



DEPARTMENT OF THE AIR FORCE  
HEADQUARTERS 377TH AIR BASE WING (AFMC)

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Mr. John Kieling, Chief  
Hazardous Waste Bureau (HWB)  
New Mexico Environment Department (NMED)  
2905 Rodeo Park Road  
Santa Fe, New Mexico 87505

Dear Mr. Kieling

In response to your conditional approval of the Kirtland Air Force Base (AFB) *EDB Interim Measure Implementation Plan*, I am submitting Kirtland AFB's response to the five conditions set forth in your letter dated 10 March 2015. The attached permitting timeline schedule, revised *Final Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan*, and response to EPA comments table address your request for an additional permitting timeline schedule, separate extraction well construction work plan, response to EPA concerns for the January 2014 aquifer test results and additional extraction well aquifer testing requirements.

Please contact Mr. L. Wayne Bitner at (505) 853-3484 or at [ludie.bitner@us.af.mil](mailto:ludie.bitner@us.af.mil) or Mr. Scott Clark at (505) 846-9017 or at [scott.clark@us.af.mil](mailto:scott.clark@us.af.mil) if you have questions.

Sincerely



TOM D. MILLER, Colonel USAF  
Commander

Attachments:

- Attch 1: Schedule with permitting timelines
- Attch 2: Revised Final Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan
- Attch 3: Response to Comments Table for comments received from EPA on Jan 2014 Aquifer Testing Report

cc:

- NMED (Roberts) w/ attach
- NMED-HWB (Cobrain, McDonald) w/attach
- NMED (McQuillan, Longmire) w/attach
- NMED-GWQB (Schoeppner) w/attach
- NMED-PSTB (Reuter) w/attach
- NMED-OGC (Kendall) w/o attach

EPA Region 6 (King) w/o attach  
AFCEC-CZRY (Bodour) w/o attach  
Public Info Repository, AR/IR, and File w/attach

**40 CFR 270.11  
DOCUMENT CERTIFICATION  
MARCH 2015**

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



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TOM D. MILLER, Colonel, USAF  
Commander, 377th Air Base Wing

This document has been approved for public release.



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KIRTLAND AIR FORCE BASE  
377th Air Base Wing Public Affairs



March 25, 2015

**Subject: Kirtland Air Force Base Bulk Fuel Facility – EDB Interim Measure Implementation Plan, Revised Final**

This letter is in response to the March 10, 2015 New Mexico Environment Department (NMED) approval with conditions of the Kirtland Air Force Base (AFB) Bulk Fuel Facility ethylene dibromide (EDB) Interim Measure Implementation Plan prepared by CB&I Federal Services LLC (CB&I) for the U.S. Army Corps of Engineers (USACE), Albuquerque District, under Contract No. W912DY-10-D-0014. The letter includes the following responses to the conditions listed in the letter.

**Condition 1**

*The Permittee shall add estimated permitting timelines to the Attachment 1 Schedule and submit the revised schedule to NMED within 15 days of receipt of this letter.*

Attachment 1 of the original submittal has been updated to include estimated permitting timelines for the groundwater monitoring wells, temporary treatment system, and permanent treatment system. In addition to adding estimate permitting timelines, the schedule dates have been updated to reflect current task schedules for completion of the groundwater monitoring wells and the treatment systems.

**Condition 2**

*The Permittee shall submit a separate work plan, subject to NMED approval, for construction of extraction well KAFB-106228. The depth, screened interval, and pump setting of extraction well KAFB-106228 will be determined after sampling results are available for probe well KAFB-106212, and any deeper probe wells that may be required at that location in accordance with the August 1, 2014 work plan. The extraction well work plan also shall describe how the observation wells screened at various zones in the vicinity of extraction well KAFB-106228 will be used to determine aquifer response during the pump test.*

The designs of extraction well KAFB-106228 and five deep groundwater monitoring wells have been finalized and submitted to the NMED on March 19, in the *Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum #3*. The Work Plan Addendum includes the depth, screened interval, and pump setting of extraction well KAFB-106228, the depth and screened interval for the deep groundwater monitoring wells, and the sampling results from probe well KAFB-106212.

The following text has been added to Section 2.2 of the final *Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan* (Attachment 2) to describe how observation wells screened at various zones in the vicinity of extraction well KAFB-106228 will be used during aquifer testing.

Because extraction well KAFB-106228 is expected to span the shallow, intermediate, and deep zones, monitoring wells completed in all three zones will be used as observation points during the constant rate aquifer test in order to monitor the aquifer response. Based on observed lithology at probe well KAFB-106212, and results from a sequence stratigraphy analysis completed by AECOM, it is expected that wells screened in the shallow zone may respond differently than those screened in the Intermediate and deep zones. The varied response may be a result of increased finer-grained material observed

at approximately 460 feet below ground surface. The finer-grained layer, also referred to as the “450-foot clay”, spans the screened interval of many of the shallow wells and the layer appears to drop in elevation to the northeast. The Intermediate and Deep zone wells are primarily located below the 450 foot clay and within a contiguous hydrogeologic unit. It is thus anticipated that the Intermediate and Deep zone wells should have similar hydraulic responses. However, vertical heterogeneity may be cause for small hydrogeologic response variances. As a result, wells screened in different lithologic zones with respect to the 450 foot clay will initially be analyzed separately to determine what impact this layer has on the hydrologic response of the different lithologic zones in the aquifer. Analysis of the results will also take into account on other outside influences such as barometric pressure changes and regional groundwater rise.

### **Condition 3**

*The Permittee shall review the comments provided by the U.S. Environmental Protection Agency on the January 2014 aquifer testing results (copy attached) to ensure that the discrepancies and issues noted are not repeated in the pump testing of extraction well KAFB-106228.*

Attachment 3 of this letter is a table documenting the comments received from the U.S. Environmental Protection Agency on the January 2014 aquifer testing results. Each comment is addressed in the table and, where appropriate, revisions have been made in the revised final *Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan* (Attachment 2).

### **Condition 4**

*The aquifer testing report shall include, in addition to the information described in the aquifer test work plan, an optimal pumping rate for extraction well KAFB-106228 for the period of time up until additional extraction wells begin to operate. The optimal pumping rate may, or may not, be equal to the maximum sustainable pumping rate determined during the step-drawdown test. The Permittee may propose to adjust the pumping rate of extraction well KAFB-106228, subject to NMED approval, based on actual water level and water quality data as pumping and extraction of EDB proceed. As additional extraction wells are drilled and testing in the future, the Permittee shall evaluate the combined pumping effects of KAFB-106228 along with the additional extraction wells, and shall propose optimal pumping rates for each well in the extraction well system.*

The results of the aquifer test, including the calculated transmissivity and storativity, will be used in conjunction with groundwater modeling to determine the optimal pumping rate for extraction well KAFB-106228 for the period of time up until additional extraction wells begin to operate. The optimal pumping rate may, or may not, be equal to the maximum sustainable pumping rate determined during the step-drawdown test. The pumping rate may be adjusted, subject to NMED approval, based on actual water-level and water-quality data collected as pumping and extraction of EDB proceed. The proposed optimal pumping rate for KAFB-106228 will be included in the *Aquifer Pilot-Test Report*. Section 2.3 of the *Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan* (Attachment 2) has been revised to include this discussion.

### **Condition 5**

*Approval of the Implementation Plan does not completely resolve the violations addressed in the January 15, 2015 NOV. The violations in the NOV shall be deemed to be resolved upon written notification by NMED that the Permittee has successfully completed all actions in the August 1, 2014 Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan, and October 9, 2014 Work Plan Addendum.*

Kirtland AFB acknowledges and understands that violations in the NOV will only be considered to be resolved upon receipt of written notification from the NMED. Kirtland AFB is committed to meeting the requirements and timeline in the January 15, 2015 NOV from the NMED as well as the August 1, 2014 *Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan* and the October 9, 2014 *Work Plan Addendum*.

# ATTACHMENT 1

## Schedule

Task/Activity Name	Start Date	Finish Date
Install New Monitoring Wells	December 8, 2014	May 25, 2015
OSE and CoA Permitting for Monitoring Wells	September 5, 2014	January 13, 2015
Install 5 shallow & intermediate well clusters	December 8, 2014	March 17, 2015
Install Probe Well	January 19, 2015	February 19, 2015
Work Plan Addendum Part 3 (deep well & extraction well design)	March 10, 2015	March 24, 2015
Install 5 Deep Wells	April 1, 2015	May 25, 2015
Temporary Pump & Treat System	January 20, 2015	June 18, 2015
Letter WP Addendum Part 2 (Temporary P&T System)	January 20, 2015	February 10, 2015
Well Vault & 4" Influent Pipeline (200 gpm)	January 26, 2015	June 18, 2015
OSE Drilling Permit for Extraction Well	October 17, 2014	January 16, 2015
OSE Change of Water Rights	January 19, 2015	April 10, 2015
Extraction Well	April 23, 2015	May 19, 2015
NMED GWQB Discharge Permit for Infiltration Gallery	September 5, 2014	November 28, 2014
Permanent Pump & Treat System	October 3, 2014	October 12, 2015
Basis of Design	October 3, 2014	April 20, 2015
Permanent GW Treatment Equipment and Building	December 12, 2014	October 12, 2015
8" Influent Pipeline (600 gpm)	TBD	TBD
Permitting for Treated Water Discharge	TBD	TBD
Permanent GW Effluent Pipeline & Discharge System	January 26, 2015	October 12, 2015

Schedule dates updated based on current task schedules (Update on March 24, 2015)



## **ATTACHMENT 2**

### **Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan**

**KIRTLAND AIR FORCE BASE  
ALBUQUERQUE, NEW MEXICO**

**GROUNDWATER EXTRACTION WELL KAFB-106228  
AQUIFER PILOT-TEST WORK PLAN  
BULK FUELS FACILITY SPILL  
SOLID WASTE MANAGEMENT UNITS ST-106 AND SS-111**

**March 2015**

***Prepared for***

U.S. Army Corps of Engineers  
Albuquerque District  
Albuquerque, New Mexico 87109

USACE Contract No. W912DY-10-D-0014  
Delivery Order 0002

***Prepared by***

CB&I Federal Services LLC  
2440 Louisiana Blvd. NE, Suite 300  
Albuquerque, New Mexico 87110



## **NOTICE**

This work plan was prepared for the U.S. Army Corps of Engineers by CB&I Federal Services LLC for the purpose of aiding in the implementation of a final remedial action plan under the U.S. Air Force Environmental Restoration Program. As the report relates to actual or possible releases of potentially hazardous substances, its release prior to a final decision on remedial action may be in the public's interest. The limited objectives of this report and the ongoing nature of the Environmental Restoration Program, along with the evolving knowledge of site conditions and chemical effects on the environment and health, must be considered when evaluating this report, since subsequent facts may become known that may make this report premature or inaccurate.

Government agencies and their contractors registered with the Defense Technical Information Center should direct requests for copies of this report to: Defense Technical Information Center, Cameron Station, Alexandria, Virginia 22304-6145.

Non-government agencies may purchase copies of this document from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY		2. REPORT DATE March 2015	3. REPORT TYPE AND DATES COVERED Work Plan for Aquifer Testing in July 2015	
4. TITLE AND SUBTITLE Groundwater Extraction Well KAFB-106228, Aquifer Pilot-Test Work Plan Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111			5. FUNDING NUMBERS USACE Contract No. W912DY-10-D-0014 Delivery Order 0002	
6. AUTHOR V. Bracht, R. Hobbs J. Teo				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CB&I Federal Services LLC 2440 Louisiana Blvd. NE, Suite 300 Albuquerque, New Mexico 87110			8. PERFORMING ORGANIZATION REPORT NUMBER KAFB-015-0005c	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) USACE Albuquerque District 4101 Jefferson Plaza NE Albuquerque, New Mexico 87109-3435 Project Manager: John McBee			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
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MARCH 2015**

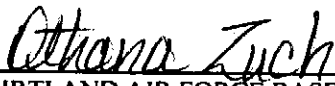
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision according to a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system,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



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TOM D. MILLER, Colonel, USAF  
Commander, 377th Air Base Wing

This document has been approved for public release.



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377th Air Base Wing Public Affairs



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## PREFACE

This Groundwater Extraction Well KAFB-106228, Aquifer Pilot-Test Work Plan has been prepared by CB&I Federal Services LLC (CB&I), for the U.S. Army Corps of Engineers (USACE), under Contract W912DY-10-D-0014, Delivery Order 0002. It pertains to the Kirtland Air Force Base Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, located in Albuquerque, New Mexico. This work plan was prepared in accordance with all applicable federal, state, and local laws and regulations, including the New Mexico Hazardous Waste Act, New Mexico Statutes Annotated 1978, New Mexico Hazardous Waste Management Regulations, Resource Conservation and Recovery Act, and regulatory correspondence between the New Mexico Environment Department Hazardous Waste Bureau and the U.S. Air Force, dated April 2, June 4, August 6, and December 10, 2010.

This work will be performed under the authority of USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. Mr. John McBee is the USACE Albuquerque District Project Manager; Mr. Wayne Bitner, Jr. is the Kirtland Air Force Base Restoration Section Chief; and Dr. Michael Amdurer is the CB&I Project Manager. This work plan was prepared by Virginia Bracht, Rachel Hobbs, and James Teo.



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Michael Amdurer PG, PhD  
CB&I Federal Services LLC  
Project Manager

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## ACRONYMS AND ABBREVIATIONS

µg/L	microgram(s) per liter
AFB	Air Force Base
BFF	Bulk Fuels Facility
CB&I	CB&I Federal Services LLC
EDB	ethylene dibromide (also known as 1,2-dibromoethane)
EPA	U.S. Environmental Protection Agency
ft	feet/foot
GAC	granular activated carbon
gpm	gallons per minute
ID	identification
MCL	maximum contaminant level
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NOV	Notice of Violation
TAT	turn-around time
TPH	total petroleum hydrocarbon
USACE	U.S. Army Corps of Engineers



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## **EXECUTIVE SUMMARY**

This work plan for aquifer testing using groundwater extraction well KAFB-106228, to be performed by CB&I Federal Services LLC (CB&I), is submitted for the U.S. Army Corps of Engineers (USACE) under contract W912DY-10-D-0014, Delivery Order 0002. This work plan was prepared in response to the January 15, 2015 New Mexico Environment Department (NMED) letter, “Notice Of Violation Interim Groundwater Extraction And Additional Characterization Bulk Fuels Facility Spill Solid Waste Management Units ST-106 and SS-111”, and describes the following activities:

- A step-drawdown test will be conducted on well KAFB-106228 in order to evaluate the optimal constant rate aquifer test pumping rate.
- A constant rate aquifer test will be conducted using well KAFB-106228 as the pumping well to evaluate aquifer conditions within the dissolved-phase ethylene dibromide (EDB) plume, downgradient of the historical light non aqueous phase liquid area.
- Extracted water will be treated by a temporary treatment system and discharged at Zia Park via surface application using sprinklers, and/or to a stormwater detention pond on Kirtland Air Force Base property, if necessary.

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# 1. INTRODUCTION

## 1.1 Scope of Activities

This work plan has been developed to further assess hydrogeologic parameter conditions within the Upper Santa Fe aquifer local to the dissolved phase ethylene dibromide (EDB) contaminant extent. Results from this aquifer test may be used to help evaluate groundwater flow characteristics such as storativity, transmissivity, and hydraulic conductivity. This work plan has also been prepared in response to the New Mexico Environment Department (NMED) Notice of Violation (NOV) dated January 15, 2015, which requires the submission of an aquifer pilot-test work plan for the aquifer testing of extraction well KAFB-106228 within 45 days of the date of the NOV. This work plan outlines the activities required to perform aquifer testing using extraction well KAFB-106228 and has been prepared in accordance with the following documents:

- *Notice Of Violation Interim Groundwater Extraction And Additional Characterization Bulk Fuels Facility Spill Solid Waste Management Units ST-106 and SS-111* (NMED, 2015; Appendix A)
- *Kirtland Air Force Base Bulk Fuels Facility—Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan—Revision 1* (Groundwater Extraction Work Plan; U.S. Army Corps of Engineers [USACE], 2014a)
- NMED approval with conditions of *Kirtland Air Force Base Bulk Fuels Facility—Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan* dated August 20, 2014 (NMED, 2014)
- Suggested Operating Procedures for Aquifer Pumping Tests (U.S. Environmental Protection Agency [EPA], 1993; Appendix A)
- *Kirtland Air Force Base Bulk Fuels Facility—Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum* (USACE, 2014b)
- Kirtland Air Force Base (AFB) Resource Conservation and Recovery Act Permit (NMED, 2010)

The **planned** extraction well, KAFB-106228, will be used as a pumping well to conduct an aquifer test to further characterize the aquifer hydraulic properties in the area downgradient of the source, and will ultimately be used to extract contaminated groundwater from the aquifer for treatment.

The following milestones must be completed prior to aquifer testing using KAFB-106228:

- Installation and development of the “probe well” KAFB-106212
- Sampling of the probe well KAFB-106212
- Design of the extraction well KAFB-106228 based on data obtained from the installation and sampling of KAFB-106212
- Installation of extraction well KAFB-106228
- Development of extraction well KAFB-106228
- Installation and development of monitoring wells KAFB-106213, KAFB-106214, KAFB-106215, KAFB-106216, KAFB-106217, KAFB-106218, KAFB-106225, KAFB-106226, and KAFB-106227 to be used as observation points for the aquifer test

Figure 1-1 illustrates the planned locations of extraction well KAFB-106228 and observation points.

Existing and newly installed monitoring wells serve a dual purpose as contaminant monitoring wells and as observation points for the constant rate aquifer test. Subsequent references to monitoring wells within this document assume that the monitoring wells and observation points are one and the same. The design of the extraction well [was](#) finalized following the sampling of the probe well KAFB-106212, which was installed on February 16, 2015. The purpose of probe well KAFB-106212, which has been installed as a deep zone monitoring well, is to address the dissolved phase EDB plume vertical extent data gap (USACE, 2014a). This work plan [was](#) developed [concurrently with](#) the drilling, installation, development, and sampling of probe well KAFB-106212 , which provided additional data [to](#) further inform the design, development, and aquifer testing of extraction well KAFB-106228. [The finalized design for KAFB-106228 and well development procedures are included in the Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum #3 \(USACE, 2015\), which was submitted to the NMED on March 19, 2015. The final well construction diagrams for all wells utilized during aquifer testing, including extraction well KAFB-106228 and monitoring wells, will be provided in the Aquifer Pilot-Test Report.](#)

As described in the Groundwater Extraction Work Plan (USACE, 2014a) and the *Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum #2* (CB&I Federal Services LLC [CB&I], 2015), groundwater from extraction well KAFB-106228 will be pumped through a double-walled, high-density, polyethylene pipeline to a temporary groundwater treatment system located just east of Louisiana Boulevard on Kirtland AFB property. Groundwater will be treated to remove EDB and any other organics to below maximum contaminant levels (MCLs) prior to surface discharge at Zia Park and/or the Kirtland AFB stormwater detention pond, where the water will percolate into the vadose zone soil.

## 1.2 Aquifer Test Schedule and Assumptions

The schedule for the aquifer testing is located in Appendix B. This schedule is tentative and dependent upon sequenced work occurring prior to the aquifer testing. The schedule includes line items pertaining to the design, procurement, installation, and permitting of the temporary treatment system. This includes activities related to well installation and development, discharge conveyance piping, the temporary treatment system, and release of treated water via surface discharge at Zia Park and/or the Kirtland AFB stormwater detention pond.

Figure 1-2 presents a conceptual plan outlining events that may affect the planned aquifer test at well KAFB-106228. Key decision events are shown within each of the respective diamond shapes and are numbered sequentially. The key decision events include:

- If groundwater EDB concentrations in probe well KAFB-106212 are greater than the MCL (0.05 micrograms per liter [ $\mu\text{g/L}$ ]), an additional deeper probe well will need to be drilled and sampled to discern the vertical extent of EDB groundwater contamination before the design of extraction well KAFB-106228 can be finalized.
- If the Office of the State Engineer does not approve the Change of Water Rights permit for KAFB-106228, pumping at extraction well KAFB-106228 cannot occur. Currently the Change of Water Rights permit is being reviewed by the Office of the State Engineer.

- If NMED Groundwater Quality Bureau does not issue temporary permission, or a temporary discharge permit, to discharge the treated water, pumping at extraction well KAFB-106228 cannot occur. CB&I is currently developing the request for temporary permission.
- If the Zia Park sprinkler irrigation system cannot accommodate the pumping rate determined from the step-drawdown test, then the remaining excess water will be transferred to the Kirtland AFB stormwater detention pond. However, if treated water cannot be disposed of through either Zia Park or the stormwater detention pond at Kirtland AFB, then the constant rate aquifer test will be delayed until the full treatment and treated water disposal system is operational.

The current schedule assumes that each of the aforementioned activities will be completed. In such case, aquifer testing is scheduled to start at well KAFB-106228 on July 1, 2015, and conclude on July 20, 2015.

The planned pumping and recovery testing includes [step-drawdown testing](#), 3 to 7 days of drawdown testing, and 3 to 7 days of recovery testing. Following the completion of field work, an aquifer testing report will be prepared, reviewed, and issued in the fall of 2015.

## 2. AQUIFER TESTING

Aquifer testing at KAFB-106228 will consist of two phases. In the first phase, a step-drawdown test will be conducted to determine the optimum pumping rate for the constant rate aquifer test. For the step-drawdown test, extraction well KAFB-106228 will be pumped at varying rates to assess the maximum sustainable pumping rate. In the second phase, a constant rate aquifer test will be conducted to evaluate conditions in the aquifer downgradient from the Bulk Fuels Facility (BFF) spills site.

The constant rate aquifer test will include 3 to 7 days of pumping, and 3 to 7 days of recovery; although the final durations may vary based on aquifer response. During pumping and recovery, groundwater level changes (drawdown) in extraction well KAFB-106228 and the monitoring wells (Figure 1-1 and Table 2-1) will be monitored using both transducers and manual water level measurements. The drawdown, measured in response to the pumping, will be used to assess the transmissivity and storage coefficient of the aquifer. Water level recovery will also be monitored after the pumping is discontinued, until at least 98 percent recovery to pre-pumping static water level, to provide recovery data for use in verifying pumping test and well efficiency assessment.

General steps that will be performed to complete the step-drawdown and constant rate aquifer tests are as follows. Additional details pertaining to each test are described in Sections 2.1 and 2.2.

### *General Test Procedures*

1. Equipment used in the aquifer test will be inspected to ensure that it is in good working order, and where appropriate, that fuel, batteries, and power sources are available and stable.
2. Measuring and testing equipment will be calibrated and/or tested before use. All transducers will be time synchronized as part of the calibration process.
3. Downhole equipment will be decontaminated using deionized water and Alconox®.
4. The well heads will be visually inspected for damage or obstructions that could hinder the water level recorder or pump insertion and removal.



5. Potentiometric head elevations in extraction well KAFB-106228, and at the respective monitoring wells, will be measured with electric tape water level meters and recorded along with the date and time. Military time (24-hour) will be used for all data collection. Separate data sheets will be used for each monitoring well. Time measurement intervals may vary from the extraction well to more distant monitoring wells, and these will be determined prior to the start of testing.
6. The pump (nominally 480 volt, 3 phase, 40-horsepower, Grundfos submersible; capable of pumping 50 to 150 gallons per minute [gpm] at a constant rate) will be installed in the pumping well, along with a pressure transducer (In-Situ LevelTROLL<sup>®</sup> 700) and associated electrical supply lines. The transducer cable will be installed within a polyvinyl chloride casing sounding tube as the assembly is lowered into the well. The installed transducer will be capable of operating reliably within the range of water level induced heads anticipated both in static and pumping conditions. The initial transducer placement will be a minimum of 5 feet (ft) above the pump intake. Transducer placement will be adjusted if pump turbulence affects reading stability. The final transducer placement will be established during the step-drawdown testing. Prior to the constant rate aquifer test, the transducer will be placed no less than 5 ft below the anticipated maximum drawdown of the constant rate aquifer test based on the step-drawdown test.
7. The position of the pump intake inside the well will be a minimum of 10 ft above the bottom of the well. The height of the water column from the static water level to the pump intake will be noted. For the step-drawdown test, the pump will be placed at the center of the submerged well screen. The pump placement during the constant rate aquifer test may be adjusted based on the results of the step-drawdown test. During step-drawdown testing, pumping rates may be adjusted to ensure the drawdown will not be so great as to cause the pump to cavitate. All information, including the depth of the pump intake and pressure transducer location, will be recorded.
8. Transducers will be installed in extraction well KAFB-106228 and selected monitoring wells (Figure 1-1 and Table 2-1). The transducers will be installed at a position inside each well that is below the anticipated water level during maximum drawdown, and does not exceed the maximum head limitation for the transducer. The anticipated maximum drawdown will be determined based on the results of the step-drawdown test, and by preliminary predictive modeling. Manual water level measurements<sup>1</sup> will be taken when transducers are installed and when they are removed to correct for potential transducer drift. During pumping and recovery, data will be checked every two hours during work hours in case of transducer failure. However, at the start of the constant rate aquifer test, manual water levels will be recorded in monitoring wells KAFB-106035, KAFB-106036, KAFB-106037, and KAFB-106212 at 1-minute intervals during the first 10 minutes, at 10-minute intervals from 10 minutes to 100 minutes, and at 2-hour intervals during working hours thereafter. To minimize variance, designated electric tape water level meters will be assigned to specific well clusters, and not crossed between unassigned wells. The depths of the transducers below the water surface will be recorded using the data logger. The electric tape water level meter identification (ID) number and the transducer ID number will be recorded with the water level data.
9. Three monitoring wells located downgradient from the plume at the KAFB-106225 well cluster will have transducers installed to monitor shallow, intermediate and deep zone barometric water level fluctuations during the test. These fluctuations will be used to factor out the barometric fluctuations in the aquifer test monitoring wells. Three transducers will be installed in monitoring wells KAFB-106201, KAFB-106202, and KAFB-106203, near production well KAFB-3; and three

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<sup>1</sup> Based on discussions at the January 21, 2015 Hydrogeology Working Group Meeting (Albuquerque, New Mexico), a revised protocol is being developed by CB&I to address measuring tape calibration.

transducers will be installed in monitoring well KAFB-1064, KAFB-106099, and KAFB-106100, near the VA production well. These monitoring wells, in combination with monitoring well at well clusters KAFB-106216 and KAFB-106213 will be used to help correct for influences that pumping well KAFB-3 or the VA production well may have on the upper Santa Fe aquifer potentiometric surface. Review of the potentiometric surface data at each of the aforementioned well clusters will help assess potential lag times and the extent of KAFB-3 or the VA production well hydraulic influence. Additionally, sub-regional trends caused by the Ridgecrest production well series may be evaluated within the 7-day period of pre-test data. Local production wells KAFB-15 and KAFB-16 are not expected to hydraulically influence the observation points associated with the constant rate aquifer test.

