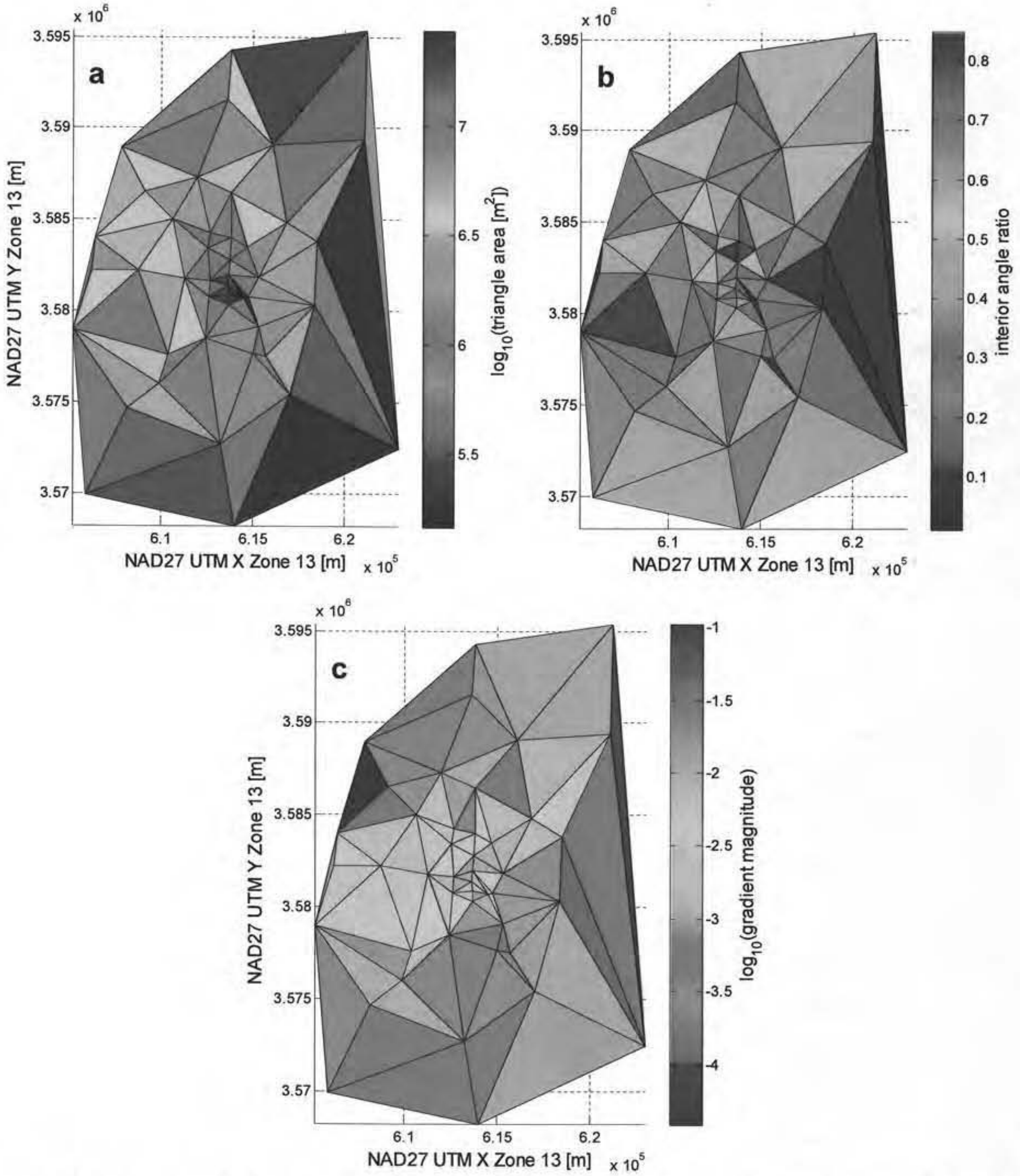


Figure 3-5. Distribution of geometry metrics for 2007 Culebra well network: (a) area of triangle, (b) angle ratio, and (c) May 2007 freshwater head gradient magnitude.

Figure 3-6 shows scatter plots of the quantities represented spatially in Figure 3-5 (each dot represents a triangle); these illustrate that there is essentially no correlation (positive or negative) between the triangle angle ratio and area (a), or the angle ratio and the magnitude of the gradient (b). This is because angle ratio represents the triangle shape, while shape and size are two unrelated quantities (in this case). Additionally, the gradient is a function of the head observed at the wells, while the angle ratio is not affected by observed head. Figure 3-6c indicates a possible, but very weak, negative correlation between the size of triangles and the gradient magnitude. There is a greater density of wells within the WIPP LWB, where steeper gradients are observed; this trend is corrupted by the anomalous steep gradients associated with large triangles containing SNL-6 and SNL-15.

Based on this heuristic analysis, the angle ratio is thought to be an adequate primary metric for triangle quality. Triangle size is considered to be independent information, but it is not directly correlated with a desired monitoring network objective. While smaller triangles resolve more detail than larger ones, a dense network is much more expensive and large triangles are allowable in the portions of the domain further from the WIPP land withdrawal boundary. This metric obviously only considers the network geometry; there may be important hydrologic or geologic information to be gained from locating a well at locations which may be sub-optimal solely from a geometric point of view.

Freshwater head gradient direction and magnitude are illustrated in Figure 3-7 using vectors scaled to the gradient magnitude. Figure 3-7a shows the network for the 2007 Culebra monitoring network, while Figure 3-7b shows the remaining network after leaving out SNL-6 and SNL-15, which are non-representative of heads west of the composite H2/M2 – H3/M3 Rustler halite margins (Johnson, 2009). Leaving out these two wells removes the spurious large gradients around these wells, but also changes the overall shape of the network on the eastern third of the domain (see Figure 3-7).

Figure 3-8 and Figure 3-9 show the same quantities in Figure 3-5 and Figure 3-6 for the Delaunay triangles that correspond to the existing network without SNL-6 and SNL-15. Most of the triangles in the domain are unaffected by leaving these wells out, since only 10 triangles include either of these points in the existing network. Apparent changes elsewhere in the domain are due to rescaling of the color gradient in the figures, because the minimum or maximum values are linked to triangles changed by leaving out these two wells. The steeper gradient across the WIPP LWB is more evident in Figure 3-8c (due to color scaling). The negative correlation between area and gradient is also clearer in Figure 3-9c, as most of the large triangles with steep gradients were connected to the low values in either SNL-6 or SNL-15.

This section introduces the triangle interior angle ratio as a continuous metric that identifies isosceles-like triangles and is not spuriously correlated to triangle size or observed gradient between head observations at wells. Based on the comparison with and without SNL-6 and SNL-15, these wells are left out of any analysis that requires head values (i.e., the remove-one-well analysis)

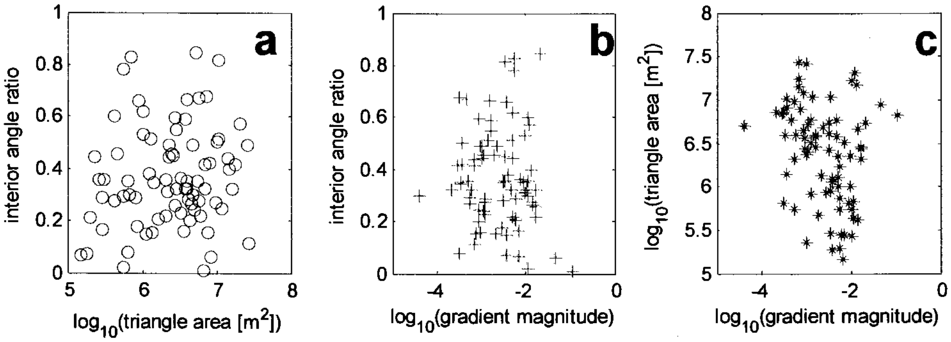


Figure 3-6. Scatter plots of relationships between different triangle metrics for 2007 Culebra well network.

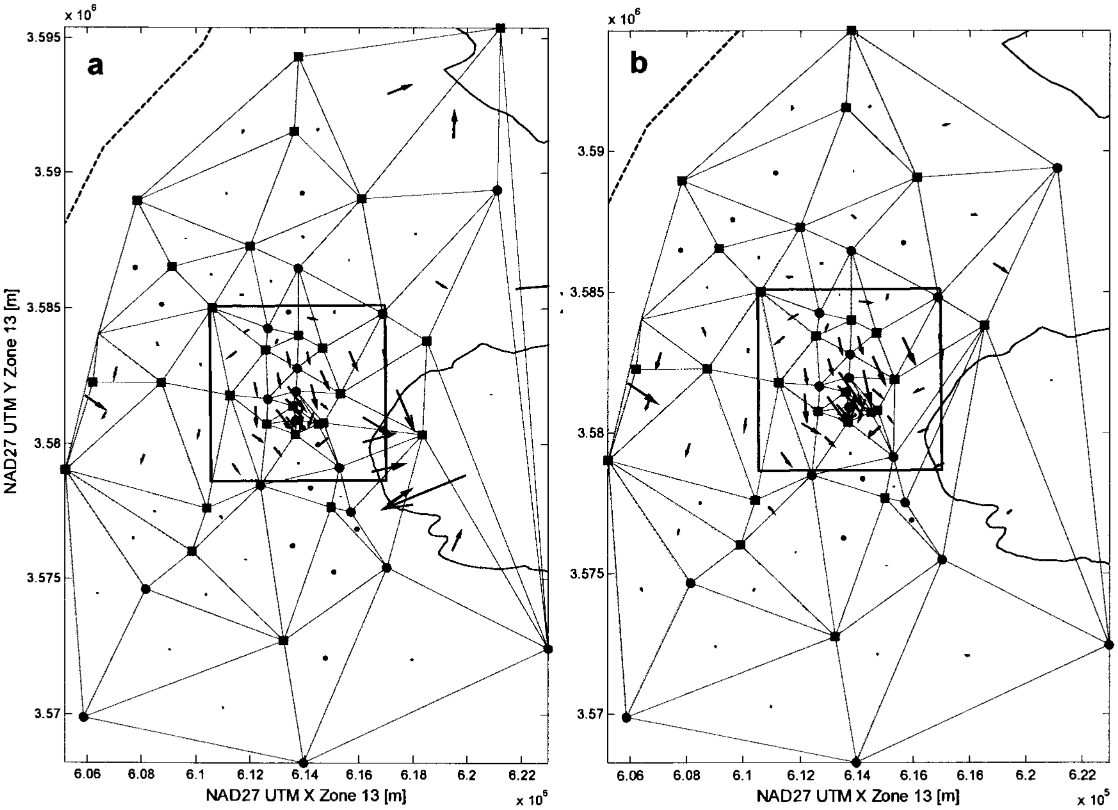


Figure 3-7. Delaunay triangles for 2007 Culebra network (a) with and (b) without SNL-6 and SNL-15. Gradient plotted as arrows (tails starting at center of triangle); length of arrow is proportional to magnitude gradient, arrow orientation indicates groundwater flow direction. WIPP LWB (black solid), M2/H2 - M3/H3 composite Rustler halite margins (magenta), and no-flow (black dashed) boundaries shown.

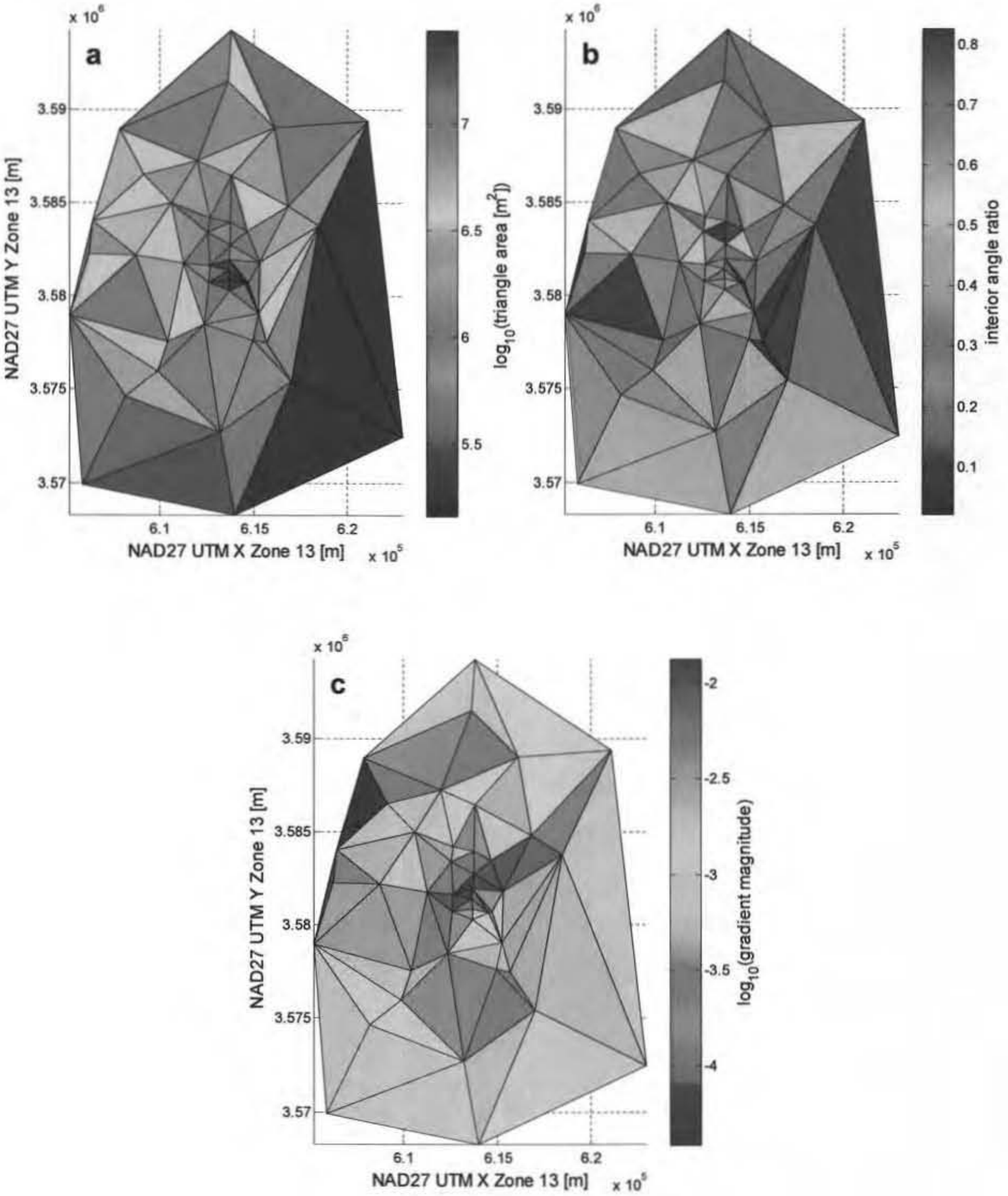


Figure 3-8. Distribution of triangle geometry metrics: (a)triangle size, (b) interior angle ratio, and (c) May 2007 freshwater head gradient magnitude for 2007 network without SNL-6 and SNL-15

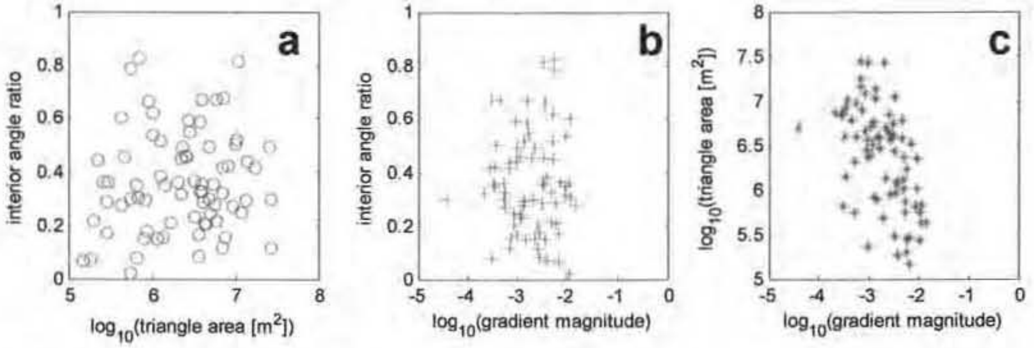


Figure 3-9. Scatter plots of relationships between different triangle metrics for 2007 network without SNL-6 and SNL-15.

3.3. Add One New Well

Similar to Section 2.4.1, we explore the effects of adding one more monitoring well to the network, but using the angle ratio metric discussed in the previous section. For each model cell in the Culebra MODFLOW model grid, a monitoring point is added, and the triangulation process is repeated. Statistics regarding the resulting triangular network are summarized in the following plots.

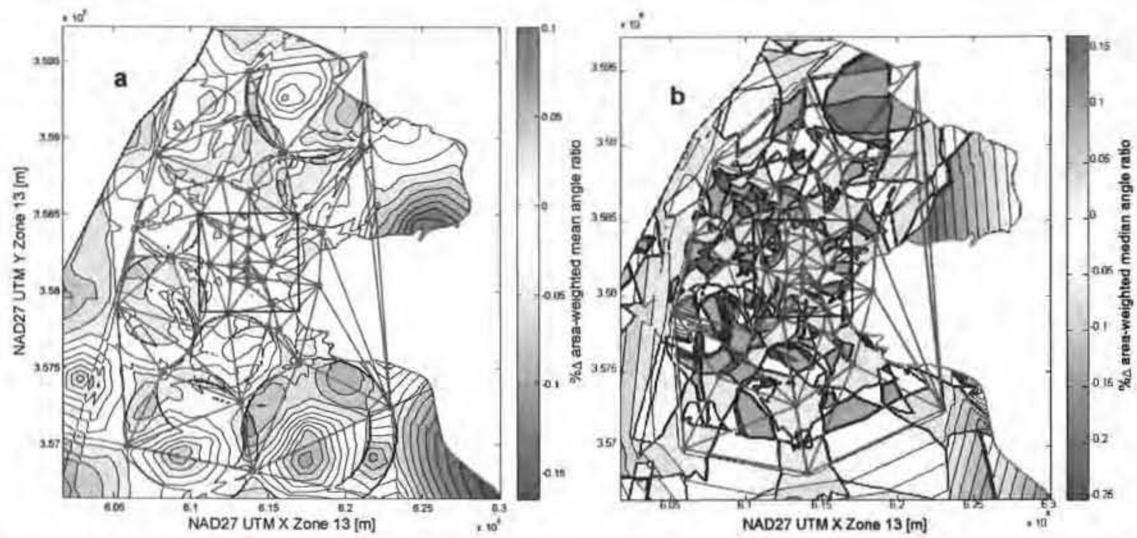


Figure 3-10. Increase (red) or decrease (blue) in area-weighted (a) median and (b) mean angle ratio for triangle network, due to one additional well.

The addition of an observation point can only be judged using geometry metrics, because the head that would be observed at the new location is yet unknown. Figure 3-10 shows the 2007 Culebra monitoring network (red circles are well locations, green lines are the Delaunay triangles for the 2007 Culebra well network). Contour colors indicate whether adding a well at that location and re-triangulating the network (not shown) would increase or decrease the interior angle ratio, averaged over the model domain.

The mean and median angle ratios shown in Figure 3-10 are weighted by triangle area. Each triangle's angle ratio is multiplied by its area, and then the mean or median of these products (for all the triangles in the network) is divided by the total area covered by the network. The total area inside the convex hull surrounding the whole network may increase if the proposed monitoring point is located outside the convex hull of the current network.

Areas that are blue in Figure 3-10 indicate locations where a new well would create additional large elongate triangles in the Delaunay network. Triangles with low angle ratios make poor estimators of the local gradient. Areas between wells in the southern and eastern parts of the domain show the largest relative increase (red) in both the mean and median triangle shape metric averaged across the model domain. The north-central portion of the domain shows a large positive increase in the median triangle shape metric, but not in the mean (the median is less sensitive to large changes in a single triangle, e.g., along the southern edge of the network). An additional monitoring point at a red location in Figure 3-10a or b would be the best in terms of the relative geometry of the resulting network. These locations change large elongate triangles into smaller triangles with three similar angles; smaller, more symmetric triangles are better for estimating local gradients, given the same relation between the observed gradient and measurement error.

McKenna and Wahi (2006) (and likewise the 2004 version of this analysis) performed statistical analyses of three-point estimators to evaluate their ability to estimate the gradient from three point measurements, as a function of the relative head measurement error (RHME), the orientation of the principle groundwater flow direction, and triangle shape. This analysis only takes the triangle shape or size into account. Triangles that are small and symmetric, but which cover an area of very low gradient magnitude may be bad estimators as well, given the current distribution of heads. This analysis only considers the geometry of the network.

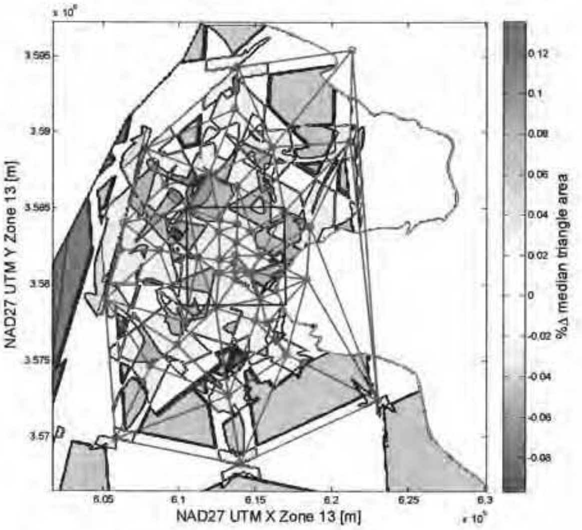


Figure 3-11. Increase (red) or decrease (blue) in median triangle area, due to including one additional well

In Figure 3-11, the relative change in the median triangle size is shown for the same scenario of adding one additional well to the network. Although triangle size is not the main metric, it shows different information from the angle ratio plot. Since adding a monitoring point to the network will always create more triangles, but the total network area will only change if the additional well is outside the original convex hull; Figure 3-11 shows whether the additional location will make nearby triangles smaller or larger. Most of the regions within and near the WIPP LWB are blue, indicating the triangles in the proposed network will on average become smaller, while new wells located at the extremities of the existing network will increase the median triangle size, especially the area along the southern end of the no-flow boundary (see bright red area in west-central portion of Figure 3-11).

Following common sense, Figure 3-11 shows that adding monitoring locations near the edges of the domain will add more large triangles to the existing network. Adding a point near the middle of the domain will instead add more small triangles to the existing network, since the density of wells inside the WIPP LWB is already high. This does not consider the fact that expanding the overall size of the monitoring network would likely add useful information, regardless of the network shape.

3.4. *Remove One Steel Well*

Compared to the addition of a new well, more can be said about the removal of a well from the network, since heads have been observed at the location proposed for removal. In this section, the effect of removing a well is computed by first copying the results of triangulation (which assigns a piecewise-constant gradient value to every point inside the convex hull) onto points corresponding to the centers of the finite-difference cells of the MODFLOW model grid. Only points in the MODFLOW grid which fall within the convex hull are compared.

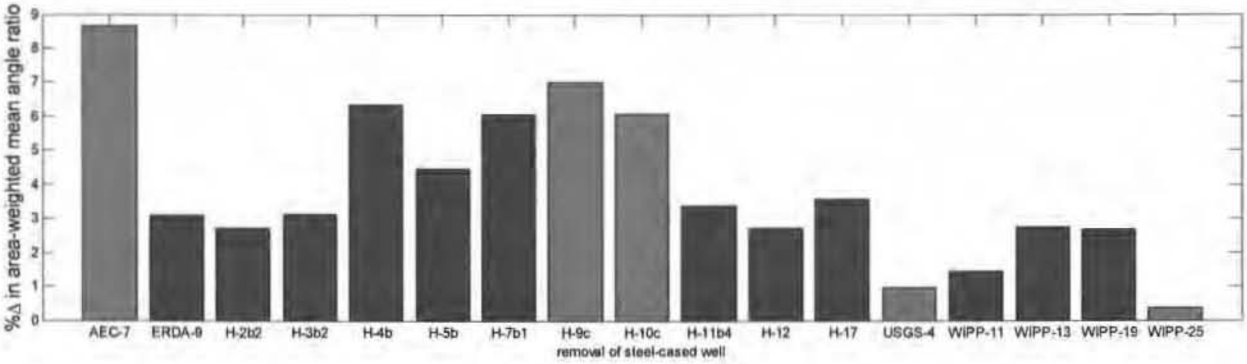


Figure 3-12. Change in mean area-weighted angle ratio (averaged over model domain) upon removal of each steel well from monitoring network (no SNL-6 or SNL-15). Red bars are wells located on convex hull.

In Figure 3-12, AEC-7 has the largest impact on the mean area-weighted angle ratio metric. Excluding the steel cased wells which form the boundary of the triangulation (shown in red) leaves H-4b, H-7b1, and H-5b with the largest impact, with wells USGS-4 and WIPP-25 having the smallest impact, even though they makeup part of the convex hull.

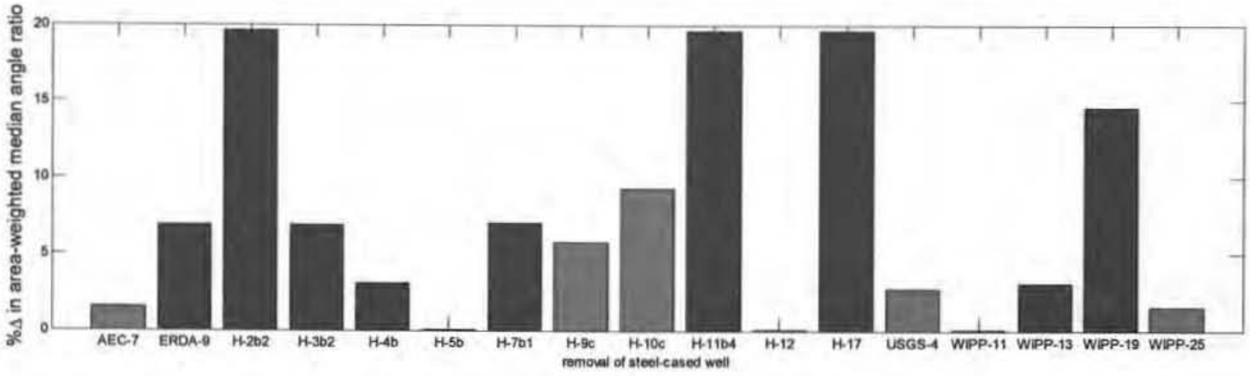


Figure 3-13. Change in median area-weighted angle ratio upon removal of each steel well from monitoring network (no SNL-6 or SNL-15).

In Figure 3-13 H-2b2, H-11b4 and H-17has the approximately the same impact on the median area-weighted angle ratio, but wells H-2b2, H-11b4 and WIPP-19 now also have large percent change values (compared to Figure 3-12). These two bar charts (Figure 3-12 and Figure 3-13) correspond to Figure 3-10 parts a and b for the case of removing one well to the network.

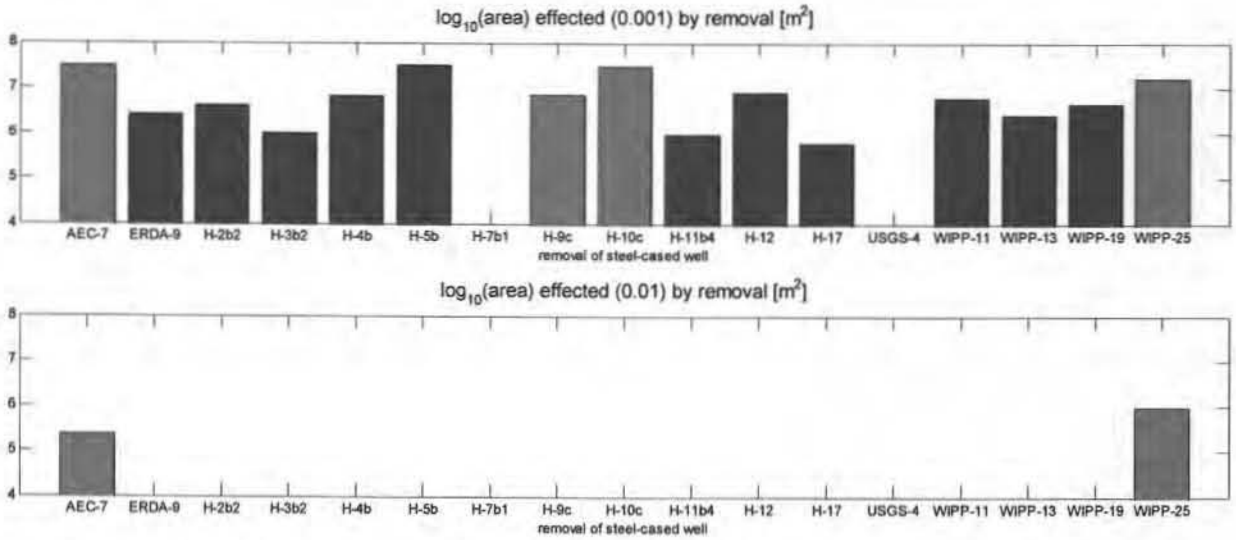


Figure 3-14. Area affected (Δ gradient magnitude ≥ 0.01) by removal of steel well

Figure 3-14 shows the area affected by the predicted change in gradient between the 2007 monitoring network and the reduced network with the corresponding steel-cased well removed. The changed area is defined as the area where the relative change in gradient magnitude is greater than or equal to 0.01 (lower figure) or 0.001 (upper figure). After removing each well, the Delaunay triangulation is recomputed, and the observed gradient is computed for each resulting triangle. The marked difference between the two bar charts in Figure 3-14 indicates that although there is a very large amount of area that would be slightly affected by removing any one steel well (large number of bars in the upper figure), there is very little of the model domain that would be significantly affected by any one well being removed (bottom figure).

Table 3-1. Ranking of steel-cased wells based on triangle gradient estimators. A low numerical rank indicates importance.

	%Δ mean angle ratio		%Δ median angle ratio		average rank
H-17	3.58	7	19.61	1	4
H-10c	6.09	4	9.27	5	4.5
H-11b4	3.38	8	19.61	1	4.5
H-7b1	6.07	5	7.04	6	5.5
H-9c	7.02	2	5.75	9	5.5
H-2b2	2.73	12	19.61	1	6.5
H-4b	6.34	3	3.09	10	6.5
AEC-7	8.65	1	1.51	14	7.5
H-3b2	3.13	9	6.87	7	8
ERDA-9	3.09	10	6.87	7	8.5
WIPP-19	2.70	14	14.61	4	9
H-5b	4.47	6	0.00	16	11
WIPP-13	2.75	11	3.08	11	11
USGS-4	0.96	16	2.74	12	14
H-12	2.72	13	0.00	17	15
WIPP-11	1.44	15	0.00	15	15
WIPP-25	0.36	17	1.51	13	15

These bars represent the areas colored in the figures in the figures in Section 9.0. The individual figures in Section 9.0 show the localized effects of removing a well from the network; the colored areas only immediately surround the well being removed. The effects due to removing wells in areas with small triangles (e.g., inside and near the WIPP LWB) will obviously only propagate out to a small area. Wells that are part of large triangles along the periphery of the domain will affect larger areas when removed.

3.5. *Remove Two Steel Wells*

Using the same list of "probable" wells from section 2.4.3 (kriging variance reduction), the local gradient estimator analysis of the previous section can be repeated for each of the networks with one of the steel-cased wells already removed. Table 3-2 shows the cumulative effect that removing two steel-cased wells has on the domain-average mean angle ratio (see Figure 3-12 for the corresponding single-well analysis). The percent changes (illustrated in the color image) show that removing any pair of wells including H-10c (row 9) or most wells in a pair with well H-7b1 (row 7, column 4) lead to improvements in the geometric layout of the observation wells, because these wells are involved in several large elongate triangles. These types of improvements are not the goal of this analysis. Well H-9c (row 8) shows the largest decrease in the domain-average angle ratio metric, corresponding to the worst effects on the well network; this well is on the southern edge of the network.

Table 3-3 shows how median triangle size in the network increases (red) or decreases (blue) as pairs of steel-cased wells are removed from the network. Removing other steel-cased wells in conjunction with H-10c (row 9) would decrease average triangle size because the convex hull becomes smaller upon removal of this well.

Table 3-2. Change in domain-average mean angle ratio upon removal of 2 steel-cased wells. Image illustrates percentages given in table, in same row/column order.

		WIPP-25		WIPP-13		H-12		H-7b1	
1	AEC-7	3.7%	1	5.7%	1	5.7%	1	9.5%	1
2	ERDA-9	-1.4%	9	0.3%	9	0.2%	8	3.5%	8
3	H-2b2	-1.7%	11	-0.1%	10	-0.1%	10	3.2%	10
4	H-3b2	-1.4%	8	0.3%	8	0.3%	7	3.5%	7
5	H-4b	1.8%	2	3.4%	2	3.4%	2	6.7%	3
6	H-5b	-0.1%	5	1.6%	5	1.6%	4	4.8%	4
7	H-7b1	1.5%	3	3.2%	4	3.2%	3		
8	H-9c	-10.1%	16	-8.3%	16	-4.1%	16	-4.8%	16
9	H-10c	1.1%	4	3.2%	3	0.4%	6	7.3%	2
10	H-11b4	-1.1%	7	0.6%	7	0.5%	5	3.8%	6
11	H-12	-1.8%	12	-0.1%	11			3.2%	11
12	H-17	-0.9%	6	0.8%	6	-1.2%	12	4.0%	5
13	USGS-4	-3.7%	15	-1.8%	15	-1.8%	15	-3.9%	15
14	WIPP-11	-3.0%	14	-0.8%	13	-1.4%	13	1.9%	13
15	WIPP-13	-1.7%	10			-0.1%	9	3.2%	9
16	WIPP-19	-1.8%	13	-0.1%	12	-0.1%	11	3.1%	12
17	WIPP-25			-1.7%	14	-1.8%	14	1.5%	14

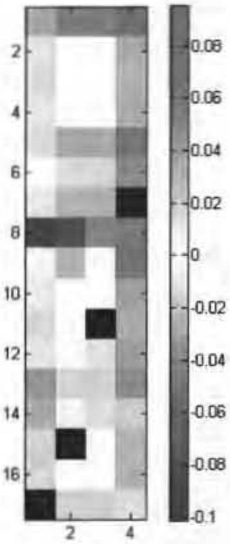
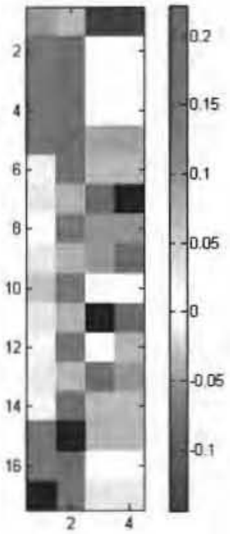


Table 3-3. Change in domain-average median triangle size upon removal of 2 steel-cased wells. Image illustrates percentages given in table, in same row/column order.

		WIPP-25		WIPP-13		H-12		H-7b1	
1	AEC-7	-5.2%	16	-3.4%	16	-14.4%	16	-14.4%	16
2	ERDA-9	15.2%	3	21.9%	2	0.0%	3	0.0%	3
3	H-2b2	15.2%	3	21.9%	2	0.0%	3	0.0%	3
4	H-3b2	15.2%	3	21.9%	2	0.0%	3	0.0%	3
5	H-4b	16.5%	1	22.1%	1	8.5%	1	8.5%	1
6	H-5b	1.7%	8	16.1%	8	-3.4%	10	-3.4%	9
7	H-7b1	-1.7%	12	6.7%	12	-8.3%	14		
8	H-9c	0.0%	11	15.2%	11	-5.2%	12	-5.2%	12
9	H-10c	-1.7%	12	6.7%	12	-5.2%	12	-8.3%	14
10	H-11b4	6.1%	7	15.9%	9	0.0%	3	0.0%	3
11	H-12	-1.7%	12	6.7%	12			-8.3%	14
12	H-17	1.7%	8	15.9%	9	0.0%	3	-3.4%	9
13	USGS-4	-1.7%	12	6.7%	12	-8.3%	14	-5.2%	12
14	WIPP-11	1.7%	8	21.3%	6	-3.4%	10	-3.4%	9
15	WIPP-13	16.5%	1			6.7%	2	6.7%	2
16	WIPP-19	15.2%	3	21.9%	2	0.0%	3	0.0%	3
17	WIPP-25			16.5%	7	-1.7%	9	-1.7%	8



3.6. *Local Gradient Estimator Summary*

The local gradient estimator analysis presented in this section considers the effects of adding a well and removing a well or two, from the perspective of the network and head gradient estimation geometry. The metric which was used to compare potential triangular networks was mainly the ratio of the maximum and minimum angles, with the median triangle size used as a secondary metric.

3.7. Local Gradient Estimator Run Control Summary

The local gradient estimator analysis performed in this section is described here in terms of files, programs, and scripts used. The required files are on the CD and are described in sufficient detail to allow recreation of the results given in the text. All the analysis in this section was done using MATLAB, and the calculation and plotting of results are partially mixed together in the scripts.

3.7.1. Triangles: add a well

The MATLAB script `triangles_add_one.m` (Section 8.3.1) is the main script that performs the calculations for the evaluation of additional locations in terms of Delaunay triangles. This section describes the script's basic behavior. The first lines of this script load in the required data from files (lines 1 to 30). A rectangular array of *x* and *y* locations (UTM NAD27 Zone 13 [m]) are created using `meshgrid()` (lines 32 through 34), which is then compared to the polygon defining the active model domain using `inpolygon()` (line 36), to determine the cells that are inside the active MODFLOW domain. These matrices are then unwrapped into vectors to simplify indexing (line 40).

The main loop of this script (lines 45 through 111) goes over each potential new location (plus one for the base case with no additional monitoring locations), re-triangulating the network (line 59). The results of `delaunay()`is a matrix with three columns corresponding to the three vertices of each triangle, and a row for each triangle. The values in this matrix are integer indices pointing to the values of the *x* and *y* coordinates passed to `delaunay()`. For example, if `tri=delaunay(x,y)`, where `x` and `y` are each a vector of 3 locations, `tri` will be a 1×3 matrix, where the corners of the triangle specified by the first (and only) row of `tri` are obtained addressed like `x(tri(1,[1,2,3])), y(tri(1,[1,2,3]))`. The `geom` matrix stores the results of the geometric calculations for each triangle in the network; rows 1-3 are the lengths of the sides (computed using the Pythagorean theorem – lines 70 to 77), rows 4-6 are the angles between the sides (computed using the cosine law – lines 80 to 87), and row 7 is the area of the triangle (computed using the built-in MATLAB function `polyarea()` – line 90). The interior angle ratio is computed from the maximum and minimum interior angles (line 93). Some summary statistics regarding the entire triangle network are saved into the matrix `Q`; the area-weighted angle ratio average and median are computed, as wells as the average and median triangle size are computed (lines 95 to 109).

After looping over all possible locations, the matrix `Q` contains different average results for each point in the domain that is inside the active MODFLOW flow domain. The results for the existing Culebra network with (Figure 3-5, Figure 3-6, and Figure 3-7) and without SNL-6 and SNL-15 (Figure 3-7, Figure 3-8, and Figure 3-9) were plotted from the `geom` matrix, for the case with no additional wells.

These summarizing results (`Q` matrix) are saved to ASCII file (lines 116 to 123 – see files in `analysis\triangle_metric\output\` directory on CD) and plotted to make color contour maps shown in Figure 3-10, and Figure 3-11.

The MATLAB script `redwhitemap.m` (see Section 8.3.2) is used by the `triangles_add_one.m` script just described, to create a color legend corresponding to blue being negative, red being positive and white being zero, based on a vector of data passed. This script only is used for creating a colormap for plotting figures in MATLAB, but is included here for completeness.

3.7.2. Triangles: removal steel-cased wells

The `triangles_remove_one.m` MATLAB script (Section 8.3.3) does much of the same that the `triangles_add_one.m` script in the previous section did, but it also computes things related to the freshwater head gradient across triangles between wells.

Similar to the previous triangle metric script, the first portion of the script loads data from file (lines 8 to 34), but here a series of nested for loops are used to find the wells on the convex hull (for marking them in the bar chart figures – lines 38 to 46). The main loop of the script re-computes the metrics related to the triangle, removing a different steel-cased well each time through the loop. In addition to geometry metrics related to the triangles (`geom` and `Q` matrices, line 144 through 176), the gradient defined by the freshwater head observed at the three corners of the triangles is also computed using Cramer's rule and saved into the `coeff` matrix (lines 98 to 122).

The gradient estimates are individual values for each triangle in the network (piecewise constant), but to compare the effects of removing a well from the network, which will result in a different network, the values are copied onto a 100 m square grid at each step (lines 125 to 136). This is done by cycling through the triangles in the network (typically about 30 or 40 triangles), each time selecting the cells from the 100 m square grid that are inside the triangle (using `inpolygon()`), assigning the gradient from the triangle to all the cells that fall inside it. The rest of the script is used to plot figures for the analysis report (Figure 3-12, Figure 3-13, and Figure 3-14, and the figures in Section 9.0), using the data computed in the main loop.

The `triangles_remove_two.m` MATLAB script does essentially the same thing as the remove-one script, but takes a list of four "likely to be P&Aed" wells, removing each of these first, then doing the remove-one-well process outlined above. The matrices resulting from this script are made into Table 3-2 and Table 3-3.

4.0 Model Correlation Analysis

In addition to the variance reduction and local gradient estimator approaches to monitoring network design, a third approach is used here to incorporate uncertainty captured in the performance assessment (PA) simulation into the monitoring network design. These calculations also incorporate recent updates in the geologic conceptual model and the influence of these updates on the spatial distribution of transmissivity within the Culebra. These recent updates in the geologic conceptual model have been used to produce the base transmissivity fields used in this study and are summarized in the Culebra T-fields summary report (Kuhlman, 2010b).

4.1. Background

The goal of this portion of the report is to include a third independent metric in the overall optimization that specifically addresses the PA monitoring network design goal of providing head and aquifer transmissivity data for defensible calibration of PA models. Additionally, the approach developed here specifically incorporates PA information in the form of groundwater travel times from the repository area to the boundaries of the WIPP LWB. This approach makes use of the existing ensemble of calibrated transmissivity fields (Hart et al., 2009) such that no additional groundwater flow and/or transport modeling is necessary.

4.2. Calculating Sensitivity Coefficients

The sensitivity of model outputs to changes in model inputs arises in the calibration, uncertainty analysis, and cost optimization of both analytic and numerical models. A model can range in complexity from a linear analytic expression to a complex numerical model. In general, a sensitivity coefficient, S, is calculated as the partial derivative of a model output with respect to each model input parameter:

$$S_{ij} = \frac{\partial O_i}{\partial P_j} \tag{10}$$

where S_{ij} is the sensitivity coefficient of the model prediction, O, at the i^{th} observation point to the j^{th} model parameter, P_j. S_{ij} is an $n \times m$ matrix (i.e., the Jacobian matrix) with the number of rows equal to the number of model parameters (n) and the number of columns equal to the number of observations (m) (Zheng and Bennett, 2002). S_{ij} is often given in a normalized or dimensionless form, through appropriate scaling factors; this matrix often plays a key role in parameter estimation techniques such as in the conjugate gradient, Newton iteration, or Levenberg-Marquard algorithms.

4.2.1. Sensitivity Equation Method

The expression governing the process which controls how parameters (P_j) are related to outputs (O_i) can sometimes be differentiated using calculus. This method is usually only applicable to simple lumped-parameter or analytic equation models. Although this approach is quite problem-specific, it leads to closed-form expressions for the sensitivity matrix. The form of the sensitivity equations often provides insight to the underlying process without needing to evaluate the problem for specific parameter values. Because the PA model considered here is an ensemble of calibrated MODFLOW models with irregular distribution of parameters and boundary conditions, this analytic sensitivity equation approach is infeasible.

4.2.2. Perturbation Approach

The derivative in Equation (10) can be approximated using finite differences. A small perturbation is made in a single model input (ΔP_j), leading to a set of perturbed model outputs which are differenced with model predictions from a base case $O_i(P_j)$, and normalized by the change in the parameter.

$$S_{ij} = \frac{\partial O_i}{\partial P_j} \approx \frac{O_i(P_j + \Delta P_j) - O_i(P_j)}{\Delta P_j} \tag{11}$$

This is the most generally-applicable and widely-used approach to estimating sensitivity coefficients; for example, this is the approach taken in inverse-modeling codes such as PEST (Doherty, 2002).

If a model has *n* parameters for which sensitivity information is desired, then at least *n*+1 model runs must be performed to compute the one-sided finite difference given in Equation (11). For higher-order accuracy, often 2*n*+1 model runs can be used to estimate derivatives via centered finite differences. For large highly-parameterized models (i.e., thousands of parameters or more), the perturbation approach often leads to unmanageably large computing demands. For the inverse problem, there are many approaches for either reducing the number of parameters which require derivatives; e.g., pilot points and singular value decomposition are both methods used with PEST in the WIPP Culebra PA model calibration (Hart et al., 2009).

When working with an ensemble of independent calibrated models, S_{ij} is computed separately for each realization, and then ensemble sensitivity can be computed by appropriately averaging across the realizations. Although this approach was used to calibrate the PA models and the resulting PEST-computed sensitivity matrices (i.e., Jacobians) are saved in CVS, this approach was not used due to two complications. First, the sensitivities in the MODFLOW model are computed between observed heads and pilot point values (not particle travel times to individual parameter values in the model grid). Second, these sensitivity matrices were only computed at the beginning of the calibration, due to the use of the singular value decomposition, which works with "super pilot points" rather than the pilot points themselves.

4.2.3. Adjoint Sensitivity Approach

An alternate approach to computing S_{ij} using finite differences is the use of the adjoint sensitivity equations, where a system of adjoint equations are derived (similar in form to the diffusion equation) and solved using the same model grid with modified boundary conditions and source terms. The sensitivity coefficients are related directly to the adjoint variable, rather than the main variable (typically head or pressure). Although this method is very problem-specific, it has the advantage of making the number of model runs needed to compute S_{ij} proportional to the number of model predictions or observations (*m*), rather than the number of model parameters (*n*) (see e.g., Sykes et al., (1985) (1985)). The adjoint approach was used at WIPP during the CCA, in the GRASPII inverse modeling code (see e.g., RamaRao and Reeves (1990)).

Like the perturbation-based approach, the adjoint method works independently on each realization, requiring appropriate averaging across realizations to develop ensemble-based estimates of parameter sensitivity to model predictions.

4.2.4. Sampling-Based Correlation Approach

In the three sensitivity calculation approaches outlined above, the changes in model predictions, due to perturbing each parameter are kept separate; the derivative in Equation 10 is a partial derivative indicating all other independent variables are held constant while each P_j is varied. Individually perturbing each of the model parameters has the benefit of isolating each parameter's effects on the model predictions, but it demands a large number of forward model runs to fill in the large sensitivity matrix. For the WIPP Culebra PA flow model, we have an existing ensemble of calibrated model realizations, which can be used to statistically investigate the correlation between input parameters and the predictions in a post-mortem sense, after all the model runs are finished. The previous three approaches were for a single realization, requiring averaging to reach an ensemble average; the correlation-based approach uses all the realizations to develop a proxy for sensitivity applicable to the WIPP PA model results.

The correlation-based approach used here begins with an ensemble of 100 calibrated models and the metric for relative importance of one model parameter over another is the parameter's correlation with the model prediction, across the ensemble of model realizations.

Each of the 100 simulations associated with the calibrated T-fields prepared for CRA 2009 PABC (Hart et al., 2009) is a realization where all the parameters are "perturbed" together, rather than individually perturbing parameters by ΔP_j. For a given element in the Culebra flow model, there are 100 values of each parameter (e.g., transmissivity); a histogram of $\log_{10}(K_{\mathrm{eff}})$ in a cell south of the WIPP site, and histogram of the travel time to the WIPP LWB are plotted across all 100 realizations in Figure 4-1.

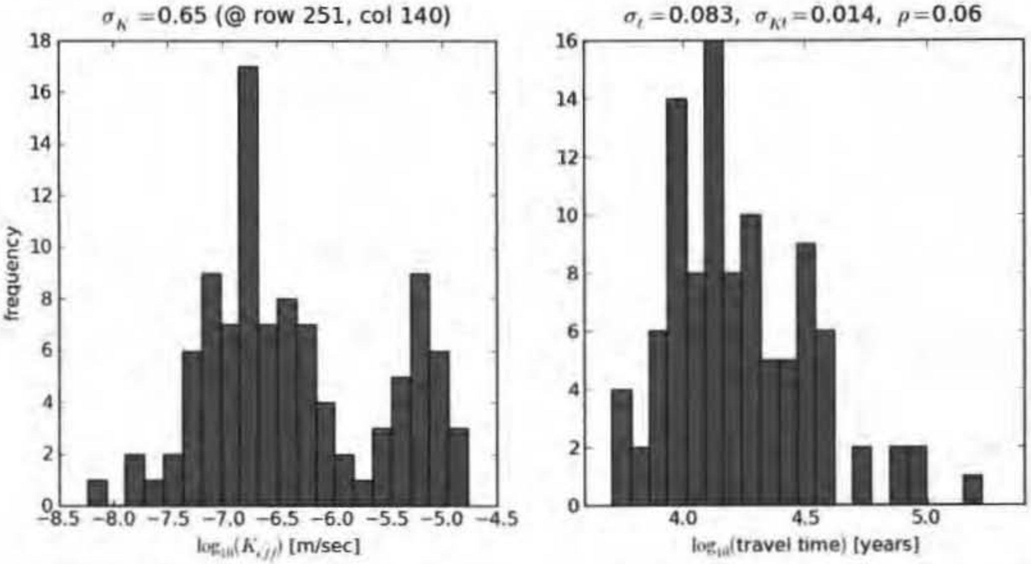


Figure 4-1. Example histograms of a model parameter ($\log_{10}(K_{\mathrm{eff}})$) at a particular cell and model prediction ($\log_{10}$(travel time to WIPP LWB)) across all 100 realizations.

The ensemble correlation approach requires multiple calibrated model realizations, and therefore captures some of the uncertainty captured by the ensemble of models. This is in contrast with the perturbation or adjoint sensitivity approaches which take one calibrated model and use it to estimate parameter sensitivity (essentially assuming a linear approximation of the actual model). To capture the uncertainty given by the ensemble, the perturbation sensitivity approach would have to be performed for each realization of the ensemble – a computationally exasperating process (tens of thousands of individual parameters in each of hundreds of models, with potentially long run-times for each forward run).

McKenna (2004) compared sensitivity coefficients computed using the sampling correlation approach for 100 realizations to those computed with the perturbation sensitivity approach for a single realization, and found that they were similarly but not identically distributed. Although in the sampling-based approach it is not possible to completely differentiate between true and spurious correlations (partial correlation does account for some of this in a statistical sense), the approach is used here based on its computational feasibility and the availability of the 100 realizations.

As opposed to S_{ij}, which is the slope of the linearized relationship between model inputs and outputs, the correlation coefficient, ρ, is a measure of the quality of the linear relationship between two variables (regardless of slope). The correlation coefficient is given by

$$\rho_{PO} = \frac{\frac{1}{n}\sum_{i=1}^{n}(P_i - m_P)(O_i - m_O)}{\sigma_O\sigma_P} = \frac{\sigma_{PO}}{\sigma_O\sigma_P} \qquad (12)$$

Where σ_P is the variance of the parameter P, m_P and m_O are the means of P and O respectively, σ_O is the variance of the observation O, and σ_{PO} is the covariance between P and O. ρ indicates the portion of the variance of O which is explained by the variance in P, through an assumed linear relationship (e.g., see Isaaks and Srivastava, (1989), Chapter 3).

When there is more than one free parameter varied at a time, partial correlation is defined as the correlation attributable to a single variable, statistically holding others constant (e.g., see Helton, et al., (2006) §6.4). Partial correlation is demonstrated for the case where a third variable Z is introduced into the problem illustrated in Equation (12);

$$\rho_{PO.Z} = \frac{\rho_{PO} - \rho_{PZ}\rho_{OZ}}{\sqrt{(1-\rho_{PZ}^2)(1-\rho_{OZ}^2)}} \qquad (13)$$

where the variables to the right of the dot in the subscript are statistically held constant. This expression reduces the correlation between two variables, by the amount attributed to the spurious correlation between both variables and a third one (here Z). When dealing with more than three variables, there are two primary approaches to computing partial correlation. Conceptually, the simplest is a recursive definition, which is an extension of Equation (13) (e.g., (Spiegel and Stephens, 1999), chapter 15),

$$\rho_{PO.YZ} = \frac{\rho_{PO.Z} - \rho_{PY.Z}\rho_{OY.Z}}{\sqrt{(1-\rho_{PY.Z}^2)(1-\rho_{OY.Z}^2)}} = \frac{\rho_{PO.Y} - \rho_{PZ.Y}\rho_{OZ.Y}}{\sqrt{(1-\rho_{PZ.Y}^2)(1-\rho_{OZ.Y}^2)}} \qquad (14)$$

but this recursive approach becomes difficult to compute as the number of variables gets above 4 or 5 (being impossible for hundreds or thousands of variables as in the case for the WIPP model). An alternate definition of Equation (14), in terms of correlation matrices is

$$\rho_{ij.(k\neq i,j)} = \frac{-a_{ij}}{\sqrt{a_{ii}\, a_{jj}}} \tag{15}$$

where $\rho_{ij.(k\neq i,j)}$ is the partial correlation of variables *i* and *j*, accounting for the effects of all other variables; a_{ij} is the matrix inverse of the symmetric correlation matrix *C*, which in the 3×3 case is

$$C = -\begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} \tag{16}$$

Often *C* can be poorly scaled and computing partial correlation due to many variables can be numerically unstable, as *C* can be nearly singular and therefore has an ill-defined inverse. The COTS statistical software R includes an implementation (cor2pcor) which computes partial correlation of systems with many variables, utilizing a numerically stable pseudo-inverse approach, automatically scaling the matrices to improve stability. Even though the improved numerical approaches help, the matrix-based approach is intractable for very large problems, because a $n\times n$ matrix must be made (where *n* is the number of active parameters, here over 50,000) in memory; even for single-precision variables this is on the order of a 30-gigabyte matrix. A comparison is made between regular and partial correlation in the results section, using only the area immediately surrounding the WIPP site.

4.3. Model Correlation Results

The calibration of the 100 *T* fields to steady-state and transient heads did not incorporate the groundwater travel time as an estimation variable. The travel time from the center of the WIPP panels (also the location of the Culebra well C-2737) to the WIPP LWB was a separate calculation done after the *T* fields were calibrated; see Figure 4-2 for the travel times and Figure 4-3 for the particle tracks across all 100 realizations.

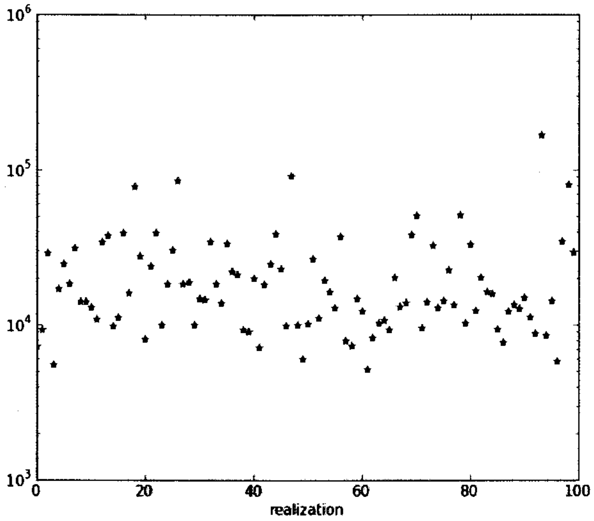


Figure 4-2. Travel times to WIPP LWB for conservative particle (non-dispersive, reactive, with no decay) for 100 realizations used in correlation analysis

The sampling-based sensitivity approach was applied to the results of the 100 calibrated *T* fields and used to determine the sensitivity of the groundwater travel time to the WIPP boundary with respect to the simulated heads, and effective hydraulic conductivity K_{eff} (the geometric mean of the *x*- and *y*-direction hydraulic conductivities),

—— ———— – (17)

where *A* is the horizontal hydraulic conductivity anisotropy and $K_y=K_xA$. Transmissivity (*T*) and hydraulic conductivity (*K*) differ in the Culebra MODFLOW model by a constant thickness, which does not affect correlation calculations. The distribution of K_{eff}, including the mean and standard deviation, across all 100 realizations is plotted in Figure 4-4. The results of these calculations for the K_{eff} are shown in Figure 4-5. Nearly all the wells shown in Figure 4-5 were used in the calibration of the K_{eff} parameter fields (except AEC-7 – see discussion in Section 1.5).

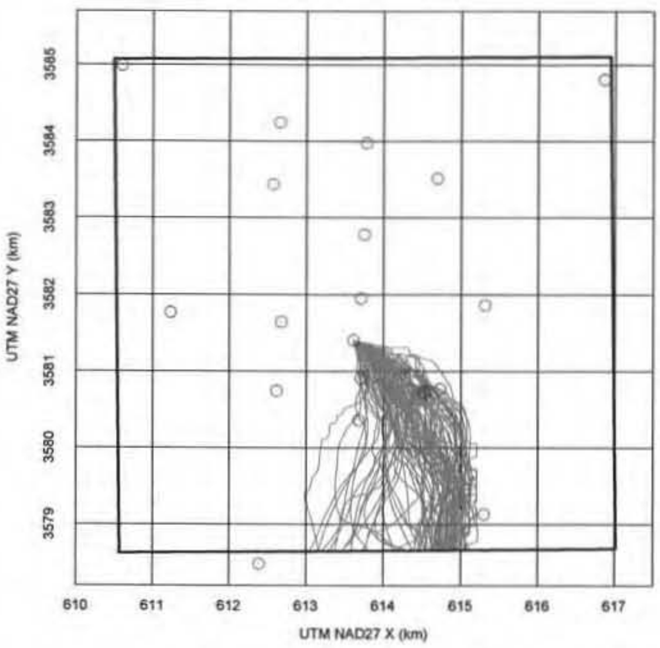


Figure 4-3. Marked water particle tracks from each of the 100 realizations; each track goes from the release point at C-2737 to the WIPP LWB (heavy black square). Green circles are Culebra monitoring wells.

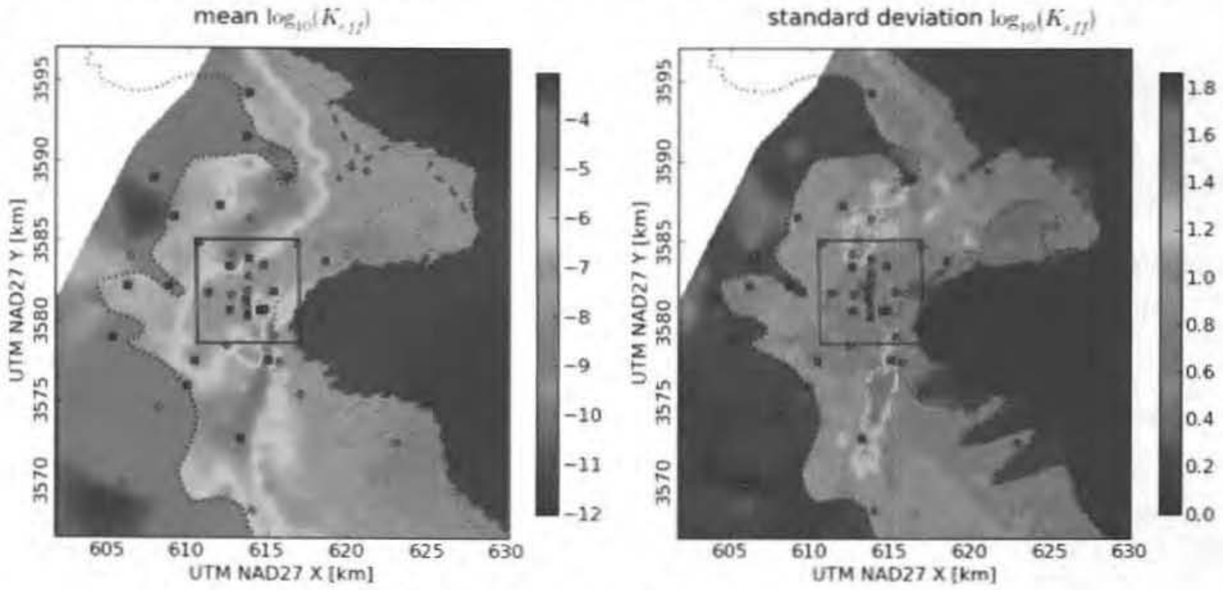


Figure 4-4. Mean and standard deviation of $\log_{10}(K_{eff})$ across all 100 realizations

The correlation results for K_{eff} (see Figure 4-5) show that the magnitudes of the correlation coefficients are not very large in most areas, signifying weak to moderate correlation, both positive and negative, between the travel time to the WIPP boundary and K values used in the model to calculate those travel times. However, the results clearly show regions of relatively higher and lower travel time sensitivity to the two input parameters. The partial correlation statistic (see Figure 4-6) is computed for K_{eff} in each element near the WIPP LWB, accounting for cross-correlation between each element and all other K_{eff} values in the vicinity of WIPP (within 1.5 km of the LWB). Although there are small differences in the distribution of the partial and standard correlation coefficients, the main difference is the absolute value. The partial correlation coefficient is approximately 100 times smaller than the standard correlation coefficient.

