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Secretary Flynn,

Kirtland Air Force Base (AFB) acknowledges receipt of your "Notice of Violation (NOV), 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" dated 15 January 2015.

The Ethylene Dibromide (EDB) Interim Measure Implementation Plan, attached, has been developed to address the concerns outlined in your NOV. This document also includes a timeline and aquifer test work plan for completion of required actions.

Please contact Mr. L. Wayne Bitner at (505) 853-3484 or at ludie.bitner@us.af.mil, or Mrs. Victoria R. Branson at (505) 846-6362 or at Victoria.branson@us.af.mil, if you have further questions.

Sincerely

TOM D. MILLER, Colonel, USAF
Commander

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FEBRUARY 2015

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

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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

February 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
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NOTICE

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This work plan for aquifer testing using groundwater extraction well KAFB-106228 was prepared by CB&I Federal Services LLC for the U.S. Army Corps of Engineers under contract W912DY-10-D-0014, Delivery Order 0002. This work plan was prepared in accordance with the January 15, 2015 New Mexico Environment Department 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 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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TOM D. MILLER, Colonel, USAF
Commander, 377th Air Base Wing

This document has been approved for public release.

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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.

Michael Amdurer

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 proposed 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 will be 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 has been developed with the understanding that the drilling, installation, development, and sampling of probe well KAFB-106212 will provide additional data that will further inform the design, development, and aquifer testing of extraction well KAFB-106228. Revisions to this work plan and well development procedures will be included in a third letter work plan addendum to be submitted to NMED outlining any changes or updates. The third letter work plan addendum will also include the final well construction diagrams for extraction well KAFB-106228 and monitoring wells utilized in the aquifer testing.

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. The third letter work plan addendum will further describe the influent pipeline, temporary treatment system, and temporary discharge system.

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 [µg/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, constant rate aquifer testing is scheduled to start at well KAFB-106228 on July 6, 2015, and conclude on July 20, 2015. The planned pumping and recovery testing includes 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® 700) and associated electrical supply lines. The transducer cable will be secured at periodic intervals to the polyvinyl chloride casing 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[1] 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 also be installed in monitoring wells located at the KAFB-106201 cluster, near production well KAFB-3. These monitoring wells, in combination

[1] 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.

with monitoring well at well clusters KAFB-106216 and KAFB-106213 will be used to help correct for influences that pumping well KAFB-3 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 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, Veterans Administration well, 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. The weather station located at the Albuquerque International Sunport (nominally 13,500 ft southwest of extraction well KAFB-106228 and at a similar ground surface elevation) will be used as the barometric pressure station and will help quantify barometric variances within the extraction and monitoring wells.

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 2 hours, with no recovery between steps. If the well is not capable of that performance, 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 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.

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. Additionally, 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. If pumping and KAFB-3 influences the water levels observed in the monitoring wells during aquifer testing, data from the pressure transducers in these three wells will be used to correct the data for KAFB-3 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 55-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.

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.

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 µg/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 well 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.

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 caputure 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, 2011).

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 (Shaw Environmental & Infrastructure, Inc., 2011) 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, 2011). 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® 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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FIGURES

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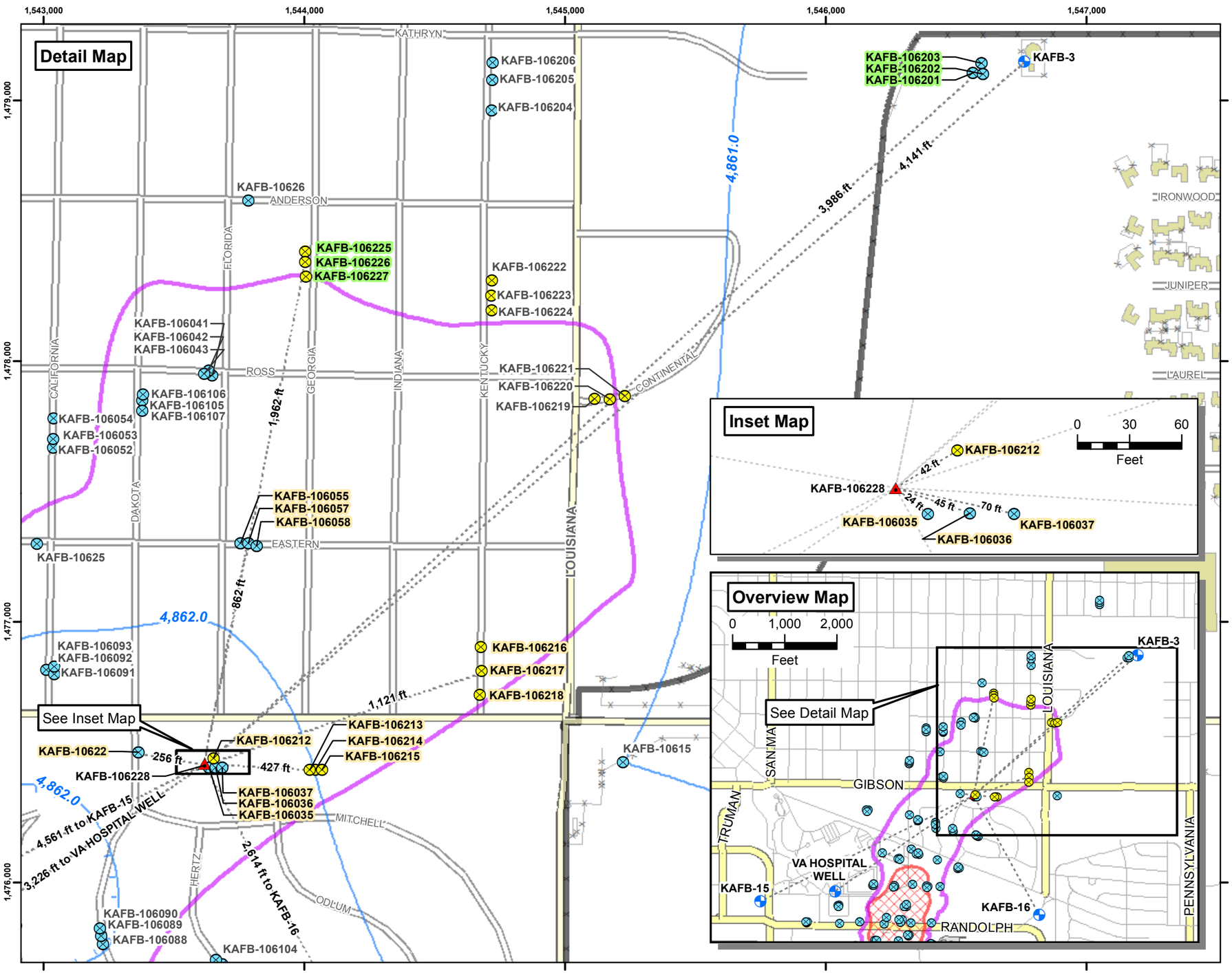
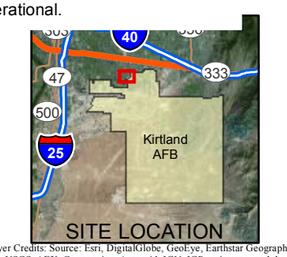


Legend

- 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-106157.

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



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N

Revision Date: 02/16/15

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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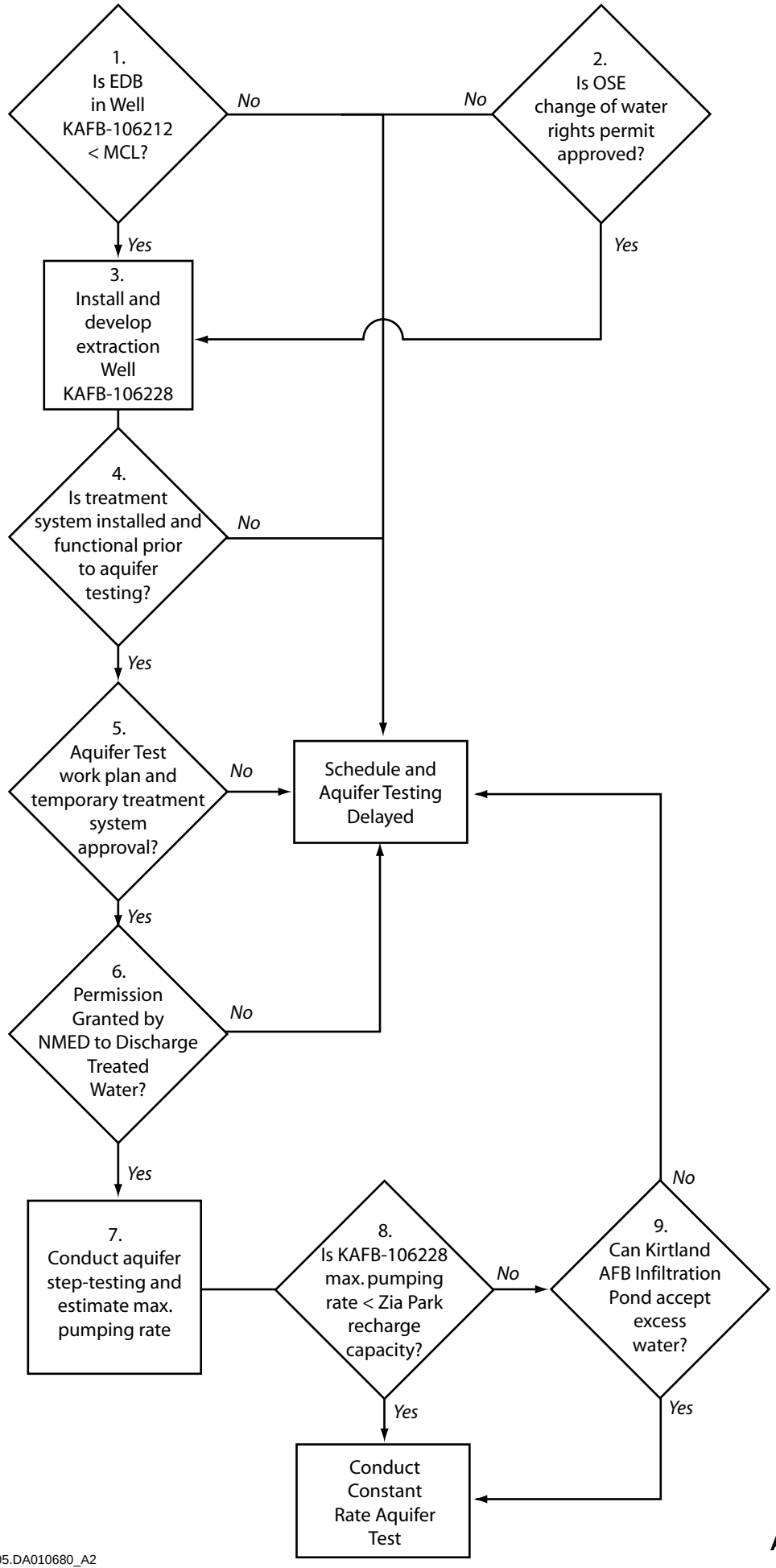