10. Water level recording will start at least one week prior to the start of pumping in each of the monitoring wells, including the background monitoring wells, to quantify potentiometric surface variances (i.e., barometric pressure effects) within each well. During this week of water level recording, the pressure transducers will be set to log the water level every 20 minutes. Three automatically logging barometric pressure sensors will be used to quantify barometric variances during testing. One will be located at KAFB-106228, one will be located at the KAFB-106225 background monitoring cluster, and one will be located at the KAFB-106201 cluster.
11. When pumping is to begin, the recording frequencies in the pressure transducers for the aquifer test will be set. A true logarithmic water level measurement schedule will be used for the pumping well with the first readings at 4 per second and increasing up to 5-minute intervals later in the test. This schedule will be set on the pressure transducers using the “true logarithmic” option with a maximum interval of 5 minutes. The transducers in the monitoring wells will be set to record water levels at 1-minute intervals, starting at least 24 hours prior to the start of the test.

## 2.1 Step-Drawdown Test

After KAFB-106228 has been developed and prior to conducting the constant discharge test, a step-drawdown (variable rate) test will be performed to determine the optimum flow rate for the long-term test. Flow rates for the step-drawdown test will be approximately 50, 100, and 150 gpm, although the maximum flow rate for the step-drawdown test may be limited by the flow rate achievable by the temporary treatment and discharge system, which will be used for the disposition of aquifer test water. Each step will be conducted for 3 hours, with no recovery between steps. If the well is not capable of maintaining the planned flow rates, the test may be stopped and NMED will be contacted to discuss conducting the test at a lower discharge rate.

Following the step-drawdown test, the aquifer will be allowed to recover for at least 24 hours. A pressure transducer will record drawdown during pumping and recovery. Pressure transducers will be used to

record water level changes during pumping and recovery in the four nearest monitoring wells and the six background monitoring wells (Table 2-1). Water level measurements will be obtained from the extraction well (KAFB-106228) at the frequency described in Section 2.0, Item 11 above.

After the step-drawdown test is completed, the data will be used to evaluate the efficiency of the well, to determine the qualitative magnitude of drawdown at given pump rates, and to provide generalized aquifer properties (i.e., transmissivity). The aquifer parameters will be applied to groundwater modeling predictions of aquifer response at the monitoring wells proposed for the constant rate aquifer test. Transducer placement and range will be based on this model information. Well efficiency will be determined as described in *Groundwater and Wells* (Driscoll, 1986, pp. 554 through 559). Aquifer properties will be determined using graphical methods described in Driscoll (pp. 558 and 559) or through the application of step test analysis routines available in commercial aquifer tests programs (AQTESOLV™, Schlumberger –Aquifer Test ESI- Aquifer Win32). The “optimal” pumping rate is the minimum rate at which drawdown can be achieved in monitoring wells.

## **2.2 Constant Rate Aquifer Test**

A 72-hour (3 days) to 168-hour (7 days) constant rate aquifer test will be performed using extraction well KAFB-106228 as the pumping well. Nearby monitoring wells will be used as observation points during the aquifer test. Both manual and recording transducer water levels will be obtained. Figure 1-1 illustrates the location of extraction well KAFB-106228 and the respective monitoring wells that will be used as observation points during the aquifer test. Distances between extraction well KAFB-106228 and the aquifer test observation points are also provided on Figure 1-1. The constant rate aquifer test will be complete after the rate of drawdown in well KAFB-106228 has stabilized for at least 24 hours, or after a minimum pumping duration of 72 hours, whichever is later. *If the well is not capable of maintaining the planned flow rate, the test may be stopped and NMED will be contacted to discuss conducting the test at a*

lower discharge rate. If no drawdown is observed in monitoring wells by this time, NMED will be contacted to discuss the data collected to date and any further actions.

Because extraction well KAFB-106228 is expected to span the shallow, intermediate, and deep zones, monitoring wells completed in all three zones will be used as observation points during the constant rate aquifer test in order to monitor the aquifer response. Based on observed lithology at probe well KAFB-106212, and results from a sequence stratigraphy analysis completed by AECOM, it is expected that wells screened in the shallow zone may respond differently than those screened in the intermediate and deep zones. The varied response may be a result of increased finer grained material observed at approximately 460 feet below ground surface. The finer-grained layer, also referred to as the “450-foot clay”, spans the screened interval of many of the shallow wells and the layer appears to drop in elevation to the northeast. The intermediate and deep zone wells are primarily located below the 450-foot clay and within a contiguous hydrogeologic unit. It is thus anticipated that the intermediate and deep zone wells should have similar hydraulic responses. However, vertical heterogeneity may be cause for small hydrogeologic response variances. As a result, wells screened in different lithologic zones with respect to the 450-foot clay will initially be analyzed separately to determine what impact this layer has on the hydrologic response of the different lithologic zones in the aquifer. Analysis of the results will also take into account on other outside influences such as barometric pressure changes and regional groundwater rise.

Wells KAFB-106225, KAFB-106226, and KAFB-106227 are outside the expected zone of influence and will be used as background monitoring wells. Pressure transducers will be installed in each well to monitor, and correct for, intrinsic potentiometric head fluctuations (i.e., barometric influences) in the shallow, intermediate, and deep groundwater zones. Wells KAFB-106201, KAFB-106202, and KAFB-106203 are located outside extraction well KAFB-106228’s expected zone of influence and are near production well KAFB-3. Wells KAFB-1064, KAFB-106099, and KAFB-106100 are located outside extraction well KAFB-106228’s expected zone of influence and are near the VA production well. If

pumping at KAFB-3 or the VA production well influences the water levels observed in the monitoring wells during aquifer testing, data from the pressure transducers in these wells will be used to correct the data for production well pumping.

Following pumping, the aquifer will be allowed to recover for at least the same length of time as the duration of pumping. Pressure transducers in the pumping well and in the monitoring wells will record drawdown during pumping and recovery.

Specific steps to complete the constant rate aquifer test are as follows:

1. The optimal pumping rate will be selected based on the results of the step-drawdown test, as described in Section 2.1. However, the final pumping rate may be governed by both the discharge permit issued by the NMED Groundwater Quality Bureau and the discharge capabilities at Zia Park and/or the Kirtland AFB stormwater detention pond.
2. The pump will be started at the scheduled time and the valve or flow regulator will be adjusted to maintain a constant rate of discharge. The pump start time and flow rate will be recorded at the start of the test and every 15 minutes for the first hour after the start of pumping. A totalizer will be in the discharge line to keep track of the total volume of water discharged during testing.
3. Water levels will be monitored using pressure transducers and data loggers during pumping. Transducer data will be reviewed every 2 hours during the working day to assess groundwater elevations. The water level data will be evaluated during the test and, if necessary, the recording frequencies of the data loggers will be adjusted.
4. Wellhead flow meter readings will be observed and recorded once per hour during working hours. Additionally, flow meter readings will be taken outside of working hours at the EPA recommended hours of 8 PM and 2 AM daily (EPA, 1993, Appendix B). If the flow rates recorded during the day vary by more than 5 percent, additional overnight readings may be necessary. The initial flow meter reading frequency will be on the order of 1 minute to 10 minutes during the first hour of the pumping test.
5. Near the end of the pumping period, the pumping well data logger will be reset to record the recovery test. A true logarithmic water level measurement schedule will be used for the pumping well with the first readings at 4 per second and increasing up to 5-minute intervals later in the test. The monitoring wells will remain on the one minute recording schedule.
6. The pump will be shut down at the scheduled stopping time and the time will be recorded.
7. Water level recovery at the observation points will be recorded until the water level in the pumping well has recovered and stabilized. The measured recovery time will be at a minimum equal to the

pumping time and water has recovered to a minimum of 98 percent of the pre-pumping static water level.

8. A water level measurement using an electric tape water level meter will be taken at each of the observation points once the recovery period has ended. The measurements and times will be recorded.
9. Additional depth-to-water measurements may be taken following complete well recovery in order to monitor post-test trends in water levels.
10. Data will be reviewed in the field to help ensure the validity of the test. Once the aquifer test is satisfactorily completed, all downhole equipment will be removed and decontaminated, and wellheads will be secured.

The above procedures may be modified based on field conditions and data observations.

### 2.3 Aquifer Test Analysis

Both pumping and recovery data from wells with an observable drawdown will be used to evaluate the aquifer test. If no drawdown is observed in any of the monitoring wells, then only the data from extraction well KAFB-106228 will be used.

The constant rate aquifer test data will be evaluated using a combination of manual graphic techniques and commercial aquifer test software, such as AQTESOLV™ (Duffield, 2007). The data will be evaluated for spurious data, corrected for barometric pressure, regional trends, and production well pumping based on background wells, and then subjected to analysis. Because the lithology at the site contains discontinuous silt and clay layers, the aquifer may act as a semi-confined aquifer. Analysis methods representing both confined and unconfined aquifers will be applied. Solutions that both fit the data and the conceptual model of the aquifer will be chosen as representative. Monitoring well data will be analyzed to estimate transmissivity, storativity, and hydraulic conductivity in the aquifer between the extraction well and the monitoring wells. Extraction well data will be analyzed to estimate transmissivity and hydraulic conductivity in the immediate vicinity of the extraction well. Estimates of storativity using a single well are prone to error; therefore, storativity will not be estimated using only data from the extraction well. [Because of the stratified and lithologically varied nature of the geology in the area,](#)

pumping in KAFB-106228 is expected to primarily impact the thickness of the aquifer across which it is screened. Consequently, the saturated screen length will be used as the aquifer thickness input for all solution methods for both the step-drawdown test and constant rate test. In addition, an initial vertical to horizontal anisotropy ratio of 0.1 will be assumed. Sensitivity analyses will be performed to verify using these values.

The following methods will be used to analyze data from all monitoring wells where drawdown is observed:

- The Cooper-Jacob (1946) straight line time-drawdown method will be used to estimate aquifer transmissivity, storativity, and hydraulic conductivity.
- The Jacob (1950) straight line distance-drawdown method will be used to estimate aquifer transmissivity, storativity, and hydraulic conductivity.
- The Dougherty-Babu (1984) method for a confined aquifer will be used to estimate aquifer transmissivity and hydraulic conductivity.
- The Moench (1997) method for an unconfined aquifer will be used to estimate aquifer transmissivity and hydraulic conductivity.
- The Theis (1935)/Hantush (1961a, 1961b) method for a confined aquifer will be used to estimate aquifer transmissivity and hydraulic conductivity.

Recovery data will be analyzed using both a residual-drawdown plot and an Agarwal (1980) plot. The Agarwal (1980) plot uses a simple data transformation to allow the application of standard curve-matching techniques (Duffield, 2007). The following methods will be used to analyze recovery data from the extraction well:

- The Dougherty-Babu (1984) solution for a confined aquifer will be used to estimate aquifer transmissivity and hydraulic conductivity.
- The Moench (1997) solution for an unconfined aquifer will be used to estimate aquifer transmissivity and hydraulic conductivity.

All solutions will be reported in a table, which will identify the solutions chosen as representative and the rationale for choosing them. An appendix to the aquifer test report will be provided containing any calculations and graphs used for manual graphical solutions, and copies of all AQTESOLV™ (Duffield, 2007) derived solutions.

The results of aquifer test, including the calculated transmissivity and storativity, will be used in conjunction with groundwater modelling to determine the optimal pumping rate for extraction well KAFB-106228 for the period of time up until additional extraction wells begin to operate. The optimal pumping rate may, or may not, be equal to the maximum sustainable pumping rate determined during the step-drawdown test. The pumping rate may be adjusted, subject to NMED approval, based on actual water level and water quality data as pumping and extraction of EDB proceed. The optimal pumping rate will be included in the KAFB-106228 Aquifer Pilot-Test Report.



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### 3. TEMPORARY GROUNDWATER TREATMENT SYSTEM

The groundwater from the aquifer test is expected to contain EDB at levels that will exceed regulatory limits. As described in the Groundwater Extraction Work Plan (USACE, 2014a), groundwater from extraction well KAFB-106228 will be pumped through a double-walled, high-density, polyethylene pipeline to a groundwater treatment system located just east of Louisiana Boulevard on Kirtland AFB property (Figure 3-1).

The NOV delivered by NMED requires a June 30, 2015, deadline for operation of the extraction well and treatment system. In order to meet the June 30, 2015, date and perform well development and aquifer testing in a timely manner, a temporary treatment system capable of treating up to 150 gpm of contaminated groundwater on a short-term basis and 100 gpm on a continuous basis will be rented and placed on Kirtland AFB at the point where the pipeline from the extraction well enters the Base.

Figure 3-2 illustrates a process flow diagram of the temporary treatment system.

The groundwater from the aquifer test is expected to contain EDB at levels between 0.5 and 2  $\mu\text{g/L}$ . All other volatile organic compounds should be below detection limits. The treatment system will be comprised of multiple carbon beds, each containing virgin coconut shell based activated carbon. The carbon beds will be arranged as two parallel trains (one running, and one as a standby to be used in case of breakthrough). Each train will consist of either two or three carbon beds in series. The first bed (or beds) of each train will provide the contact time required for EDB removal. The final bed is provided as a back-up adsorber and is unlikely to see any contaminants. Pre-filters will be provided at the inlet of the carbon adsorbers and post-filters on the outlet. The pre-filters protect the carbon beds from plugging with solids from the extraction well and the post-filters are provided to remove carbon fines from the treated water. As was done during aquifer testing conducted in the fall of 2013, treated groundwater will initially be held in frac tanks and sampled and analyzed on an expedited basis to demonstrate that effluent

constituents are below their respective MCLs and the water can be re-infiltrated to the subsurface (Section 4).

A maximum of 36,000 gallons of water will be extracted during the step-drawdown test. Following treatment of the water extracted during the step-drawdown test, the water will be containerized in frac tanks, each with a capacity of 21,000 gallons. This water will be sampled before it is released to the infiltration system (described below) to ensure that it meets discharge criteria. Secondary containment barriers will be installed around each treatment component and the frac tanks as a preventative measure in case of any leaks. Water generated during the constant rate aquifer test will be treated in the same manner as water generated during the step-drawdown test. However, the volume of water produced during the constant rate aquifer test (a maximum volume of 1.5 million gallons) will be too large to store in the planned frac tanks. Therefore, this water will go directly to the infiltration system, which will consist of a sprinkler infiltration system at Zia Park, and if needed the Kirtland AFB stormwater detention pond adjacent to Randolph Avenue on Kirtland AFB property (Figure 3-1).

The existing effluent point of the detention pond will be blocked to prevent treated water from entering the Kirtland AFB stormwater system. Although both Zia Park and the Kirtland AFB stormwater detention pond may be used to receive treated discharge water, Zia Park will serve as the primary discharge location. Furthermore, water generated during the step-drawdown test will first be discharged at Zia Park to help estimate the infiltration capacity at this location. If Zia Park cannot accommodate discharge rates corresponding to the maximum rates achieved during the step-drawdown test, then the Kirtland AFB stormwater detention pond shall be used to accommodate excess discharge.

Section 4 outlines sampling plans for both the step-drawdown test and the constant rate aquifer test to monitor the treatment system's effectiveness. If breakthrough is detected between the granular activated carbon (GAC) units, the constant rate aquifer test will be stopped, and the treatment system will be

evaluated to determine where treatment has been insufficient and how it can be revised to complete the constant rate aquifer test. Because water generated during the step-drawdown test will be containerized, a contingency plan is not necessary for this first part of the test.

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## 4. SAMPLING

This section describes the samples that will be collected during aquifer testing. Section 4.1 describes pre-treatment characterization samples that will be collected from extraction well KAFB-106228. Section 4.1 also describes the samples that will be collected post-treatment to verify that the treatment system is operating properly. Sections 4.2 and 4.3 describe the processes used to collect, package, and ship samples.

### 4.1 Sampling and Analysis of Extracted Groundwater Pre- and Post-Treatment

Following development of extraction well KAFB-106228, and prior to aquifer testing, a groundwater sample will be collected and analyzed for EDB by Method SW8011 and metals by Method SW6010B. Based on a review of cumulative groundwater data for the area, only EDB has been detected above the NMED Groundwater Standards (20.6.4 New Mexico Administrative Code [NMAC]). Redox sensitive metals, such as manganese, are also a potential concern if the extraction well capture zone extends to groundwater exhibiting reducing conditions. Other constituents, including total petroleum hydrocarbon (TPH)-Gasoline Range Organics and TPH-Diesel Range Organics, have not been detected within the vicinity of the KAFB-106228 capture zone at concentrations exceeding the NMED Groundwater Standard or equivalent for the respective compounds.

When the constant rate aquifer testing commences, pre-treatment groundwater will be collected once per day during pumping. Pre-treatment samples will be collected from the temporary treatment system influent pipeline and analyzed for EDB by SW8011 with a 6-hour turn-around time (TAT). Field water quality parameters, including temperature, pH, conductivity, dissolved oxygen, oxidation-reduction potential, and alkalinity will be collected in the morning and in the afternoon during each day of pumping. Table 4-1 lists samples to be collected during the step-drawdown and constant rate aquifer tests.

During the aquifer test, it is likely that the extracted groundwater will exceed regulatory criteria for EDB prior to treatment. As described in Section 3, carbon treatment will be used to remove contaminants during both the step-drawdown and constant rate aquifer tests. Effluent from each of the three respective carbon beds will be sampled and analyzed to confirm that the discharged water meets regulatory criteria.

#### **4.1.1 Sampling of Treated Groundwater during Step-Drawdown Test**

The first set of samples from the carbon treatment system will be collected near the end of the step-drawdown test when the groundwater feed rate to the carbon beds is at the maximum rate. Samples will be collected from the respective outlets of the three carbon beds and submitted for analysis of EDB by Method SW8011 and metals by Method SW6010B with a 72-hour TAT for both analyses. At the end of the step-drawdown test, the system will be shut down until the results of these analyses are received and it is confirmed that contaminants of concern in the treated water are below regulatory criteria.

Treated water from the step-drawdown test will be containerized in the 21,000 gallon frac tanks. If the treated water does not meet the NMED Groundwater Standards (20.6.4 NMAC), the temporary groundwater treatment system design will be revised to achieve the needed criteria and expanded constant rate test capacity. The containerized water will be re-treated until it meets requirements. Once the effectiveness of the groundwater treatment system has been demonstrated during the step-drawdown test and treated water below regulatory criteria is discharged to Zia Park and/or the Kirtland AFB stormwater detention pond, the constant rate aquifer test will commence.

#### **4.1.2 Sampling of Treated Groundwater during Constant Rate Aquifer Test**

During the constant rate aquifer test, daily influent samples will continue each morning. Samples will also be collected at the outlet of the primary, secondary, and tertiary carbon beds and submitted for analysis of EDB by Method SW8011. EDB samples will be analyzed by Hall Environmental Laboratory in Albuquerque, New Mexico and preliminary data will be available by the close of business the same day.

These EDB samples will monitor for contaminant breakthrough of the carbon beds, allowing the treatment system to be shut down in a timely manner if breakthrough does occur through either of the first two GAC units. Closely monitoring the primary and secondary GAC unit effluent will ensure protection of the tertiary GAC unit and prevent possible breakthrough.

The sampling and analysis of groundwater samples will be conducted as outlined in Section 3.1.1.2 of the NMED-approved Quality Assurance Project Plan (USACE, 2011b).

## 4.2 Sample Collection

Samples will be collected for field parameter and laboratory analysis. A sample chain-of-custody can be found in Table 4-2. Collection of samples will adhere to requirements outlined in the Groundwater Investigation Work Plan (USACE, 2011a) and will follow the procedures below:

1. Sample containers will be labeled before sample collection.
2. EDB samples will be collected first and in accordance with volatile organic analysis sample collection procedures. The samples will be carefully filled to avoid overflow and tapped so entrapment of air is minimized and no head space exists.
3. Dissolved metals analysis may be field-filtered according to procedures presented below. If field filtration is not performed, the sample container must be clearly marked to state “laboratory filtration required.”
4. Samples for field parameter measurements will be collected last.
5. Filtering of field samples (dissolved iron and manganese) will use a cellulose-based membrane filter of 0.45-micron, nominal pore size. The sample must be filtered immediately after collection to minimize changes in the concentration of the substance of interest. Samples are only passed through the filtration apparatus once. Samples are then preserved immediately as required. All paperwork accompanying samples to the laboratory will clearly state that the samples have been field-filtered, in order to avoid second filtration at the laboratory. Field filtering of water samples will be conducted as follows:
  - a. The filter apparatus will be decontaminated and cleaned.
  - b. The sample will be poured into the filter apparatus and filtered through a cellulose-based membrane filter of 0.45-micron, nominal size. To condition the filter, half of the sample volume will be passed through the filter apparatus and filter paper and then discarded. The full sample



volume will then be filtered and collected in the appropriate sample container. Samples are only passed through the filter once.

- c. Samples will be preserved immediately, as required.

### **4.3 Sample Packaging and Shipping**

Sample packaging and shipping requirements are designed to maintain sample integrity from the time a sample is collected until it is received at the analytical laboratory. All chain-of-custody forms, sample labels, custody seals, and other sample documents will be completed as specified in the Quality Assurance Project Plan (USACE, 2011b). Specific procedures for packaging and shipping of environmental samples are presented below.

1. A sample label, completed with indelible ink, will be attached to the sample bottle.
2. A picnic cooler (e.g., Coleman<sup>®</sup> or other sturdy cooler) will typically be used as a shipping container. In preparation for shipping samples, the drain plug will be taped shut so that no fluids, such as melted ice, will drain out of the cooler during shipment. A large plastic bag may be used as a liner for the cooler. Packing material, such as bubble wrap, or Styrofoam beads, will be placed in the bottom of the liner.
3. The containers will be placed in the lined picnic cooler. Cardboard separators may be placed between the containers at the discretion of the shipper.
4. All samples for chemical analysis must be shipped cooled to 6 degrees Celsius with wet ice. All samples will require icing before shipment. A temperature blank will be included in each shipment of water samples.
5. The liner will be taped closed, if used, and sufficient packing material will be used to prevent sample containers from making contact or rolling around during shipment.
6. A copy of the chain-of-custody form will be placed inside the cooler.
7. The cooler will be closed and taped shut with strapping tape (filament-type).
8. Custody seals will be placed on the cooler. Clear tape will be placed over the custody seals to help prevent them from being accidentally torn or ripped off.
9. The cooler of samples will be shipped via an overnight carrier. A standard air bill is necessary for shipping environmental samples.