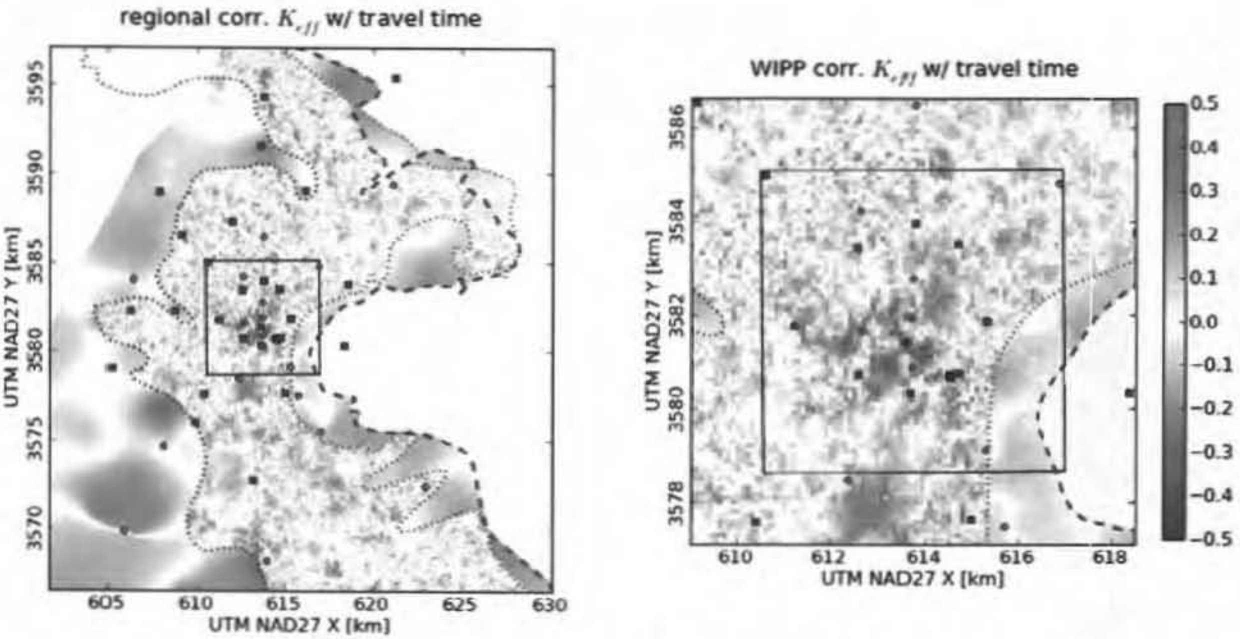


Figure 4-5. Correlation coefficient between $\log_{10}(K_{eff})$ and $\log_{10}$ travel time to WIPP LWB. Steel-cased wells are red circles; fiberglass-cased wells are green squares. Salado dissolution and Rustler halite margins are indicated with dashed lines. Plot on right contains same data plotted on left.

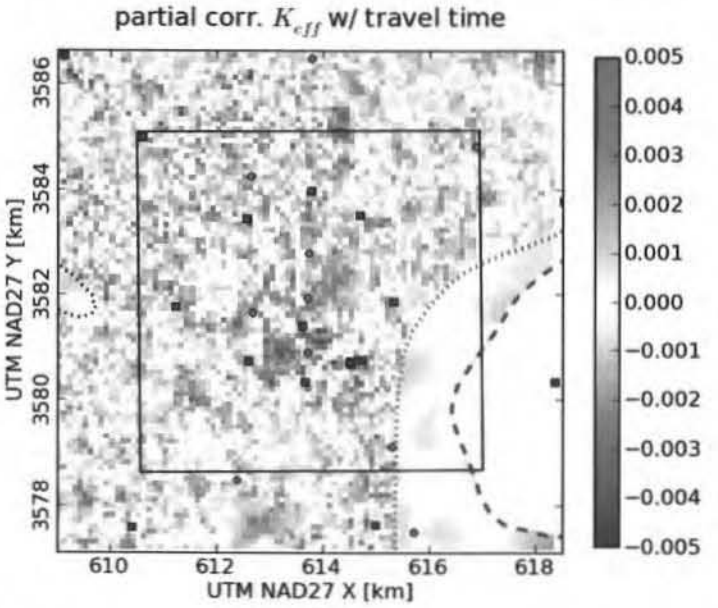


Figure 4-6. Partial correlation between log10(K_{eff}) and $\log_{10}$(travel time) to WIPP LWB

The distribution of model-generated head, across all 100 realizations, is shown in Figure 4-7; here the $\log_{10}$ of the standard deviation is plotted to emphasize the variation in the head across the WIPP LWB. It is interesting to note that visually, areas with the highest variability in K_{eff}

(Figure 4-4) – one of the main inputs to the Culebra flow model – do not correlate with areas of the highest variability in head (Figure 4-7).

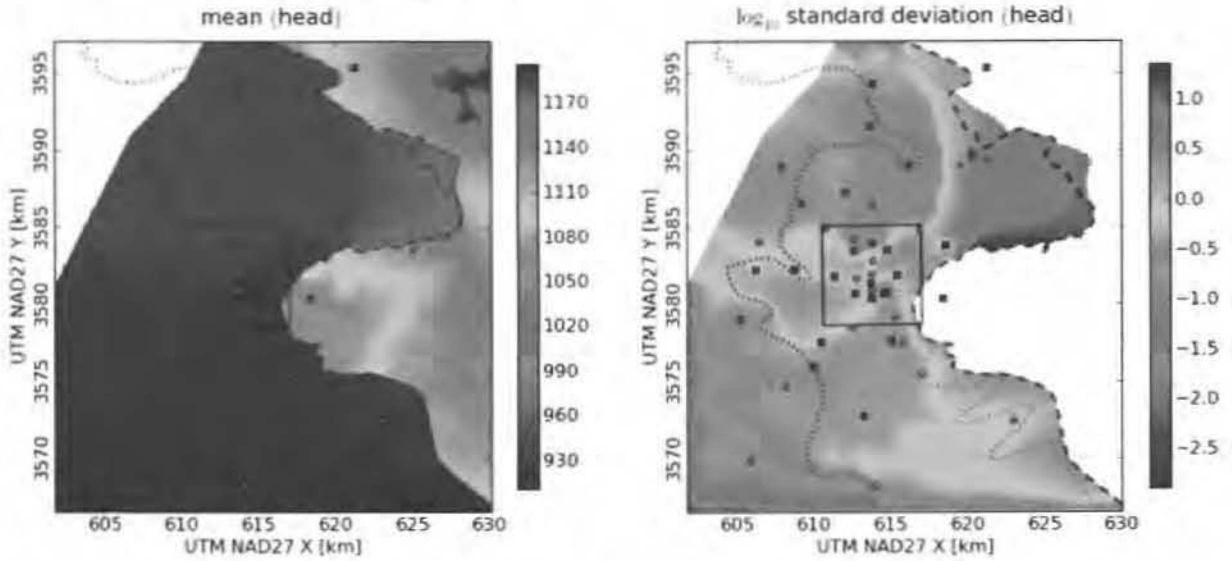


Figure 4-7. Mean and $\log_{10}$ standard deviation of model-simulated head across all 100 realizations

Figure 4-8 shows correlation of $\log_{10}$ model-predicted travel time to model-predicted head (output vs. output); this field is much more smoothly varying than the map of correlation between $\log_{10}$ travel time and K_{eff} (output vs. input). These results are consistent with the difference between model outputs (which must obey the diffusion equation) and the model outputs (which only are forced to have certain geostatistical structure, but are otherwise random).

The partial correlation statistic between model-generated heads and travel times is given in Figure 4-9. Like K_{eff} to travel-time correlation, the partial correlation coefficient is much smaller, but the difference here is only a factor of approximately 30, rather than 100.

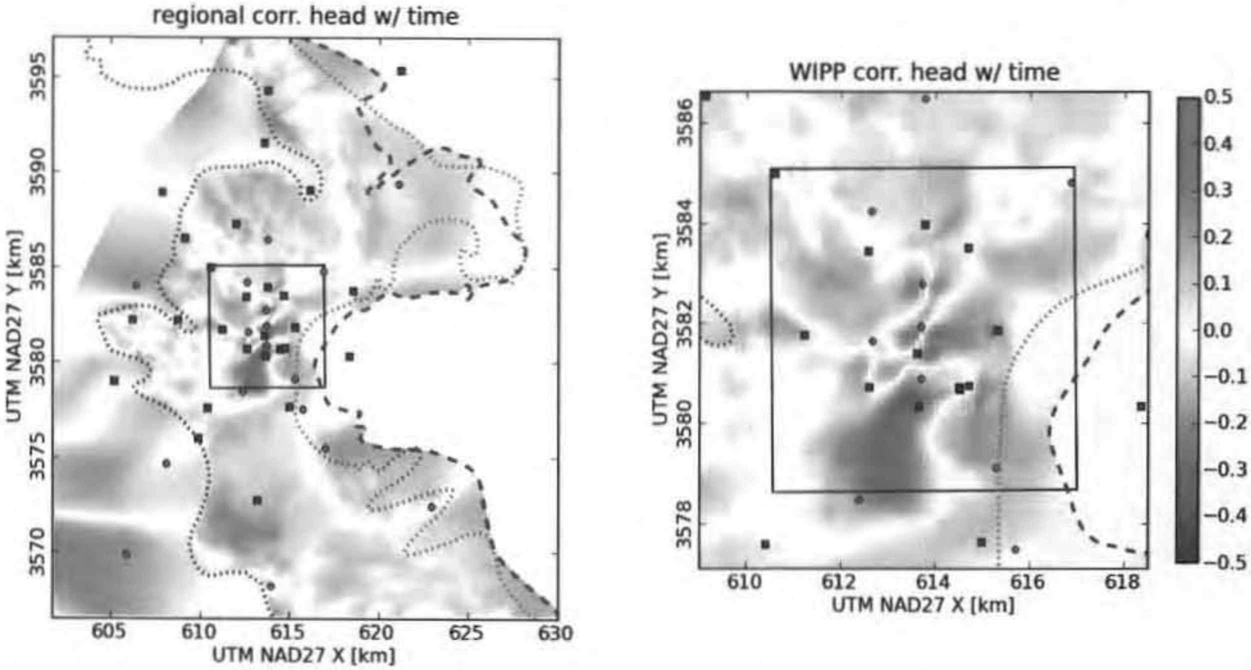


Figure 4-8. Correlation coefficient between model-predicted heads and $\log_{10}$(travel time) to WIPP LWB. Plot on right contains same data plotted on left.

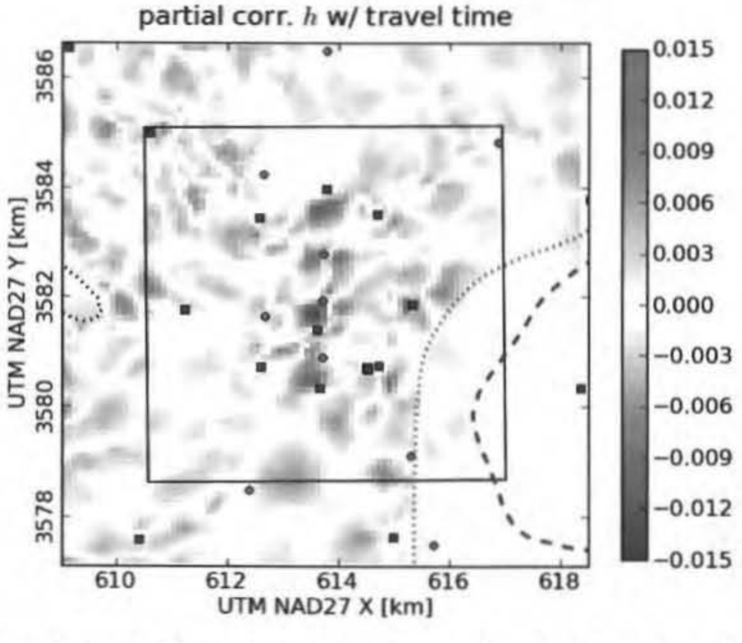


Figure 4-9. Partial correlation coefficient between model-predicted heads and $\log_{10}$(travel time) to WIPP LWB.

The model correlation analysis is the only one of the three given in this report which is not sensitive to the clustering of existing wells. Aside from the fact that the model was calibrated with data collected at the wells, the location of the individual Culebra monitoring wells and model correlation to inputs or output are largely de-coupled. The locations of highest model input/output correlation might occur adjacent to existing monitoring wells.

4.4. Remove One Steel Well

The results of the sampling-based correlation analysis are sampled at locations across the model domain, corresponding to the locations of existing steel-cased wells. The results of this are given in Table 4-1, where the numbers are simply the numerical values sampled from the images of correlation results shown in Figure 4-5 and Figure 4-8.

Table 4-1. Correlation-based analysis results at locations of steel-cased wells. A smaller rank number indicates a higher correlation and therefore assumed importance.

	$\rho\ K_{eff}$	$\lvert\rho\ K_{eff}\rvert$	rank	ρ head	$\lvert\rho$ head$\rvert$	rank	avg rank
ERDA-9	-2.989×10^{-1}	2.989×10^{-1}	1	-2.050×10^{-1}	2.050×10^{-1}	2	1.5
H-3b2	-9.670×10^{-2}	9.670×10^{-2}	6	-1.936×10^{-1}	1.936×10^{-1}	3	4.5
WIPP-19	-9.941×10^{-2}	9.941×10^{-2}	5	1.885×10^{-1}	1.885×10^{-1}	5	5
H-12	1.553×10^{-1}	1.553×10^{-1}	3	-1.462×10^{-1}	1.462×10^{-1}	8	5.5
WIPP-11	1.502×10^{-1}	1.502×10^{-1}	4	-9.576×10^{-2}	9.576×10^{-2}	9	6.5
WIPP-13	2.199×10^{-1}	2.199×10^{-1}	2	-6.001×10^{-2}	6.001×10^{-2}	11	6.5
WIPP-25	-4.109×10^{-2}	4.109×10^{-2}	13	2.250×10^{-1}	2.250×10^{-1}	1	7
USGS-4	-5.631×10^{-2}	5.631×10^{-2}	11	-1.931×10^{-1}	1.931×10^{-1}	4	7.5
AEC-7	7.392×10^{-2}	7.392×10^{-2}	8	7.241×10^{-2}	7.241×10^{-2}	10	9
H-11b4	-5.339×10^{-2}	5.339×10^{-2}	12	1.734×10^{-1}	1.734×10^{-1}	6	9
H-4b	3.852×10^{-2}	3.852×10^{-2}	14	-1.627×10^{-1}	1.627×10^{-1}	7	10.5
H-5b	-7.394×10^{-2}	7.394×10^{-2}	7	1.670×10^{-4}	1.670×10^{-4}	17	12
H-10c	6.302×10^{-2}	6.302×10^{-2}	9	-1.243×10^{-2}	1.243×10^{-2}	16	12.5
H-17	5.662×10^{-2}	5.662×10^{-2}	10	3.295×10^{-2}	3.295×10^{-2}	15	12.5
H-7b1	-1.089×10^{-2}	1.089×10^{-2}	16	5.448×10^{-2}	5.448×10^{-2}	12	14
H-9c	-2.776×10^{-2}	2.776×10^{-2}	15	5.202×10^{-2}	5.202×10^{-2}	13	14
H-2b2	2.715×10^{-3}	2.715×10^{-3}	17	3.768×10^{-2}	3.768×10^{-2}	14	15.5

The results in Table 4-1 are sorted by the average rank between the steel-cased wells for the K_{eff} / $\log_{10}$ travel time correlation (see Figure 4-5) and the head / $\log_{10}$ travel time correlation (see Figure 4-8). A smaller rank number indicates a higher relative correlation in the two cases. Wells with large rank numbers are wells that are located in areas with less correlation between model inputs and outputs.

4.5. Model Correlation Summary

Here, we approximate a true sensitivity analysis using a sampling-based correlation analysis. These sampling-based correlation coefficients are consistent with, but different from, the average sensitivities calculated as numerical derivatives, as was illustrated in (McKenna, 2004). The advantage of this approach to approximating sensitivity is that it is computationally efficient. The sampling-based sensitivity coefficients require an ensemble of calibrated K_{eff} fields, which is computationally burdensome, but they provide an integrated measure of correlation to all of the calibrated K_{eff} fields at once. This approach captures the non-uniqueness of the K_{eff} calibration by using all 100 calibrated fields and also provides a measure of output sensitivity to the input variables at all locations within the domain.

Application of the sampling-based sensitivity approach to the Culebra shows distinct regions of higher and lower correlation to travel time with respect to both calibrated heads and K_{eff}. For travel time sensitivity with respect to heads, the regions of high and low sensitivity are broad and fall mainly within and directly to the south of the WIPP site. Results of travel time sensitivity with respect to K_{eff} show regions of high and low sensitivity that are considerably more localized. The two regions with the greatest absolute correlation for both K_{eff} and model-predicted head are near the C-2737 release point, between the release point and the southern edge of the WIPP LWB, and immediately upstream (north) of the C-2737 release point. These regions of high or low sensitivity can be identified and targeted for additional head monitoring wells and measurements of K_{eff}. Results of the spatial sensitivity calculations are combined with results of other approaches to monitoring well optimization in the following section

4.6. Model Correlation Run Control Summary

4.6.1. Model file checkout and pre-processing run control (Linux)

The model inputs (transmissivity and anisotropy) and outputs (head) were checked out from the `Tfields` and `MiningMod` CVS repositories that are accessible from the PA Linux cluster (`alice.sandia.gov`). The same files exist for each calibrated model realization (see Table 4-2), and they exist in 100 subdirectories with the names `rnnn`, where *nnn* is a three-digit number corresponding to the realization name (the numbers range from 001 to 999 and are therefore non-contiguous). The Bash shell script `checkout_model_data.sh` (Section 8.4.1) checks the required files out of CVS (lines 9, 18, 49, and 51), does some manipulation of the directories to simplify the resulting directory structure (lines 30 through 44), and converts the binary MODFLOW head files to ASCII arrays (line 67). Finally the entire file tree of input and output files are zipped up to simplify transfer to Windows from Linux (see lines 72 to 75 – located on the CD in the `analysis\model_correlation` directory inside the `model_files.zip` archive).

Table 4-2. Model files from each calibrated MODFLOW realization

Model File	Description
`rnnn/modeled_K_field.mod`	calibrated transmissivity field for realization r*nnn*
`rnnn/modeled_A_field mod`	calibrated anisotropy field for realization r*nnn*
`rnnn/modeled_head.hed`	model-generated steady-state head for realization r*nnn*
`rnnn/dtrk.out`	particle tracking results for realization r*nnn*
`rnnn/{Update,Update2,}`	empty file indicating if the realization originated in the `Update` or `Update2` directories (potentially no file).

The Python script `head_bin2ascii.py` (Section 8.4.2) is used on Linux to convert the binary MODFLOW head files (saved as record-based Fortran unformatted files) to ASCII arrays, based upon the knowledge of the type of data to be expected in the files. Lines 4 through 54 of this Python script define the `FortranFile()` class which is used to encapsulate the functionality needed to read the binary files. Two utility functions (`reshapev2m()` and `floatmatsave()`) are defined in lines 56 through 70. The structure of the MODFLOW binary head files are quite simple; each files is comprised of a single header record and a single array of single-precision head values unwrapped as a vector. The header record contains integers related to the size of the model array subsequently saved, and the head array is saved after that. The Python script reshapes the vector into an array and writes it to an ASCII file in floating point format (line 111).

4.6.2. Partial correlation analysis run control (Windows)

The utility Python script `load_model_data.py` (Section 8.4.3) is called as a library from two other Python scripts to load the 100 realizations of MODFLOW input and output files. This script loops over the 100 r*nnn* subdirectories reading hydraulic conductivity, horizontal anisotropy, travel time to the WIPP LWB, and the model-generated steady-state heads (see Table 4-2). The script then takes the $\log_{10}$ of the K, A and travel times, and defines a logical mask (`wippmask`) for addressing a subset of the model domain only including the WIPP LWB and a buffer of cells surrounding it (lines 58 to 62).

Once the zip archive of ASCII model files is transferred to Windows, the analysis begins with the Python script `export_pcor_inputs.py`, (Section 8.4.4) which loads the results of the 100 realizations (importing the functionality from the `load_model_data.py` script at line 2), saving the results to two large matrices to be processed in R for partial correlation analysis. The matrices saved include the travel time to the WIPP LWB (a single column) concatenate with the head or K_{eff} matrices from a region including the WIPP LWB and a 1,500-m buffer surrounding the LWB, due to a limitation of the approach. A correlation matrix comprised of every model parameter (or head) to every other parameter (or head) is made, the full 307×284=87,188 model cells would result in a correlation matrix with 7,601,921,721 entries (over 56 gigabytes at double precision). The smaller subset of model parameters (WIPP LWB is 64 100-m elements wide and tall + a buffer of 15 elements on each side) results in a large correlation matrix that only has 78,092,569 entries (just under 596 megabytes at double precision). The R script `compute_partial_correlations.R` (Section 8.4.5) simply reads in the matrices saved by the Python script, performs the partial correlation analysis using optimized and numerically stable algorithms (a scaled pseudo-inverse, rather than the simpler – but numerically unstable – matrix inverse), then writes the partial correlation between travel time to the WIPP LWB and either K_{eff} or head in each model cell inside the area surrounding the WIPP site (the last column of the resulting partial correlation matrix – see lines 12 and 19). Output from `export_pcor_inputs.py` and output from `compute_partial_correlations.R` are saved on the CD, along with the intermediate files, in the `analysis\model_correlation\output\` directory.

4.6.3. Correlation analysis run control (Windows)

The Python script `spearman_rank_coefficient.py` (Section 8.4.6) also loads the model data using the `load_model_data.py` module, and also loads the results of the partial correlation calculation done in R (lines 31 to 39). In the loop from lines 41 to 62, the script computes the head vs. travel time and K_{eff} vs. travel time correlations across the 100 realizations at each element in the model domain. The partial correlation results and standard correlation results are then plotted in several forms for figures in the text (Figure 4-1, Figure 4-2, Figure 4-5, Figure 4-6, Figure 4-8, and Figure 4-9), and saved as matrices for later analysis (files located on CD in the `analysis\model_correlation\output\` directory).

5.0 Combining Approaches

This section discusses the combination of the three approaches towards quantifying both the quality of proposed monitoring well locations, and the relative importance of existing steel-cased well locations

5.1. One Additional Monitoring Location

Three different approaches to identifying optimal additional monitoring well locations have been computed. In the case of the geostatistical estimation variance reduction approach, the change in the estimation variance can be computed after adding more wells. However, the results of this approach leads to many locations with high propensity to reduce overall estimation variance and the results of this approach do not uniquely identify one or even a handful of optimal locations for additional wells. To some extent, combining all three of the approaches into a single map reduces this non-uniqueness. Here, the three approaches are combined to provide a combined score, S_c, that identifies the best locations for new wells. The higher the value of the score is, the better that location is for a new well.

The combined score is the sum of the three different fields calculated in the three monitoring approaches scaled appropriately and combined as

$$S_c = \sigma^2_{OK} + A_r + |r_s| \quad \textbf{(18)}$$

The three components of S_c are the relative change in the average ordinary kriging variance, σ^2_{OK}, the change in the average triangle interior angle ratio, and the absolute value of the correlation coefficient between travel time to the WIPP boundary and either the estimated transmissivity or head, r_s, each compared relative to the 2007 network. The absolute value of the rank correlation coefficient is used since both positive and negative correlations are of equal importance for locating new monitoring wells. The triangle interior angle ratio is handled differently, because for that metric, negative values are poor places to locate wells. Figure 5-1 shows histograms of the fields that contribute to S_c.

Four different combinations of the input fields are considered, requiring six total input fields. The resulting fields will be comprised of the following four cases:

1. Δ mean kriging variance + Δ mean triangle angle ratio + ρ K_{eff},
2. Δ mean kriging variance + Δ mean triangle angle ratio + ρ head,
3. Δ median kriging variance + Δ median triangle angle ratio + ρ K_{eff},
4. Δ median kriging variance + Δ median triangle angle ratio + ρ head;

either the correlation of travel times to head or Keff are used, and either the mean or median relative kriging and triangle metrics are used.

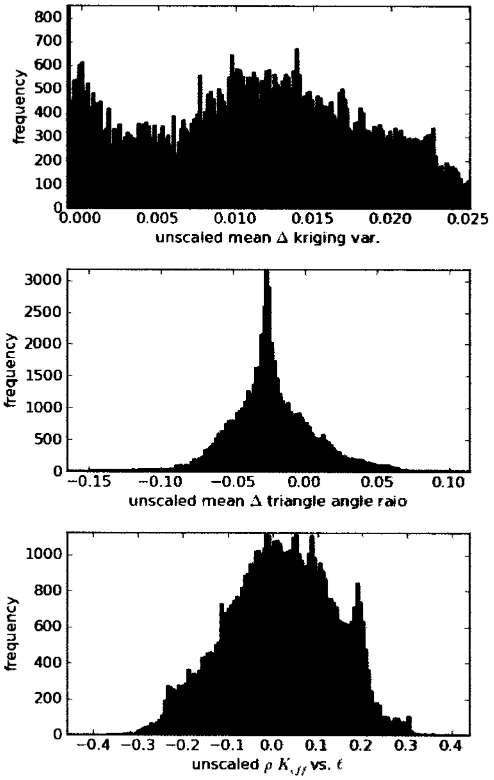


Figure 5-1. Histograms of each component of S_c, before applying scaling.

The three metrics in S_c are already unitless, as reported in their individual previous sections. The results are rescaled here to give them common ranges (a width of unity). The rescaling is accomplished as

$$S_c = \frac{\sigma_{OK}^2 - \min(\sigma_{OK}^2)}{\max(\sigma_{OK}^2) - \min(\sigma_{OK}^2)} + \frac{A_r}{\max(A_r) - \min(A_r)} + \frac{|r_s| - \min(|r_s|)}{\max(|r_s|) - \min(|r_s|)} \tag{19}$$

where the `max()` and `min()` operators define the maximum and minimum values of the different components of the combined score across the entire calculation domain. The triangle metric is handled differently than the others, as it is not shifted to a zero-based origin (no "–min(A_r)" in the numerator); this was done because the negative values of change with respect to the interior angle metric indicate that adding a well at a given location would degrade the quality of the overall average well network.

Histograms of the scaled components to S_c are plotted in Figure 5-2. The top row of plots for the relative change in the kriging variance are simply scaled to the [0,1] interval (they already had a distribution with a minimum value of zero). These distributions are slightly skewed towards 0.0, more so for the change in the median kriging variance. In the second row of plots for the relative change in the triangle angle ratio are scaled to a unit width interval, but they are not shifted (now covering approximately the [-0.6,0.4] interval). These distributions are centrally distributed about a non-zero negative value. The absolute value of the correlation coefficient distribution (bottom row) is now strongly skewed towards 0.0, after taking the absolute value (the original distribution in Figure 5-1 was roughly symmetric about 0.0).

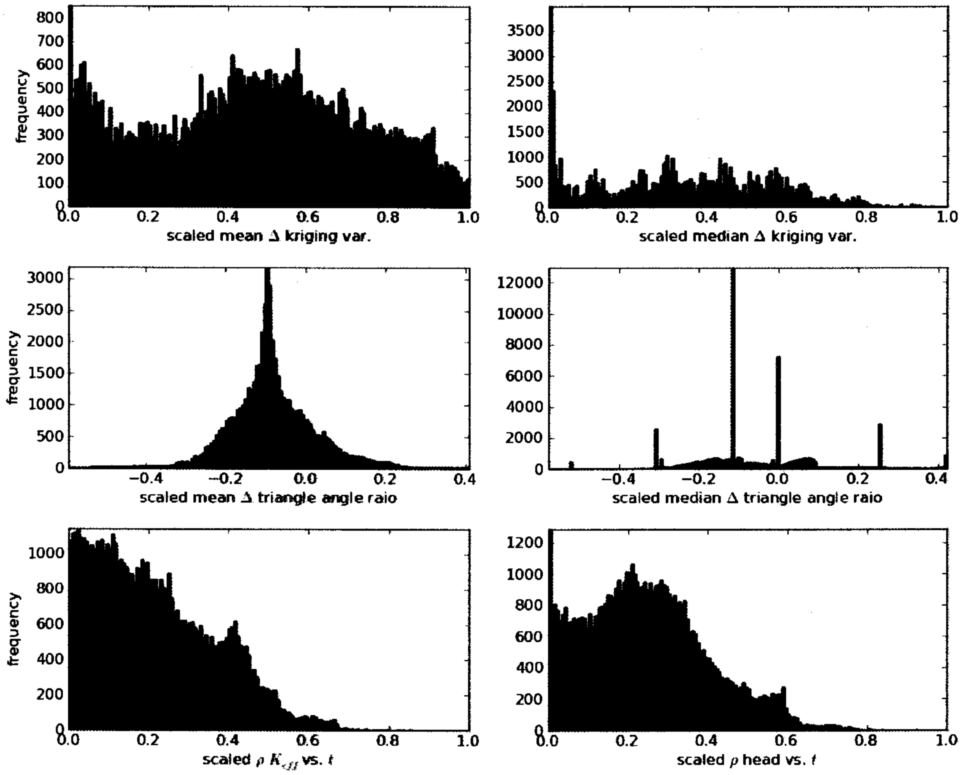


Figure 5-2. Histograms of each component of S_c, after applying scaling

Other than the scaling, one additional change is made to the fields for the mean and median kriging variance. These fields are computed on a two times coarser grid than the triangle angle ratio or the correlation coefficients. The use of this multiplier is to accommodate the long run times for the kriging calculations. The fields resulting from the kriging calculation are copied onto the finer mesh by copying each of the kriging matrix cell's values (without averaging) into the four cells covering the same area in the finer grid. This process is similar to how values were copied from the MODFLOW to SECOTP2D modeling grids in the CRA 2009 PABC calculations (see Kuhlman, (2010a), Appendix A, §1.7).

5.1.1. Results

The theoretical minimum and maximum combined score values for any location in any of the four cases are -0.6 and 2.4 respectively. An image map of the combined score value for case 1 is shown in Figure 5-3. The resulting field is light colored (low score) in most areas surrounding the WIPP LWB and near monitoring wells in the 2007 well network. The resulting image for case 2 is shown in Figure 5-4. The resulting distribution of the case 2 results has lower low values (some negative values, indicated in yellow), and the dark blue location, indicating a good possible location, are more localized than for the means of the same variables (Figure 5-3).

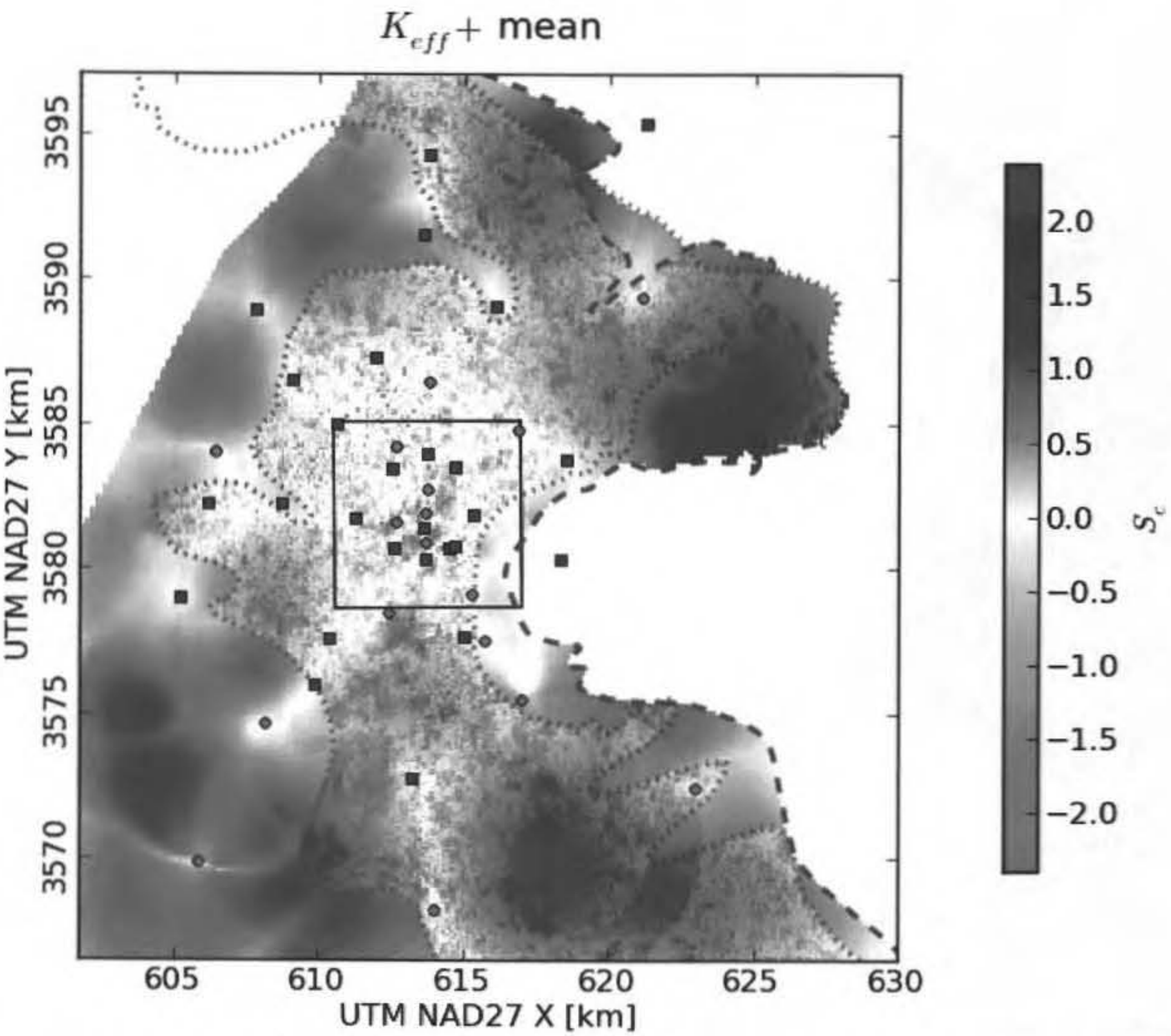


Figure 5-3. Combined scaled results for case 1, using mean Δ kriging variance, mean Δ triangle shape metric, and correlation between K_{eff} and $\log_{10}$ particle travel time. Fiberglass-cased wells are green squares, steel-cased wells are red circles; Salado dissolution and Rustler halite margins are dashed lines; WIPP LWB is black square.

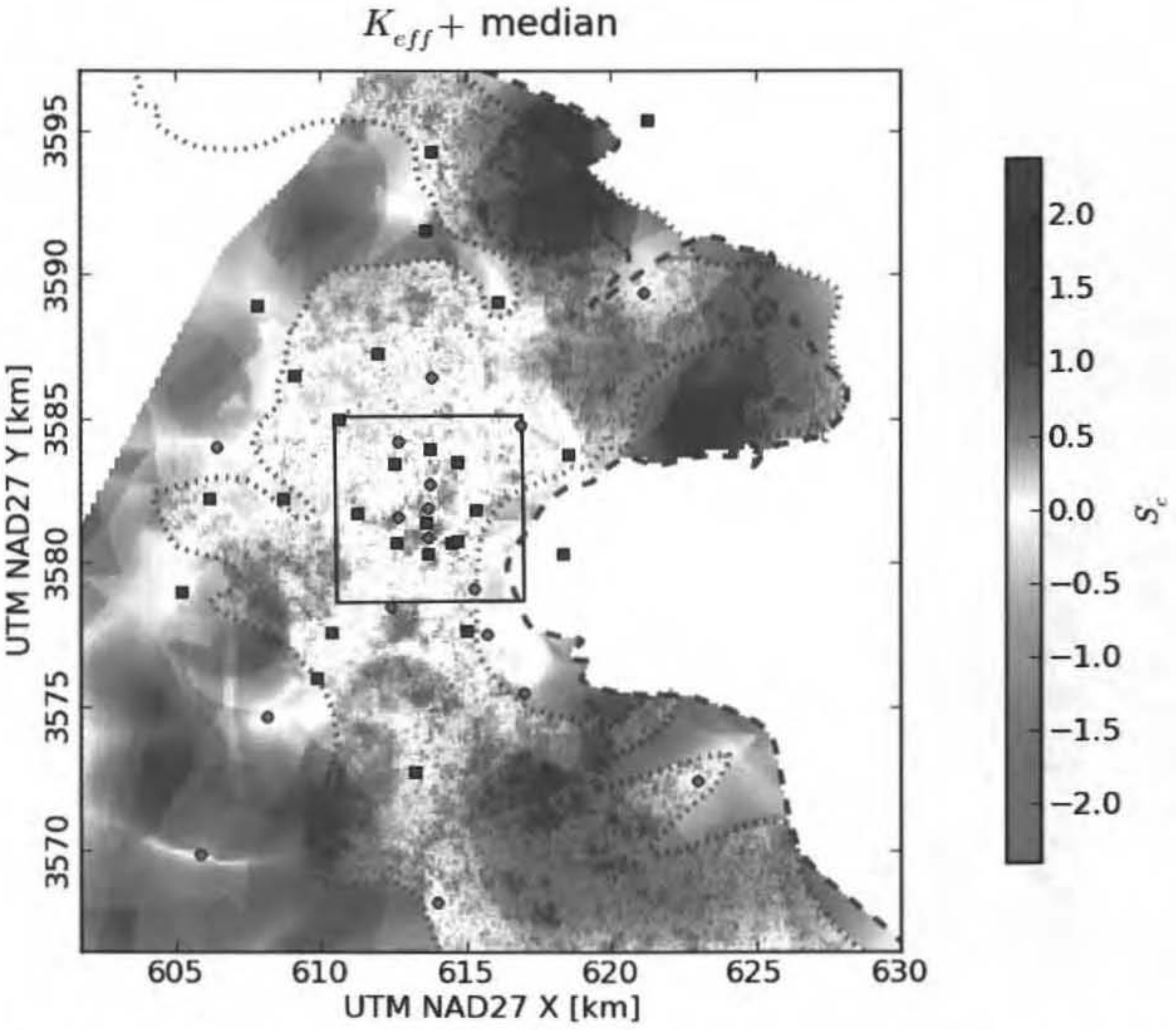


Figure 5-4. Combined scaled results for case 2, using median Δ kriging variance, median Δ triangle shape metric, and correlation between K_{eff} and $\log_{10}$ particle travel time.

The image map showing the results for case 3 is plotted in Figure 5-5. These results are smoother than cases 1 and 2, as was the case for the correlation coefficients that these results contain. There are more isolated possible locations inside the WIPP LWB in case 3 than in cases 1 and 2 (blue areas). The image map showing the results for case 4 is plotted in Figure 5-6. Similar to the differences observed between cases 1 and 2 (Figure 5-3 and Figure 5-4), case 4 has more negative locations (yellow), and the high values outside the WIPP LWB (blue) are more localized than the case considering the mean parameters.

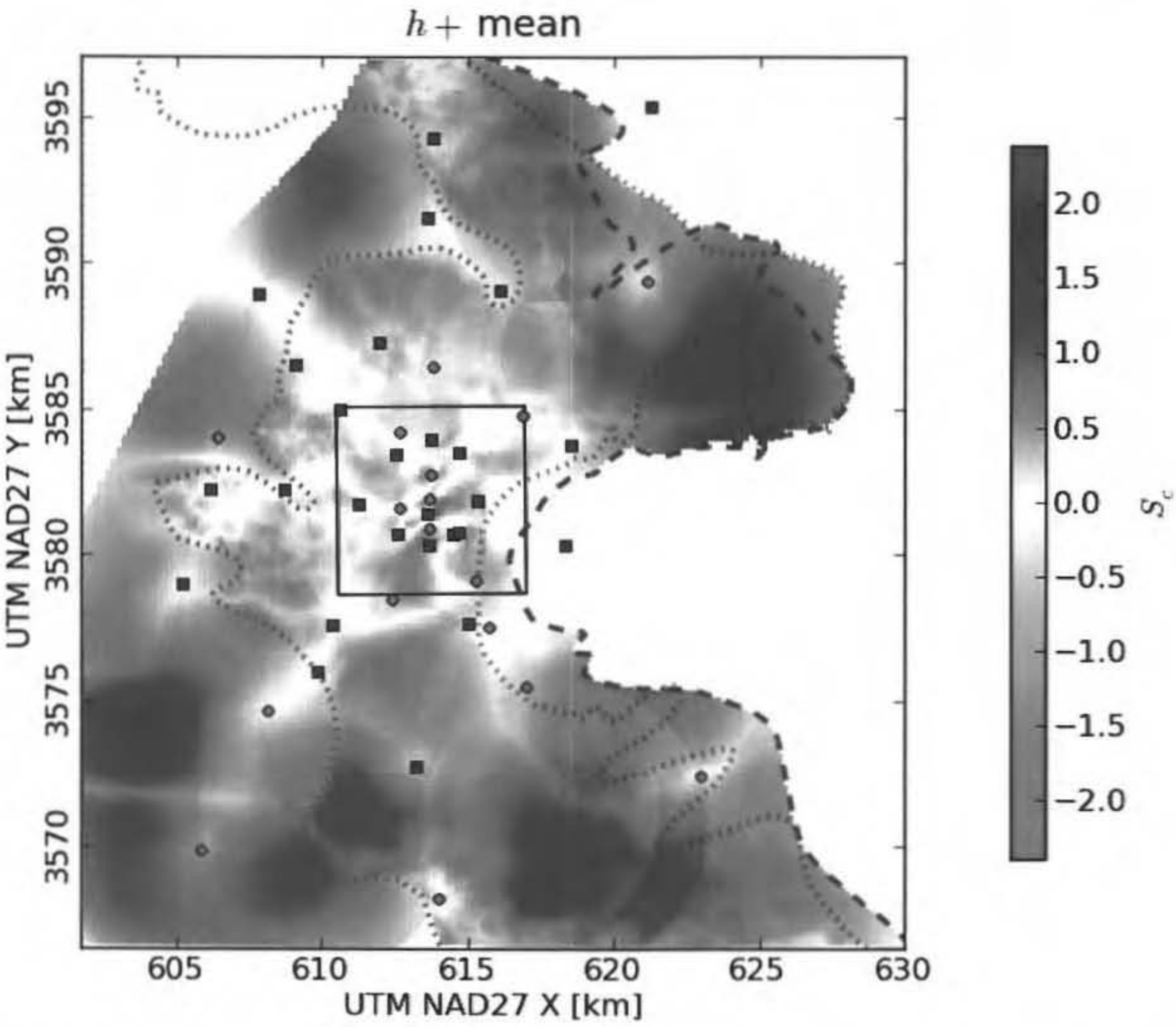


Figure 5-5. Combined scaled results for case 3, using mean Δ kriging variance, mean Δ triangle shape metric, and correlation between modeled head and $\log_{10}$ particle travel time.

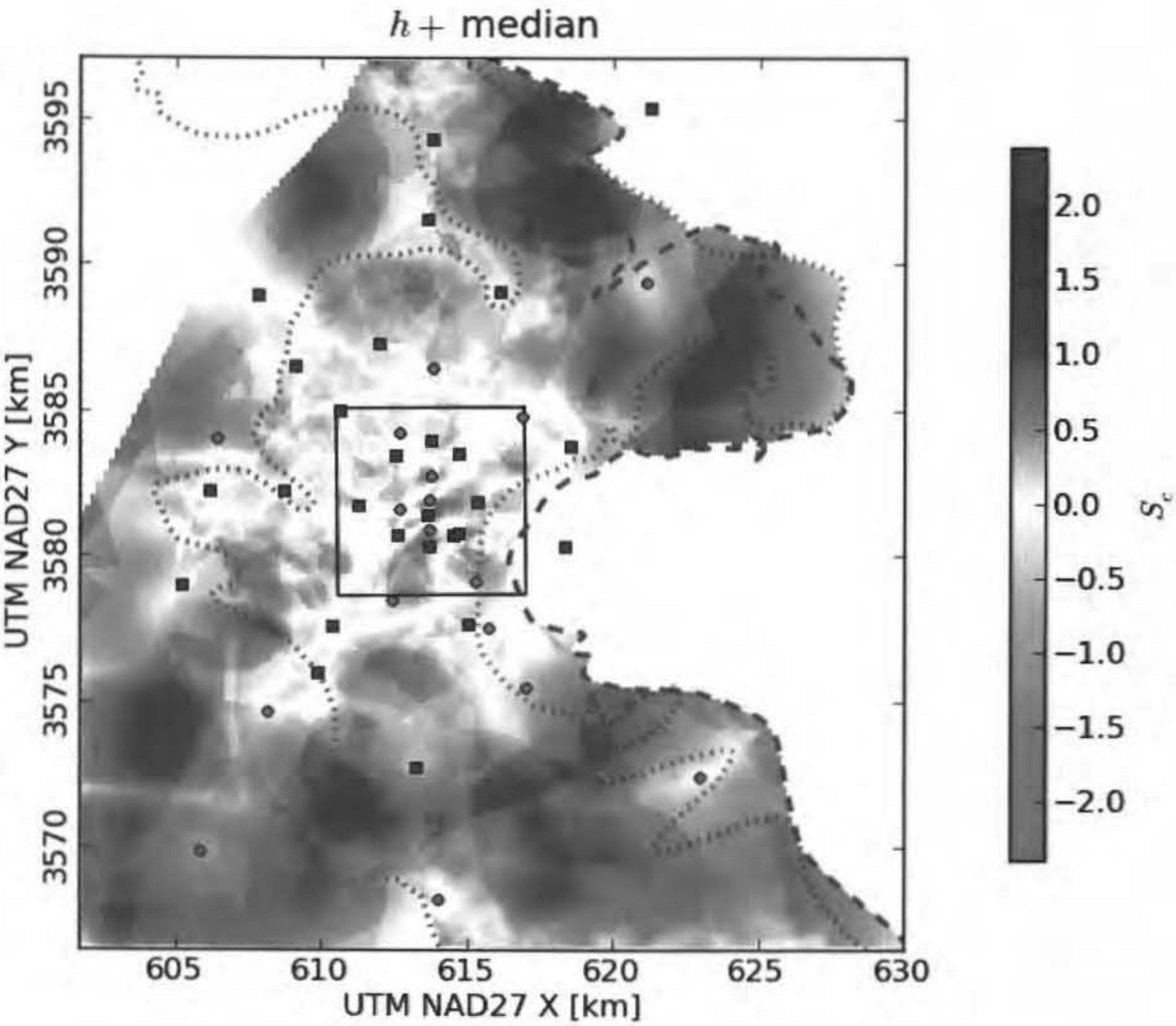


Figure 5-6. Combined scaled results for case 4, using median Δ kriging variance, median Δ triangle shape metric, and correlation between modeled head and $\log_{10}$ particle travel time.

The results of cases 3 and 4 indicate there are areas resulting in relatively high S_c scores inside the WIPP LWB, specifically in the south-central (north of H-4b) and east-central portions (east of the WIPP site buildings). The results in cases 1 and 2 do not indicate any significant high S_c score areas inside the WIPP LWB. This indicates that the methods considered here indicate areas inside the WIPP LWB might be useful for head-monitoring locations regarding head, but additional T values from testing new wells might not be as necessary.

The results outside the WIPP LWB are more focused in cases 2 and 4 (Figure 5-4 and Figure 5-6), where the medians, rather than the means are used. In these cases the two areas with the highest S_c scores (dark blue to purple) are north of the WIPP site between SNL-1 and AEC-7, as well as south of the WIPP site between the DOE Gnome-Coach site (USGS-4) and SNL-12.

In cases 1 and 3, the best new locations for wells would be east of the WIPP LWB, specifically east of SNL-8 and southeast of AEC-7, and south of the WIPP LWB between H-9c and H-10c, also north and west of the DOE Gnome-Coach site (USGS-4).

5.2. Remove One Steel Well

The results of the remove-one-well analyses from the previous sections were plotted together in Figure 5-7. Symbols are scaled according to numerical rank, small rank number correlating to small symbol size.

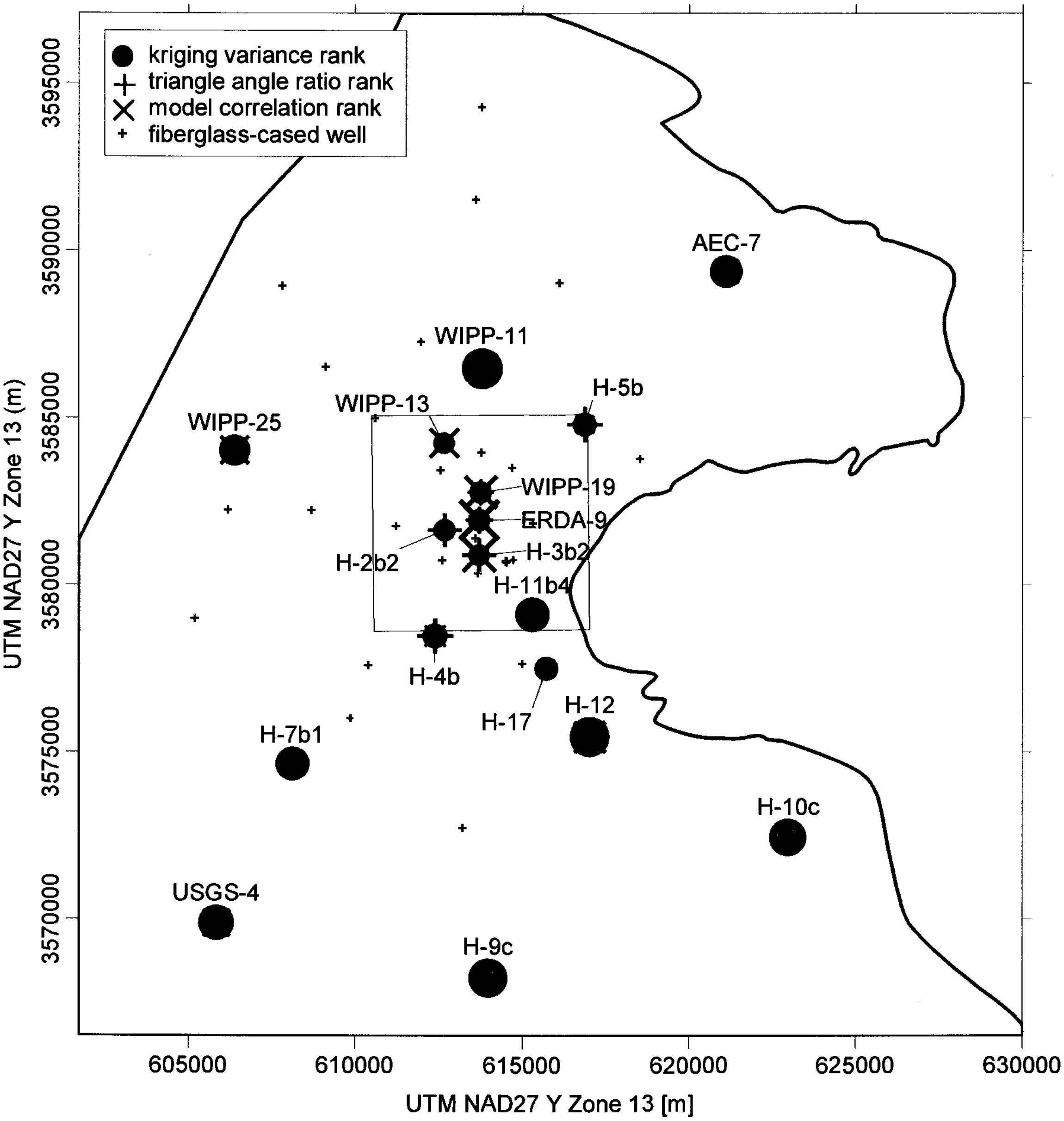


Figure 5-7. Composite plot of steel-cased well rankings from previous sections. Large symbols correspond to greater relative importance for each of the three measures.

Figure 5-7 shows the trend in the kriging variance reduction (filled red circles), where wells inside the WIPP LWB typically have a poor rank, and therefore removing them will have little impact on the kriging variance averaged across the entire model domain (H-11b4 being a slight exception). The results of the triangle gradient estimator maximization process (blue crosses) shows the wells indicated as being most valuable are located in the central and south-east portion of the domain. Aside from the locations inside the WIPP LWB, the wells with high rank regarding the gradient estimator approach are steel wells that are not very near fiberglass-cased wells (H-10c, H-9c, H-12, H-4b, H-5b and AEC-7). The model correlation results are shown as green X's, with the distribution of important steel-cased wells being a more scattered about the MODFLOW model area. These results do not depend on current well locations, aside from the fact that the current wells were used to calibrate the model. ERDA-9 and H-3b2 are in locations where head and Keff are correlated to the model predicted travel time to the WIPP LWB, as would generally be expected. USGS-4, H-12, WIPP-11 and WIPP-25 also have high ranks based on correlation of model results, which are more difficult to explain. The high ranks of these locations are likely due to spurious correlation between the data used in the correlation.

5.2.1. Summary

Three different approaches to monitoring network optimization were used to identify locations where additional wells could improve the network. These three approaches identify: 1) locations where additional wells will reduce the uncertainty in predicting head values at locations without wells; 2) locations where an additional well will allow for maximum improvement in the ability of the existing monitoring well network to identify changes in the magnitude and orientation of the hydraulic gradient by maximizing the quality of local gradient estimators that can be created; and 3) locations where the performance assessment measure of advective travel time to the WIPP boundary is most correlated to the value of head or transmissivity.

These three approaches to monitoring network design all attempt to optimize the network with respect to different objectives. Combining all three of these approaches is done by rescaling each of the raw maps of estimation variance, additional local gradient estimators and sensitivity to have a range (minimum to maximum) of 1.0 and to be unitless. The final combined score maps show the best places to locate additional wells to meet all three objectives when each of the three objectives is given equal weight. The higher the combined score is, the better the location is for a new well. The final combined maps are similar with some minor, but important differences depending on whether or not sensitivity with respect to head or K_{eff} is included in the combined score.

5.3. Method Combination Run Control

The Python script `combine_plot_methods.py` (Section 8.5) loads in the results of the previous three sections, normalizing them to the range $0 \leq x \leq 1$ and summing them up to create composite plots (Figure 5-3 through Figure 5-6) illustrating the optimum location for additional monitoring wells. Histograms of each component before (Figure 5-1) and after (Figure 5-2) scaling are also made for assessing the relative effect each of the three components has on the overall result.

6.0 Conclusions

A set of measurements made in 42 head monitoring wells in the Culebra within and surrounding the WIPP from 2007 were used in this analysis. This set of observations mostly coincided with the freshwater heads used for steady-state calibration of the CRA 2009 PABC MODFLOW model. This head-monitoring network provided the input data for three different approaches to optimizing the monitoring well network. Optimization is interpreted broadly here to include both the identification of new locations where wells could be added to the network to meet some objective and also identification of existing wells that could be removed from the monitoring network as they provide redundant information. The three different approaches to monitoring network optimization examined here are: 1) geostatistical variance reduction; 2) local gradient estimation using combinations of three wells; and 3) sampling-based spatial sensitivity coefficients. In short, the gradient has not changed significantly since the 2004 analysis.

6.1. Summary of Calculations

Geostatistical variance reduction is a fairly common optimization approach (e.g., Rouhani, (1985)) that exploits several properties of the kriging variance to identify new locations where a well could be added to an existing monitoring network to provide the greatest reduction in estimation variance. The same approach can be used to determine existing wells that, upon removal from the monitoring network, provide the smallest increase in the overall estimation variance. Kriging provides an ideal approach to these calculations as the estimation variance calculated through kriging is only a function of the data configuration and not the data values. Therefore, the estimation variance reduction/increase for the addition/removal of a new well can be calculated prior to adding/removing that well from the network. This calculation assumes that the variogram calculated for the head, or residual, values in the network does not change with the addition/removal of a well.

Application of the geostatistical estimation variance calculations to the Culebra network shows that there are many locations where a well can be added to the network that will produce a maximum reduction in the average estimation variance. These locations are all outside of the WIPP site boundaries and the majority of these locations are near the extremities of the MODFLOW model domain. Adding new wells within the WIPP site boundary will not have a significant impact on the estimation variance. The geostatistical estimation variance calculations were also applied to the problem of determining which existing wells to remove from the network. Results for this problem can easily be calculated; however, for removal of more than one well at a time, it is necessary to know what combinations of wells need to be removed to make the problem tractable. Four different base cases were run here and the results show that simultaneous removal of WIPP-13 and another steel-cased well makes an insignificant change in the estimation variance relative to the full 42-well network, while removal of either of other pairs of steel-cased wells has a significant impact (Table 2-5). Averaged across the entire model domain, the removal of wells USGS-4, H-9c, H-10c and AEC-7 would have the largest effect (Figure 2-14). Averaged across the WIPP LWB, removal of wells H-4b, H-5b, H-17 and H-7b1 would have the largest effect (Figure 2-16).

A Delaunay triangulation of the wells in the 2007 monitoring network provides a platform for estimating the quality of triangles as gradient estimators. The interior angle ratio (max angle / min angle) is used as a metric for quantifying the quality of a given arrangement of wells. Local gradient estimators were used to identify the best places to locate additional monitoring wells and the existing wells that could be removed from the network with the smallest impact on the ability of the network to estimate in the gradient.

Results of the calculations to identify locations for additional monitoring wells show that new wells should be located outside of the WIPP site. Additional monitoring wells could optimally be placed north and east of the WIPP LWB, or south between existing wells (Figure 3-10). The well removal calculations were done by removing one well at a time from each of three base case scenarios. Removal of wells in the western portion of the domain, outside the WIPP LWB, has little effect on the quality of the network from the point of view of the triangular gradient estimators (Table 3-1 and Figure 5-7). The removal of steel-cased wells in the southeast or inside the WIPP LWB would have the largest effect on the overall network.

The third approach to monitoring network optimization explored in this report is that of using model correlation to identify locations for new wells where some model output of interest (e.g., travel time) is most sensitive to the transmissivity or head at that location. These correlation coefficients are calculated through a sampling-based technique across 100 calibrated K_{eff} fields. The sampling-based sensitivity coefficients are shown as a map of the sensitivity of the travel time from the repository to the WIPP site boundary with respect to head and transmissivity (Figure 4-5 and Figure 4-8). The results with respect to head show a smoothly varying sensitivity field with large regions of positive and negative correlation between head and travel time. The results with respect to K_{eff} have much more localized regions of positive and negative correlation with travel time being most sensitive to transmissivity at a location directly south of the WIPP site boundary. It is noted that increased knowledge of the spatial variation of the Culebra transmissivity is not a goal of the long-term monitoring network, but transmissivity is an input to the T field calibration process used as input to further PA calculations.

As a final step, the results of the geostatistical estimation variance calculations, the local gradient estimation and the spatial sensitivity coefficients were combined into two “combined score” maps. These maps show, on a normalized scale, the best locations to locate new monitoring wells. In general, these areas are outside of the WIPP site.

6.2. Reexamination of Monitoring Goals

The different purposes, goals and factors that must be taken into account in the design of the Culebra long-term monitoring network were stated in Section 1.2. These goals come from a variety of sources, mainly the state and federal regulatory bodies with WIPP oversight and the ability of the network to provide needed inputs to PA models. Practical factors impacting network design require that the total number of wells in the monitoring network be minimized and that certain wells be retained in the network. The monitoring network should also serve as a vehicle to provide new information to the hydrologic and geologic conceptual models.

The first monitoring network goal is to allow for *determination of the direction and rate of groundwater flow across the WIPP site*. Triangular gradient estimators were developed to meet this goal (Section 3.0). Independently obtained head measurements cannot by themselves determine the direction and magnitude of the hydraulic gradient. For a confined aquifer with a mainly two-dimensional flow pattern, head measurements at three separate locations are necessary to determine the orientation and magnitude of the gradient. Small equilateral triangles are typically the best for estimating gradients over an area from point head measurements, assuming the observed heads result in a gradient large enough to measure over the ambient noise in the system.

The second monitoring goal is to *provide data needed to infer causes of changes in water levels.* Detecting water level change can be done in a single well and an implicit requirement to meet this goal is that there are enough wells in key locations both within and around the WIPP site to detect any water level changes. Checking for the adequate distribution of wells in and around the WIPP site is accomplished using a geostatistical variance reduction approach (Section 2.0). These calculations identify where additional wells are needed and which existing wells can be removed from the network. After a change in water level is detected, the cause of that change must be inferred. There must be enough wells in the proper configuration to infer the cause of a change. The geostatistical variance reduction and three-point estimator approaches to monitoring network design provide networks that maintain enough well density with the proper configurations to infer causes of changes.

The third goal is that the *monitoring network must provide spatially distributed head data adequate to allow both defensible boundary conditions to be inferred for Culebra flow models and defensible calibration of those models.* This goal is related to the previous one in that a network that provides enough wells with the spatial distribution and configuration to detect and infer causes of changes in water levels should also provide the data necessary to infer boundary conditions and calibrate Culebra flow models. Therefore both the geostatistical variance reduction and the gradient estimator approaches and the data gaps and redundancies that they identify apply to this goal as well. Additionally, a third approach to monitoring network design based on model correlation analysis was developed to explicitly incorporate the results of calibrated groundwater flow models directly into the monitoring network design. The set of calibrated groundwater models used as the basis of this third approach incorporates the latest geologic and hydrologic conceptual models. This approach to monitoring network design defines areas along the boundaries and within the groundwater flow model where the model results are most sensitive to the calibrated values of head and transmissivity. Regions of high sensitivity are targeted for future well locations.