Figure 1-2

Aquifer Test Schedule And Assumptions Groundwater Extraction Well KAFB-106228 Aquifer Testing Work Plan

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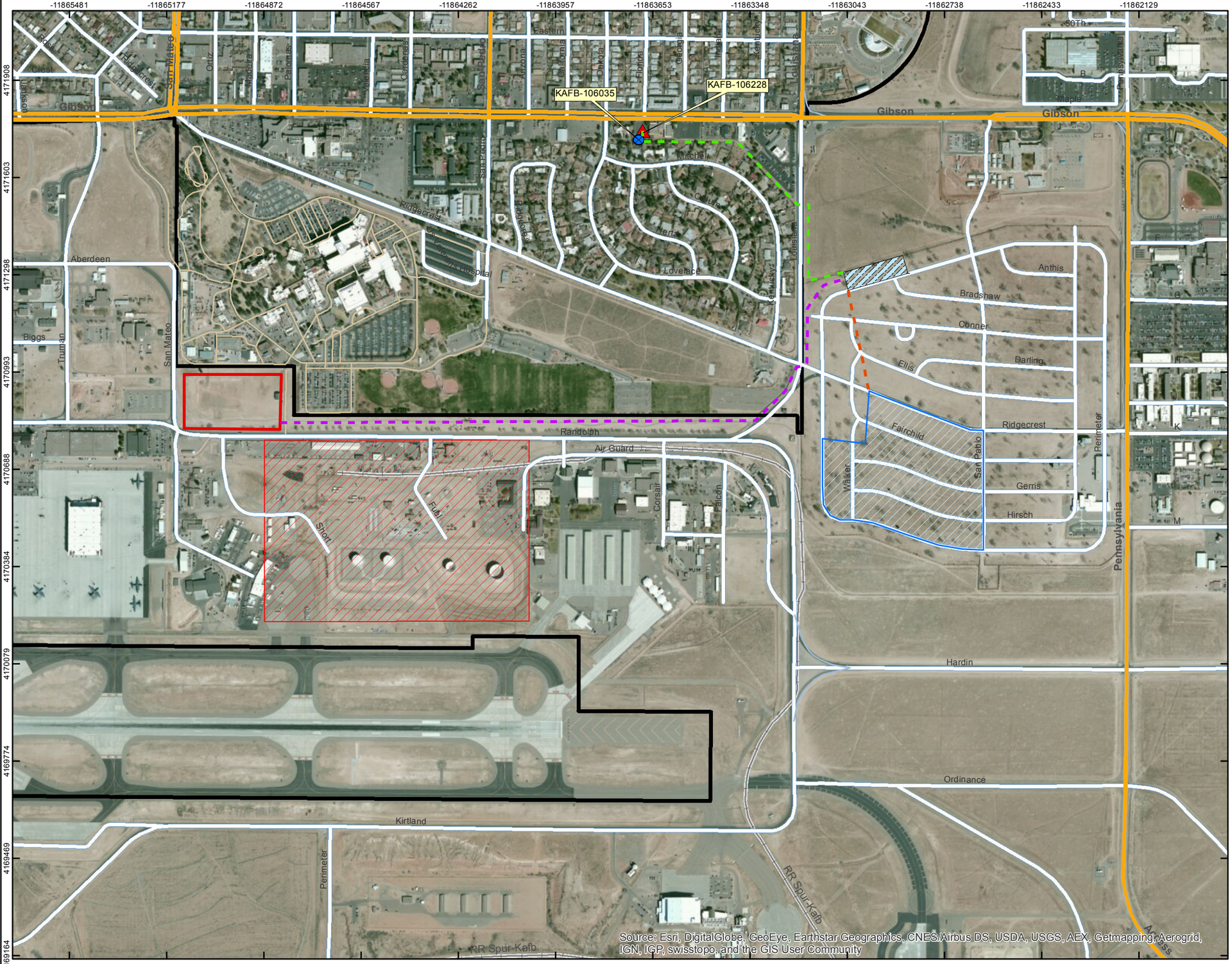

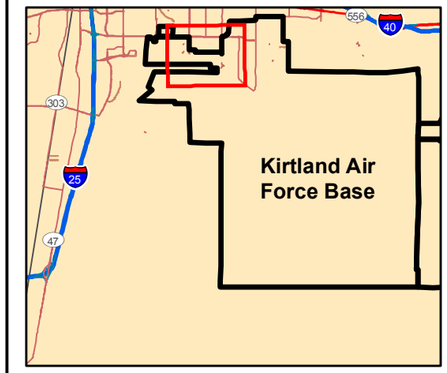

LEGEND

- 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

N

0 500 1,000 Feet

Projection : NAD_1983_StatePlane_New_Mexico_Central_FIPS_3002_Feet

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

FIGURE 3-1

SCHEMATIC CONVEYANCE PIPING AND TEMPORARY TREATMENT SYSTEM

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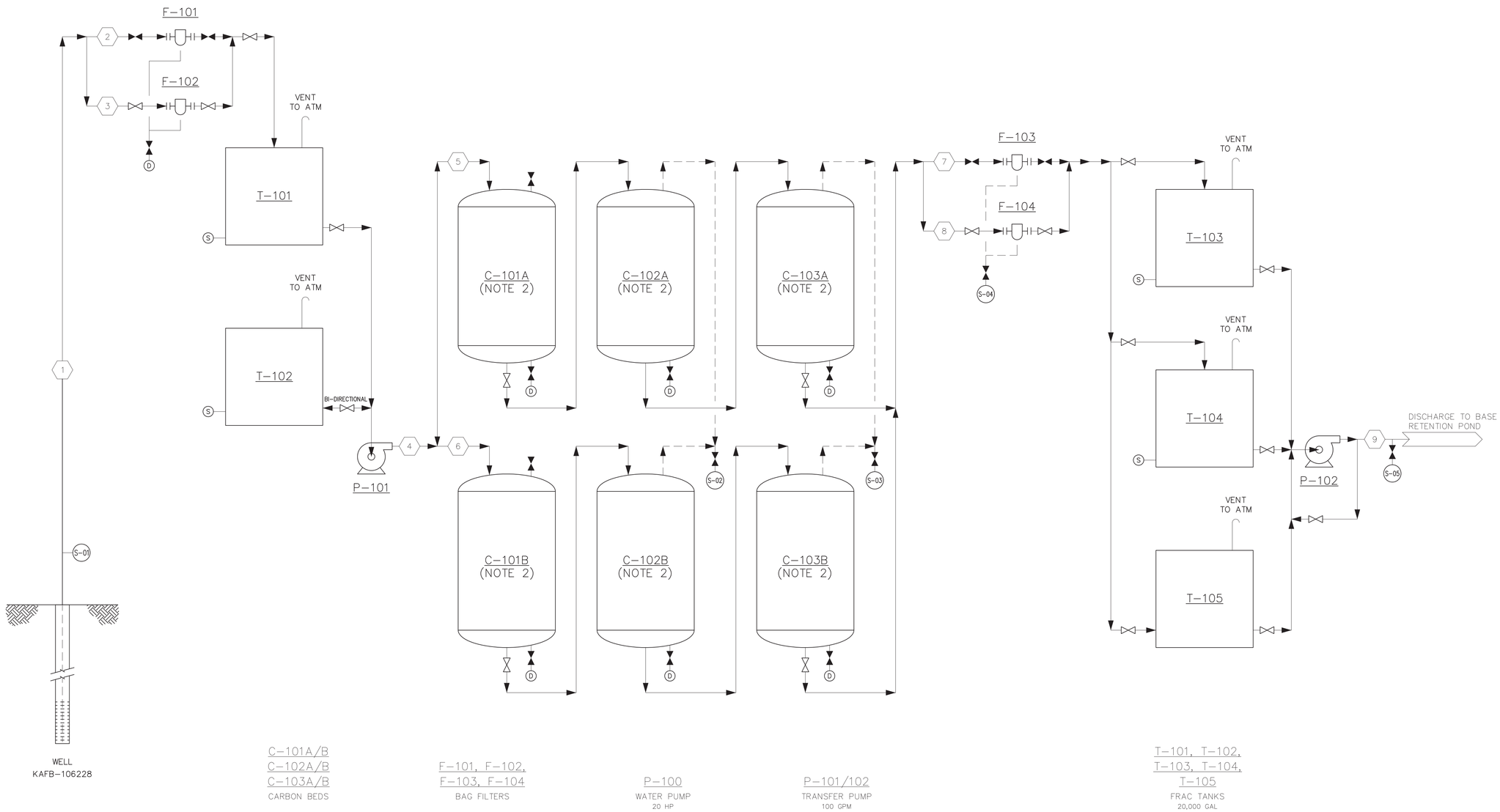
Project Number: 140705



NOTE:

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

LEGEND:

SAMPLE PORT

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

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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:

Form: CM5-830-00-FM-02104 CB ANSI D.dwg

File: 140705-001-PR-01-400002.dwg
Plot Date/Time: Jan 27, 2015 – 1:53pm
Plotted By: edwin.anderson

TABLES

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Table 2-1. Aquifer Test Well Summary

Well ID	Target Aquifer Zone	Horizontal Distance from KAFB-106228 (feet)[b]	Pumping Test Use
KAFB-106228[a]	Shallow to Deep	0	Extraction Well
KAFB-106035	Shallow	24	Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106212[a]	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[a]	Shallow	427	Observation Well for the Constant Rate Test
KAFB-106214[a]	Intermediate		Observation Well for the Constant Rate Test
KAFB-106215[a]	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[a]	Shallow	1,121	Observation Well for the Constant Rate Test
KAFB-106217[a]	Intermediate		Observation Well for the Constant Rate Test
KAFB-106218[a]	Deep		Observation Well for the Constant Rate Test
KAFB-106225[a]	Shallow	1,962	Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106226[a]	Intermediate		Background Observation Well for the Step-Drawdown and Constant Rate Tests
KAFB-106227[a]	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

[a]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.