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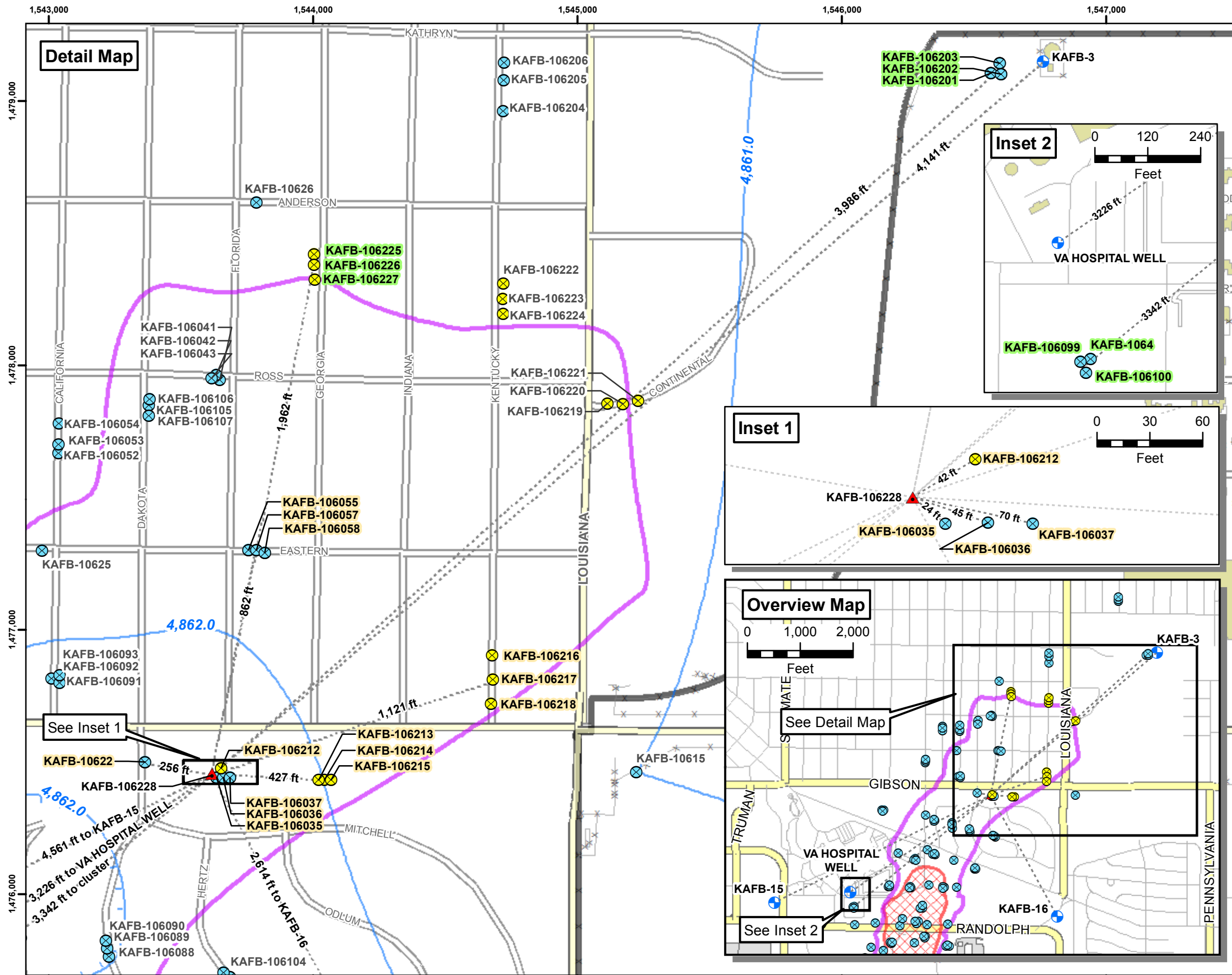
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- USACE, 2014b. *Kirtland Air Force Base Bulk Fuels Facility—Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum - Final*. Prepared by CB&I Federal Services LLC for the USACE Albuquerque District under USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. October.
- USACE, 2011a. *Groundwater Investigation Work Plan, Kirtland Air Force Base Bulk Fuels Facility (BFF) Spill, Solid Waste Management Units ST-106 and SS-111*. Prepared by Shaw Environmental & Infrastructure, Inc. for the USACE Albuquerque District under USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. March.
- USACE, 2011b. *Quality Assurance Project Plan, Bulk Fuels Facility (BFF) Spill, Solid Waste Management Units ST-106 and SS-111, Kirtland Air Force Base, Albuquerque, New Mexico*. Prepared by Shaw Environmental & Infrastructure, Inc. for the USACE Albuquerque District under USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. April.

## **FIGURES**

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### Legend

- ▲ Extraction Well
- ⊗ Planned Monitor Well
- ⊗ Monitor Well
- Water Supply Well
- July 2014 Groundwater Level Contour (ft above msl)
- Groundwater Depression
- - - Distance Line
- Dissolved Plume Extent (July 2014)
- ⊗ Historical Area of Observed NAPL (July 2009)

⊗ KAFB-106035 Aquifer Test Observation Point

⊗ KAFB-106201 Aquifer Test Background Observation Point

Distance lines represent the horizontal distance from the approximate center of each well cluster or observation well to pumping test well KAFB-106228.

Water supply wells KAFB-15 and KAFB-16 are non-operational.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Revision Date: 03/09/15

0 200 400 800  
Feet  
1 inch = 400 feet

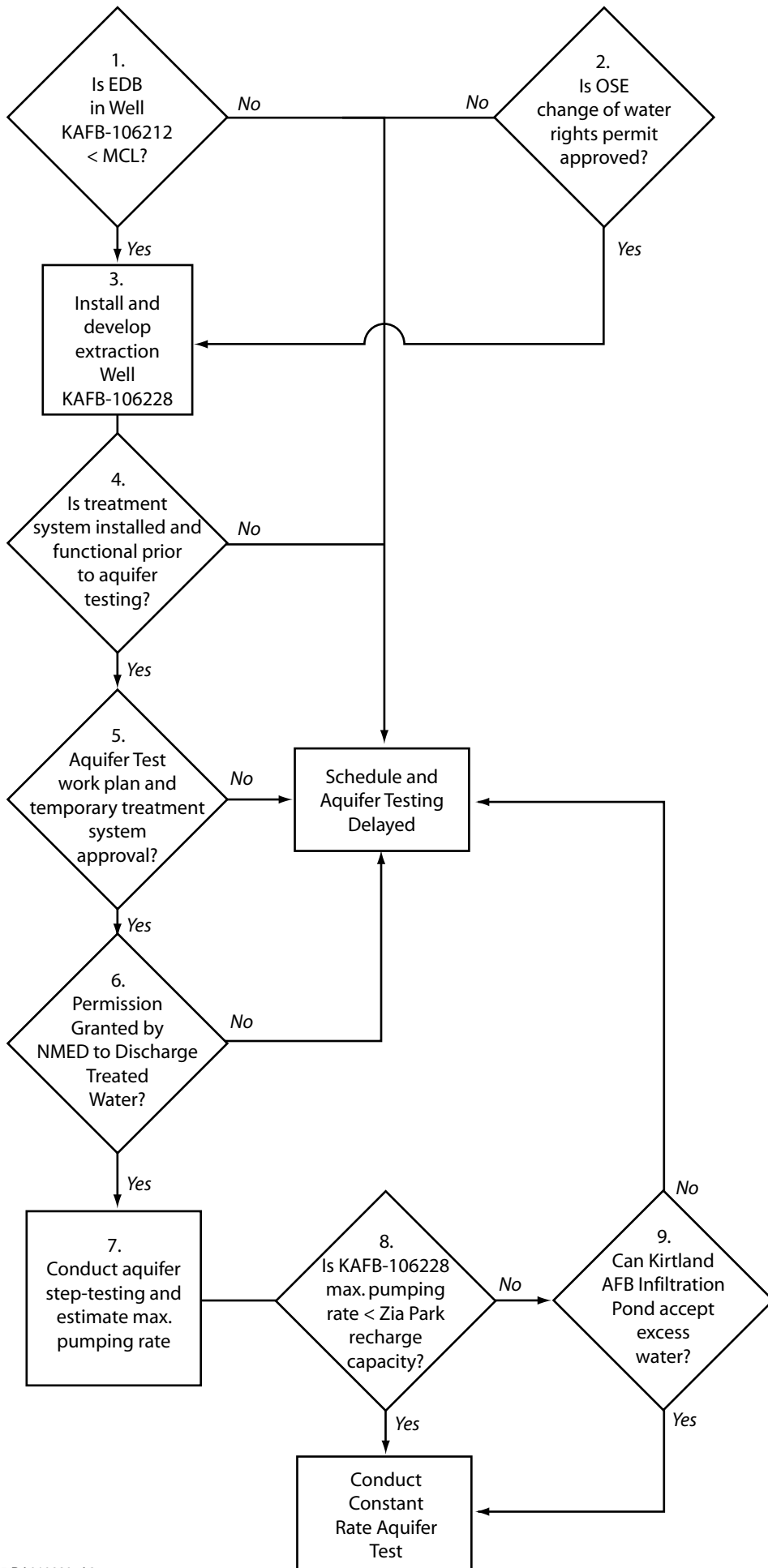
Projection : NAD83 State Plane New Mexico Central FIPS3002 Feet

GROUNDWATER EXTRACTION WELL  
KAFB-106228 AQUIFER TESTING WORK PLAN  
BULK FUELS FACILITY  
KIRTLAND AIR FORCE BASE, NEW MEXICO

FIGURE 1-1

AQUIFER TEST WELL  
LOCATIONS

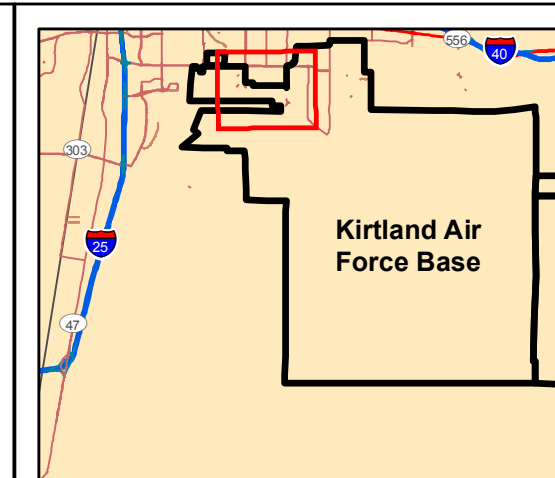
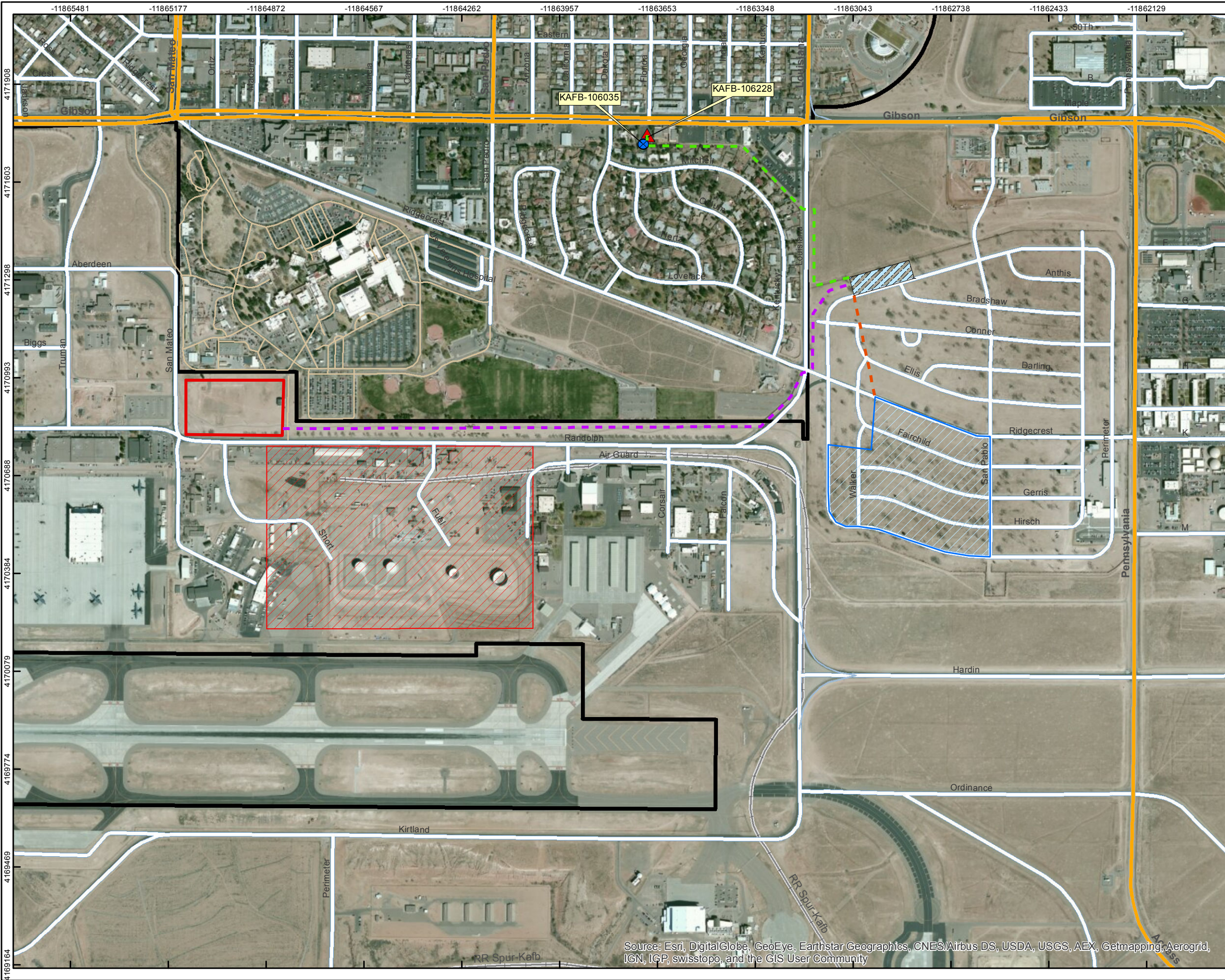
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**Figure 1-2**  
**Aquifer Test Schedule**  
**And Assumptions**  
**Groundwater Extraction**  
**Well KAFB-106228**  
**Aquifer Testing Work Plan**



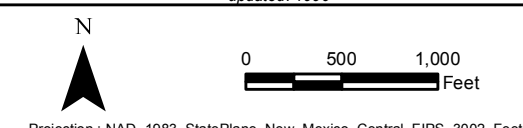
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**LEGEND**

- Bulk Fuels Facility (Sites ST-106 and SS-111)
- Installation Boundary
- Pump and Treat Remediation Components**
- Proposed Extraction Well Location
- Groundwater Monitoring Well
- Proposed Land Application Area
- Retention Pond
- Proposed Temporary Treatment System Location
- Influent from Well
- Discharge to Retention Pond
- Discharge to Surface Application/Sprinklers

Source: USGS Digital Raster Graphics (Topographic Maps) [MSRMAPS.COM]  
 7.5 Minute Quadrangle, Albuquerque East 1:24000  
 updated: 1990



GROUNDWATER EXTRACTION WELL KAFB-106228  
 AQUIFER TESTING WORK PLAN  
 BULK FUELS FACILITY  
 KIRTLAND AIR FORCE BASE, NEW MEXICO

FIGURE 3-1

SCHMATIC CONVEYANCE PIPING AND  
 TEMPORARY TREATMENT SYSTEM

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

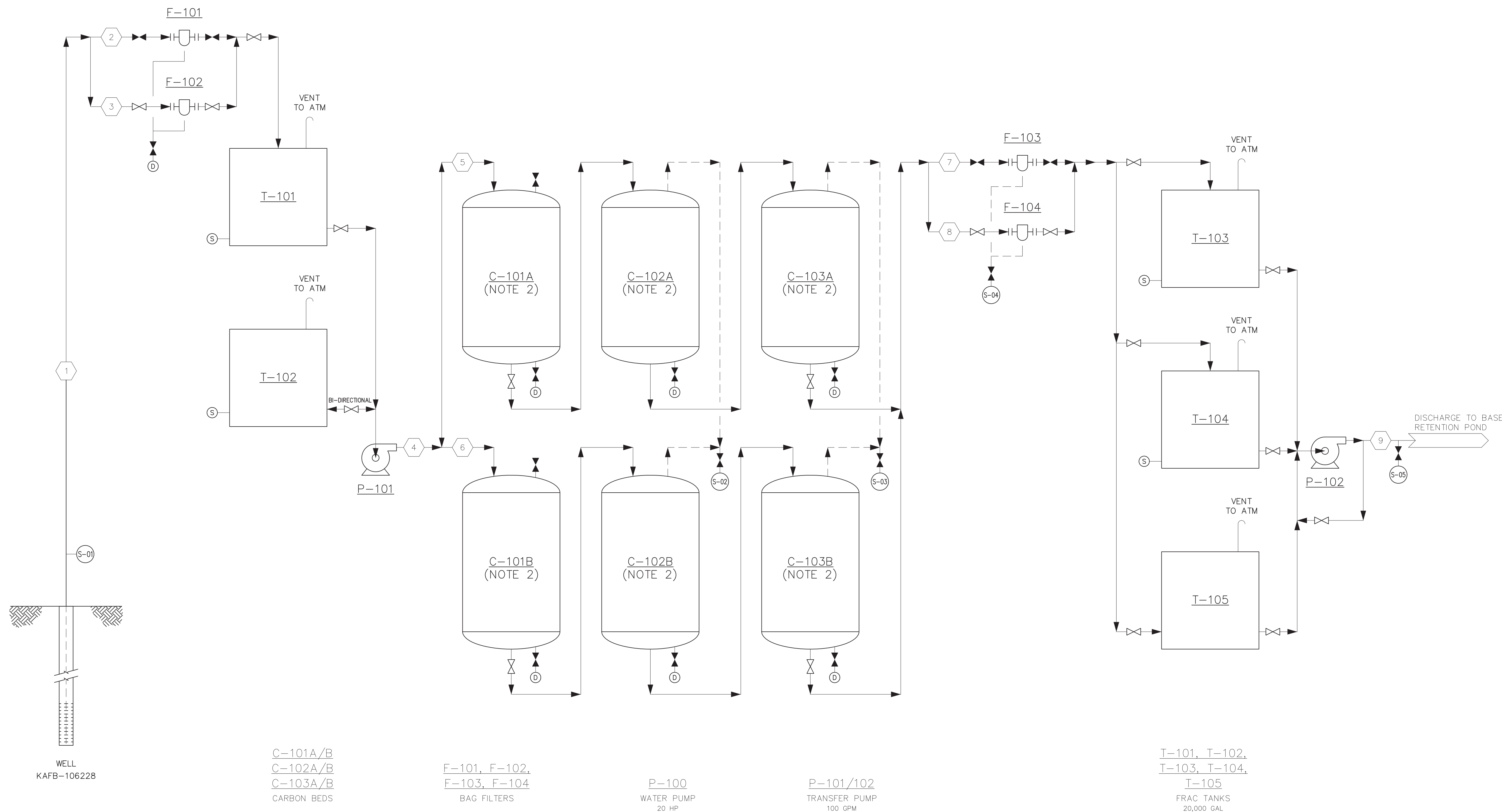
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NOTE:

1. BY-PASS TO BE USED IN WELL DEVELOPMENT.
2. TWO OR THREE BED CONFIGURATION BASED ON RENTAL AVAILABILITY.

LEGEND:

- ▼ SAMPLE PORT
- ⊙ SAMPLE PORT



WELL  
KAFB-106228

C-101A/B  
C-102A/B  
C-103A/B  
CARBON BEDS

F-101, F-102,  
F-103, F-104  
BAG FILTERS

P-100  
WATER PUMP  
20 HP

P-101/102  
TRANSFER PUMP  
100 GPM

T-101, T-102,  
T-103, T-104,  
T-105  
FRAC TANKS  
20,000 GAL

**FOR REVIEW ONLY! - NOT FOR CONSTRUCTION**

PRELIMINARY PROGRESS DRAWINGS ARE NOT FOR CONSTRUCTION OR FABRICATION. BILL OF MATERIALS, SHOP DRAWINGS, ETC., CREATED FROM THESE DRAWINGS MAY BE REVISED AT THE EXPENSE OF THE CONTRACTOR.

STREAM NO.	1	2	3	4	5	6	7	8	9	10								
COMPONENT																		
WATER	gpm	100	100	100	100	100	100	100	100	100								

PROFESSIONAL SEAL

U.S. ARMY ENGINEER DISTRICT  
CORPS OF ENGINEERS  
ALBUQUERQUE, NEW MEXICO

CB&I FEDERAL SERVICES LLC  
312 DIRECTORS DRIVE  
KNOXVILLE, TENNESSEE 37923  
865-690-3211

FIGURE 3-2  
TEMPORARY GROUNDWATER TREATMENT SYSTEM  
PROCESS FLOW DIAGRAM  
PHASE IV MID-PLUME PUMP & TREAT SYSTEM

FOR: BULK FUELS FACILITY, KIRTLAND AFB, NM

PROJECT NO: 140705 DWG NO: 140705-001-PR-01-000002 REV:

NOTES	REFERENCE DRAWINGS	NO.	REVISION	DRAWN	CK'D	APPD	DATE	DRAWN: EGA	CK'D: SES	APPD:	DATE: 1/27/15	SCALE: NONE

File: 140705-001-PR-01-000002.dwg  
Date: 1/27/15 11:53am  
Plotted By: edward.anderson

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## TABLES

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**Table 2-1. Aquifer Test Well Summary**

Well ID	Target Aquifer Zone	Horizontal Distance from KAFB-106228 (feet) <sup>b</sup>	Pumping Test Use
KAFB-106228 <sup>a</sup>	Shallow to Deep	0	Extraction Well
KAFB-106035	Shallow	24	Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106212 <sup>a</sup>	Beneath Deep Zone	42	Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106036	Intermediate	45	Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106037	Deep	70	Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-10622	Shallow	256	Observation Well for the Constant Rate Test
KAFB-106213 <sup>a</sup>	Shallow	427	Observation Well for the Constant Rate Test
KAFB-106214 <sup>a</sup>	Intermediate		Observation Well for the Constant Rate Test
KAFB-106215 <sup>a</sup>	Deep		Observation Well for the Constant Rate Test
KAFB-106055	Shallow	862	Observation Well for the Constant Rate Test
KAFB-106057	Intermediate		Observation Well for the Constant Rate Test
KAFB-106058	Deep		Observation Well for the Constant Rate Test
KAFB-106216 <sup>a</sup>	Shallow	1,121	Observation Well for the Constant Rate Test
KAFB-106217 <sup>a</sup>	Intermediate		Observation Well for the Constant Rate Test
KAFB-106218 <sup>a</sup>	Deep		Observation Well for the Constant Rate Test
KAFB-106225 <sup>a</sup>	Shallow	1,962	Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106226 <sup>a</sup>	Intermediate		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106227 <sup>a</sup>	Deep		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-1064	Shallow	3,342	Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106099	Intermediate		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106100	Deep		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106201	Shallow	3,986	Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106202	Intermediate		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106203	Deep		Background Observation Well for the Step-Drawdown and Constant Rate Tests

<sup>a</sup>These wells are either recently completed or have not yet been drilled. Well completion diagrams with final construction details will be included in an addendum to this work plan.

<sup>b</sup>With the exception of wells KAFB-106035, KAFB-106036, and KAFB-106037, the horizontal distance provided for cluster wells is the distance from the proposed location of KAFB-106228 to the center of the monitoring well cluster. Precise distances to each monitoring well will be determined after all of the monitoring wells are installed and surveyed, and those distances will be used in the aquifer test analysis.

ID - Identification



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**Table 4-1. Sampling Plan for Step-Drawdown Test and Constant Rate Aquifer Test**

<b>Aquifer Test Stage</b>	<b>Location</b>	<b>Frequency</b>	<b>Analytical Parameters</b>	<b>Laboratory</b>	<b>Turn-Around Time</b>	<b>Total No. of Samples (depending duration of constant rate test)</b>
Prior to step-drawdown test	Extraction well KAFB-106228	once	EDB by SW8011, Metals by SW6010B	Empirical Laboratories	72 hrs for EDB and metals	1
During highest pumping rate of step-drawdown test	Effluent of primary GAC unit	once	EDB by SW8011, Metals by SW6010B	Empirical Laboratories	72 hrs for EDB and metals	1
During highest pumping rate of step-drawdown test	Effluent of secondary GAC unit	once	EDB by SW8011, Metals by SW6010B	Empirical Laboratories	72 hrs for EDB and metals	1
During highest pumping rate of step-drawdown test	Effluent of tertiary GAC unit	once	EDB by SW8011, Metals by SW6010B	Empirical Laboratories	72 hrs for EDB and metals	1
Full duration of constant rate test	Influent-prior to treatment	once per day	EDB by SW8011	Hall Analytical Laboratories	6 hr	3-7
Full duration of constant rate test	Effluent of primary GAC unit	once per day	EDB by SW8011	Hall Analytical Laboratories	6 hr	3-7
Full duration of constant rate test	Effluent of secondary GAC unit	once per day	EDB by SW8011	Hall Analytical Laboratories	6 hr	3-7
Full duration of constant rate test	Effluent of tertiary GAC unit	once per day	EDB by SW8011	Hall Analytical Laboratories	6 hr	3-7

EDB 1,2-dibromoethane  
GAC granular activated carbon  
hrs hours

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**APPENDIX A**  
**Pertinent Letters and Guidance**

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*Adria Badoure*  
**NEW MEXICO**  
**ENVIRONMENT DEPARTMENT**



210 748 4035

395 8426

SUSANA MARTINEZ  
 Governor

JOHN A. SANCHEZ  
 Lieutenant Governor

Harold Karmels Building  
 1190 Saint Francis Drive (87505)  
 P.O. Box 5469, Santa Fe, NM 87502-5469  
 Phone (505) 827-2855 Fax (505) 827-0310  
[www.nmenv.state.nm.us](http://www.nmenv.state.nm.us)

RYAN FLYNN  
 Cabinet Secretary

BUTCH TONGATE  
 Deputy Secretary

January 15, 2015

Colonel Tom D. Miller  
 Base Commander  
 377 ABW/CC  
 2000 Wyoming Blvd. SE  
 Kirtland AFB, NM 87117-5606

John Pike  
 Director, Environmental Management Services  
 377 MSG  
 2050 Wyoming Blvd. SE, Suite 116  
 Kirtland AFB, NM 87117-5270

**RE: NOTICE OF VIOLATION  
 INTERIM GROUNDWATER EXTRACTION AND ADDITIONAL  
 CHARACTERIZATION  
 BULK FUELS FACILITY SPILL  
 SOLID WASTE MANAGEMENT UNITS ST-106 AND SS-111  
 KIRTLAND AIR FORCE BASE  
 EPA ID# NM9570024423, HWB-KAFB-14-MISC**

Dear Colonel Miller and Mr. Pike:

On August 21, 2013, the United States Air Force (“USAF” or “Permittee”) and the New Mexico Environment Department (“NMED”) presented a plan for the implementation of certain interim measures at the Albuquerque-Bernalillo County Water Utility Authority Governing Board Meeting. In accord with the Kirtland Air Force Base (“Base”) Hazardous Waste Treatment Facility Operating Permit No. NM9570024423 (“Permit”) and the New Mexico Hazardous Waste Act, NMSA 1978, Sections 74-4-1 to 74-4-14 (“the Act”), NMED required the implementation of interim measures to reduce and prevent migration of hazardous wastes and hazardous waste constituents from the Bulk Fuels Facility Spill at the Base while long-term corrective action remedies are evaluated. See Permit Sections 6.0 and 6.2.2.2.12.1. The interim measures were necessary based on the extent of the fuel spill, its location and the amount of time needed to establish and implement corrective measures under the Resource Conservation and Recovery Act (“RCRA”). The third interim measure, also referred to as Task 3, was to address the Ethylene Dibromide (“EDB”) and be implemented by December 31, 2014.