In addition to meeting these three goals, a number of other factors were considered in the design of the monitoring network. These included preserving the locations of existing fiberglass and steel-cased wells, identifying wells that provide redundant information, incorporating current hydrologic and geologic conceptual models and identifying locations where questions in the conceptual models can be addressed and/or locations where the groundwater flow models used in PA calculations are correlated to the local values of head and transmissivity. Both the geostatistically-based variance reduction approach and the three-point estimator approach to monitoring network design explicitly considered minimization of the number of wells in the monitoring network through removal of existing wells. Tradeoffs between the minimization of the wells in the network and the ability of the network to provide information on changes in heads were examined. The monitoring network design done here was focused on optimization approaches that are readily quantified into different objective functions. Meeting certain, less easily quantified, factors such as locations where conceptual model questions can be addressed is more difficult and the monitoring networks designed here did not explicitly address this factor.

The results of the calculations done to meet the monitoring goals and the other factors are combined into a series of maps (Figure 5-3 through Figure 5-6) that show the best locations for adding wells to the monitoring network. A map has also been created showing which existing steel-cased wells are the most and least important to maintain within the monitoring network (Figure 5-7).

7.0 Bibliography

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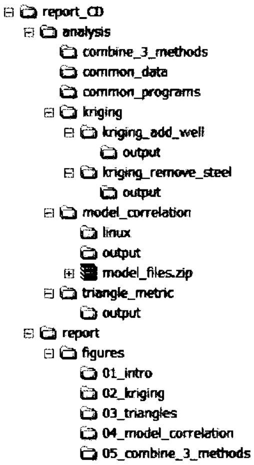
8.0 Run Control Script Listings

This appendix lists the source code for the scripts written for and used in this analysis report, and documents them to allow their reasonable verification and future use, according to NP 19-1. The scripts listed in this section neither model physical phenomena nor solve differential equations that model physical phenomena. Rather they are utility codes that process inputs and summarize outputs for other modeling codes (i.e., KT3D). The scripts are heavily commented (green text) to allow the flow of the execution to be easily followed.

8.1. Listing of Files Included on CD

The following directory listing (Table 8-1) corresponds to the directory tree given after it in Figure 8-1.



```
⊟ report_CD
  ⊟ analysis
      combine_3_methods
      common_data
      common_programs
    ⊟ kriging
      ⊟ kriging_add_well
          output
      ⊟ kriging_remove_steel
          output
    ⊟ model_correlation
        linux
        output
      ⊞ model_files.zip
    ⊟ triangle_metric
        output
  ⊟ report
    ⊟ figures
        01_intro
        02_kriging
        03_triangles
        04_model_correlation
        05_combine_3_methods
```

Figure 8-1. Directory Tree of CD

Table 8-1. CD Directory listing

```
C:\report_CD>dir /S /TC
 Volume in drive C is DriveC
 Volume Serial Number is 542A-10F7

 Directory of C:\report_CD

04/10/2010  10:50 AM    <DIR>          .
04/10/2010  10:50 AM    <DIR>          ..
04/07/2010  12:42 PM    <DIR>          analysis
04/07/2010  12:42 PM    <DIR>          report
               0 File(s)              0 bytes

 Directory of C:\report_CD\analysis

04/07/2010  12:42 PM    <DIR>          .
04/07/2010  12:42 PM    <DIR>          ..
04/07/2010  12:51 PM    <DIR>          combine_3_methods
04/07/2010  12:44 PM    <DIR>          common_data
04/07/2010  12:50 PM    <DIR>          common_programs
04/07/2010  12:43 PM    <DIR>          kriging
04/07/2010  12:43 PM    <DIR>          model_correlation
04/07/2010  12:43 PM    <DIR>          triangle_metric
               0 File(s)              0 bytes

 Directory of C:\report_CD\analysis\combine_3_methods

04/07/2010  12:51 PM    <DIR>          .
```

Table 8-1. CD Directory listing

```
04/07/2010  12:51 PM    <DIR>          ..
04/11/2010  12:10 PM            10,136 combine_plot_methods.py
04/11/2010  04:11 PM               997 composite_remove_one_steel.dat
               2 File(s)         11,133 bytes

 Directory of C:\report_CD\analysis\common_data

04/07/2010  12:44 PM    <DIR>          .
04/07/2010  12:44 PM    <DIR>          ..
04/10/2010  01:46 PM             1,776 2007_well_data.dat
04/10/2010  01:46 PM             1,823 2007_well_data_for_trend.dat
04/10/2010  01:46 PM             1,606 2007_well_data_for_triangles.dat
04/10/2010  01:46 PM             2,210 2007_well_data_with_names.dat
04/10/2010  01:46 PM               379 2007_well_names.dat
04/10/2010  01:46 PM               331 2007_well_names_for_triangles.dat
04/10/2010  01:46 PM             1,694 base_data.dat
04/10/2010  01:46 PM             5,415 h2_200711.bln
04/10/2010  01:46 PM             5,799 h3_200711.bln
04/10/2010  01:46 PM         1,395,622 model_cells_100_inside_totalbdry.dat
04/10/2010  01:46 PM           350,196 model_cells_200_inside_totalbdry.dat
04/10/2010  01:46 PM           156,766 model_cells_300_inside_totalbdry.dat
04/10/2010  01:46 PM            87,626 model_cells_400_inside_totalbdry.dat
04/10/2010  01:46 PM            56,668 model_cells_500_inside_totalbdry.dat
04/10/2010  01:46 PM            40,040 model_cells_600_inside_totalbdry.dat
04/10/2010  01:46 PM                64 model_domain_specs.dat
04/10/2010  01:46 PM               105 modflow_boundary.bln
04/10/2010  01:46 PM               189 no-flow-area-only.bln
04/10/2010  01:46 PM             8,532 total_boundary.bln
04/10/2010  01:46 PM               105 wipp_boundary.bln
              20 File(s)      2,116,946 bytes

 Directory of C:\report_CD\analysis\common_programs

04/07/2010  12:50 PM    <DIR>          .
04/07/2010  12:50 PM    <DIR>          ..
04/07/2010  12:45 PM           157,184 KT3D.EXE
04/07/2010  12:50 PM             1,807 redwhitemap.m
               2 File(s)        158,991 bytes

 Directory of C:\report_CD\analysis\kriging

04/07/2010  12:43 PM    <DIR>          .
04/07/2010  12:43 PM    <DIR>          ..
04/07/2010  12:49 PM    <DIR>          kriging_add_well
04/07/2010  12:50 PM    <DIR>          kriging_remove_steel
               0 File(s)              0 bytes

 Directory of C:\report_CD\analysis\kriging\kriging_add_well

04/07/2010  12:49 PM    <DIR>          .
04/07/2010  12:49 PM    <DIR>          ..
04/07/2010  12:52 PM               882 generate_model_cell_masks.m
04/07/2010  12:44 PM            11,658 krig_plus_one.py
04/07/2010  12:45 PM               327 kt3d_driver.bat
04/10/2010  01:47 PM    <DIR>          output
04/07/2010  12:46 PM                92 shared_data.py
               4 File(s)         12,959 bytes

 Directory of C:\report_CD\analysis\kriging\kriging_add_well\output

04/10/2010  01:47 PM    <DIR>          .
04/10/2010  01:47 PM    <DIR>          ..
04/10/2010  01:47 PM           262,416 addone_mod_results_corrcoef.dat
04/10/2010  01:47 PM           268,008 addone_mod_results_max.dat
04/10/2010  01:47 PM           263,199 addone_mod_results_mean.dat
04/10/2010  01:47 PM           263,393 addone_mod_results_median.dat
04/10/2010  01:47 PM           271,115 addone_mod_results_stdev.dat
04/10/2010  01:47 PM           262,416 addone_wipp_results_corrcoef.dat
```

Table 8-1. CD Directory listing

```
04/10/2010  01:47 PM           267,024 addone_wipp_results_max.dat
04/10/2010  01:47 PM           266,686 addone_wipp_results_mean.dat
04/10/2010  01:47 PM           262,416 addone_wipp_results_median.dat
04/10/2010  01:47 PM           268,976 addone_wipp_results_stdev.dat
04/10/2010  01:47 PM                26 base_stats.out
04/11/2010  03:43 PM           196,812 X.dat
04/11/2010  03:42 PM           218,680 Y.dat
              13 File(s)      3,071,167 bytes

 Directory of C:\report_CD\analysis\kriging\kriging_remove_steel

04/07/2010  12:50 PM    <DIR>          .
04/07/2010  12:50 PM    <DIR>          ..
04/07/2010  12:52 PM             1,696 krig_remove_one_steel.py
04/07/2010  12:52 PM             2,381 krig_remove_two_steel.py
04/10/2010  01:47 PM    <DIR>          output
04/09/2010  11:58 AM            64,512 remove_one_well_results2_2010.xls
04/09/2010  11:59 AM           164,352 remove_two_well_results3.xls
               4 File(s)        232,941 bytes

 Directory of C:\report_CD\analysis\kriging\kriging_remove_steel\output

04/10/2010  01:47 PM    <DIR>          .
04/10/2010  01:47 PM    <DIR>          ..
04/10/2010  01:50 PM             1,671 model_results_one.dat
04/10/2010  01:48 PM             4,161 remove_two_model.csv
04/10/2010  01:48 PM             4,131 remove_two_wipp.csv
04/10/2010  01:50 PM             1,604 wipp_results_one.dat
               4 File(s)         11,567 bytes

 Directory of C:\report_CD\analysis\model_correlation

04/07/2010  12:43 PM    <DIR>          .
04/07/2010  12:43 PM    <DIR>          ..
04/11/2010  02:02 PM               719 compute_partial_correlations.R
04/11/2010  01:57 PM               613 export_pcor_inputs.py
04/11/2010  02:13 PM    <DIR>          linux
04/11/2010  01:58 PM             1,975 load_model_data.py
04/11/2010  11:51 AM       120,751,461 model_files.zip
04/11/2010  01:58 PM    <DIR>          output
04/07/2010  12:55 PM             7,611 spearman_rank_coefficient.py
               5 File(s)    120,762,379 bytes

 Directory of C:\report_CD\analysis\model_correlation\linux

04/11/2010  02:13 PM    <DIR>          .
04/11/2010  02:13 PM    <DIR>          ..
04/11/2010  11:51 AM             2,169 checkout_model_data.sh
04/11/2010  11:51 AM             3,714 head_bin2ascii.py
               2 File(s)          5,883 bytes

 Directory of C:\report_CD\analysis\model_correlation\output

04/11/2010  01:58 PM    <DIR>          .
04/11/2010  01:58 PM    <DIR>          ..
04/11/2010  02:52 PM         1,084,380 corr_head_vs_time.dat
04/11/2010  02:52 PM         1,072,200 corr_keff_vs_time.dat
04/11/2010  01:58 PM        10,670,500 head_trav.dat
04/11/2010  02:12 PM           171,444 hpc.out
04/11/2010  03:59 PM         1,126,533 keff_mean.out
04/11/2010  01:58 PM         9,786,982 keff_trav.dat
04/11/2010  03:59 PM         1,046,563 keff_var.out
04/11/2010  02:12 PM           185,720 kpc.out
               8 File(s)     25,144,322 bytes

 Directory of C:\report_CD\analysis\triangle_metric

04/07/2010  12:43 PM    <DIR>          .
```

Table 8-1. CD Directory listing

```
04/07/2010  12:43 PM    <DIR>          ..
04/10/2010  03:52 PM    <DIR>          output
04/07/2010  12:53 PM             6,230 triangles_add_one.m
04/07/2010  12:54 PM            13,051 triangles_remove_one.m
04/07/2010  12:54 PM             7,735 triangles_remove_two.m
               3 File(s)         27,016 bytes

 Directory of C:\report_CD\analysis\triangle_metric\output

04/10/2010  03:52 PM    <DIR>          .
04/10/2010  03:52 PM    <DIR>          ..
04/10/2010  03:53 PM         1,395,622 triangles_add_one_mean.dat
04/10/2010  03:53 PM         1,395,622 triangles_add_one_median.dat
               2 File(s)      2,791,244 bytes

 Directory of C:\report_CD\report

04/07/2010  12:42 PM    <DIR>          .
04/07/2010  12:42 PM    <DIR>          ..
04/09/2010  10:38 AM    <DIR>          figures
               0 File(s)              0 bytes

 Directory of C:\report_CD\report\figures

04/09/2010  10:38 AM    <DIR>          .
04/09/2010  10:38 AM    <DIR>          ..
04/09/2010  10:39 AM    <DIR>          01_intro
04/09/2010  10:39 AM    <DIR>          02_kriging
04/09/2010  10:39 AM    <DIR>          03_triangles
04/09/2010  10:40 AM    <DIR>          04_model_correlation
04/09/2010  10:40 AM    <DIR>          05_combine_3_methods
               0 File(s)              0 bytes

 Directory of C:\report_CD\report\figures\01_intro

04/09/2010  10:39 AM    <DIR>          .
04/09/2010  10:39 AM    <DIR>          ..
04/09/2010  10:38 AM            13,001 fig01_fiber_vs_steel_well_locations.srf
               1 File(s)         13,001 bytes

 Directory of C:\report_CD\report\figures\02_kriging

04/09/2010  10:39 AM    <DIR>          .
04/09/2010  10:39 AM    <DIR>          ..
04/10/2010  01:03 PM             3,798 krig_add_one_plotting.m
04/09/2010  12:01 PM           983,627 may2007_variogram_modela.srf
04/09/2010  10:53 AM        16,893,066 perturbation_spread_of_variograms.srf
04/10/2010  11:40 AM           111,616 piecewise_linear_trend.xls
04/09/2010  11:57 AM            15,469 remove_one_steel_well.srf
04/09/2010  10:53 AM            28,672 trend_surface_remove_one_results.xls
               6 File(s)     18,036,248 bytes

 Directory of C:\report_CD\report\figures\03_triangles

04/09/2010  10:39 AM    <DIR>          .
04/09/2010  10:39 AM    <DIR>          ..
04/09/2010  10:40 AM             2,072 random_points_triangle_explanation.mat
04/09/2010  10:42 AM             4,384 three_point_estimator_fig.m
04/09/2010  10:42 AM           539,206 three_point_estimator_log10r.tif
04/09/2010  12:00 PM         1,150,768 three_triangle_metrics.fig
04/09/2010  10:40 AM         1,317,464 triangulation_explanation.fig
               5 File(s)      3,013,894 bytes

 Directory of C:\report_CD\report\figures\04_model_correlation

04/09/2010  10:40 AM    <DIR>          .
04/09/2010  10:40 AM    <DIR>          ..
```

Table 8-1. CD Directory listing

```
 Directory of C:\report_CD\report\figures\05_combine_3_methods

04/09/2010  10:40 AM    <DIR>          .
04/09/2010  10:40 AM    <DIR>          ..
               0 File(s)              0 bytes

     Total Files Listed:
              81 File(s)    175,409,691 bytes
              65 Dir(s)  147,501,948,928 bytes free
```

8.2. Kriging Variance Minimization Scripts

The following scripts were used in the kriging variance minimization (see Section 2.0).

8.2.1. R script `plot_linear_fit_summary.R`

The following R script computes the linear fit surface (Equation 1, in Section 2.1) and the related summary statistics given in Figure 2-3 and Table 2-1 using built-in statistical functions.

```r
# this R script computes the best fit linear model through the freshwater
# head data and plots some summary statistics included as figures in the
# analysis report.

# load in data
wells <- read.table('../../common_data/2007_well_data_for_trend.dat')
row.names(wells) <- read.table('../../common_data/2007_well_names.dat')$V1
names(wells) <- c('x','y','fwh','res','casing','flag')
attach(wells)

# don't select SNL-6 and SNL-15 (they have -999 in res column)
# and don't use redundant H-19 wells
mask <- flag == 1
wells.lm <- lm(fwh[mask]~x[mask]+y[mask])
summary(wells.lm)
par(mfrow=c(2,2))
plot(wells.lm)
```

8.2.2. Python script `remove_one_variogram_effects.py`

The following Python script computes the best-fit trend surface through the dataset after individually removing each steel-cased well. The two outputs from this script are the effects of removing a well on the best-fit linear surface (see Figure 2-4) and the resulting smaller-by-one datasets used to compute experimental variograms via Surfer in Figure 2-6.

```python
import numpy as np
import os

modelDat = np.loadtxt(r'..\..\common_data\model_domain_specs.dat')

# use midpoint of model domain for origin of surface fitting
# to improve condition number of matrices in least-squares fitting
xmid = (modelDat[2,0] + modelDat[1,0])/2.0
ymid = (modelDat[2,1] + modelDat[1,1])/2.0

fh = open(r'..\..\common_data\2007_well_names.dat','r')
names = [line.rstrip() for line in fh]
fh.close()

wellDat = np.loadtxt(r'..\..\common_data\2007_well_data_for_trend.dat',dtype=np.float64)

# data columns: X,Y,FWH,res,casing,flag
# FWH :: may 2007 freshwater head
# res :: residual computed using R
```

```
# casing :: 1=steel, 0=fiberglass/pvc
# flag :: 0= do not use in trend analysis, 2=do not use at all,
#         1= use in both trend & variogram analysis

fh = open('trend_surface_remove_one_results.csv','w')
fh.write('well,sum squared error,condition number,rank,R^2,A,B,C,gradient,angle\n')

trendWells = wellDat[wellDat[:,5]==1]
trendNames = [name for (i,name) in enumerate(names) if wellDat[i,5]==1]
ntwells = trendWells.shape[0]
trendNames.append('base_case')

# additional wells used in variogram analysis, but not in trend analysis H-19b{2,3,4,5,6,7}
varioWells = wellDat[wellDat[:,5]==0]
varioNames = [name for (i,name) in enumerate(names) if wellDat[i,5]==0]
nvwells = varioWells.shape[0]

for i in xrange(ntwells+1):
    if i==ntwells or np.abs(trendWells[i,4] - 1.0) < 0.01:

        # make a mask that is all true
        mask = trendWells[:-1,0] > 1.0

        # set the current steel well to false
        if i < ntwells:
            mask[i] = False

        tX = trendWells[mask,0] - xmid
        tY = trendWells[mask,1] - ymid
        tH = trendWells[mask,2]

# using numpy recompute linear trend & compute residuals
# compute statistics about change removing each well has on estimated surface
# relative change in angle, slope & offset of surface
# write wells & residuals to file

        trendA = np.concatenate((tX[:,None],tY[:,None],np.ones((tX.shape[0],1))),axis=1)

        x,residues,rank,singulars = np.linalg.lstsq(trendA,tH)
        # residues is "squared Euclidian norm"

        cond = np.max(singulars)/np.min(singulars)
        # coefficient of determination
        rsq = 1.0 - residues/np.sum((tH - np.mean(tH))**2)
        # rsq = 1 - SS_err / SS_tot

        # write summary of fit as a line in file
        fh.write(','.join(str(z) for z in (trendNames[i],residues[0],cond,rank,rsq[0])) +',')
        fh.write('%.7e,%.7e,' % tuple(x[0:2])) # A and B
        fh.write('%.7e,' % (x[2] - x[0]*xmid - x[1]*ymid,)) # C corrected to original coords
        fh.write(','.join(str(z) for z in (np.sqrt(x[0]**2 + x[1]**2),
                                           np.arctan2(x[1],x[0])/np.pi*180.0))+'\n')

        tHpred = np.dot(trendA,x)
        outdata = np.concatenate((trendWells[mask,0:2],
                                  tHpred[:,None],(tHpred-tH)[:,None]),axis=1)

        # write all trend data to separate file for variogram analysis in Surfer
        np.savetxt('trend_results_'+trendNames[i]+'.dat',outdata,fmt='%.2f')

fh.close()
```

8.2.3. Python script `krig_plus_one.py`

The following Python script drives the GSLIB kriging program `kt3d.exe` during the kriging variance minimization process for adding one well (where it is called as a program). The script is also imported as a library in the remove-one and remove-two kriging variance reduction scripts. This script imports `shared_data.py` (line 8) to act as a container for storing shared variables, and uses the MS-DOS batch script `kt3d_driver.bat` (line 70) to manage directories and executables related to kt3d execution.

```
import os
```

```
import threading
from time import sleep
import numpy as np
from scipy.stats import rankdata
from math import ceil

import shared_data as sh

# this script is part of AP-111
# this python script adds an observation point at points
# in the model domain, each time calling KT3D.exe to krig the
# current network along with this additional observation.

# the kriging variance is read in and some statistics are saved
# for comparison and plotting.

def krig(ii,jj,xx,yy,nxx,nyy,x00,y00,dxx,dyy,base=False,addone=True):
    """ write KT3D input file, call kt3d.exe,
    and read in results for summarizing in global array."""

    # write kt3d parameter file
    d = '%03d_%03d' % (ii,jj)
    os.popen('mkdir ' + d)
    fname = os.path.join(d,'KT3D.PAR')
    fpar = open(fname,'w')

    fpar.write("""Parameters for KT3D\n********************\n\nSTART OF PARAMETERS:
data.dat                        \\file with data
1   2   0   4   0               \\   columns for X, Y, Z, var, sec var
-1.0e21   1.0e21                 \\   trimming limits
0                                \\option: 0=grid, 1=cross, 2=jackknife
xvk.dat                          \\file with jackknife data
1   2   0   3    0               \\   columns for X,Y,Z,vr and sec var
0                                \\debugging level: 0,1,2,3
kt3d.dbg                         \\file for debugging output
kriged.out                         \\file for kriged output
%(nxx)d  %(x00)g  %(dxx)g           \\nx,xmn,xsiz
%(nyy)d  %(y00)g  %(dyy)g           \\ny,ymn,ysiz
1    0.5    1.0                  \\nz,zmn,zsiz
1    1      1                    \\x,y and z block discretization
0    44                          \\min, max data for kriging
44                               \\max per octant (0-> not used)
40000.0  40000.0  1.0            \\maximum search radii
90.0   0.0   0.0                 \\angles for search ellipsoid
1     0.0                        \\0=SK,1=OK,2=non-st SK,3=exdrift
0 0 0 0 0 0 0 0 0                \\drift: x,y,z,xx,yy,zz,xy,xz,zy
0                                \\0, variable; 1, estimate trend
extdrift.dat                     \\gridded file with drift/mean
1                                \\  column number in gridded file
1    3.0                         \\nst, nugget effect
3   40.0    90.0     0.0   0.0         \\it,cc,ang1,ang2,ang3
           7500.0 7500.0  10.0       \\a_hmax, a_hmin, a_vert\n""" % vars())
    fpar.close()

    # write data back to file, adding new point to end
    finput = open(os.path.join(d,'data.dat'),'w')
    finput.write('data for kriging data + 1 new well \n5 \nX \nY \nfwh \nres \ncasing \n')
    finput.write(sh.data)
    if base == False and addone == True:
        # add one data point (5 columns, tab delimited)
        finput.write('%8.1f\t%9.1f\t 100.00 \t1.00\t0 ' % (xx,yy))
    finput.close()

    # run KT3D via MS-DOS batch script
    output = os.popen('kt3d_driver.bat ' + d)
    for line in output:
        pass
    failure = output.close()
    if failure:
        print '*** KT3D failed ***',ii,jj
    else:
        print '(%03i,%03i) ' % (ii,jj),

    ## read in and calculate summary statistics on kriging variance
    # output from kt3d is a vector, reshape it into a matrix
    var = np.reshape(np.loadtxt(os.path.join(d,'kriged.out'),
                                skiprows=4,usecols=(1,)),(nyy,nxx))

    if base == True:
        sh.base_case_mod =  (var[mod_m[0]:mod_m[1], mod_n[0]:mod_n[1]])
        sh.base_case_wipp = (var[wipp_m[0]:wipp_m[1], wipp_n[0]:wipp_n[1]])
```

```
        # write base case kriging variance as a matrix for contouring
        np.savetxt('kriged_base_case_var_img.dat',sh.base_case_mod,fmt='%.3f')

    var_mod =  var[mod_m[0]:mod_m[1], mod_n[0]:mod_n[1]]
    var_wipp = var[wipp_m[0]:wipp_m[1], wipp_n[0]:wipp_n[1]]

    # use lock when writing to global variable to prevent thread collisions
    with threading.Lock():
        # compute statistics for sub-block corresponding to model domain,
        # masked by the cells which are inside the area of interest

        # change in aoi-wide standard deviation
        sh.mod_results[ii,jj,0] = (sh.base_case_mod[aoimask].std() -
                                       var_mod[aoimask].std())/
                                       sh.base_case_mod[aoimask].std()
        # change in aoi-wide average
        sh.mod_results[ii,jj,1] = (np.average(sh.base_case_mod[aoimask]) -
                                       np.average(var_mod[aoimask]))/
                                       np.average(sh.base_case_mod[aoimask])

        # change in aoi-wide median
        sh.mod_results[ii,jj,2] = (np.median(sh.base_case_mod[aoimask]) -
                                       np.median(var_mod[aoimask]))/
                                       np.median(sh.base_case_mod[aoimask])

        # correlation coefficient between cases
        sh.mod_results[ii,jj,3] = 1.0 - np.corrcoef(sh.base_case_mod[aoimask].flatten(),
                                                 var_mod[aoimask].flatten())[0,1]

        # change in max variance
        sh.mod_results[ii,jj,4] = (sh.base_case_mod[aoimask].max() -
                                    var_mod[aoimask].max())

        # same statistics for land-withdrawl boundary sub-block
        sh.wipp_results[ii,jj,0] = (sh.base_case_wipp[wippmask].std() -
                                        var_wipp[wippmask].std())/
                                        sh.base_case_wipp[wippmask].std()
        sh.wipp_results[ii,jj,1] = (np.average(sh.base_case_wipp[wippmask]) -
                                        np.average(var_wipp[wippmask]))/
                                        np.average(sh.base_case_wipp[wippmask])
        sh.wipp_results[ii,jj,2] = (np.median(sh.base_case_wipp[wippmask]) -
                                        np.median(var_wipp[wippmask]))/
                                        np.median(sh.base_case_wipp[wippmask])
        sh.wipp_results[ii,jj,3] = 1.0 - np.corrcoef(sh.base_case_wipp[wippmask].flatten(),
                                                  var_wipp[wippmask].flatten())[0,1]
        sh.wipp_results[ii,jj,4] = (sh.base_case_wipp[wippmask].max() -
                                    var_wipp[wippmask].max())


##################################################
# common stuff that is useful for adding or removing wells from the network
# included below, imported elsewhere.

# coordinates of wipp land-withdrawl boundary (McKenna 2004) AP-111, p 13
# averaged to be a N-S square for simple array addressing (it is nearly square anyway)
fh = open(r'..\common_data\wipp_boundary.dat')
wipp_file = [l.rstrip() for l in fh]
fh.close()
coords = []

# corners listed in file in order :NE,SE,SW,NW,NE (NE repeated to close loop)
for line in wipp_file[:-1]:
    coords.append([float(z) for z in line.split()])

wipp_x = ((coords[2][0] + coords[1][0])/2.0, (coords[0][0] + coords[3][0])/2.0)
wipp_y = ((coords[2][1] + coords[3][1])/2.0, (coords[0][1] + coords[1][1])/2.0)

# output grid (the model domain) specifications, number of elements reduced by
# a multiplier to make the run-time feasible
mult = 4.0
fh = open(r'..\common_data\model_domain_specs.dat')
moddata = [l.rstrip() for l in fh]
fh.close()

# always rounds up when determining number of elements
nx,ny = [int(ceil(float(z)/mult)) for z in moddata[0].split()]
x0,y0 = [float(z) for z in moddata[1].split()]
x1,y1 = [float(z) for z in moddata[2].split()]
dx,dy = [float(z)*mult for z in moddata[3].split()]
```

```
# make vectors
x = np.array([x0 + i*dx for i in range(nx)])
y = np.array([y0 + i*dy for i in range(ny)])

# check that everything adds up correctly to fill the domain
assert abs(x[-1] - x1) < dx, abs(y[-1] - y1) < dy

# saved from matlab, this array has 1.00E+0 for cells inside area of interest and
# 0.00E+0 for cells outside
size = mult*100
intmask = np.loadtxt(r'..\common_data\model_cells_%(size)d_inside_totalbdry.dat' % vars())
aoimask = intmask > 0.99

print 'model domain',intmask.sum(),'true out of',np.size(intmask)

# make outerproduct matricies for Matlab plotting
X = np.outer(np.ones(ny),x)
Y = np.outer(y,np.ones(nx))

# indicies for this grid corresponding to the wipp lwb
wipp_n = (int((wipp_x[0] - x0)/dx), int((wipp_x[1] - x0)/dx))
wipp_m = (int((wipp_y[0] - y0)/dy), int((wipp_y[1] - y0)/dy))
sh.base_case_wipp = np.zeros((wipp_m[1]-wipp_m[0], wipp_n[1]-wipp_n[0]))

wippmask = aoimask[wipp_m[0]:wipp_m[1], wipp_n[0]:wipp_n[1]]
wippcheck = np.zeros(np.shape(wippmask))
wippcheck[wippmask] = 1.0
print 'WIPP boundary',wippcheck.sum(),'true out of',np.size(wippmask)

# indicies corresponding to the model domain
mod_n = (int((x0 - x0)/dx), int((x0 - x0)/dx) + nx)
mod_m = (int((y0 - y0)/dy), int((y0 - y0)/dy) + ny)
sh.base_case_mod = np.zeros((mod_m[1]-mod_m[0], mod_n[1]-mod_n[0]))

format = '%.5e'

# read observed data as one long string
fh = open(r'..\common_data\2007_well_data.dat','r')
sh.data = fh.read().strip() # strip off ending / beginning whitespace
fh.close()

# make sure data file ends in a newline
if sh.data[-1] != '\n':
    sh.data = sh.data + '\n'


# ####################################################
# only run from here below if called as a program (rather than
# imported as a library)

if __name__ == '__main__':

    # global arrays to write results into
    sh.mod_results =  np.ones((ny,nx,5))
    sh.wipp_results = np.ones((ny,nx,5))

    krig(0,0,0.0,0.0,nx,ny,x0,y0,dx,dy,base=True)
    f = open('base_stats.out','w')
    # mean, median, std dev
    f.write(' '.join([str(x) for x in (sh.mod_results[0,0,1],sh.mod_results[0,0,2],
                                       sh.mod_results[0,0,0],'\n')]))
    f.write(' '.join([str(x) for x in (sh.wipp_results[0,0,1],sh.wipp_results[0,0,2],
                                       sh.wipp_results[0,0,0],'\n')]))
    f.close()

    for j in xrange(nx):
        print ' '
        for i in xrange(ny):
            # don't do calculation if point is outside area of interest
            if aoimask[i,j] == True:
                while True:
                    # limit the number of threads (8 processors)
                    if threading.activeCount() <= 8:
                        threading.Thread(target=krig,
                                         args=(i,j,X[i,j],Y[i,j],nx,ny,
                                               x0,y0,dx,dy,False)).start()
                        break
                    else:
                        sleep(0.015)

    # wait for all the worker threads to finish before writing output
```

```
    while True:
        if threading.activeCount() > 1:
            sleep(1.0)
        else:
            break

    # write output in Matlab-friendly matrix format
    names = ['stdev','mean','median','corrcoef','max']

    for i,name in enumerate(names):
        print 'writing', name,i
        np.savetxt('addone_mod_results_' + name + '.dat',  sh.mod_results[:,:,i],fmt=format)
        np.savetxt('addone_wipp_results_' + name + '.dat', sh.wipp_results[:,:,i],fmt=format)

    np.savetxt('X.dat',X,fmt='%.1f')
    np.savetxt('Y.dat',Y,fmt='%.1f')
```

8.2.4. Python script `shared_data.py`

The following short Python script is used to allow data to be saved and shared in a common module (see line 8 of `krig_plus_one.py`, line 7 of `krig_remove_one_steel.py`).

```
""" this is just for putting global data in, so
it can be seen between modules"""

pass
```

8.2.5. MS-DOS batch script `kt3d_driver.bat`

The following MS-DOS batch script is called by the Python scripts (see line 70 of `krig_plus_one.py`) that drive kt3d, and is actually responsible for calling `kt3d.exe`, first creating a temporary directory and copying the executable and input files into that directory. This allows the scripts to be threaded and have more than one copy of kt3d running at a time.

```
echo off
rem kriging plus one driver script
rem this batch file copies the executable into a working directory
rem runs it (it expects a standard input filename KT3D.PAR)
rem and deletes the executable
copy /B /Y KT3D.EXE %1
copy /A /Y response %1
chdir %1
KT3D.EXE < response
del /F KT3D.EXE response
chdir ..\
```

8.2.6. MATLAB script `generate_model_cell_masks.m`

The following MATLAB script generates ASCII matrix files representing the model grid, indicating whether each cell is inside or outside the active MODFLOW region (relying on the MATLAB built-in command `inpolygon()` to do most of the work). The text files generated by this script are read in by krig_plus_one.py (line 176 of Section 8.2.1).

```
% this Matlab script exports arrays representing whether a cell
% from the model grid is inside or outside the area of interest
% for use in python scripts

clear
totalbdry = load('..\common_data\total_boundary.dat');

% model grid (for 100x100 elements - the base size)
grid = load('..\common_data\model_domain_specs.dat');
nx = grid(1,1);    ny = grid(1,2);
xmin = grid(2,1);  ymin = grid(2,2);
```

```
xmax = grid(3,1);  ymax = grid(3,2);
dx = grid(4,1);    dy = grid(4,2);
clear grid;

for mult = 1:6
    [X,Y] = meshgrid(xmin:mult*dx:xmax, ymin:mult*dy:ymax);
    % create logical mask
    INSIDE = inpolygon(X,Y,totalbdry(:,1),totalbdry(:,2));
    % convert to real to save (Matlab can't write logical values to ASCII)
    inside = +INSIDE;
    filename = ['model_cells_',sprintf('%d',100*mult),'_inside_totalbdry.dat'];
    save('-ASCII',filename,'inside')
end
```

8.2.7. Python script `krig_remove_one_steel.py`

The following Python script imports the main `krig()` routine from `krig_plus_one.py` (see Section 8.2.1), but instead of adding more locations and re-kriging, a single steel-cased well is removed from the existing dataset and the remaining set is re-kriged.

```
import sys
import numpy as np

# most of the functionality is defined in krig_plus_one; import to re-use code
sys.path.append(r'..\kriging_add_well')
import krig_plus_one as k
import shared_data as shared

# this python script removes an observation point, each time calling
#  KT3D.exe to krig the remaining network

fh = open(r'..\common_data\2007_well_names.dat','r')
names = [line.rstrip() for line in fh]
fh.close()

# fifth column is casing type (1=steel, 0=fiberglass)
fh = open(r'..\common_data\2007_well_data.dat','r')
wells = [line.rstrip().split() for line in fh]
fh.close()

shared.mod_results = np.zeros((len(wells)+1,1,5))
shared.wipp_results = np.zeros((len(wells)+1,1,5))

# base case, for computing percentage change
shared.data = '\n'.join('\t'.join(w) for w in wells)
print 'base_case',
k.krig(len(wells),0,0.0,0.0,k.knx,k.kny,k.kx0,k.ky0,k.dx,k.dy,base=True,addone=False)

fm = open('model_results_one.dat','w')
fw = open('wipp_results_one.dat','w')

stnames = []

# remove one steel cased well
for i,well in enumerate(wells):
    if int(well[4]) == 1:
        stnames.append(names[i])

        # make a copy and delete current well from copy
        cwells = list(wells)
        del cwells[i]
        shared.data = '\n'.join('\t'.join(w) for w in cwells)

        print names[i],
        k.krig(i,0,0.0,0.0,k.knx,k.kny,k.kx0,k.ky0,k.dx,k.dy,base=False,addone=False)
        fm.write(', '.join([str(x) for x in shared.mod_results[i,0,:]]))
        fm.write(', ' + names[i] + '\n')
        fw.write(', '.join([str(x) for x in shared.wipp_results[i,0,:]]))
        fw.write(', ' + names[i] + '\n')

fw.close()
fm.close()
```

8.2.8. Python script `krig_remove_two_steel.py`

The following Python script is analogous to that in Section 8.2.6, except a list of most-likely-to-be-removed steel-cased wells are first removed before removing a second steel-cased wells and re-kriging the results. The main functionality of this routine is imported from the Python script `krig_plus_one.py` (see Section 8.2.1).

```
import sys
import numpy as np

# most of the functionality is defined in krig_plus_one; import to re-use code
sys.path.append(r'..\kriging_add_well')
import krig_plus_one as k
import shared_data as shared

# this python script removes an observation point, each time calling
#  KT3D.exe to krig the remaining network

fh = open(r'..\common_data\2007_well_names.dat','r')
names = [line.rstrip() for line in fh]
fh.close()

# fourth column is casing type (1=steel, 0=fiberglass)
fh = open(r'..\common_data\2007_well_data.dat','r')
wells = [line.rstrip().split() for line in fh]
fh.close()

# perform the "remove one well" analysis for the networks modulo the
# following "likely to not be replaced" wells
firstWell = ['WIPP-25','WIPP-13','H-12','H-7b1']

shared.mod_results = np.zeros((len(wells)+1,1,5))
shared.wipp_results = np.zeros((len(wells)+1,1,5))

# same base-case used throughout to allow comparison
shared.data = '\n'.join('\t'.join(w) for w in wells)
print 'base case',
k.krig(len(wells),0,0.0,0.0,k.knx,k.kny,k.kx0,k.ky0,k.dx,k.dy,base=True,addone=False)

fm = open('model_results_two.dat','w')
fw = open('wipp_results_two.dat','w')

stnames = []

# remove one of the first steel cased wells
for first in firstWell:
    # find index in list
    ifirst = names.index(first)

    # make a local copy of well list
    cwells = list(wells)

    # remove first steel well
    del cwells[ifirst]

    # cycle through remaining steel wells
    for i,well in enumerate(wells):
        if int(well[4]) == 1:
            if ifirst != i:

                stnames.append(names[i])

                # make another copy of list, removing second well
                ccwells = list(cwells)
                del ccwells[i]

                # collapse back into string
                shared.data = '\n'.join('\t'.join(w) for w in ccwells)

                print names[ifirst],names[i],
                k.krig(i,0,0.0,0.0,k.knx,k.kny,k.kx0,k.ky0,k.dx,k.dy,base=False,addone=False)
                fm.write(', '.join([str(x) for x in shared.mod_results[i,0,:]])+',')
                fm.write(', '.join((names[ifirst],names[i])) + '\n')
                fw.write(', '.join([str(x) for x in shared.wipp_results[i,0,:]])+',')
```

```
                fw.write(', '.join((names[ifirst],names[i])) + '\n')

fw.close()
fm.close()
```

8.3. Triangle Metric Maximization Scripts

The following scripts were used in the local gradient estimation or triangle metric maximization portion of the analysis (see Section 3.0).

8.3.1. MATLAB script `triangles_add_one.m`

The following MATLAB script computes and plots figures related to the triangle interior angle ratio metric. Each location in the model domain is added to the current network and the statistics are re-computed.

```
clear
% this Matlab script asses the benefit of adding a new well, where
% locations on the MODFLOW model grid are used as potential locations.
% This approach is geometry-based only;

% the ratio min(angle)/max(angle) is used as a metric for the "quality" of
% a triangle.  More equilateral (ratio=1) triangles would be better.

addpath '..\common_programs\'
wells = load('..\common_data\2007_well_data_for_triangles.dat');
margin = load('..\common_data\composite_23_margin.dat');
noflow = load('..\common_data\no_flow_boundary.dat');
totalbdry = load('..\common_data\total_boundary.dat');
WIPP = load('..\common_data\wipp_boundary.dat');

% default qhull options, except QbB, which scales domain to unit box (since
% UTM coordinates are numerically large and can lead to significant
% roundoff error)
triopts = {'Qt','QbB','Qc','Qz'};

xt=wells(:,1);
yt=wells(:,2);
nw = size(xt,1);

% model grid
grid = load('..\common_data\model_domain_specs.dat');
nx = grid(1,1);    ny = grid(1,2);
xmin = grid(2,1);  ymin = grid(2,2);
dx = grid(4,1);    dy = grid(4,2);
clear grid;

[X,Y] = meshgrid(linspace(xmin,xmin+nx*dx,nx), ...
    linspace(ymin,ymin+ny*dy,ny));
D = numel(X);

INSIDE = reshape(inpolygon(X,Y,totalbdry(:,1),totalbdry(:,2)),D,1);
INSIDE(D+1) = 1;

% observation points in a long x,y vector
Z(1:D,1:2) = [reshape(X,D,1),reshape(Y,D,1)];

Q = zeros(D,5);
numt = zeros(D,1);

for jj=1:D+1

    % only points between no-flow and h2/h3 halite boundaries are
    % candidate sites, skip the others
    if INSIDE(jj)

        if jj==D+1
            x=xt;
            y=yt;
        else
            x = [xt; Z(jj,1)];
            y = [yt; Z(jj,2)];
        end

```

```
        tri = delaunay(x,y,triopts);

        nt = size(tri,1);
        geom = zeros(size(tri,1),7);  % 3 sides, 3 angles, area, # pts inside

        % calculate geometric things related to triangles
        % lengths from Pythagorean theorem
        % angles from cosine law
        % area from Matlab built-in fcn

        % length of side a (2->3)
        geom(1:nt,1) = sqrt((x(tri(:,3)) - x(tri(:,2))).^2 + ...
            (y(tri(:,3)) - y(tri(:,2))).^2);
        % length of side b (3->1)
        geom(1:nt,2) = sqrt((x(tri(:,1)) - x(tri(:,3))).^2 + ...
            (y(tri(:,1)) - y(tri(:,3))).^2);
        % length of side c (1->2)
        geom(1:nt,3) = sqrt((x(tri(:,2)) - x(tri(:,1))).^2 + ...
            (y(tri(:,2)) - y(tri(:,1))).^2);

        % angle 1 between sides b & c in radians
        geom(1:nt,4) = acos((sum(geom(:,2:3).^2,2) - geom(:,1).^2)./ ...
            (2.0*prod(geom(:,2:3),2)));
        % angle 2 between sides a & c in radians
        geom(1:nt,5) = acos((sum(geom(:,1:2:3).^2,2) - geom(:,2).^2)./ ...
            (2.0*prod(geom(:,1:2:3),2)));
        % angle 3 between sides b & a in radians
        geom(1:nt,6) = acos((sum(geom(:,1:2).^2,2) - geom(:,3).^2)./ ...
            (2.0*prod(geom(:,1:2),2)));

        % area of triangle - use MATLAB built-in function
        geom(1:nt,7) = polyarea(x(tri(:,1:3)),y(tri(:,1:3)),2);

        % compute triangle comparison criterias
        ang_ratio = min(geom(:,4:6),[],2)./max(geom(:,4:6),[],2);

        % area-weighted angle ratio
        Q(jj,1) = sum(ang_ratio(:).*geom(:,7))/(nt*sum(geom(1:nt,7)));

        % non-weighted angle ratio average
        Q(jj,2) = sum(ang_ratio(:))/nt;

        % area-weighted angle ratio median
        Q(jj,3) = median(ang_ratio(:).*geom(:,7))/sum(geom(1:nt,7));
        numt(jj) = nt;

        % mean triangle area
        Q(jj,4) = sum(geom(:,7))/nt;

        % median triangle area
        Q(jj,5) = median(geom(:,7));
    end
end

% reset values outside area of interest to not-a-number
% so they are not plotted.

% save results for use in final 3-way combination of results
out = reshape(squeeze((Q(1:end-1,1)-Q(D+1,1))./Q(D+1,1)),ny,nx);
out(~INSIDE(1:end-1)) = -999;
save('triangles_add_one_mean.dat','out','-ASCII');
out = reshape(squeeze((Q(1:end-1,3)-Q(D+1,3))./Q(D+1,3)),ny,nx);
out(~INSIDE(1:end-1)) = -999;
save('triangles_add_one_median.dat','out','-ASCII');
clear out;

Q(~INSIDE(1:end-1),1:end) = NaN;
numt(~INSIDE(1:end-1)) = NaN;

scrnsz = get(0,'ScreenSize');

%% plot results
figure()
ceil(max(numt)-min(numt))
contourf(X,Y,reshape(numt(1:D),ny,nx),3);
colorbar;
daspect([1,1,1]);
hold on
tri = delaunay(xt,yt,triopts);
triplot(tri,xt,yt,'g','LineWidth',0.5);
plot(xt,yt,'or','LineWidth',2)
```

```
140   plot(margin(:,1),margin(:,2),'-m','LineWidth',2)
      plot(noflow(:,1),noflow(:,2),'--k','LineWidth',2)
142   plot(WIPP(:,1),WIPP(:,2),'-k','LineWidth',1.5)
      xlabel('NAD27 UTM x Zone 13 [m]','FontSize',14)
144   ylabel('NAD27 UTM y Zone 13 [m]','FontSize',14)
      title('Total number of triangles in network')
146   % measured from inside of figure window (no borders or toolbars included)
      % position -> [left, bottom, width, height]
148   set(gcf,'Position',[10,50,(scrnsz(4)-120)*0.95,scrnsz(4)-120])
      % make file printed at screen size, rather than bad default
150   set(gcf, 'PaperPositionMode', 'auto');
      print('-dmeta','triangles_add1_total_number.emf')
152
      type2 = {'scaled_mean_angle','unscaled_mean_angle','median_angle','mean_area','median_area'};
154   cblab = {'%\Delta area-weighted mean angle ratio', ...
               '%\Delta mean angle ratio', ...
156            '%\Delta area-weighted median angle ratio', ...
               '%\Delta mean triangle area', '%\Delta median triangle area'};
158   txt = {'a','','b','','',''};
      white = 0.0;
160   for ii=1:5
          clf;
162       data = squeeze((Q(1:D,ii) - Q(D+1,ii))./Q(D+1,ii));
          contourf(X,Y,reshape(data,ny,nx),20);
164       colormap(redwhitemap(data,white));
          cb = colorbar;
166       set(get(cb,'ylabel'),'string',cblab{ii},'FontSize',14);
          daspect([1,1,1]);
168       hold on
          tri = delaunay(xt,yt,triopts);
170       triplot(tri,xt,yt,'g','LineWidth',2)
          plot(xt,yt,'or','LineWidth',2)
172       plot(margin(:,1),margin(:,2),'-m','LineWidth',2)
          plot(noflow(:,1),noflow(:,2),'--k','LineWidth',2)
174       plot(WIPP(:,1),WIPP(:,2),'-k','LineWidth',1.5)
          xlabel('NAD27 UTM X Zone 13 [m]','FontSize',14)
176       ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',14)
          set(gcf,'Position',[10,50,(scrnsz(4)-120)*0.85,scrnsz(4)-120])
178       set(gcf, 'PaperPositionMode', 'auto');
          text(6.05E5,3.594E6,txt{ii},'FontSize',24,'FontWeight','bold');
180       brighten(0.5);
          print('-dmeta', ['triangles_add1_',type2{ii},'.emf'])
182   end
```

8.3.2. MATLAB function `redwhitemap.m`

The following MATLAB script is a function for computing the red-white-blue color maps used in the plotting of figures in this section; see line 161 of `triangles_add_one.m` in section 8.3.1.

```
function [ map ] = redwhitemap( data, white )
%REDWHITEMAP create a specific color map from
% blue = min to red=max with wite at a specific number

mindata = min(min(data));
maxdata = max(max(data));

nlevels = 64;

map = zeros(nlevels,3);

if mindata >= white
    % ** all data will be colored red (no blue or white)

    mindata = white;

    % compute color at midpoint of each bin, rather than at max or min
    xn = mindata + (0.5:1.0:(nlevels-0.5))*(maxdata - mindata)/nlevels;

    % white -> red
    map(xn >= white,1) = 1;    % red
    map(xn >= white,2) = (maxdata - xn(xn >= white))/(maxdata - white);  % green
    map(xn >= white,3) = map(xn >= white,2);  % blue


elseif maxdata <= white
```

```
    % ** all data will be colored blue (no red or white)

    maxdata = white;

    % compute color at midpoint of each bin, rather than at max or min
    xn = mindata + (0.5:1.0:(nlevels-0.5))*(maxdata - mindata)/nlevels;

    % blue -> white
    map(xn < white,1) = (xn(xn < white) - mindata)/(white - mindata);  % red channel
    map(xn < white,2) = map(xn < white,1);  % green
    map(xn < white,3) = 1;        % blue

else
    % ** data will be blue, red, and white

    % compute color at midpoint of each bin, rather than at max or min
    xn = mindata + (0.5:1.0:(nlevels-0.5))*(maxdata - mindata)/nlevels;

    % blue -> white
    map(xn < white,1) = (xn(xn < white) - mindata)/(white - mindata);  % red channel
    map(xn < white,2) = map(xn < white,1);  % green
    map(xn < white,3) = 1;        % blue

    % white -> red
    map(xn >= white,1) = 1;    % red
    map(xn >= white,2) = (maxdata - xn(xn >= white))/(maxdata - white);  % green
    map(xn >= white,3) = map(xn >= white,2);  % blue

end
end
```