[b]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

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

Aquifer Test Stage	Location	Frequency	Analytical Parameters	Laboratory	Turn-Around Time	Total No. of Samples (depending duration of constant rate test)
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

Table 4-2. Sample Chain of Custody

CHAIN OF CUSTODY

Ref. Document # _____

Page _____ of _____

Project Number: _____
Project Name / Location: _____
Purchase Order #: _____

Project Contact: _____
(Name & phone #)

Shipment Date: _____
Waybill Number: _____
Lab Destination: _____
Lab Contact Name / ph. #: _____

Send Report To: _____
Phone/Fax Number: _____
Address: _____
City: _____

Sampler's Name(s):

Sample ID Number	Sample Description	Collection Information: Date	Time	Method	Matrix	# of containers	Preservative / Container / Beginning depth (ft)	Ending depth (ft)	Analyses Requested								Cooler Temperature
Temperature Blank																	

Special Instructions:

Turnaround Time: Standard 10 Day ☐ 24-hr ☐ 48-hr ☐ 3-day ☐ 5-day

Level Of QC Required: I II III Project Specific:

Relinquished By: Date: Time:
Received By: Date: Time:
Relinquished By: Date: Time:
Received By: Date: Time:

Method Codes
C = Composite G = Grab

Matrix Codes
DW = Drinking Water SO =Soil
GW = Ground Water
WW = Waste Water
V = Vapor

APPENDIX A

Pertinent Letters and Guidance

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United States Environmental Protection Agency | Office of Research and Development | Office of Solid Waste and Emergency Response | EPA/540/S-93/503 February 1993

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

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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.

<u>Aquifer Location</u>

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

<u>Aquifer Boundaries</u>

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

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.

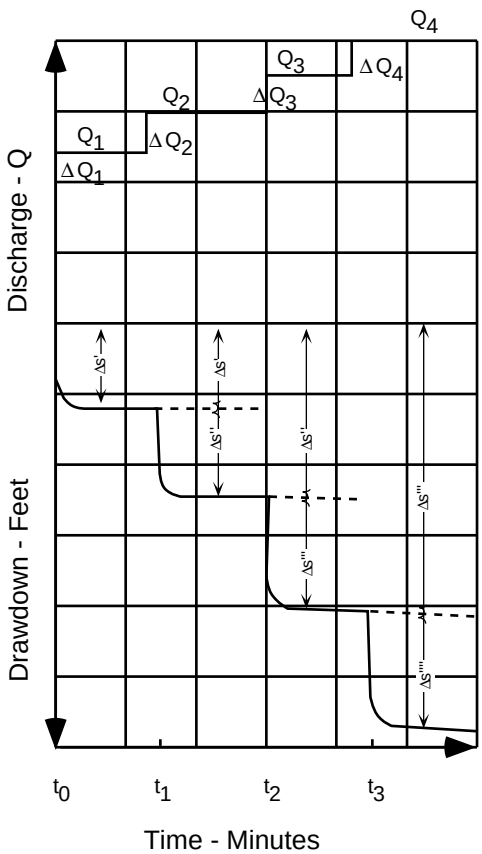

Figure 1. Variation of discharge and drawdown in multiple discharge tests (step drawdown tests).

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

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

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

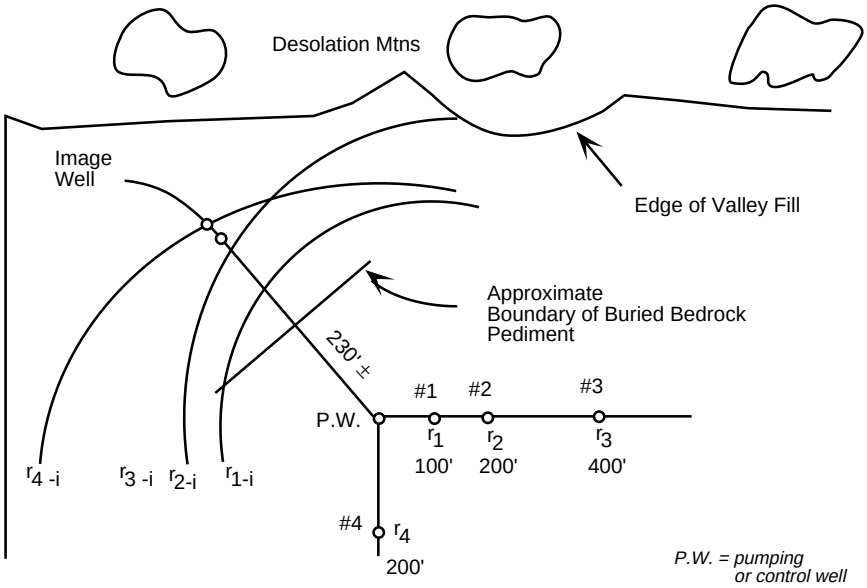

Figure 2. Observation well/pumping well location to determine buried impermeable boundary.

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

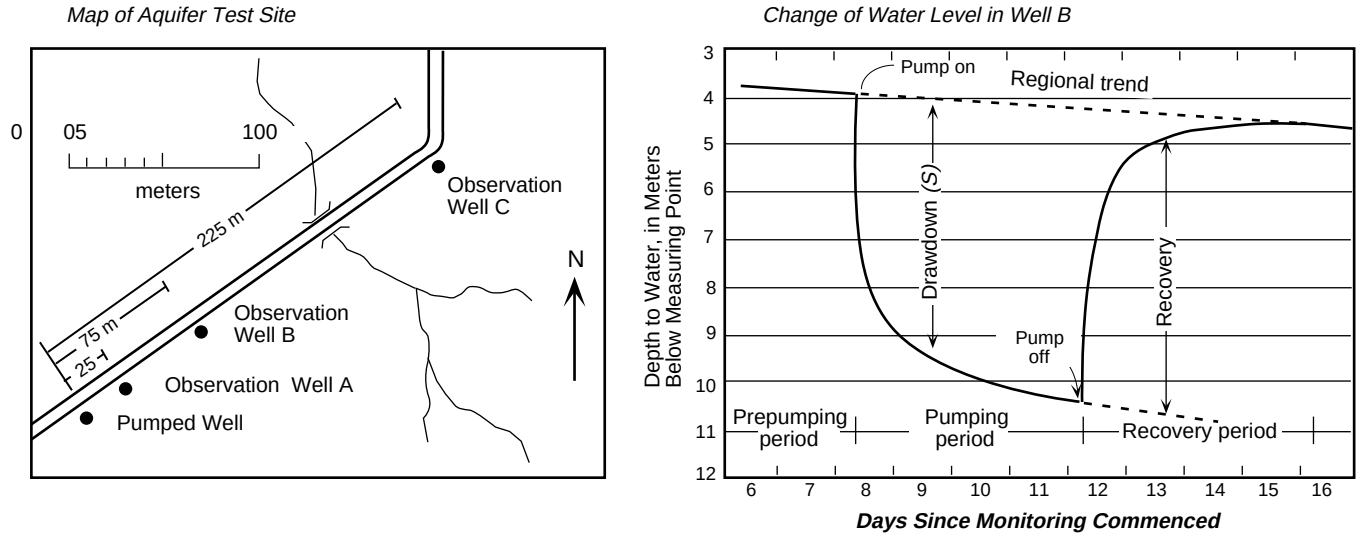

Figure 3. Example test site showing baseline, pumping test, and recovery water level measurements in one of the wells.

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

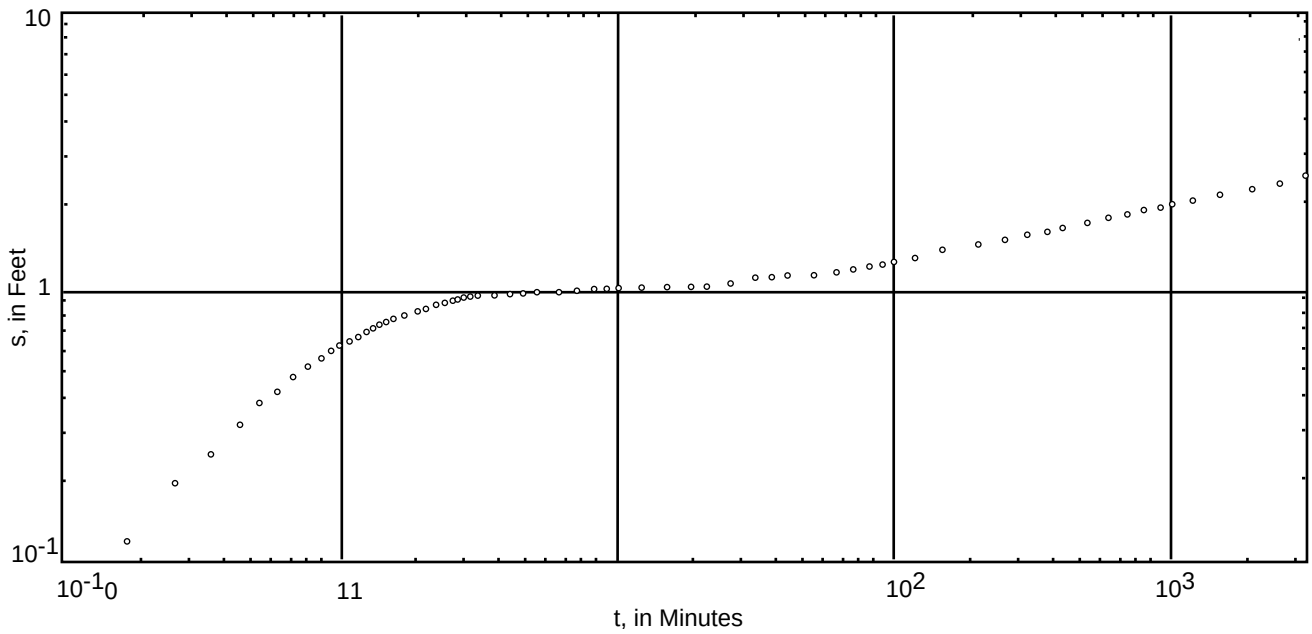

Figure 4. Logarithmic plot of s vs t for observation well.

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

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.