In a letter dated April 24, 2014, NMED reiterated expectations for interim measure deadlines, including the deadline for the EDB interim measure: “Ethylene Dibromide (EDB) (design and implement interim treatment of dissolved phase EDB that has migrated off site north of the Base, end of 4<sup>th</sup> Q, 2014).”



On April 8, 2014, NMED received a "white paper" proposing an approach to Task 3 which involved increasing the pumping rate of Kirtland Well #3, a public drinking water supply well, in order to draw the EDB contamination into this well for removal by carbon treatment. By a letter dated June 6, 2014, NMED reiterated its position, previously communicated in a meeting on May 7, 2014, that any proposal to intentionally induce migration of EDB through an extensive volume of non-contaminated groundwater was not acceptable. NMED noted that time spent on consideration of this concept threatened compliance with the December 31, 2014 deadline for the EDB interim measure. Also, NMED required the submission of a work plan for the EDB plume by June 30, 2014.

On June 26, 2014, USAF requested an extension of the June 30 deadline until July 30, 2014. In a letter dated July 10, 2014, following a presentation by KAFB on June 18, 2014, NMED granted an extension to August 1, 2014, for submission of the EDB work plan. NMED imposed certain requirements for submission of the EDB work plan.

On August 1, 2014, NMED received the EDB work plan from USAF. By letter of August 20, 2014, NMED approved the work plan, imposed certain conditions on the performance of the plan, and reiterated that the December 31, 2014 deadline for design and implementation of the EDB interim measure remained in effect. Upon approval of the work plan, it became an enforceable condition of the Permit. *See* Permit Section 6.2.2.2.12.3.

As of the date of this letter, the Permittee has failed to implement the EDB interim measure as described in the August 1, 2014 work plan. The Permittee is therefore in violation of the Permit and the Act. In accord with the NMED Hazardous Waste Civil Penalty Policy ("Policy"), the Permittee is subject to a civil penalty of \$10,000 plus an additional \$5,000 for each day this violation continues, subject to upward or downward adjustment in accordance with the Policy.

Further, NMED is aware that USAF has been developing an approach to address the EDB interim measure that significantly expands upon the August 1, 2014 work plan. Specifically, at a September 17, 2014 meeting of the Albuquerque-Bernalillo County Water Utility Authority Governing Board, Mr. Mark Correll, Deputy Assistant Secretary of the Air Force for Environment, Safety and Infrastructure, presented several potential courses of action that would provide a more robust interim measure for the dissolved phase EDB. Each option involved the installation of up to seven additional extraction wells, with the difference being the timing of the installation. When implemented, this approach would result in the operation of eight extraction wells, rather than one extraction well as provided in the August 1, 2014 work plan. As has been previously communicated to USAF, NMED supports in principle the concept of expanding upon the August 1, 2014 work plan; however, USAF's announced intention to pursue such expansion does not negate its liability for the failure to comply with the existing December 31, 2014 deadline for implementation of the approved EDB interim measure work plan.

NMED is aware that external factors (difficulty in obtaining landowner permission and discovery of abandoned munitions) have already delayed progress in achieving the expansion milestones as proposed at the September 17, 2014 meeting. Also, the expansion of the August 1, 2014 work plan has not been formally reviewed and approved by NMED.

Therefore, within 45 days of the date of this Notice of Violation, the Permittee shall submit a proposed plan to collapse the dissolved phase EDB contamination plume. The *EDB Interim Measure Implementation Plan* shall include the following elements:

1. A schedule for completion of all actions in the August 1, 2014 Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan, and October 9, 2014 Work Plan Addendum, as previously approved by NMED. See Attachment A for additional details regarding this schedule.
2. An aquifer pilot test work plan for the hydraulic testing of extraction well 106228. The aquifer pilot test work must be prepared in accordance with the EPA "Suggested Operating Procedures for Aquifer Pumping Tests," <http://www.epa.gov/superfund/remedytech/tsp/download/sopaqu.pdf>, or other procedures approved by NMED. The aquifer pilot test work plan must include a detailed description of the proposed aquifer testing that includes a step-drawdown test and a constant discharge test and all related activities including, but not limited to, analytical testing, a description of equipment and all methods and procedures for conducting the test and analyzing the acquired data.
3. A description of all other actions and milestones necessary to collapse the dissolved phase EDB plume. This description shall include commitments to submit, at the appropriate time in the future, technical work plans and completion reports for the following activities:
  - a. Additional aquifer performance testing;
  - b. Aquifer test reports for extraction well 106228 and other tested wells;
  - c. Computer modeling of groundwater flow paths, travel times and extraction well capture zones as necessary to locate and design additional extraction wells;
  - d. Drilling and construction of additional monitoring wells, if necessary, to define the horizontal and vertical extent of EDB contamination;
  - e. Drilling and construction of additional monitoring wells, if necessary, to conduct aquifer performance testing;
  - f. Drilling and construction of up to seven additional extraction wells, anticipated to include three wells in 2015 and four wells in 2016;
  - g. Modifications, if necessary, to the collection, treatment and disposal system for extraction water; and
  - h. Modifications to the quarterly groundwater monitoring program, if necessary, to monitor the effectiveness of the interim measure and to ensure that the interim measure will not cause EDB to migrate into a drinking water supply well.

The EDB Interim Measure Implementation Plan and all other work plans, schedules and completion reports required by this Notice of Violation shall be subject to NMED review and approval.

The violations addressed by this Notice of Violation shall be deemed to cease upon written notification by NMED that the Permittee has successfully completed all actions in the August 1, 2014 Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan, and October 9, 2014 Work Plan Addendum. NMED reserves the right to require additional monitoring wells or extraction wells in addition to those discussed above, if necessary,

to stabilize and collapse the dissolved phase EDB plume while final comprehensive corrective action measures are selected.

Finally, while NMED is disappointed with USAF's inability to meet the mutually agreed upon deadline for implementing a plan to attack the dissolved phase EDB, we remain supportive of USAF's expanded EDB treatment plan outlined last September and will consider abating a portion of the penalties if USAF is able to begin treating contaminated groundwater by the end of June. Ultimately, while plans are an important part of the process, NMED will not be satisfied until USAF begins treating the contaminated groundwater. Please contact Katie Roberts of my staff at (505) 827-2855 if you have any questions regarding this Notice of Violation.

Yours truly,



---

Ryan Flynn  
Cabinet Secretary  
New Mexico Environment Department

Cc: Dep. Sec. B. Tongate, NMED  
K. Roberts, NMED  
A. Bodour, AFCEC  
Col. T. Haught, KAFB  
D. Wilson, KAFB  
L. Bitner, USAF  
B. Gallegos, AEHD  
F. Shean, ABCWUA  
L. King, EPA-Region 6 (6PD-N)

ATTACHMENT A  
REQUIREMENTS FOR SCHEDULE OF COMPLETION OF AUGUST 1, 2014 WORK PLAN

The Permittee shall submit daily drilling summary reports to NMED by email for each day that drilling and well installation operations are active. The daily email reports shall summarize the activities for that day, and shall summarize the activities expected to be performed on the following work day. The daily email reports shall include a copy of the handwritten lithologic log, prepared by the Permittee's site geologist, of earth materials encountered for each day that the drill hole advances. The occurrence of worker injuries or safety shutdowns, if any, also shall be noted in the daily email reports.

The schedule shall include anticipated dates for the installation of all monitoring wells specified in the work plan. Installation is considered to be complete once the well casing has been installed to its final position and the casing rim can be measured relative to the ground surface. Development of each well must be completed within 21 days of the completion of well installation.





# Ground Water Issue

## Suggested Operating Procedures for Aquifer Pumping Tests

Paul S. Osborne\*

The Regional Superfund Ground Water Forum is a group of ground-water scientists, representing EPA's Regional Superfund Offices, organized to exchange up-to-date information related to ground water remediation at Superfund sites.

A very important aspect of ground water remediation is the capability to determine accurate estimates of aquifer hydraulic characteristics. This document was developed to provide an overview of all the elements of an aquifer test to assist RPMs and OSCs in the initial design of such tests or in the review of tests performed by other groups.

For further information, contact Jerry Thornhill, RSKERL-Ada, 405/436-8604 or Paul Osborne, EPA Region VIII, 303/293-1418.

### INTRODUCTION

In recent years, there has been an increased interest in ground water resources throughout the United States. This interest has resulted from a combination of an increase in ground water development for public and domestic use; an increase in mining, agricultural, and industrial activities which might impact ground water quality; and an increase in studies of already contaminated aquifers. Decision-making agencies involved in these ground water activities require studies of the aquifers to develop reliable information on the hydrologic properties and behavior of aquifers and aquitards.

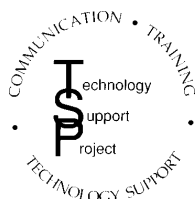
The most reliable type of aquifer test usually conducted is a pumping test. In addition, some site studies involve the use of short term slug tests to obtain estimates of hydraulic conductivity, usually for a specific zone or very limited portion of the aquifer. It should be emphasized that slug tests provide

very limited information on the hydraulic properties of the aquifer and often produce estimates which are only accurate within an order of magnitude. Many experts believe that slug tests are much too heavily relied upon in site characterization and contamination studies. This group of professionals recommends use of slug testing during the initial site studies to assist in developing a site conceptual model and in pumping test design.

This document is intended as a primer, describing the process for the design and performance of an "aquifer test" (how to obtain reliable data from a pumping test) to obtain accurate estimates of aquifer parameters. It is intended for use by those professionals involved in characterizing sites which require corrective action as well as those which are proposed for ground water development, agricultural development, industrial development, or disposal activities. The goal of the document is to provide the reader with a complete picture of all of the elements of aquifer (pumping) test design and performance and an understanding of how those elements can affect the quality of the final data.

The determination of accurate estimates of aquifer hydraulic characteristics is dependent on the availability of reliable data from an aquifer test. This document outlines the planning, equipment, and test procedures for designing and conducting an accurate aquifer test. The design and operation of a slug test is not included in this document, although slug tests are often run prior to the design and implementation of an aquifer test. The slug test information can be very useful in developing the aquifer test design (see ASTM D-18

\* *Regional Ground Water Expert, U.S. EPA, Region VIII*



### Superfund Technology Support Center for Ground Water

**Robert S. Kerr Environmental  
Research Laboratory  
Ada, Oklahoma**

Technology Innovation Office  
Office of Solid Waste and Emergency  
Response, US EPA, Washington, DC

Walter W. Kovalick, Jr., Ph.D.  
Director

---

Committee, D4050 and D4104). If an accurate conceptual model of the site is developed and the proper equipment, wells, and procedures are selected during the design phase, the resulting data should be reliable. The aquifer estimates obtained from analyzing the data will, of course, depend on the method of analysis.

This document is not intended to be an overview of aquifer test analysis. The analysis and evaluation of pumping test data is adequately covered by numerous texts on the subject (Dawson and Istok, 1991; Kruseman and de Ridder, 1991; Walton, 1962; and Ferris, Knowles, Brown, and Stallman, 1962). It should be emphasized, however, that information on the methods for analyzing test data should be reviewed in detail during the planning phase. This is especially important for determining the number, location, and construction details for all wells involved in the test.

A simple "pump" (specific capacity) test involves the pumping of a single well with no associated observation wells. The purpose of a pump test is to obtain information on well yield, observed drawdown, pump efficiency, and calculated specific capacity. The information is used mainly for developing the final design of the pump facility and water delivery system. The pump test usually has a duration of 2 to 12 hours with periodic water level and discharge measurements. The pump is generally allowed to run at maximum capacity with little or no attempt to maintain constant discharge. Discharge variations are often as high as 50 percent. Short-term pump tests with poor control of discharge are not suitable for estimating parameters needed for adequate aquifer characterization. If the pump test is, however, run in such a way that the discharge rate varies less than 5 percent and water levels are measured frequently, the test data can also be used to obtain some reliable estimates of aquifer performance. It should be emphasized that an estimate of aquifer transmissivity obtained in this manner will not be as accurate as that obtained using an aquifer test including observation wells.

By controlling the discharge variation and pumping for a sufficient duration, it is possible to obtain reliable estimates of transmissivity using water level data obtained during the pump test. However, this method does not provide information on boundaries, storativity, leaky aquifers, and other information needed to adequately characterize the hydrology of an aquifer. For the purpose of this document, an aquifer test is defined as a controlled field experiment using a discharging (control) well and at least one observation well.

The aquifer test is accomplished by applying a known stress to an aquifer of known or assumed dimensions and observing the water level response over time. Hydraulic characteristics which can be estimated, if the test is designed and implemented properly, include the coefficient of storage, specific yield, transmissivity, vertical and horizontal permeability, and confining layer leakage. Depending on the location of observation wells, it may be possible to determine the location of aquifer boundaries. If measurements are made on nearby springs, it may also be possible to determine the impact of pumping on surface-water features.

## **TEST DESIGN**

Adequate attention to the planning and design phase of the

aquifer pumping test will assure that the effort and expense of conducting a test will produce useful results. Individuals involved in designing an aquifer test should review the relevant ASTM Standards relating to: 1) appropriate field procedures for determining aquifer hydraulic properties (D4050 and D4106); 2) selection of aquifer test method (D4043); and 3) design and installation of ground water monitoring wells (D5092). The relevant portions of these standards should be incorporated into the design.

All available information regarding the aquifer and the site should be collected and reviewed at the commencement of the test design phase. This information will provide the basis for development of a conceptual model of the site and for selecting the final design. It is important that the geometry of the site, location and depth of observation wells and piezometers, and the pumping period agree with the mathematical model to be used in the analysis of the data. A test should be designed for the most important parameters to be determined, and other parameters may have to be de-emphasized.

### ***Aquifer Data Needs***

The initial element of the test design, formulating a conceptual model of the site, involves the collection and analysis of existing data regarding the aquifer and related geologic and hydrologic units. All available information on the aquifer itself, such as saturated thickness, locations of aquifer boundaries, locations of springs, information on all on-site and all nearby wells (construction, well logs, pumping schedules, etc.), estimates of regional transmissivities, and other pertinent data, should be collected. Detailed information relating to the geology and hydrology is needed to formulate the conceptual model and to determine which mathematical model should be utilized to estimate the most important parameters. It is also important to review various methods for the analyses and evaluation of pumping test data (Ferris, Knowles, Brown, and Stallman, 1962; Kruseman and De Ridder, 1991; and Walton, 1962 and 1970). Information relating to the various analytical methods and associated data needs will assist the hydrologist in reviewing the existing data, identifying gaps in information, and formulating a program for filling any gaps that exist.

The conceptual model of the site should be prepared after carrying out a detailed site visit and an evaluation of the assembled information. The review of available records should include files available from the U. S. Geological Survey, appropriate state agencies, and information from local drillers with experience in the area. Formulation of a conceptual model should include a brief analysis of how the local hydrology/geology fits into the regional hydrogeologic setting.

### **Aquifer Location**

The depth to, thickness of, areal extent of, and lithology of the aquifer to be tested should be delineated, if possible.

### **Aquifer Boundaries**

Nearby aquifer discontinuities caused by changes in lithology or by incised streams and lakes should be mapped. All known and suspected boundaries should be mapped such that

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observation wells can be placed (chosen) where they will provide the best opportunity to measure the aquifer's response to the pumping and the boundary effects during the pumping test.

### Hydraulic Properties

Estimates of all pertinent hydraulic properties of the aquifers and pertinent geologic units must be made by any means feasible. Estimates of transmissivity and the storage coefficient should be made, and if leaky confining beds are detected, leakage coefficients should be estimated. The estimation of transmissivity and the storage coefficient should be carried out by making a close examination of existing well logs and core data in the area or by gathering information from nearby aquifer tests, slug tests, or drill stem tests conducted on the aquifer(s) in question. It may also be feasible to run a slug test on the wells near the site to get preliminary values. (See ASTM Committee D-18 Standards D4044 and D4104). It should be noted that some investigators have found that slug tests often produce results which are as much as an order of magnitude low. Although some investigators have reported results which are two orders of magnitude high because the sand pack dominated the test. Such tests will, however, provide a starting point for the design. If no core analyses are available, the well log review should form a basis for utilizing an available table which correlates the type of aquifer material with the hydraulic conductivity. If detailed sample results from drill holes are available and they have grain size analyses, there are empirical formulas for estimation of transmissivity. Estimation of storage coefficient is more difficult, but can be based on the expected porosity of the material or the expected confinement of the aquifer. It is recommended that a range of values be chosen to provide a worst case and best case scenario (Freeze and Cherry, 1979). Trial calculations of well drawdown using these estimated values should be made to finalize the design, location, and operation of test and observation wells (Ferris and others, 1962; Campbell and Lehr, 1972; and Stallman, 1971).

If local perched aquifers are of a significant size and location to impact the pump test, this impact should be estimated if possible. The final test design should include adequate monitoring of any perched aquifers and leaky confining beds. This might involve the placing of piezometers into and/or above the leaky confining zone or into the perched aquifer.

### ***Evaluation of Existing Well Information***

Because the drilling of new production wells and observation wells expressly for an aquifer test can be expensive, it is advisable to use existing wells for conducting an aquifer test when possible. However, many existing wells are not suitable for aquifer testing. They may be unsuitably constructed (such as a well which is not completed in the same aquifer zone as the pumping well) or may be inappropriately located. It is also important to note that well logs and well completion data for existing facilities are not always reliable. Existing data should be verified whenever possible. The design of each well, whether existing or to be drilled, must be carefully considered to determine if it will meet the needs of the proposed test plan and analytical methods. Special attention must be paid to well location, the depth and interval of the well screen or perforation, and the present condition of existing perforations.

After the process of developing the site model and determining which analytical methods should be used, it is possible to move to the final design stage. The final stage of the design involves development of the key elements of the aquifer test: 1) number and location of observation wells; 2) design of observation wells; 3) approximate duration of the test; and 4) discharge rate.

### ***Design of Pumping Facility***

There are seven principal elements to be considered during the pumping facility design phase: 1) well construction; 2) the well development procedure; 3) well access for water level measurements; 4) a reliable power source; 5) the type of pump; 6) the discharge-control and measurement equipment; and 7) the method of water disposal. These elements are discussed in the following sections.

#### Well Construction

The diameter, depth and position of all intervals open to the aquifer in the pumping well should be known, as should total depth. The diameter must be large enough to accommodate a test pump and allow for water level measurements. All openings to the aquifer(s) must be known and only those openings located in the aquifer to be tested should be open to the well during the testing. If the pumping well has to be drilled, the type, size, and number of perforations should be established using data from existing well logs and from the information obtained during the drilling of the new well itself. The screen or perforated interval should be designed to have sufficient open area to minimize well losses caused by fluid entry into the well (Campbell and Lehr, 1972; and Driscoll, 1986).

A well into an unconsolidated aquifer should be completed with a filter pack in the annular space between the well screen and the aquifer material. To design an adequate filter pack, it is essential that the grain size makeup of the aquifer be defined. This is generally done by running a sieve analysis of the major lithologic units making up the aquifer. The sizing of the filter pack will depend on the grain size distribution of the aquifer material. The well screen size would be established by the sizing of the chosen filter pack (Driscoll, 1986). The filter pack should extend at least one (1) foot above the top of the well screen. A seal of bentonite pellets should be placed on top of the filter pack. A minimum of three (3) feet of pellets should be used. An annulus seal of cement and/or bentonite grout should be placed on top of the bentonite pellets. The well casing should be protected at the surface with a concrete pad around the well to isolate the wellbore from surface runoff (ASTM Committee D-18, D5092; and Barcelona, Gibb, and Miller, 1983).

#### Well Development

Information on how the pumping well was constructed and developed should be collected during the review of existing site information. It may be necessary to interview the driller. If the well has not been adequately developed, the data collected from the well may not be representative of the aquifer. For instance, the efficiency of the well may be reduced, thereby causing increased drawdown in the pumping well. When a well is pumped, there are two components of



drawdown: 1) the head losses in the aquifer; and 2) the head losses associated with entry into the well. A well which is poorly constructed or has a plugged well screen will have a high head loss associated with entry into the well. These losses will affect the accuracy of the estimates of aquifer hydraulic parameters made using data from that well. If the well is suspected to have been poorly developed, or nothing is known, it is advisable to run a step drawdown test on the well to determine the extent of the problem. The step drawdown test entails conducting three or more steps of increasing discharge, producing drawdown curves such as shown in Figure 1. The data provided by the step drawdown test (multiple discharge test) can be analyzed using various techniques (Rorabough, 1953; and Driscoll, 1986) to obtain an estimate of well entry losses. If a determination is made that plugging results in significant losses, the well should be redeveloped prior to the pumping test using a surge block and/or a pump until the well discharge is clear: i. e. the development results in the well achieving acceptable turbidity unit limits (Driscoll, 1986). In many cases, running a step drawdown test to determine well efficiency after the well has been surged is needed to assess the results of the development process. The results of the post development test should be compared with the step-drawdown test run prior to development. This analysis will provide a means of verifying the success of the well development.

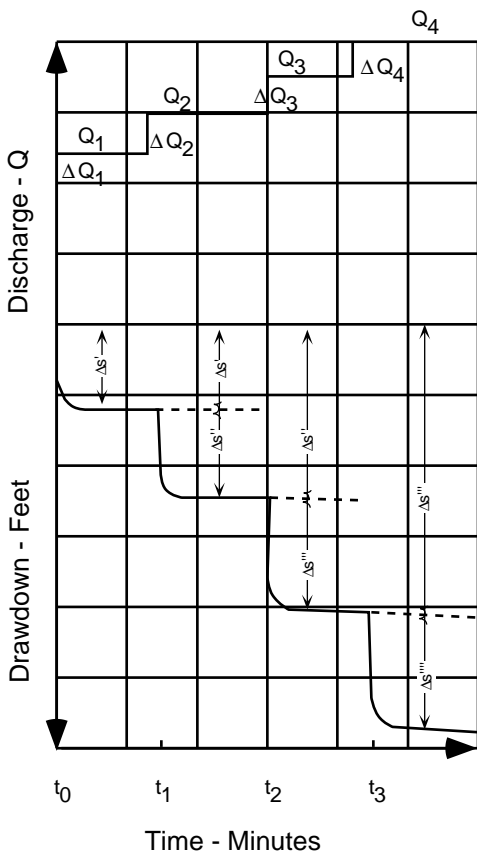


Figure 1. Variation of discharge and drawdown in multiple discharge tests (step drawdown tests).

### Water Level Measurement Access

It must be possible to measure depth to the water level in the pumping well before, during, and after pumping. The quickest and generally the most accurate means of measuring the water levels in the pumped well during an aquifer test is to use an electric sounder or pressure transducer system. The transducer system may be expensive and may be difficult to install in an existing well. It may be possible to run a 1/4 inch copper line into the well as an air line. If the control well is newly constructed, the continuous copper line should be strapped to the pump column as it is being installed. If it is correctly installed, an air line can be used with somewhat less accuracy than an electric sounder or steel tape. An air line with a bubbler and either a transducer or precision pressure gage should be adequate for running an aquifer test.

With adequate temperature compensation, a surface mounted pressure transducer is as precise as one that is submerged. Steel tapes cannot always be used quickly enough in a pumping well, except in wells with a small depth to water (less than 100 feet) where the pump test crew has a fair amount of experience and the well is modified for access of the steel tape. Such modification often involves hanging a 3/4 inch pipe in the well as access for the steel tape. The pipe should be capped at the bottom with numerous 1/16 to 1/8 inch holes drilled in the pipe and cap (especially needed for wells subject to cascading water or surging). This will dampen water-level surging caused by the pump and will eliminate the problems caused by cascading water. In general, the use of a steel tape is usually confined to the later stages of the pump test where rapid changes in water levels are not occurring.

In cases where the pump is isolated by a packer to allow production from a particular zone, a transducer system should be used to monitor pumping hydraulic heads. It is important, however, to calibrate the transducers before and after the test. In addition, reference checks with an electric sounder or steel tape should be made before, during, and after the test. The ASTM Standard Test Method for determining subsurface liquid levels in a borehole or monitoring well (D4750) should be reviewed as part of the design process.

### Reliable Power Source

Having power continuously available to the pump, for the duration of the test, is crucial to the success of the test. If power is interrupted during the test, it may be necessary to terminate the test and allow for sufficient recovery so that pre-pumping water-level trends can be extrapolated. At that point, a new test would be run. If, however, brief interruptions in power occur late in the test, the affect of the interruption can be eliminated by pumping at a calculated higher rate for some period so that the average rate remains unchanged. The increased rate must be calculated such that the final portion of the test compensates for the pumpage that would have occurred during the interruption of pumping.

### Pump Selection

A reliable pump is a necessity during an aquifer test. The pump should be operated continuously during the test. Should a pump fail during the pumping period of the test, the time, effort, and expense of conducting the test could be

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wasted. Electrically powered pumps produce the most constant discharge and are often recommended for use during an aquifer test. However, in irrigation areas, line loads can fluctuate greatly, causing variations in the pumping rate of electric motors. Furthermore, electric motors are nearly constant-load devices, so that as the lift increases (water level declines), the pumping rate decreases. This is a particular problem for inefficient wells or low transmissivity aquifers.

The discharge of engine-powered (usually gasoline or diesel) pumps may vary greatly over a 24 hour period, requiring more frequent monitoring of the discharge rate during the test. For example, under extreme conditions a diesel-powered turbine pump may have more than a 10 percent change in discharge as a result of the daily variation in temperature. The change in air temperature affects the combustion ratio of the engine resulting in a variation in engine revolutions per minute (rpm). The greater the daily temperature range, the greater the range in engine rpm. Variations in barometric pressure may also affect the engine operation and resulting rpm. Running the engine at full throttle will reduce operational flexibility for adjusting engine rpm and the resulting discharge. In areas where outside temperatures are extreme, such as the desert or a very cold region, it may be advisable to undertake measures to prevent the engine from overheating or freezing.