8.3.3. MATLAB script `triangles_remove_one.m`

The following MATLAB script computes and plots the triangle interior angle ratio metric after individually removing each of the steel-cased wells from the network.

```
clear
% This matlab script looks at the effects that removing one of the
% steel-cased (without replacement) would have on the estimation of the
% gradient, using linear interpolation across Delauny triangles as the
% estimator.

% Load data
addpath '..\common_programs\';

% well datat (x,y,fwh,res,casing type)
wells = load('..\common_data\2007_well_data_for_triangles.dat');
names = textread('..\common_data\2007_well_names_for_triangles.dat','%s');

% the majority of this analysis should be done without SNL-6 and SNL-15,
% but some figures in text use them for comparison
RHmask = wells(:,4) > -990; % exclude SNL-6 and SNL-15
wells = wells(RHmask,:);
names = names(RHmask,:);
% RHmask = ones(size(wells,1),1);

margin = load('..\common_data\composite_23_margin.dat');
noflow = load('..\common_data\no_flow_boundary.dat');
totalbdry = load('..\common_data\total_boundary.dat');
wipp = load('..\common_data\wipp_boundary.dat');

nearwipp = [min(wipp(:,1))-750.0,max(wipp(:,1))+750.0, ...
            min(wipp(:,2))-750.0,max(wipp(:,2))+750.0];

% wells that make a convex hull around the dataset of all wells
hull = convhull(wells(:,1),wells(:,2));

steelwells = wells(wells(:,5)==1,1:3);  % fifth column indicates casing type
fiberwells = wells(wells(:,5)==0,1:3);
stnames =    {names{wells(:,5)==1}};

% wells on the hull that are also steel-cased
j=1;
for i=1:size(steelwells,1)
    for k=1:size(hull,1)
```

```
        if sqrt((steelwells(i,1) - wells(hull(k),1))^2 + ...
                (steelwells(i,2) - wells(hull(k),2))^2) < 1
            sthull(j) = i;
            j=j+1;
        end
    end
end

xt=wells(:,1);
yt=wells(:,2);
ht=wells(:,3);
nw = size(xt,1);
nst = size(steelwells,1);
Q = zeros(nst+1,3);

% calculation grid (not MODFLOW grid) is minimal grid which includes
% convex hull around data
xmin = min(xt);  ymin = min(yt);
xmax = max(xt);  ymax = max(yt);
dx = 100.0;       dy = 100.0;  % note: using 100x100 is slow.

[X,Y] = meshgrid(xmin:dx:xmax, ymin:dy:ymax);
nx = size(X,2);
ny = size(X,1);

INSIDE = inpolygon(X,Y,totalbdry(:,1),totalbdry(:,2));

npts = numel(X);

% direction and magnitude of gradient in each cell, for
% scenario of removing each steel-casing well + base case

GRAD = zeros(npts,nst+1,2);

% effects of removing one steel-casing well + base case for comparison
for jj=1:nst+1

    if jj < nst+1
        % set of x,y,h without steel casing well jj
        x = [fiberwells(:,1);steelwells(1:jj-1,1);steelwells(jj+1:nst,1)];
        y = [fiberwells(:,2);steelwells(1:jj-1,2);steelwells(jj+1:nst,2)];
        h = [fiberwells(:,3);steelwells(1:jj-1,3);steelwells(jj+1:nst,3)];
    else
        x= xt;
        y=yt;
        h=ht;
    end

    tri = delaunay(x,y);
    nt = size(tri,1);

    D = zeros(size(tri,1),1);
    coeff = zeros(size(tri,1),4);
    grad =  zeros(size(tri,1),2); % angle and magnitide of hydraulic gradient
    geom =  zeros(size(tri,1),8);  % 3 sides, 3 angles, area, # pts inside

    % compute equation for line through 3 points
    % value of determinant used in denominator of Cramer's rule
    D(1:nt) = x(tri(:,1)).*y(tri(:,2)) + x(tri(:,2)).*y(tri(:,3)) + ...
        y(tri(:,1)).*x(tri(:,3)) - x(tri(:,3)).*y(tri(:,2)) - ...
        x(tri(:,1)).*y(tri(:,3)) - x(tri(:,2)).*y(tri(:,1));

    % a (coefficient on x)
    coeff(1:nt,1) = (h(tri(:,1)).*y(tri(:,2)) + y(tri(:,1)).*h(tri(:,3)) + ...
        h(tri(:,2)).*y(tri(:,3)) - h(tri(:,3)).*y(tri(:,2)) - ...
        h(tri(:,2)).*y(tri(:,1)) - h(tri(:,1)).*y(tri(:,3)))./D;

    % b (coefficient on y)
    coeff(1:nt,2) = (x(tri(:,1)).*h(tri(:,2)) + h(tri(:,1)).*x(tri(:,3)) + ...
        x(tri(:,2)).*h(tri(:,3)) - x(tri(:,3)).*h(tri(:,2)) - ...
        x(tri(:,2)).*h(tri(:,1)) - x(tri(:,1)).*h(tri(:,3)))./D;

    % c (constant coefficient)
    coeff(1:nt,3) = (x(tri(:,1)).*y(tri(:,2)).*h(tri(:,3)) + ...
        y(tri(:,1)).*h(tri(:,2)).*x(tri(:,3)) + ...
        x(tri(:,2)).*y(tri(:,3)).*h(tri(:,1)) - ...
        x(tri(:,3)).*y(tri(:,2)).*h(tri(:,1)) - ...
        x(tri(:,2)).*y(tri(:,1)).*h(tri(:,3)) - ...
        x(tri(:,1)).*y(tri(:,3)).*h(tri(:,2)))./D;

    % compute angle and magnitude of hydraulic gradient
```

```
    grad(1:nt,1) = atan2(coeff(:,2),coeff(:,1));
    grad(1:nt,2) = sqrt(sum(coeff(:,1:2).^2,2));

    % map results from "vector" triangles to "raster" grid
    for kk=1:nt
        % result is a logical vector, indicating if the cell is in (T) or
        % out (F) side this current triangle
        IN = reshape(inpolygon(X,Y,x(tri(kk,1:3)),y(tri(kk,1:3))),npts,1);

        % sum(IN) = number of cells inside the triangle
        % ones(sum(IN))*kk = column vector of the counter kk
        % coeff(...,1:2) = x & y gradient repeated for every cell inside
        %                  that triangle, copied to correct locations in GRAD

        GRAD(IN,jj,1:2) = coeff(ones(sum(IN),1)*kk,1:2);
    end

    % calculate geometric things related to triangles
    % lengths from Pythagorean theorem
    % angles from cosine law
    % area from Matlab built-in fcn

    % length of side a (2->3)
    geom(1:nt,1) = sqrt((x(tri(:,3)) - x(tri(:,2))).^2 + ...
        (y(tri(:,3)) - y(tri(:,2))).^2);
    % length of side b (3->1)
    geom(1:nt,2) = sqrt((x(tri(:,1)) - x(tri(:,3))).^2 + ...
        (y(tri(:,1)) - y(tri(:,3))).^2);
    % length of side c (1->2)
    geom(1:nt,3) = sqrt((x(tri(:,2)) - x(tri(:,1))).^2 + ...
        (y(tri(:,2)) - y(tri(:,1))).^2);

    % angle 1 between sides b & c in radians
    geom(1:nt,4) = acos((sum(geom(:,2:3).^2,2) - geom(:,1).^2)./ ...
        (2.0*prod(geom(:,2:3),2)));
    % angle 2 between sides a & c in radians
    geom(1:nt,5) = acos((sum(geom(:,1:2:3).^2,2) - geom(:,2).^2)./ ...
        (2.0*prod(geom(:,1:2:3),2)));
    % angle 3 between sides b & a in radians
    geom(1:nt,6) = acos((sum(geom(:,1:2).^2,2) - geom(:,3).^2)./ ...
        (2.0*prod(geom(:,1:2),2)));

    % area of triangle - use MATLAB built-in function
    geom(1:nt,7) = polyarea(x(tri(:,1:3)),y(tri(:,1:3)),2);

    % compute goodness triangle criteria
    ang_ratio = min(geom(:,4:6),[],2)./max(geom(:,4:6),[],2);

    % area-weighted mean angle ratio
    Q(jj,1) = sum(ang_ratio(:).*geom(:,7))/(nt*sum(geom(1:nt,7)));

    % area-weighted median angle ratio
    Q(jj,2) = median(ang_ratio(:).*geom(:,7))/sum(geom(1:nt,7));

    % median triangle area
    Q(jj,3) = median(geom(:,7));

end

if sum(RHmask) == 44
    % plot figures showing distribution of metrics for 2007 Culebra network
    figure();
    trisurf(tri,x,y,ones(size(x),1),log10(geom(:,7)));
    view(2)
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','log_{10}(triangle area [m^2])','FontSize',12);
    text(6.06E5,3.593E6,'a','FontSize',20,'FontWeight','bold')
    brighten(0.25);
    print('-dmeta','triangles_2007_network_log10_area.emf')

    trisurf(tri,x,y,ones(size(x),1),ang_ratio);
    view(2)
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','interior angle ratio','FontSize',12);
    text(6.06E5,3.593E6,'b','FontSize',20,'FontWeight','bold')
```

```
    brighten(0.25);
    print('-dmeta','triangles_2007_network_angratio_area.emf')

    trisurf(tri,x,y,ones(size(x),1),log10(grad(:,2)));
    view(2)
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','log_{10}(gradient magnitude)','FontSize',12);
    text(6.06E5,3.593E6,'c','FontSize',20,'FontWeight','bold')
    brighten(0.25);
    print('-dmeta','triangles_2007_network_gradmag_area.emf')

    figure()
    subplot(131)
    plot(log10(geom(:,7)),ang_ratio,'o')
    xlabel('log_{10}(triangle area [m^2])')
    ylabel('interior angle ratio')
    axis([5,8,0,1])
    text(7.5,0.9,'a','FontSize',22,'FontWeight','bold')
    subplot(132)
    plot(log10(grad(:,2)),ang_ratio,'+')
    xlabel('log_{10}(gradient magnitude)')
    ylabel('interior angle ratio')
    axis([-5,0,0,1])
    text(-0.6,0.9,'b','FontSize',22,'FontWeight','bold')
    subplot(133)
    plot(log10(grad(:,2)),log10(geom(:,7)),'*')
    ylabel('log_{10}(triangle area [m^2])')
    xlabel('log_{10}(gradient magnitude)')
    axis([-5,0,5,8])
    text(-0.6,7.7,'c','FontSize',22,'FontWeight','bold')
    print('-dmeta','scatter_plots_2007_network_metrics.emf')

    figure()
    triplot(tri,x,y)
    axis('image')
    hold on
    plot(fiberwells(:,1),fiberwells(:,2),'bs', ...
        'MarkerSize',6,'MarkerFaceColor','b');
    plot([steelwells(1:i-1,1);steelwells(i+1:nst,1)], ...
         [steelwells(1:i-1,2);steelwells(i+1:nst,2)],'ro', ...
        'MarkerSize',6,'MarkerFaceColor','r');
    plot(margin(:,1),margin(:,2),'-m','LineWidth',2);
    plot(noflow(:,1),noflow(:,2),'--k','LineWidth',2);
    plot(wipp(:,1),wipp(:,2),'-k','LineWidth',2);
    midx = sum(x(tri(:,1:3)),2)/3.0;
    midy = sum(y(tri(:,1:3)),2)/3.0;
    quiver(midx,midy,-coeff(:,1),-coeff(:,2),2.5,'k','LineWidth',2)
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    text(6.06E5,3.594E6,'a','FontSize',22,'FontWeight','bold')
    print('-dmeta','vector_plots_2007_network.emf')
else
    % plot figures showing distribution of metrics for 2007 Culebra network (no SNL-6 or SNL-15)
    figure();
    trisurf(tri,x,y,ones(size(x),1),log10(geom(:,7)));
    view(2)
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','log_{10}(triangle area [m^2])','FontSize',12);
    text(6.06E5,3.593E6,'a','FontSize',20,'FontWeight','bold')
    brighten(0.25);
    print('-dmeta','triangles_noSNL15-6_network_log10_area.emf')

    trisurf(tri,x,y,ones(size(x),1),ang_ratio);
    view(2)
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','interior angle ratio','FontSize',12);
    text(6.06E5,3.593E6,'b','FontSize',20,'FontWeight','bold')
    brighten(0.25);
    print('-dmeta','triangles_noSNL15-6_network_angratio_area.emf')

    trisurf(tri,x,y,ones(size(x),1),log10(grad(:,2)));
    view(2)
```

```
    axis('image')
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    cb = colorbar;
    set(get(cb,'ylabel'),'string','log_{10}(gradient magnitude)','FontSize',12);
    text(6.06E5,3.593E6,'c','FontSize',20,'FontWeight','bold')
    brighten(0.25);
    print('-dmeta','triangles_noSNL15-6_network_gradmag_area.emf')

    figure()
    subplot(131)
    plot(log10(geom(:,7)),ang_ratio,'o')
    xlabel('log_{10}(triangle area [m^2])')
    ylabel('interior angle ratio')
    axis([5,8,0,1])
    text(7.5,0.9,'a','FontSize',22,'FontWeight','bold')
    subplot(132)
    plot(log10(grad(:,2)),ang_ratio,'+')
    xlabel('log_{10}(gradient magnitude)')
    ylabel('interior angle ratio')
    axis([-5,0,0,1])
    text(-0.6,0.9,'b','FontSize',22,'FontWeight','bold')
    subplot(133)
    plot(log10(grad(:,2)),log10(geom(:,7)),'*')
    ylabel('log_{10}(triangle area [m^2])')
    xlabel('log_{10}(gradient magnitude)')
    axis([-5,0,5,8])
    text(-0.6,7.7,'c','FontSize',22,'FontWeight','bold')
    print('-dmeta','scatter_plots_noSNL15-6_network_metrics.emf')

    figure()
    triplot(tri,x,y)
    axis('image')
    hold on
    plot(fiberwells(:,1),fiberwells(:,2),'bs', ...
        'MarkerSize',6,'MarkerFaceColor','b');
    plot([steelwells(1:i-1,1);steelwells(i+1:nst,1)], ...
         [steelwells(1:i-1,2);steelwells(i+1:nst,2)],'ro', ...
        'MarkerSize',6,'MarkerFaceColor','r');
    plot(margin(:,1),margin(:,2),'-m','LineWidth',2);
    plot(noflow(:,1),noflow(:,2),'--k','LineWidth',2);
    plot(wipp(:,1),wipp(:,2),'-k','LineWidth',2);
    midx = sum(x(tri(:,1:3)),2)/3.0;
    midy = sum(y(tri(:,1:3)),2)/3.0;
    quiver(midx,midy,-coeff(:,1),-coeff(:,2),0.5,'k','LineWidth',2)
    xlabel('NAD27 UTM X Zone 13 [m]','FontSize',12)
    ylabel('NAD27 UTM Y Zone 13 [m]','FontSize',12)
    text(6.06E5,3.594E6,'b','FontSize',22,'FontWeight','bold')
    print('-dmeta','vector_plots_noSNL15-6_network.emf')
end

% save results to file for making tables
stnames
out = abs(100.0*(Q(1:nst,1:3)-Q(ones(nst,1)*(nst+1),1:3))./Q(ones(nst,1)*(nst+1),1:3));
save('triangles_remove_one_well.dat','out','-ASCII');

figure()
scrnsz = get(0,'ScreenSize');

% change in mean interior angle-ratio of network
figure()
ylab = {'%\Delta in area-weighted mean angle ratio', ...
        '%\Delta in area-weighted median angle ratio', ...
        '%\Delta in median triangle area'};

fname = {'mean_angle','median_angle','median_area'};

for i=1:3
    clf
    tmp=abs(100.0*(Q(1:nst,i)-Q(nst+1,i))./Q(nst+1,i));
    bar(1:nst,tmp,'r');
    hold on;
    tmp(sthull(:)) = 0.0;
    bar(1:nst,tmp,'b');
    xlabel('removal of steel-cased well');
    ylabel(ylab{i},'fontsize',13);
    set(gcf,'PaperType','tabloid')
    set(gca,'XTickMode','manual');
    set(gca,'XTick',1:nst);
    set(gca,'XTickLabel',stnames);
    set(gcf,'PaperPositionMode','auto')
```

```
    set(gcf,'Position',[10,50,0.85*scrnsz(3),0.33*scrnsz(4)])
    print('-dmeta',['triangles_remove1_',fname{i},'_compare.emf'])
end

% relative difference between gradient without steel well and base case
BASE = GRAD(1:npts,ones(nst,1)*(nst+1),1:2);
DIFF = (GRAD(1:npts,1:nst,1:2) - BASE)./BASE;
mag = sqrt(sum((GRAD(:,1:nst,1:2) - GRAD(:,ones(nst,1)*(nst+1),1:2)).^2,3));

% area "effected" by removal of well (square meters)
clf;
subplot(211)
tol = 1.0E-3;
mask = mag > tol;
mask(~INSIDE) = false;
count = zeros(nst,1);
for j=1:nst
    count(j) = sum(mag(:,j) > tol);
end
tmp = dx*dy*(count);
bar(1:nst,log10(tmp),'r');
hold on;
tmp(sthull(:)) = 0.0;
bar(1:nst,log10(tmp),'b');
xlabel('removal of steel-cased well');
title('log_{10}(area) effected (0.001) by removal [m^2]','fontsize',13);
axis([0,nst+1,4,8]);
set(gcf,'PaperType','tabloid')
set(gca,'XTickMode','manual');
set(gca,'XTick',1:nst);
set(gca,'XTickLabel',stnames);
subplot(212)
tol = 1.0E-2;
mask = mag > tol;
mask(~INSIDE) = false;
count = zeros(nst,1);
for j=1:nst
    count(j) = sum(mag(:,j) > tol);
end
tmp = dx*dy*(count);
bar(1:nst,log10(tmp),'r');
hold on;
tmp(sthull(:)) = 0.0;
bar(1:nst,log10(tmp),'b');
xlabel('removal of steel-cased well');
title('log_{10}(area) effected (0.01) by removal [m^2]','fontsize',13);
axis([0,nst+1,4,8]);
set(gcf,'PaperType','tabloid')
set(gca,'XTickMode','manual');
set(gca,'XTick',1:nst);
set(gca,'XTickLabel',stnames);

set(gcf,'PaperPositionMode','auto')
set(gcf,'Position',[10,50,0.85*scrnsz(3),0.5*scrnsz(4)])
print('-dmeta','triangles_remove1_effected_logarea_compare.emf')

DIFF(~INSIDE,:,:) = NaN;

% change in gradient magnitude upon removal of steel well
clf;
DIFF2 = GRAD(1:npts,1:nst,1:2) - BASE;  % not normalized
LEN = sqrt(DIFF2(1:npts,1:nst,1).^2 + DIFF2(1:npts,1:nst,2).^2);
tmp = sum(LEN(mask),1)./count;
bar(1:nst,tmp,'r');
tmp(sthull(:)) = 1.0;
bar(1:nst,tmp,'b');
set(gca,'YScale','log')
hold on;
xlabel('removal of steel-cased well');
ylabel('\Delta in gradient magnitude from well removal','fontsize',13);
set(gcf,'PaperType','tabloid')
set(gca,'XTickMode','manual');
set(gca,'XTick',1:nst);
set(gca,'XTickLabel',stnames);
set(gcf,'PaperPositionMode','auto')
set(gcf,'Position',[10,50,0.85*scrnsz(3),0.33*scrnsz(4)])
print('-dmeta','triangles_remove1_gradmag_compare.emf')

% change in mean gradient angle upon removal of steel well
clf;
angle = abs(atan2(DIFF2(1:npts,1:nst,2), DIFF2(1:npts,1:nst,1)));
```

```
tmp = sum(angle(mask),1)./count;
bar(1:nst,tmp,'r');
hold on;
tmp(sthull(:))=0.0;
bar(1:nst,tmp,'b');
xlabel('removal of steel-cased well');
ylabel('|\Delta in gradient direction| from well removal','fontsize',13);
v=axis();
axis([v(1:2),0,pi])
set(gca,'YTick',0:pi/4:pi);
set(gca,'YTickLabel','0|45|90|135|180');
set(gcf,'PaperType','tabloid')
set(gca,'XTickMode','manual');
set(gca,'XTick',1:nst);
set(gca,'XTickLabel',stnames);
set(gcf,'PaperPositionMode','auto')
set(gcf,'Position',[10,50,0.85*scrnsz(3),0.33*scrnsz(4)])
print('-dmeta','triangles_remove1_gradang_compare.emf')

gradHSVimage = zeros(ny,nx,3);

% largest magnitude change seen in any figure (for consistent scaling)
maxmag = max(max(log10(sqrt(DIFF(:,:,1).^2 + DIFF(:,:,2).^2))));

figure();
for i=1:nst

    % easier to re-compute than save
    x = [fiberwells(:,1);steelwells(1:i-1,1);steelwells(i+1:nst,1)];
    y = [fiberwells(:,2);steelwells(1:i-1,2);steelwells(i+1:nst,2)];

    % wells that make a convex hull for the dataset less one well
    localhull = convhull(x(:),y(:));
    LOCINSIDE = inpolygon(X,Y,x(localhull),y(localhull));

    clf()
    mag = sqrt(reshape(DIFF(:,i,1).^2,ny,nx) + reshape(DIFF(:,i,2).^2,ny,nx));
    rex = reshape(DIFF(:,i,1),ny,nx);
    rey = reshape(DIFF(:,i,2),ny,nx);
    angle = abs(atan2(rey,rex));

    % clear results outside the convex hull of the reduced dataset.
    mag(~LOCINSIDE) = NaN;
    angle(~LOCINSIDE) = NaN;

    % map angle onto hue and log10(magnitude) onto brightness (assume full
    % saturation)

    % data range: 0 <= theta <= +pi
    blue = 0.6534;  % red is 1.0; scale range from blue to red
    gradHSVimage(:,:,1) = (1.0 - blue)*angle./pi + blue;
    gradHSVimage(:,:,2:3) = 1.0;  % full saturation / brightness

    logmag = log10(mag);
    minmag = log10(tol);

    % reset values lower than tolerance to tolerance
    logmag(logmag < minmag) = minmag;
    gradALPHA = (logmag - minmag)./(maxmag - minmag);

    h = image(hsv2rgb(gradHSVimage));
    set(h,'XData',X(1,:)); % assign coorinates to pixels to allow
    set(h,'YData',Y(:,1)); % overlays to be plotted over image
    set(h,'AlphaData',gradALPHA);  % make "no-change" areas clear
    axis xy   % flip y-axis from image convention to plot convention

    daspect([1,1,1]);
    hold on;
    title(stnames{i},'fontsize',15);
    xlabel('NAD27 UTM x Zone 13 [m]');
    ylabel('NAD27 UTM y Zone 13 [m]');

    tri = delaunay(x,y);
    triplot(tri,x,y,'-g','LineWidth',1/3);

    hold on
    plot(fiberwells(:,1),fiberwells(:,2),'bs', ...
        'MarkerSize',9,'MarkerFaceColor','b');
    plot([steelwells(1:i-1,1);steelwells(i+1:nst,1)], ...
        [steelwells(1:i-1,2);steelwells(i+1:nst,2)],'ro', ...
        'MarkerSize',9,'MarkerFaceColor','r');
```

```
    plot(steelwells(i,1),steelwells(i,2),'ko', ...
        'LineWidth',2.5,'MarkerEdgeColor','r', ...
        'MarkerSize',14,'MarkerFaceColor','k');

    plot(margin(:,1),margin(:,2),'-m','LineWidth',2);
    plot(noflow(:,1),noflow(:,2),'--k','LineWidth',2);
    plot(wipp(:,1),wipp(:,2),'-k','LineWidth',2);

    if strcmp(stnames{i},'H-2b2') || strcmp(stnames{i},'ERDA-9') || ...
            strcmp(stnames{i},'H-3b2') || strcmp(stnames{i},'WIPP-19')
        % for on-site wells, zoom in to WIPP LWB area
        axis(nearwipp);
    else
        axis([xmin,xmax,ymin,ymax]);
    end
    set(gcf,'PaperPositionMode','auto')
    set(gcf,'PaperType','usletter')
    set(gcf,'Position',[10,50,(scrnsz(4)-120)*0.85,scrnsz(4)-120])
    print('-dmeta',['triangles_grad_change_',stnames{i},'.emf']);
end
```

8.3.4. MATLAB script `triangles_remove_two.m`

The following MATLAB script computes and plots the triangle interior angle metric upon removal of two steel wells from the well network.

```
clear
% This matlab script looks at the effects that removing one of the
% steel-cased (without replacement) would have on the estimation of the
% gradient, using linear interpolation across Delauny triangles as the
% estimator.

firstWell = {'WIPP-25','WIPP-13','H-12','H-7b1'};
nfst = size(firstWell,2);

% Load data
addpath '..\common_programs\';

% well datat (x,y,fwh,res,casing type)
wells = load('..\common_data\2007_well_data_for_triangles.dat');
names = textread('..\common_data\2007_well_names_for_triangles.dat','%s');

RHmask = wells(:,4) > -990; % exclude SNL-6 and SNL-15
wells = wells(RHmask,:);
names = names(RHmask,:);

margin = load('..\common_data\composite_23_margin.dat');
noflow = load('..\common_data\no_flow_boundary.dat');
totalbdry = load('..\common_data\total_boundary.dat');

% wells that make a convex hull around the dataset of all wells
hull = convhull(wells(:,1),wells(:,2));

steelwells = wells(wells(:,5)==1,1:3);  % fifth column indicates casing type
fiberwells = wells(wells(:,5)==0,1:3);
stnames =   {names{wells(:,5)==1}};

% wells on the hull that are also steel-cased
j=1;
for i=1:size(steelwells,1)
    for k=1:size(hull,1)
        if sqrt((steelwells(i,1) - wells(hull(k),1))^2 + ...
                (steelwells(i,2) - wells(hull(k),2))^2) < 1
            sthull(j) = i;
            j=j+1;
        end
    end
end

xt=wells(:,1);
yt=wells(:,2);
ht=wells(:,3);
nw = size(xt,1);
```

```
nst = size(steelwells,1);
Q = zeros(nst+1,nfst,2);
Q = NaN;

stnames{nst+1} = 'BASE-CASE';

% calculation grid (not MODFLOW grid) is minimal grid which includes
% convex hull around data
xmin = min(xt);  ymin = min(yt);
xmax = max(xt);  ymax = max(yt);
dx = 100.0;       dy = 100.0;  % note: using 100x100 is slow.

[X,Y] = meshgrid(xmin:dx:xmax, ymin:dy:ymax);
nx = size(X,2);
ny = size(X,1);

INSIDE = inpolygon(X,Y,totalbdry(:,1),totalbdry(:,2));

npts = numel(X);

% direction and magnitude of gradient in each cell, for
% scenario of removing each steel-casing well + base case

GRAD = ones(npts,nst+1,2);

% effects of removing one steel-casing well + base case for comparison
for mm=1:nfst
    for jj=1:nst+1

        % two steel wells must be different
        if ~strcmp(firstWell{mm},stnames{jj})

            if jj < nst+1
                % set of x,y,h without steel casing well jj or mm
                x = [fiberwells(:,1);steelwells(~strcmp(stnames(1:nst),stnames{jj}) & ...
                                               ~strcmp(stnames(1:nst),firstWell{mm}),1)];
                y = [fiberwells(:,2);steelwells(~strcmp(stnames(1:nst),stnames{jj}) & ...
                                               ~strcmp(stnames(1:nst),firstWell{mm}),2)];
                h = [fiberwells(:,3);steelwells(~strcmp(stnames(1:nst),stnames{jj}) & ...
                                               ~strcmp(stnames(1:nst),firstWell{mm}),3)];
            else
                x = xt;
                y = yt;
                h = ht;
            end

            tri = delaunay(x,y);
            nt = size(tri,1);

            D = zeros(size(tri,1),1);
            coeff = zeros(size(tri,1),4);
            grad = zeros(size(tri,1),2); % angle and magnitide of hydraulic gradient
            geom = zeros(size(tri,1),8);  % 3 sides, 3 angles, area, # pts inside

            %% compute equation for line through 3 points
            % value of determinant used in denominator of Cramer's rule
            D(1:nt) = x(tri(:,1)).*y(tri(:,2)) + x(tri(:,2)).*y(tri(:,3)) + ...
                y(tri(:,1)).*x(tri(:,3)) - x(tri(:,3)).*y(tri(:,2)) - ...
                x(tri(:,1)).*y(tri(:,3)) - x(tri(:,2)).*y(tri(:,1));

            % a (coefficient on x)
            coeff(1:nt,1) = (h(tri(:,1)).*y(tri(:,2)) + y(tri(:,1)).*h(tri(:,3)) + ...
                h(tri(:,2)).*y(tri(:,3)) - h(tri(:,3)).*y(tri(:,2)) - ...
                h(tri(:,2)).*y(tri(:,1)) - h(tri(:,1)).*y(tri(:,3)))./D;

            % b (coefficient on y)
            coeff(1:nt,2) = (x(tri(:,1)).*h(tri(:,2)) + h(tri(:,1)).*x(tri(:,3)) + ...
                x(tri(:,2)).*h(tri(:,3)) - x(tri(:,3)).*h(tri(:,2)) - ...
                x(tri(:,2)).*h(tri(:,1)) - x(tri(:,1)).*h(tri(:,3)))./D;

            % c (constant coefficient)
            coeff(1:nt,3) = (x(tri(:,1)).*y(tri(:,2)).*h(tri(:,3)) + ...
                y(tri(:,1)).*h(tri(:,2)).*x(tri(:,3)) + ...
                x(tri(:,2)).*y(tri(:,3)).*h(tri(:,1)) - ...
                x(tri(:,3)).*y(tri(:,2)).*h(tri(:,1)) - ...
                x(tri(:,2)).*y(tri(:,1)).*h(tri(:,3)) - ...
                x(tri(:,1)).*y(tri(:,3)).*h(tri(:,2)))./D;

            % compute angle and magnitude of hydraulic gradient
            grad(1:nt,1) = atan2(coeff(:,2),coeff(:,1));
            grad(1:nt,2) = sqrt(sum(coeff(:,1:2).^2,2));
```

```
            grad(1:nt,3) = max(h(tri(:,1:3)),[],2) - min(h(tri(:,1:3)),[],2);

            % map results from "vector" triangles to "raster" grid
            for kk=1:nt
                % result is a logical vector, indicating if the cell is in (T) or
                % out (F) side this current triangle
                IN = reshape(inpolygon(X,Y,x(tri(kk,1:3)),y(tri(kk,1:3))),npts,1);

                % sum(IN) = number of cells inside the triangle
                % ones(sum(IN))*kk = column vector of the counter kk
                % coeff(...,1:2) = x & y gradient repeated for every cell inside
                %                  that triangle, copied to correct locations in GRAD

                GRAD(IN,jj,1:2) = coeff(ones(sum(IN),1)*kk,1:2);
            end
            %% calculate geometric things related to triangles
            % lengths from Pythagorean theorem
            % angles from cosine law
            % area from Matlab built-in fcn

            % length of side a (2->3)
            geom(1:nt,1) = sqrt((x(tri(:,3)) - x(tri(:,2))).^2 + ...
                (y(tri(:,3)) - y(tri(:,2))).^2);
            % length of side b (3->1)
            geom(1:nt,2) = sqrt((x(tri(:,1)) - x(tri(:,3))).^2 + ...
                (y(tri(:,1)) - y(tri(:,3))).^2);
            % length of side c (1->2)
            geom(1:nt,3) = sqrt((x(tri(:,2)) - x(tri(:,1))).^2 + ...
                (y(tri(:,2)) - y(tri(:,1))).^2);


            % angle 1 between sides b & c in radians
            geom(1:nt,4) = acos((sum(geom(:,2:3).^2,2) - geom(:,1).^2)./ ...
                (2.0*prod(geom(:,2:3),2)));
            % angle 2 between sides a & c in radians
            geom(1:nt,5) = acos((sum(geom(:,1:2:3).^2,2) - geom(:,2).^2)./ ...
                (2.0*prod(geom(:,1:2:3),2)));
            % angle 3 between sides b & a in radians
            geom(1:nt,6) = acos((sum(geom(:,1:2).^2,2) - geom(:,3).^2)./ ...
                (2.0*prod(geom(:,1:2),2)));

            % area of triangle - use MATLAB built-in function
            geom(1:nt,7) = polyarea(x(tri(:,1:3)),y(tri(:,1:3)),2);

            % compute goodness triangle criteria
            ang_ratio = min(geom(:,4:6),[],2)./max(geom(:,4:6),[],2);

            % area-weighted angle ratio
            Q(jj,mm,1) = sum(ang_ratio(:).*geom(:,7))/sum(geom(1:nt,7));

            % median triangle area
            Q(jj,mm,2) = median(geom(1:nt,7));
        else
            Q(jj,mm,1:2) = NaN;
        end
    end
end

scrnsz = get(0,'ScreenSize');

BASE = Q(ones(1,nst)*(nst+1),:,1:2);
plt = (Q(1:nst,:,1:2) - BASE)./BASE;

figure()
h1 = imagesc(plt(1:nst,:,1));
axis('image')
%colormap(redwhitemap(reshape(plt(:,:,1),numel(plt(:,:,1)))));
colorbar()
figure()
h2 = imagesc(plt(1:nst,:,2));
axis('image')
%colormap(redwhitemap(reshape(plt(:,:,2),numel(plt(:,:,2)))));
colorbar()
```

8.4. Model Parameter Correlation Maximization Scripts

The first two scripts are run in Linux, then the following Python and R scripts are run in Windows and are used to compute the correlation and partial correlation results used in the analysis.

8.4.1. Bash shell script `checkout_model_data.sh`

The following Linux Bash shell script is run to check the Culebra MODFLOW model inputs and results needed out from CVS, convert the binary head output files to ASCII, perform directory manipulations and zip the results into a single file for transfer to Windows XP.

```
#!/bin/bash

# this Bash script is run in Linux and checks out the model files
# required to perform the model correlation analysis.

repo=/nfs/data/CVSLIB

# check out the list of the final 100 fields used from AP-144
cvs -d ${repo}/MiningMod checkout Inputs/keepers

# move it into the current directory
mv Inputs/keepers .
rm -rf Inputs

# checkout model inputs from Tfields repository in CVS (AP-114 Task 7)
for d in `cat keepers`; do
  # checkout transmissivity and anisotropy fields
  cvs -d ${repo}/Tfields checkout Outputs/${d}/modeled_{K,A}_field.mod
done

# modify the path of "updated" T-fields, so they are all at the
# same level in the directory structure (to make these agree w/ mining mod repository)

if [ -a keepers_short ]; then
    # delete any pre-existing files here,
    # since file is concatenated to in next loop
    rm keepers_short
fi

for d in `cat keepers`; do
  bn=`basename ${d}`
  # test whether it is a compound path
  if [ ${d} != ${bn} ]; then
      dn=`dirname ${d}`
      mv ./Outputs/${d}/ ./Outputs/

      # put an empty file in the directory to indicate
      # what the directory was previously named
      touch ./Outputs/${bn}/${dn}
  fi

  # create a keepers list without directories
  echo ${bn} >> keepers_short
done

# get output files from MiningMod CVS repository
for d in `cat keepers_short`; do
    # checkout particle tracking results (R0 is no mining replicate)
    cvs -d ${repo}/MiningMod checkout Outputs/R0/${d}/dtrk.out
    # checkout binary heads
    cvs -d ${repo}/MiningMod checkout Outputs/R0/${d}/modeled_head.bin

    # move files into existing directories
    mv Outputs/R0/${d}/{dtrk.out,modeled_head.bin} Outputs/${d}/
done

# remove intermediate directories
rm -rf Outputs/R0
rm -rf Outputs/Update
rm -rf Outputs/Update2

# convert binary MODFLOW head output to ascii for use in AP-111 analysis
for d in `cat keepers_short`; do
```

```
    cd Outputs/${d}
    ln -sf ../../head_bin2ascii.py .
    python head_bin2ascii.py
    rm ./head_bin2ascii.py
    rm ./modeled_head.bin
    cd ../..
done

# zip results up for transfer to windowz
cd Outputs
zip -r model_files.zip r???
mv model_files.zip ../
```

8.4.2. Python script `head_bin2ascii.py`

The following Python script is run in Linux to convert the binary MODFLOW head output files to ASCII format, for transfer to Windows XP for further analysis. This script is called by the Bash shell script `checkout_model_data.sh` that checks the data out of CVS and does the looping over the directories.

```
import struct
from sys import argv,exit

class FortranFile(file):
    """ modified from May 2007 Enthought-dev mailing list post by Neil Martinsen-Burrell"""

    def __init__(self,fname, mode='r', buf=0):
    file.__init__(self, fname, mode, buf)
    self.ENDIAN = '<'  # little endian
        self.di = 4  # default integer (could be 8 on 64-bit platforms)

    def readReals(self, prec='f'):
        """Read in an array of reals (default single precision) with error checking"""
        # read header (length of record)
    l = struct.unpack(self.ENDIAN+'i',self.read(self.di))[0]
    data_str = self.read(l)
    len_real = struct.calcsize(prec)
    if l % len_real != 0:
        raise IOError('Error reading array of reals from data file')
    num = l/len_real
    reals = struct.unpack(self.ENDIAN+str(num)+prec,data_str)
        # check footer
    if struct.unpack(self.ENDIAN+'i',self.read(self.di))[0] != l:
        raise IOError('Error reading array of reals from data file')
    return list(reals)

    def readInts(self):
        """Read in an array of integers with error checking"""
    l = struct.unpack('i',self.read(self.di))[0]
    data_str = self.read(l)
    len_int = struct.calcsize('i')
    if l % len_int != 0:
        raise IOError('Error reading array of integers from data file')
    num = l/len_int
    ints = struct.unpack(str(num)+'i',data_str)
    if struct.unpack(self.ENDIAN+'i',self.read(self.di))[0] != l:
        raise IOError('Error reading array of integers from data file')
    return list(ints)

    def readRecord(self):
        """Read a single fortran record (potentially mixed reals and ints)"""
        dat = self.read(self.di)
        if len(dat) == 0:
            raise IOError('Empy record header')
    l = struct.unpack(self.ENDIAN+'i',dat)[0]
    data_str = self.read(l)
        if len(data_str) != l:
            raise IOError('Didn''t read enough data')
        check = self.read(self.di)
        if len(check) != 4:
            raise IOError('Didn''t read enough data')
    if struct.unpack(self.ENDIAN+'i',check)[0] != l:
        raise IOError('Error reading record from data file')
    return data_str
```

```
def reshapev2m(v,nx,ny):
    """Reshape a vector that was previously reshaped in C-major order from a matrix,
    back into a C-major order matrix (here a list of lists)."""
    m = [None]*ny
    n = nx*ny
    for i,(lo,hi) in enumerate(zip(xrange(0, n-nx+1, nx), xrange(nx, n+1, nx))):
        m[i] = v[lo:hi]
    return m

def floatmatsave(filehandle,m):
    """Writes array to open filehandle.
    Outer list is rows, inner lists are columns."""

    for row in m:
        f.write(''.join([' %9.4f' % col for col in row]) + '\n')

# open file and set endian-ness
try:
    infn,outfn = argv[1:3]
except:
    print '2 command-line arguments not given, using default in/out filenames'
    infn = 'modeled_head.bin'
    outfn = 'modeled_head.hed'

ff = FortranFile(infn)

# currently this assumes a single-layer MODFLOW model (or at least only one layer of output)

# format of MODFLOW header in binary layer array
fmt = '<2i2f16s3i'
# little endian, 2 integers, 2 floats,
#    16-character string (4 element array of 4-byte strings), 3 integers

while True:
    try:
        # read in header
        h = ff.readRecord()

    except IOError:
        # exit while loop
        break

    else:
        # unpack header
        kstp,kper,pertim,totim,text,ncol,nrow,ilay = struct.unpack(fmt,h)

        # print status/confirmation to terminal
        print kstp,kper,pertim,totim,text,ncol,nrow,ilay

        h = ff.readReals()

ff.close()

f = open(outfn,'w')

floatmatsave(f,reshapev2m(h,ncol,nrow)[::-1])
f.close()
```

8.4.3. Python script `load_model_data.py`

The following Python script is not called by itself, but instead is used as a library in two other Python scripts. This script loads the model input (transmissivity and anisotropy fields) and model output (head) from each of the 100 calibrated MODFLOW realizations.

```
import numpy as np
from os.path import join
from glob import glob

datadir = '../../../common_data/'
fh = open(datadir + 'model_domain_specs.dat','r')
nx,ny =     [int(x) for x in fh.readline().strip().split()]
xmin,ymin = [float(x) for x in fh.readline().strip().split()]
xmax,ymax = [float(x) for x in fh.readline().strip().split()]
fh.close()
```

```
dt = np.float64  # "double precision"

# number of fields and elements in each
numf = 100
numel = nx*ny
ndata = 3
tcorr = np.zeros((ndata+1,numel),dtype=dt)
hcorr = np.zeros((ndata,numel),dtype=dt)
trav = np.zeros((numf,),dtype=dt)

dpi = 160
figsize = (14,6)

kdat = np.zeros((numf,numel),dtype=dt)
adat = np.zeros((numf,numel),dtype=dt)
hdat = np.zeros((numf,numel),dtype=dt)

# loop over all the directories, read input
for i,d in enumerate(glob('r???')):
    print i,d
    # x (row) log10 hydraulic conductivity
    kdat[i,:] = np.loadtxt(join(d,'modeled_K_field.mod'),dtype=dt)
    # log10 ratio y/x (col/row) for conductivity
    adat[i,:] = np.loadtxt(join(d,'modeled_A_field.mod'),dtype=dt)

    # log10 travel time to LWB is first column, last row
    fn = open(join(d,'dtrk.out'),'r')
    trav[i] = float(fn.readlines()[-1].split()[0])
    fn.close()

    # read in modflow head (saved in file as a matrix already)
    hdat[i,:] = np.loadtxt(join(d,'modeled_head.hed'),dtype=dt)[::-1,:].reshape((numel,))

kdat = np.log10(kdat)
adat = np.log10(adat)
trav = np.log10(trav)

hdat[hdat == -999] = np.NaN

tflat = trav.flatten()
kdat[kdat < -15] = np.NaN
keff = kdat + 0.5*adat

print 'min log effective k:',np.nanmin(keff)
print 'max log effective k:',np.nanmax(keff)

# define a mask that selects the WIPP LWB area + a buffer of cells around it
wippmask = np.zeros((307,284),dtype='bool') # false boolean array
buffer = 15
wippmask[121-buffer:185+buffer,88-buffer:152+buffer] = True
wippmask.shape = (307*284,)

print 'successfully loaded model data'
```

8.4.4. Python script `export_pcor_inputs.py`

The following Python script calls the library `load_model_data.py` to read in the model data, then exports the K_{eff} and head data for an area surrounding the WIPP LWB for use in the following R script that does the partial correlation analysis.

```
import numpy as np
from load_model_data import *

# save large matrix: nrows = 100
# ncols = # elements (here (64 + (buffer * 2))**2 + 1 for travel time)

# save imported data for use in R
# for partial correlation analysis

# perform outer difference, then only use upper triangle of tensor

np.savetxt('keff_trav.dat',
           np.concatenate((keff[:,wippmask],trav[:,None]),axis=1),
           fmt='%.7f')
```

```
np.savetxt('head_trav.dat',
           np.concatenate((hdat[:,wippmask],trav[:,None]),axis=1),
           fmt='%.7f')

print 'saved data for partial correlation analysis in R'
```

8.4.5. R script `compute_partial_correlations.R`

The following R script loads in the data exported by `export_pcor_inputs.py`, computes the partial correlation of K_{eff} and head in each cell to travel times and head to travel times, accounting for the effects K_{eff} or head in all other cells.

```
# read in the matrix that has realizations as rows (100) and parameters as columns
# (k or h at model cells and travel time as last column)

k <- read.table('keff_trav.dat')
library(corpcor)

# this takes a lot of RAM (> 2GB)
pc <- pcor.shrink(k)

# write all rows, last column to file (partial correlation of each k  to travel time
# holding effects of all other k values constant)
write.table(pc[,dim(pc)[1]],'kpc.out',row.names=FALSE,col.names=FALSE)

h <- read.table('head_trav.dat')
pc <- pcor.shrink(h)

# write all rows, last column to file (partial correlation of each k  to travel time
# holding effects of all other k values constant)
write.table(pc[,dim(pc)[1]],'hpc.out',row.names=FALSE,col.names=FALSE)
```

8.4.6. Python script `spearman_rank_coefficient.py`

The following Python script computes correlation statistics between the results of the Culebra model calibration (particle tracking times to the WIPP LWB) and the Culebra model input files, creating plots of the results for the report.

```
import numpy as np
from os.path import join
from glob import glob
import matplotlib
matplotlib.use('Agg') # to improve memory usage
import matplotlib.pyplot as plt
import matplotlib.colors as colors

# save code for loading data in separate module
from load_model_data import *

def finish_fig(extents):
    '''Add common things to figures'''
    plt.hold = True
    plt.xlabel('UTM NAD27 X [km]')
    plt.axis(extents)
    locs,labels = plt.xticks()
    plt.xticks(locs,(locs/1000.0).astype('|S3'))
    plt.ylabel('UTM NAD27 Y [km]')
    locs,labels = plt.yticks()
    plt.yticks(locs,(locs/1000.0).astype('|S4'),rotation=90)
    plt.plot(wipp[:,0],wipp[:,1],'k-',linewidth=1)
    plt.plot(h2[:,0],h2[:,1],'g--',linewidth=2)
    plt.plot(h3[:,0],h3[:,1],'r:',linewidth=2)
    plt.plot(salado[:,0],salado[:,1],'k:',linewidth=2)
    plt.plot(wells[fiberg,0],wells[fiberg,1],'gs',markersize=4)
    plt.plot(wells[~fiberg,0],wells[~fiberg,1],'ro',markersize=4)
    plt.axis('image')
    plt.axis(extents)

# load in partial-correlation data exported from R
pck = np.zeros((307*284,),dtype=dt)
```

```
pch = np.zeros((307*284,),dtype=dt)

pch[wippmask] = np.loadtxt('hpc.out',dtype=dt)
pck[wippmask] = np.loadtxt('kpc.out',dtype=dt)

pck.shape = (307,284)
pch.shape = (307,284)

print 'successfully loaded partial correlation data'

for n in xrange(numel):
    if n % 10000 == 0:
        print n

    # A = travel time from C-2737 to WIPP LWB (global)
    # B = head at same cell as property (local)
    # Tx vs A/B
    # Ty vs A/B
    # Teff vs A/B
    # A vs B

    data1 = [kdat[:,n],  kdat[:,n] + adat[:,n], kdat[:,n] + 0.5*adat[:,n]]
    hflat = hdat[:,n].flatten()

    for i,d in enumerate(data1):
        dflat = d.flatten()
        tcorr[i,n] = np.corrcoef(dflat,tflat)[0,1]
        hcorr[i,n] = np.corrcoef(dflat,hflat)[0,1]

    tcorr[ndata,n] = np.corrcoef(hflat,tflat)[0,1]

# blank out no-flow area
tcorr[np.isnan(kdat[0,:])[None,:]] = np.NaN
hcorr[np.isnan(kdat[0,:])[None,:]] = np.NaN

# clean up some temporary things
del data1
del hflat
del dflat

wipp = np.loadtxt(datadir+'wipp_boundary.dat')
h2 = np.loadtxt(join(datadir,'h2_200711.dat'),delimiter=',')
h3 = np.loadtxt(join(datadir,'h3_200711.dat'),delimiter=',')
salado = np.loadtxt(join(datadir,'mrgn_dissolution.dat'),skiprows=5)
wells = np.loadtxt(datadir+'2007_well_data.dat')
fiberg = wells[:,4] == 0.0

# regional left,right,bottom,top
regext = (xmin,xmax,ymin,ymax)

# wipp area left,right,bottom,top
wippext = (wipp[:,0].min() - 1500.0, wipp[:,0].max() + 1500.0,
           wipp[:,1].min() - 1500.0, wipp[:,1].max() + 1500.0)

cmap = colors.LinearSegmentedColormap.from_list('bwr',('blue','white','red'))
norm1 = colors.Normalize(vmin=-1,vmax=+1)
norm2 = colors.Normalize(vmin=-0.5,vmax=+0.5)
normsm1 = colors.Normalize(vmin=-0.015,vmax=+0.015)
normsm2 = colors.Normalize(vmin=-0.005,vmax=+0.005)

plt.figure(1)
plt.semilogy(10.0**trav,'k*')
plt.xlabel('realization')
plt.ylabel('years travel time to WIPP LWB')
plt.savefig('travel_times.png')
plt.close(1)

fmt = '%.5e'
fn = ['_kx_','_ky_','_keff_']
nn = ['K_x', 'K_y','K_{eff}']

# plot comparisons of partial and regular Keff correlation inside WIPP
plt.figure(1,figsize=figsize,dpi=dpi)
plt.subplot(121)
plt.imshow(tcorr[2,:].reshape((ny,nx)),interpolation='nearest',
           cmap=cmap,norm=norm2,extent=regext)
plt.colorbar(shrink=0.8)
finish_fig(wippext)
plt.title('corr. $K_{eff}$ w/ travel time')
plt.subplot(122)
plt.imshow(pck.reshape((ny,nx)),interpolation='nearest',
```

```
           cmap=cmap,norm=normsm2,extent=regext)
plt.colorbar(shrink=0.8)
finish_fig(wippext)
plt.title('partial corr. $K_{eff}$ w/ travel time')
plt.savefig('Keff_partial_travel_time_corr.png')
plt.close(1)

# plot comparisons of partial and regular head correlation inside WIPP
plt.figure(1,figsize=figsize,dpi=dpi)
plt.subplot(121)
plt.imshow(tcorr[ndata,:].reshape((ny,nx)),interpolation='nearest',
           cmap=cmap,norm=norm2,extent=regext)
plt.colorbar(shrink=0.8)
finish_fig(wippext)
plt.title('corr. $h$ w/ travel time')
plt.subplot(122)
plt.imshow(pch.reshape((ny,nx)),interpolation='nearest',
           cmap=cmap,norm=normsm1,extent=regext)
plt.colorbar(shrink=0.8)
finish_fig(wippext)
plt.title('partial corr. $h$ w/ travel time')
plt.savefig('h_partial_travel_time_corr.png')
plt.close(1)

# write results (reshaped into matrix form)
for j,f in enumerate(fn):
    np.savetxt('corr'+f+'vs_time.dat', tcorr[j,:].reshape((ny,nx)),fmt=fmt)

    plt.figure(1,figsize=figsize,dpi=dpi)
    plt.subplot(121)
    plt.imshow(tcorr[j,:].reshape((ny,nx)),interpolation='nearest',
               cmap=cmap,norm=norm2,extent=regext)
    finish_fig(regext)
    plt.title('regional corr. $' + nn[j] + '$ w/ travel time')
    plt.subplot(122)
    plt.imshow(tcorr[j,:].reshape((ny,nx)),interpolation='nearest',
               cmap=cmap,norm=norm2,extent=regext)
    plt.colorbar(shrink=0.8)
    finish_fig(wippext)
    plt.title('WIPP corr. $' + nn[j] + '$ w/ travel time')
    plt.savefig(f[1:] + 'travel_time_corr.png')
    plt.close(1)

    np.savetxt('corr'+f+'vs_head.dat', hcorr[j,:].reshape((ny,nx)),fmt=fmt)

    plt.figure(2,figsize=figsize,dpi=dpi)
    plt.subplot(121)
    plt.imshow(hcorr[j,:].reshape((ny,nx)),interpolation='nearest',
               cmap=cmap,norm=norm1,extent=regext)
    finish_fig(regext)
    plt.title('regional corr. $' + nn[j] + '$ w/ head')
    plt.subplot(122)
    plt.imshow(hcorr[j,:].reshape((ny,nx)),interpolation='nearest',
               cmap=cmap,norm=norm1,extent=regext)
    plt.colorbar(shrink=0.8)
    finish_fig(wippext)
    plt.title('WIPP corr. $' + nn[j] + '$ w/ head')
    plt.savefig(f[1:] + 'heads_corr.png')
    plt.close(2)

np.savetxt('corr_head_vs_time.dat', tcorr[ndata,:].reshape((ny,nx)),fmt=fmt)

plt.figure(4,figsize=figsize,dpi=dpi)
plt.subplot(121)
plt.imshow(tcorr[ndata,:].reshape((ny,nx)),interpolation='nearest',
           cmap=cmap,norm=norm2,extent=regext)
finish_fig(regext)
plt.title('regional corr. head w/ time')
plt.subplot(122)
plt.imshow(tcorr[ndata,:].reshape((ny,nx)),interpolation='nearest',
           cmap=cmap,norm=norm2,extent=regext)
plt.colorbar(shrink=0.8)
finish_fig(wippext)
plt.title('WIPP corr. head w/ time')
plt.savefig('heads_vs_travel_time_corr.png')
plt.close(4)

# compute variance across all realizations for output and each parameter
print 'travel time to WIPP LWB:\tmean:%.8e\tstd:%.8e\n' % \
    (trav.sum()/100.0,np.sqrt(np.var(trav)))

```

```
data = [kdat, kdat+adat, kdat+0.5*adat]
dnam = ['kx_', 'ky_', 'keff_']
dnnm = ['$\\log_{10}(K_x', '$\\log_{10}(K_y', '$\\log_{10}(K_{eff}']

for j,(dat,nam) in enumerate(zip(data,dnam)):
    std = np.sqrt(np.var(dat,axis=0).reshape((ny,nx)))
    std[std < 1.0E-10] = 0.0
    mean = (dat.sum(axis=0)/100.0).reshape((ny,nx))
    np.savetxt(nam+'var.out',std,fmt=fmt)
    np.savetxt(nam+'mean.out',mean,fmt=fmt)
    plt.figure(3,figsize=figsize,dpi=dpi)
    plt.subplot(121)
    plt.imshow(mean,interpolation='nearest',extent=regext)
    plt.colorbar(shrink=0.8)
    finish_fig(regext)
    plt.title('mean ' + dnnm[j] + ')$')
    plt.subplot(122)
    plt.imshow(std,interpolation='nearest',extent=regext, norm=colors.Normalize(vmin=0.0))
    plt.colorbar(shrink=0.8)
    finish_fig(regext)
    plt.title('$\\log_{10}$ standard deviation ' + dnnm[j] + ')$')
    plt.savefig(nam + 'avg_std.png')
    plt.close(3)
```

8.5. Combination of Three Methods Scripts

8.5.1. Python script `combine_plot_methods.py`

The following Python script combines the results of the three individual methods, plots the figures in the text, and samples the results at steel-cased well locations to create the table in the text.

```
import numpy as np
import matplotlib
matplotlib.use('Agg')
import matplotlib.pyplot as plt
import matplotlib.colors as colors
from os.path import join
from itertools import chain

# weights used for recombination
w = (0.5,1.0,1.0)

def normalize_field(f):
    """pass a field with NaN in places outside active modflow region"""
    fmin = np.nanmin(f)
    fmax = np.nanmax(f)
    return (f-fmin)/(fmax-fmin)

def normalize_triangle(f):
    fmin = np.nanmin(f)
    fmax = np.nanmax(f)
    return f/(fmax-fmin)

def spread_field(fsm,factor=2):
    """map a field that is a subset of the 307x284 field onto the large field"""
    flarge = np.empty((fsm.shape[0]*factor,fsm.shape[1]*factor),dtype=fsm.dtype)
    for j,row in enumerate(fsm):
        drow = list(chain(*[(x,x) for x in row]))
        flarge[2*j,:] = drow
        flarge[2*j+1,:] = drow
    return flarge[0:-1,:]

def finish_fig(extents):
    '''Add common things to figures'''
    plt.hold = True
    plt.xlabel('UTM NAD27 X [km]')
    plt.axis(extents)
    locs,labels = plt.xticks()
    plt.xticks(locs,(locs/1000.0).astype('|S3'))
    plt.ylabel('UTM NAD27 Y [km]')
    locs,labels = plt.yticks()
    plt.yticks(locs,(locs/1000.0).astype('|S4'),rotation=90)
    plt.plot(wipp[:,0],wipp[:,1],'k-',linewidth=1)
    plt.plot(h2[:,0],h2[:,1],'g--',linewidth=2)
    plt.plot(h3[:,0],h3[:,1],'r:',linewidth=2)
    plt.plot(salado[:,0],salado[:,1],'b:',linewidth=2)
```

```
    plt.plot(wells[fiberg,0],wells[fiberg,1],'gs',markersize=4)
    plt.plot(wells[steel,0],wells[steel,1],'ro',markersize=4)
    plt.axis('image')
    plt.axis(extents)

datadir = join('..','common_data')

fh = open(join(datadir,'model_domain_specs.dat'),'r')
nx,ny =     [int(x) for x in fh.readline().strip().split()]
xmin,ymin = [float(x) for x in fh.readline().strip().split()]
xmax,ymax = [float(x) for x in fh.readline().strip().split()]
fh.close()

wipp = np.loadtxt(join(datadir,'wipp_boundary.dat'))
h2 = np.loadtxt(join(datadir,'h2_200711.dat'),delimiter=',')
h3 = np.loadtxt(join(datadir,'h3_200711.dat'),delimiter=',')
salado = np.loadtxt(join(datadir,'mrgn_dissolution.dat'),skiprows=5)
wells = np.loadtxt(join(datadir,'2007_well_data.dat'))

fhwn = open(join(datadir,'2007_well_data_with_names.dat'),'r')
# names are last column of each row, but not including 2 wells in CH region
steel_well_names = [x.rstrip().split()[-1] for x in fhwn if x.split()[-2] == '1']
fhwn.close()

fiberg = wells[:,4] == 0.0
steel = wells[:,4] == 1.0

wellij = np.zeros((steel.sum(),2),'int')
wellij[:,0] = np.floor((wells[steel,0] - xmin)/100.0)
wellij[:,1] = np.floor((ymin - wells[steel,1])/100.0)

# regional left,right,bottom,top
regext = (xmin,xmax,ymin,ymax)

# wipp area left,right,bottom,top
wippext = (wipp[:,0].min() - 1500.0, wipp[:,0].max() + 1500.0,
           wipp[:,1].min() - 1500.0, wipp[:,1].max() + 1500.0)

fs = (18,9)

# read in mean/medain kriging + 1 results
# these are on a mesh with 1/4 as many elements (1/2 as many in each direction)
# and therefore must be mapped onto the MODFLOW grid

kmean = np.loadtxt(join('..','kriging_add_well','addone_mod_results_mean.dat'))
kmedian = np.loadtxt(join('..','kriging_add_well','addone_mod_results_median.dat'))

kmean[kmean==1] = np.NaN      # blank out areas outside MODFLOW active areas
kmedian[kmedian==1] = np.NaN

nkmean = normalize_field(kmean)
nkmedian = normalize_field(kmedian)

kmean = spread_field(kmean)[::-1,:]
kmedian = spread_field(kmedian)[::-1,:]

nkmean = spread_field(nkmean)[::-1,:]  # flip wrt y
nkmedian = spread_field(nkmedian)[::-1,:]

# read in the results of the add-one analysis for triangles
tmean = np.loadtxt(join('..','triangle_add_well','triangles_add_one_mean.dat'))
tmedian = np.loadtxt(join('..','triangle_add_well','triangles_add_one_median.dat'))

tmean[tmean==-999] = np.NaN      # blank out areas outside MODFLOW active areas
tmedian[tmedian==-999] = np.NaN

ntmean = normalize_triangle(tmean)[::-1,:]
ntmedian = normalize_triangle(tmedian)[::-1,:]

# read in correlation results (handling the NaN in the file)
fhk = open(join('..','model_correlation','CRA2009_model',
                         'final_100_fields','corr_keff_vs_time.dat'),'r')
kl = []
for line in fhk:
    kl.append([float(x) for x in
               line.strip().replace('1.#QNANe+00','-999').split()])
fhk.close()
kcorr = np.array(kl)
del kl

fhh = open(join('..','model_correlation','CRA2009_model',
```

```
                        'final_100_fields','corr_head_vs_time.dat'),'r')
hl = []
for line in fhh:
    hl.append([float(x) for x in
               line.strip().replace('1.#QNANe+00','-999').replace('-1.#IND0e+00','1.0E-
16').split()])
fhh.close()
hcorr = np.array(hl)
del hl

# set -999 substituted above back to NaN
kcorr[kcorr==-999]=np.NaN
kcorr[np.isnan(tmean[::-1,:])]=np.NaN
hcorr[hcorr==-999]=np.NaN
hcorr[np.isnan(tmean[::-1,:])]=np.NaN

nkcorr = normalize_field(np.abs(kcorr))  # should already be flipped
nhcorr = normalize_field(np.abs(hcorr))

# ####################
# compute the remove-one analysis for correlation results from sampling-based correlation
analysis
fh = open('corr_remove_one_steel.dat','w')

fh.write('\t'.join(steel_well_names) + '\n')
np.savetxt(fh,kcorr[wellij[:,1],wellij[:,0]][None,:],fmt='%.6e',delimiter='\t')
np.savetxt(fh,hcorr[wellij[:,1],wellij[:,0]][None,:],fmt='%.6e',delimiter='\t')
fh.close()

# plot up histograms of distribution in each field
plt.figure(1,figsize=(12.5,10))
bins = 150

plt.subplot(321)
plt.hist(nkmean[~np.isnan(nkmean)].flatten(),bins=bins)
plt.ylabel('frequency')
plt.xlabel(r'scaled mean $\Delta$ kriging var.')
plt.axis('tight')

plt.subplot(322)
plt.hist(nkmedian[~np.isnan(nkmedian)].flatten(),bins=bins)
plt.xlabel(r'scaled median $\Delta$ kriging var.')
plt.axis('tight')

plt.subplot(323)
plt.hist(ntmean[~np.isnan(ntmean)].flatten(),bins=bins)
plt.ylabel('frequency')
plt.xlabel(r'scaled mean $\Delta$ triangle angle raio')
plt.axis('tight')

plt.subplot(324)
plt.hist(ntmedian[~np.isnan(ntmedian)].flatten(),bins=bins)
plt.xlabel(r'scaled median $\Delta$ triangle angle raio')
plt.axis('tight')

plt.subplot(325)
plt.hist(nkcorr[~np.isnan(nkcorr)].flatten(),bins=bins)
plt.ylabel('frequency')
plt.xlabel(r'scaled $\rho$ $K_{eff}$ vs. $t$')
plt.axis('tight')

plt.subplot(326)
plt.hist(nhcorr[~np.isnan(nhcorr)].flatten(),bins=bins)
plt.xlabel(r'scaled $\rho$ head vs. $t$')
plt.axis('tight')

plt.subplots_adjust(hspace=0.3)
plt.savefig('histograms_of_distributions.png')
plt.close(1)

# plot up histograms of original (unscaled) distribution in each field
plt.figure(1,figsize=(12.5,10))
bins = 150

plt.subplot(321)
plt.hist(kmean[~np.isnan(kmean)].flatten(),bins=bins)
plt.axis('tight')
plt.ylabel('frequency')
plt.xlabel(r'unscaled mean $\Delta$ kriging var.')

plt.subplot(322)
```

```
plt.hist(kmedian[~np.isnan(kmedian)].flatten(),bins=bins)
plt.axis('tight')
plt.xlabel(r'unscaled median $\Delta$ kriging var.')

plt.subplot(323)
plt.hist(tmean[~np.isnan(tmean)].flatten(),bins=bins)
plt.axis('tight')
plt.ylabel('frequency')
plt.xlabel(r'unscaled mean $\Delta$ triangle angle raio')

plt.subplot(324)
plt.hist(tmedian[~np.isnan(tmedian)].flatten(),bins=bins)
plt.axis('tight')
plt.xlabel(r'unscaled median $\Delta$ triangle angle raio')

plt.subplot(325)
plt.hist(kcorr[~np.isnan(kcorr)].flatten(),bins=bins)
plt.axis('tight')
plt.ylabel('frequency')
plt.xlabel(r'unscaled $\rho$ $K_{eff}$ vs. $t$')

plt.subplot(326)
plt.hist(hcorr[~np.isnan(hcorr)].flatten(),bins=bins)
plt.axis('tight')
plt.xlabel(r'unscaled $\rho$ head vs. $t$')

plt.subplots_adjust(hspace=0.3)
plt.savefig('histograms_of_original_distributions.png')
plt.close(1)

cmap = colors.LinearSegmentedColormap.from_list('rwg',('red','orange','white','blue','purple'))
nrm = colors.Normalize(vmin=-2.4,vmax=2.4)
#cmap = 'jet'
out = np.zeros((307,284,4))

## combine results linearly with multipliers
# mean and median + keff and head = 4 results
plt.figure(1)
#out[:,:,0] = np.sqrt((w[0]*nkcorr)**2 + (w[1]*nkmean)**2 + (w[2]*ntmean)**2)
out[:,:,0] = w[0]*nkcorr + w[1]*nkmean + w[2]*ntmean
plt.imshow(out[:,:,0],interpolation='nearest',extent=regext,cmap=cmap,norm=nrm)
cb = plt.colorbar(shrink=0.8)
cb.set_label('$S_c$')
plt.title('$K_{eff} +$ mean')
finish_fig(regext)
plt.savefig('combined_results_map_Keff_mean.png')
plt.close(1)

plt.figure(1)
#out[:,:,1] = np.sqrt((w[0]*nhcorr)**2 + (w[1]*nkmean)**2 + (w[2]*ntmean)**2)
out[:,:,1] = w[0]*nhcorr + w[1]*nkmean + w[2]*ntmean
plt.imshow(out[:,:,1],interpolation='nearest',extent=regext,cmap=cmap,norm=nrm)
cb = plt.colorbar(shrink=0.8)
cb.set_label('$S_c$')
plt.title('$h +$ mean' )
finish_fig(regext)
plt.savefig('combined_results_map_h_mean.png')
plt.close(1)

plt.figure(1)
#out[:,:,2] = np.sqrt((w[0]*nkcorr)**2 + (w[1]*nkmedian)**2 + (w[2]*ntmedian)**2)
out[:,:,2] = w[0]*nkcorr + w[1]*nkmedian + w[2]*ntmedian
plt.imshow(out[:,:,2],interpolation='nearest',extent=regext,cmap=cmap,norm=nrm)
cb = plt.colorbar(shrink=0.8)
cb.set_label('$S_c$')
plt.title('$K_{eff} +$ median' )
finish_fig(regext)
plt.savefig('combined_results_map_Keff_median.png')
plt.close(1)

plt.figure(1)
#out[:,:,3] = np.sqrt((w[0]*nhcorr)**2 + (w[1]*nkmedian)**2 + (w[2]*ntmedian)**2)
out[:,:,3] = w[0]*nhcorr + w[1]*nkmedian + w[2]*ntmedian
plt.imshow(out[:,:,3],interpolation='nearest',extent=regext,cmap=cmap,norm=nrm)
cb = plt.colorbar(shrink=0.8)
cb.set_label('$S_c$')
plt.title('$h +$ median' )
finish_fig(regext)
plt.savefig('combined_results_map_h_median.png')
plt.close()

```

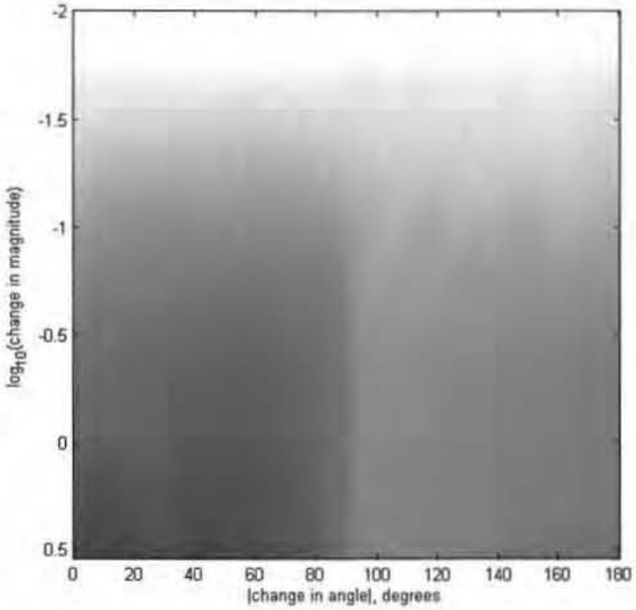
```
# ########################################
# save table of results at steel-cased wells
fh = open('composite_remove_one_steel.dat','w')

fh.write('\t'.join(steel_well_names) + '\n')
for j in [0,1,2,3]:
    np.savetxt(fh,out[wellij[:,1],wellij[:,0],j][None,:],fmt='%.6e',delimiter='\t')
fh.close()
```

9.0 Remove One Steel Well Figures

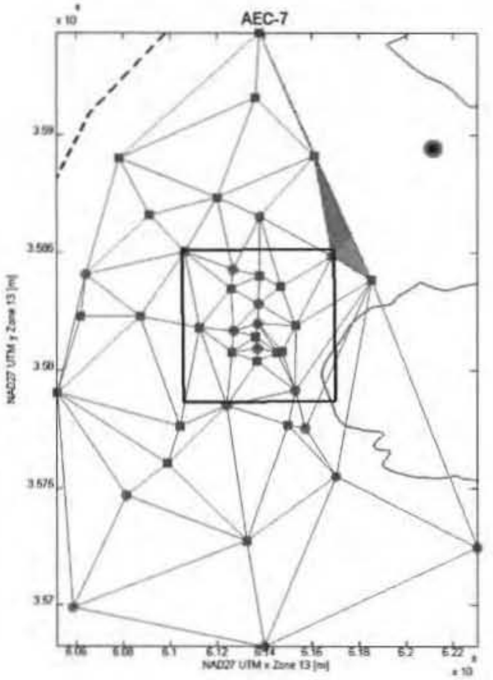
The following set of 18 figures (1 colormap and 17 map plots) shows the computed impact on the estimated local gradient from removal of a single steel-cased well from the Culebra monitoring network. Two different types of changes are being illustrated; changes in both gradient and magnitude are represented by the hue and saturation of the color, respectively. White areas in the figures correspond to areas where the change in the predicted gradient is less than the threshold value (0.01), while the deeply colored areas indicate a large change in the magnitude of the gradient. Hot (red) colors indicate the magnitude of the change in angle, with cool colors (blue) indicating no change in direction (both factors are illustrated in the 2D color map below).

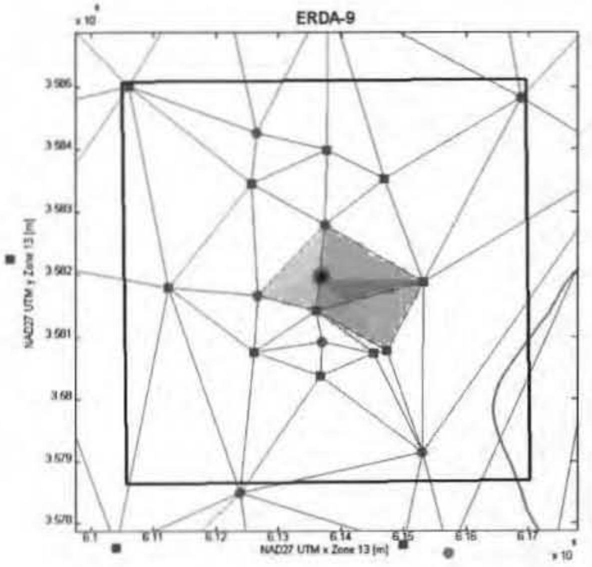
For example, if removing a well causes the gradient to change in magnitude only by the maximum amount, the region would be filled with dark blue. Likewise, if the gradient direction change completely (180 degrees) upon removing the well, but the gradient magnitude only changed slightly, the region would be filled with a faint red or pink color. Magenta indicates a change of 90 degrees, halfway between red and blue.

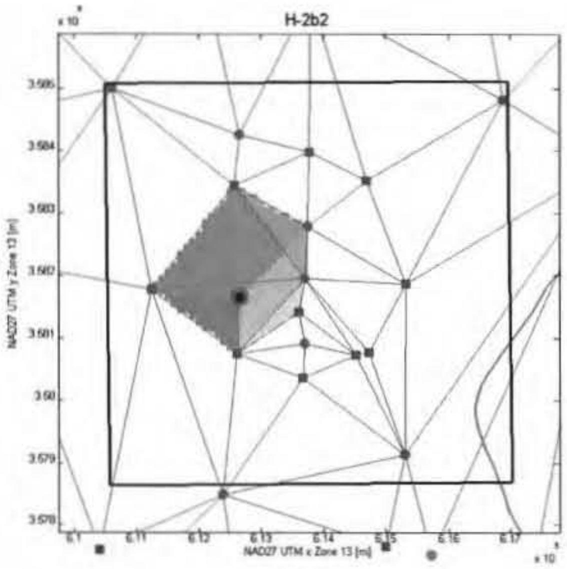


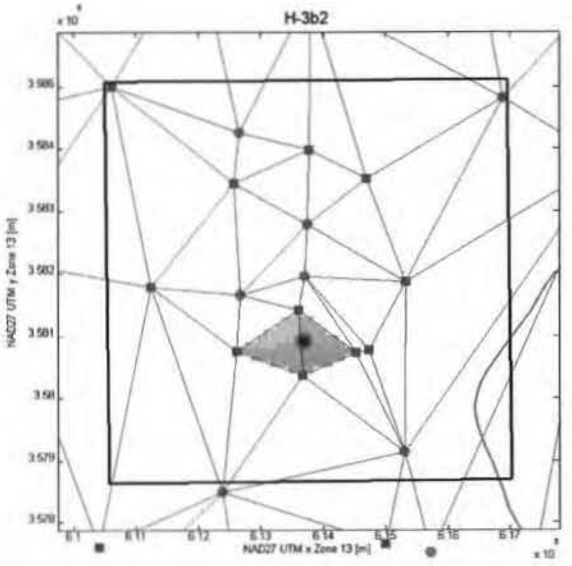
Each figure shows the localized effects on the gradient magnitude estimate, due to removing a steel-cased well from the network. The colors (representing changes above the threshold) are only found in the triangles directly connected to the removed point.