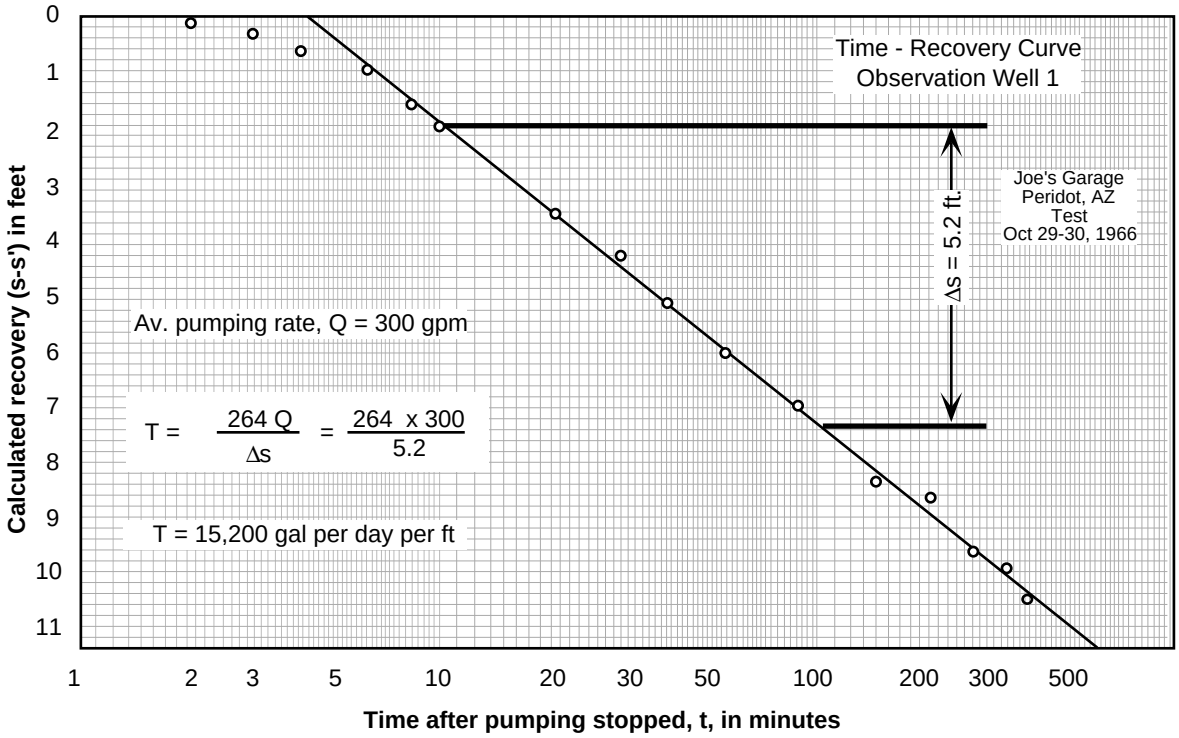

Figure 5. Time recovery curve for observation well - October 30, 1966.

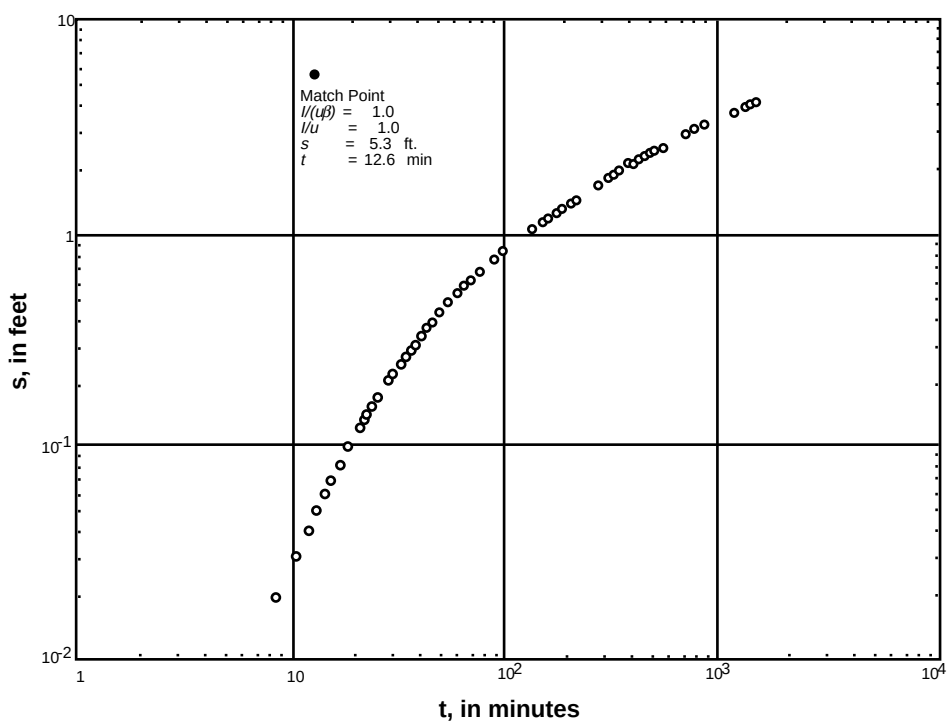

Figure 6. Logarithmic plot of s vs t for Observation Well 23S/25E-17Q_2 at Pixley, CA.

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

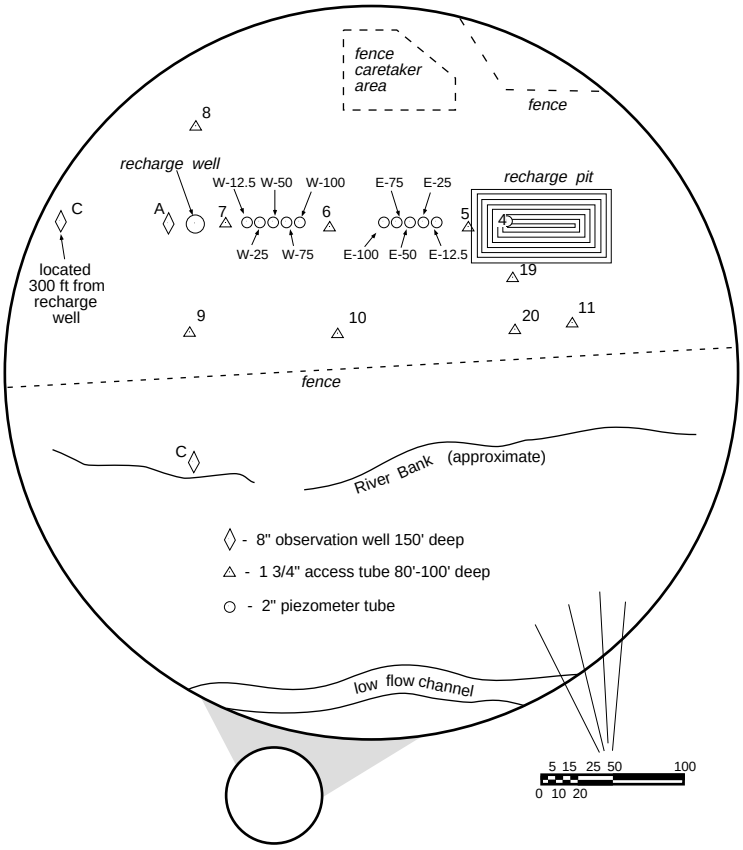

Figure 7. Recharge facility well layout.

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

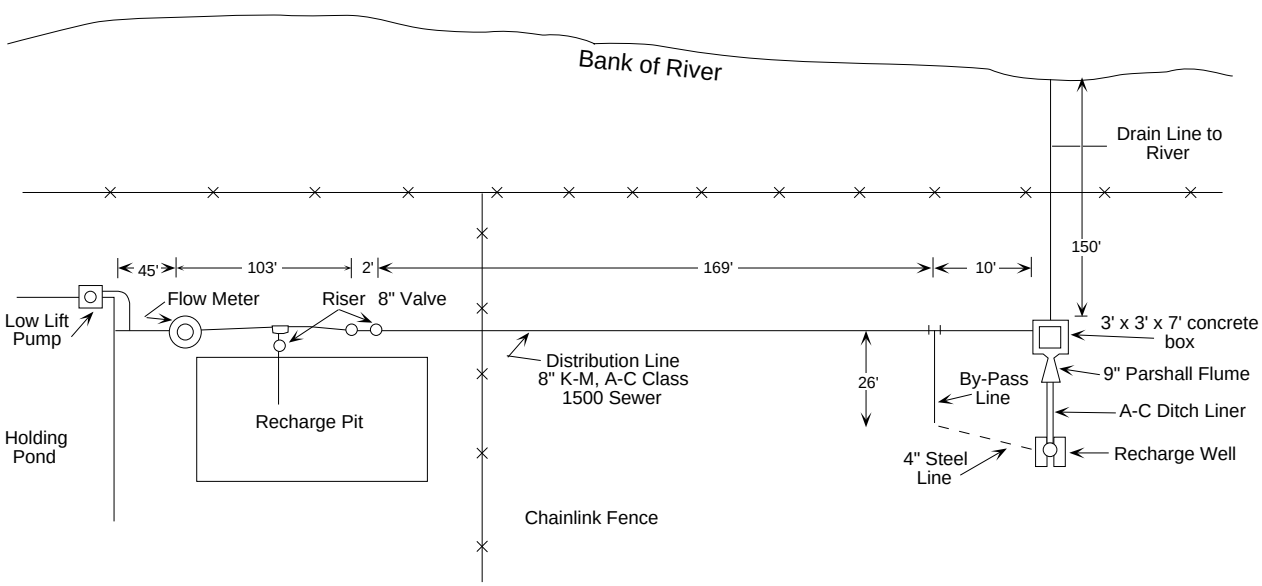

Figure 8. Water distribution and drainage facilities at the artificial recharge site.