In order to obtain good data during the period of recovery at the end of pumping, it is necessary to have a check valve installed at the base of the pump column pipe in the discharging well. This will prevent the back flow of water from the column pipe into the well when the pumping portion of the test is terminated and the recovery begins. Any back flow into the well will interfere with or totally mask the water level recovery of the aquifer and this would make any aquifer analysis based on recovery data useless or, at best, questionable (Schafer, 1978).

#### Discharge-Control and Measurement Equipment

The well bore and discharge lines should be accessible for installing discharge control and monitoring equipment. When considering an existing well for the test well to be pumped (control well), the well must either already be equipped with discharge measuring and regulating equipment, or the well must have been constructed such that the necessary equipment can be added.

Control of the pumping rate during the test requires an accurate means for measuring the discharge of the pump and a convenient means of adjusting the rate to keep it as nearly constant as possible. Common methods of measuring well discharge include the use of an orifice plate and manometer, an inline flow meter, an inline calibrated pitot tube, a calibrated weir or flume, or, for low discharge rates, observing the length of time taken for the discharging water to fill a container of known volume (e.g. 5 gallon bucket; 55 gallon drum).

In addition to the potentially large variation in discharge associated with the pump motor or engine, the discharge rate is also related to the drop in water level near the pumping well during the aquifer test. As the pumping lift increases, the rate of discharge at a given level of power (such as engine rpm) will decrease. The pump should not be operated at its maximum rate. As a general rule, the pumping unit, including the engine, should be designed so that the maximum pumping

rate is at least 20 percent more than the estimated long term sustainable yield of the aquifer. The long term yield of the aquifer should be determined by collecting data on pumping rates in nearby wells. If possible, a short term test of one to two hours should be run when the pump is installed. This test data should be compared to the historic data as part of the estimation process.

The pumping rate can be controlled by placing valves on the discharge line and/or by placing controls on the pump power source. A valve installed in the discharge line to create back pressure provides effective control of the discharge rate while conducting an aquifer test, especially when using an electric-powered pump. A rheostatic control on the electric pump will also allow accurate control of the discharge rate. When an engine-powered pump is being utilized, installation of a micrometer throttle adjustment device to accurately control engine rpm is recommended in addition to a valve in the line.

#### Water Disposal

Discharging water immediately adjacent to the pumping well can cause problems with the aquifer test, especially in tests of permeable unconfined alluvial aquifers. The water becomes a source of recharge which will affect the results of the test. It is essential that the volumes of produced water, the storage needs, the disposal alternatives, and the treatment needs be assessed early in the planning process. The produced water from the test well must be transported away from the control well and observation wells so it cannot return to the aquifer during the test. This may necessitate the laying of a temporary pipeline (sprinkler irrigation line is often used) to convey the discharge water a sufficient distance from the test site. In some cases, it may be necessary to have on-site storage, such as steel storage tanks or lined ponds. This is especially critical when testing contaminated zones where water treatment capacity is not available. The test designer should carefully review applicable requirements of the RCRA hazardous waste program, the underground injection control program, and the surface water discharge program prior to making decisions about this phase of the design. It may be necessary to obtain permits for on-site storage and final disposal of the contaminated fluids. Final disposal could involve treatment and reinjection into the source aquifer or appropriate treatment and discharge.

#### ***Design of Observation Well(s)***

##### Verification of well response

As part of the process of selecting the location of the observation wells needed for the chosen aquifer test design, existing wells should be tested for their suitability as observation wells. The existing information regarding well construction should be reviewed as a screening mechanism for identifying suitable candidates. The wells that are identified as potential observation wells should be field tested to verify that they are suitable for monitoring aquifer response. The perforations or well screens of abandoned wells tend to become restricted by the buildup of iron compounds, carbonate compounds, sulfate compounds or bacterial growth as a result of not pumping the well. Consequently, the response test is one of the most important pre-pumping examinations to be made if such wells are to be used for observation (Stallman, 1971; and Black and Kip, 1977). The

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reaction of all wells to changing water levels should be tested by injecting or removing a known volume of water into each well and measuring the subsequent change of water level. Any wells which appear to have poor response should be either redeveloped, replaced, or dropped from consideration in favor of another available well selected.

#### Total Depth

In general, observation wells should penetrate the tested aquifer to the same stratigraphic horizon as the well screen or perforated interval of the pumping well. This will require close evaluation of logs to adjust for dipping formations. This assumes the observation well is to be used for monitoring response in the same aquifer from which the discharging well is pumping. Actual screen design will depend on aquifer geometry and site specific lithology. If the aquifer test is designed to detect hydraulic connection between aquifers, one observation well should be screened in the strata for which hydraulic inter-connection is suspected. Depending on how much information is needed, additional wells screened in other strata may be needed (Bredehoeft and others, 1983; Walton, 1970; Dawson and Istok, 1991; and Hamlin, 1983).

#### Well Diameter

In general, observation well casing should have a diameter just large enough to allow for accurate, rapid water level measurements. A two-inch well casing is usually adequate for use as an observation well in shallow aquifers which are less than 100 feet in depth. They are, however, often difficult to develop. A four- to six-inch diameter well will withstand a more vigorous development process, and should have better aquifer response when properly developed. Additionally, a four or six inch diameter well may be required if a water-depth recorder is planned, depending on the type of recording equipment to be used. The difficulties in drilling a straight hole usually dictate that a well over 200 feet deep be at least four inches in diameter.

#### Well Construction

Ideally, the observation well(s) should have five to twenty feet of perforated casing or well screen near the bottom of the well. The final well screened interval(s) will depend on the nature of geologic conditions at the site and the types of parameters to be estimated. Any openings which allow water to enter the well from aquifers which are not to be tested should be sealed or closed off for the duration of the test. Ideally, the annular space between the casing and the hole wall should be gravel packed adjacent to the perforated interval to be tested. The use of a filter pack in wells with more than one screened interval will, however, create a problem. There is no reliable method for sealing the annular space of any unwanted filter packed interval even though the screen can be isolated. The size of the filter material should be based on the grain size distribution of the zone to be screened (preferably based on a sieve analysis of the material). The screen size should be determined based on the filter pack design (Driscoll, 1986). The space above the gravel should be sealed with a sufficient amount of bentonite or other grout to isolate the gravel pack from vertical flow from above. If the bentonite does not extend to the surface, it will be necessary to put a cement seal on top of the bentonite prior to back filling the remaining annular space. A concrete pad should be placed around the well to

prevent surface fluids from entering the annular material. After installation is finished, the observation well should be developed by surging with a block, and/or submersible pump (Campbell and Lehr, 1972; and Driscoll, 1986) for a sufficient period (usually several hours) to meet a pre-determined level of turbidity.

#### Radial Distance and Location Relative to the Pumped Well

If only one observation well is to be used, it is usually located 50 to 300 feet from the pumped well. However, each test situation should be evaluated individually, because certain hydraulic conditions may exist which warrant the use of a closer or more distant observation well. If the test design requires multiple observation wells, the wells are often placed in a straight line or along rays that are perpendicular from the pumping well. In the case of multiple boundaries or leaky aquifers, the observation wells need to be located in a manner which will identify the location and effect of the boundaries. If the location of the boundary is suspected before the test, it is desirable to locate most of the wells along a line parallel to the boundary and running through the pumping well, as shown in Figure 2. If aquifer anisotropy is expected, the observation wells should be located in a pattern based on the suspected or known anisotropic conditions at the site (Bentall and others, 1963; Ferris and others, 1962; Walton, 1962 and 1970; and Dawson and Istok, 1991). If the principal directions of anisotropy are known, drawdown data from two wells located on different rays from the pumping well will be sufficient. If the principal directions of anisotropy are not known, at least three wells on different rays are needed.

### **FIELD PROCEDURES**

Well thought out field procedures and accurate monitoring equipment are the key to a successful aquifer test. The following three sections provide an overview of the methods and equipment for establishing a pre-test baseline condition and running the test itself.

#### ***Necessary Equipment for Data Collection***

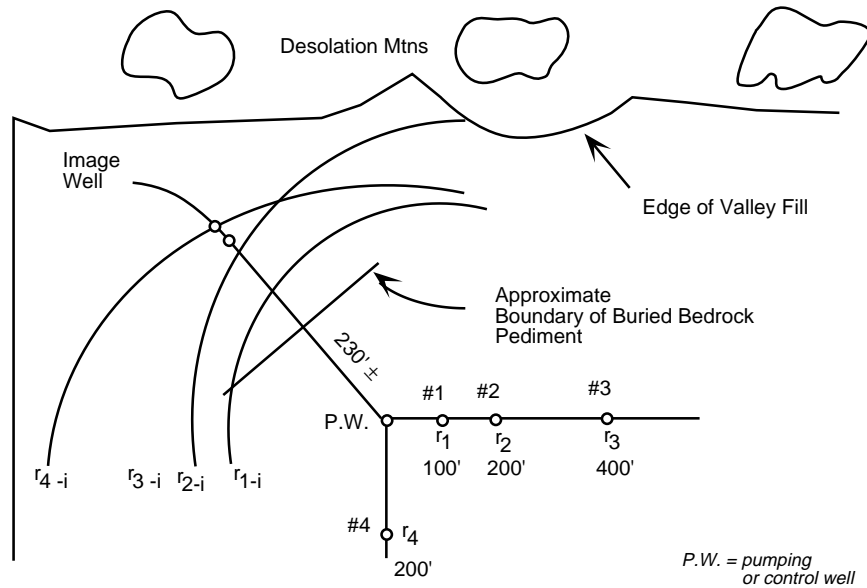
During an aquifer test, equipment is needed to measure/record water levels, well discharges, and the time since the beginning of the test, and to record accumulated data. Appendix One contains a detailed description of the types of equipment commonly used during an aquifer test. Appendix Two is an example form for recording test data.

#### ***Establish Baseline Trend***

Collecting data on pre-test water levels is essential if the analysis of the test data is to be completely successful. The baseline data provides a basis for correcting the test data to account for on-going regional water level changes. Although the wells on-site are the main target for baseline measurements, it is important to measure key wells adjacent to the site and to account for off-site pumping which may affect the test results.

#### Baseline water levels

Prior to beginning the test, it will be necessary to establish a



**Figure 2. Observation well/pumping well location to determine buried impermeable boundary.**

baseline trend in the water levels in the pumping and all observation wells. As a general rule, the period of observation before the start of the test ( $t_0$ ), should be at least one week. Baseline measurements must be made for a period which is sufficient to establish the pre-pumping water level trends on site (see Figure 3). The baseline data must be sufficient to explain any differences between individual observation wells. As shown in Figure 3, the water levels in on-site wells were declining prior to the test. The drawdown during the test must be corrected to account for the pre-pumping trend.

#### Nearby pumping activities

During the baseline measurements, the on-off times should be recorded for any nearby wells in use. The well discharge rates should be noted as should any observed changes in the proposed on-site control well and observation wells. Baseline water level measurements should be made in all off-site wells within the anticipated area of influence. As shown in Figure 3, the baseline period should be sufficient to establish the pretest pumping trends and to explain any differences in trends between individual off-site wells.

Significant effects due to nearby pumping wells can often be removed from the test data if the on-off times of the wells are monitored before and during the test. Interference effects may not, however, always be observable. In any case, changes associated with nearby pumping wells will make analysis more difficult. If possible, the cooperation of nearby well owners should be obtained to either cease pumping prior to and during the test period or to control the discharge of these wells during the baseline and test period. The underlying principle is to minimize changes in regional effects during the baseline, test and recovery periods.

#### Barometric pressure changes

During the baseline trend observation period, it is desirable to

monitor and record the barometric pressure to a sensitivity of plus or minus 0.01 inches of mercury. The monitoring should continue throughout the test and for at least one day to a week after the completion of the recovery measurement period. This data, when combined with the water level trends measured during the baseline period, can be used to correct for the effects of barometric changes that may occur during the test (Clark, 1967).

#### Local activities which may affect test

Changes in depth to water level, observed during the test, may be due to several variables such as recharge, barometric response, or "noise" resulting from operation of nearby wells, or loading of the aquifer by trains or other surface disturbances (King, 1982). It is important to identify all major activities (especially cyclic activities) which may impact the test data. Enough measurements have to be made to fully characterize the pre-pumping trends of these activities. This may necessitate the installation of recording equipment. A summary of this information should be noted in the comments section of the pumping test data forms.

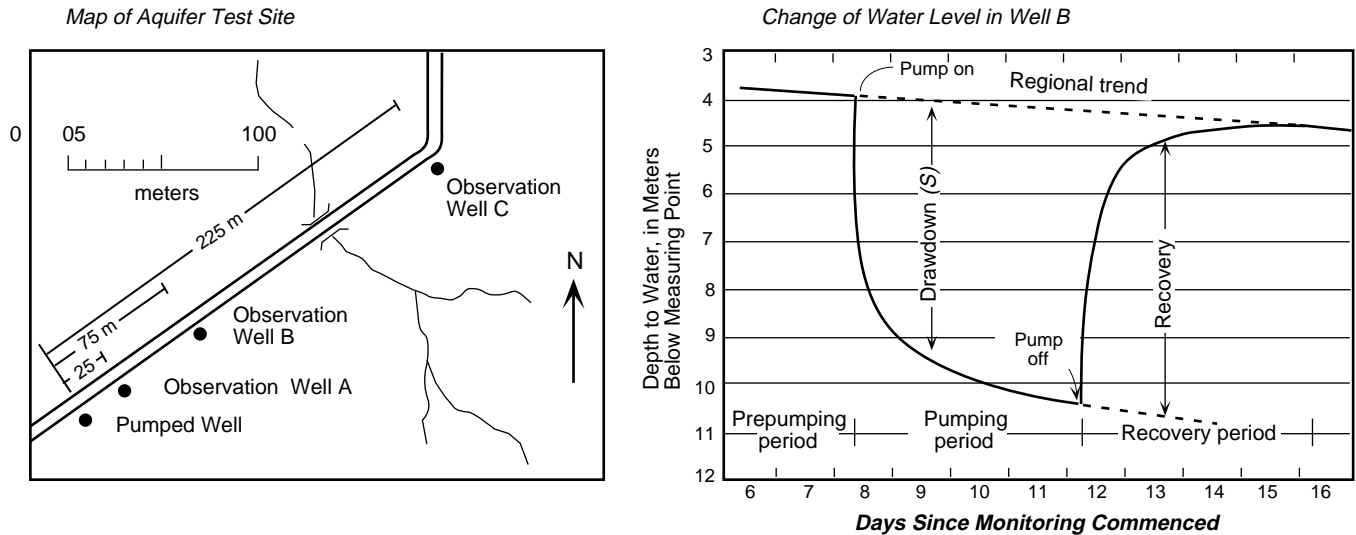
### **Test Procedures**

#### Initial water level measurements

Immediately before pumping is to begin, static water levels in all test wells should be recorded. Measurements of drawdown in the pumping well can be simplified by taping a calibrated steel tape to the electric sounder wire. The zero point of the tape may be taped at the point representing static water level. This will enable the drawdown to be measured directly rather than by depth to water.

#### Measuring water levels during test

If drawdown is expected in the observation well(s) soon after



**Figure 3. Example test site showing baseline, pumping test, and recovery water level measurements in one of the wells.**

testing begins and continuous water level recorders are not installed, an observer should be stationed at each observation well to record water levels during the first two to three hours of testing. Subsequently, a single observer is usually able to record water levels in all wells because simultaneous measurements are unnecessary. If there are numerous observation wells, a pressure transducer/data-logging system should be considered to reduce manpower needs.

Time frame for measuring water levels

Table 1 shows the recommended maximum time intervals for recording water levels in the pumped well. NOTE: the times provided in Table 1 are only the maximum recommended time intervals--more frequent measurements may be taken if test conditions warrant. For instance, it is recommended that water level measurements be taken at least every 30 seconds for the first several minutes of the test (see ASTM Committee D-18, D 4050). Figure 4 is a hypothetical logarithmic plot of drawdown versus time for an observation well. This plot illustrates the need for the frequency of measurements given in Table 1. As shown on the plot, frequent measurements during early times are needed to define the drawdown curve. The data used in Figure 4 was collected with a downhole pressure transducer and electronic data recording equipment. Thus, water levels could be collected about every 6 seconds initially and less frequently as the test progresses. As time since pumping started increases, the logarithmic scale dictates that less frequent measurements are needed to adequately define the curve.

Measurements in the observation well(s) should occur often enough and soon enough after testing begins to avoid missing the initial drawdown values. Actual timing will depend on the aquifer and well conditions which vary from test area to test area. Estimates for timing should be made during the planning stages of aquifer testing using estimated aquifer parameters based on the conceptual model of the site.

**Table 1. Maximum Recommended Time Intervals for Aquifer Test Water Level Measurements\***

0 to 3 minutes .....	every 30 seconds
3 to 15 minutes .....	every minute
15 to 60 minutes .....	every 5 minutes
60 to 120 minutes .....	every 10 minutes
120 min. to 10 hours .....	every 30 minutes
10 hours to 48 hours .....	every 4 hours
48 hours to shut down .....	every 24 hours

\* Dr. John Harshbarger, personal communication, 1968.

Monitoring discharge rate

During the initial hour of the aquifer test, well discharge in the pumping well should be monitored and recorded as frequently as practical. Ideally, the pretest discharge will equal zero. If it does not, the discharge should be measured for the first time within a minute or two after the pump is started.

It is important when starting a test to bring the discharge up to the chosen rate as quickly as possible. How frequently the discharge needs to be measured and adjusted for a test depends on the pump, well, aquifer, and power characteristics. Output from electrically driven equipment requires less frequent adjustments than from all other pumping equipment. Engine-driven pumps generally require adjustments several times a day because of variation that occurs in the motor performance due to a number of factors, including air temperature effects. At a minimum, the discharge should be checked four times per day: 1) early

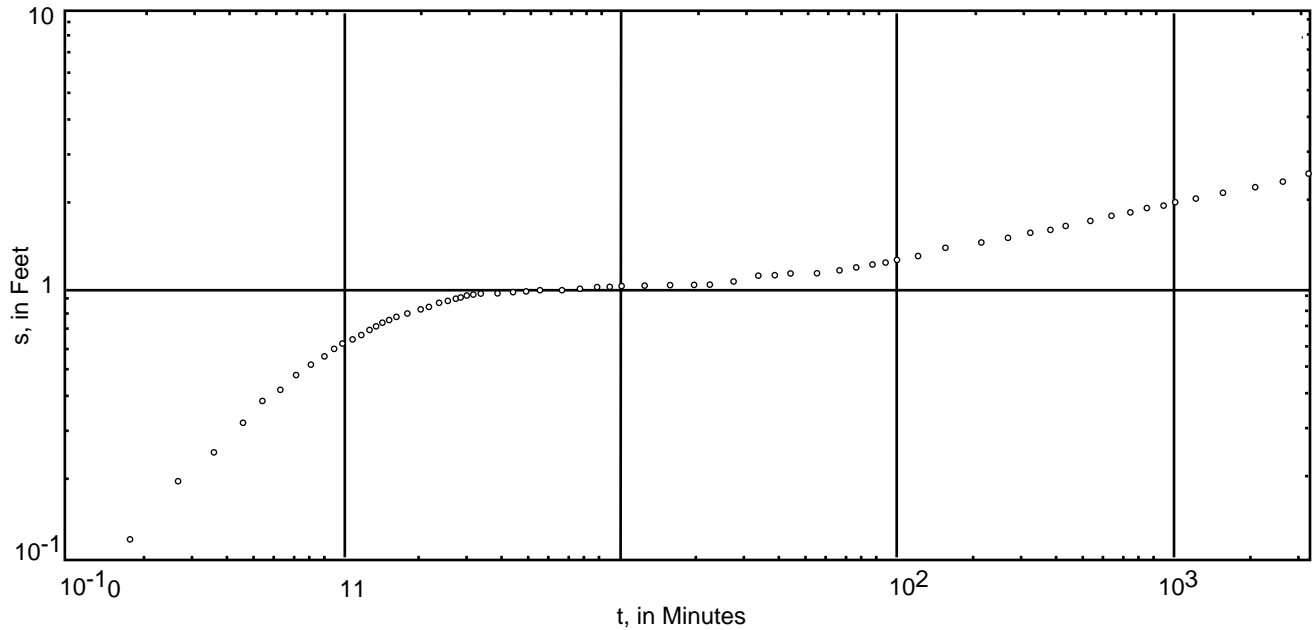


Figure 4. Logarithmic plot of  $s$  vs  $t$  for observation well.

morning (2 AM); 2) mid-morning (10 AM); 3) mid-afternoon (3 PM); and 4) early evening (8 PM). The discharge should never be allowed to vary more than plus or minus 5 percent (Ferris, J. G., personal communication, 1/19/68). The lower the discharge rate, the more important it is to hold the variation to less than 5 percent. The variation of discharge rate has a large effect on permeability estimates calculated using data collected during a test. The importance of controlling the discharge rate can be demonstrated using a sensitivity analysis of pumping test data. An analysis of this type indicates that a 10 percent variation in discharge can result in a 100 percent variation in the estimate of aquifer transmissivity. Thus, short-term pumping tests with poor control of discharge are not suitable for estimating parameters needed for adequate site characterization. If, however, the pumping test is run in such a way that the discharge rate varies less than 5 percent and water levels are measured frequently, the short-term pumping test data can be used to obtain some reliable estimates of aquifer performance.

It should be emphasized, however, that some random, short-term variations in discharge may be acceptable, if the average discharge does not vary by more than plus or minus 5 percent. A systematic or monotonic change in discharge (usually, a decrease in discharge with increasing time) is, however, unacceptable.

#### Water level recovery

Recovery measurements should be made in the same manner as the drawdown measurements. After pumping is terminated, recovery measurements should be taken at the same frequency as the drawdown measurements listed above in Table 1.

#### Length of test

The amount of time the aquifer should be pumped depends on the objectives of the test, the type of aquifer, location of suspected boundaries, the degree of accuracy needed to establish the storage coefficient and transmissivity, and the rate of pumping. The test should continue until the data are adequate to define the shape of the type curve sufficiently so that the parameters required are defined. This may require pumping for a significant period after the rate of water level change becomes small (so called water level "stabilization"). This is especially the case when the locations of boundaries or the effects of delayed drainage are of interest. Their influence may occur a few hours after pumping starts (see Figure 3), or it may be days or weeks. Some aquifer tests may never achieve equilibrium, or exhibit boundary effects.

Although it is not necessary for the pumping to continue until equilibrium is approached, it is recommended that pumping be continued for as long as possible and at least for 24 hours. Recovery measurements should be made for a similar period or until the projected pre-pumping water level trend has been attained. The costs of running the pump a few extra hours are low compared with the total costs of the test, and the improvement in additional information gained could be the difference between a conclusive and an inconclusive aquifer test.

#### Water disposal

As discussed previously, the water being pumped must be disposed of legally within applicable local, State, and Federal

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rules and regulations. This is especially true if the ground water is contaminated or is of poor quality compared to that at the point of disposal. During the pumping test, the individuals carrying out the test should carry out water quality monitoring as required by the test plan and any necessary disposal permits. This monitoring should include periodic checks to assure that the water disposal procedures are following the test design and are not recharging the aquifer in a manner that would adversely affect the test results. The field notes for the test should document when and how monitoring was performed.

#### Recordkeeping

All data should be recorded on the forms prepared prior to testing (See Appendix 2). An accurate recording of the time, water level, and discharge measurements and comments during the test will prove valuable and necessary during the data analyses stage following the test.

#### Plotting data

During the test, a plot of drawdown versus time on semi-log paper should always be prepared and updated as new data is collected for each observation well. A plot of the data prepared during the actual test is essential for monitoring the status and effectiveness of the test. The plot of drawdown versus time will reveal the effects of boundaries or other hydraulic features if they are encountered during the test, and will indicate when enough data for a solution have been recorded. A semi-log or log-log mass plot of water level data from all observation wells should be prepared as time allows. Such a plot can be used to show when aquifer conditions are beginning to affect individual wells. More importantly, it enables the observer to identify erroneous data. This is especially important if transducers are being used for data collection. The utilization of a portable PC with a graphics package is an option for use in carrying out additional field manipulation of the data. It should not, however, be a substitute for a manual plot of the data.

#### Precautions

- (a) Care should be taken for all observers to use the same measuring point on the top of the well casing for each well. If it is necessary to change the measuring point during the test, the time at which the point was changed should be noted and the new measuring point described in detail including the elevation of the new point.
- (b) Regardless of the prescribed time interval, the actual time of measurement should be recorded for all measurements. It is recognized that the measurements will not be taken at the exact time intervals suggested.
- (c) If measurements in observation well(s) are taken by several individuals during the early stages of testing, care should be taken to synchronize stop watches to assure that the time since pumping started is standardized.
- (d) It is important to remember to start all stop watches at the time pumping is started (or stopped if performing a recovery test).
- (e) Comments can be valuable in analyzing the data. It is

important to note any problems, or situations which may alter the test data or the accuracy with which the observer is working.

- (f) If several sounders are to be used, they should be compared before the start of the test to assure that constant readings can be made. If the sounder in use is changed, the change should be noted and the new sounder identified in the notes.

### **PUMPING TEST DATA REDUCTION AND PRESENTATION**

All forms required for recording the test data should be prepared prior to the start of the test and should be attached to a clip board for ease of use in the field. It is an option to have a portable PC located on-site with appropriate spreadsheets and graphics package to allow for easier manipulation of the data during the test. The hard copy of the forms should be maintained for the files.