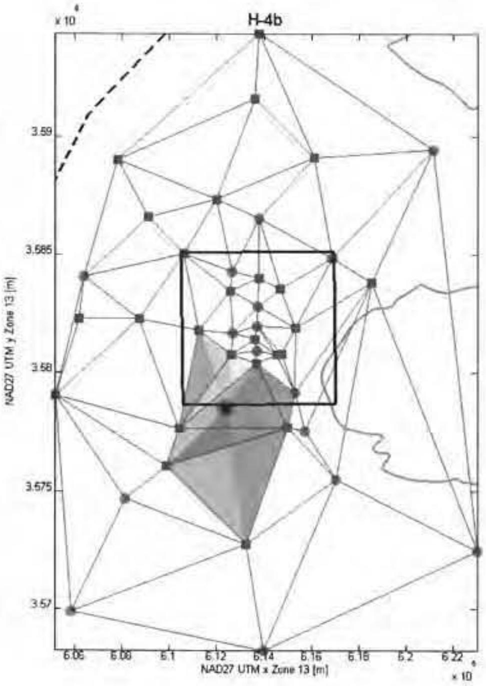
For wells that have no effect outside the WIPP LWB, the plot area is reduced to this smaller area. The Delaunay triangles corresponding to the reduced monitoring network are plotted on the figure; the original triangles are not shown.

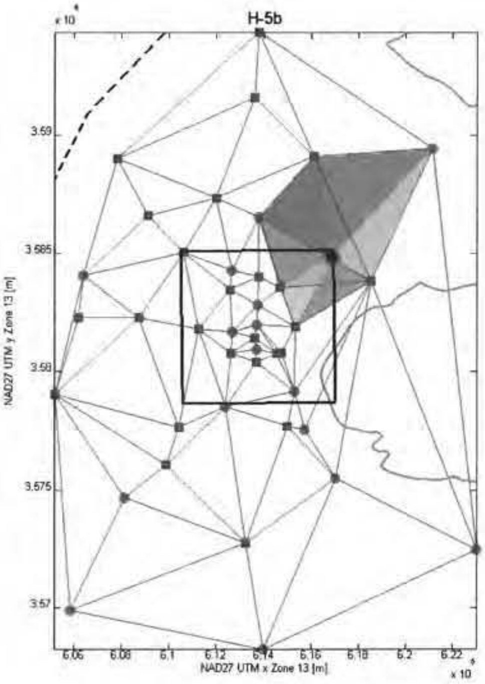

AEC-7
x 10^6
NAD27 UTM y Zone 13 [m]
NAD27 UTM x Zone 13 [m]
x 10^5

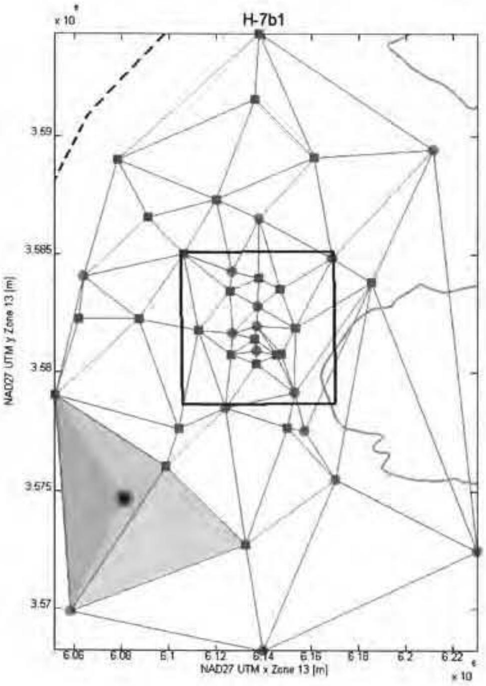

ERDA-9
x 10^6
NAD27 UTM y Zone 13 [m]
NAD27 UTM x Zone 13 [m]
x 10^5

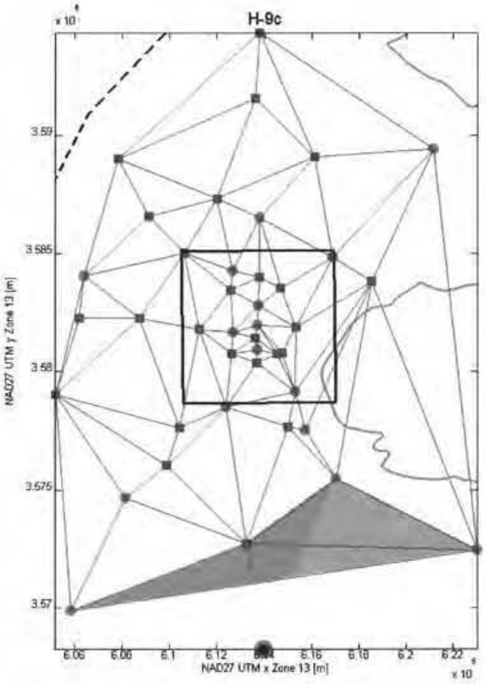

H-2b2
x 10^6
NAD27 UTM y Zone 13 [m]
NAD27 UTM x Zone 13 [m]
x 10^5

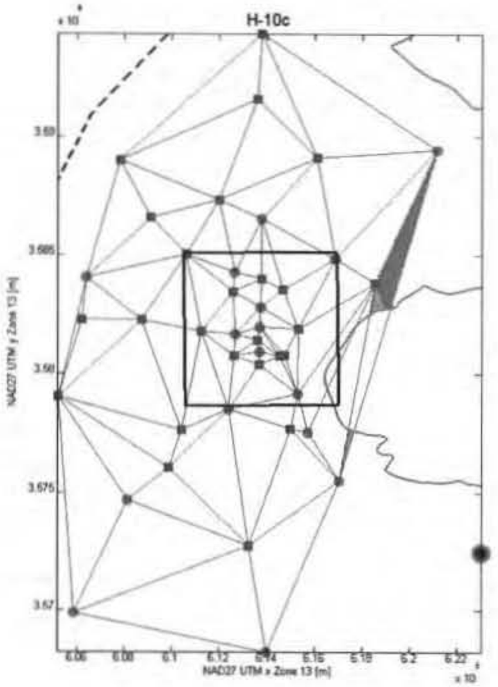

H-3b2
x 10^6
NAD27 UTM y Zone 13 [m]
NAD27 UTM x Zone 13 [m]
x 10^5

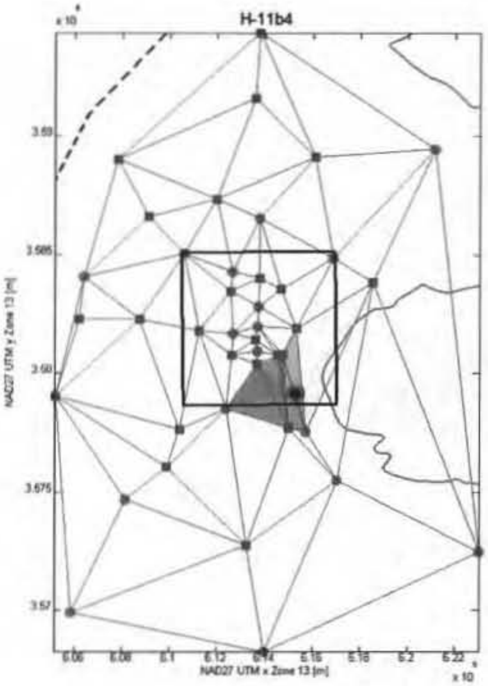

H-4b
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]

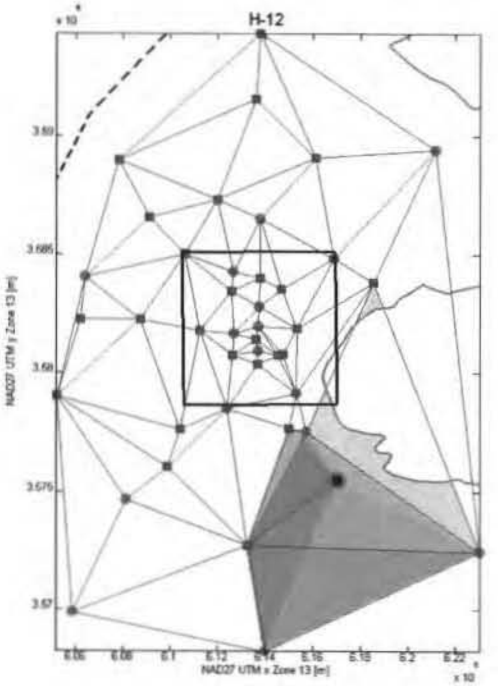

H-5b
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]

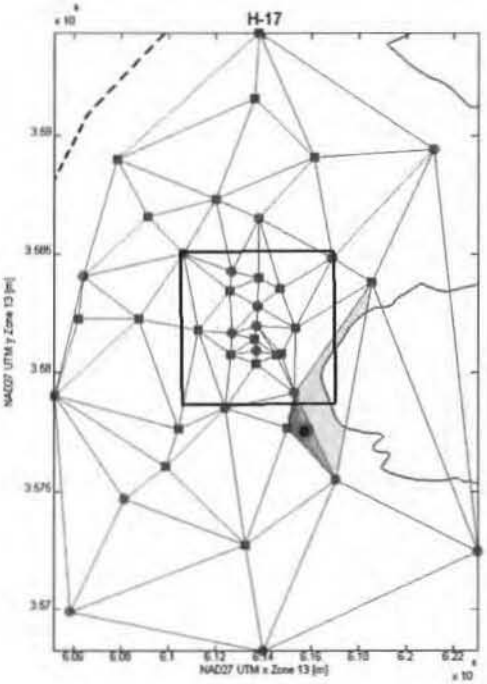

H-7b1
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]

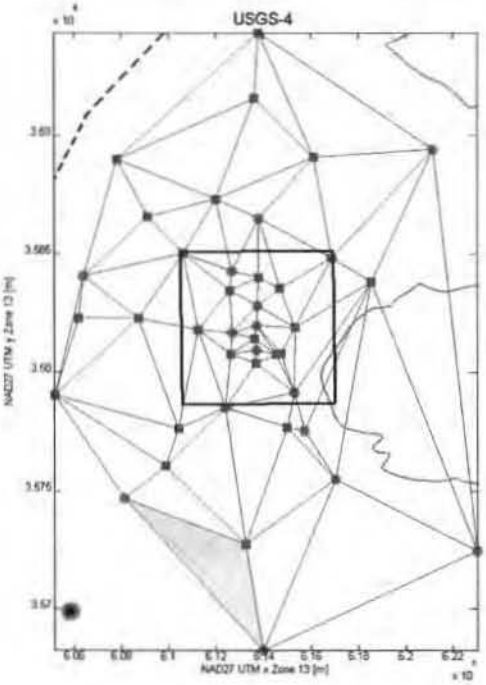

H-9c
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]

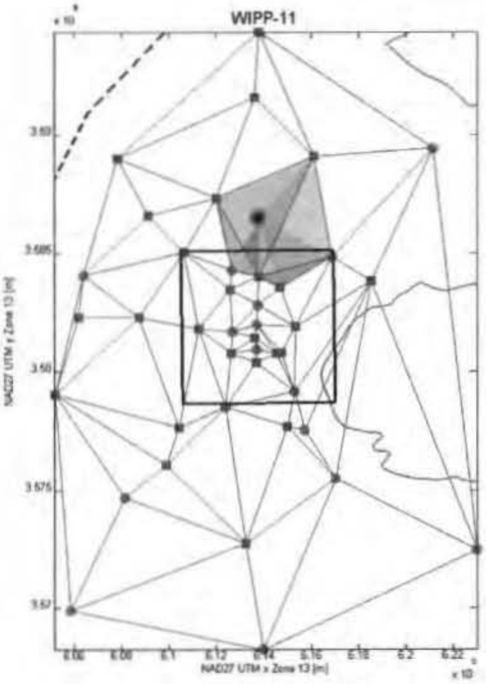

H-10c
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


H-11b4
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


H-12
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


H-17
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


USGS-4
x 10^6
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


WIPP-11
x 10^6
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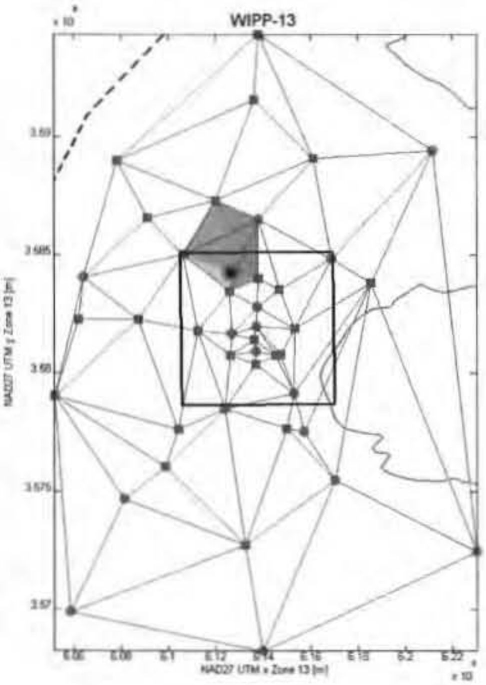
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


WIPP-13
x 10^6
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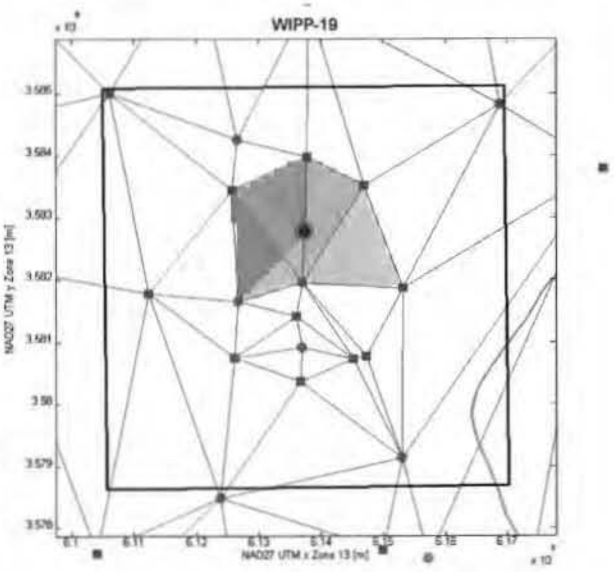
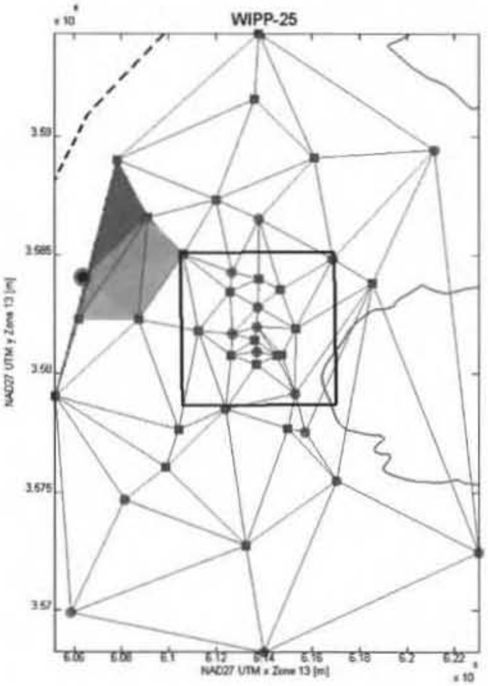
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
x 10^5
NAD27 UTM x Zone 13 [m]


WIPP-19
x 10^6
3.585
3.584
3.583
3.582
3.581
3.58
3.579
3.578
NAD27 UTM y Zone 13 [m]
6.1
6.11
6.12
6.13
6.14
6.15
6.16
6.17
x 10^5
NAD27 UTM x Zone 13 [m]


WIPP-25
x 10
3.59
3.585
3.58
3.575
3.57
NAD27 UTM y Zone 13 [m]
6.06
6.08
6.1
6.12
6.14
6.16
6.18
6.2
6.22
NAD27 UTM x Zone 13 [m]
x 10

DOE/WIPP-95-2154

BASIC DATA REPORT

DOE/WIPP--95-2154

For

WQSP 1
WQSP 2
WQSP 3
WQSP 4
WQSP 5
WQSP 6
WQSP 6a

MASTER

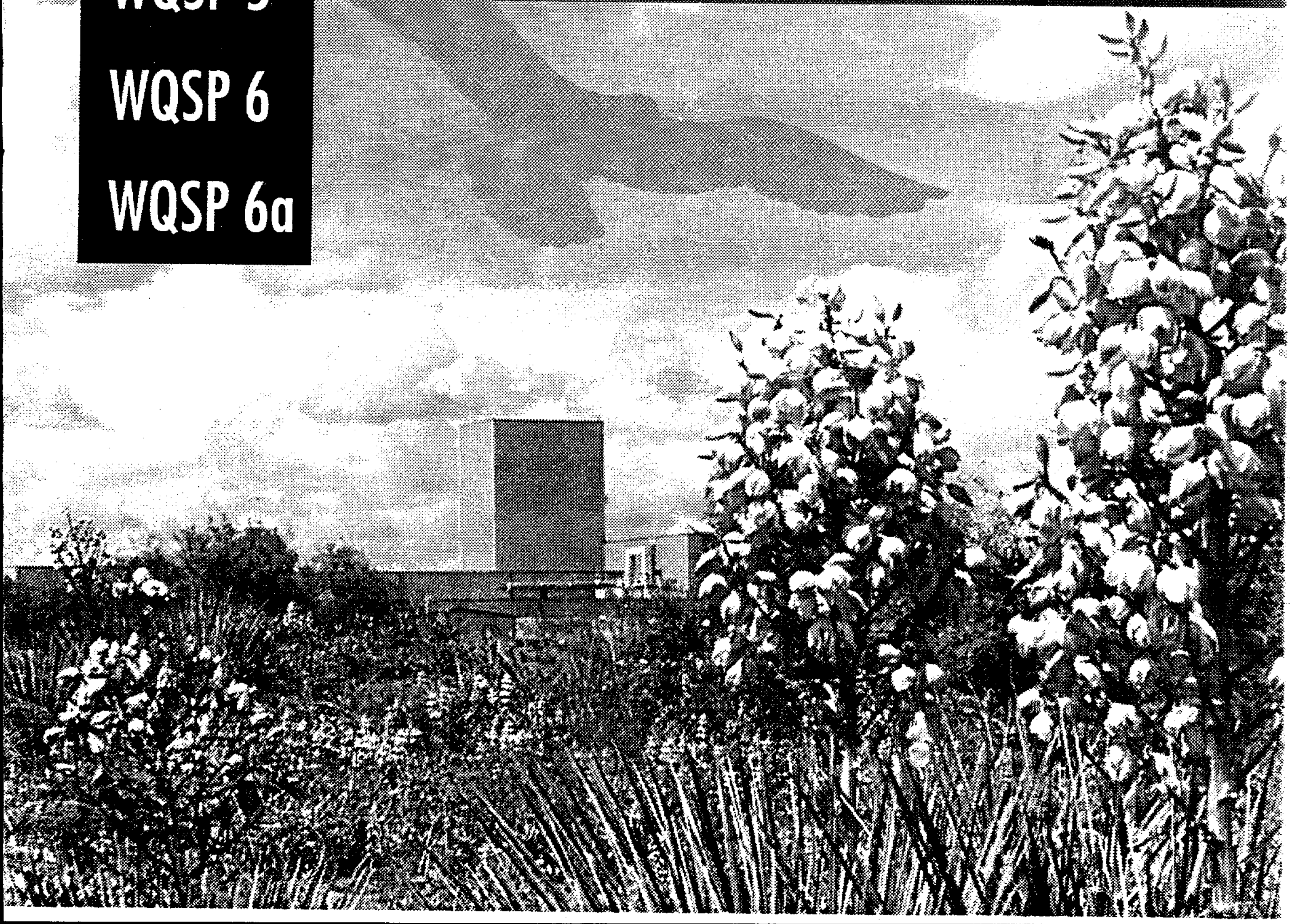


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Table of Contents

List of Tables and Figures

Attachments

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico about 30 miles east of Carlsbad, New Mexico. The WIPP was authorized by Congress in 1979 (Public Law 96-194) and given the mission to provide "...a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." The WIPP is intended to receive, handle, and permanently dispose of transuranic waste. To fulfill this mission, the U.S. Department of Energy is constructing a full scale facility to demonstrate both technical and operational principles of the permanent storage/disposal of transuranic waste. Technical aspects are those concerned with the design, construction, and performance of subsurface structures. Operational aspects refer to the receiving, handling, and emplacement of transuranic waste in salt. The facility is also designed for in situ studies and experiments in salt. The Water Quality Sampling Program (WQSP) evaluates the physical and chemical properties of the groundwater above the repository horizon that are part of the technical performance aspects.

2.0 Purpose of the Water Quality Sampling Program Wells

The objective of the WQSP is to collect representative groundwater samples from water-bearing zones in the area of the WIPP site. These data assist in meeting the requirements of site characterization. The WQSP wells drilled in 1994 are intended to provide representative, reproducible, and defendable quality data that are free of well construction bias. These seven wells were drilled along the boundary of the Off Limits Area under an U.S. Environmental Protection Agency (EPA) directive and enhance the current groundwater monitoring network.

3.0 Description of Drilling Program

Wells WQSP#1 through WQSP#6a are located (Figure 3-1) in east-central Eddy County, New Mexico in the T22S, R31E (Table 3-1). This drilling program was initiated by Westinghouse Electric Corporation and involved a number of subcontractors. Each of their contributions to the program are provided below.

An archeological survey was performed at the locations of the new monitoring wells by Pecos Archeological Consultants. This survey was conducted on May 26 and June 16, 1994 for the six drill pads and new access roads constructed for this program. One archeological site was recorded with significant cultural remains within the impact zone. This site was avoided by rerouting one of the access roads to a drill pad. The description is intentionally vague to protect

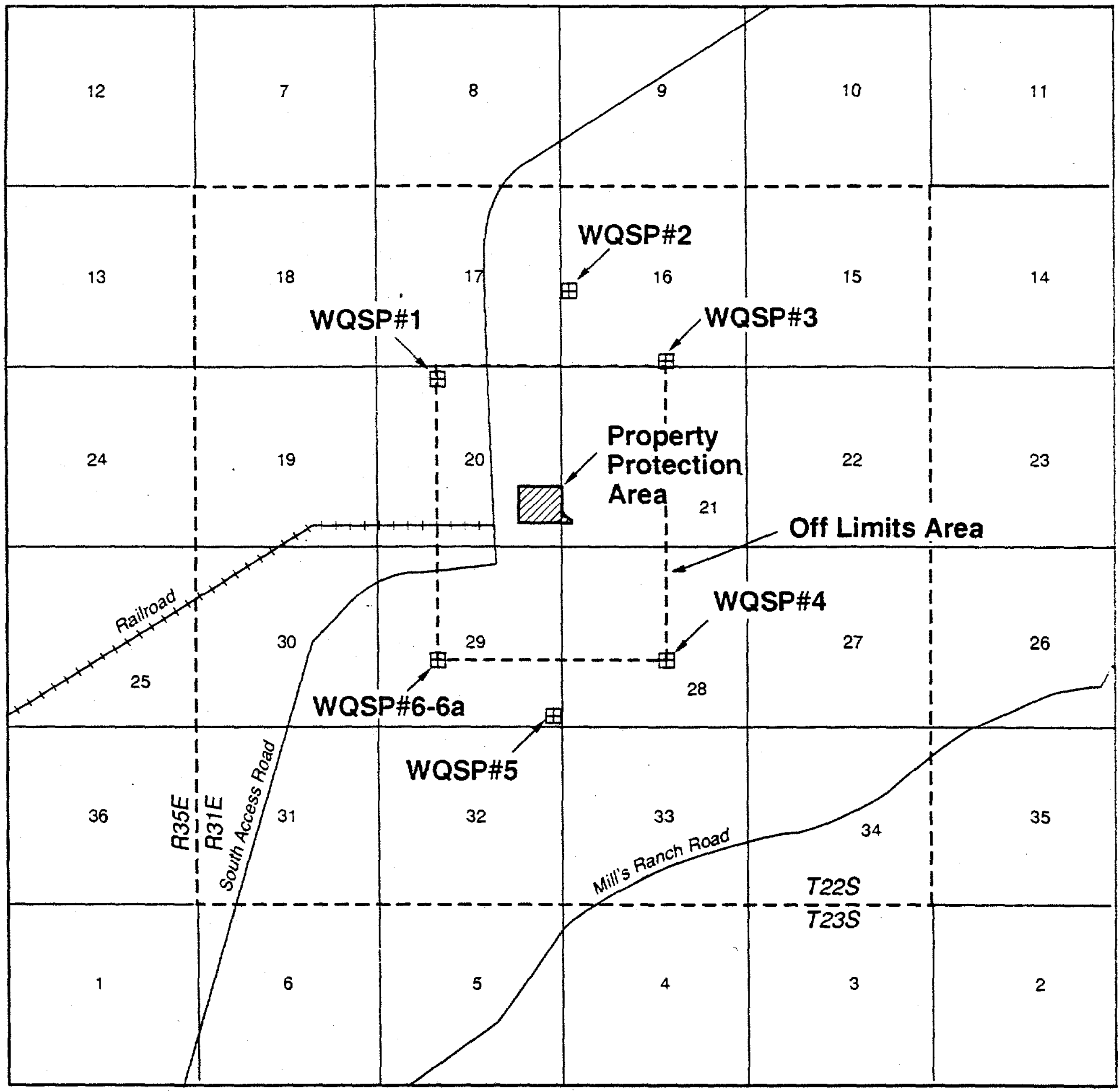


Figure 3-1
Location of WQSP Wells 1 to 6a

Table 3-1
Location Information for the 1994 Water Quality Sampling Program (WQSP) Boreholes

Borehole ID	State Plane Coordinate		Elevation amsl	Location T22S R31E	Coordinates (feet)	
	East	North				
WQSP#1	663600	503774	3416.6	Section 20	101 FNL	1422 FWL
WQSP#2	667598	505542	3461.4	Section 16	1646 FSL	142 FWL
WQSP#3	670576	504030	3477.5	Section 16	96 FSL	2162 FEL
WQSP#4	670658	495000	3430.5	Section 28	1632 FSL	2136 FEL
WQSP#5	667170	493666	3381.6	Section 29	330 FSL	340 FEL
WQSP#6	663691	494942	3361.8	Section 29	1626 FSL	1461 FWL
WQSP#6a	663625	494969	3361.2	Section 29	1653 FSL	1395 FWL

- FNL - feet from north line
- FSL - feet from south line
- FWL - feet from west line
- FEL - feet from east line
- amsl - above mean sea level

the location of this site. Unauthorized collection, vandalism, or excavation of cultural remains is prohibited under the Archeological Resources Protection Act (ARPA) (16 USC §470aa et seq).

The access roads to the drill locations, the drill pads, and the pits were constructed by MMP Construction. The drill pads are 100 ft by 100 ft, topped with construction grade caliche, and occupy approximately 2.29 acres. At each location, two pits were constructed approximately 30 ft by 15 ft and approximately 10 ft deep and lined with high density polyethylene plastic. One pit contained the discharged cuttings and fluids from the drilling; the other pit was divided into two sections, with one side containing the drilling mud, and the other side containing non-potable water. WQSP#6 and WQSP#6a occupy the same drill pad; however, four discharge pits were constructed at this location. After drilling and well development, these pits were filled with soil.

The wells were drilled by West Texas Water Well Service from September to November of 1994 (Table 3-2). Grab samples of the cuttings were taken by IT Corporation every 20 ft to track formations penetrated and to stop open-hole drilling in time to core the Culebra Member of the Rustler Formation. The core was described by INTERA. A condensed well summary, stratigraphic summary, cuttings description, Culebra core description (Dewey Lake core description for WQSP#6a), hole history, and geophysical logs (Century Geophysical Corporation) are presented as appendices in this report.

The drilling plan for the six new monitoring wells provided an option for additional wells to be drilled should water be encountered in the Dewey Lake Formation. Water in the Dewey Lake Formation was encountered in only one well, WQSP#6. WQSP#6a, located approximately 100 ft west of WQSP#6, was terminated within the upper portion of the Dewey Lake Formation for further investigation.

3.1 WQSP#1

WQSP #1 is located 101 ft from the north line and 1422 ft from the west line in Section 20, T22S, R31E in Eddy County, New Mexico. The well was drilled from September 13 through 16, 1994, and encountered 40 ft of Santa Rosa Formation, 482 ft of Dewey Lake Formation, and 174 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 696 ft to 737 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs

Table 3-2
Drilling Information for the 1994 Water Quality Sampling Program (WQSP) Boreholes

Borehole ID	Drill Dates	Total depth (feet)	Cored Interval (feet)	Unit
WQSP#1	September 13-16, 1994	737	696-737	Culebra
WQSP#2	September 6-10, 1994	846	800-846	Culebra
WQSP#3	October 20-26, 1994	879	833-879	Culebra
WQSP#4	October 5-7, 1994	800	740-798	Culebra
WQSP#5	October 12-13, 1994	681	648-676	Culebra
WQSP#6	September 22-30, 1994	617	568-617	Culebra
WQSP#6a	October 28-31, 1994	225	160-220	Dewey Lake

- SPC_NAD27 - State plane coordinates _ North American Datum Model 27 were run in the hole and include: caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity. The geophysical logs were run in this hole before it was reamed, therefore, approximately 40 ft of slough prevented the logging tool from reaching the bottom of the hole. The rest of the wells were reamed before they were logged.

3.2 WQSP#2

WQSP #2 is located 1646 ft from the south line and 142 ft from the west line in Section 16, T22S, R31E in Eddy County, New Mexico. The well was drilled from September 6 through 10, 1994, and encountered 147 ft of Santa Rosa Formation, 486 ft of Dewey Lake Formation, and 215 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 800 ft to 846 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs were run the entire length of the hole and include: caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity.

3.3 WQSP#3

WQSP #3 is located 96 ft from the south line and 2162 ft from the east line in Section 16, T22S, R31E in Eddy County, New Mexico. The well was drilled from October 20 through 26, 1994, and encountered 155 ft of Santa Rosa Formation, 513 ft of Dewey Lake Formation, and 212 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 833 ft to 879 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs were run the entire length of the hole and include: caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity.

3.4 WQSP#4

WQSP #4 is located 1632 ft from the south line and 2136 ft from the east line in Section 28, T22S, R31E in Eddy County, New Mexico. The well was drilled from October 5 through 7, 1994, and encountered 78 ft of Santa Rosa Formation, 510 ft of Dewey Lake Formation, and 212 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 740 ft to 798 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs were run the entire length of the hole and include: caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity.

3.5 WQSP#5

WQSP #5 is located 330 ft from the south line and 340 ft from the east line in Section 29, T22S, R31E in Eddy County, New Mexico. The well was drilled from October 12 through 13, 1994, and encountered 25 ft of Santa Rosa Formation, 450 ft of Dewey Lake Formation, and 206 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 648 ft to 676 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs were run the entire length of the hole and include: spontaneous potential resistivity, natural gamma, density, and neutron porosity.

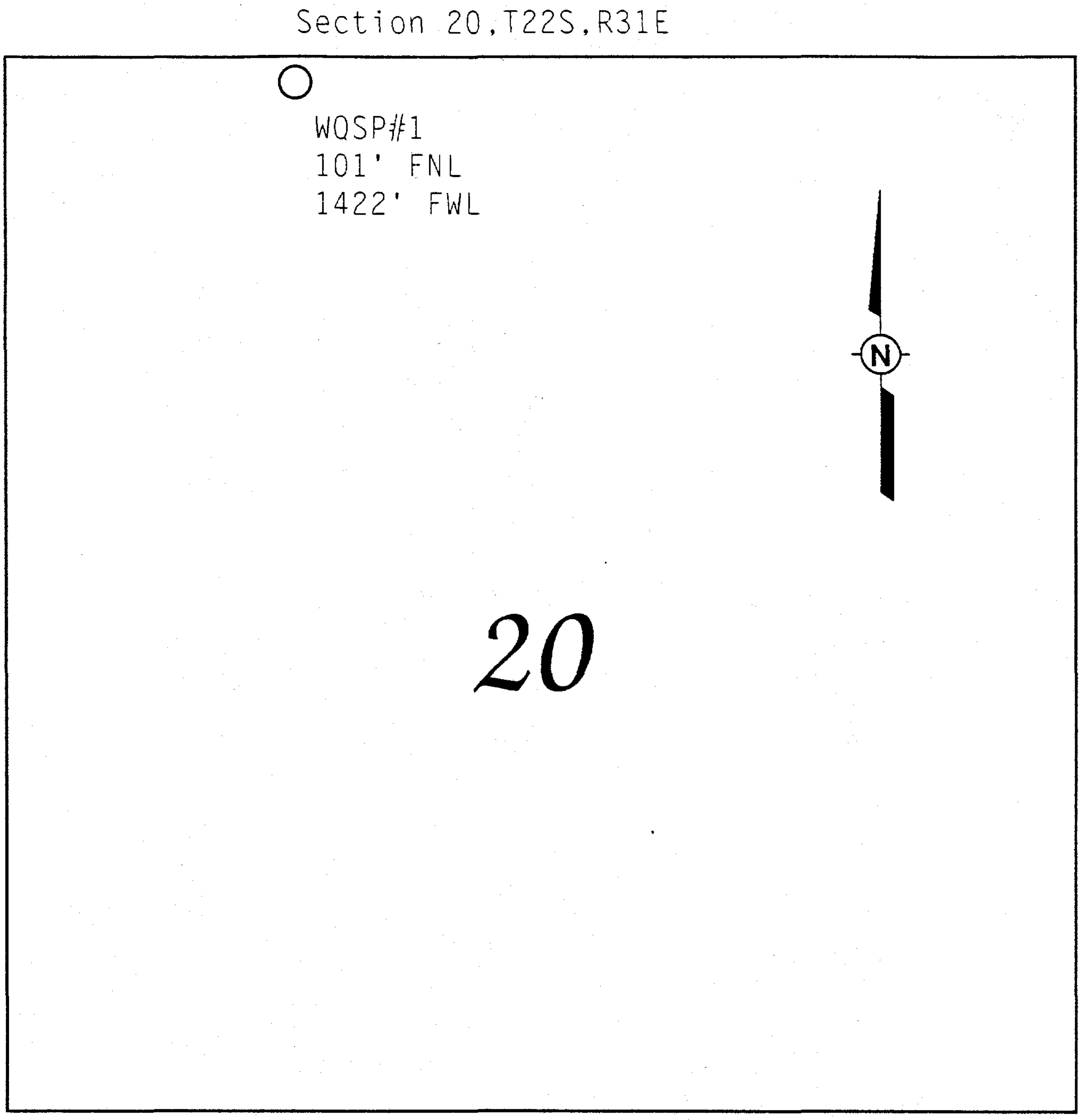
3.6 WQSP#6

WQSP #6 is located 1626 ft from the south line and 1461 ft from the west line in Section 29, T22S, R31E in Eddy County, New Mexico. The well was drilled from September 22, through October 4, 1994, and encountered 68 ft of Santa Rosa Formation, 341 ft of Dewey Lake Formation, and 208 ft of Rustler Formation. Cuttings were collected every 20 ft and the well was cored from 568 ft to 617 ft for detailed description of the Culebra Member of the Rustler Formation. Geophysical logs were run the entire length of the hole and include: deviation, caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity.

3.7 WQSP#6a

WQSP #6a is located 1653 ft from the south line and 1395 ft from the west line in Section 29, T22S, R31E in Eddy County, New Mexico. The well was drilled from October 28, through November 1, 1994, and encountered 35 ft of Santa Rosa Formation and 185 ft of Dewey Lake Formation. Cuttings were collected every 20 ft and the well was cored from 160 ft to 220 ft for detailed description of the Dewey Lake Formation. Geophysical logs were run the entire length of the hole and include: caliper, spontaneous potential, resistivity, natural gamma, and neutron porosity.

WQSP#1



Location of WQSP #1

WQSP #1
Condensed Well Summary

Location:	Section 20, T22S, R31E 101 ft from the north line 1422 ft from the west line	
Elevation: (Top of Casing)	3419.2 ft above mean sea level	
Cuttings Description:	D.S. Belski	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record	Date:	September 13 to 16, 1994
	Bottom of hole:	737 ft below land surface
	Cored interval:	696 to 737 ft
	Cuttings:	every 20 ft

WQSP #1
Stratigraphic Summary

Stratigraphic Unit	***Depth Interval Natural Gamma Log (feet)**	**Core Description**
Surficial Deposits/Santa Rosa	0-40	
Dewey Lake Redbeds	40-522	
Rustler Formation	522-689 partial	
• Forty Niner Member	522-591	
• Magenta Member	591-612	
• Tamarisk Member	612-689?	695.6-699 partial
• Culebra Member	NA	699-722
• Partial lower unnamed member	NA	722-737 partial
Maximum Recorded Depth	689	

* Geophysical logs were run before the hole was reamed. Sloughing in the hole prevented the loggers from reaching bottom.

WQSP #1
CUTTINGS DESCRIPTION

WQSP #1
Cuttings Description*

Date	Time	Sample Number	Depth (feet)	Description
08/31/94	1120	1**	6	Surficial deposits
	1125	2**	25	Surficial deposits
09/13/94	1309	1	45	Mudstone, clay, siltstone and sandstone
	1324	2	65	Siltstone and sandstone
	1353	3	85	Sandstone, siltstone, and mudstone
	1423	4	105	Siltstone and mudstone
	1433	5	125	Sandstone, siltstone, and mudstone
	1520	6	145	Siltstone, mudstone, and clay
	1546	7	165	Sandstone, siltstone, and gypsum
	1610	8	185	Siltstone, mudstone, sandstone, and gypsum
	1638	9	205	Siltstone, mudstone, and gypsum
	1707	10	225	Mudstone, siltstone, and gypsum
	1718	11	245	Siltstone, mudstone, and gypsum
09/14/94	0746	12	265	Sandstone, siltstone, and gypsum
	0759	13	285	Sandstone, siltstone, and gypsum
	0825	14	305	Sandstone, mudstone, and gypsum
	0845	15	325	Sandstone, trace gypsum
	0904	16	345	Siltstone, gypsum, and sand
	0919	17	365	Siltstone and gypsum
	0945	18	385	Sandstone, siltstone, and mudstone
	1009	19	405	Siltstone, mudstone, and sandstone
	1021	20	425	Siltstone, mudstone, and gypsum
	1040	21	445	Siltstone and mudstone
	1102	22	465	Siltstone with selenite, claystone with green reduction spots
	1112	23	485	Siltstone with selenite, claystone with green reduction spots

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling

WQSP #1
Cuttings Description (Continued) *

Date	Time	Sample Number	Depth (feet)	Description
	1131	24	505	Siltstone with selenite and fibrous gypsum
	1154	25	525	Anhydrite and gypsum
09/14/94	1219	26	545	Anhydrite and gypsum
	1235	27	565	Mud
	1306	28	585	Anhydrite and siltstone
	1318	29	605	Anhydrite
	1351	30	625	Anhydrite, selenite, and siltstone
	1413	31	645	Anhydrite
	1502	32	665	Anhydrite
	1536	33	685	Anhydrite with mud

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling

WQSP #1
CULEBRA CORE DESCRIPTION

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OF 3

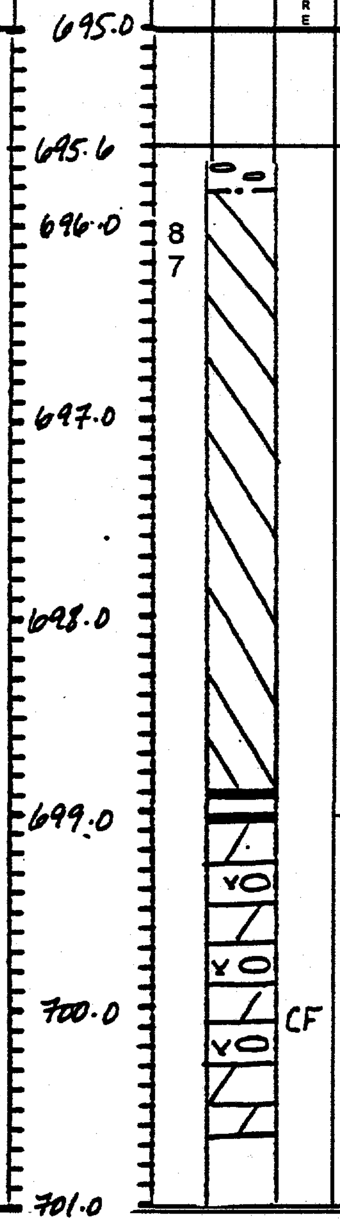
WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/15/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
		695.0					
09/15 11:25	1	695.6	87			695.6 - 699.0 ft: upper 0.2 ft of unit: red-brown mudstone with numerous subrounded-subangular pebble-sized anhydrite clasts underlain by light to dark gray mottled anhydrite with 2-3 mm gypsum laminae. Lower 0.2 ft of unit: light-brown and black interbedded clays. Sharp contact between anhydrite, clay, and underlying Culebra Member.	Tamarisk Member of Rustler Formation
		699.0			CF	699.0 - 700.6 ft: reddish gray-brown microcrystalline dolomite with numerous open vugs (1 mm - 0.25 cm). Fractures occurring along horizontal, thin (< 1 mm) clay seams.	Culebra Member of Rustler Formation



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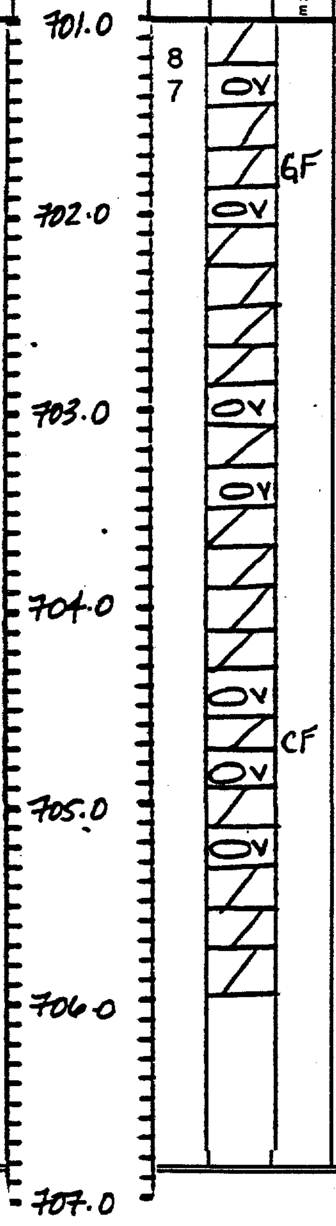
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/15/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/15	1		87			700.6 - 706.0 ft: light olive-gray microcrystalline dolomite. Upper 2 ft of unit contains infrequent open vugs up to 1.5 cm. Vugs decrease in size and increase in frequency toward base of unit (~1 mm). In lower 2.5 ft open vugs form in bands 0.1 to 0.3 ft in width. Horizontal fractures occur toward base of unit along thin (<1 mm) clay seams. In upper 2 ft of unit horizontal fractures occur along gypsum seams. Unit contains infrequent high-angle gypsum veins (2-3 mm).	Culebra Member of Rustler Formation

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OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/15/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/15 11:30	1	707.0 708.0 709.0 710.0 711.0 712.0 713.0	8 7		CF	706.0 - 710.5 ft: same dolomite as previous unit. Upper 1.5 ft highly fractured and clayey. Small (1-2 mm) vugs, open, and of moderate intensity. Vugs decrease in frequency and increase in size (0.5 - 3 cm) toward base of unit. Lower 3 ft of unit highly fractured with thin (<1 mm) clay seams and small blebs of clay.	Culebra Member of Rustler Formation ~1.5 feet of core loss

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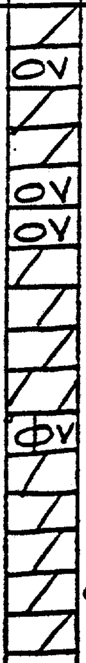
OF 1

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/15/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
		710.0 710.5					
09/15 14:31	2	712.0 714.0 716.0 718.0 720.0 722.0	27		GF GF	710.5 - 722.0 ft: light olive-gray microcrystalline dolomite, highly fractured. Numerous moderately-sized (5-10 mm) open vugs toward top of unit decreasing in frequency and size with depth. Toward base of unit vugs are sparse and gypsum filled. Evidence of infrequent gypsum filled fractures throughout unit. Contact between the Culebra Member and underlying unnamed member not visible.	Culebra Member of Rustler Formation 8.5 feet of core loss

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WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/16/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/15 17:04	3	722.0 723.0 724.0	100			722.0 - 724.5 ft: black, plastic clay with infrequent 1-2 mm gypsum stringers.	Unnamed Member of Rustler Formation
		725.0 726.0 727.0 728.0				724.5 - 726.5 ft: very dark red-brown clay with 0.1 - 0.2 ft white to pinkish white gypsum bands. Infrequent gypsum stringers up to 2 mm in width.	

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WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/16/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/15	3	728.0 729.0 730.0 731.0	100			726.5 - 732.0 ft: lighter red-brown clay with numerous gypsum veins up to 0.3 ft in width. White to pinkish-white crystalline (lath-like interlocking crystals) gypsum fill. Veins are horizontal to high angle and increase in frequency toward base of unit as clay grades into anhydrite.	Unnamed Member of Rustler Formation
		732.0 733.0 734.0				732.0 - 737.0 ft: light to dark gray mottled anhydrite with abundant 1-2 mm gypsum laminae.	

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OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#1 DIA.: 4"
LOCATION: NE1/4 NW1/4 Section 20 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 101' FSL 1422' FWL
ELEVATION: 3419.2 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/16/94
DRILL DATE: 09/15/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

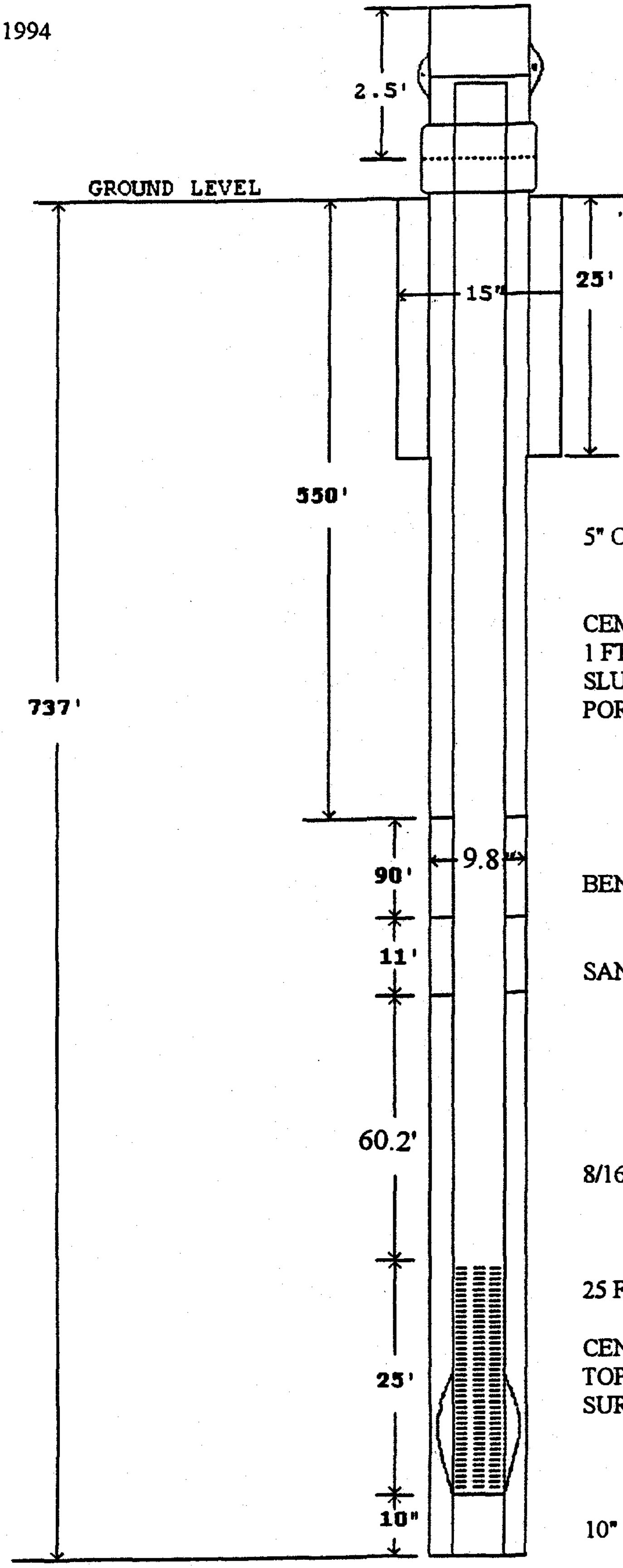
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/15 17:40	3	734.0		▨		732.0 - 737.0 ft: light to dark gray mottled anhydrite with abundant 1-2 mm gypsum laminae.	Unnamed Member of Rustler Formation
		735.0	100	▨			
		736.0		▨			
		737.0					
		738.0					
		739.0					
		740.0					

WQSP #1
HOLE HISTORY

WIPP Project
WQSP #1
Eddy County, New Mexico

September 13-16, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASING

CEMENT SLURRY MIX FROM 550 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 640 TO 550 FT

SAND PACK FROM 651 TO 640 FT

8/16 BRADY GRAVEL FROM 651 TO 712 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREEN, TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

September 13, 1994

WQSP # 1

6:30 AM - 8:00 AM - Rig down on WQSP # 2 and move to WQSP # 1
8:00 AM - 11:30 AM - Rigging up on WQSP # 1
11:30 AM - 5:00 PM - Drilling 9 7/8" hole from 25' - 245'
5:00 PM - 5:20 PM - Come out of hole & secure rig for day

September 14, 1994

WQSP # 1

6:00 AM - 6:35 AM - Carlsbad to WQSP # 1
6:35 AM - 6:45 AM - Check fluid levels
6:45 AM - 7:25 AM - Fix rotating head & T.I.H.
7:25 AM - 4:00 PM - Drill 9 7/8" hole from 245' - 693'
4:00 PM - 4:15 PM - Trip pipe out of hole
4:15 PM - 4:30 PM - Shut down rig and secure for day
4:30 PM - 5:15 PM - WQSP # 1 to Carlsbad

September 15, 1995 is missing from the drillers log, see WQSP#1 core description.

WEST TEXAS WATER WELL SERVICE

September 16, 1994

WQSP # 1

6:30 AM - 6:35 AM - Carlsbad to WQSP # 1
6:35 AM - 6:50 AM - Check & service rig
6:50 AM - 7:50 AM - Finish tripping out of hole with 3rd core run
7:50 AM - 8:30 AM - Retrieve core
8:30 AM - 9:00 AM - Breakdown core tools
9:00 AM - 12:45 PM - Rig up logger & log well
12:45 PM - 1:00 PM - Secured rig for weekend

September 20, 1994

WQSP # 1

6:00 AM - 6:30 AM - Carlsbad to WQSP # 1
6:30 AM - 6:40 AM - Check fluid levels in equipment
6:40 AM - 7:00 AM - Run bailer in casing
7:00 AM - 11:30 AM - Run 1" pipe inside 2" trimmie line to check gravel depth and remove bridge, added gravel to depth of 650′ below ground surface, placed sand pack from 650′-640′
11:30 AM - 12:40 PM - Pulled 1" pipe, mixed bentonite slurry to pump for bentonite seal from 640′-550′ - approximately 275 gallons.
12:40 PM - 1:30 PM - Rigged up to pump cement
1:30 PM - 3:00 PM - Waited on cement trucks
3:00 PM - 4:30 PM - Pump cement from 550′ to surface, circulating out to reserve pit
4:30 PM - 5:00 PM - Washout cement from lines, shut down operations for the day
5:00 PM - 5:30 PM - WQSP # 1 to Carlsbad

WEST TEXAS WATER WELL SERVICE

September 21, 1994

WQSP # 1 & 2

6:10 AM - 6:40 AM - Carlsbad to WQSP # 1
6:40 AM - 6:55 AM - Service rig
6:55 AM - 8:00 AM - Clean up location & rig down

September 22, 1994

WQSP # 1

8:50 AM - 5:30 PM - Bailed well to develop and clean up

September 28, 1994

WQSP # 1

7:25 AM - 9:30 AM - Make 24 trips with bailer, rig down, & go to get pipe trailer & pump
9:30 AM - 10:00 AM - Getting pipe trailer & pump
10:00 AM - 10:45 AM - Rig up to run pump
10:45 AM - 11:15 AM - Lunch
11:15 AM - 12:30 PM - Run pump
12:30 PM - 12:40 PM - Hook up to generator & start pumping - pump rate 13 GPM
12:40 PM - 3:30 PM - Pump well - average 10.9 GPM
Pump was set on 714' 1" gal. pipe
3:30 PM - 4:00 PM - Rig down & go to WQSP # 6

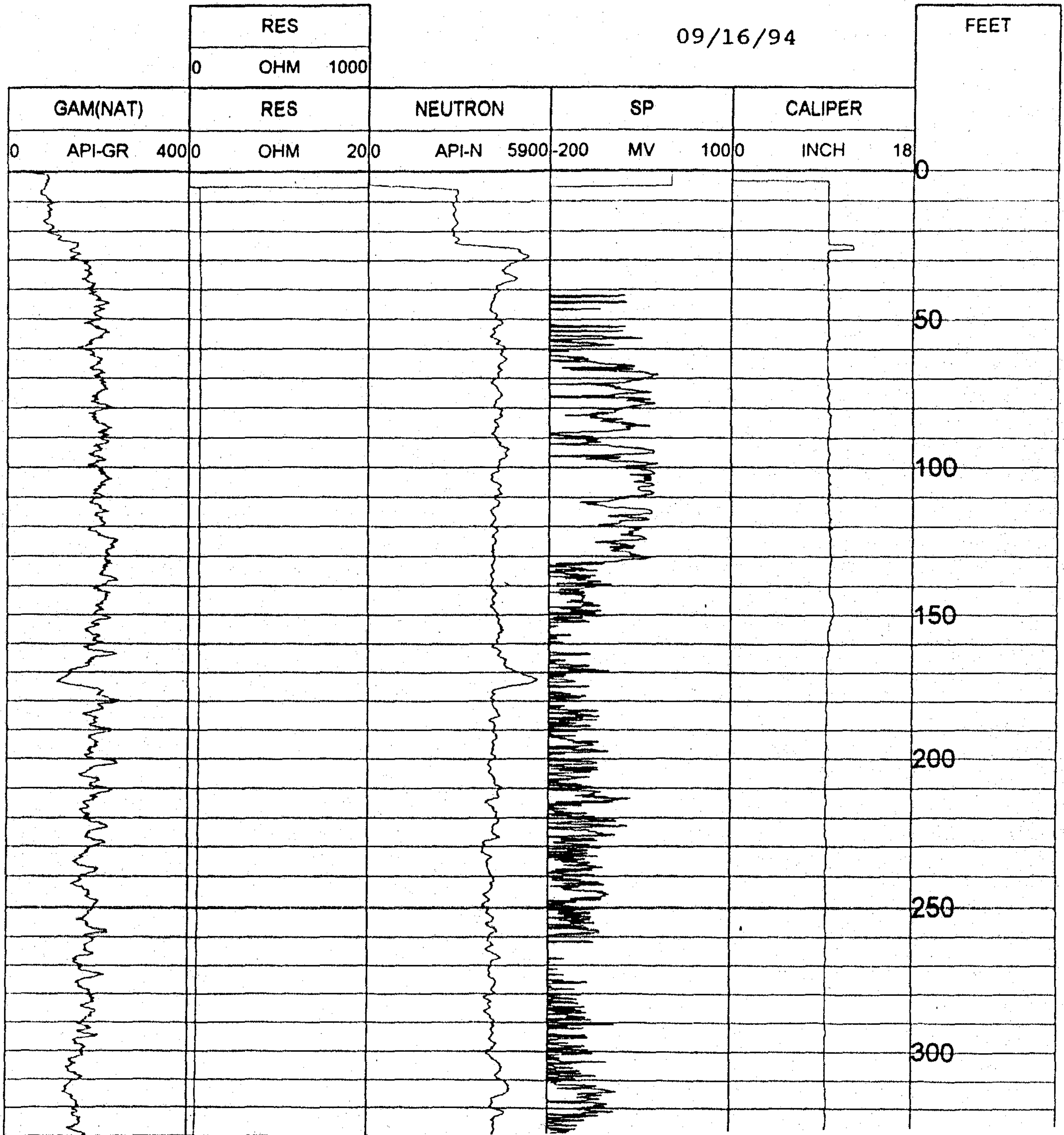
September 29, 1994

WQSP # 1

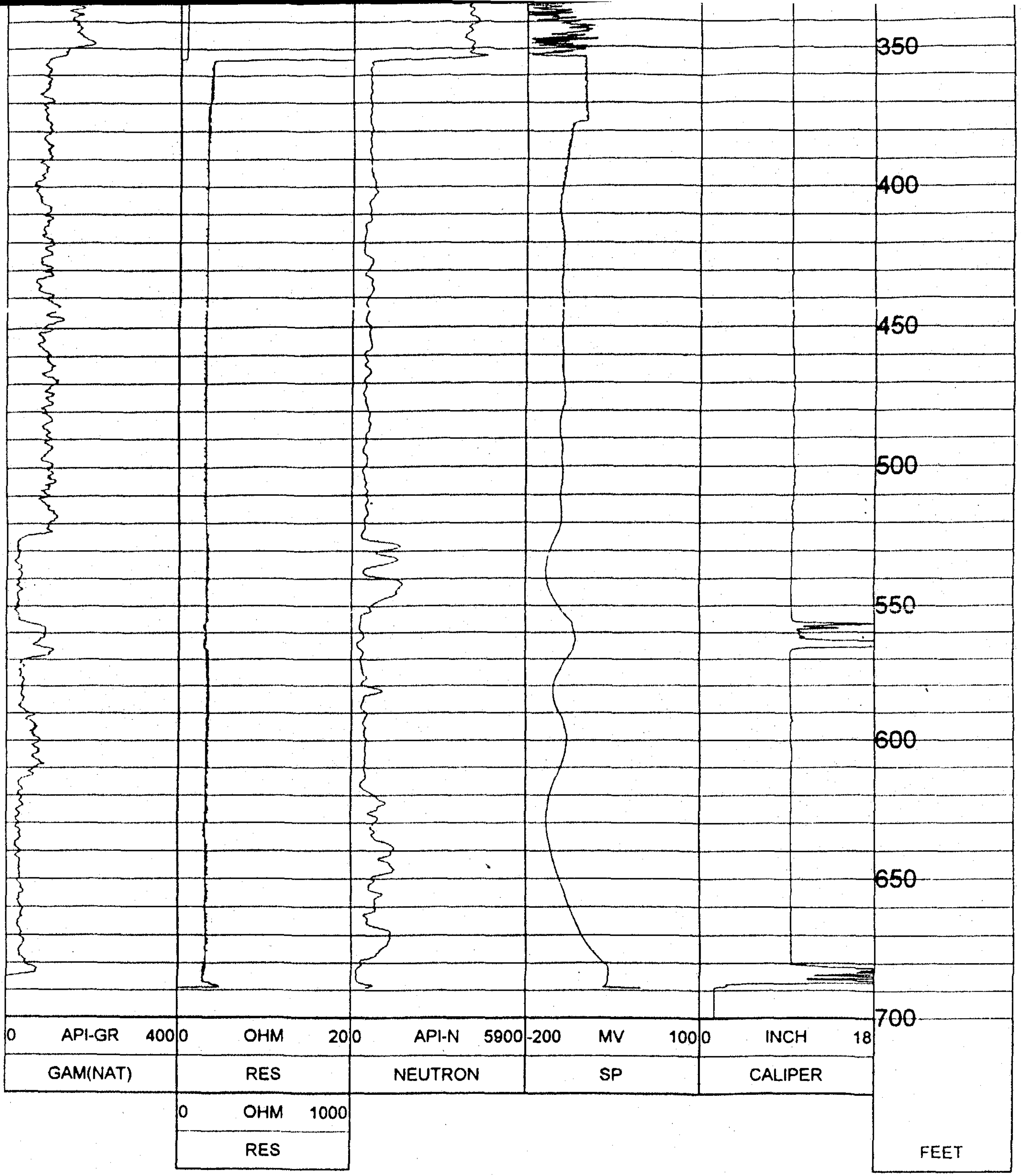
6:30 AM - 6:45 AM - Rig up to pull pump
6:45 AM - 8:00 AM - Pulled pump & rigged down
8:00 AM - 9:45 AM - Load up, straighten sand line
9:45 AM - 10:00 AM - WQSP # 1 to WQSP # 6

WQSP #1
GEOPHYSICAL LOGS

09/16/94

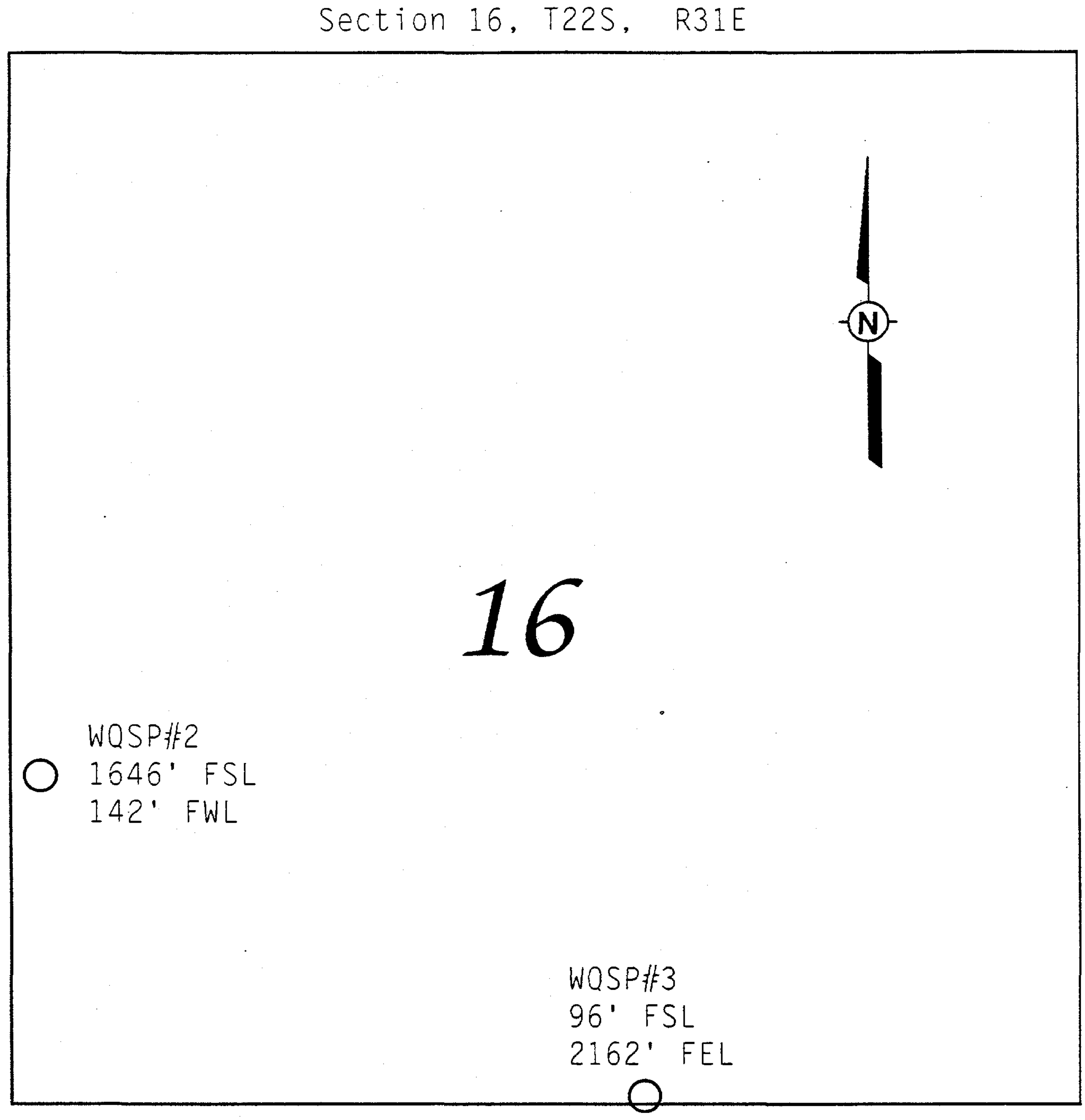

RES
0 OHM 1000
GAM(NAT)
0 API-GR 400
RES
0 OHM 20
NEUTRON
0 API-N 5900
SP
-200 MV 100
CALIPER
0 INCH 18
FEET
0
50
100
150
200
250
300

WQSP #1
Geophysical Logs



Century Geophysical Corp.