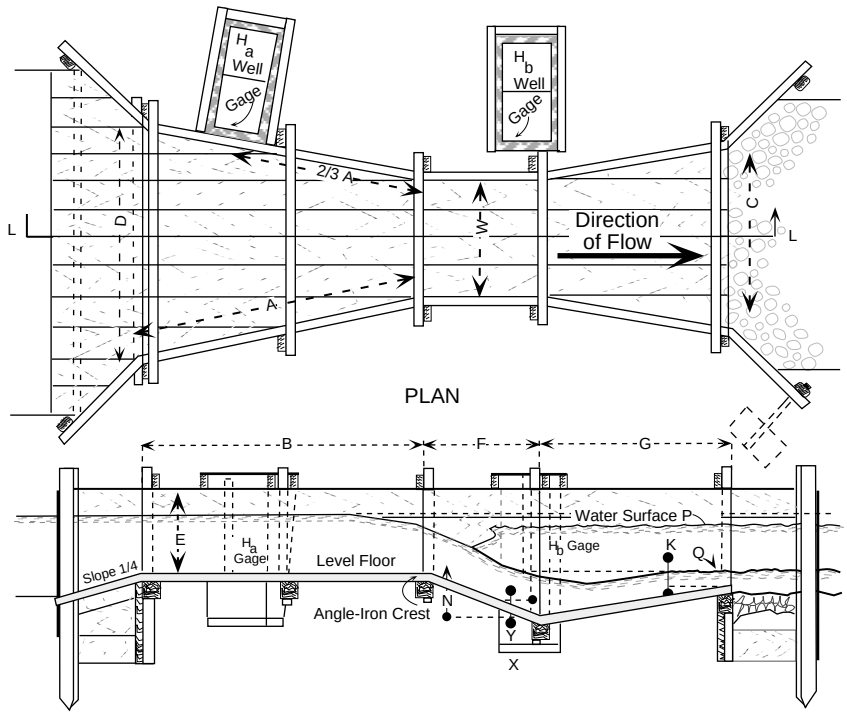

Figure 9. Parshall flume dimensions.

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
gpm	*ft*	*ft*	*percent*
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.

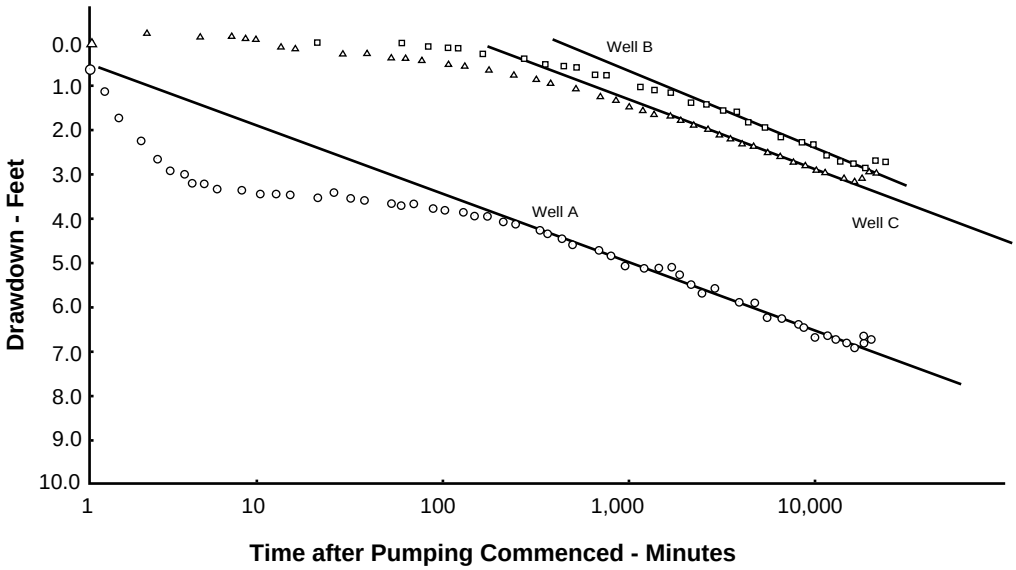

Figure 10. Drawdown versus log of time in observation wells A, B, and C during pumping of R#1.

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
			ft	*min*	*ft*	*gpd/ft*	
Well A	110	10^5	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 x 10^{-5} rather than 3 x 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.

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,

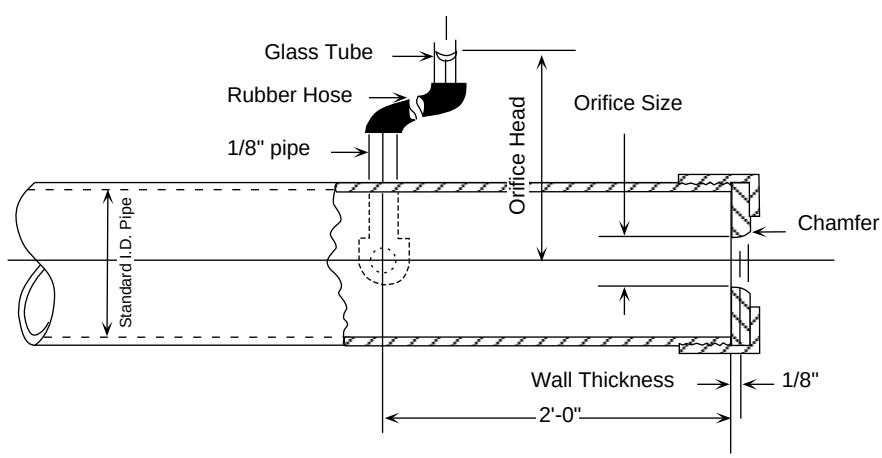

Figure 11. Diagram of orifice meter.

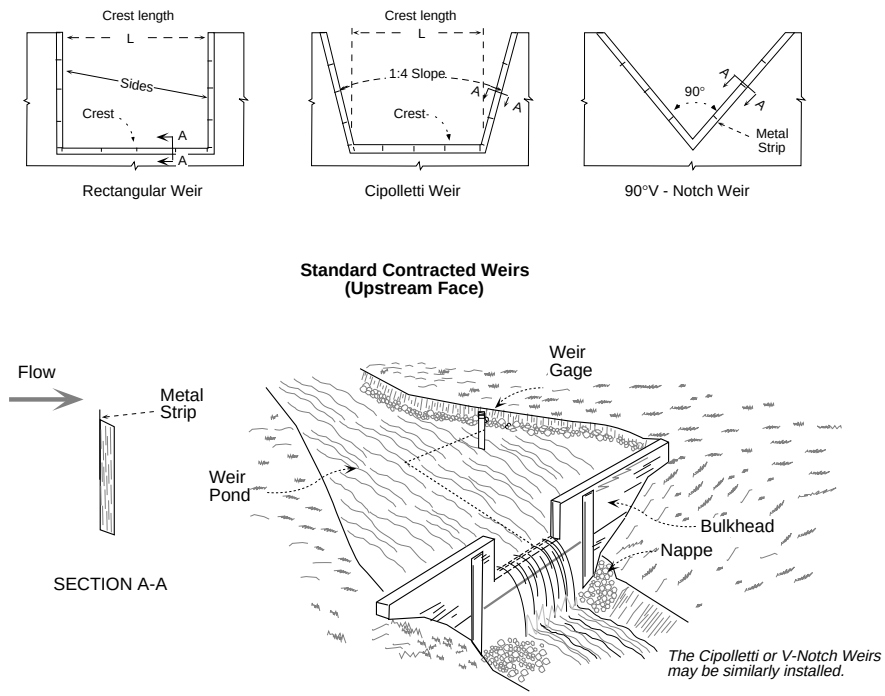

Figure 12. Standard contracted weirs, and temporary discharging at free flow.

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 TEST FIELD DATA SHEET

Continuation Sheet

Distance to pumped well _____ Bearing _____ Page _____ of _____

_____ Pumped Well No._____ Date _____

_____ Observation Well No._____ Recorded by _____

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

Acknowledgements

This paper would not have been possible without the critical assistance of a number of persons, especially Helen Simonson who had to read my often cryptic handwriting.

The following individuals reviewed the document and provided numerous technical and editorial comments:

Dr. L. G. Wilson, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona;
John McLean, US Geological Survey, Regional Hydrologist's Office, Denver, Colorado;
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Darcy Campbell, US EPA Region VIII, Denver, Colorado;
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Steve Acree, US EPA, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma; and
Dean McKinnis, US EPA Region VIII, Denver, Colorado.

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 aquifer.

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

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.

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Adria Badoure

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Governor

JOHN A. SANCHEZ
Lieutenant Governor

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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 4th 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.