#### ***Tabular Data***

All raw data in tabular form should be submitted along with the analysis and computations. The data should clearly indicate the well location(s), and date of test and type of test. All data corrections, for pre-pumping trends, barometric pressure fluctuations and other corrections should be given individually and clearly labeled. All graphs used for corrections should be referenced on the specific table. These graphs should be attached to the data package.

#### ***Graphs***

All graphs or plots should be drafted carefully so that the individual points which reflect the measured data can be retrieved. Semi-logarithmic and logarithmic data plots (see Figures 5 and 6) should be on paper scaled appropriately for the anticipated length of the test and the anticipated drawdown. All X-Y coordinates shall be carefully labeled on each plot. All plots must include the well location, date of test, and an explanation of any points plotted or symbols used.

### **ANALYSIS OF TEST RESULTS**

Data analysis involves using the raw field data to calculate estimated values of hydraulic properties. If the design and field-observation phases of the aquifer test are conducted successfully, data analyses should be routine and successful. The method(s) of analysis utilized will depend, of course, on particular aquifer conditions in the area (known or assumed) and the parameters to be estimated.

#### ***Calculations***

All calculations and data analyses must accompany the final report. All calculations should clearly show the data used for input, the equations used and the results achieved. Any assumptions made as part of the analysis should be noted in the calculation section. This is especially important if the data were corrected to account for barometric pressure changes, off-site pumping changes, or other activities which have affected the test. The calculations should reference the appropriate tables and graphs used for a particular calculation.

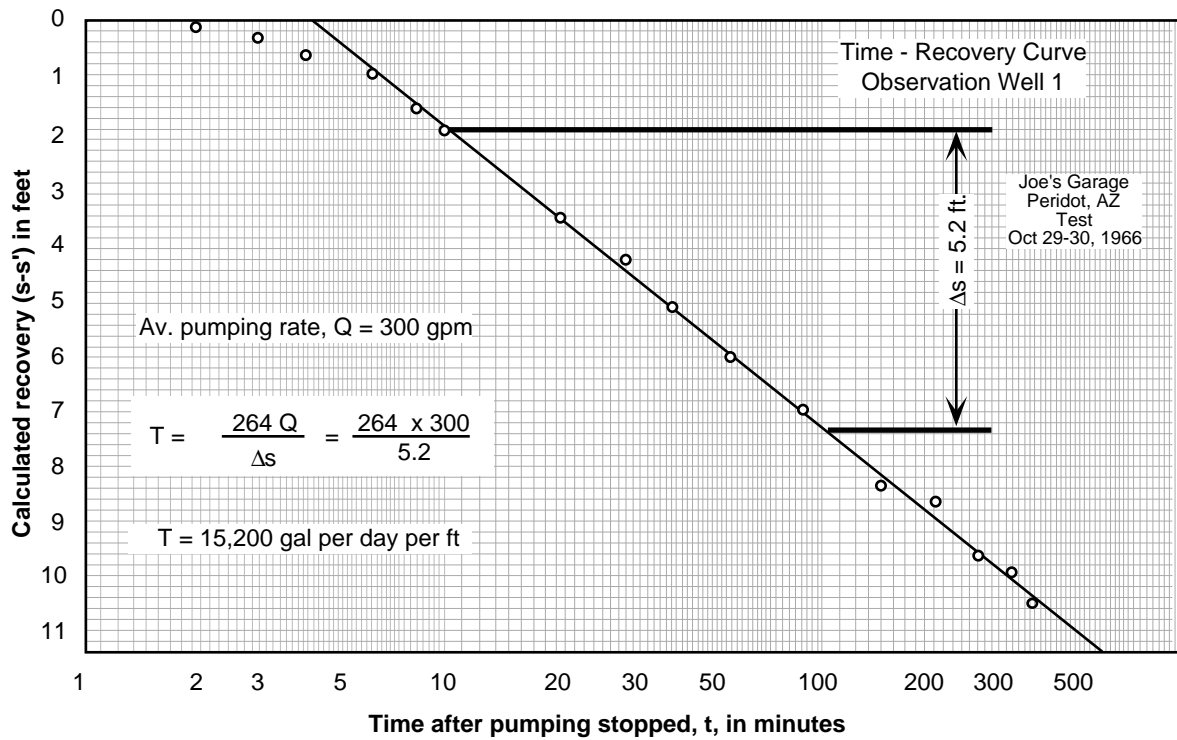


Figure 5. Time recovery curve for observation well - October 30, 1966.

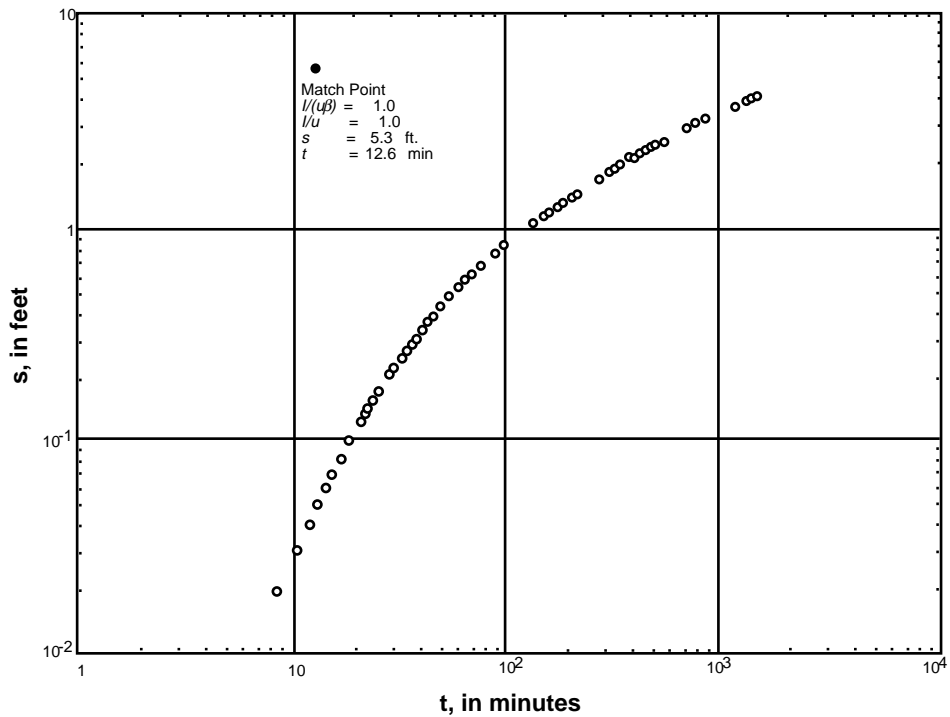


Figure 6. Logarithmic plot of s vs t for Observation Well 23S/25E-17Q<sub>2</sub> at Pixley, CA.



## Aquifer Test Results

The results of an aquifer pumping and recovery test should be submitted in narrative format. The narrative report should include the raw data in tabular form, the plots of the data, the complete calculations and a summary of the results of the test. The assumptions made in utilizing a particular method of analysis should also be included.

## SUMMARY-EXAMPLE FACILITY DESIGN

As a means of focusing the discussions presented in the preceding sections, the following example of an aquifer pumping test is described. The facility layout is shown in Figure 7. The site is located near a normally dry river channel which is subject to flood flows. The site was constructed for the purpose of carrying out experiments relating to artificial recharge of a shallow alluvial aquifer. The proposed methods of recharge involved use of a pit and a well.

The aquifer at the site is comprised of unconsolidated basin fill material, mainly silty sand and gravel with some clay lenses. The depth to water is generally greater than 50 feet and the river is a source of recharge when it flows. There are extensive gravel lenses above the water table which outcrop at the base of the river channel. These lenses occur beneath the site.

Figure 7 shows the locations of the various monitoring wells relative to the recharge facilities and the river. The well locations were selected to facilitate both characterization of the site and subsequent evaluation of the various recharge tests. The recharge well (used as the pumping well during the site aquifer tests) and the eight inch observation wells were completed to a depth of 150 feet in the upper water bearing unit of a basin fill aquifer. The depth to water in the area was about 75 feet. The recharge and observation wells were screened from about 80 feet to 140 feet. The 1-3/4 inch access tubes were 80-100 feet deep with a five-foot well screen on the bottom of each tube.

The eight-inch observation wells were placed in a line parallel to the river to assess both the effect of flood flows on the aquifer and the hydraulic characteristics of the recharge site itself. The 1-3/4 inch access tubes were positioned for monitoring ground-water movement near the top of the water table in response to aquifer recharge and discharge (pumping) tests. The two inch piezometers at varying depths were constructed to evaluate shallow ground-water movement in response to recharge.

Figure 8 is a plan view of the recharge facility showing the pumping/recharge well and the water distribution system. The pumping well was equipped with a downhole turbine pump powered by a methane driven, 6-cylinder engine. As indicated

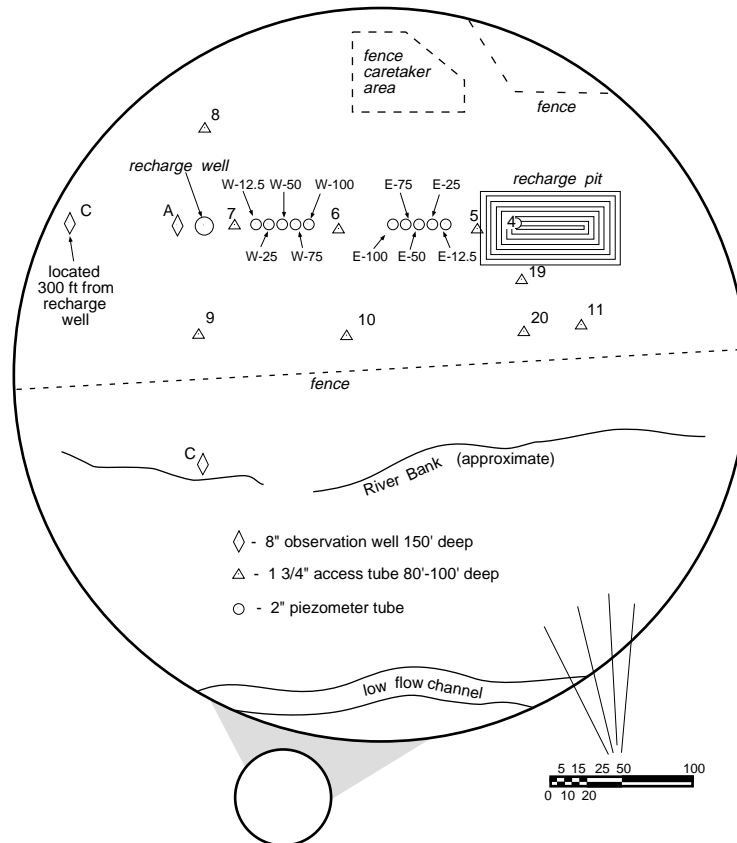


Figure 7. Recharge facility well layout.

on Figure 8, the pump discharge was measured using a Parshall flume (see Figure 9). The water from pumping tests was discharged off-site via the concrete box and distribution line. To prevent interference with test results from nearby recharge of the pumping test water, a temporary pipeline was constructed from irrigation pipe. This temporary line ran from the end of the river drain line to a point 1200 feet down stream out of the estimated area of influence. The ground water was not contaminated. Thus, special water quality monitoring was not required.

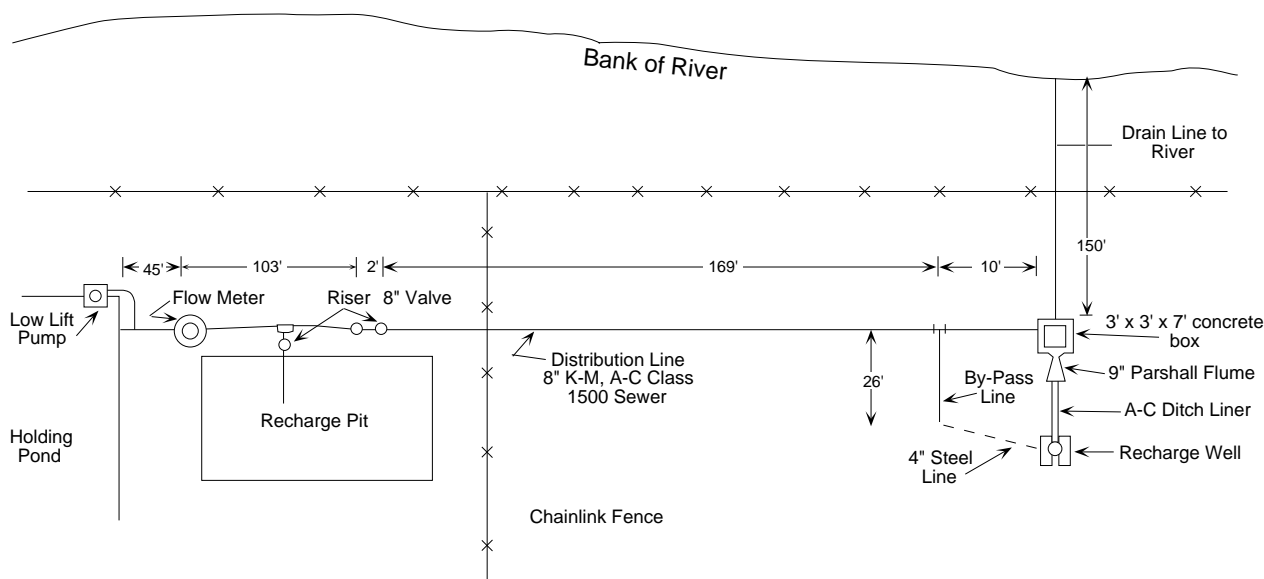
The pumping tests for site characterization involved the following monitoring procedure:

1. The eight-inch observation well closest to the recharge well (Well A) was equipped with a Stevens water stage recorder with an electric clock geared for a 4-hour chart cycle;
2. The other two eight-inch observation wells (Wells B and C) were equipped with Stevens water stage recorders with an electric clock geared for a 12-hour chart cycle;
3. The pumping well was equipped with a stilling well composed of a 3/4-inch pipe strapped to the pump column. The stilling well was drilled with 1/4-inch holes through the length. The stilling well was used for assessing the well for water level measurements with a 150-foot steel tape. The steel tape was marked in 0.01 ft. increments for the first 100 feet and in 0.1 ft. increments for the remaining 50 feet;

4. The 1-3/4 inch access wells were monitored at least once a day with a neutron moisture logger to assess changes in saturation as the water level declined in response to the test. This information was used to verify the water level declines in the regular monitoring wells and to aid in assessing the delayed drainage effects which were to be estimated using the water level response data from the eight-inch observation wells;
5. A continuous recording barograph was located in a standard construction, USDA weather station shed located between access Wells 9 and 10; and
6. The pump engine was equipped with an rpm gage to monitor pump performance and a micrometer adjustment on the throttle.

A step drawdown test and several short-term pumping tests were run at the site prior to running the principal aquifer characterization test. The step drawdown test was used as a means of selecting the final pumping test design. The short term tests were used to obtain an initial picture of aquifer response.

The results of the step drawdown test run on the recharge well after development indicated that the well was suitable for use as a test well. The results of the step test were also used to estimate well efficiency at different rates. Table 2 gives the efficiencies for three (3) discharge rates. As indicated, the well efficiency was greater than 90% for a rate of about 200



**Figure 8. Water distribution and drainage facilities at the artificial recharge site.**

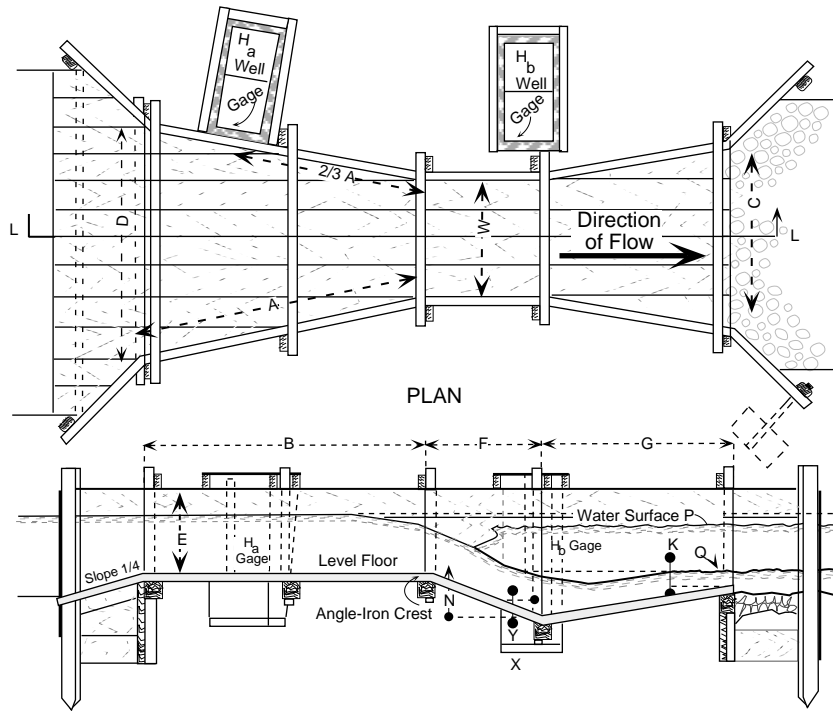


Figure 9. Parshall flume dimensions.

gpm. Based on this data, the design rate for the long-term test was set at about 200 gpm (actual average was 204 gpm).

Table 2. Well Efficiency of R#1 after 200 Minutes of Pumping

Discharge	Theoretical Drawdown	Actual Drawdown	Well Efficiency
<i>gpm</i>	<i>ft</i>	<i>ft</i>	<i>percent</i>
189	7.00	7.51	92
326	11.88	14.71	81
474	17.27	25.41	68

Because the initial short-term tests indicated that delayed drainage was an issue at the site, the main test was designed to run for a continuous period of at least 20 days. The actual scheduling of the test was established to try to avoid flow in the river as a result of a major precipitation event during the background, pumping, and recovery periods. The chosen test period was in the fall after the end of the irrigation season, which also minimized off-site pumping that might affect the results. It should be noted that two short-term tests were planned to follow the main pumping test during the winter rainy season when flow in the river was possible. This was

done to allow the impacts of an uncontrolled recharge event on the system to be assessed. The main pumping test would provide a basis for comparison.

The discharging well was measured on a time schedule per the criteria in Table 1, except that measurements for the initial 10 minute period were taken every 30 seconds. The observation wells were observed manually on the same schedule for the initial 30 minute period and then the recorders were utilized. Discharge measurements were monitored at least every 5 minutes for the first 30 minutes and then were monitored with water levels for the first 12 hours. Discharge measurements were monitored at least four times daily until the end of the test. The access tubes were monitored twice daily to assess changes in saturation near the water table.

The results from the long term pumping test are shown on Figure 10 as a semi-log data mass plot (drawdown versus log time) of the data for the three (3) observation wells. The large initial water level decline for Observation Well A is due to its close proximity to the pumping well (15 feet). The rise in water level at the end of the test was caused by a slight decrease in discharge rate.

Values of T and S were obtained by the non-equilibrium method. The plots of drawdown as a function of log time did not give a good overlay on the non-equilibrium type curve for early times. For later times, it was possible to obtain a good match. The match points obtained for the three observation wells are listed in Table 3. The values of T and S are also shown in Table 3. As indicated, the estimates of T and S were in close agreement.

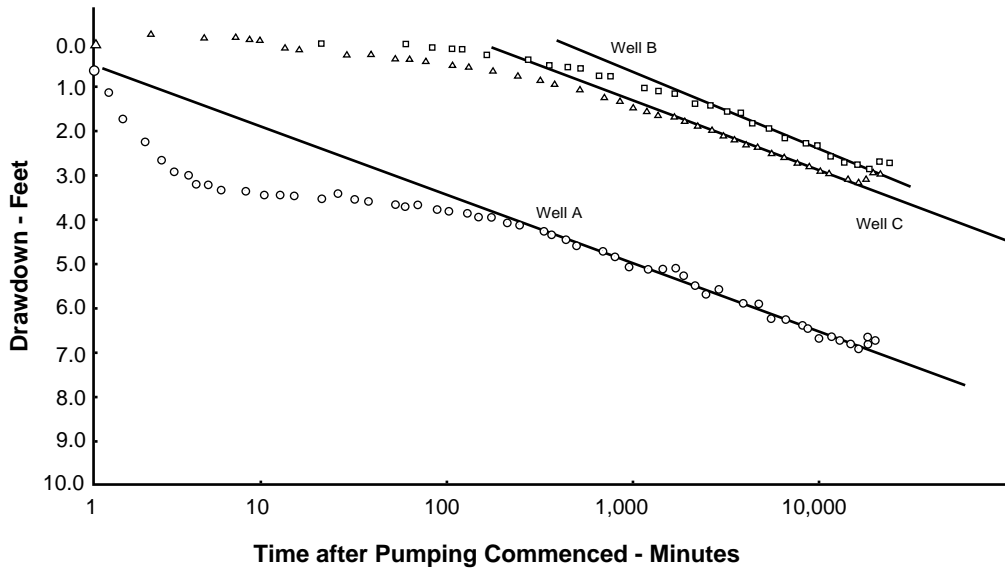


Figure 10. Drawdown versus log of time in observation wells A, B, and C during pumping of R#1.

Table 3. Values of T and S Obtained by Non-Equilibrium Equation for Discharge Conditions.

Location	w(u)	l/u	s	t	r	T	S
			<i>ft</i>	<i>min</i>	<i>ft</i>	<i>gpd/ft</i>	
Well A	110	10 <sup>5</sup>	0.62	14900	14.7	37,600	0.01
Well B	1	10	0.62	1780	280.0	37,600	0.03
Well C	1	10	0.58	530	175.4	40,200	0.03

The estimates for storativity were also in reasonable agreement. It is important to note that the test results showed delayed drainage to be a significant factor at this site. The initial estimates of storativity using data from the early part of the test were about  $1 \times 10^{-5}$  rather than  $3 \times 10^{-2}$  estimated after 20 days of pumping. This effect was expected because of the heterogeneous nature of the basin fill. As a means of comparison, water balance studies on a large well field located 15 miles away (completed in the same material) were reviewed. These

studies provided an estimate of storage coefficient (based on 10 years of pumpage) of about 0.15. Thus, it was concluded that the aquifer at the site was under water table conditions, but significant delayed drainage effects were present.

The results of the pumping tests at the site were used to characterize the site and design several long-term recharge experiments. This included monitoring design for evaluation of the effect of river flows on the regional aquifer.

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## Appendix One

### Equipment for Data Collection

#### a. Water Levels

Water level measurements can be made with electric sounders, air line and pressure gages, calibrated steel tapes, or pressure transducers (Garber and Koopman, 1968; and Bentall and others, 1963).

##### (1) Electric Sounders

- (a) An electric sounder is recommended for measuring water levels in the pumping well because it will allow for rapid, multiple water level readings, especially important during the early stages of aquifer pumping and recovery tests.
- (b) A dedicated sounder should be assigned to each observation well throughout the duration of the test. This is particularly important in ground-water quality studies to prevent cross contamination.
- (c) Each sounder should be calibrated prior to the commencement of testing to assure accurate readings during the test.

##### (2) Air Lines and Pressure Gages

- (a) Air lines are only recommended when electric sounders or steel tapes cannot be used to obtain water level measurements. Their usefulness is limited by the accuracy of the gage used and by difficulties in eliminating leakage from the air line. A gage capable of being read to 0.01 psi will be needed to obtain the necessary level of accuracy for determining water level change. A continuous copper or plastic line of known length should be strapped to the column pipe when the pump is installed. This will minimize the potential for leaks.
- (b) When air lines are used, the same precision pressure gage should be used on all wells.
- (c) Each pressure gage should be calibrated immediately prior to and after the test to assure accurate readings.
- (d) The air line and pressure gage assembly should also be calibrated prior to the test by obtaining static water level by another method, if possible.

##### (3) Calibrated Steel Tapes

- (a) Steel tapes marked to .01 ft. are preferred unless rapid water level drawdown or buildup is

anticipated. If rapid drawdown, cascading water, or high frequency oscillation are anticipated, electric sounders, float actuated recorders or pressure transducers are preferred.

- (b) Steel tapes are not recommended for use in the pumping well because of fluctuating water levels caused by the pump action, possible cascading water and the necessity for obtaining rapid water level measurements during the early portions of the aquifer pumping and recovery tests. If tapes are used, and the water level fluctuates, the well must be equipped with a means of dampening fluctuating water levels. Additional manpower will be needed during the initial stages of the test.

##### (4) Pressure Transducers

Pressure transducers are often used in situations where access to the well is restricted, such as a well where packers are being used to isolate a certain zone. They may also be applicable in large-scale tests using a computerized data collection system. Such a system will significantly reduce the manpower needed during the initial stages of a multiple well test. The most common installation uses down hole transducers with recording of the results taking place on the surface.

- (a) Transducers should be calibrated prior to installation, and should be capable of accurately detecting changes of less than .005 psi. Transducer systems which will accurately record water level changes of .001 feet are available. The resolution of transducers, however, depends on the full scale range. Where large drawdowns are expected, such resolution is not possible.
- (b) After installation, the transducers and recording equipment should be calibrated by comparing pressure readings to actual water level measurements taken with a steel tape. Periodic measurements of the water level should be made during the test to verify that the transducers are functioning properly.
- (c) The effect of barometric changes on the transducers should be determined prior to and during the test. This will require continuous monitoring of the barometric pressure at the site as well as periodic comparisons of water level and transducer readings (Clark, 1967).