WQSP#2



Location of WQSP #2

WQSP #2
Condensed Well Summary

Location:	Section 16, T22S, R31E 1646 ft from the south line 142 ft from the west line	
Elevation: (Top of Casing)	3463.9 ft above mean sea level	
Cuttings Description:	D.S. Belski	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record	Date: Bottom of hole: Cored interval: Cuttings:	September 6 to 10, 1994 848 ft below land surface 800 to 846 ft every 20 ft

WQSP #2
Stratigraphic Summary

Stratigraphic Unit	Depth Interval Natural Gamma Log (feet)	Core Description
Surficial Deposits/Santa Rosa	0-143	
Dewey Lake Redbeds	143-629	
Rustler Formation	629-844 partial	
• Forty Niner Member	629-692	
• Magenta Member	692-714	
• Tamarisk Member	714-811	800-810 partial
• Culebra Member	811-833	810-834
• Partial lower unnamed member	833-844	834-846
Maximum Recorded Depth	844	

WQSP #2
CUTTINGS DESCRIPTION

WQSP #2
Cuttings Description*

Date	Time	Sample Number	Depth (feet)	Description
08/31/94	0920	1**	6	Surficial deposits
	0928	2**	25	Surficial deposits
09/06/94	0845	1	45	Sandstone, clay, and sand
	0900	2	65	Clay, sandy siltstone, and mudstone
	0927	3	85	Clay
	1035	4	105	Sandy mudstone, clay, and sandstone
	1102	5	125	Sandstone, clay, and interbedded siltstone and sandstone
09/07/94	0824	6	145	Sandstone with minor gypsum
	1101	7	165	Mudstone
	1239	8	185	Mudstone, trace sandstone
	1259	9	205	Sandstone, clay, minor gypsum
	1323	10	215	Sandstone, clay, minor gypsum and sandstone
	1330	11	225	Sandstone
	1341	12	245	Claystone and gypsum
	1407	13	265	Sandstone and minor fibrous gypsum
	1423	14	285	Sandstone with green reduction spots
	1447	15	305	Sandstone
	1523	16	325	Sandstone
	1550	17	345	Siltstone and sandstone
	1610	18	365	Sandstone, minor fibrous gypsum
	1643	19	385	Siltstone with interbedded sandstone
	1715	20	405	Siltstone with green reduction spots, minor fibrous gypsum and clay
	1729	21	425	Siltstone with interbedded mudstone and sandstone
	1749	22	445	Sandstone, trace gypsum
09/08/94	0833	23	465	Siltstone, trace gypsum

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling

WQSP #2
Cuttings Description (Continued)*

Date	Time	Sample Number	Depth (feet)	Description
	0854	24	485	Siltstone, sandstone, trace gypsum
	0922	25	505	Siltstone, clay, trace gypsum
	0946	26	525	Mudstone, siltstone, sand, and clay
	1003	27	545	Mudstone, siltstone, sand, and clay
	1030	28	565	Sandy siltstone
	1048	29	585	Siltstone with minor gypsum
	1103	30	605	Sandy siltstone with mudstone
	1152	31	625	Siltstone, mudstone, and sand
	1154	32	630	Sandstone
09/08/94	1216	33	645	Anhydrite and clay
	1243	34	665	Siltstone, mudstone, and sand
	1313	35	685	Anhydrite with gypsum
	1326	36	705	Dolomite, damp
	1350	37	725	Anhydrite with gypsum
	1431	38	745	Gypsum and anhydrite
	1450	39	765	Gypsum and anhydrite
	1530	40	785	Gypsum
	1538	41	798	Mudstone, minor gypsum and anhydrite

---

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling

WQSP #2
CULEBRA CORE DESCRIPTION

PAGE 1
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646'FSL 142'FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/09/94
DRILL DATE: 09/09/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/09 11:29	1	800.0 801.0 802.0 803.0 804.0 805.0 806.0	91			800.0 - 810.1 ft: light to dark gray mottled anhydrite with gypsum laminae (1-2 mm). Upper 0.2 ft of unit is red-brown mudstone with subrounded to subangular pebble-sized anhydrite clasts. Lens of similar material from 804.3 - 804.5 ft with bladed selenite crystals.	Tamarisk Member of Rustler Formation

PAGE 2
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646' FSL 142' FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/09/94
DRILL DATE: 09/09/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/09	1	806.0 807.0 808.0 809.0 810.0 811.0 812.0	91			800.0 - 810.1 ft: light to dark gray mottled anhydrite with gypsum laminae (1-2 mm). Upper 0.2 ft of unit is red-brown mudstone with subrounded to subangular pebble-sized anhydrite clasts. Lens of similar material from 804.3 - 804.5 ft with bladed selenite crystals. Contact with underlying dolomite unclear.	Tamarisk Member of Rustler Formation
						810.1 - 816.0 ft: highly fractured light olive gray microcrystalline dolomite, appears clayey. Small open vugs increasing in size and decreasing in frequency with depth. Toward base gypsum-filled vugs (~ 4 cm).	Culebra Member of Rustler Formation

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OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646'FSL 142'FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/09/94
DRILL DATE: 09/09/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/09 12:30	1	812.0 813.0 814.0 815.0	91	OY ΦY ΦY	GF	810.1 - 816.0 ft: highly fractured light olive gray microcrystalline dolomite. Small open vugs increasing in size and decreasing in frequency with depth. Toward base of unit vugs are sparse (5 mm - 4.5 cm) and gypsum filled. Fractures toward base appear to have been gypsum filled.	Culebra Member of Rustler Formation 1.5 feet of core loss
		816.0					

PAGE 1
OF 1

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646'FSL 142'FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/10/94
DRILL DATE: 09/10/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/10 16:42 17:15	2	816.0 819.0 822.0 825.0 828.0	75		F GF F F CF	816.0 - 830.0 ft: light olive gray dolomite, highly fractured. Upper portion of unit contains numerous small, open vugs and infrequent gypsum filled fractures. Vugs increase in size and decrease in frequency with depth. Some vugs up to 3 cm in size, many are gypsum filled. Clay lined fractures are present toward base of unit.	Culebra Member of Rustler Formation 3.5 feet of core loss
		830.0 831.0					

PAGE 1
OF 2

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646'FSL 142'FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/10/94
DRILL DATE: 09/10/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/10 9:55	3	830.0 832.0	75		GF GF	830.0 - 833.7 ft: light olive gray microcrystalline dolomite with numerous small vugs (open) with gypsum lined fractures. Vugs decrease in frequency toward base of unit.	Culebra Member of Rustler Formation
		834.0 836.0 838.0 840.0 842.0				833.7 - 837.6 ft: transition between Culebra Member and underlying unnamed member . Upper 1.0 ft very rubbly clayey dolomite and claystone with numerous gypsum crystals. Lower portion dark black plastic clay. 837.6 - 846.0 ft: dark black rubbly claystone in upper portion turning to red-brown clay with white, pinkish-white gypsum bands. Gypsum and anhydrite percent increases toward base of unit.	Unnamed Member of Rustler Formation

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OF 2

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#2 DIA.: 4"
LOCATION: NW1/4 SW1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1646'FSL 142'FWL
ELEVATION: 3463.9 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/10/94
DRILL DATE: 09/10/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

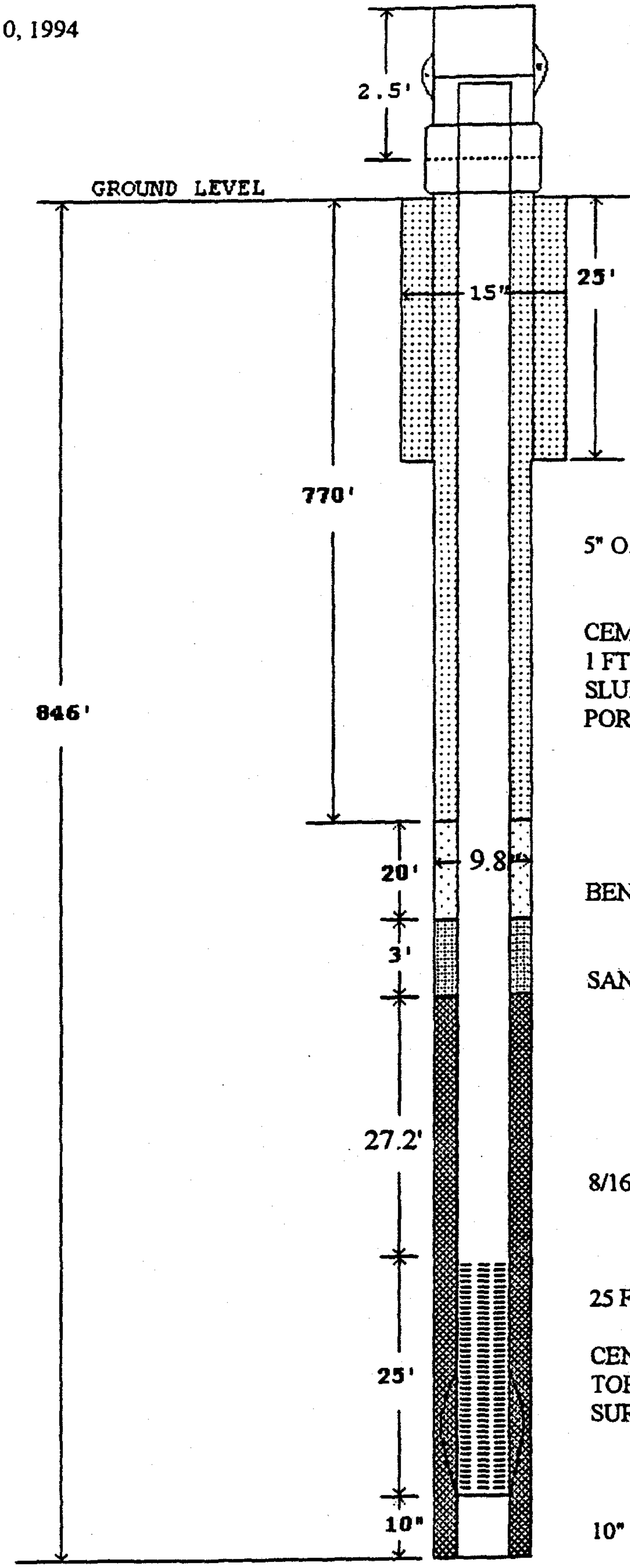
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
09/10 10:35	3	842.0 844.0 846.0	75			837.6 - 846.0 ft: dark black rubbly claystone in upper portion turning to red-brown clay with white-pink gypsum bands. Gypsum and anhydrite percentages increase toward base of unit.	Unnamed Member of Rustler Formation 4 ft of core lost

WQSP #2
HOLE HISTORY

WIPP Project
WQSP #2
Eddy County, New Mexico

September 6-10, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASING

CEMENT SLURRY MIX FROM 770 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 770 TO 790 FT

SAND PACK FROM 790 TO 793 FT

8/16 BRADY GRAVEL FROM 846 TO 793 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREEN, TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

September 6, 1994

WQSP # 2

7:30 AM - 8:15 AM - Put rotating head back together and serviced rig
8:15 AM -11:15 AM - Drilled 9 7/8" hole from 25'-125', tripped out of hole
11:30 AM - 1:10 PM - Worked on rotating head
1:10 PM - 1:30 PM - Trip drill collars, remove rotating head, & take in to machine shop
1:30 PM - 2:00 PM - Service rig and secure for the day

September 7, 1994

WQSP # 2

7:20 AM - 8:00 AM Put on rotating head & trip in hole
8:00 AM - 8:40 AM Drill 9 7/8" hole from 125' - 147'
8:40 AM - 10:10 AM Work on rotating head
10:10 AM - 7:00 PM Drill 9 7/8" hole from 147' - 461'
7:00 PM - 7:15 PM T.O.O.H. 150' shut down, secure rig for the day

September 8, 1994

WQSP # 2

6:20 AM - 6:50 AM - Carlsbad to WQSP # 2
6:50 AM - 7:15 AM - Service rig & auxiliary air compressor
7:15 AM - 8:10 AM - Work on air compressor
8:10 AM - 8:15 AM - T.I.H.
8:30 AM - 11:15 AM - Drilling 9 7/8" hole from 461'-616'
11:15 AM - 11:35 AM - Change out batteries & alternator on air compressor
11:35 AM - 4:00 PM - Drilling 9 7/8" hole from 616'-800'. Stopped drilling at this point to come out of hole & prepare for coring 9-9-94
4:00 PM - 5:30 PM - Finished blowing on well to remove cuttings, had several tight spots due to anhydrite chunks falling in hole & catching bit on trip out
5:30 PM - 6:30 PM - Serviced rig and secured for the day. Talked with company man providing core tools for job

WEST TEXAS WATER WELL SERVICE

September 9, 1994

WQSP # 2

5:40 AM - 6:15 AM - Carlsbad to WQSP # 2
6:15 AM - 6:30 AM - Check fluid levels on equipment
6:30 AM - 8:40 AM - Trip in the hole, had two feet of fill in overnight. Had t mist with foam to clean out hole
8:40 AM - 10:30 AM - Rig up core barrel
10:30 AM - 11:20 AM - Going in the hole
11:20 AM - 11:35 AM - Coring 15'
11:35 AM - 11:55 AM - Cleaning out hole
11:55 AM - 12:15 PM - Waiting on orders to core deeper
12:15 PM - 12:35 PM - Coring 1'
12:35 PM - 3:15 PM - Coming out of hole with 1st core, recovered 15', laid core barrel, broke it down, & pump into core troughs
3:15 PM - 3:45 PM - Make up core barrel & start back in hole for second run
3:45 PM - 4:40 PM - Tripping in the hole
4:40 PM - 5:15 PM - Coring 2nd run 14' - Depth 830'
5:15 PM - 6:20 PM - Come out of the hole, lay down core barrel
6:20 PM - 7:05 PM - Push out core
7:05 PM - 7:30 PM - Secure rig for day, leave location
7:30 PM - 8:10 PM - WSQP @ 2 to Carlsbad

September 10, 1994

WQSP # 2

7:00 AM - 7:40 AM - Carlsbad to WQSP # 2
7:40 AM - 7:55 AM - Service rig
7:55 AM - 8:40 AM - Trip in the hole for 3rd core run, had 55' of fill in, plug bit
8:40 AM - 9:00 AM - Come out of hole 150' & try to unload hole
9:00 AM - 9:10 AM - Run 2 jts. back in well and unload hole. Possible bridge @ 55' off bottom, back to bottom @ 10:00 AM
10:00 AM - 10:35 AM - Coring 3rd run, cut 16'
10:35 AM - 11:35 AM - Coming out of the hole w/3rd core
11:35 AM - 12:35 PM - Lay down core barrel and pump out
12:35 PM - 1:30 PM - Break down tool joints on core barrel & load on trailer
1:30 PM - 2:00 PM - Shut down rig and secure rig for week end

WEST TEXAS WATER WELL SERVICE

September 12, 1994

WQSP # 2

5:45 AM - 7:35 AM - Odessa to WIPP WQSP # 2
7:35 AM - 9:00 AM - Line pits for brine water
9:00 AM - 10:10 AM - Trip pipe in hole
10:10 AM - 11:00 AM - Mix 30 sacks sw gel to sweep hole with and remove cuttings
11:00 AM - 11:45 AM - Circulate and condition
11:45 AM - 1:05 PM - Ream 8 1/2" core hole to 9 7/8"
1:05 PM - 3:55 PM - TD 846′ circulating
3:55 PM - 4:40 PM - Trip out of hole
4:40 PM - 4:55 PM - Rig up to log well
4:45 PM - 6:45 PM - Log hole

September 21, 1994

WQSP # 1 & 2

6:10 AM - 6:40 AM - Carlsbad to WQSP # 1
6:40 AM - 6:55 AM - Service rig
6:55 AM - 8:00 AM - Clean up location & rig down
8:00 AM - 10:10 AM - Replace cable on blocks
10:10 AM - 11:30 AM - Picked up well casing for WQSP # 2 and filled pits at WQSP # 2
11:30 AM - 12:00 PM - Rigged up drilling rig on WQSP # 2
12:00 PM - 1:30 PM - Trip in the hole and tag fill in
1:30 PM - 2:10 PM - Mix mud to circulate down hole
2:10 PM - 3:00 PM - Clean out bottom of hole
3:00 PM - 3:30 PM - Circulate
3:30 PM - 4:00 PM - Trip out of hole 200′ and shut down rig
3:00 PM - 4:30 PM - Spot surface hole on WQSP #′s 5 & 6
4:30 PM - 5:00 PM - Back to Carlsbad

WEST TEXAS WATER WELL SERVICE

September 22, 1994

WQSP # 2

6:00 AM - 6:35 AM - Carlsbad to WQSP # 2
6:35 AM - 6:45 AM - Check fluid level in equipment
6:45 AM - 7:05 AM - Trip pipe in hole to check TD
7:05 AM - 7:30 AM - Circulate
7:30 AM - 8:30 AM - Trip pipe out of hole
8:30 AM - 9:10 AM - Water meter locked up - waiting on key
9:10 AM - 10:20 AM - Run 2" trimmie line
10:20 AM - 12:35 PM - Run 5" fiberglass casing, screen, & centralizers
12:35 PM - 1:00 PM - Rig up gravel hopper to gravel pack well
1:00 PM - 3:00 PM - Gravel pack well
3:00 PM - 4:00 PM - Mix bentonite slurry and spot above gravel for seal
4:00 PM - 5:30 PM - Pump cement grout to surface
5:30 PM - 6:00 PM - Pull trimmie pipe, wash up and secure rig for the day

September 23, 1994

WQSP #'s 2 & 6

6:00 AM - 6:40 AM - Carlsbad to WQSP # 2
6:40 AM - 8:15 AM - Rigged down on WQSP # 2, cleaned up location & moved to WQSP # 6
8:15 AM - 12:00 PM - Rigged up on WQSP # 6, lined pit, put rotating head on, and shut down for weekend
12:00 PM - 2:00 PM - WQSP # 6 to Odessa

September 26, 1994

WQSP # 2

8:45 AM - 12:15 PM - Bail & develop well - water level @ start of day - 351'
12:15 PM - 12:45 PM - Water level recovered from bail down point of 500' back to 400'
12:45 PM - 3:45 PM - Continued bailing to develop well - water level @ end of day - 400'
3:45 PM - 4:00 PM - Shut down unit & secured for day

WEST TEXAS WATER WELL SERVICE

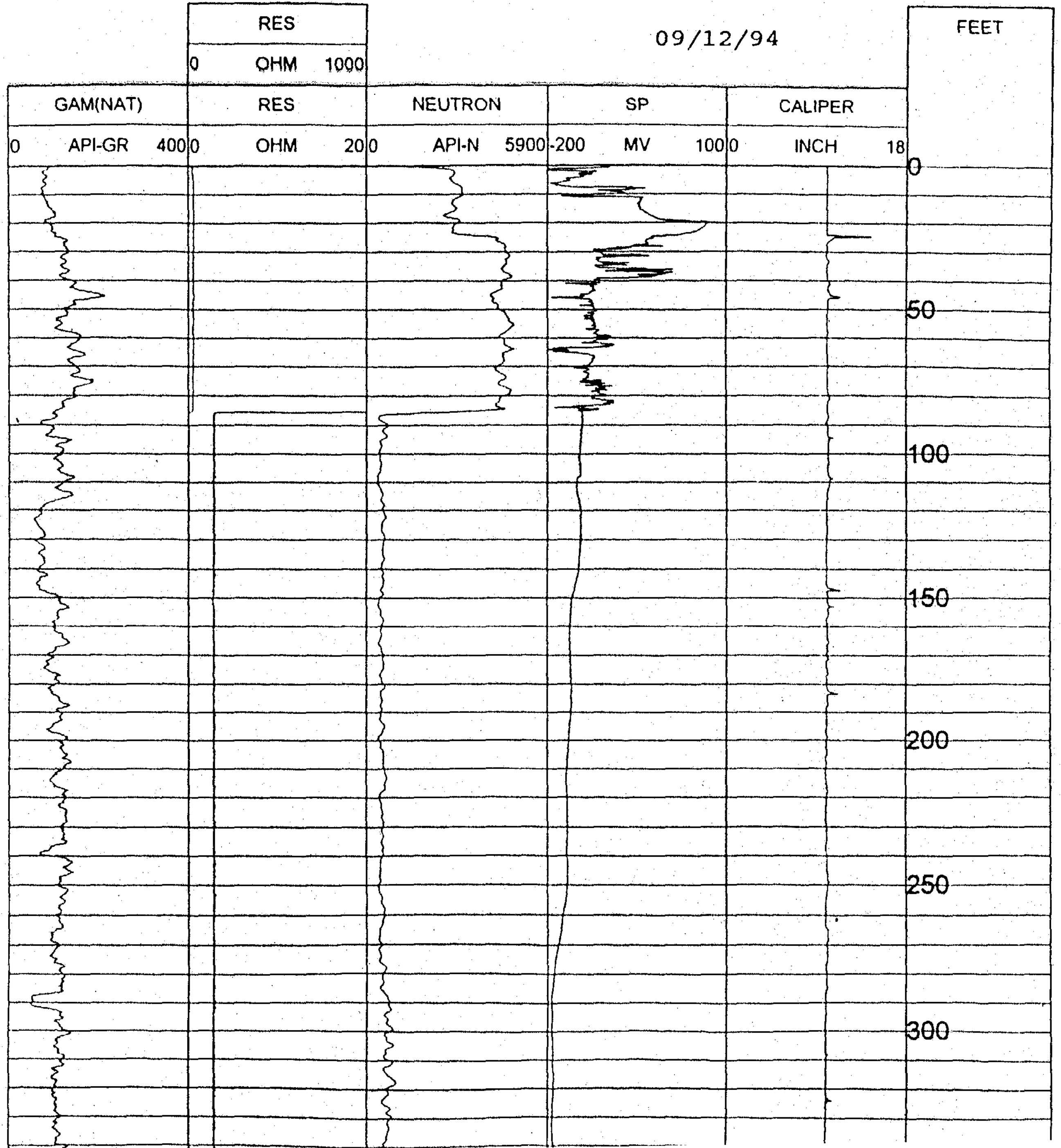
September 27, 1994

WQSP # 2

8:00 AM - 8:30 AM - Ran bailer - water level @ 400' TD 849' from top of casing
8:30 AM - 10:30 AM - Make splice on pump and ran 3 HP 230V 3 Ph 10 GPM pump in hole, start pumping @ 13 GPM
10:30 AM - 2:30 PM - Pump well to develop - avg. 10.33 gpm over 4 hours
2:30 PM - 4:00 PM - Pull pump from well
4:00 PM - 5:00 PM - WQSP # 6

WQSP #2
GEOPHYSICAL LOGS

09/12/94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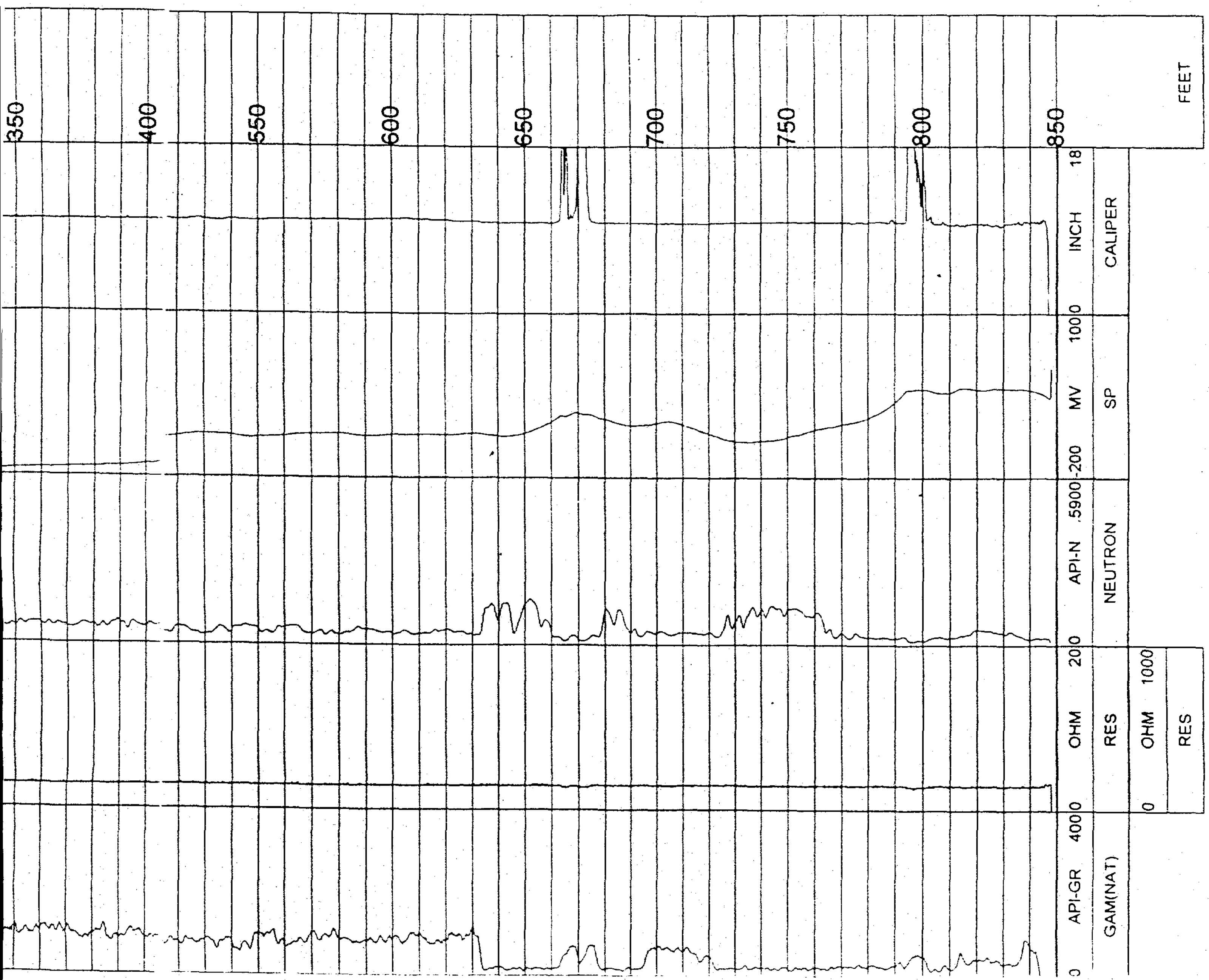
0 OHM 1000
GAM(NAT)
0 API-GR 400
RES
0 OHM 20
NEUTRON
0 API-N 5900
SP
-200 MV 100
CALIPER
0 INCH 18
FEET
0
50
100
150
200
250
300

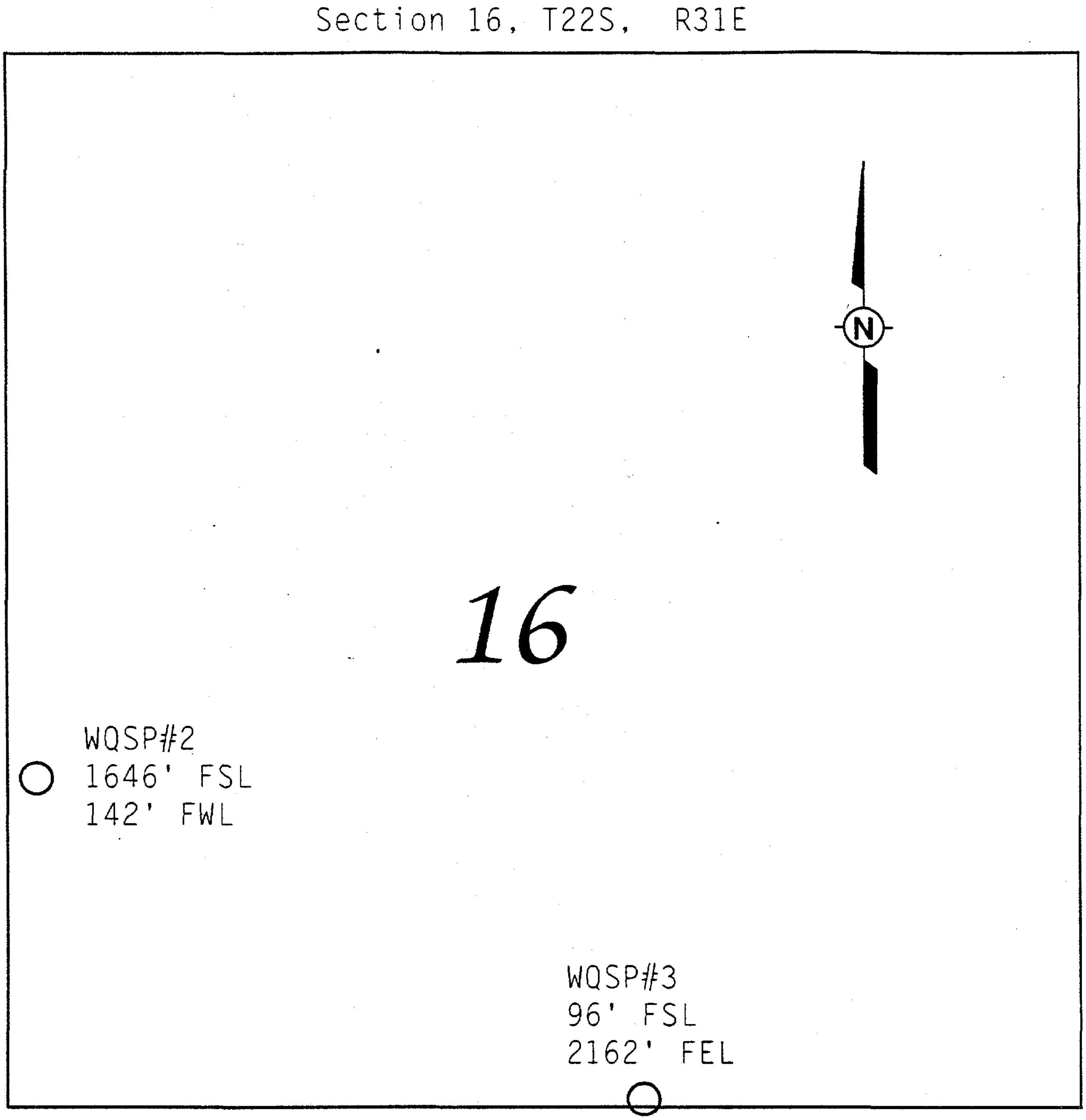
Century
GEOPHYSICAL CORP.



Best available data

WQSP #2
Geophysical Logs

WQSP#3



Location of WQSP #3

WQSP #3
Condensed Well Summary

Location:	Section 16, T22S, R31E 96 ft from the south line 2162 ft from the east line	
Elevation: (Top of Casing)	3480.3 ft above mean sea level	
Cuttings Description:	M.L. Martin	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record	Date: Bottom of hole: Cored interval: Cuttings:	October 20 to 26, 1994 880 ft below land surface 833 to 879 ft every 20 ft

WQSP #3
Stratigraphic Summary

Stratigraphic Unit	**Depth Interval Natural Gamma Log (feet)**	**Core Description**
Surficial Deposits/Santa Rosa	0-156	
Dewey Lake Redbeds	156-669	
Rustler Formation	669-881 partial	
• Forty Niner Member	669-727	
• Magenta Member	727-749	
• Tamarisk Member	749-848	833-844 partial
• Culebra Member	848-871	844-870
• Partial lower unnamed member	871-881 partial	870-879 partial
Maximum Recorded Depth	881	

WQSP #3
CUTTINGS DESCRIPTION

WQSP #3
Cuttings Description *

Date	Time	Sample Number	Depth (feet)	Description
10/03/94	1045	1**	5	Caliche
	1120	2**	25	Surficial deposits
10/20/94	0825	3	45	Sandstone
	0840	4	65	Sandstone
	0903	5	85	Sandstone
	0922	6	105	Sandstone
	0937	7	125	Mudstone
	0945	8	145	Siltstone
	1005	9	165	Siltstone and mudstone
	1020	10	185	Sandstone with minor carbonate
	1033	11	205	Mudstone interbedded with siltstone
	1055	12	225	Sandstone and siltstone
	1117	13	245	Sandstone
	1147	14	265	Mudstone, sandstone, and minor gypsum
	1242	15	285	Gypsiferous mudstone
	1255	16	305	Sandstone, carbonate, and fibrous gypsum
	1336	17	325	Mudstone interbedded with siltstone, green reduction spots, fibrous gypsum
	1414	18	345	Sandstone with carbonate
	1445	19	365	Sandstone, siltstone interbedded with mudstone, fibrous gypsum
	1515	20	385	Sandstone, mudstone, siltstone, and fibrous gypsum
10/21/94	0730	21	405	Mudstone and sandstone, limited sample, slightly damp
	0805	22	425	Sandstone, minor gypsum and mudstone, mud balls
	0839	23	445	Sandstone with minor gypsum
	0855	24	465	Siltstone and fibrous gypsum filled fractures in the sandstone

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #3
Cuttings Description (Continued) *

Date	Time	Sample Number	Depth (feet)	Description
	0915	25	485	Sandstone, trace carbonate and gypsum
	0935	26	505	Mudstone, selenite gypsum and siltstone interbedded with mudstone
10/21/94	0952	27	525	Mudstone and selenite
	1007	28	545	Gypsiferous sand, sandstone, and selenite
	1021	29	565	Sandstone and mudstone with green reduction spots, trace gypsum,
	1034	30	585	Gypsiferous mudstone with green reduction spots, trace selenite
	1048	31	605	Mudstone, sandstone, and fibrous gypsum
	1110	32	625	Siltstone, sandstone, and selenite
	1120	33	645	Siltstone, sandstone, and gypsum
	1142	34	665	Siltstone and sandstone
10/24/94	1031	35	705	Anhydrite, mudstone, and selenite
	1113	36	725	Anhydrite with minor gypsum and mudstone
	1120	37	745	Anhydrite, minor selenite, trace mudstone
	1210	38	765	Anhydrite, minor selenite, trace claystone
	1255	39	785	Anhydrite, trace claystone
	1335	40	805	Anhydrite, limited sample
	1350	41	825	Anhydrite

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #3
CULEBRA CORE DESCRIPTION

PAGE 1 OF 4	WIPP CORE-LOG INVENTORY	INTERA FORM 1400

BOREHOLE: WQSP#3 DIA.: 4"

LOCATION: NW1/4 NE1/4 Section 16 T22S R31E

ORIENTATION: Vertical Down

COORDINATES: 96' FSL 2162' FEL

ELEVATION: 3480.3 feet amsl

DRILL METHOD(S): Air Rotary

LOG BY: JBD

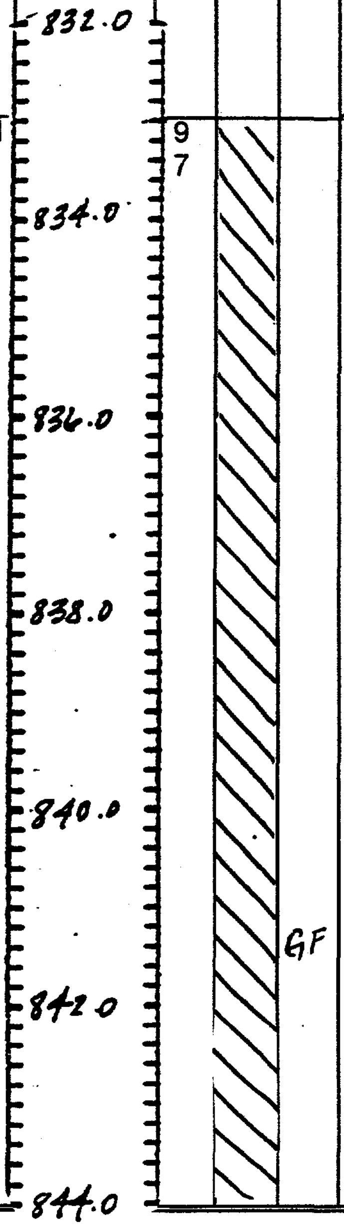
DATE: 10/25/94

DRILL DATE: 10/25/94

DRILLER: Ronnie Keith

DRILL: Gardner Denver 1500

DRILL CO.: West Texas Water Well Service



Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/25 09:35	1		97			833.0 - 844.0 ft: light to dark gray mottled anhydrite with wavy (1-3 mm) gypsum laminae. Gypsum filled fracture 0.5 cm wide from 841.2 - 844.0 ft with minor displacement.	Tamarisk Member of Rustler Formation

PAGE 2
OF 4

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#3 DIA.: 4"
LOCATION: NW1/4 NE1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 96' FSL 2162' FEL
ELEVATION: 3480.3 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/25/94
DRILL DATE: 10/25/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/25	1	844.0 846.0 848.0 850.0 852.0 854.0	97		GF GF	844.0 - 855.6 ft: light olive gray microcrystalline dolomite. Upper 0.2 ft red-gray dolomite with small (1-2 mm) elongate gypsum filled vugs grading to gray dolomite. Wavy discontinuous clay filled fractures (0.5 - 1 mm). Vugs increase in size, variety, and intensity with depth becoming large (up to 2 cm), gypsum filled, small (1 - 2 mm), and open. 853 - 855.6 ft: vugs decrease in intensity, are mainly large and some gypsum filled. Few thin, wavy discontinuous gypsum filled fractures. 853.9 - 854.5 ft: broken, rubbly, silty interval.	Culebra Member of Rustler Formation

PAGE 3
OF 4

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#3 DIA.: 4"
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ORIENTATION: Vertical Down
COORDINATES: 96' FSL 2162' FEL
ELEVATION: 3480.3 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/25/94
DRILL DATE: 10/25/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/25 10:40	1	856.0 858.0 860.0 862.0	97		GF GF GF	855.6 - 861.3 ft: light olive gray microcrystalline dolomite interbedded with brown/tan silty dolomite (laminated) with moderate open vugs some gypsum filled. Moderate gypsum filled fractures with minor displacement. Base of unit is transition to extremely vuggy non-silty dolomite. 861.3 - 864.0 ft: extremely vuggy light olive gray microcrystalline dolomite. 2-3 mm open vugs, some ≥ 2 cm, minor gypsum filled vugs. Rare thin horizontal gypsum filled fractures.	Culebra Member of Rustler Formation 1' core loss
13:40		864.0 866.0 868.0				864.0 - 870.4 ft: same dolomite as above, majority of vugs gypsum filled. Vugs increase in size and decrease in frequency with depth becoming rare to nonexistent at base of unit. Large, opaque, gypsum-filled inclusions from 867-870.4 ft. (continued on next page)	1' core loss

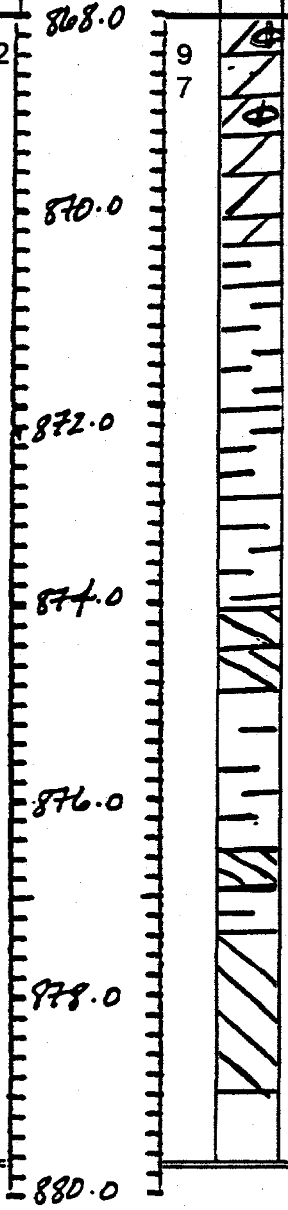
PAGE 4
OF 4

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#3 DIA.: 4"
LOCATION: NW1/4 NE1/4 Section 16 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 96' FSL 2162' FEL
ELEVATION: 3480.3 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/25/94
DRILL DATE: 10/25/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service



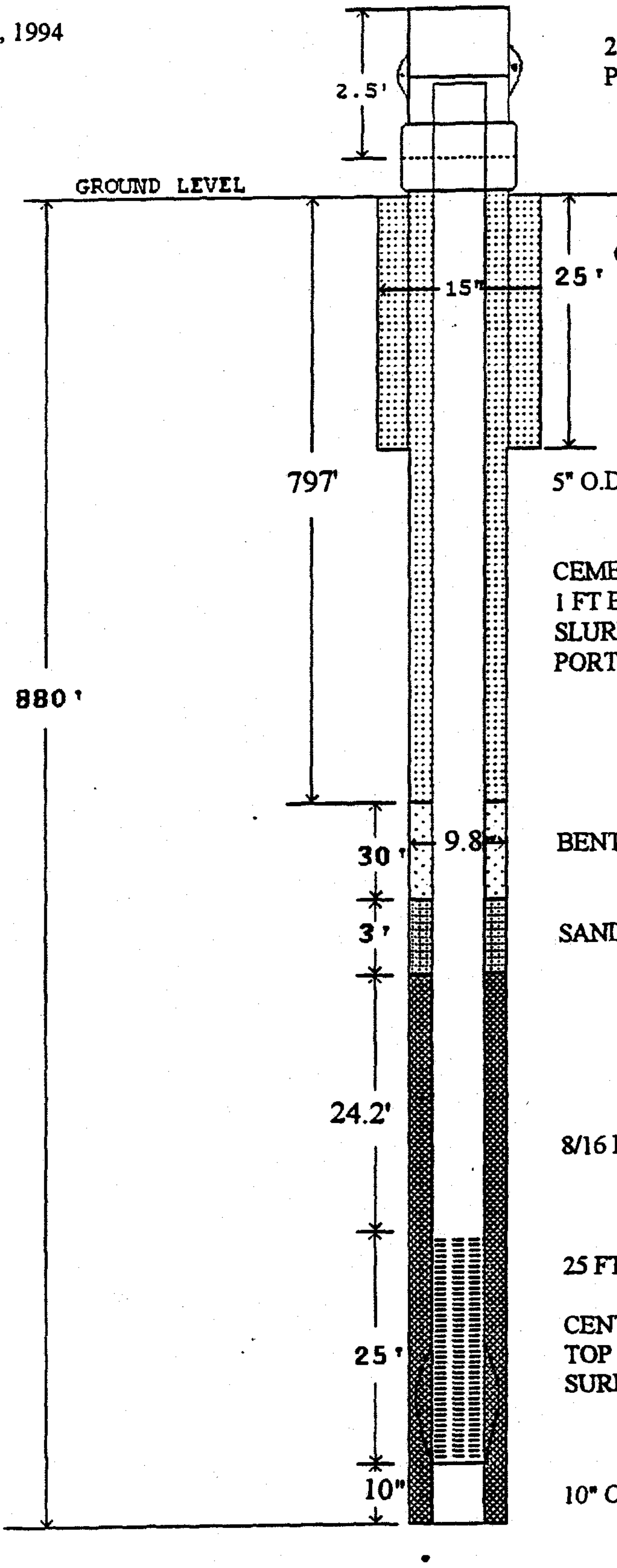
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/25 14:40	2		97			Wavy, discontinuous, vertical gypsum-filled fractures (1-2 mm) contact between Culebra and underlying unnamed member is sharp. ~1 ft of core loss.	Culebra Member of Rustler Formation
						870.4 - 873.0 ft: upper 0.9 ft black plastic clay with minor gypsum stringers grading to dark red/brown clay with minor red-pink/gray anhydrite beds.	Unnamed member of Rustler Formation
						873.0 - 877.4 ft: red/light brown mud-clay with frequent light-gray/pink anhydrite beds and high angle veins and stringers. Anhydrite decreases in frequency with depth. Rare light gray clay inclusions. Base of unit contains subrounded anhydrite pebbles (0.25 - 1 cm) and thin (5 - 6 mm) anhydrite beds.	
						877.4 - 879.0 ft: dark-light gray microcrystalline anhydrite with thin (2-4 mm) wavy gypsum laminae.	

WQSP #3
HOLE HISTORY

WIPP Project
WQSP #3
Eddy County, New Mexico

October 20-26, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASING

CEMENT SLURRY MIX FROM 796 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 827 TO 797 FT

SAND PACK FROM 830 TO 827 FT

8/16 BRADY GRAVEL FROM 880 TO 830 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREEN, TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

October 20, 1994

WQSP # 3

6:00 AM - 6:35 AM - Carlsbad to WQSP # 3
6:35 AM - 6:45 AM - Check fluid levels
6:45 AM - 7:50 AM - Finish rigging up and line pits
7:50 AM - 12:00 PM - Started drilling 9 7/8" hole from 25'. 10.75" .375W surface in place
12:00 PM - 12:30 PM - Work on air compressor
12:30 PM - 3:30 PM - Continued drilling
3:30 PM - 4:15 PM - Pulled 60' of drill pipe, service air filters on rig
4:15 PM - 5:15 PM - Secure rig & go to Carlsbad

October 21, 1994

WQSP # 3

5:50 AM - 6:30 AM - Carlsbad to WQSP # 3
6:30 AM - 6:45 AM - Check fluid levels
6:45 AM - 7:10 AM - Work on air compressor
7:10 AM - 12:30 PM - Drilling 9 7/8" from 400' on air
12:30 PM - 12:45 PM - Trip out 200' of drill pipe
12:45 PM - 3:00 PM - Replace cable on blocks
3:00 PM - 5:00 PM - Carlsbad to Odessa

October 24, 1994

WQSP # 3

6:00 AM - 8:40 AM - Odessa to WQSP # 3 (had flat in route)
8:40 AM - 8:50 AM - Check fluid levels
8:50 AM - 9:30 AM - Trip pipe in the hole
9:30 AM - 2:00 PM - Drill 9 7/8" hole from 680' to 833' on mist pump
2:00 PM - 2:30 PM - Clean out hole
2:30 PM - 3:30 PM - Trip drill pipe and collars out of hole, prepare to core
3:30 PM - 4:45 PM - Get load of water, secure rig
4:45 PM - 5:30 PM - WQSP # 3 to Carlsbad

WEST TEXAS WATER WELL SERVICE

October 25, 1994

WQSP # 3

```
 6:00 AM -  6:30 AM - Carlsbad to WQSP # 3
 6:30 AM -  6:40 AM - Check fluid levels
 6:40 AM -  7:10 AM - Wait on Weatherford
 7:10 AM -  8:10 AM - Rig up core tools
 8:10 AM -  9:20 AM - Trip in hole for 1st core run
 9:20 AM - 10:40 AM - Coring from 833' - 864', top of Culebra
                      @ 844'
10:40 AM - 10:50 AM - Clean out hole
10:50 AM - 11:50 AM - Trip out of the hole
11:50 AM - 12:30 PM - Breakout core barrel and lay down inner
                      barrel
12:30 PM -  1:00 PM - Pick up inner barrel & go back in hole
 1:00 PM -  2:00 PM - Tripping in hole
 2:00 PM -  2:30 PM - Coring from 844' - 859'
 2:30 PM -  2:40 PM - Clean out hole
 2:40 PM -  3:45 PM - Tripping out of the hole, pull inner barrel
                      & lay out on ground
 3:45 PM -  4:30 PM - Pump out core, load core tools & secure rig
 4:30 PM -  5:15 PM - WQSP # 3 to Carlsbad
```

October 26, 1994

WQSP # 3

```
 6:00 AM -  6:40 AM - Carlsbad to WQSP # 3
 6:40 AM -  6:55 AM - Check fluid levels
 6:55 AM -  8:35 AM - Trip pipe in the hole
 8:35 AM - 10:30 AM - Ream hole from 8 1/2" to 9 7/8" to
                      receive logging tools - hole reamed from
                      833' - 880'
10:30 AM - 11:00 AM - Clean out hole with foaming agents
11:00 AM - 12:05 PM - Trip out of the hole
12:05 PM -  2:30 PM - Wait on logging unit
 2:30 PM -  5:00 PM - Run logs
 5:00 PM -  5:35 PM - WQSP # 3 to Carlsbad
```

WEST TEXAS WATER WELL SERVICE

October 27, 1994

WQSP # 3

6:00 AM - 6:40 AM - Carlsbad to WQSP # 3
6:40 AM - 6:50 AM - Check fluid levels
6:50 AM - 7:35 AM - Run bailer to check if hole is open, had 40′ of fill
7:35 AM - 8:40 AM - Trip pipe in the hole
8:40 AM - 9:45 AM - Clean out hole, hit bridge at 840′. Hole was bridged over from 840′ - 860′, open from 860′ - 880′
9:45 AM - 10:35 AM - Trip out of the hole
10:35 AM - 11:15 AM - Prepare to run 2" trimmie line
11:15 AM - 12:00 PM - Run 2" trimmie line
12:00 PM - 12:15 PM - Prepare to run fiberglass screen & casing - 29 jts blank, 1 - 10′ blank bottom, 1 jt screen
12:15 PM - 2:10 PM - Running casing
2:10 PM - 2:45 PM - Rig up to gravel pack (work on mud pump)
2:45 PM - 3:45 PM - Gravel packing well with 8/16 Brady gravel from 880′
3:45 PM - 4:15 PM - Mix bentonite slurry for plug above gravel pack
4:15 PM - 4:40 PM - Rig up to cement (wait on truck)
4:40 PM - 5:20 PM - Cementing from 800′
5:20 PM - 6:10 PM - Pull 2: trimmie line
6:10 PM - 6:20 PM - Secure rig
6:20 PM - 7:00 PM - WQSP # 3 to Carlsbad

October 31, 1994

WQSP # 3

Unit # 2

7:55 AM - 9:10 AM - Arrive on location, pour 4 gallons of bleach into well, check & service unit, rig up & prepare to bail well, surge well with bailer to allow solution to work through screened interval
9:10 AM - 12:25 PM - Start bailing, water level @ 448′, TD from top of casing 803′. Made 20 trips
12:25 PM - 1:25 PM - Made 10 more trips with bailer
1:25 PM - 3:10 PM - Run test pump in well, pump set on 1" pipe @ 866′
3:10 PM - - Start pump - 7.5 GPM
3:30 PM - - Pumping 6.2 gpm
3:55 PM - - Well pumped off, shut down for the day
4:00 PM - - Left location

WEST TEXAS WATER WELL SERVICE

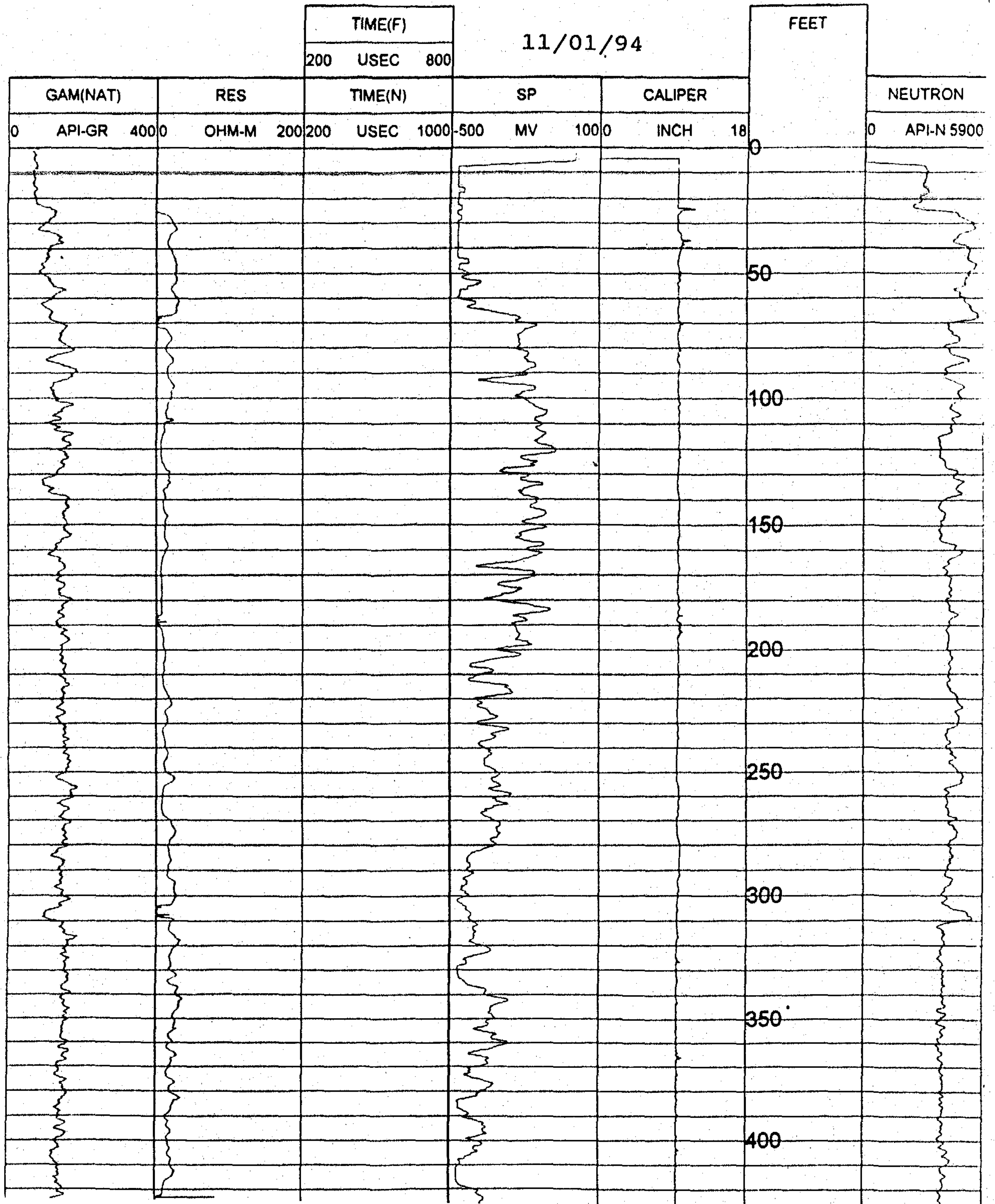
November 1, 1994

WOSP # 3

Unit # 2

6:40 AM - 7:00 AM - Arrive on location, check unit
7:00 AM - 8:40 AM - Start surging well, pumping 9 GPM
8:40 AM - - Start continuous test w/2 GPM choke in line, 65# backpressure
9:20 AM - - Change to 3 GPM choke, 40# backpressure
9:25 AM - - Pumped off well, change back to 2 GPM choke
9:35 AM - - 1.2 GPM @ 60# backpressure
9:55 AM - - .75 GPM @ 60# backpressure
10:15 AM - - .8 GPM @ 60# backpressure
10:30 AM - - .8 GPM @ 60# backpressure
10:45 AM - - .8 GPM @ 60# backpressure
11:00 AM - - .8 GPM @ 60# backpressure
11:15 AM - - .8 GPM @ 60# backpressure
11:30 AM - - .8 GPM @ 60# backpressure
11:45 AM - - .8 GPM @ 60# backpressure
12:00 PM - - .8 GPM @ 60# backpressure - shut down test
12:05 PM - 1:30 PM - Rig up, pull pump
1:30 PM - 2:55 PM - Set up to log
2:55 PM - 4:10 PM - Finish logging and wait on cement truck
4:10 PM - 4:35 PM - Cement from 147' to surface
4:35 PM - 4:45 PM - Clean up & leave location