APPENDIX B

Aquifer Test Schedule

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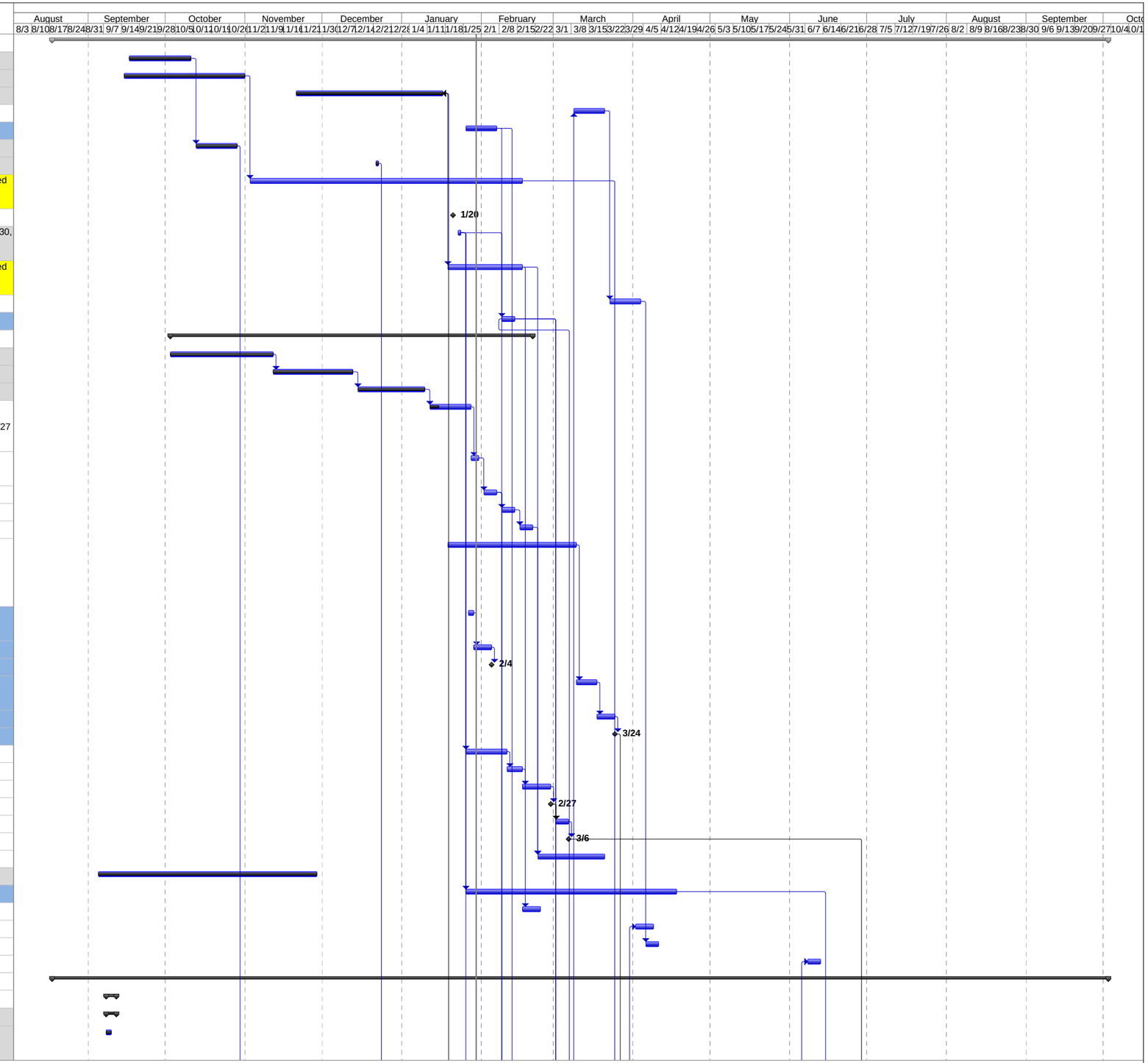
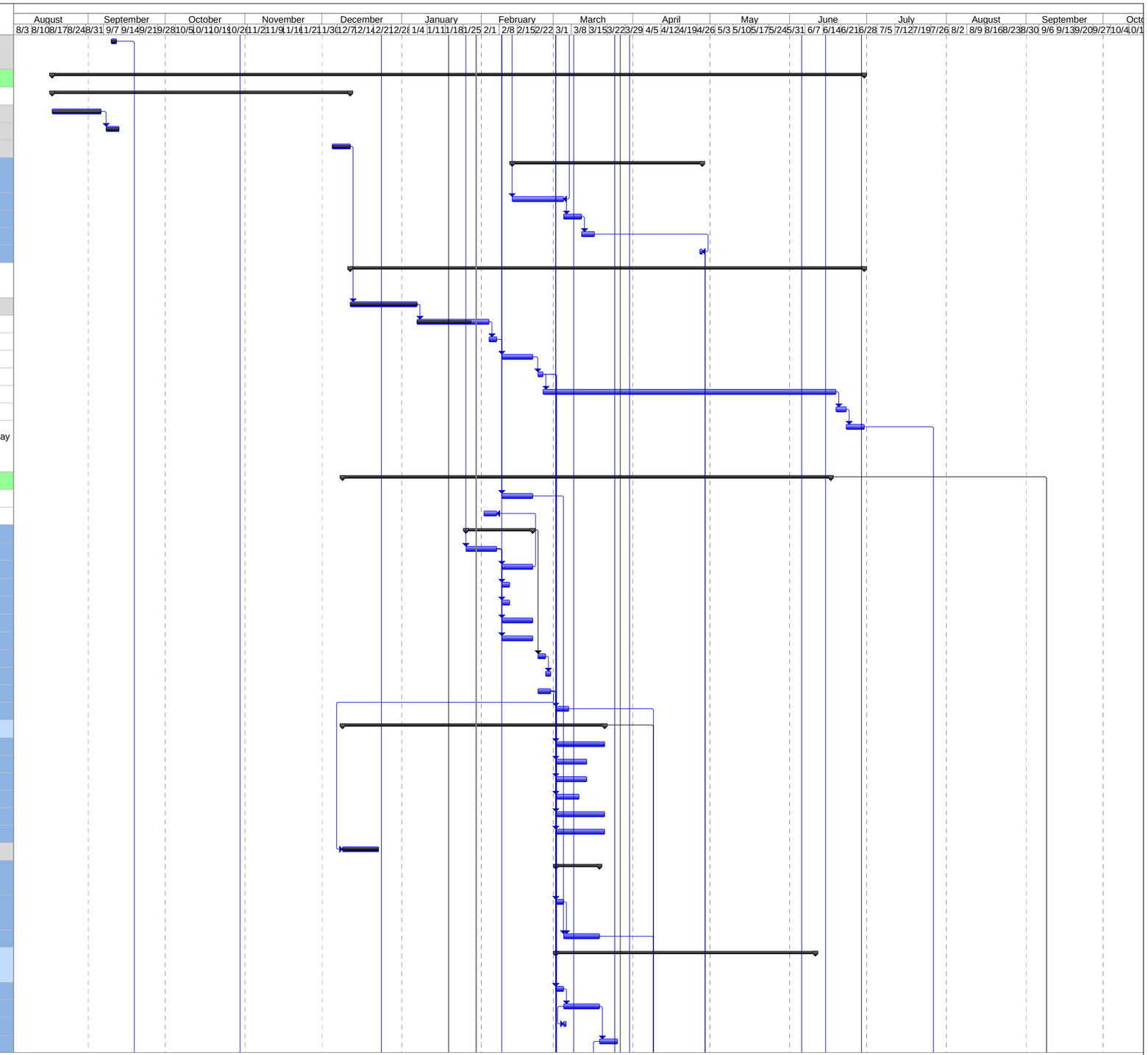
ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
0	**20%**	**Groundwater Treatment System**	**411 days**	**289 days**	**Mon 8/18/14**	**Fri 10/2/15**	
1	100%	Phase 0 Estimate	24 days	18 days	Wed 9/17/14	Fri 10/10/14	
2	100%	Phase 1, 3, and 4 EDB IM Cost Estimate	47 days	35 days	Mon 9/15/14	Fri 10/31/14	
3	100%	Phase 2 Inf Pipe and 5A Infiltration Gallery Estimate	57 days	35 days	Fri 11/21/14	Fri 1/16/15	
4	0%	Phase 5B Infiltration Gallery Estimate	12 days	10 days	Mon 3/9/15	Fri 3/20/15	
5	0%	Temporary Treatment System Estimate	12 days	10 days	Mon 1/26/15	Fri 2/6/15	
6	100%	Phase 0 Funding Approval	16 days	12 days	Mon 10/13/14	Tue 10/28/14	NTE on 1/20
7	100%	Phase 3, 4 50% NTE	1 day	1 day	Mon 12/22/14	Mon 12/22/14	
8	0%	Phase 1, 3, and 4 Funding Approval	106 days	70 days	Mon 11/3/14	Mon 2/16/15	Have not received as of 1/27
9	0%	Partial Phase 1, 3, and 4 NTE	0 days	0 days	Tue 1/20/15	Tue 1/20/15	
10	0%	Phase 2, 5A NTE	1 day	1 day	Fri 1/23/15	Fri 1/23/15	300, 310, 320, 330, 600, 610, 680
11	0%	Phases 2 and 5A Infiltration Gallery Funding Approval	29 days	21 days	Mon 1/19/15	Mon 2/16/15	Have not received as of 1/27
12	0%	Phase 5B Infiltration Gallery Funding Approval	12 days	10 days	Mon 3/23/15	Fri 4/3/15	
13	0%	Temporary Treatment System Funding Approval	5 days	5 days	Mon 2/9/15	Fri 2/13/15	
14	**72%**	**Basis of Design**	**141 days**	**95 days**	**Fri 10/3/14**	**Fri 2/20/15**	
15	100%	Draft Basis of Design	40 days	28 days	Fri 10/3/14	Tue 11/11/14	
16	100%	Draft BOD KAFB and USACE Review	31 days	21 days	Wed 11/12/14	Fri 12/12/14	
17	100%	Final Basis of Design	26 days	16 days	Mon 12/15/14	Fri 1/9/15	
18	28%	Final Basis of Design KAFB and USACE Review	16 days	12 days	Mon 1/12/15	Tue 1/27/15	USACE/AFCEC comments not received as of 1/27
19	0%	Incorporate Comments and Prepare Final BOD for NMED	3 days	3 days	Wed 1/28/15	Fri 1/30/15	
20	0%	Final BOD NMED Review	5 days	5 days	Mon 2/2/15	Fri 2/6/15	
21	0%	Final BOD Incorporate NMED Comments	5 days	5 days	Mon 2/9/15	Fri 2/13/15	
22	0%	Final BOD NMED Approval	5 days	5 days	Mon 2/16/15	Fri 2/20/15	
23	0%	KAFB-106212 (Probe Well) Installation and Sampling (see GWM Schedule)	50 days	36 days	Mon 1/19/15	Mon 3/9/15	Installation of Probe well delayed due to ROE
24	0%	Letter Work Plan Addendum Part 2 (Temporary Treatment System)	2 days	2 days	Tue 1/27/15	Wed 1/28/15	3 consecutive sampling days
25	0%	Work Plan Addendum Part 2 (TTS) NMED Review	7 days	5 days	Thu 1/29/15	Wed 2/4/15	
26	0%	Work Plan Addendum Part 2 (TTS) NMED Approval	0 days	0 days	Wed 2/4/15	Wed 2/4/15	
27	0%	Letter Work Plan Addendum Part 3 (Extraction and Deep Monitoring Well Design)	8 days	6 days	Tue 3/10/15	Tue 3/17/15	
28	0%	Addendum 3 (Ext Well Design) NMED Review	7 days	5 days	Wed 3/18/15	Tue 3/24/15	
29	0%	Addendum 3 (Ext Well Design) NMED Approval	0 days	0 days	Tue 3/24/15	Tue 3/24/15	
30	0%	KAFB-106228 Aquifer Test Work Plan	16 days	12 days	Mon 1/26/15	Tue 2/10/15	
31	0%	Aquifer Test Work Plan KAFB/USACE Review	6 days	4 days	Wed 2/11/15	Mon 2/16/15	
32	0%	Aquifer Test WP NMED Look Ahead Review	11 days	9 days	Tue 2/17/15	Fri 2/27/15	
33	0%	Final Aquifer Test WP NMED Submittal	0 days	0 days	Fri 2/27/15	Fri 2/27/15	
34	0%	Final Aquifer Test WP NMED Review	5 days	5 days	Mon 3/2/15	Fri 3/6/15	
35	0%	Aquifer Test WP Approval	0 days	0 days	Fri 3/6/15	Fri 3/6/15	
36	0%	Internal Construction Work Plan (Permanent System)	26 days	20 days	Mon 2/23/15	Fri 3/20/15	
37	100%	Discharge Permit Approval (Permanent System)	85 days	59 days	Fri 9/5/14	Fri 11/28/14	
38	0%	Discharge Permit or Permission Letter (TTS)	82 days	60 days	Mon 1/26/15	Fri 4/17/15	
39	0%	Preliminary Burrowing Owl Study (Influent Pipeline)	7 days	5 days	Tue 2/17/15	Mon 2/23/15	
40	0%	Final Burrowing Owl Study (Influent Pipeline)	7 days	5 days	Thu 4/2/15	Wed 4/8/15	
41	0%	Preliminary Burrowing Owl Study (Infiltration Gallery)	5 days	5 days	Mon 4/6/15	Fri 4/10/15	
42	0%	Final Burrowing Owl Study (Infiltration Gallery)	5 days	5 days	Mon 6/8/15	Fri 6/12/15	
43	14%	Engineering Design & Construction	411 days	289 days	Mon 8/18/14	Fri 10/2/15	
44	**100%**	**Site and Utility Investigation**	**4 days**	**4 days**	**Mon 9/8/14**	**Thu 9/11/14**	
45	**100%**	**Travel to ABQ**	**4 days**	**4 days**	**Mon 9/8/14**	**Thu 9/11/14**	
46	100%	Meeting with KAFB Utilities and Base Personnel	2 days	2 days	Mon 9/8/14	Tue 9/9/14	