#### b. Discharge Measurement

The equipment commonly used for measuring discharge in the pumping well includes orifice plates, in-line water meters, Parshall flumes and recorders, V-notch weirs, or, for low discharge rates, a container of known volume, and a stop watch (Driscoll, 1986). The choice of method will depend upon a combination of factors, including i) accuracy needed, ii) planned discharge rate, iii) facility layout, and iv) point of discharge. If, for instance, it is

necessary to discharge the water a half mile from the pump, a flume or weir will probably not be used, because the distance between the point of discharge control and the point of discharge would make logistics too difficult. An in-line flow meter or a pitot tube would be the most likely calibrated devices (U.S. Bureau of Reclamation, 1981; King, 1982; U.S. EPA, 1982; and Leopold and Stevens, 1987).

(1) Orifice Plate

- (a) Orifice plates with manometers (see Figure 11) are an inexpensive and accurate means of obtaining discharge measurements during testing. The thin plate orifice is the best choice for the typical pump test. An orifice plate has an opening smaller than that of the discharge pipe. A manometer is installed into and onto the end of the discharge pipe. The diameter of the plate opening must be small enough to ensure that the discharge pipe behind the plate is full at the chosen rate of discharge. The reading shown on the manometer represents the difference between the upstream and downstream heads.
- (b) Assuming the devices are manufactured accurately and are installed correctly, an orifice plate will provide an accuracy of between two and five percent. The orifice tube must be horizontal and full at all times to achieve the design accuracy.
- (c) The accuracy should be established prior to testing by pumping into a container of known volume over a given time. This should be repeated for several rates.

(2) In-line Flow Meter

- (a) In-line flow meters can give accurate readings of the flow if they are installed and calibrated properly. The meter must be located sufficiently far from valves, bends in the pipe, couplings, etc., to minimize turbulence which will affect the

accuracy of the meter. **The meter must be installed so that it is completely submerged during operation.**

- (b) Use of a meter is an easy way to monitor the discharge rate by recording the volume of flow through the meter using a totalizer or other means at one minute intervals and subtracting the two readings. Some meters register instantaneous rate of flow and total flow volume.
- (c) The meter should be calibrated after installation (prior to the test) to insure its accuracy.

(3) Flumes and Weirs

- (a) There are numerous accurate flumes and weirs on the market. The choice depends mainly on the approximate discharge anticipated, the location of the discharge point and the nature of the facility. The cost of installation will preclude use at many non-permanent facilities.
- (b) The weir (see Figure 12) or flume should be located close to the pump. There should be a permanent recorder on the device as well as means of making manual measurements (e.g., staff gage).
- (c) The discharge canal should have a sufficient length of unobstructed upstream channel so as not to affect the accuracy of the chosen weir or flume.

(4) Pitot Tube

- (a) The pitot tube is a velocity meter which is installed in the discharge pipe to establish the velocity profile in the pipe. Commercially available devices consist of a combined piezometer and a total head meter.
- (b) The tube must be installed at a point such that the upstream section is free of valves, tees,

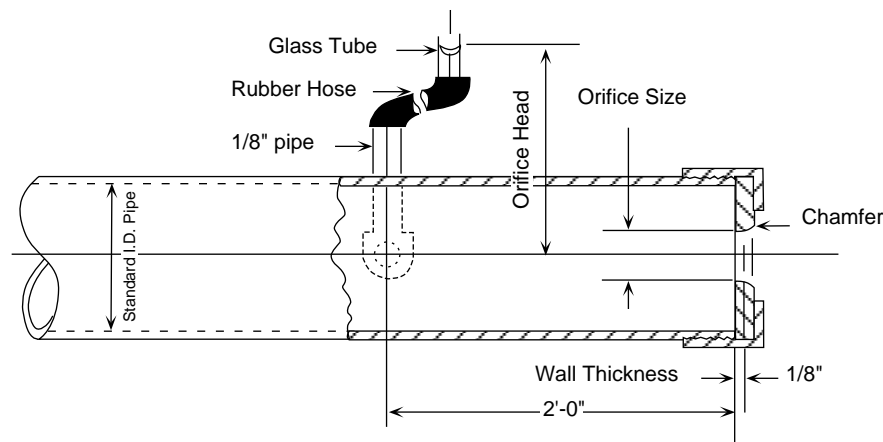
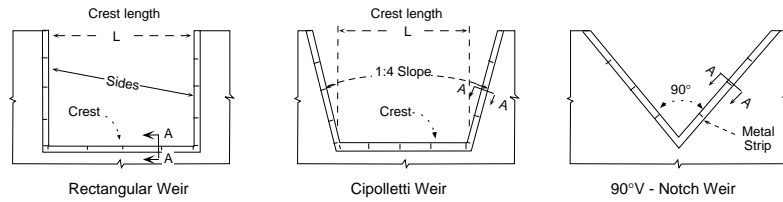
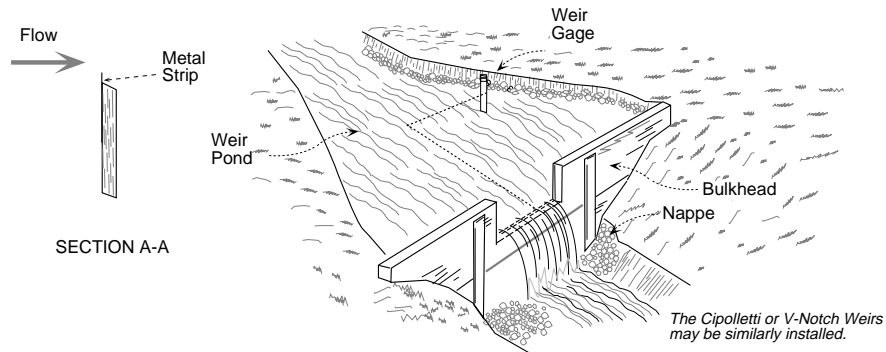


Figure 11. Diagram of orifice meter.



**Standard Contracted Weirs  
(Upstream Face)**



**Figure 12. Standard contracted weirs, and temporary discharging at free flow.**

elbows, etc., for a minimum distance equal to 15 to 20 times the pipe diameter to minimize turbulence at the location of the tube.

- (c) Since the pitot tube becomes inaccurate at low velocities, the diameter of the pipe should be small enough to maintain reasonably high velocities.

**(5) Container of Known Volume and Stop Watch**

- (a) The use of a container of known volume and a stop watch is a simple way to measure the discharge rate of a low volume discharging well.
- (b) By recording the length of time taken for the discharging water to fill a container of known volume, the discharge rate can be calculated.
- (c) This method can be used only where it is possible to precisely measure the time interval required for a known volume to be collected. If rates are sufficiently high so that water "sloshes" in the container, or they prohibit development of a relatively smooth surface on the water in the container, this method is likely to be inaccurate. Restricting use of this method to flows of less than 10 gpm is probably a conservative rule of thumb.

**c. Discharge Regulation**

- (1) The size of the discharge line and the gate valve

should be such that the valve will be from one-half to three-fourths open when pumping at the desired rate (during the initial phase of the test) with a full pipe.

- (2) The valve should be placed a minimum of five (5) pipe diameters down-stream from an in-line flow meter, to ensure that the pipe is full and flow is not disturbed by excessive turbulence. In the case of some meters, such as a pitot tube, an in-line manometer, or an orifice plate, the valve would need to be upstream. (In this case the pipe downstream of the valve must be sized to be full at all times.)

**d. Time**

- (1) A stop watch is recommended for use during an aquifer pumping and recovery test. Time should be recorded to the nearest second while drawdown is rapid, and to the nearest minute as the time period between measurements is increased beyond 15 minutes.
- (2) If more than one stop watch is to be used during the testing, then all watches should be synchronized to assure that there is no error caused by the imprecise measurements of elapsed time.
- (3) Accuracy of time is critical during the early stage of a pump or aquifer test and it is crucial to have all stop watches reflect the exact time. Later in the test the time recorded to the nearest minute becomes less critical.
- (4) A master clock should be kept on site for tests longer than one day. This will provide a backup in case of

stop watch problems.

## Appendix Two

### Recording Forms

It is very important that each well data form stand alone. The data forms must contain all information which may have a bearing on the analysis of the data. See the suggested format for pumping test data recording sheets located at the end of this appendix. The form should allow for the following data to be recorded on the data sheet for each well:

- (a) date
- (b) temperature
- (c) discharge rate
- (d) weather
- (e) well location
- (f) well number
- (g) owner of the well
- (h) type of test (drawdown or recovery)
- (i) description of measuring point

- (j) elevation of measuring point
- (k) type of measuring equipment
- (l) radial distance from center of pumped well to the center of the observation well
- (m) static depth to water
- (n) person recording the data
- (o) page number of total pages

In addition to the above information to be recorded on each page, the forms should have columns for recording of the following data:

- (a) the elapsed time since pumping started, shown as the value (t)
- (b) the elapsed time since pumping stopped, shown as (t')
- (c) the depth in feet to the water level
- (d) drawdown or recovery of the water level in feet
- (e) the time since pumping started divided by the time since pumping stopped, shown as (t/t')
- (f) the discharge rate in gallons per minute
- (g) a column for comments to note any problems encountered, weather changes (i.e. barometric changes, precipitation), natural disasters, or other pertinent data.

### AQUIFER TEST FIELD DATA SHEET

Page \_\_\_ of \_\_\_

\_\_\_\_\_ Pumped Well No. \_\_\_\_\_ Date \_\_\_\_\_  
 \_\_\_\_\_ Observation Well No. \_\_\_\_\_ Weather \_\_\_\_\_  
 Owner \_\_\_\_\_ Location \_\_\_\_\_  
 Observers: \_\_\_\_\_

Measuring Point is \_\_\_\_\_ which is \_\_\_\_\_ feet above/below surface.  
 Static Water Level \_\_\_\_\_ feet below land surface.  
 Distance to pumped well \_\_\_\_\_ feet. Type of Test \_\_\_\_\_  
 Discharge rate of pumped well \_\_\_\_\_ gpm (gallons per minute).  
 Total number of observation wells \_\_\_\_\_ .  
 Water Measurement Technique \_\_\_\_\_ .  
 Recorded by \_\_\_\_\_ . Temperature during test \_\_\_\_\_ .

Clock Time	Elapsed Time Since Pump Started or Stopped (min)	Depth to Water Below Land (feet)	Drawdown or Recovery (feet)	Discharge or Recharge (GPM)	t/t'	Comments





aquifer.

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## Glossary

**Aquifer:** A unit of geologic material that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of ground water to wells and springs. The term was originally defined by Meinzer (1923, p. 30) as any water-bearing formation. Syn: water horizon; ground-water reservoir; nappe; aquafer.

**Aquifer Test:** A test involving the withdrawal of measured quantities of water from, or addition of water to, a well and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition.

**Aquitard:** A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a confining bed storage unit for ground water. Cf: aquifuge; aquiclude.

**Capillary Fringe:** The lower subdivision of the zone of aeration, immediately above the water table in which the interstices contain water under pressure less than that of the atmosphere, being continuous with the water below the water table but held above it by surface tension. Its upper boundary with the intermediate belt is indistinct, but is sometimes defined arbitrarily as the level at which 50 percent of the interstices are filled with water. Syn: zone of capillarity; capillary-moisture zone.

**Confined Aquifer:** An aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than that of the aquifer itself; an aquifer containing confined ground water. Syn: artesian

**Confining Bed:** A confining bed is a unit of distinctly less permeable geologic material stratigraphically adjacent to an aquifer. "Aquitard" is a commonly used synonym. Confining beds can have a wide range of hydraulic conductivities and a confining bed of one area may have a hydraulic conductivity greater than an aquifer of another area.

**Drawdown:** The vertical distance between the static water level and the surface of the cone of depression at a given location and point of time.

**Effective Porosity:** Effective porosity refers to the amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the volume of interconnected pores and openings to the volume of rock.

**Ground Water:** Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.

**Hydraulic Conductivity:** Hydraulic conductivity,  $K$ , replaces the term "coefficient of permeability" and is a volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Hydraulic conductivity is a function of the properties of the medium and the fluid viscosity and specific gravity; intrinsic permeability times specific gravity divided by viscosity. Dimensions are  $L/T$  with common units being centimeters per second or feet/day.

**Hydraulic Gradient:** Hydraulic gradient is the change in head per unit of distance in the direction of maximum rate of decrease in head.

**Hydraulic Head:** Hydraulic head is the sum of two components: the elevation of the point of measurement and the pressure head.

**Intrinsic Permeability:** Intrinsic permeability,  $k$ , is a property of the porous medium and has dimensions of  $L^2$ . It is a measure of the resistance to fluid flow through a given porous medium. It is, however, often used incorrectly to mean the same thing as hydraulic conductivity.

**Porosity:** Porosity of a rock or soil expresses its property of containing interstices or voids and is the ratio of the volume of interstices to the total volume, expressed as a decimal or percentage. Total porosity is comprised of primary and secondary openings. Primary porosity is controlled by shape, sorting and packing arrangements of grains and is independent of grain size. Secondary porosity is that void space created sometime after the initial formation of the porous medium due to secondary solution phenomena and fracture formation.

**Potentiometric Surface:** Potentiometric surface is an imaginary surface representing the static head of ground water and defined by the level to which water will rise in a well under static conditions. The water table is a particular potentiometric surface for an

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unconfined aquifer representing zero atmospheric gage pressure.

Recharge Zone: A recharge zone is the area in which water is absorbed and added to the saturated soil or geologic formation, either directly into a formation, or indirectly by way of another formation.

Residual Drawdown: The difference between the original static water level and the depth to water at a given instant during the recovery period.

Saturated Zone: The saturated zone is that part of the water-bearing material in which all voids are filled with water. Fluid pressure is always greater than or equal to atmospheric, and the hydraulic conductivity does not vary with pressure head.

Specific Capacity: The rate of discharge of a water well per unit of drawdown, commonly expressed in gpm/ft. It varies with duration of discharge.

Specific Storage: Specific storage,  $S$ , is defined as the volume of water that a unit volume of aquifer releases from storage because of expansion of the water and compression of the matrix or medium under a unit decline in average hydraulic head within the unit volume. For an unconfined aquifer, for all practical purposes, it has the same value as specific yield. The dimensions are  $L^1$ . It is a property of both the medium and the fluid.

Specific Yield: Specific yield is the fraction of drainable water yielded by gravity drainage when the water table declines. It is the ratio of the volume of water yielded by gravity to the volume of rock. Specific yield is equal to total porosity minus specific retention. Dimensionless.

Storage Coefficient: The storage coefficient,  $S$ , or storativity, is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in hydraulic head. It is dimensionless.

Transmissivity: Transmissivity,  $T$ , is defined as the rate of flow of water through a vertical strip of aquifer one unit wide extending the full saturated thickness of the aquifer under a unit hydraulic gradient. It is equal to hydraulic conductivity times aquifer saturated thickness. Dimensions are  $L^2/t$ .

Unconfined Ground Water: Unconfined ground water is water in an aquifer that has a water table. Also, it is aquifer water found at or near atmospheric pressure.

Unsaturated Zone: The unsaturated zone (also referred to as the vadose zone) is the soil or rock material between the land surface and water table. It includes the capillary fringe. Characteristically this zone contains liquid water under less than atmospheric pressure, with water vapor and other gases generally at atmospheric pressure.

Water Table: The water table is an imaginary surface in an unconfined water body at which the water pressure is atmospheric. It is essentially the top of the saturated zone.

Well Efficiency: The well efficiency is the theoretical

drawdown divided by the measured drawdown. The theoretical drawdown is estimated by using pumping test data from several observation wells to construct a distance drawdown graph to estimate drawdown in the pumping well if there were no losses.

### **Selected Material**

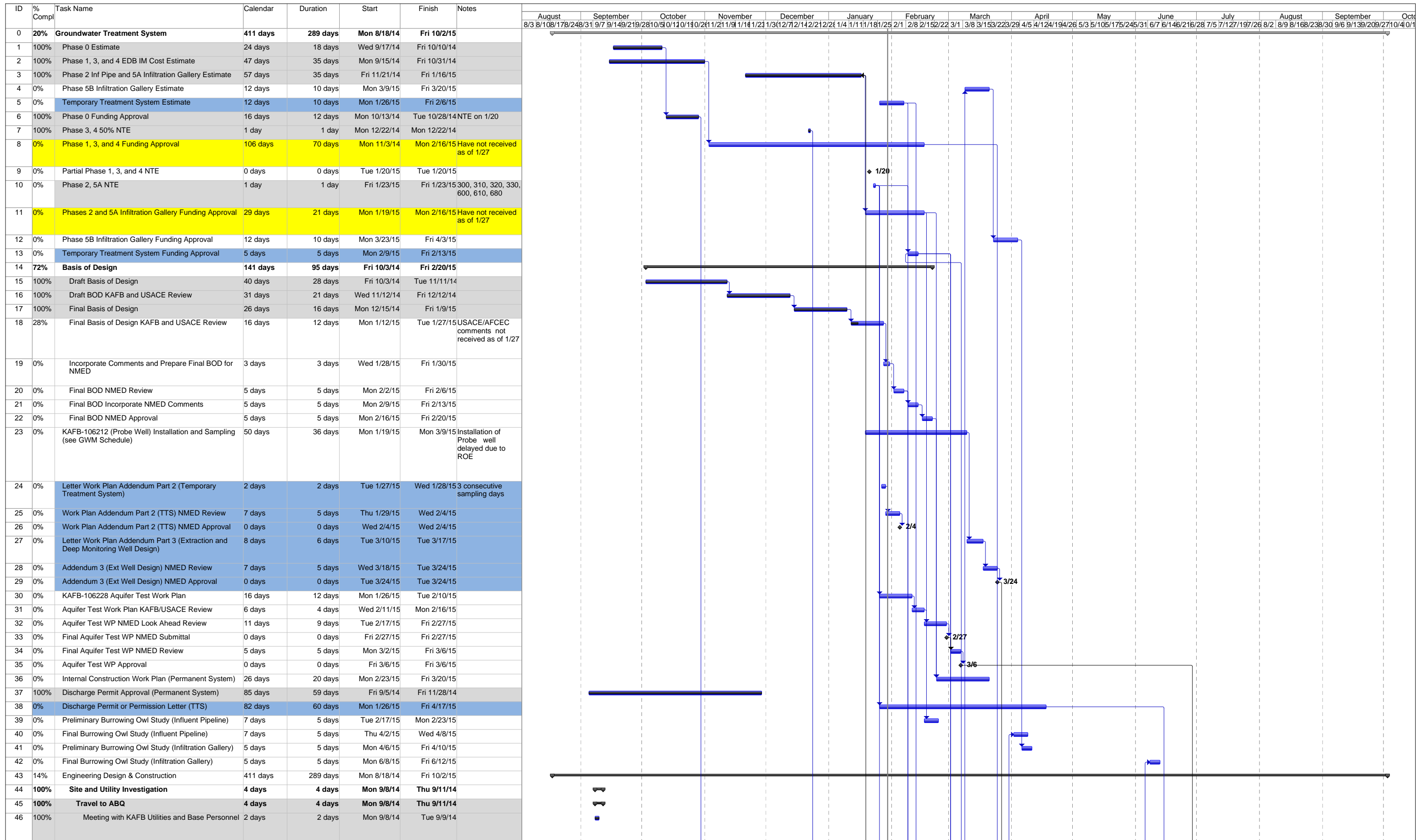
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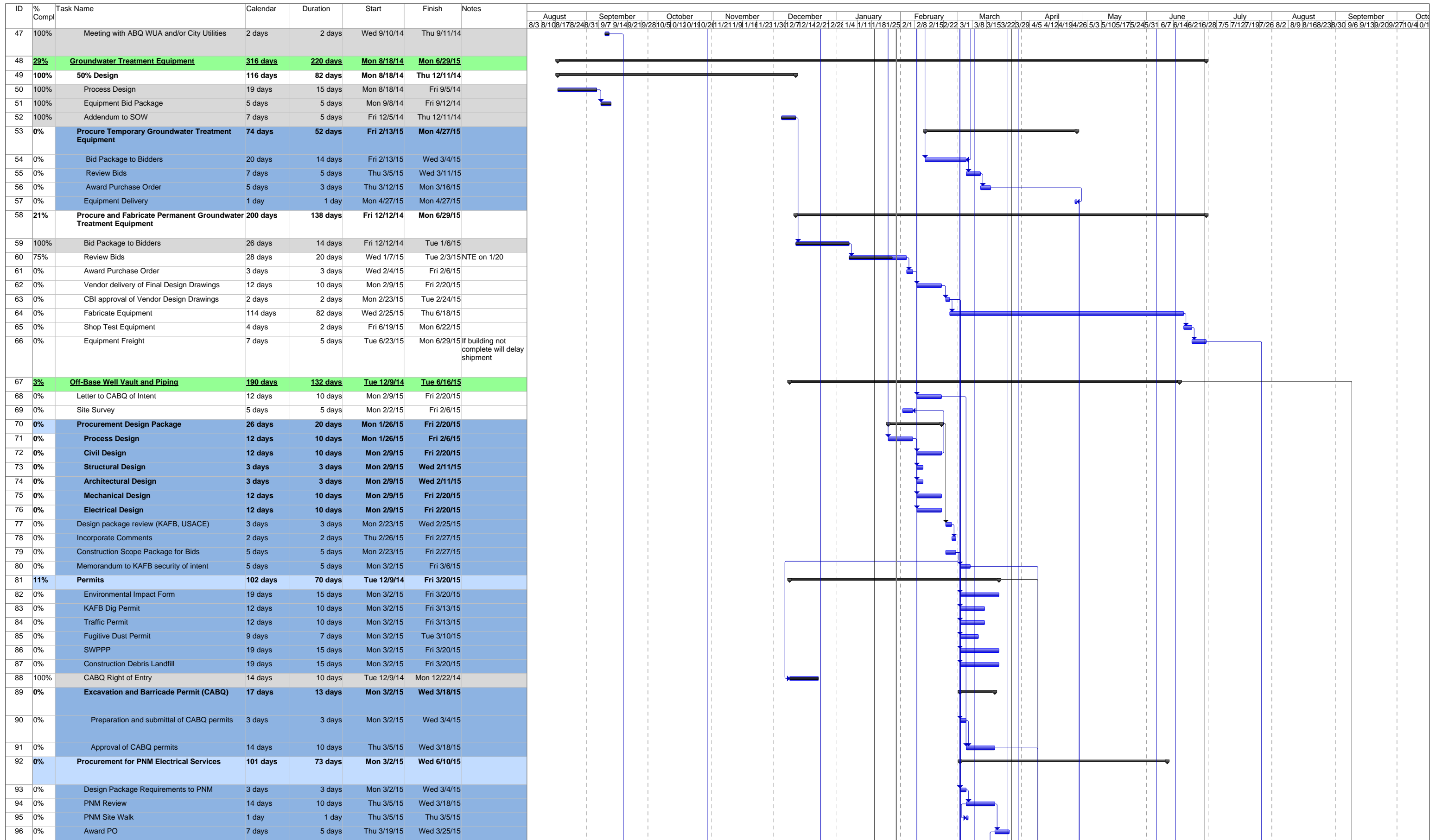


**APPENDIX B**  
**Aquifer Test Schedule**

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## **ATTACHMENT 3**

### **Response to Comments Received from U.S. Environmental Protection Agency**

<b>Project:</b>		Kirtland AFB			
<b>Document:</b>		Fourth Quarter CY 2013 Aquifer Testing Results, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, Kirtland Air Force Base, Albuquerque, New Mexico, January 2014			
<b>Contract:</b>					
<b>Reviewer:</b>		EPA	<b>Section:</b>		<b>Date:</b> 17 January 2014
<b>Comment #</b>	<b>Reference</b>	<b>Comment</b>			<b>Response</b>
1	General Comments	The EPA review was limited to the aquifer test components of the report and did not examine sections related to groundwater chemistry analysis.			<b>Concur.</b>
2	General Comments	<p>Generally, the step test and constant rate tests both had problems due to inability to maintain target flow rates. The need to reduce flow rates by one half during the constant rate test is particularly problematic for the following reasons:</p> <ul style="list-style-type: none"> <li>• Reduces quality of and confidence in overall pumping and recovery data sets</li> <li>• Violates assumption of constant discharge.</li> <li>• Reduced stress on the aquifer that may have resulted in measureable drawdown at more observation wells and greater drawdown at wells where measureable drawdown was observed</li> <li>• Lack of response at numerous observation wells reduces ability to identify and evaluate potential anisotropy.</li> <li>• Smaller radius of influence.</li> </ul>			<p><b>Concur:</b> The inability to maintain target flow rates at KAFB-106157 was most likely due to bio-clogging of the filter pack during the time between well installation (December 2011) and development (September 2013). That issue is not expected at KAFB-106228 for the following reasons:</p> <ol style="list-style-type: none"> <li>1. Well development at KAFB-106228 will be conducted until certain well efficiency standards are met. The well development plan will be provided in the third letter work plan addendum, scheduled for delivery to the NMED on March 11, 2015.</li> <li>2. The aquifer test using KAFB-106228 is scheduled to be completed within 2 months of well installation.</li> </ol> <p>The following language has been added to Section 2.2 of the KAFB-106228 Aquifer Pilot-Test Work Plan:          “If the well is not capable of maintaining the planned flow rates, the test may be stopped and NMED will be contacted to discuss conducting the test at a lower discharge rate.”</p>
3	General Comments	Despite the limitations identified for this aquifer test, the preferred estimates of hydraulic conductivity and storativity summarized in the conclusions are generally consistent with each other, with other available estimates (e.g. slug test analyses), with typical hydraulic properties of known aquifer materials, and in the case of storativity, an unconfined aquifer.			<b>Concur.</b>
4		It would be helpful to number the equations presented in the report.			<b>Concur:</b> Equations will be numbered in the KAFB-106228 Aquifer Pilot-Test Report.
Section 2					
5	Section2, page 6	The list of parameters for the step-drawdown test includes a saturated thickness of 80 ft. Why does this value differ from the 100 ft value listed on page 9 for the constant rate test?			<p><b>Concur:</b> The discrepancy noted by the EPA was corrected in a later version of the report, which was not submitted. In order to avoid a similar discrepancy in the future, the following language has been added to Section 2.3 of the KAFB-106228 Aquifer Pilot-Test Work Plan:</p> <p>“Because of the stratified and lithologically varied nature of the geology in the area, pumping in KAFB-106228 is expected to primarily impact the thickness of the aquifer across which it is screened. Consequently, the saturated screen length will be used as the aquifer thickness input for all solution methods for both the step-drawdown test and constant rate test. In addition, an initial vertical to horizontal anisotropy ratio of 0.1 will be assumed. Sensitivity analyses will be performed to verify using these values.”</p>
6		An examination of the step-drawdown test raw data indicates there were abnormal drawdown values during the first time-step between approximately 10 and 100 seconds and again at approximately 200 seconds. What is the cause of these anomalous drawdown measurements?			<b>Concur:</b> The anomalous drawdown values were the result of the pumping rate stabilizing to 50 gpm. The inability to maintain target flow rates and how this issue will be addressed at KAFB-106228 are described in the response to Comment 2 of this table.