WQSP #3
GEOPHYSICAL LOGS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-500 MV 100
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NEUTRON
0 API-N 5900
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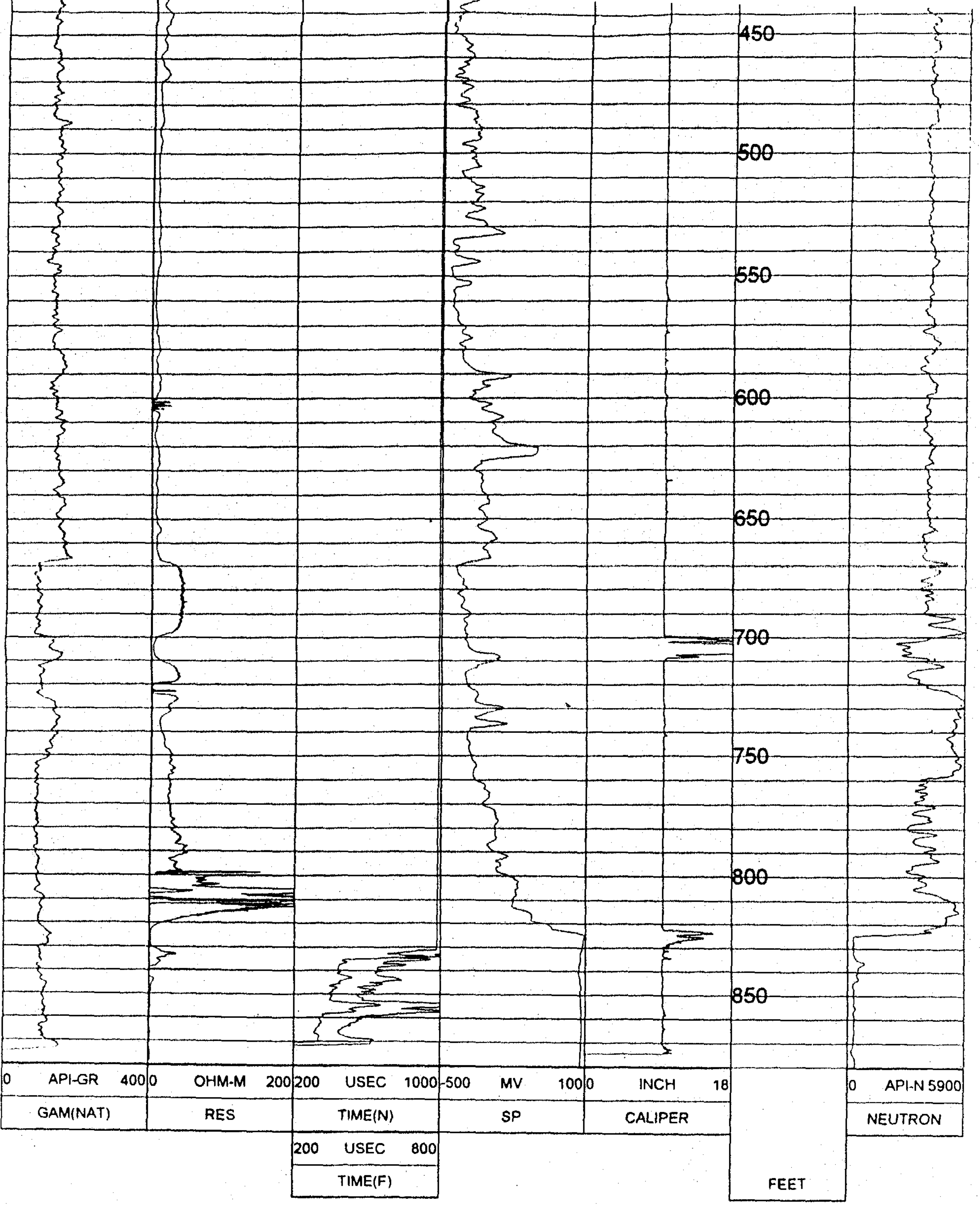
50
100
150
200
250
300
350
400

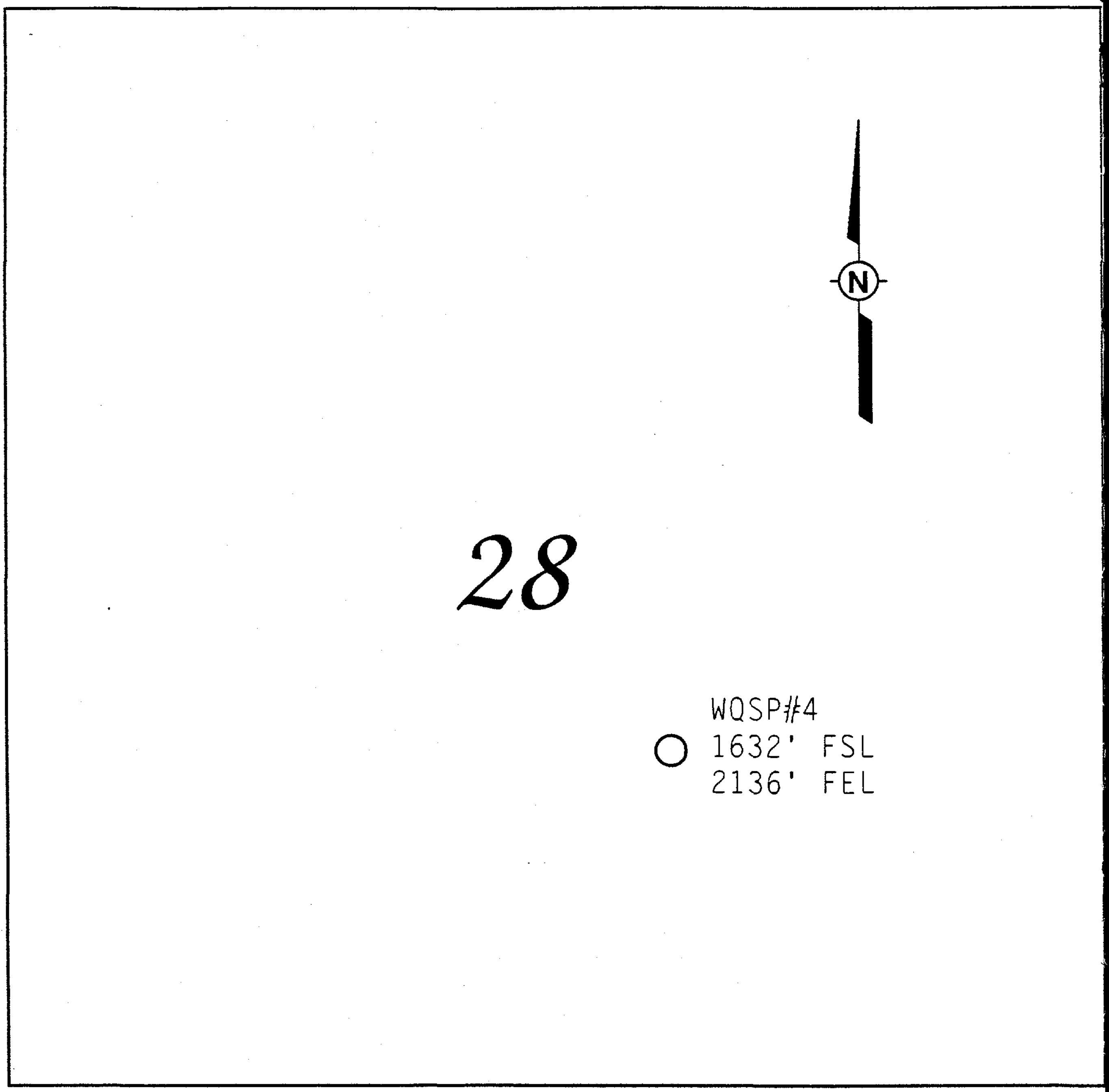
11/01/94



WQSP #3
Geophysical Logs

WQSP#4

Section 28, T22S, R31E



Location of WQSP #4

WQSP #4
Condensed Well Summary

Location:	Section 28, T22S, R31E 1632 ft from the south line 2136 ft from the east line	
Elevation: (Top of Casing)	3433.0 ft above mean sea level	
Cuttings Description:	M.L. Martin	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record:	Date: Bottom of hole: Cored interval: Cuttings:	October 5 to 7, 1994 800 ft below land surface 740 to 798 ft every 20 ft

WQSP #4
Stratigraphic Summary

Stratigraphic Unit	Depth Interval Natural Gamma Log (feet)	Core Description
Surficial Deposits/Santa Rosa	0-78	
Dewey Lake Redbeds	78-588	
Rustler Formation	588-802 partial	
• Forty Niner Member	588-652	
• Magenta Member	652-672	
• Tamarisk Member	672-770	740-765.6 partial
• Culebra Member	770-790	765.6-790.8
• Partial lower unnamed member	790-802 partial	790.8-798 partial
Maximum Recorded Depth	802	

WQSP #4
CUTTINGS DESCRIPTION

WQSP #4
Cuttings Description*

Date	Time	Sample Number	Depth (feet)	Description
10/03/94	0930	1**	5	Caliche
	0955	2**	25	Surficial deposits
10/05/94	0820	1	45	Siltstone, mudstone, and clay
	0834	2	65	Sandstone, siltstone, mudstone, and mud
	0903	3	85	Siltstone and mudstone
	0923	4	105	Mudstone and siltstone
	0939	5	125	Mudstone and Siltstone
	1003	6	145	Sandstone and mudstone
	1025	7	165	Siltstone, mudstone, trace gypsum
	1043	8	185	Siltstone and sandstone
	1104	9	205	Mudstone, trace fibrous gypsum and sandstone
	1130	10	225	Sandstone and fibrous gypsum
	1157	11	245	Siltstone and sandstone with green reduction spots, fibrous gypsum
	1225	12	265	Sandstone with green reduction spots, minor carbonate
	1258	13	285	Siltstone, sandstone, trace gypsum
	1327	14	305	Siltstone, sandstone, trace gypsum
	1402	15	325	Siltstone and sandstone
	1432	16	345	Mudstone and sandstone with green reduction spots
	1451	17	365	Mudstone and sandstone with green reduction spots, minor carbonate, and trace gypsum
	1510	18	385	Silt and sandstone with green reduction spots, minor fibrous gypsum
	1538	19	405	Sandstone, mudstone, minor gypsum, and silt, damp
	1547	20	425	Silt with gypsum, mudstone, and sandstone
10/06/64	0735	21	445	Silt, sand, and gypsum
	0804	22	465	Silt and sandstone with gypsum filled fractures

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #4
Cuttings Description (Continued) *

Date	Time	Sample Number	Depth (feet)	Description
	0821	23	485	Silt with gypsum, sandstone with green reduction spots, damp
	0850	24	505	Mudstone, silt, and gypsum
10/06/94	0910	25	525	Mudstone with selenite
	0922	26	545	Sandstone with green reduction spots, selenite and fibrous gypsum
	0945	27	565	Mudstone, trace selenite
	1001	28	585	Sandy mudstone with green reduction spots, selenite
	1045	29	605	Anhydrite
	1114	30	625	Sandy gypsiferous siltstone, damp
	1136	31	645	Anhydrite
	1225	32	665	Anhydrite, claystone, trace dolomite
	1310	33	685	Anhydrite, claystone, minor dolomite, trace gypsum
	1350	34	705	Anhydrite, gypsum, claystone, trace dolomite
	1445	35	725	Anhydrite, gypsum, and clay
	1515	36	740	Anhydrite, selenite, and clay

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #4
CULEBRA CORE DESCRIPTION

PAGE 1
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#4 DIA.: 4"
LOCATION: NE1/4 SE1/4 Section 28 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1632′FSL 2136′FEL
ELEVATION: 3433.0 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/07/94
DRILL DATE: 10/07/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/07 09:30	1	740.0 742.0 744.0 746.0 748.0 750.0 752.0	100			740.47 - 746.0 ft: red-brown muddy clay with angular anhydrite clasts (≤ 0.25 cm), isolated gypsum crystals (~ 4-5 mm), and light gray clay inclusions. Some rare fibrous gypsum fragments (~ 0.25 cm).	Tamarisk Member of Rustler Formation
						746.0 - 765.4 ft: light-dark gray mottled microcrystalline anhydrite with thin (~1 mm) wavy gypsum laminae grading to coarsely crystalline light-dark gray mottled anhydrite at 749.0 ft. Anhydrite is coarsely crystalline from 749.0 - 752.3 ft. (continued on next page)	

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OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#4 DIA.: 4"
LOCATION: NE1/4 SE1/4 Section 28 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1632'FSL 2136'FEL
ELEVATION: 3433.0 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/07/94
DRILL DATE: 10/07/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/07	1	752.0 754.0 756.0 758.0 760.0 762.0 764.0	100	▨		Dark band of gray microcrystalline anhydrite with thin lenses of gypsum, some fibrous from 752.3 - 753.0 ft. Dark brown clay seam (~ 0.10 ft thick) interbedded at 752.5 ft. Remainder of unit light with dark gray mottled microcrystalline anhydrite.	Tamarisk Member of Rustler Formation

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OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#4 DIA.: 4"
LOCATION: NE1/4 SE1/4 Section 28 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1632'FSL 2136'FEL
ELEVATION: 3433.0 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/07/94
DRILL DATE: 10/07/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/7 11:00	1	764.0	100			765.4 - 765.6 ft: gray-brown clay.	Tamarisk Member of Rustler Formation
		766.0 768.0			F GF	765.6 - 771.5 ft: upper 0.5 ft red-gray microcrystalline dolomite, laminated with numerous open vugs (< 1 - 5 mm) grading to light olive gray dolomite. 766.1 - 767.1 ft: decrease in frequency of vugs, numerous thin (1-2 mm) vertical gypsum filled fractures, gypsum vein (1-3 cm) from 766.6 - 767.2 isolated large open vugs. Remainder of unit very vuggy (≤ 1 mm), highly fractured - some gypsum healed.	Culebra Member of Rustler Formation lower ~2 ft broken and bagged
10/7 13:55		770.0 772.0 774.0 776.0	73.6			771.47 - 775.47 ft: same dolomite as above. Upper foot is extremely vuggy (1-4 mm). Open vugs decrease in frequency with depth, increase in size and become gypsum filled. Gypsum vein (~4 cm), vertical, extends 4 ft. See Next Page	

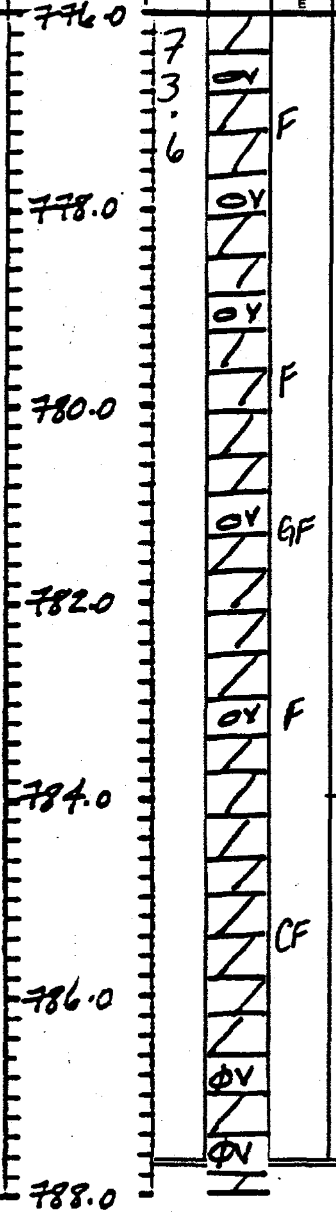
PAGE 4
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#4 DIA.: 4"
LOCATION: NE1/4 SE1/4 Section 28 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1632' FSL 2136' FEL
ELEVATION: 3433.0 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/07/94
DRILL DATE: 10/07/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/07	2		73.6		F F GF F	775.47 - 784.8 ft: same dolomite as above, highly fractured, clayey, with large (4 cm) lenticular, open vugs. Some fractures gypsum healed.	Culebra Member of Rustler Formation broken and bagged (sample bags #1-5) top-bottom ~7' core loss
					CF	784.8 - 790.8 ft: same dolomite as above, thinly laminated horizontal clay lined fractures decreasing in width toward base of unit, large gypsum filled irregular vugs (4-5 cm). (continued on next page)	

PAGE 5
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#4 DIA.: 4"
LOCATION: NE1/4 SE1/4 Section 28 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1632'FSL 2136'FEL
ELEVATION: 3433.0 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/07/94
DRILL DATE: 10/07/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

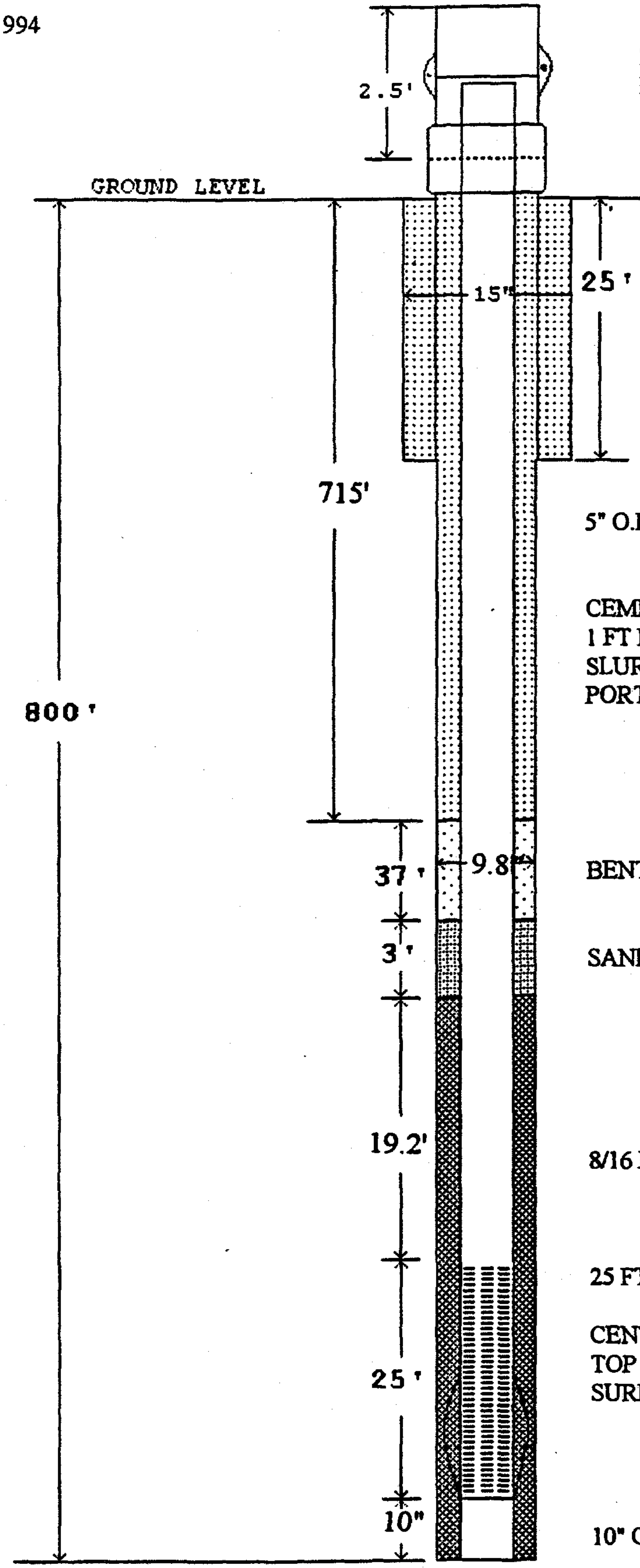
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/7 15:30	2	788.0 790.0	73.6			~2 - 4 cm band of intraformational conglomerate at very base of unit. Sharp contact between Culebra Member and unnamed member.	Culebra Member of Rustler Formation
		792.0 794.0				790.8 - 795.6 ft: black, plastic clay with thin (1-2 mm) white gypsum stringers (vertical) and isolated lenticular gypsum inclusion. Black clay grades to red-brown muddy clay with minor anhydrite interbeds.	Unnamed Member of Rustler Formation
		796.0 798.0				795.6 - 798.0 ft: dark to light gray mottled microcrystalline anhydrite grading to white-pink at depth with red/brown mud-clay interbeds.	

WQSP #4
HOLE HISTORY

WIPP Project
WQSP #4
Eddy County, New Mexico

October 5-7, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASING

CEMENT SLURRY MIX FROM 715 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 752 TO 715 FT

SAND PACK FROM 755 TO 752 FT

8/16 BRADY GRAVEL FROM 800 TO 755 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREE
TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

October 5, 1994

WQSP # 4

5:55 AM - 6:30 AM - Carlsbad to WQSP # 4
6:30 AM - 6:40 AM - Check fluid levels
6:40 AM - 7:40 AM - Work on rotating head
7:40 AM - Start drilling operations running 9 7/8" mill tooth bit, 10.75" surface, set & cemented to 25'

October 6, 1994

WQSP # 4

5:55 AM - 6:30 AM - Carlsbad to WQSP # 4
6:30 AM - 6:40 AM - Check fluid levels
6:40 AM - 6:50 AM - Trip pipe back to bottom
6:50 AM - 7:20 AM - Wait on Ron
7:20 AM - 3:30 PM - Drilling 9 7/8" hole from 428' to 740'
3:30 PM - 4:00 PM - Circulate to clean up hole
4:00 PM - 4:50 PM - Trip out of hole & prepare to core
4:50 PM - 5:30 PM - WQSP # 4 to Carlsbad

Had to go on mist pump & adding foam @ 648'

WEST TEXAS WATER WELL SERVICE

October 7, 1994

WQSP # 4

5:55 AM - 6:30 AM - Carlsbad to WQSP # 4
6:30 AM - 6:40 AM - Check fluid levels
6:40 AM - 7:30 AM - Rig up core barrel
7:30 AM - 8:30 AM - Trip core barrel in for 1st run
8:30 AM - 9:15 AM - Clean out hole of fill in
9:15 AM - 10:40 AM - Core from 740.47 - 772
10:40 AM - 10:50 AM - Clean out hole
10:50 AM - 11:35 AM - Tripping out of hole
11:35 AM - 12:00 PM - Breakout inner barrel and lay on ground
12:00 PM - 12:30 PM - Pick up inner barrel
12:30 PM - 12:45 PM - Pump out core
12:45 PM - 1:30 PM - Start back hole for 2nd run
1:30 PM - 1:40 PM - Clean out hole
1:40 PM - 3:30 PM - Coring
3:30 PM - 4:15 PM - Tripping out of hole
4:15 PM - 4:50 PM - Break off jars and pull inner barrel to lay down
4:50 PM - 5:15 PM - Pump out core
5:15 PM - 6:00 PM - Load core tools and secure rig
6:00 PM - 8:00 PM - WQSP # 4 to Odessa

October 10, 1994

WQSP # 4

5:30 AM - 7:30 AM - Odessa to WQSP # 4
7:30 AM - 8:00 AM - Service rig
8:00 AM - 9:30 AM - Trip pipe in the hole
9:30 AM - 12:00 PM - Ream hole from 8 1/2" to 9 7/8" from 740' - 800'
12:00 PM - 12:10 PM - Clean out hole
12:10 PM - 1:10 PM - Trip out of hole
1:10 PM - 1:30 PM - Rig up logging unit
1:30 PM - 3:15 PM - Log well
3:15 PM - 4:20 PM - Work on rig & load casing
4:20 PM - 5:00 PM - WQSP # 4 to Carlsbad

WEST TEXAS WATER WELL SERVICE

October 11, 1994

WQSP # 4

5:30 AM - 6:30 AM - Carlsbad to WQSP # 4
6:30 AM - 6:40 AM - Check fluid levels
6:40 AM - 6:55 AM - Measure hole depth to check for fill in - TD 800′
6:55 AM - 8:55 AM - Run 2" trimmie line in hole
8:55 AM - 10:40 AM - Run 5" fiberglass casing
1 - 10" x 5" bottom
1 - 25′ x 5″ .020 screen
767′ x 5" blank casing
Bottom cap, slip cap, centralizers
10:40 AM - 12:00 PM - Gravel pack w/ 8-16 gravel from 800′ - 755′
12:00 PM - 12:15 PM - Mix bentonite plug and spot above gravel pack
12:15 PM - 1:35 PM - Wait on cement
1:35 PM - 2:30 PM - Pump cement
2:30 PM - 3:00 PM - Pull 2" trimmie line
3:00 PM - 3:20 PM - Rig down
3:20 PM - 4:40 PM - Move and rig up on WQSP # 5
4:40 PM - 5:25 PM - WQSP # 5 to Carlsbad

October 12, 1994

WQSP # 4

Unit @ 2

8:30 AM - Arrived on WQSP # 6, rig up pulling unit to pull test pump
9:00 AM - 11:00 AM - Pulled test pump and moved to WQSP # 4
11:00 AM - 1:30 PM - Rigged up and waited on cement
1:30 PM - 4:00 PM - Bailed on well to develop and clean up any fines left by gravel pack TD 800′

WEST TEXAS WATER WELL SERVICE

October 13, 1994

WQSP # 4

Unit # 2

6:45 AM - - Arrive on location, check & service unit
7:35 AM - 7:50 AM - Make 5 runs with bailer
7:50 AM - 9:00 AM - Make splice on test pump, get ready to run
9:00 AM - 10:50 AM - Run 3 HP 20 GPM test pump
10:50 AM - 11:35 Am - Make electrical hook up and put on wellhead
11:35 AM - - Start pump open ended - 12 GPM
11:40 AM - - 12 GPM
11:45 AM - - 11.75 GPM
11:50 AM - - 11.5 GPM
11:55 AM - - 11 GPM
12:00 PM - - 9.75 GPM
12:20 PM - - 9.25 GPM
12.35 PM - - 8.75 GPM
1:05 PM - - 8 GPM
1:35 PM - - 8 GPM
2:05 PM - - 8 GPM
2:35 PM - - 8 GPM
3:05 PM - - 7.75 GPM
3:35 PM - - 7.75 GPM Stopped pumping
3:35 PM - 4:15 PM - Surged well and shut down operations for the day
4:15 PM - 4:25 PM - Back to WQSP # 5
4:25 PM - 5:15 PM - Help Ronny come out of hole

October 14, 1994

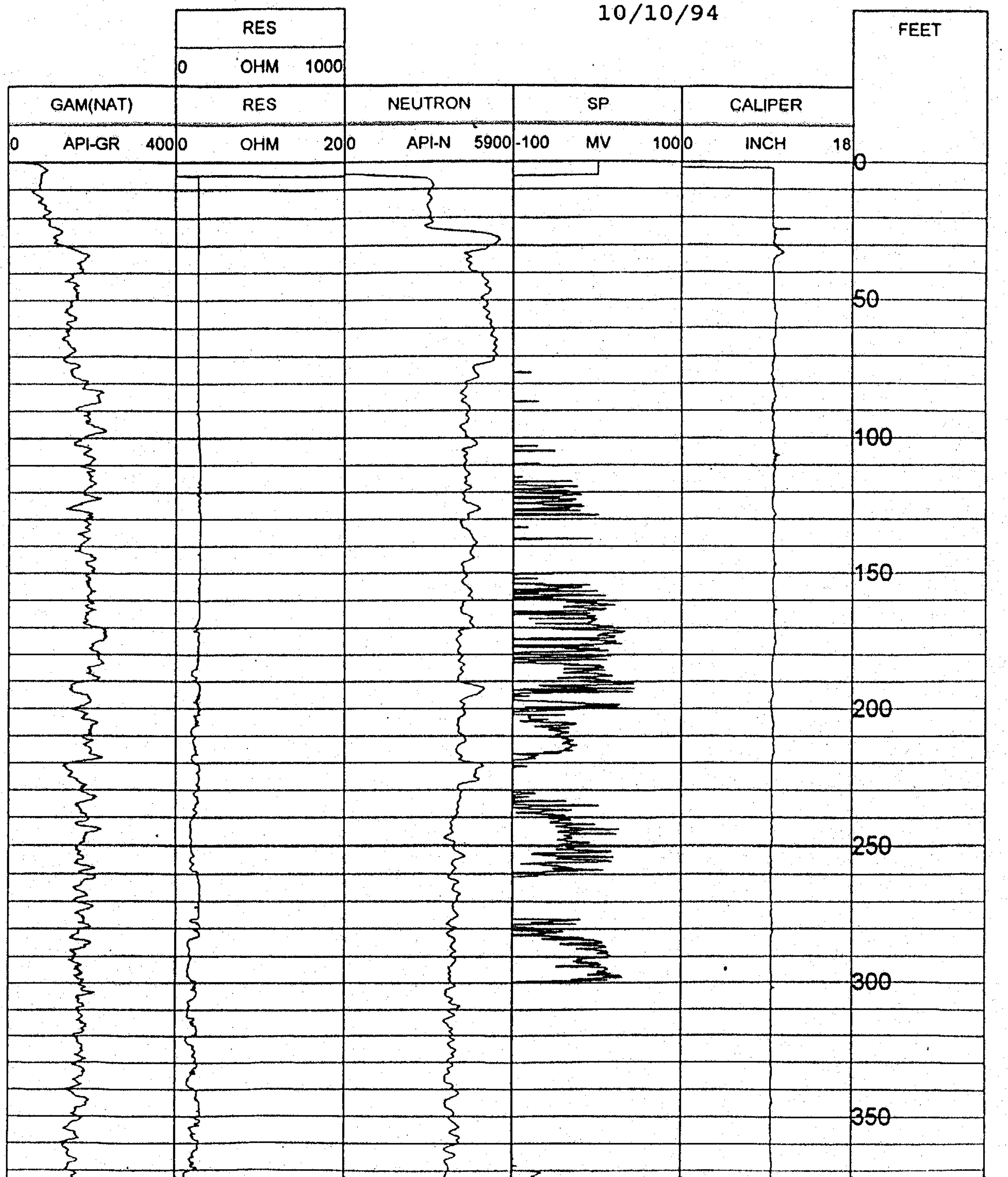
WQSP # 4

Unit # 2

7:15 AM - - Surged well 20 times in effort to try and dirty up fluid being pumped
8:15 AM - - Stopped surging well and began pumping constant, open ended discharge
8:20 AM - - Pumping 12 GPM, clear discharge
8:25 AM - - Pumping 11.5 GPM, clear discharge
8:30 AM - - Pumping 10.5 GPM, clear discharge
8:35 AM - - Pumping 10 GPM, clear discharge
8:40 AM - - Pumping 9.75 GPM, clear discharge
8:45 AM - - Pumping 9.5 GPM, clear discharge
8:50 AM - - Pumping 9.25 GPM, clear discharge
8:55 AM - - Pumping 9.25 GPM, clear discharge
9:00 AM - - Pumping 9 GPM, clear discharge
1:00 PM - - Shut down operations for weekend
1:00 PM - 3:00 PM - Returned to Odessa

WQSP 4#
GEOPHYSICAL LOGS

10/10/94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RES
0 OHM 20
NEUTRON
0 API-N 5900
SP
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CALIPER
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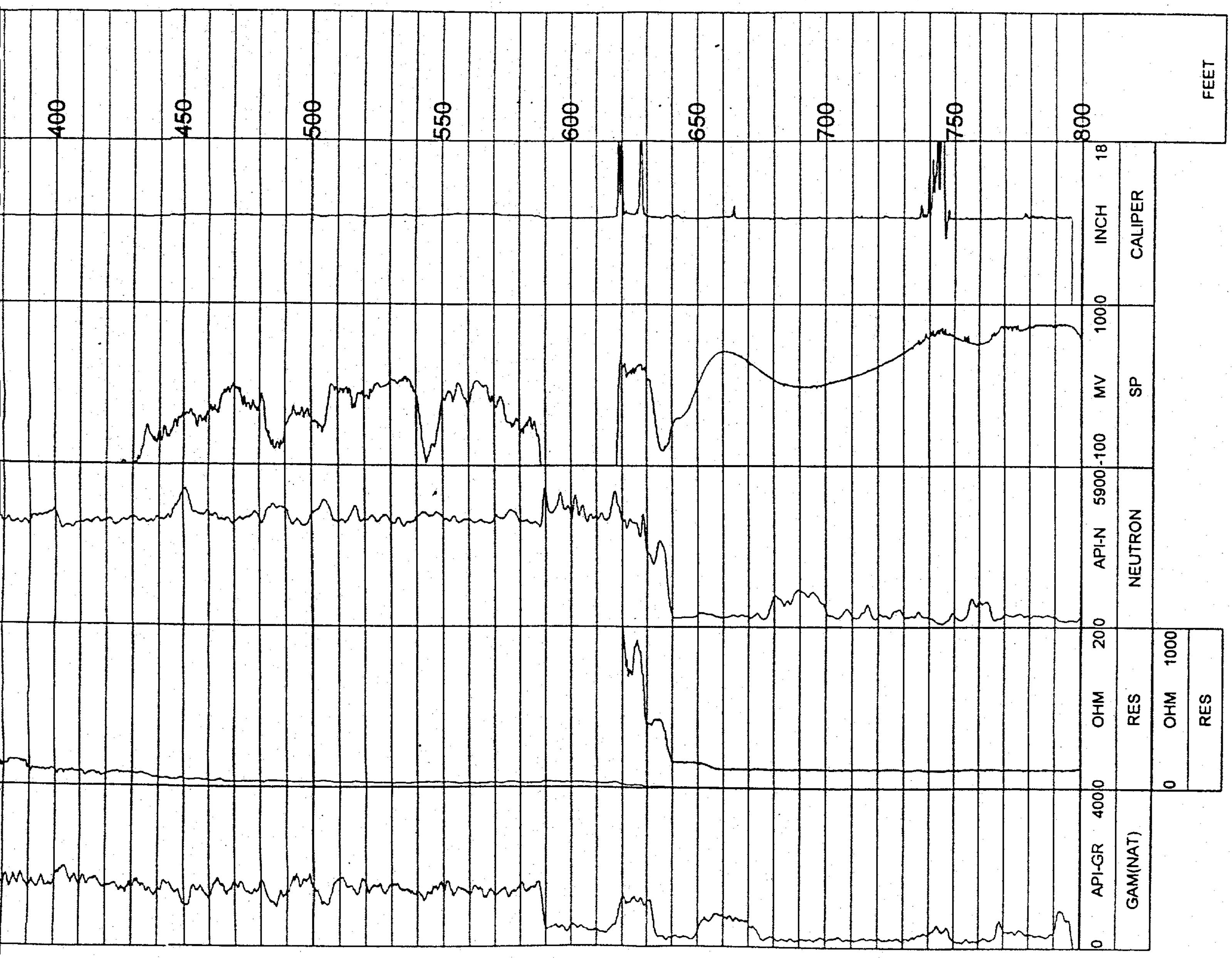
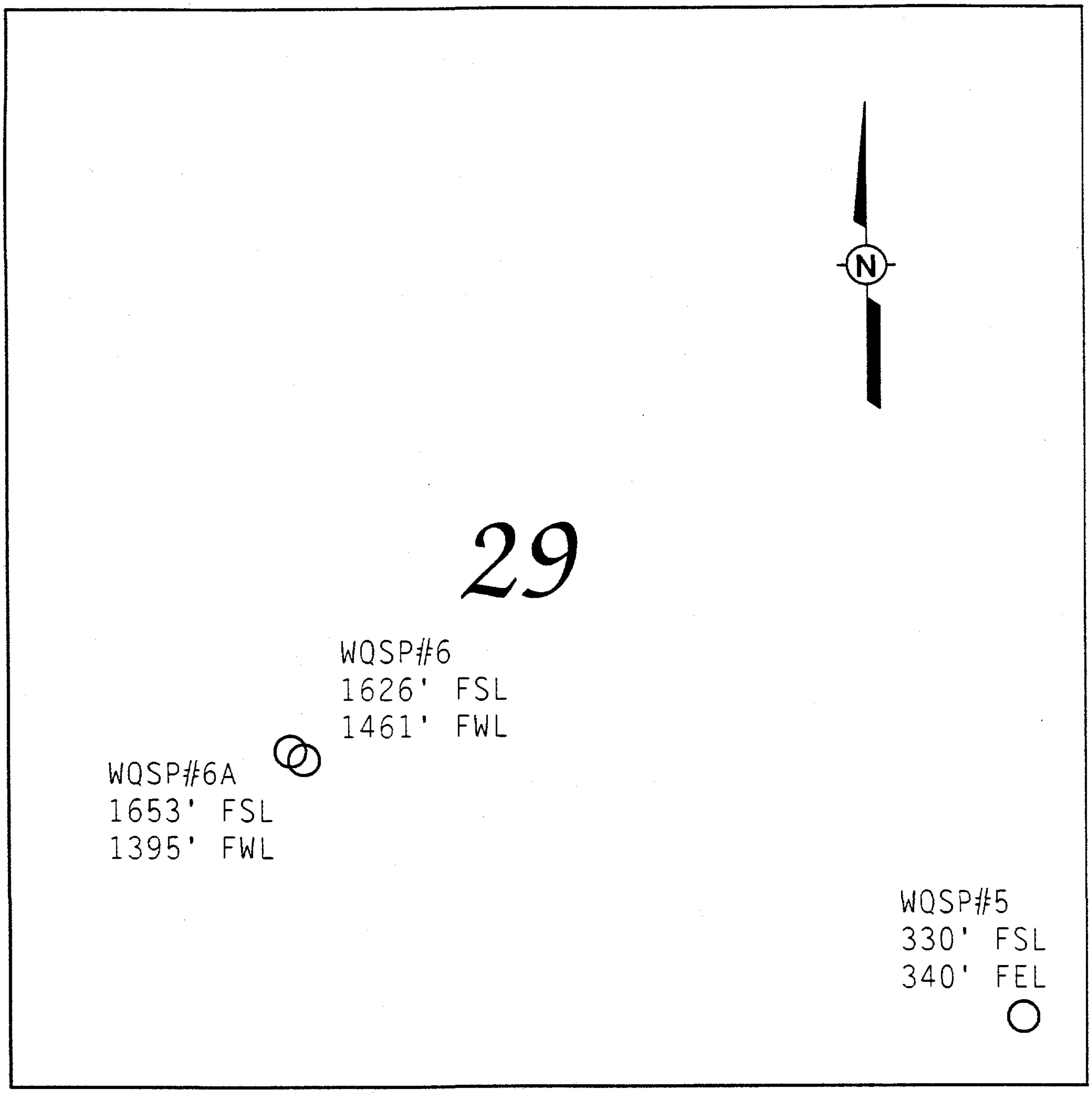
FEET
0
50
100
150
200
250
300
350

Century Geophysical Corp.



WQSP #4
Geophysical Logs

WQSP#5



Section 29, T22S, R31E

Location of WQSP #5

WQSP #5
Condensed Well Summary

Location:	Section 29, T22S, R31E 330 ft from the south line 340 ft from the east line	
Elevation: (Top of Casing)	3384.4 ft above mean sea level	
Cuttings Description:	M.L. Martin	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record	Date:	October 12 to 13, 1994
	Bottom of hole:	683 ft below land surface
	Cored interval:	648 to 676 ft
	Cuttings:	every 20 ft

WQSP #5
Stratigraphic Summary

Stratigraphic Unit	**Depth Interval Natural Gamma Log (feet)**	**Core Description**
Surficial Deposits/Santa Rosa	0-25	
Dewey Lake Redbeds	25-475	
Rustler Formation	475-683 partial	
• Forty Niner Member	475-530	
• Magenta Member	530-554	
• Tamarisk Member	554-648	
• Culebra Member	648-669	648-674
• Partial lower unnamed member	669-683	674-676 partial
Maximum Recorded Depth	683	

WQSP #5
CUTTINGS DESCRIPTION

WQSP #5
Cuttings Description *

Date	Time	Sample Number	Depth (feet)	Description
09/22/94	0935	1**	4	Caliche
	0940	2**	25	Mudstone
10/12/94	0825	3	45	Sandstone and mudstone
	0833	4	65	Mudstone and sandstone
	0855	5	85	Sandstone
	0910	6	105	Mudstone with green reduction spots, damp
	0925	7	125	Mudstone, damp
	0936	8	145	Sandy siltstone with gypsum
	0950	9	165	Mudstone, fibrous gypsum
	1014	10	185	Mudstone and sandstone with green reduction spots, minor gypsum
	1025	11	205	Sandstone
	1045	12	225	Sandstone and mudstone with green reduction spots, damp
	1110	13	245	Mudstone and sandstone
	1120	14	265	Mudstone laminated with fibrous gypsum, sandstone, minor gypsum
	1140	15	285	Sandy mudstone, sandstone with minor gypsum
	1153	16	305	Mudstone and sandstone with green reduction spots, fibrous gypsum
	1210	17	325	Mudstone with green reduction spots, minor gypsum
	1233	18	345	Sandstone interbedded with fibrous gypsum
	1245	19	365	Sandstone, trace gypsum
	1308	20	385	Sandy mudstone interbedded with gypsum, trace carbonate
	1335	21	405	Sandstone with green reduction spots and gypsiferous siltstone
10/12/94	1353	22	425	Sandstone with green reduction spots, laminated with fibrous gypsum
	1416	23	445	Gypsiferous mudstone laminated with fibrous gypsum, damp
	1440	24	465	Mudstone with green reduction spots, minor gypsum
	1504	25	485	Anhydrite, minor gypsum, sandstone and carbonate

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #5

Cuttings Description (Continued) *

Date	Time	Sample Number	Depth (feet)	Description
	1535	26	505	Gypsiferous siltstone, carbonate
10/13/94	0810	27	545	Anhydrite, mudstone, trace carbonate
10/13/94	0847	28	565	Anhydrite
	0920	29	585	Anhydrite, mudstone, trace dolomite
	1005	30	605	Anhydrite, mudstone, trace dolomite
	1050	31	625	Anhydrite and claystone
	1115	32	645	Anhydrite

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* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #5
CULEBRA CORE DESCRIPTION

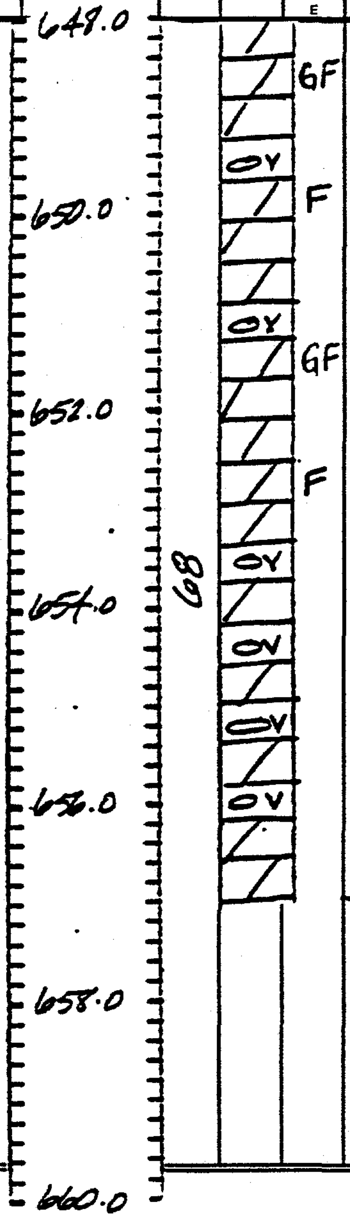
PAGE 1
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#5 DIA.: 4"
LOCATION: SE1/4 SE1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 330' FSL 340' FEL
ELEVATION: 3384.4 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/13/94
DRILL DATE: 10/13/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/13 2:20	1		68			648.0 - 657.0 ft: light olive gray microcrystalline dolomite, thinly laminated, with 1-2 mm wide irregular gypsum healed fractures and rare, small (1-2 mm) open vugs. At 655.0 ft vugs become larger (up to 2 inches), irregular and increase in frequency, rock has a distinct "Swiss cheese" texture. Highly fractured, clayey intervals occur between 649.2-649.9 and 652.6-652.7 ft. Rubbly, clayey, but competent interval occurs between 653.4 - 655.0 ft with rare (≤ 0.25 cm) vugs. Contact between Culebra Member and overlying Tamarisk Member not observed.	Culebra Member of Rustler Formation
						657.0 - 666.0 ft: core loss.	9 feet of core loss

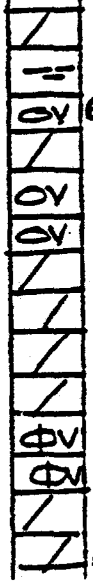
PAGE 2
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#5 DIA.: 4"
LOCATION: SE1/4 SE1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 330' FSL 340' FEL
ELEVATION: 3384.4 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/13/94
DRILL DATE: 10/13/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/13	1	660.0 662.0 664.0				657.0 - 666.0 ft: core loss.	Culebra Member of Rustler Formation 9 feet of core loss
		666.0 668.0 670.0 672.0	89		6F	666.0 - 674.4 ft: same dolomite as above, extremely vuggy, most vugs are small and rock has a "sponge-like" texture. Some vugs are interconnected by dissolution and are highly irregular in shape. Vugs tend to form horizontal bands (~0.10 ft thick). Some dissolution pockets are gypsum filled. Vugs decrease in frequency with depth. Short, irregular gypsum-healed fractures and clay lens toward top of units. (continued on next page)	

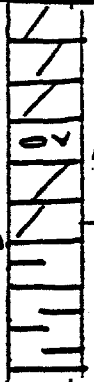
PAGE 3
OF 3

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#5 DIA.: 4"
LOCATION: SE1/4 SE1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 330' FSL 340' FEL
ELEVATION: 3384.4 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/13/94
DRILL DATE: 10/13/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

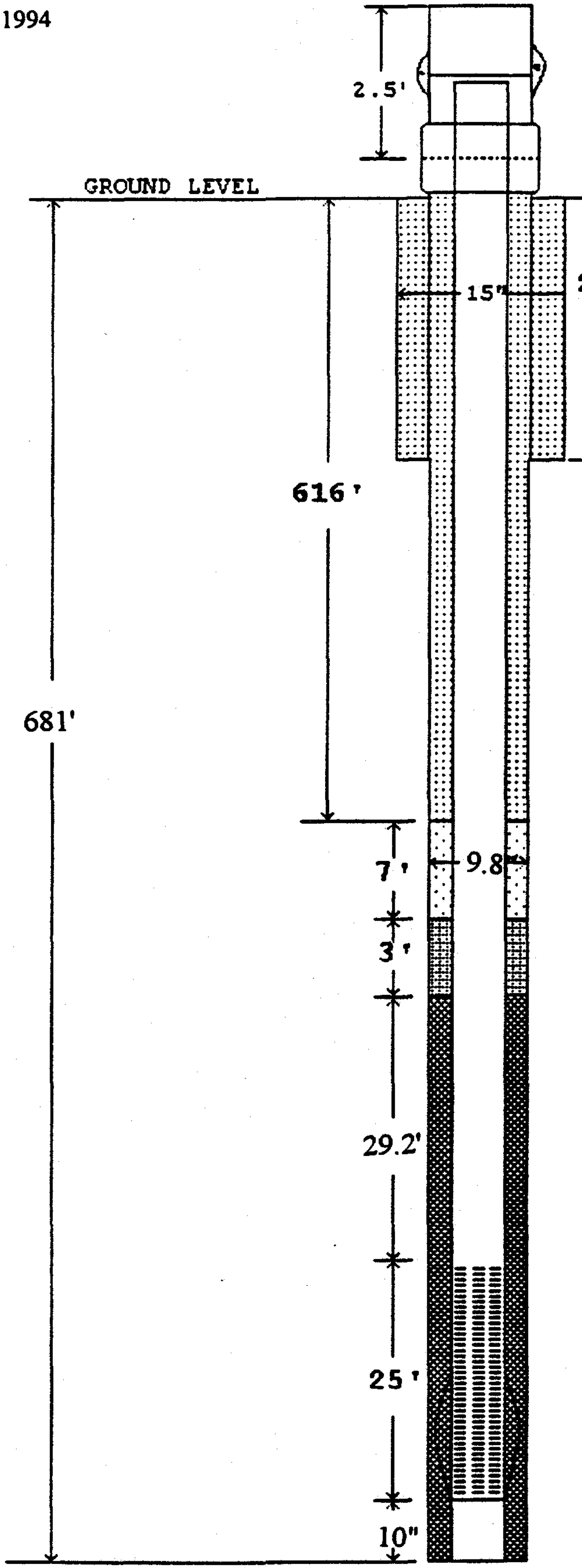
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
		672.0					
10/13					F	highly fractured interval at 673.5 ft grading to more competent rock at 674.4 ft. Contact between Culebra Member and unnamed member is gradational.	Culebra Member of Rustler Formation
	1	674.0	68			674.4 - 676.0 ft: compact, gypsiferous, black clay grading to red-brown clay with gypsum interbeds and stringers.	Unnamed Member of Rustler Formation
4:15		676.0					
		678.0					
		680.0					
		682.0					
		684.0					

WQSP #5
HOLE HISTORY

WIPP Project
WQSP #5
Eddy County, New Mexico

October 12-13, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO
PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING
CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASIN

CEMENT SLURRY MIX FROM 613 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 623 TO 613 FT

SAND PACK FROM 626 TO 623 FT

8/16 BRADY GRAVEL FROM 681 TO 626 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREE
TOP OF SCREEN, AND AT 60 FT INTERVALS TO
SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

September 22, 1994

WQSP # 5 & WQSP # 6

9:00 AM - 12:00 PM - Drilled, set 10.75" surface casing, cemented

October 12, 1994

WQSP # 5

6:00 AM - 6:35 AM - Carlsbad to WQSP # 5
6:35 AM - 6:50 AM - Check fluid levels
6:50 AM - 8:00 AM - Finish rigging up
8:00 AM - 12:30 PM - Start drilling from 25'. 10.75" .375W surface nipple pre-set to 25' & cemented to surface
12:30 PM - 3:45 PM - Drilling 9 7/8" hole, started to get wet at 505', shut down for the day
3:45 PM - 4:00 PM - Pull out of hole 3 stands & shut down
4:00 PM - 4:35 PM - WQSP # 5 to Carlsbad

October 13, 1994

WQSP # 5

5:50 AM - 6:30 AM - Carlsbad to WQSP # 5
6:30 AM - 6:45 AM - Check fluid levels
6:45 AM - 8:05 AM - Trip back in hole to start drilling
8:05 AM - 11:15 AM - Drilling 9 7/8" hole from 505' to 648' on mist pump using foam
11:15 AM - 11:30 AM - Circulate hole to clean up
11:30 AM - 12:15 PM - Trip out of hole to set up coring operation.
12:15 PM - 1:45 PM - Pick up core barrel assembly and go in hole to core
1:45 PM - 2:15 PM - Pull up and put on 5' pup joint.
2:15 PM - 4:15 PM - Coring 1st run 8 1/2" bit cutting 4" core
4:15 PM - 4:25 PM - Circulate foam, clean up before T.O.O.H.
4:25 PM - 5:25 PM - T.O.O.H.
5:25 PM - 5:45 PM - Breakout core barrel, lay down inner barrel
5:45 PM - 6:30 PM - Pump out core, recovered 22'10"
6:30 PM - 7:00 PM - Load core tools
7:00 PM - 7:40 PM - WQSP # 5 to Carlsbad

WEST TEXAS WATER WELL SERVICE

October 18, 1994

WQSP # 5

5:50 AM - 7:40 AM - Odessa to WQSP # 5
7:40 AM - 7:50 AM - Move and spot logging trailer
7:50 AM - 8:10 AM - Wait on logger
8:10 AM - 11:00 AM - Run camera in WQSP # 5
11:00 AM - 12:50 PM - Trip pipe back in well
12:50 PM - 2:00 PM - Ream hole from 8 1/2" to 9 7/8" from 648' - 683'
2:00 PM - 2:30 PM - Clean out hole
2:30 PM - 3:05 PM - Pull 8 jts of drill pipe and secure rig for the day
3:05 PM - 4:00 PM - Get load of water & pump diesel
4:00 PM - 4:30 PM - WQSP @ 5 to Carlsbad

11:00 AM - 1:00 PM - Barrett pulled pump out of WQSP # 4

October 19, 1994

WQSP # 5

5:30 AM - 6:30 AM - Carlsbad to WQSP # 5
6:30 AM - 6:40 AM - Check fluid levels
6:40 AM - 8:00 AM - Trip pipe back to bottom & clean out hole
8:00 AM - 8:50 AM - Trip pipe out of hole
8:50 AM - 9:50 AM - Run 2" trimmie line
9:50 AM - 11:20 AM - Run 5" fiberglass casing, screen
11:20 AM - 12:30 PM - Gravel pack well w/8-16 gravel
12:30 PM - 1:00 PM - Mix bentonite seal & pumped
1:00 PM - 1:45 PM - Wait on cement trucks
1:45 PM - 2:30 PM - Started cementing operations
2:30 PM - 3:00 PM - Pull 2" trimmie line
3:00 PM - 3:30 PM - Rig down
3:30 PM - 4:00 PM - Move to WQSP # 3, start rigging up & get load of water
4:00 PM - 4:30 PM - Secure rig and equipment
4:30 PM - 5:10 PM - WQSP # 3 to Carlsbad

October 20, 1994

WQSP # 5

1:30 PM - 5:15 PM - Rigged up on WQSP # 5, started developing well with bailer, made 9 trips. TD of well 683', static water level 394'

WEST TEXAS WATER WELL SERVICE

October 21, 1994

WOSP # 5

Unit # 2

6:35 AM - 7:20 AM - Arrive on location, check & service unit, prepare to run test pump
7:20 AM - 8:55 AM - Run 3 HP test pump on 32 joints of 1" galvanized pipe, pump set 672'
8:55 AM - - Start pumping well @ 13.25 GPM
9:00 AM - - 12.75 GPM
9:05 AM - - 11.75 GPM
9:10 AM - - 11 GPM
9:15 AM - - 10.25 GPM
9:20 AM - - 2.50 GPM with 150# backpressure
9:25 AM - - 2.75 GPM
9:30 AM - - 2.50 GPM
9:40 AM - - 3 GPM
9:45 AM - - 3 GPM shut down & allow to recover
10:10 AM - - Start surging well to further develop
10:55 AM - - Start pumping, set rate @ 3:00 PM, 150# backpressure
3:00 PM - - Pump was shut off, making .8 GPM

October 24, 1994

WOSP # 5

Unit # 2

9:35 AM - - Start surging
11:35 AM - - Start test 225 GPM @ 150# back pressure
12:50 PM - - 1.75 GPM @ 170# back pressure
2:20 PM - - 2.5 GPM @ 150# back pressure
2:30 PM - - 2.75 GPM @ 150# back pressure
2:40 PM - - 1.75 GPM @ 150# back pressure
3:15 PM - - 1.75 GPM @ 0# back pressure
3:25 PM - - 1.75 GPM
3:45 PM - - 1.9 GPM
3:50 PM - - 1.9 GPM
Shut down for the day

WEST TEXAS WATER WELL SERVICE

October 25, 1994

WQSP # 5

Unit # 2

6:55 AM - 9:00 AM - Surge well to further develop, and pump well at intermittent times

9:00 AM - 10:50 AM - Pump well @ 2.1 GPM down to 1.9 GPM. Shut pump down and add 5 gallons of Clorox bleach to break down any existing polymer left in well between gravel pack & wellbore

10:50 AM - 12:00 PM - Surge well to help break down and further develop formation

12:00 PM - 4:00 PM - Install 2 GPM choke and begin pumping well at 2.6 GPM with 170# back pressure

1:00 PM - - 1.85 GPM @ 70 #

4:00 PM - - 1.8 GPM @ 50#
Shut down unit for the day

October 26, 1994

WQSP # 5

Unit # 2

7:00 AM - 7:20 AM - Arrive on location, service & check unit, rig up and prepare to pull pump

7:20 AM - 9:15 AM - Pull test pump

9:15 AM - 10:30 AM - Remain rigged up, load & secure trailer, wait on logging unit

10:30 AM - 2:10 PM - Run logs on WQSP # 5, rig down, go to WQSP # 3 to log

WQSP # 5

Unit # 2

7:00 AM - - Arrive on location ,service & check unit, rig up and prepare to pull test pump

7:20 AM - 9:15 AM - Pull test pump

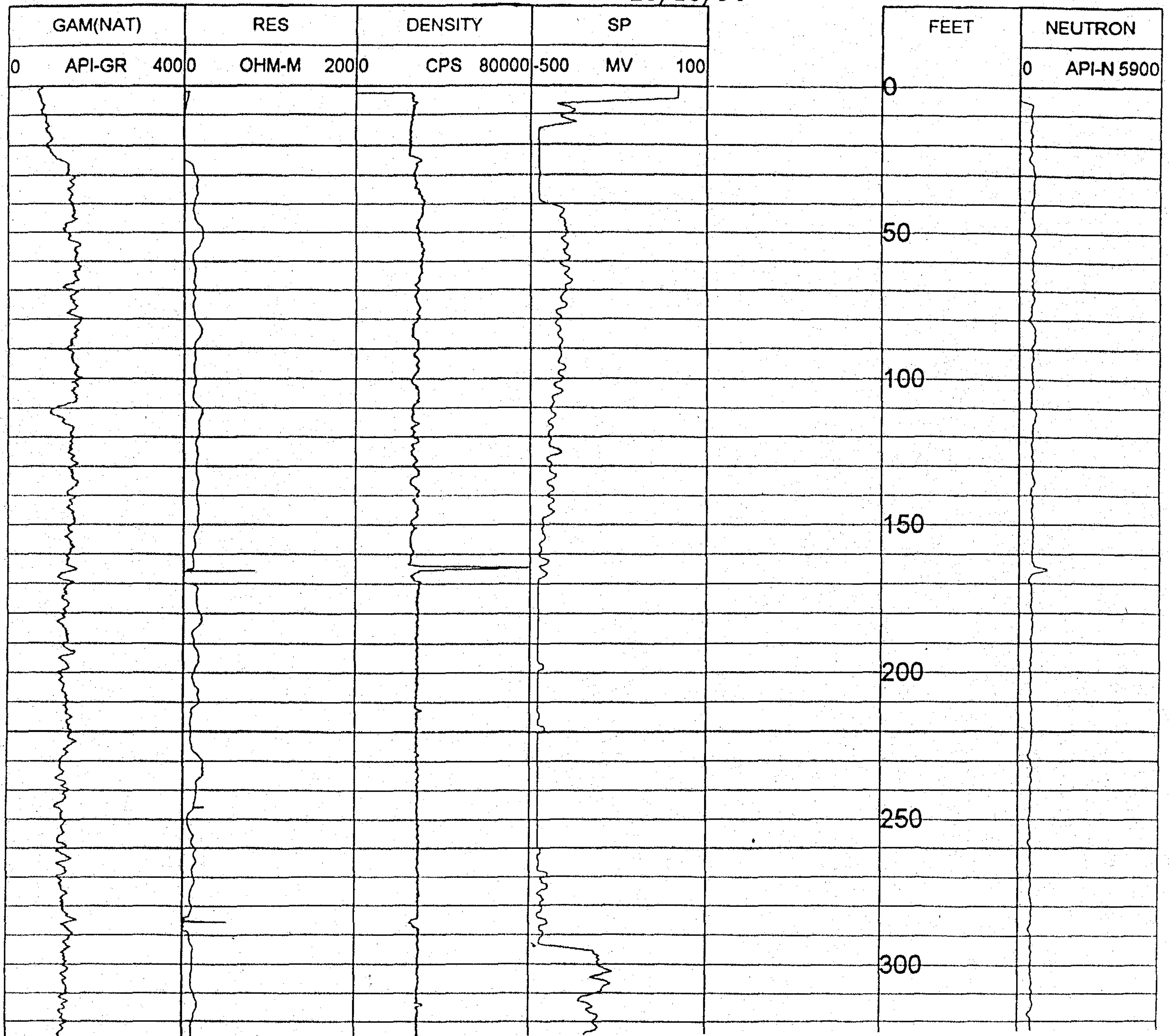
9:15 AM - 10:00 AM - Load and secure trailer to move to WQSP # 3

10:00 AM - 10:30 AM - Wait on logging unit

10:30 AM - 2:10 PM - Run logs and move to WQSP # 3

WQSP #5
GEOPHYSICAL LOGS

10/26/94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SP
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NEUTRON
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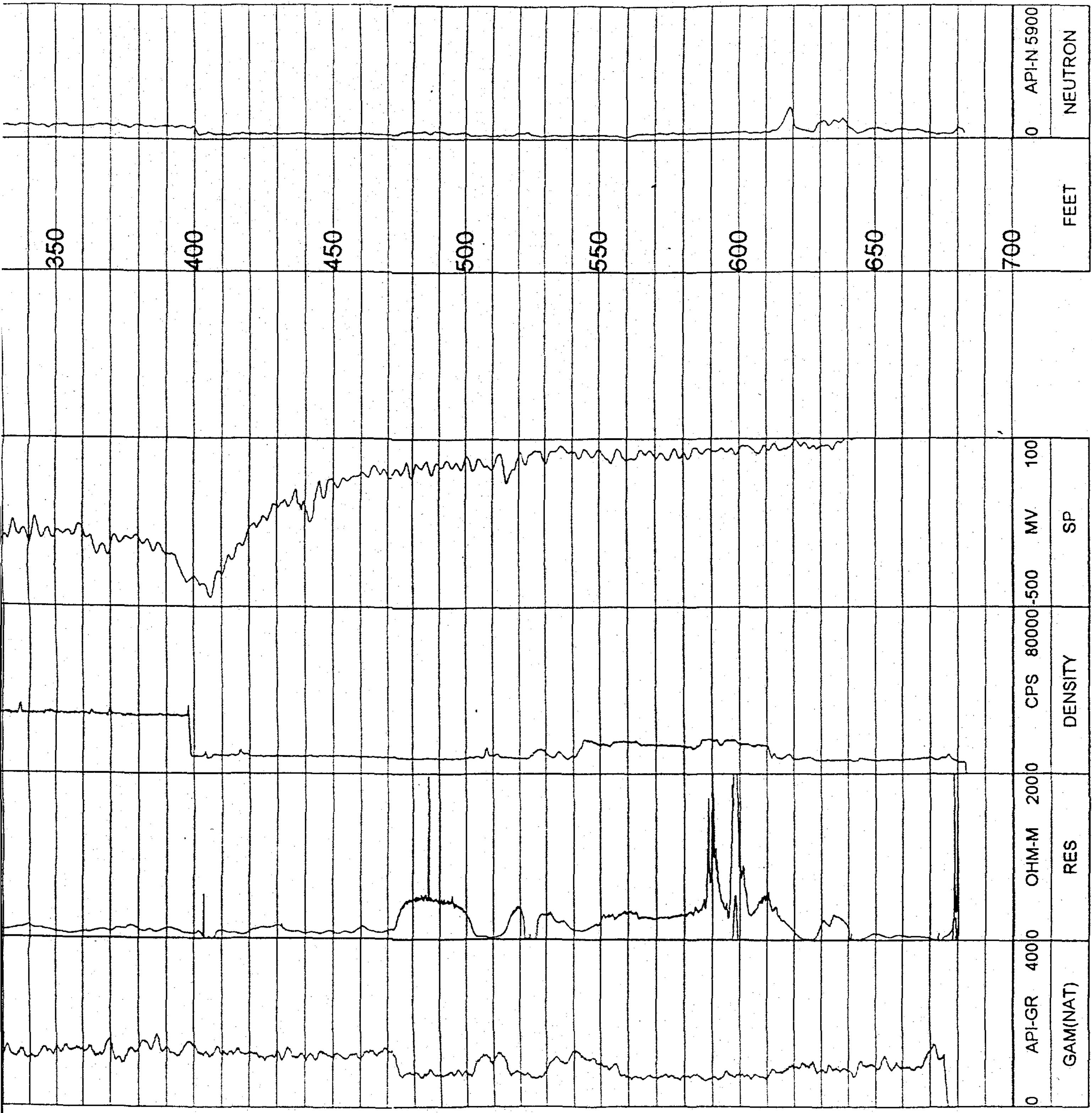
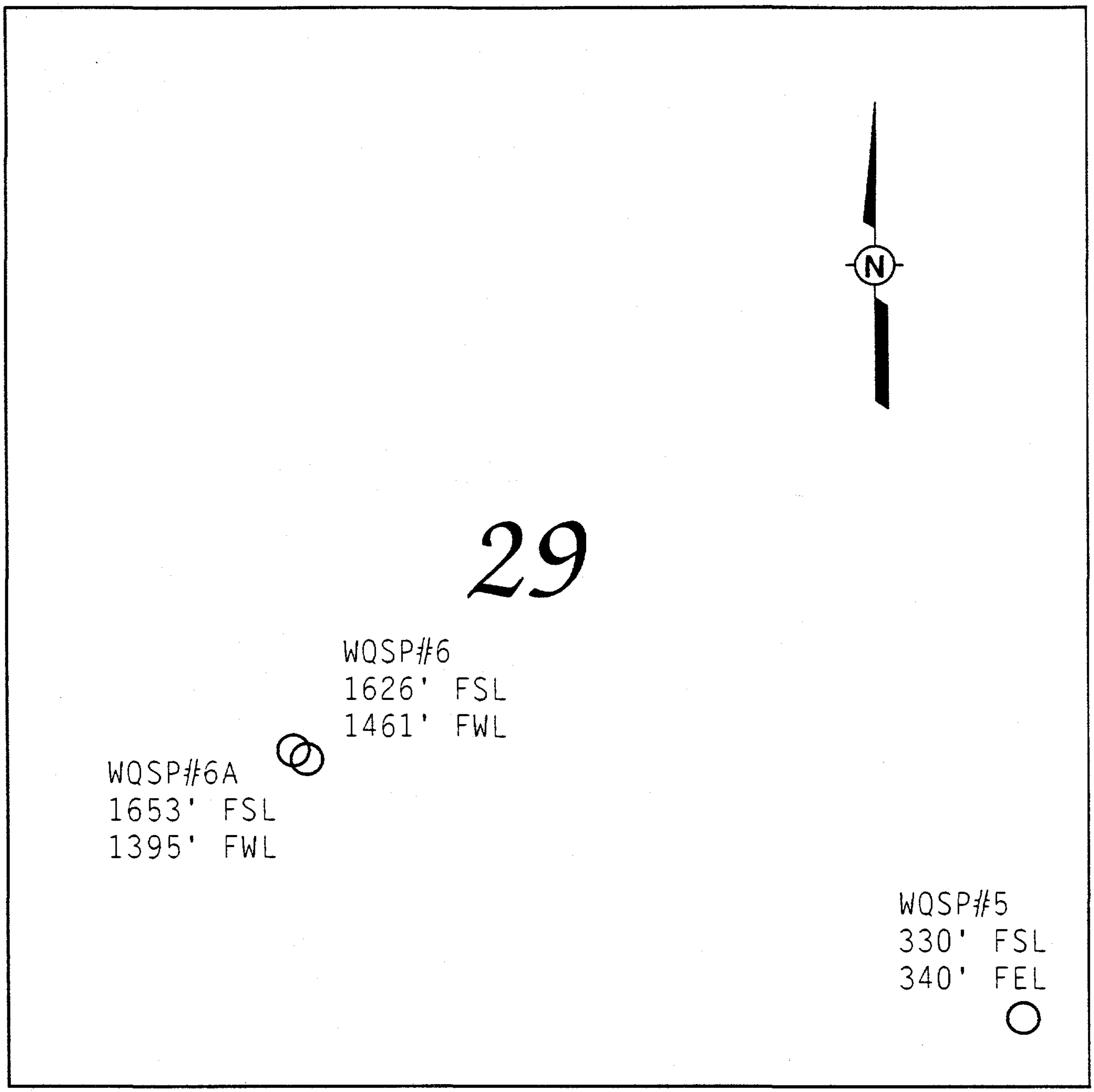
Century
GEOPHYSICAL CORP.