Project: Groundwater Treatment Syste
Date: Fri 1/30/15

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Critical | Critical Split | Progress | Deadline

ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
47	100%	Meeting with ABQ WUA and/or City Utilities	2 days	2 days	Wed 9/10/14	Thu 9/11/14	
48	**29%**	**Groundwater Treatment Equipment**	**316 days**	**220 days**	**Mon 8/18/14**	**Mon 6/29/15**	
49	**100%**	**50% Design**	**116 days**	**82 days**	**Mon 8/18/14**	**Thu 12/11/14**	
50	100%	Process Design	19 days	15 days	Mon 8/18/14	Fri 9/5/14	
51	100%	Equipment Bid Package	5 days	5 days	Mon 9/8/14	Fri 9/12/14	
52	100%	Addendum to SOW	7 days	5 days	Fri 12/5/14	Thu 12/11/14	
53	**0%**	**Procure Temporary Groundwater Treatment Equipment**	**74 days**	**52 days**	**Fri 2/13/15**	**Mon 4/27/15**	
54	0%	Bid Package to Bidders	20 days	14 days	Fri 2/13/15	Wed 3/4/15	
55	0%	Review Bids	7 days	5 days	Thu 3/5/15	Wed 3/11/15	
56	0%	Award Purchase Order	5 days	3 days	Thu 3/12/15	Mon 3/16/15	
57	0%	Equipment Delivery	1 day	1 day	Mon 4/27/15	Mon 4/27/15	
58	**21%**	**Procure and Fabricate Permanent Groundwater Treatment Equipment**	**200 days**	**138 days**	**Fri 12/12/14**	**Mon 6/29/15**	
59	100%	Bid Package to Bidders	26 days	14 days	Fri 12/12/14	Tue 1/6/15	
60	75%	Review Bids	28 days	20 days	Wed 1/7/15	Tue 2/3/15	NTE on 1/20
61	0%	Award Purchase Order	3 days	3 days	Wed 2/4/15	Fri 2/6/15	
62	0%	Vendor delivery of Final Design Drawings	12 days	10 days	Mon 2/9/15	Fri 2/20/15	
63	0%	CBI approval of Vendor Design Drawings	2 days	2 days	Mon 2/23/15	Tue 2/24/15	
64	0%	Fabricate Equipment	114 days	82 days	Wed 2/25/15	Thu 6/18/15	
65	0%	Shop Test Equipment	4 days	2 days	Fri 6/19/15	Mon 6/22/15	
66	0%	Equipment Freight	7 days	5 days	Tue 6/23/15	Mon 6/29/15	If building not complete will delay shipment
67	**3%**	**Off-Base Well Vault and Piping**	**190 days**	**132 days**	**Tue 12/9/14**	**Tue 6/16/15**	
68	0%	Letter to CABQ of Intent	12 days	10 days	Mon 2/9/15	Fri 2/20/15	
69	0%	Site Survey	5 days	5 days	Mon 2/2/15	Fri 2/6/15	
70	**0%**	**Procurement Design Package**	**26 days**	**20 days**	**Mon 1/26/15**	**Fri 2/20/15**	
71	**0%**	**Process Design**	**12 days**	**10 days**	**Mon 1/26/15**	**Fri 2/6/15**	
72	**0%**	**Civil Design**	**12 days**	**10 days**	**Mon 2/9/15**	**Fri 2/20/15**	
73	**0%**	**Structural Design**	**3 days**	**3 days**	**Mon 2/9/15**	**Wed 2/11/15**	
74	**0%**	**Architectural Design**	**3 days**	**3 days**	**Mon 2/9/15**	**Wed 2/11/15**	
75	**0%**	**Mechanical Design**	**12 days**	**10 days**	**Mon 2/9/15**	**Fri 2/20/15**	
76	**0%**	**Electrical Design**	**12 days**	**10 days**	**Mon 2/9/15**	**Fri 2/20/15**	
77	0%	Design package review (KAFB, USACE)	3 days	3 days	Mon 2/23/15	Wed 2/25/15	
78	0%	Incorporate Comments	2 days	2 days	Thu 2/26/15	Fri 2/27/15	
79	0%	Construction Scope Package for Bids	5 days	5 days	Mon 2/23/15	Fri 2/27/15	
80	0%	Memorandum to KAFB security of intent	5 days	5 days	Mon 3/2/15	Fri 3/6/15	
81	**11%**	**Permits**	**102 days**	**70 days**	**Tue 12/9/14**	**Fri 3/20/15**	
82	0%	Environmental Impact Form	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
83	0%	KAFB Dig Permit	12 days	10 days	Mon 3/2/15	Fri 3/13/15	
84	0%	Traffic Permit	12 days	10 days	Mon 3/2/15	Fri 3/13/15	
85	0%	Fugitive Dust Permit	9 days	7 days	Mon 3/2/15	Tue 3/10/15	
86	0%	SWPPP	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
87	0%	Construction Debris Landfill	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
88	100%	CABQ Right of Entry	14 days	10 days	Tue 12/9/14	Mon 12/22/14	
89	**0%**	**Excavation and Barricade Permit (CABQ)**	**17 days**	**13 days**	**Mon 3/2/15**	**Wed 3/18/15**	
90	0%	Preparation and submittal of CABQ permits	3 days	3 days	Mon 3/2/15	Wed 3/4/15	
91	0%	Approval of CABQ permits	14 days	10 days	Thu 3/5/15	Wed 3/18/15	
92	**0%**	**Procurement for PNM Electrical Services**	**101 days**	**73 days**	**Mon 3/2/15**	**Wed 6/10/15**	
93	0%	Design Package Requirements to PNM	3 days	3 days	Mon 3/2/15	Wed 3/4/15	
94	0%	PNM Review	14 days	10 days	Thu 3/5/15	Wed 3/18/15	
95	0%	PNM Site Walk	1 day	1 day	Thu 3/5/15	Thu 3/5/15	
96	0%	Award PO	7 days	5 days	Thu 3/19/15	Wed 3/25/15	