Comment #	Reference	Comment	Response
7		Suggest that a plot of pumping well drawdown during the step-drawdown test be included in the final submittal, inclusive of all three steps.	<b>Concur:</b> This plot will be provided in the KAFB-106228 Aquifer Pilot-Test Report.
8	Section 2.1 Page 6	Section 2.1, page 6: The reviewer was unable to identify where the use of average discharge rate for the entire step-drawdown test for analysis of recovery data is considered standard industry practice (with specific reference to EPA, 1993). Please provide additional information substantiating this is a standard practice.	<b>Concur:</b> Page 11 of the referenced text (EPA, 1993) provides an example of a recovery test using the average pumping rate from the pumping period. It is not standard practice to analyze recovery for a step-drawdown test. When recovery data analyzed for a variable-rate test, the last pumping rate prior to the end of the test is typically used (Kruseman and DeRidder, 1994).  The purpose of the proposed step-drawdown test is to determine the pumping rate for the constant-rate test. As a result, recovery data for the step-drawdown test at KAFB-106228 will not be analyzed to determine aquifer parameters.
9		The drawdown curve presented in Figure 2-1 for the 100 gpm time-step of the step-drawdown test seems non-typical. What could cause the shape of this curve to be sinusoidal?	<b>Concur:</b> This comment refers to specific data from testing at KAFB-106157. The sinusoidal shape of the curve may have been a result of bio-clogging of the filter pack, which we do not expect to occur at KAFB-106228 (see response to Comment 2 of this table). Any non-typical results at KAFB-106228 will be evaluated and discussed in the KAFB-106228 Aquifer Pilot-Test Report.
10		Consistent with the Work Plan and standard industry practice, each step of the step-drawdown test was conducted for two hours (about 7200 seconds). However, examination of pumping well drawdown during the constant rate test (Figure 3-1) indicates that the rate of drawdown increases significantly at approximately 10,000 seconds, beyond the duration of the second time step. Step lengths of three hours or more would have identified the accelerated drawdown and may have resulted in selection of a lower flow rate for the constant rate test. This observation should be considered if additional aquifer testing will be performed for characterization of the fuel spill area.	<b>Concur:</b> The KAFB-106228 Aquifer Pilot-Test Work Plan has been revised to state that the length of each step for the step drawdown test will be 3 hours.
11		It does not appear that the AQTESOLV solutions for the step-drawdown test (pumping or recovery) were included in the files provided to the EPA by NMED	<b>Concur:</b> AQTESOLV solutions for the step-drawdown test will be provided in the KAFB-106228 Aquifer Pilot-Test Report.
12	Section 2.2 Pages 6&7	Estimation of the non-linear well loss coefficient and associated exponent (C and P) is briefly described and the estimated values of C and P were determined to be 1 and 1.75, respectively. It does not appear that the AQTESOLV solution from which C and P were estimated was included in the files provided to the EPA by NMED. Consequently, these estimates could not be evaluated. According to Walton (1962), the value of C for properly developed and designed wells is generally less than 5 sec <sup>2</sup> /ft <sup>5</sup> . A C value of 1 suggests that the pumping well is properly designed and adequately developed. This is inconsistent with the report conclusions	<b>Concur:</b> AQTESOLV solutions from which C and P are estimated will be provided in the KAFB-106228 Aquifer Pilot-Test Report.
13	Section 2.2 Pages 6&7	The report did not present estimates of the linear well loss coefficients (B) and did not identify the specific analysis used to estimate B (Kruseman and de Ridder, 1990 offers several methods). Consequently, the evaluation of B values could not be performed. Recommend including this information in the final submittal, including AQTESOLV solutions or other calculations, as appropriate. Linear well losses result from items such as screen entrance head loss, filter pack head loss and potentially other sources of head loss in the penetration zone such as residual mud (if used), biofouling and inadequate development. Kruseman and de Ridder (1990) indicate that linear well losses can be considerably more significant than losses due to turbulent flow as estimated by C.	<b>Concur:</b> The following equation from Kruseman and DeRidder (1994) will be used to estimate B for any time during pumping: $s_w = BQ + CQ^P$ Where: s <sub>w</sub> is the drawdown at a given time (length) and is measured during testing B is the linear well loss coefficient at the time of s <sub>w</sub> Q is the pumping rate (volume/time), and is recorded during testing C is the non-linear well loss coefficient, and is analyzed for in AQTESOLV P is the non-linear well loss exponent, and is analyzed for in AQTESOLV  The equation will be rearranged as follows: $B = \frac{s_w - CQ^P}{Q}$  A discussion of the calculations and estimates of B will be provided in the KAFB-106228 Aquifer Pilot Test Report.



Comment #	Reference	Comment	Response
14		The need to reduce the discharge rate during the third time step is not ideal. Could this have affected the calculation of the C, P and B variables resulting in underestimation of the predicted drawdown at the proposed 100 gpm discharge rate? The selection of this discharge rate for the constant rate test was demonstrated to be incorrect.	<b>Concur:</b> See the response to Comment 2 for measures that will be taken to ensure stable pumping rates during the step-drawdown test at KAFB-106228.
15		11 Were any attempts made to estimate well efficiency as was proposed in the Aquifer Testing Work Plan (October 2013)?	<b>Concur:</b> Well efficiency was not estimated for KAFB-106157. Well efficiency will be evaluated during well development at KAFB-106228. The well development plan will be provided in the Groundwater Extraction Pilot Implementation and Additional Plume Characterization Letter Work Plan Addendum #3 (Addendum #3), delivered to the NMED on March 19, 2015.
Section 3			
16	Section 3.1	Section 3.1 states that “The filter pack material and screen slot size used in well construction (Appendix A) were selected to allow water to flow freely from the aquifer material into the well.” Recommend that the data collected and analysis performed to substantiate proper well design (i.e. minimization of well losses associated with screen and filter pack selection) should be provided in the final submittal. As described in Driscoll (1986) improper well design can result in significant well losses – independent of adequate well development or potential biofouling of the filter pack, as has been suggested.	<b>Concur:</b> The final design of KAFB-106228 will be informed by the drilling, installation, development, and sampling of probe well KAFB-106212. In addition, well development will be conducted until well efficiency and specific capacity targets are met, as described in Addendum #3.
17		The slot size for the KAFB-106157 well screen has been consistently identified as 0.03-in; however, the filter pack gradation varies between the well completion log, soil boring log and various written descriptions of the well design contained in other documents. The well completion diagram provided in Appendix A indicates both 8/12 and 10/20 filter pack gradations. Is it an 8/12 or 10/20 filter pack? Forms, logs, tables and written descriptions should be corrected for consistency with as-built conditions.	<b>Concur:</b> The filter pack used at KAFB-106157 was 8/12 Colorado Silica Sand. Correct and consistent forms, logs, tables, and written descriptions will be provided regarding well completion details for KAFB-106228.
18	Section 3.1 Page 8	Clogging of the filter pack due to biological activity is a plausible explanation, although currently unproven. Is there a way that the potential for biofouling can be evaluated and confirmed (e.g. down-hole video)? Is it possible that well losses increased over time during the aquifer test as a result of biofouling? If biofouling is confirmed to be the primary cause of well losses, would the suggested approach of biocide injection and redevelopment provide a permanent solution or would this likely become a recurring issue?	<b>Concur:</b> This comment is specific to KAFB-106157. It is not expected that there will be any fouling of KAFB-106228 prior to the aquifer test (see response to Comment 2).
19	Section 3.1 Page 8	The report states that the well remained undeveloped for nearly two years due to delays in work plan approvals. The administrative record indicates NMED approved well development on February 24, 2012, approximately two months after KAFB-106157 was installed. This approval indicated that a hazardous waste permit would be needed to treat the development water and further noted that an emergency permit could be issued for this activity, but none was requested. On June 28, 2012, NMED again approved well development, including a second alternative for managing the development water. This is approximately six months after completion of KAFB-106157. While not ideal, this is far less than the nearly two years described in the January 27 Draft Aquifer Test Letter Report. The conditions imposed by NMED were consistent with RCRA and added additional complexity to the proposed well development efforts; however, these conditions should have been foreseen and were not insurmountable. Well development could have been completed considerably sooner than September 2013	<b>Concur:</b> Comment is specific to KAFB-106157. Well development at KAFB-106228 will be conducted until certain well efficiency standards are met. The well development plan is provided in Addendum #3. Aquifer testing at KAFB-106228 is scheduled to occur within 2 months of well installation.
20		Was concern about potential biofouling (or other similar issues) due to delayed well development ever articulated prior to issuing this report?	<b>Concur:</b> Comment is specific to KAFB-106157. Well development at KAFB-106228 will be conducted until certain well efficiency standards are met. The well development plan is provided in Addendum #3. Aquifer testing at KAFB-106228 is scheduled to occur within 2 months of well installation.
21	Section 3.1 Page 9	This section states that the aquifer test only impacted intermediate and deep observation wells screened in the same zone as the pumping well. Should this be shallow and intermediate observation wells? The report indicates that measureable drawdown was not detected in deep observation wells.	<b>Concur:</b> The KAFB-106228 Aquifer Pilot-Test Report will discuss which aquifer zones are impacted by pumping.

Comment #	Reference	Comment	Response
22	Section 3.2 Page 10	The report describes variations in water levels due to changes in barometric pressure and the calculation of barometric efficiency. It is also evident that water level data were corrected for changes in barometric pressure (e.g. see Figure 1-3); however, the manner in which water levels were corrected for changes in barometric pressure are not described in the report. Please clarify.	<p><b>Concur:</b> The method of corrections for barometric pressure will be described in the KAFB-106228 Aquifer Pilot-Test Report. Barometric pressure will be corrected for using a combination of barometric pressure loggers and water level changes observed at a background-monitoring well cluster. The barometric efficiency of each observation point and the extraction well will be calculated using water level and barometric pressure data collected during the week of monitoring prior to the step-drawdown test. The following equation will be used to calculate barometric efficiency (Kruseman and DeRidder, 1994):</p> $BE = \frac{\Delta h}{\Delta p/\gamma}$ <p>Where:  BE is barometric pressure (percent)  <math>\Delta h</math> is the change in water level (length)  <math>\Delta p</math> is the change in atmospheric pressure (force/length<sup>2</sup>)  <math>\gamma</math> is the specific weight of the water (force/length<sup>3</sup>)</p> <p><math>\Delta p/\gamma</math> is the barometric pressure expressed in length of a liquid (such as inches of water column).</p> <p>If a lag time is observed between changes in atmospheric pressure and corresponding changes in water level, the time of the atmospheric pressure changes will be shifted during analysis to correspond with the time of the changes in water level to account for the lag time.</p>
23		It is unclear which excel tables provided to the EPA by NMED contain corrected data, if any. Observation well transducer data files for the constant rate test were not included in the files provided to the EPA by NMED and consequently not reviewed	<b>Concur:</b> Observation well transducer files will be included in the KAFB-106228 Aquifer Pilot-Test Report.
24		The values on the Y-axis (drawdown) in Figure 3-1 appear to be in reverse order. Drawdown decreasing from 35 ft to ~5-10 ft as pumping progresses does not make sense.	<b>Concur:</b> Axes will be correctly oriented for graphs provided in the KAFB-106228 Aquifer Pilot-Test Report.
25		The pumping well drawdown curve (Figure 3-1) indicates accelerated drawdown beginning at approximately 10,000 seconds. Could this be related to some type of boundary effect where the cone of depression intersects an area of lower conductivity?	<b>Concur:</b> This is possible. During step-drawdown testing at KAFB-106228, steps will be increased to 3 hours to allow additional time to evaluate data for boundary effects prior to the constant rate test. In addition, well development will be performed until well efficiency and specific capacity targets are reached (these targets are provided in Addendum #3). This should rule out impacts from the filter pack if any accelerated drawdown is observed.
26		According to the <i>Evaluating Hydrocarbon Removal from Source Zones and its Effect on Dissolved Plume Longevity and Magnitude Depletion</i> (American Petroleum Institute, 2002), groundwater flow through a LNAPL zone is reduced. The approximately ten-foot rise in water levels in the LNAPL source area may have caused vertical smearing of the LNAPL at approximately residual concentrations within the upper saturated zone. Considering that some thickness of the saturated zone may have been at residual LNAPL concentrations prior to the water table rise, this could represent approximately 10 percent or more of the assumed 100 foot aquifer thickness evaluated during the aquifer test. Is it plausible that the presence of entrapped LNAPL could result in reduced groundwater flow and accelerated drawdown observed in the pumping well drawdown curve?	<b>Concur:</b> It is plausible that the presence of entrapped LNAPL could result in reduced groundwater flow and accelerated drawdown observed in a pumping well drawdown curve; however, it is not expected that the LNAPL area will have impacted the KAFB-106157 aquifer test. This is because KAFB-106157 is located approximately 100 feet from the edge of observed LNAPL, the well is constructed with a 100 foot well screen (as noted in the comment), and it draws water from a 360 degree radius; even if there was submerged LNAPL it is not expected to have impacted groundwater flow to the well during the short-term aquifer testing. KAFB-106228 is approximately 1,500 feet downgradient of the historic LNAPL area, and model simulations for the projected pumping rates do not show any migration of LNAPL towards KAFB-106228.
27		Can the available aquifer test data be used to estimate when the cone of depression developed during the constant rate test would have intersected the entrapped LNAPL source zone?	<b>Concur:</b> It is not expected that the LNAPL area will impact this aquifer test, as KAFB-106228 is approximately 1,500 feet downgradient of the historic LNAPL area, and model simulations for the projected pumping rates do not show any migration of LNAPL towards KAFB-106228.

Comment #	Reference	Comment	Response
28	Section 3.2 Page 10	Is it possible to plot corrected displacement for KAFB-10610, -106032 and -106082 (Figures 3-2, 3-3 and 3-4)? This may help accentuate the “external, non-quantifiable influences” observed in displacement data from these wells as described on page 10.	<b>Concur:</b> This comment is specific to the data from the KAFB-106157 aquifer test. Observed and corrected displacement will be provided for all observation wells in the KAFB-106228 Aquifer Pilot-Test Report.
29	Section 3.2 Page 10	It seems unlikely that pumping of the VA well would potentially affect KAFB-10610 and -106082 and not other observation wells in the vicinity (including -106083, which is the intermediate well in the same cluster as -106082). Also see KAFB-106073, -074 and -075 which are relatively close to the VA well, yet show no apparent response to external influences.	<b>Concur:</b> Comment is specific to data from the KAFB-106157 aquifer test. Pumping Well KAFB-3 is the production well most likely to impact the aquifer test at KAFB-106228; KAFB 3 is located approximately 4,140 feet to the northeast of KAFB-106228. The cluster of monitoring wells (KAFB-106201, KAFB-106202, and KAFB-106203) near KAFB-3 will be used as background monitoring wells to correct the data for any influence from KAFB-3. Although the majority of the monitoring wells are between KAFB-106228 and KAFB-3, the VA well is located approximately 3,230 feet to the southwest of KAFB-106228. The cluster of monitoring wells (KAFB-1064, KAFB-106099, and KAFB-106100) nearest to the VA wells will also have pressure transducers installed to correct the data for any influence from the VA well (Section 2.2 of the KAFB-106228 Aquifer Test Work Plan).
30		The background displacement data collected from KAFB-10610 between the step and constant rate tests exhibits an approximate diurnal drawdown and recovery cycle. This cycle appears independent of water level changes caused by variations in barometric pressure. Is this potentially reflecting the influence of the VA well or some other nearby pumping well?	<b>Concur:</b> Comment is specific to data from the KAFB-106157 aquifer test. Any similar phenomena during the aquifer test at KAFB-106228 will be evaluated and the source identified, if possible in order to correct the data.
31		The response to changes in barometric pressure in KAFB-10610 seems dampened relative to other wells (e.g. KAFB-10618 and -106033) during the background monitoring period. Is there a plausible explanation(s) for this behavior? Could this be related to KAFB-10610 being located within the LNAPL source area?	<b>Concur:</b> Comment is specific to data from the KAFB-106157 aquifer test. None of the observation points for the aquifer test at KAFB-106228 are within the LNAPL source area.
32		Is the VA well on a separate electrical meter? Would it be possible to determine when the VA well was pumping based on electrical power records?	<b>Concur:</b> We were unable to determine when the VA well was pumping during the aquifer test at KAFB-106157. Please see response to Comment 29 for monitoring potential impacts of the VA well during the aquifer test at KAFB-106228.
33		Considering the proximity of the VA well to the plume, and a suggestion in the report that operation of the VA well could have affected water levels in at least two observation wells, consideration should be given to installing transducers in several observation wells proximal to the VA well and collecting data during several periods of known VA well operation. The EPA understands that the VA well typically runs a few to several times per day.	<b>Concur:</b> Transducers will be installed into observation wells proximal to the VA well as per comment 29.
34		Although the measured displacements are very small, examination of the corrected displacement curves in Figures F-3, F-4, F-5 and F-7 suggest a response to pumping at the initial 95 gpm flow rate. Once the flow was dropped to 45 gpm, the corrected drawdown levels off and becomes practicably indistinguishable from background noise. However, the corrected displacements in F-5 and F-7 (KAFB-106075 and -106084) do seem to indicate a response consistent with both the start and stop of the constant rate test (disagree with statement on page 10 that no drawdown was observed in these wells but agree that the available drawdown and recovery data from these wells are not useful for analyses). Apparent responses were also noted in several deep wells suggesting that a higher flow rate could have resulted in measureable drawdown in deep observation wells.	<b>Concur:</b> Comment is specific to data from the KAFB-106157 aquifer test. The same issues are not anticipated during the aquifer test at KAFB-106228.
35	Section 3.2 Page 10	The radius of influence estimates appear reasonable based upon the constant rate test performed. Radius of influence estimates can also be derived from distance drawdown plots. The r0 values on Figures 3-15 and 3-16 suggest a slightly larger radius of influence ranging between 460 and 550 feet. Although the concept of pumping well capture zones was not addressed in this report, a point of clarification worth making at this juncture is that capture zones are typically smaller than the cone of depression due to the impact of regional hydraulic gradients	<b>Concur:</b> The KAFB-106228 Aquifer Pilot-Test Report will clarify that capture zones are typically smaller than the cone of depression due to the impact of regional hydraulic gradients.
36	Section 3.2 Page 10	Text states that the Cooper-Jacob (1946) straight-line time drawdown analysis was conducted on three observation wells. The list of wells identified includes KAFB-106157 which is the pumping well. It should be KAFB-106083.	<b>Concur:</b> This comment is specific to the analysis of data from the KAFB-106157 aquifer test. Wells used in all analyses will be correctly identified for the KAFB-106228 Aquifer Pilot-Test Report.
37	Section 3.2 Page 10	The Cooper-Jacob (1946) straight-line time drawdown method and Jacob (1950) distance drawdown method are subject to several simplifying assumptions (e.g. pumping well fully penetrates the aquifer, pumping well is 100% efficient, etc.). Recommend that the report include a summary of the simplifying assumptions for all analyses performed (including AQTESOLV solutions) and identify how site-specific deviations from these ideal conditions could affect the calculated estimates of aquifer properties (T and S).	<b>Concur:</b> Simplifying assumptions will be discussed in the KAFB-106228 Aquifer Pilot-Test Report for all analyses performed on the data.

Comment #	Reference	Comment	Response
38	Section 3.2 Page 10	Driscoll (1986) states that recovery measurements following variable rate tests cannot be used to estimate aquifer parameters. Please substantiate how use of an average discharge rate from a variable rate test is appropriate for recovery data analyses (step-test, straight-line time drawdown and straight-line distance drawdown).	<b>Concur.</b> Please see response to Comment 8. The purpose of the proposed step-drawdown test is to determine the pumping rate for the constant-rate test. As a result, recovery data for the step-drawdown test at KAFB-106228 will not be analyzed to determine aquifer parameters.
39	Table 3-1	On Table 3-1 the units of transmissivity are identified as ft <sup>3</sup> /day – it should be ft <sup>2</sup> /day	<b>Concur:</b> Correct units will be used for all tables submitted with the KAFB-106228 Aquifer Pilot-Test Report.
40		The EPA was able to reproduce some of the transmissivity estimates (within rounding uncertainties) presented in Table 3-1 and using the equation presented at the top of page 11. In other cases, the EPA was not able to reproduce the calculated T estimates. The variable responsible for the apparent discrepancy in T estimates is the Δ(h <sub>0</sub> -h) term. The following table identifies potential discrepancies in Δh <sub>0</sub> -h) (see shaded values). Based on the information provided in the report, the reason for differences in Δh <sub>0</sub> -h) cannot be determined. Please confirm appropriate values and correct the report, if necessary.  <b>TABLE IN LETTER</b>	<b>Concur:</b> Comment is specific to data from the KAFB-106157 aquifer test. Appropriate values for the aquifer test at KAFB-106228 will be determined, confirmed, and reported in the KAFB-106228 Aquifer Pilot-Test Report.
41		On Figure 3-11, the Δ(h <sub>0</sub> -h) value of 0.0.095 is a typo. It appears that it should be ~0.12 ft based upon review of information presented on this figure; however, it is apparent that a value of 0.095 was used to calculate the estimated T for KAFB-10618 (pumping) presented in Table 3-1.	<b>Concur:</b> Comment is specific to the data from the KAFB-106157 aquifer test. Correct values will be determined, confirmed, and used in for data analysis in the KAFB-106228 Aquifer Pilot-Test Report.
42		The EPA was unable to reproduce S estimates (Table 3-1) for the straight-line drawdown and recovery analyses using the t <sub>0</sub> value in units of minutes as indicated by the equations presented at the top of page 11. The EPA was able to reproduce the S estimates (within rounding uncertainties) when t <sub>0</sub> values were in units of days. Was the incorrect unit specified for t <sub>0</sub> in the report? Please make appropriate corrections to the report as necessary.	<b>Concur:</b> . Units used for all calculations will be clearly stated in the KAFB-106228 Aquifer Pilot-Test Report.
43		The EPA was unable to reproduce T and S estimates (Table 3-1) for the distance-drawdown analyses using the equations presented at the bottom of page 11. The EPA was able to reproduce the reported values (within rounding uncertainties) using equations 9.11 and 9.12 of Driscoll (1986). Were incorrect distance drawdown equations presented in the report? Please make appropriate corrections to the report as necessary.	<b>Concur:</b> The distance drawdown equations presented in the KAFB-106157 Aquifer Test Report were checked and found to be correct, and CB&I personnel were able to reproduce the reported values using equations presented in the report. However, the units reported were not consistent, and the report did not clarify the unit conversions used in the calculations. This may have resulted in the EPA being unable to reproduce the T and S estimates. The following equations were presented in the previous report, and will be used to calculate storativity and transmissivity for the distance-drawdown analysis of the KAFB-106228 aquifer test (Kruseman and DeRidder, 1994):  $T = \frac{2.3Q}{2\pi\Delta(h_0 - h)}$ $S = \frac{2.25Tt}{r_0^2}$ <p>Where:  T = transmissivity (length<sup>2</sup>/time)  S = storativity (dimensionless)  Q = pumping rate (volume/time)  Δ(h<sub>0</sub> - h) = drawdown per log cycle of distance (length)  t = time at which analysis was done (time)  r<sub>0</sub> = the distance at which the straight line intercepted the 0 drawdown axis (length)</p> <p>Any consistent units may be used in this equation. Data used for all calculations will be presented with consistent units, with conversion factors given as necessary. All calculations will be verified prior to reporting.</p>

Comment #	Reference	Comment	Response
44		Recommend that worksheets presenting aquifer parameter calculations and input variables should be provided to substantiate the values presented in Table 3-1.	<b>Concur:</b> Worksheets with calculations and input values will be provided in the KAFB-106228 Aquifer Pilot Test Report.
Section 4			
45		Concur that apparent significant well losses in KAFB-106157 preclude its utility as an extraction well without rehabilitation. Rehabilitation will also be necessary if NMED requires additional aquifer testing using this well.	<b>Concur:</b> KAFB-106157 will not be used in this aquifer test.
46		Ideally the recovery data are best used to evaluate and corroborate pumping well data, rather than as a singular dataset. Concur that due to apparent significant well losses, the recovery data from the pumping well are the preferred dataset for this assessment.	<b>Concur:</b> Comment is specific to the KAFB-106157 aquifer test. See the response to Comment 2 for measures that will be taken to ensure stable pumping rates during the aquifer test at KAFB-106228.
47		Concur that the aquifer property estimates based on the observation well data are preferred for this assessment and are a better measure of the aquifers hydrologic conditions at the downgradient edge of LNAPL area.	<b>Concur:</b> Comment is specific to the KAFB-106157 aquifer test. Data collected during the aquifer test at KAFB-106228 will be evaluated to determine which set of data is preferred for the assessment of the aquifer hydrologic conditions in the vicinity of KAFB-106228.