WQSP #5
Geophysical Logs

WQSP#6



Section 29, T22S, R31E

Location of WQSP #6

WQSP #6
Condensed Well Summary

Location:	Section 29, T22S, R31E 1626 ft from the south line 1461 ft from the west line	
Elevation: (Top of Casing)	3363.8 ft above mean sea level	
Cuttings Description:	M.L. Martin	
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax	
Drilling Record	Date: Bottom of hole: Cored interval: Cuttings:	September 22, to October 4, 1994 617 ft below land surface 568 to 617 ft every 20 ft

WQSP #6
Stratigraphic Summary

Stratigraphic Unit	**Depth Interval Natural Gamma Log (feet)**	**Core Description**
Surficial Deposits/Santa Rosa	0-68	
Dewey Lake Redbeds	68-409	
Rustler Formation	409-620	
• Forty Niner Member	409-474	
• Magenta Member	474-497	
• Tamarisk Member	497-588	568-582 partial
• Culebra Member	588-606	582-607
• Partial lower unnamed member	606-620	607-617 partial
Maximum Recorded Depth	620	617

WQSP #6
CUTTINGS DESCRIPTION

WQSP #6
Cuttings Description *

Date	Time	Sample Number	Depth (feet)	Description
09/22/94	1050	1**	5	Surficial deposits
	1110	2**	25	Mudstone, sandstone, and clay
09/26/94	0903	3	45	Mudstone with green reduction spots
	0914	4	65	Sandstone with green reduction spots
	1015	5	85	Sandstone with green reduction spots
	1030	6	105	Siltstone, trace gypsum
	1043	7	125	Siltstone, damp
	1055	8	145	Siltstone and sand, damp
	1112	9	165	Sandy siltstone, damp
	1147	10	185	Mudstone and sand
	1203	11	205	Mudstone and sandstone
	1245	12	225	Sandstone, mudstone with green reduction spots, gypsum
	1325	13	245	Sandstone, siltstone, and selenite
	1340	14	265	Sandstone, selenite, and siltstone, limited sample
	1410	15	285	Sandstone and sandy siltstone with green reduction spots, selenite
	1435	16	305	Sandstone and gypsum
	1515	17	325	Sandy siltstone, sandstone, selenite
	1540	18	345	Sandy siltstone, sandstone, minor gypsum
	1550	19	365	Sandstone and siltstone with green reduction spots
09/27/94	1010	20	385	Sandy siltstone and sandstone with green reduction spots, minor gypsum
	1045	21	405	Gypsum, sandstone, and sandy siltstone
09/28/94	1035	22	425	Anhydrite, gypsum, and sandstone with green reduction spots
	1155	23	445	Anhydrite and gypsum
	1235	24	465	Anhydrite and gypsum

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #6
Cuttings Description (Continued) *

Date	Time	Sample Number	Depth (feet)	Description
	1325	25	485	Anhydrite, gypsum, dolomite
	1410	26	505	Anhydrite, trace dolomite
	1520	27	525	Anhydrite
09/28/94	1645	28	545	Anhydrite and gypsum
	1810	29	565	Mud, minor anhydrite and gypsum, limited sample
	1835	30	568	Anhydrite and mud

* Cuttings description is for stratigraphic control not geologic description.

** Auger drilling.

WQSP #6
CULEBRA CORE DESCRIPTION

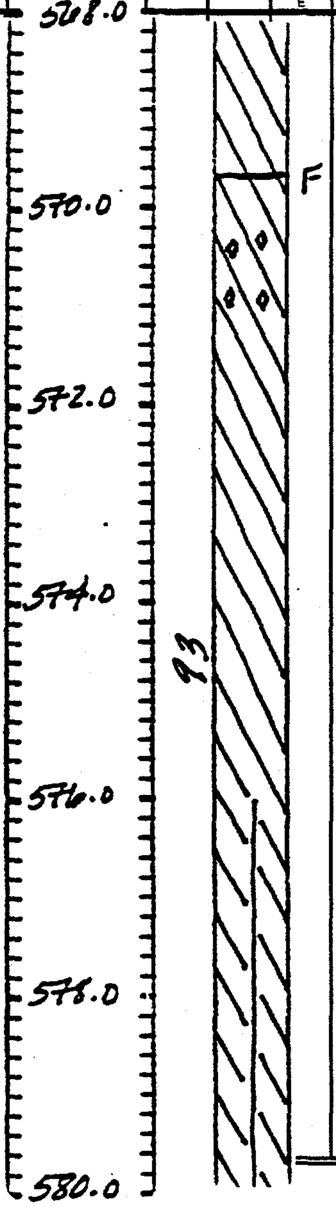
PAGE 1
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6 DIA.: 4"
LOCATION: NE1/4 SW1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1626' FSL 1461' FWL
ELEVATION: 3363.8 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/29/94
DRILL DATE: 09/29/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service



Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
9/29 10:10	1		93			568.0 - 582.0 ft: light to dark gray mottled microcrystalline anhydrite with 1-2 mm wavy gypsum laminae. Horizontal fracture at 569.7 ft overlain by ~0.75 cm thick gypsum band. Interval of sparsely laminated anhydrite from 570.0 - 571.2 ft with numerous 1-2 mm isolated euhedral gypsum crystals. A prominent 2-4 cm thick continuous gypsum vein (vertical) occurs from 576.0 - 580.0 ft. Gradational contact between Tamarisk Member and underlying Culebra Member.	Tamarisk Member of Rustler Formation

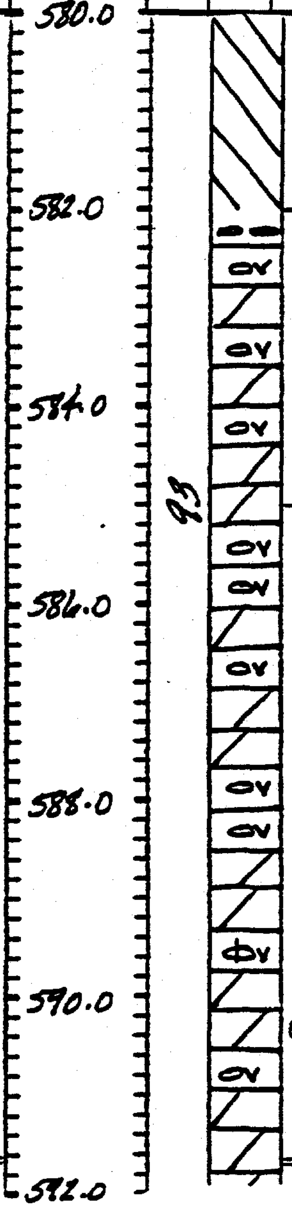
PAGE 2
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6 DIA.: 4"
LOCATION: NE1/4 SW1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1626' FSL 1461' FWL
ELEVATION: 3363.8 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/29/94
DRILL DATE: 09/29/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service



Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
9/29	1	580.0 - 582.0	93			See previous page.	Tamarisk Member of Rustler Formation
		582.0 - 585.0				582.0 - 585.0 ft: brown-gray microcrystalline dolomite with (0.25-1 cm) open vugs and moderate horizontal fractures ~2 cm wide band of dolomite with rounded anhydrite clasts (~0.5 cm) at 582.2 ft.	Culebra Member of Rustler Formation
		585.0 - 592.0			GF CF	585.0 - 596.6 ft: light olive gray, thinly laminated microcrystalline dolomite with numerous small open vugs (1-2 mm) and moderate horizontal fracturing. Vugs increase in size, decrease in frequency and are sparse and fibrous gypsum filled at 589.9 ft. A continuous 1-2 mm gypsum-filled fracture occurs from 590.3 - 591.1 ft. Highly fractured clayey intervals with bladed gypsum crystals and numerous open vugs from 589.9 - 590.3 ft and 591.1 - 591.2 ft. (continued on next page)	

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OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6 DIA.: 4"
LOCATION: NE1/4 SW1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1626' FSL 1461' FWL
ELEVATION: 3363.8 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/29/94
DRILL DATE: 09/29/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
9/29 1:38	1	592.0 594.0 596.0	95		CF GF	Toward base of unit vugs decrease in size and increase in frequency. Clay filled fractures and thin (0.5-1 mm) gypsum healed fractures increase in frequency with depth. Fractures are thin, wavy, and discontinuous.	Culebra Member of Rustler Formation 2 feet of core loss
9/30	2	598.0 600.0 602.0 604.0	87.5		CF GF	596.6 - 606.85 ft: same dolomite as above. Upper foot interbedded with vuggy (up to 0.25 cm) dolomite rubble in a red-brown mud/clay matrix. 597.6 - 600.2 ft: dolomite is clayey, highly fractured with numerous (1-2 mm) open vugs. Remainder of unit is competent with numerous small vugs, some connected by dissolution to form vertical and horizontal bands up to 3 cm in length. Thin, discontinuous gypsum-healed fractures (1-2 mm) increase in frequency with depth. (continued on next page)	2.5 feet of core loss

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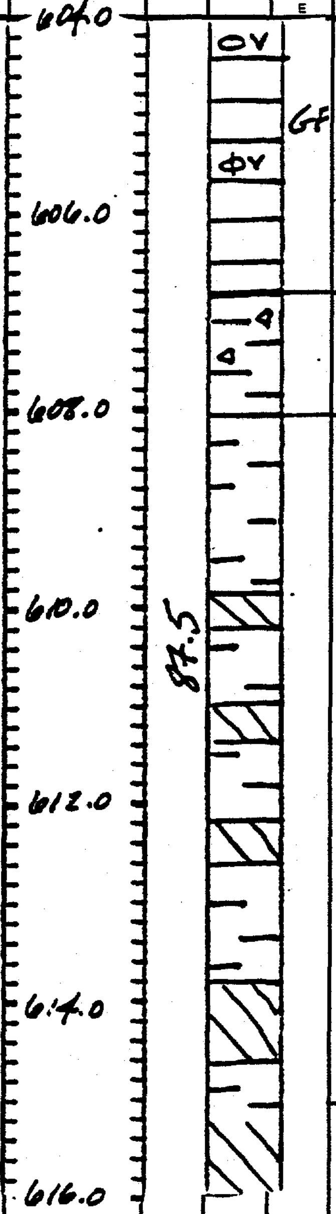
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6 DIA.: 4"
LOCATION: NE1/4 SW1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1626' FSL 1461' FWL
ELEVATION: 3363.8 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/29/94
DRILL DATE: 09/29/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service



Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
9/30					GF	Toward base of unit, vugs decrease with some becoming gypsum filled. Contact between Culebra Member and underlying unnamed member is sharp.	Culebra Member of Rustler Formation
						606.85 - 608.1 ft: black plastic clay with rare isolated gypsum crystals (1-2 mm).	Unnamed Member of Rustler Formation
	2		87.5			608.1 - 615.2 ft: upper 2 ft black-brown clay interbedded with light gray anhydrite grading to red-brown mudstone with numerous light gray-pinkish anhydrite interbeds, high angle veins, and stringers.	
						615.2 - 616.6 ft: light-dark gray mottled anhydrite with thin (1-2 mm) wavy gypsum laminae.	

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OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6
DIA.: 4"
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ORIENTATION: Vertical Down
COORDINATES: 1626' FSL 1461' FWL
ELEVATION: 3363.8 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 09/29/94
DRILL DATE: 09/29/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

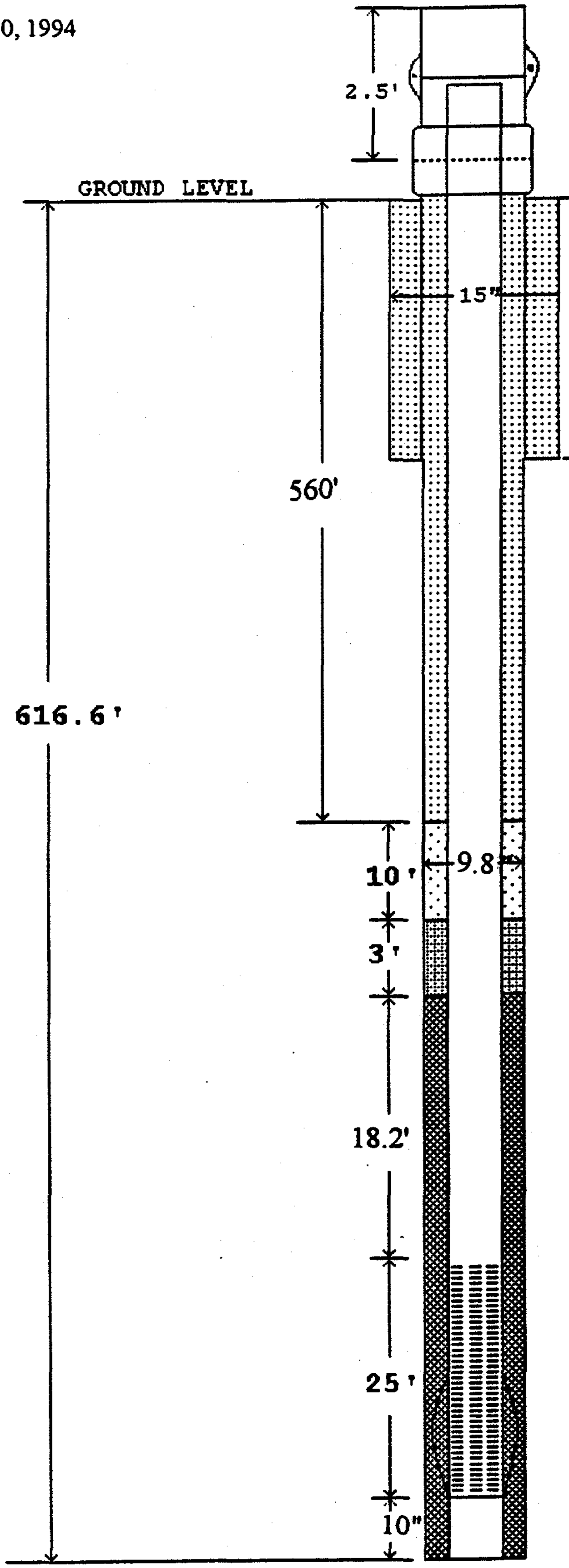
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
9/30	2	616.0	87.5	▨		See previous page.	Unnamed Member of Rustler Formation
		618.0					
		620.0					

WQSP #6
HOLE HISTORY

WIPP Project
WQSP #6
Eddy County, New Mexico

September 22-30, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASIN

CEMENT SLURRY MIX FROM 560 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 570 TO 560 FT

SAND PACK FROM 570 TO 567 FT

8/16 BRADY GRAVEL FROM 681 TO 626 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREE
TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

September 22, 1994

WQSP # 5 & WQSP # 6

9:00 AM - 12:00 PM - Drilled, set 10.75" surface casing, cemented

September 23, 1994

WQSP #'s 2 & 6

6:00 AM - 6:40 AM - Carlsbad to WQSP # 2
6:40 AM - 8:15 AM - Rigged down on WQSP # 2, cleaned up location & moved to WQSP # 6
8:15 AM - 12:00 PM - Rigged up on WQSP # 6, lined pit, put rotating head on, and shut down for weekend
12:00 PM - 2:00 PM - WQSP # 6 to Odessa

September 26, 1994

WQSP # 6

5:40 AM - 7:40 AM - Odessa to WQSP # 6
7:40 AM - 8:00 AM - Service rig
8:00 AM - 11:20 AM - Drilling 9 7/8" hole on air
11:20 AM - 4:00 PM - Started drilling on air/mist pump due to amount of water being made in Dewey Lake formation. Est. 40-50 GPM
4:00 PM - 4:15 PM - Trip pipe out of hole 200'. Total footage for the day 367'
4:15 PM - 4:30 PM - Secure rig for the day

September 27, 1994

WQSP # 6

6:15 AM - 6:50 AM - Carlsbad to WQSP # 6
6:50 AM - 7:00 AM - Service rig
7:00 AM - 8:10 AM - Fill pits with brine water and mix sw gel
8:10 AM - 9:30 AM - Trip in hole, had 15' of fill, cleaned out & circulated 30 minutes
9:30 AM - 11:40 AM - Drilling 9 7/8" hole on fluid from 367'-415'
11:40 AM - 12:30 PM - Take yoke off drive shaft, return to Odessa for parts
12:30 PM - 4:00 PM - Rig down waiting on parts
4:00 PM - 5:00 PM - Replace parts & ready rig for drilling Wednesday morning

WEST TEXAS WATER WELL SERVICE

September 28, 1994

WQSP # 6

6:00 AM - 6:35 AM - Carlsbad to WQSP # 6
6:35 AM - 6:45 AM - Check fluid levels
6:45 AM - 6:50 AM - Trip pipe back to bottom
6:50 AM - 7:50 AM - Drilled 4′
7:50 AM - 10:10 AM - Make bit trip
10:10 AM - 4:00 PM - Drilling 9 7/8" hole
4:00 PM - 4:20 PM - Circulate bottoms up, look as samples
4:20 PM - 6:50 PM - Continue drilling to core point. Quit drilling @ 568′
6:50 PM - 7:00 PM - WQSP # 6 to Carlsbad

September 29, 1994

WQSP # 6

5:45 AM - 6:20 AM - Carlsbad to WQSP # 6
6:20 AM - 6:30 AM - Check fluid levels
6:30 AM - 6:50 AM - Trip back to bottom
6:50 AM - 7:00 AM - Circulate
7:00 AM - 7:40 AM - Trip out of the hole - 568′
7:40 AM - 8:45 AM - Rig up core tools
8:45 AM - 10:10 AM - Trip in the 1st run with core barrel
10:10 AM - 10:30 AM - Circulate
10:30 AM - 2:30 PM - Coring - very slow on fluid
2:30 PM - 2:50 PM - Circulating
2:50 PM - 3:40 PM - Coming out of hole 28′ cut 596′
3:40 PM - 4:00 PM - Breakdown core barrel, lay on ground
4:00 PM - 4:30 PM - Pick up core barrel T.I.H.
4:30 PM - 5:00 PM - Pump core out of first barrel
5:00 PM - 5:15 PM - Secure rig for day

WEST TEXAS WATER WELL SERVICE

September 30, 1994

WQSP # 6

5:50 AM - 6:20 AM - Carlsbad to WQSP # 6
6:20 AM - 6:30 AM - Check fluid levels
6:30 AM - 7:00 AM - Trip pipe and core barrel in hole for 2nd run
7:00 AM - 8:30 AM - Clean out 12′ of fill before coring
8:30 AM - 11:30 AM - Core from 596′ - 616.6′
11:30 AM - 11:50 AM - Circulate
11:50 AM - 1:00 PM - Trip out of hole
1:00 PM - 1:40 PM - Lay down core barrel and pump out core
1:40 PM - 2:25 PM - Breakdown core tools and load on trailer
2:25 PM - 2:50 PM - Trip collars in hole
2:50 PM - 3:00 PM - Shut down operations and secure rig for weekend
3:00 PM - 5:00 PM - WQSP # 6 to Odessa

October 3, 1994

WQSP # 6

5:30 AM - 7:30 AM - Odessa to WQSP # 6
7:00 AM - 7:40 AM - Check fluid levels
7:40 AM - 8:40 AM - Trip in hole with drill pipe
8:40 AM - 11:30 AM - Ream hole from 8 1/2" to 9 7/8"
11:30 AM - 12:30 PM - Circulate and condition hole for logging
12:30 PM - 1:30 PM - Trip out of hole for logs
1:30 PM- 3:30 PM - Log well - 616.60′
3:30 PM - 4:00 PM - Shut down operations for day

UNIT 2

5:30 AM - 7:30 AM - Odessa to WQSP # 6
7:30 AM - 9:00 AM - Unload screen storage pad south of site, and load surface casing on trailer
9:00 AM - 10:00 AM - Unload surface casing @ WQSP # 4 and WQSP # 3
10:00 AM - 1:30 PM - Set & cement surface on WQSP #′s 3 & 4
1:30 PM - 2:00 PM - Load trimmie line on trailer to take to WQSP # 6
2:00 PM - 4:00 PM - Help out at WQSP # 6 preparing to run casing 10-4-94

WEST TEXAS WATER WELL SERVICE

October 4, 1994

WQSP # 6

6:00 AM - 6:35 AM - Carlsbad to WQSP # 6
6:35 AM - 6:45 AM - Check fluid levels
6:45 AM - 7:00 AM - Run weighted joint on sandline in well to check for fill - none found
7:00 AM - 7:45 AM - Move rig and reset, prepare to run 2" trimmie line
7:45 AM - 8:30 AM - Run 2" trimmie line
8:30 AM - 10:00 AM - Run 5" OD fiberglass casing & screen. 10′ blank, 25′ of .020 slot screen, 584.10′ of blank casing
10:00 AM - 11:15 Am - Trimmie lined 2100# of 8/16 gravel pack into well
11:15 AM - 12:00 PM - Mixed sw gel/water plug to pump on top of gravel pack for bentonite seal
12:00 PM - 1:45 PM - Wait on cement
1:45 PM - 3:10 PM - Circulate cement from top of bentonite seal to surface
3:10 PM - 3:30 PM - Pull trimmie line
3:30 PM - 4:00 PM - Rig down and move to WQSP # 4
4:00 PM - 5:00 PM - Rig up and line pit on WQSP # 4
5:00 PM - 5:40 PM - WQSP # 4 to Carlsbad

October 5, 1994

WQSP # 6 TD 616.6

1:00 PM - - Arrived on location, set up and grease unit Change out bailers and go in the hole
1:45 PM - - Fluid level @ 174′ due to mud left inside casing
1:45 PM - 4:00 PM - Bailed on well to develop, remove mud and fines, made 33 trips with bailer, retrieving 335 gallons of fluid. Shut down for the day, returned to Carlsbad

WEST TEXAS WATER WELL SERVICE

October 6, 1994

WQSP # 6

Unit # 2

6:45 AM - - Arrive at location, check unit and prepare to bail
6:55 AM - - Start bailing, water level recovered to 417′ overnight
6:55 AM - 10:00 AM - Continued bailing well to develop. Bailed water level to 605′ in 31 trips, recovering 315 gallons of fluid. Let well set for 10 minutes, fluid level recovered 5 1/2 ′
10:00 AM - 10:45 AM - Made 5 more runs with bailer, shut down operations to go and get water truck
10:45 AM - 11:45 AM - WQSP # 6 to WQSP # 4 to get water truck
11:45 AM - 12:00 PM - Dump 20 bbls of fresh water to help breakdown mud in form & further develop well
12:00 PM - 12:10 PM - Rig up unit to start bailing again
12:10 PM - 3:35 PM - Bailed on well - water level 585′
3:35 PM - 4:45 PM - Work on hydraulic pump on unit & shut down for the day

October 7, 1994

WQSP # 6

Unit # 2

7:30 AM - 7:45 AM - Arrive on location, set up unit & prepare to bail
7:45 AM - 8:00 AM - Started bailing well - water level @ 413′ made 5 trips with bailer, laid bailer down and prepared to run pump
8:00 AM - 9:50 AM - Ran 1 1/2 HP 5 GPM to further develop well, ran air line provided by Ron to determine fluid level, since well is a marginal producer
9:50 AM - 10:30 AM - Rig up test equipment, hook up generator to run pump
10:30 AM - - Start pumping well, meter reading 019393, pumping 7.5 GPM
10:47 AM - - Stop pumping to let well recover
12:00 PM - - Start pump @ 6 GPM with 23# back pressure
12:12 PM - - Stop pump, pressure drop to 0#
1:47 PM - - Start pump @ 6 GPM 23#
1:51 PM - - Stop pump
3:00 PM - - Start pump @ 6 GPM 22#
3:08 PM - - Stop pump had 4#
3:15 PM - - Shut down operations

WEST TEXAS WATER WELL SERVICE

<u>October 10, 1994</u>

Unit # 2

8:30 AM - - Arrive @ WQSP # 6, rig up on well to lower pump 10'; top of pump set @ 598'. Airline 99#, swl 364.3'

8:47 AM - - Start pump w/gate valve open - well pumping 7.5 gpm

8:52 AM - - Airline pressure 80#, back pressure 20#, 7.5 gpm, pumping level 408.2'

8:56 AM - - Increased back pressure to 60#, pumping 5.75 gpm

	- Airline Pressure	Back Pressure	GPM	Draw-down	Pumping level
8:58 AM	80#	60#	5.5	94.7'	459.1'
9:00 AM -	48#	60#	5.5	117.8'	482.1'
9:02 AM -		80#	5		
9:04 AM -	42#	80#	5	131.7'	496'
9:05 AM -	40#	80#	5	136.3'	500.6'
9:10 AM -	30#	75#	4.5	159.4'	
9:15 AM -	23#	100#	3.5	175.6'	
9:20 AM -	18#	97#	3.25	187.1'	539.9'
9:25 AM -	13#	110#	2.75	198.7'	563'
9:30 AM -	11#	120#	2	203.3'	567.6'
9:35 AM -	10#	130#	1.25	205.6'	569.9'
9:40 AM -	9#	130#	1.25	207.9'	572.2'
9:45 AM -	8#	129#	1.25	210.2'	574.5'
9:50 AM -	8#	135#	1	210.2'	574.5'
9:55 AM -	7#	135#	.75	212.5'	576.8'
10:00 AM -	6#	135#	.75	214.8'	579.1'
10:05 AM -	6#	135#	.75	214.8'	579.1'
10:10 AM -	5#	135#	.75	217.1'	581.4'
10:20 AM -	5#	135#	.75	217.1'	581.4'
10:30 AM -	5#	135#	.75	217.1'	581.4'
10:40 AM -	<5#	135#	.75	217.1'	581.4'
10:50 AM -	<5#	140#	.50	217.1'	581.4'
11:00 AM -	<5#	140#	.50	217.1'	581.4'
11:15 AM -	<5#	140#	.50+	217.1'	581.4'
11:30 AM -	5#	140#	.50+	217.1'	581.4'

Shut pump off and started recovery test of well

WEST TEXAS WATER WELL SERVICE

October 10, 1994

11:30 AM - 5#
11:31 AM - 5#
11:32 AM - 5#+
11:33 AM - 5#+
11:34 AM - 5#+
11:35 AM - 6#
11:40 AM - 6#+
11:45 AM - 7.5#
11:50 AM - 8#
11:55 AM - 10#
12:00 PM - 10#
12:10 PM - 12#
12:20 PM - 14#
12:30 PM - 17#
12:45 PM - 20#
1:00 PM - 23#
1:30 PM - 29#
2:30 PM - 38#
3:30 PM - 46#
10-11-94
6:30 AM - 90#
7:30 AM - 92#

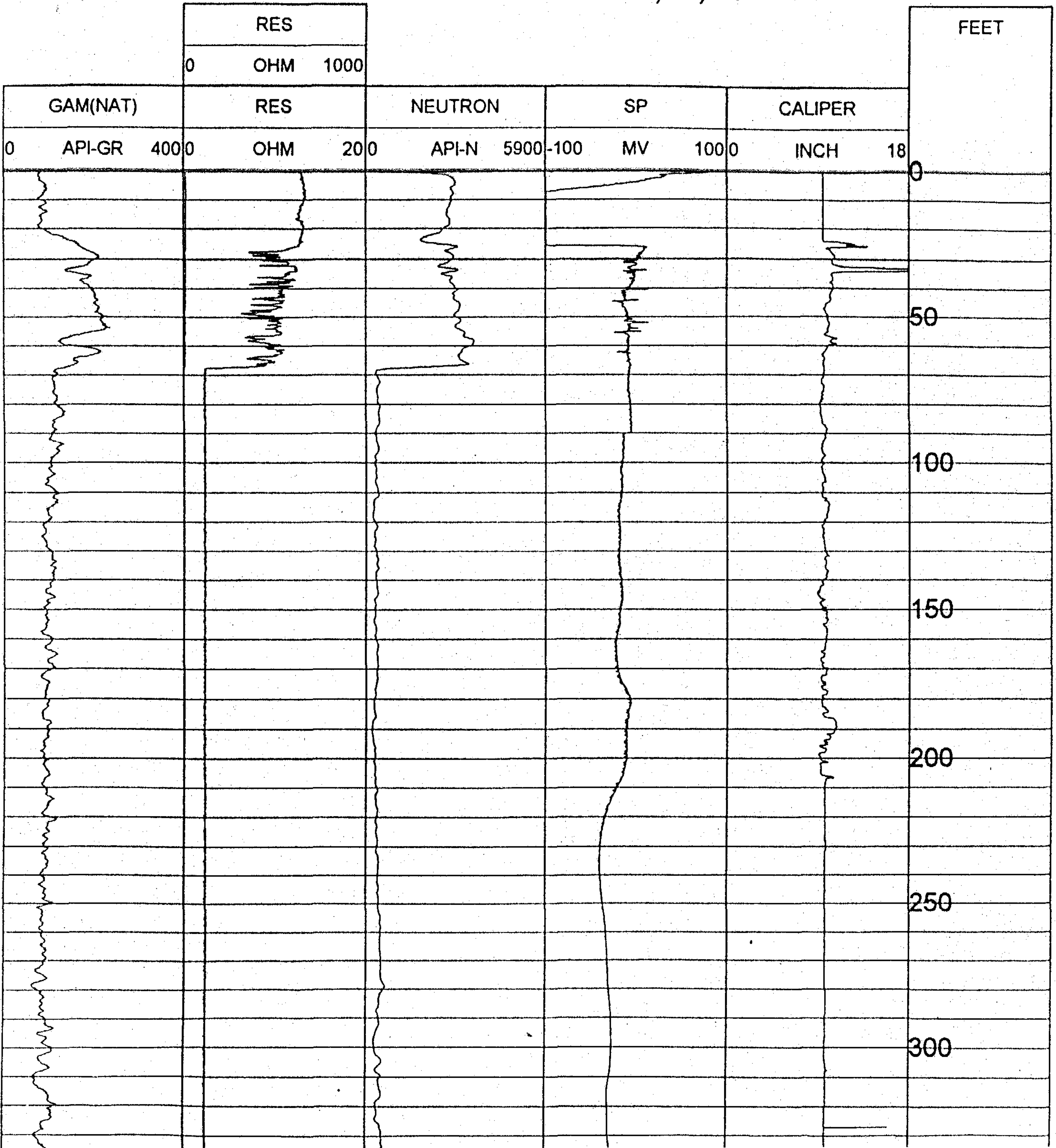
October 12, 1994

Unit @ 2

8:30 AM - Arrived on WQSP # 6, rig up pulling unit to pull test pump
9:00 AM - 11:00 AM - Pulled test pump and moved to WQSP # 4
11:00 AM - 1:30 PM - Rigged up and waited on cement
1:30 PM - 4:00 PM - Bailed on well to develop and clean up any fines left by gravel pack TD 800'

WQSP #6
GEOPHYSICAL LOGS

10/03/94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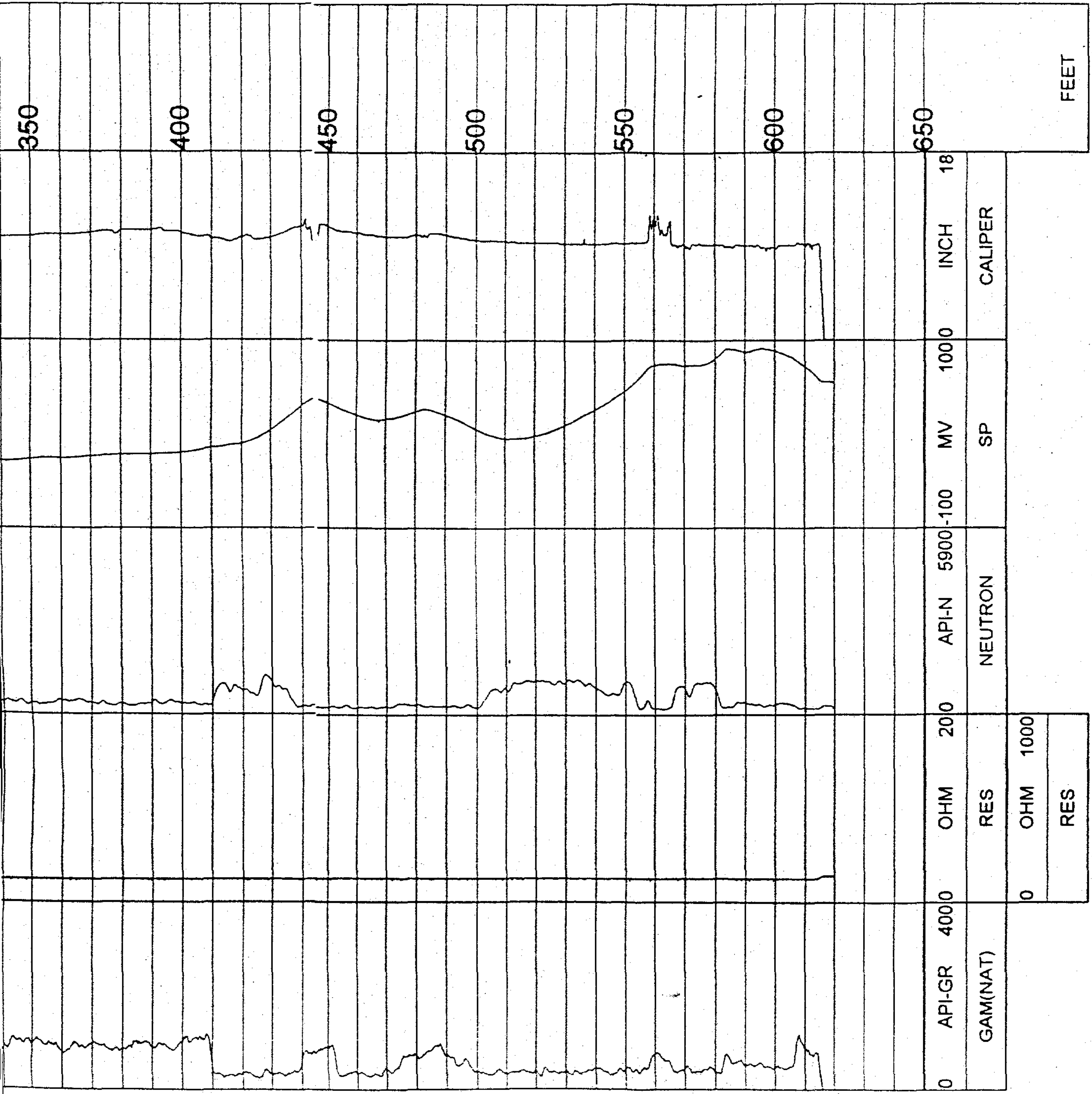
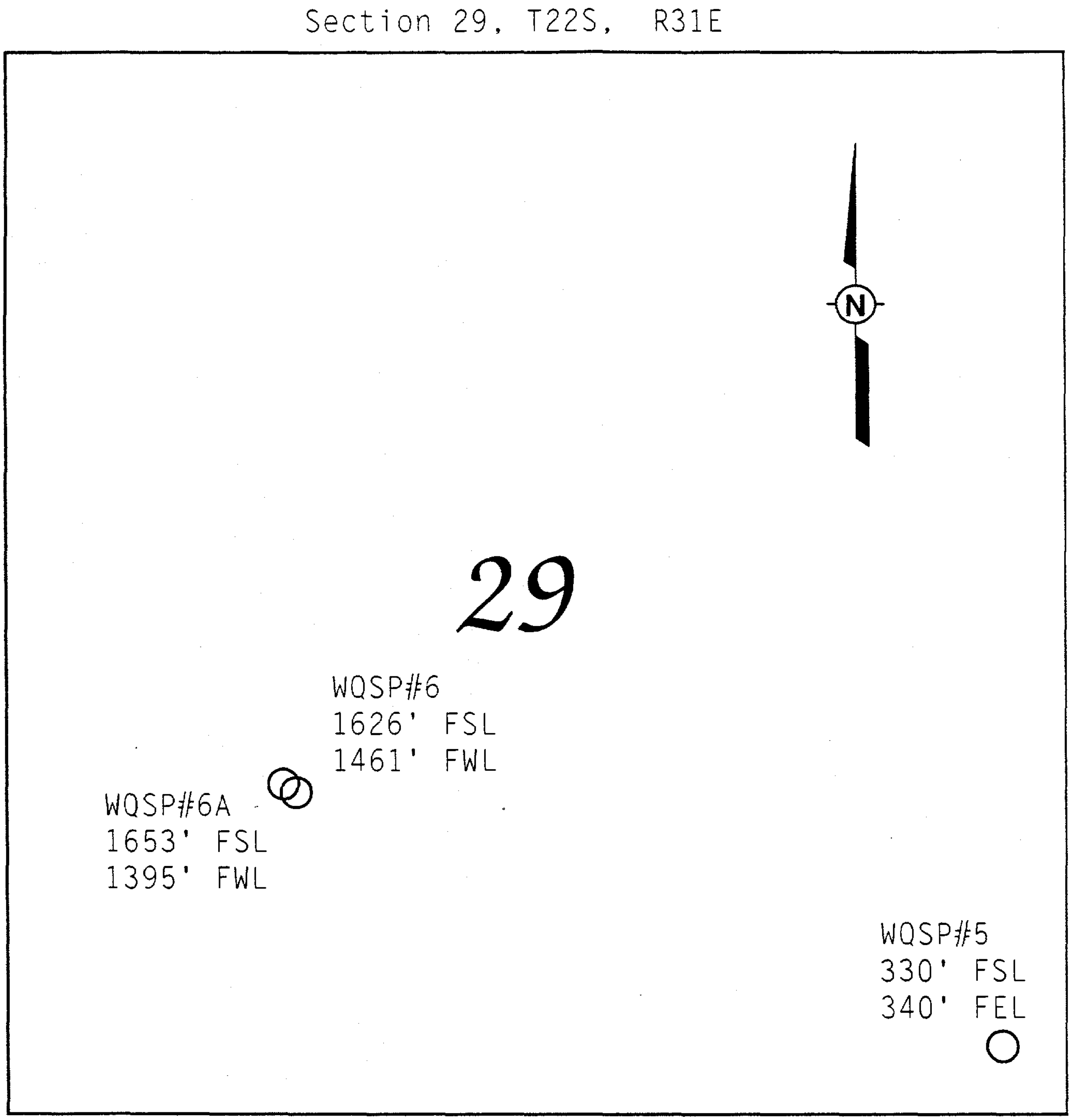
0 OHM 1000
GAM(NAT)
0 API-GR 400
RES
0 OHM 20
NEUTRON
0 API-N 5900
SP
-100 MV 100
CALIPER
0 INCH 18
FEET
0
50
100
150
200
250
300

Century Geophysical Corp.



WQSP #6
Geophysical Logs

WQSP#6a



Location of WQSP #6a

WQSP #6a
Condensed Well Summary

Location:	Section 29, T22S, R31E 1653 ft from the south line 1395 ft from the west line
Elevation: (Top of Casing)	3364.7 ft above mean sea level
Cuttings Description:	M.L. Martin
Drilling Contractor:	West Texas Water Well Service 3432 W. University, Odessa, Texas 79764 (915) 381-2687 phone (915) 381-7853 fax
Drilling Record	Date: October 28, to November 1, 1994 Bottom of hole: 225 ft below land surface Cored interval: 160 ft to 220 ft Cuttings: every 20 ft

WQSP #6a
Stratigraphic Summary

Stratigraphic Unit	**Depth Interval Natural Gamma Log (feet)**	**Core Description**
Surficial Deposits/Santa Rosa	0-35	
Dewey Lake Redbeds (partial)	35-220	160-220

WQSP #6a
CUTTINGS DESCRIPTION

(see WQSP 6)

WQSP #6a
DEWEY LAKE FORMATION
CORE DESCRIPTION

PAGE 1
OF 5

WIPP CORE-LOG INVENTORY

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FORM 1400

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ORIENTATION: Vertical Down
COORDINATES: 1653' FSL 1395' FWL
ELEVATION: 3364.7 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/31/94
DRILL DATE: 10/31/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/31 10:00		160.0 162.0 164.0 166.0 168.0 170.0 172.0				160.0 - 191.0 ft: light to dark red-brown siltstone with numerous green-gray reduction spots varying in size and frequency. Spots occur randomly and in bands - the majority are 1-2 mm in diameter some form lenses up to 2 cm. In frequent, thin randomly oriented gypsum-filled fractures, clay lenses occur from 180.6-181.2 ft and some coarser grained (sandy) intervals. A broken, rubbly, silty interval occurs from 186.0-188.1 ft underlain by more competent siltstone. Unit has frequent horizontal fractures along bedding planes. At base of unit there is 2.5 ft of core loss.	Dewey Lake Formation

PAGE 2
OF 5

WIPP CORE-LOG INVENTORY

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DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo.	FRACTURE	DESCRIPTION	REMARKS
10/31	1	172.0 174.0 176.0 178.0 180.0 182.0 184.0				160.0 - 191.0 ft: light to dark red-brown siltstone with numerous green-gray reduction spots varying in size and frequency. Spots occur randomly and in bands - the majority are 1-2 mm in diameter some form lenses up to 2 cm. In frequent, thin randomly oriented gypsum-filled fractures, clay lenses occur from 180.6-181.2 ft and some coarser grained (sandy) intervals. A broken, rubbly, silty interval occurs from 186.0-188.1 ft underlain by more competent siltstone. Unit has frequent horizontal fractures along bedding planes. At base of unit there is 2.5 ft of core loss.	Dewey Lake Formation

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OF 5

WIPP CORE-LOG INVENTORY

INTERA
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LOG BY: JBD
DATE: 10/31/94
DRILL DATE: 10/31/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/31 11:00	1	184.0 186.0 188.0 190.0				160.0 - 191.0 ft: light to dark red-brown siltstone with numerous green-gray reduction spots varying in size and frequency. Spots occur randomly and in bands - the majority are 1-2 mm in diameter some form lenses up to 2 cm. In frequent, thin randomly oriented gypsum-filled fractures, clay lenses occur from 180.6-181.2 ft and some coarser grained (sandy) intervals. A broken, rubbly, silty interval occurs from 186.0-188.1 ft underlain by more competent siltstone. Unit has frequent horizontal fractures along bedding planes. At base of unit there is 2.5 ft of core loss.	Dewey Lake Formation 2.5' of core loss
10/31 12:35	2	192.0				191.0 - 192.6 ft: crumbly, highly fractured red-brown siltstone with reduction spots (gray-green) and some gray-green clay lenses.	
		194.0 196.0				192.6 - 205.6 ft: see next page.	

PAGE 4 OF 5	**WIPP CORE-LOG INVENTORY**	INTERA FORM 1400

BOREHOLE: WQSP#6a DIA.: 4"

LOCATION: NE1/4 SW1/4 Section 29 T22S R31E

ORIENTATION: Vertical Down

COORDINATES: 1653' FSL 1395' FWL

ELEVATION: 3364.7 feet amsl

DRILL METHOD(S): Air Rotary

LOG BY: JBD

DATE: 10/31/94

DRILL DATE: 10/31/94

DRILLER: Ronnie Keith

DRILL: Gardner Denver 1500

DRILL CO.: West Texas Water Well Service

Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
		196.0				192.6 - 205.6 ft: Competent dark red-brown siltstone with coarsely crystalline anhydrite occurring in 1-2 mm horizontal bands along bedding planes. Numerous reduction spots (1-2 mm, up to 0.5 cm) in varying frequency, isolated and in bands. Thin (1-2 mm) randomly oriented gypsum-healed fractures. Siltstone is coarser grained and appears more porous along bedding planes. Clayey, rubbly intervals occur from 203.2-203.4 ft and 205-205.6 ft.	Dewey Lake Formation
		198.0					
		200.0					
		202.0					
		204.0					
		206.0				205.6 - 220.0 ft: see next page.	
		208.0					

PAGE 5
OF 5

WIPP CORE-LOG INVENTORY

INTERA
FORM 1400

BOREHOLE: WQSP#6a DIA.: 4"
LOCATION: NE1/4 SW1/4 Section 29 T22S R31E
ORIENTATION: Vertical Down
COORDINATES: 1653' FSL 1395' FWL
ELEVATION: 3364.7 feet amsl
DRILL METHOD(S): Air Rotary

LOG BY: JBD
DATE: 10/31/94
DRILL DATE: 10/31/94
DRILLER: Ronnie Keith
DRILL: Gardner Denver 1500
DRILL CO.: West Texas Water Well Service

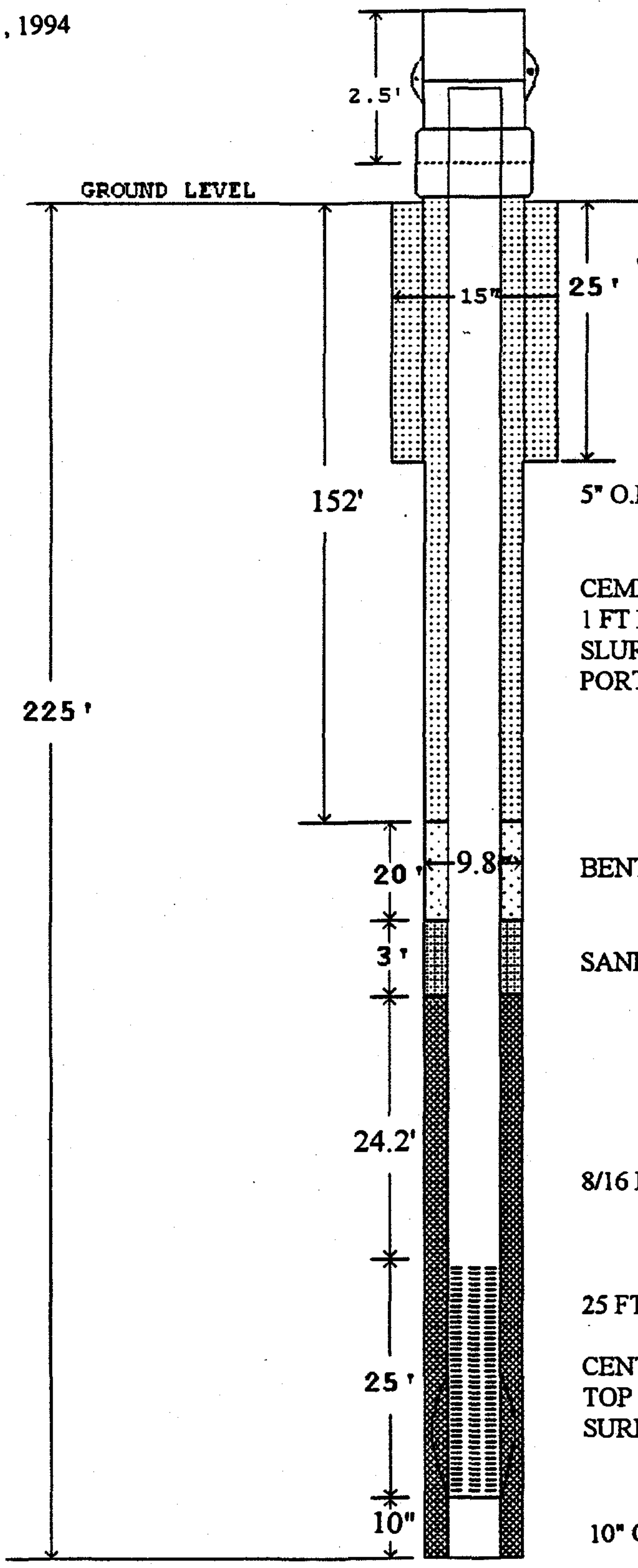
Time/ date	RUN	Depth feet	%	Geo	FRACTURE	DESCRIPTION	REMARKS
10/31		208.0				205.6 - 220.0 ft: competent light red-brown siltstone with very prominent, frequent, selenite bands, veins, and stringers. Prominent gray-green reduction bands and lenses. Unit has thin, wavy bedding.	Dewey Lake Formation
		210.0					
	2	212.0					
		214.0					
		216.0					
		218.0					
		220.0					

WQSP #6a
HOLE HISTORY

WIPP Project
WQSP #6a
Eddy County, New Mexico

October 28-31, 1994

WEST TEXAS WATER WELL SERVICE
RIG #15



2.5 FT EXTENSION WITH LOCKABLE CAP TO PROTECT WELL CASING

10.75 X 0.375 WALL SURFACE CASING CEMENTED IN A 15" HOLE

5" O.D. X 0.280 WALL BLANK FIBERGLASS CASING

CEMENT SLURRY MIX FROM 152 FT TO 1 FT
1 FT BELOW SURFACE
SLURRY IS 7 GALLONS WATER TO 1 CU FT
PORTLAND-ASTM C1510-92

BENTONITE SEAL FROM 172 TO 152 FT

SAND PACK FROM 175 TO 172 FT

8/16 BRADY GRAVEL FROM 225 TO 175 FT

25 FT OF 5" O.D. FIBERGLASS 0.020 SLOT SCREEN

CENTRALIZERS LOCATED AT BOTTOM OF SCREEN, TOP OF SCREEN, AND AT 60 FT INTERVALS TO SURFACE

10" OF BLANK 5" O.D. CASING

WEST TEXAS WATER WELL SERVICE

October 28, 1994

WQSP # 6A

6:00 AM - 6:40 AM - Carlsbad to WQSP # 3
6:40 AM - 6:50 AM - Check fluid levels
6:50 AM - 8:00 AM - Rig down on WQSP # 3
8:00 AM - 9:30 AM - Work on rig
9:30 AM - 10:10 AM - Rig up on WQSP # 6A
10:10 AM - 11:30 AM - Drill 9 7/8" hole from 25' - 130'
11:30 AM - 12:00 PM - Shut down and secure rig for weekend
12:00 AM - 2:30 PM - WQSP # 6A to Odessa

October 31, 1994

WQSP # 6A

5:40 AM - 7:35 AM - Odessa to WQSP # 6A
7:35 AM - 7:50 AM - Check fluid levels
7:50 AM - 8:00 AM - Trip pipe in hole
8:00 AM - 8:15 AM - Wait on Mary and Ray
8:15 AM - 8:40 AM - Drill 9 7/8" hole from 130' - 160'
8:40 AM - 9:00 AM - Trip pipe out of hole & prepare to core
9:00 AM - 10:15 AM - Rig up core barrel, trip in hole w/core assembly
10:15 AM - 11:10 AM - Core from 160' - 191'
11:10 AM - 11:50 AM - Pull core
11:50 AM - 12:05 PM - Pick up 2nd inner barrel
12:05 PM - 12:35 PM - Trip in hole with core barrel assembly
12:35 PM - 1:20 PM - Coring from 191' - 220'
1:20 PM - 2:00 PM - Trip out of hole and break down core barrel
2:00 PM - 2:30 PM - Pump out core
2:30 PM - 3:35 PM - Break down core barrel assembly and load on trailer
3:35 PM - 3:55 PM - Service rig and shut down for the day
3:55 PM - 4:00 PM - WQSP # 6A to Carlsbad

WEST TEXAS WATER WELL SERVICE

November 1, 1994

WQSP # 6A

5:50 AM - 6:30 AM - Carlsbad to WQSP # 6A
6:30 AM - 7:00 AM - Work on rig
7:00 AM - 8:20 AM - Wait on logging unit
8:20 AM - 9:55 AM - Run camera
9:55 AM - 10:55 AM - Run geophysical logs
10:55 AM - 12:10 PM - Trip pipe back in the hole & ream 8 1/2" to 9 7/8" hole from 160' - 225'
12:10 PM - 12:40 PM - Trip out of the hole to run casing
12:40 PM - 1:05 PM - Run trimmie line
1:05 PM - 2:00 PM - Run casing (10" x5" blank, 29.6' x5" fiberglass pipe with 25' .020 slot, 187' of 5" fiberglass blank)
2:00 PM - 2:40 PM - Start gravel packing from 225' - 175'
2:40 PM - 3:10 PM - Mix & pump bentonite seal 175' - 172 '
3:10 PM - 4:00 PM - Cement through 2" trimmie line from 152' to surface
4:00 PM - 4:30 PM - Clean up grout machine, trimmie line, secure rig for the day
4:30 PM - 5:15 PM - WQSP # 6A to Carlsbad

November 2, 1994

WQSP # 6A

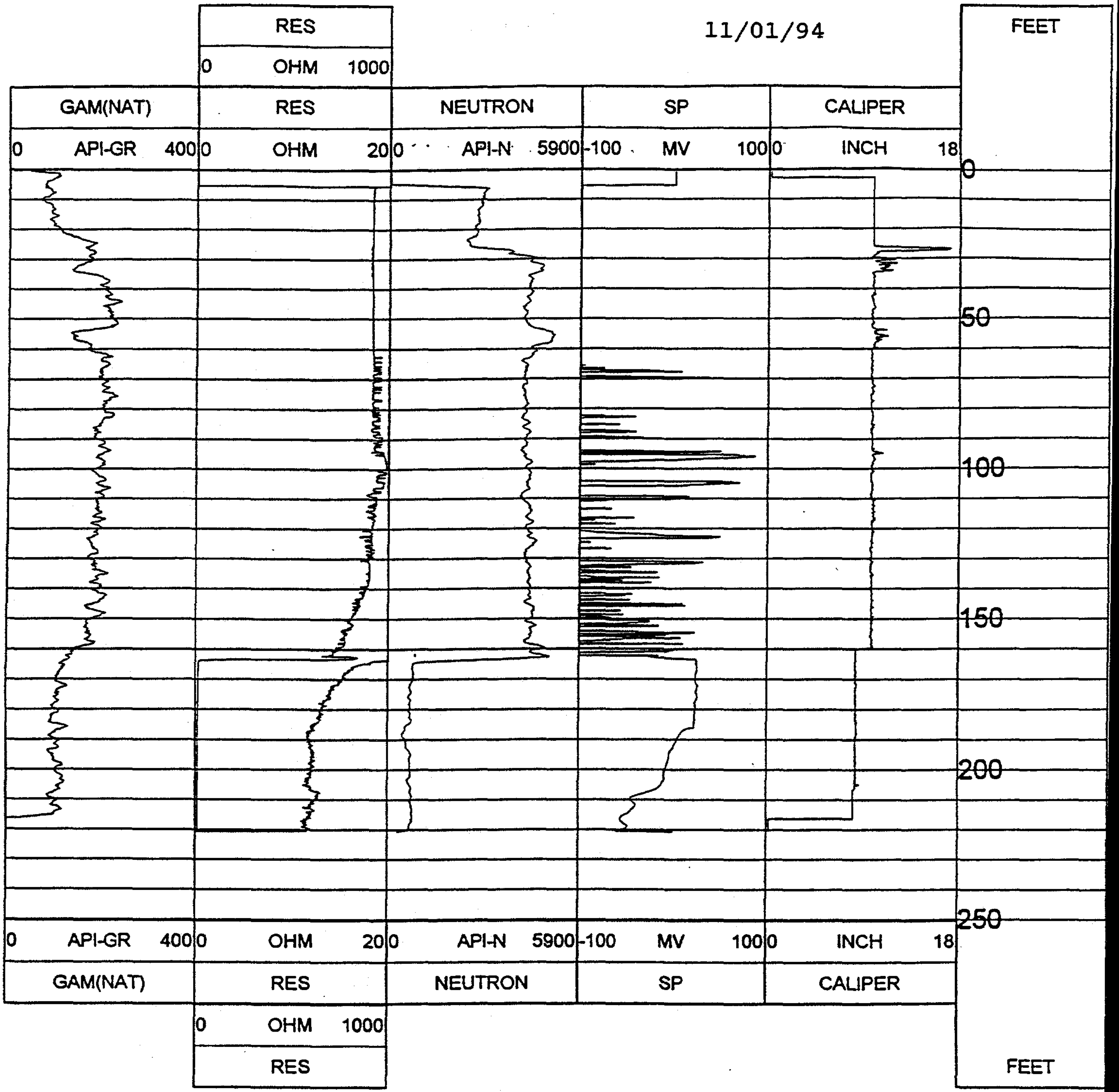
6:00 AM - 6:40 AM - Carlsbad to WQSP # 6A
6:40 AM - 11:15 Am - Rig down, pick up on location, secure load & depart for Odessa

Unit # 2

9:00 AM - 10:00 AM - Made 20 trips with bailer
10:00 AM - 10:45 AM - Run pump in well 6A to develop & test
10:45 AM - 11:15 AM - Rig up discharge and hook up to control box
11:15 AM - 12:00 PM - Wait on generator
12:10 PM - - Start pump to develop well-pumping 30 GPM
12:20 PM - - Pumping 30 GPM, clear no turbidity
12:35 PM - - Pumping 28 GPM, clear-shut off & surge 6 times
12:50 PM - - Started pumping 30 GPM, water clears up within 60 seconds
1:15 PM - - Pumping 28 GPM
1:25 PM - - Pumping 28 GPM
1:45 PM - - Pumping 28 GPM
2:15 PM - - Pumping 28 GPM

WQSP #6a
GEOPHYSICAL LOGS

Century
GEOPHYSICAL CORP.



WQSP #6A
Geophysical Logs