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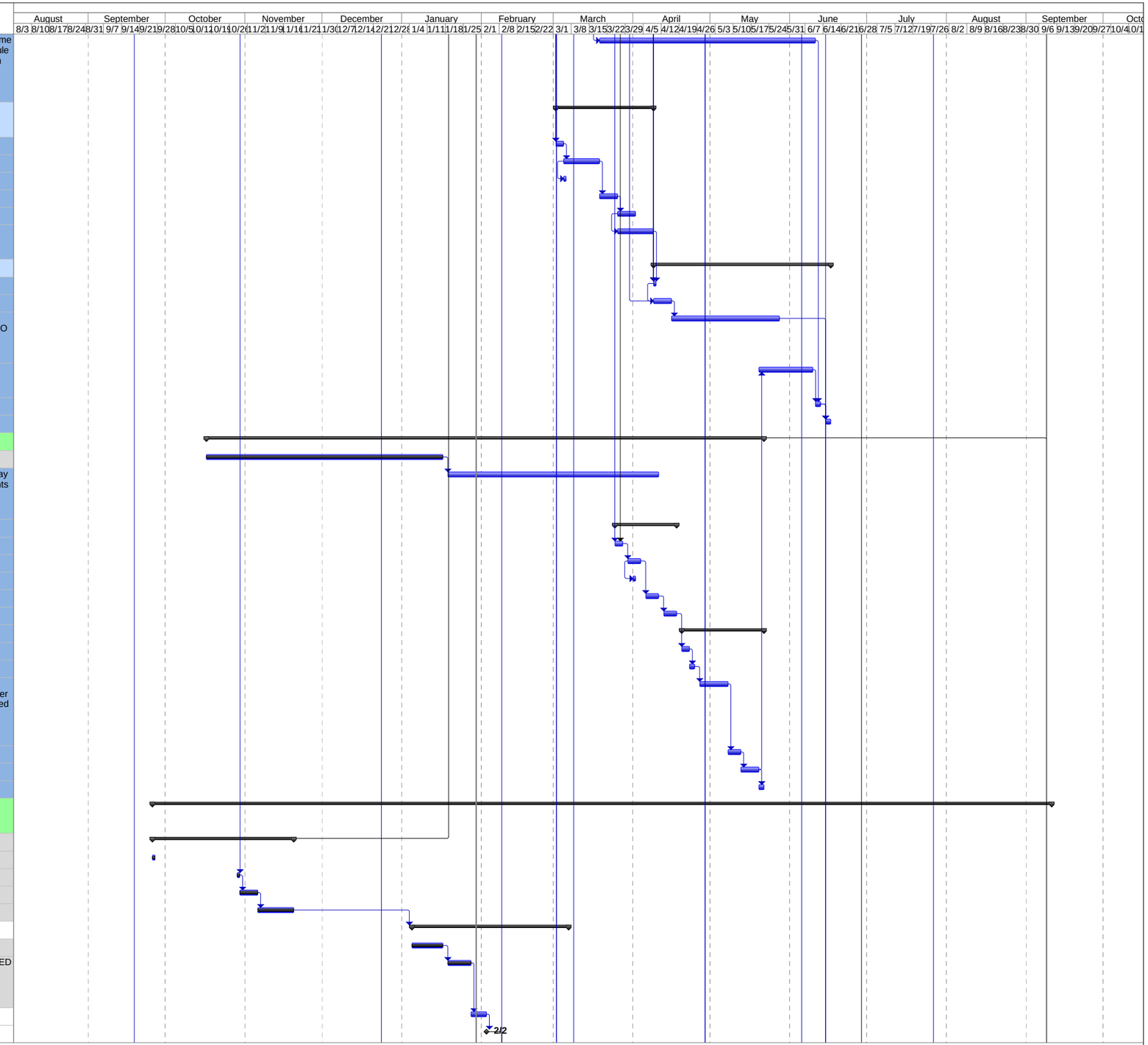
ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
97	0%	PNM Power Drop Construction	84 days	60 days	Thu 3/19/15	Wed 6/10/15	PNM standard time is 4 mos; schedule assumes we can expedite...
98	**0%**	**Procurement for Construction Services**	**38 days**	**28 days**	**Mon 3/2/15**	**Wed 4/8/15**	
99	0%	Bid Package to Construction Bidders	3 days	3 days	Mon 3/2/15	Wed 3/4/15	
100	0%	Out for Bid	14 days	10 days	Thu 3/5/15	Wed 3/18/15	
101	0%	Contractor Site Walk	1 day	1 day	Thu 3/5/15	Thu 3/5/15	
102	0%	Review Bids	7 days	5 days	Thu 3/19/15	Wed 3/25/15	
103	0%	Award PO	7 days	5 days	Thu 3/26/15	Wed 4/1/15	
104	0%	Contractor Base Access	14 days	10 days	Thu 3/26/15	Wed 4/8/15	Possible to expedite?
105	**0%**	**Construction**	**69 days**	**49 days**	**Thu 4/9/15**	**Tue 6/16/15**	
106	0%	Construction Kick-Off Meeting	1 day	1 day	Thu 4/9/15	Thu 4/9/15	
107	0%	Influent Pipe Mobilization	7 days	5 days	Thu 4/9/15	Wed 4/15/15	
108	0%	Influent Pipeline Construction	42 days	30 days	Thu 4/16/15	Wed 5/27/15	Final duration determined at PO award
109	0%	Wellhead Construction (AFTER WELL INSTALL)	21 days	15 days	Wed 5/20/15	Tue 6/9/15	
110	0%	Pump Installation	2 days	2 days	Thu 6/11/15	Fri 6/12/15	
111	0%	Influent Pipe Demobilization	2 days	2 days	Mon 6/15/15	Tue 6/16/15	
112	**37%**	**Extraction Well KAFB-106228 Installation**	**217 days**	**149 days**	**Fri 10/17/14**	**Thu 5/21/15**	
113	100%	OSE Non-Consumptive Permit	92 days	60 days	Fri 10/17/14	Fri 1/16/15	
114	0%	OSE Change of Water Rights	82 days	60 days	Mon 1/19/15	Fri 4/10/15	Assumes no delay due to water rights holder protest
115	**0%**	**Extraction Well Procurement**	**24 days**	**18 days**	**Wed 3/25/15**	**Fri 4/17/15**	
116	0%	Bid Package to Construction Bidders	3 days	3 days	Wed 3/25/15	Fri 3/27/15	
117	0%	Out for Bid	5 days	5 days	Mon 3/30/15	Fri 4/3/15	
118	0%	Contractor Site Walk	1 day	1 day	Wed 4/1/15	Wed 4/1/15	
119	0%	Review Bids	5 days	5 days	Mon 4/6/15	Fri 4/10/15	
120	0%	Award PO	5 days	5 days	Mon 4/13/15	Fri 4/17/15	
121	**0%**	**Extraction Well Field Work**	**32 days**	**24 days**	**Mon 4/20/15**	**Thu 5/21/15**	
122	0%	Site Prep (Utility Locate, Laydown, Barricade)	3 days	3 days	Mon 4/20/15	Wed 4/22/15	
123	0%	Mobilization	2 days	2 days	Thu 4/23/15	Fri 4/24/15	
124	0%	Drilling of KAFB-106228 (Extraction)	11 days	9 days	Mon 4/27/15	Thu 5/7/15	Assumes drilling before OSE Water Rights is approved if needed
125	0%	Construction of KAFB-106228	5 days	3 days	Fri 5/8/15	Tue 5/12/15	
126	0%	Development of KAFB-106228 (Initial)	7 days	5 days	Wed 5/13/15	Tue 5/19/15	
127	0%	Demobilization	2 days	2 days	Wed 5/20/15	Thu 5/21/15	
128	**9%**	**Permanent Discharge Piping & Infiltration Gallery**	**350 days**	**244 days**	**Fri 9/26/14**	**Thu 9/10/15**	
129	**100%**	**Percolation test Phase 1**	**55 days**	**39 days**	**Fri 9/26/14**	**Wed 11/19/14**	
130	100%	Percolation Test PO Execution	1 day	1 day	Fri 9/26/14	Fri 9/26/14	
131	100%	Percolation Test Work Plan Submittal	1 day	1 day	Wed 10/29/14	Wed 10/29/14	
132	100%	Percolation Test Work Plan Approval	7 days	5 days	Thu 10/30/14	Wed 11/5/14	
133	100%	Percolation Test and Report	14 days	10 days	Thu 11/6/14	Wed 11/19/14	
134	**41%**	**Percolation test Phase 2**	**61 days**	**45 days**	**Mon 1/5/15**	**Fri 3/6/15**	
135	100%	Phase 2 Perc Test Work Plan	12 days	10 days	Mon 1/5/15	Fri 1/16/15	
136	100%	Phase 2 Work Plan AFCEC/USACE Review	9 days	7 days	Mon 1/19/15	Tue 1/27/15	Delivered to NMED on 1/27/2015
137	0%	Phase 2 Work Plan NMED Review	6 days	4 days	Wed 1/28/15	Mon 2/2/15	
138	0%	Phase 2 Work Plan NMED Approval	0 days	0 days	Mon 2/2/15	Mon 2/2/15	



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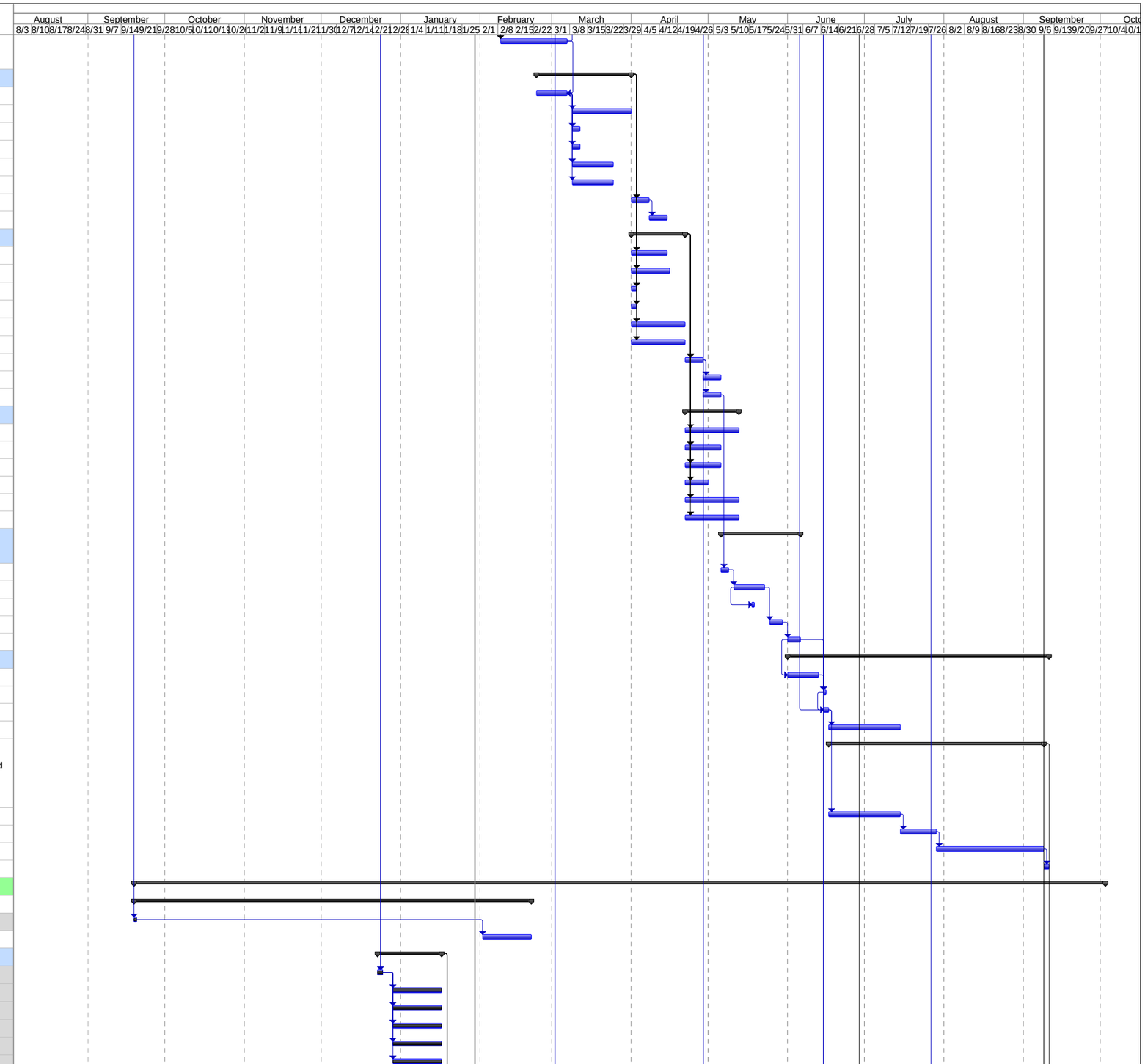
ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
139	0%	Phase 2 Testing and Report	26 days	20 days	Mon 2/9/15	Fri 3/6/15	Received NTE funding 1/23
140	**0%**	**50% Design**	**37 days**	**27 days**	**Mon 2/23/15**	**Tue 3/31/15**	
141	**0%**	**Process Design**	**12 days**	**10 days**	**Mon 2/23/15**	**Fri 3/6/15**	
142	**0%**	**Civil Design**	**23 days**	**17 days**	**Mon 3/9/15**	**Tue 3/31/15**	
143	**0%**	**Structural Design**	**3 days**	**3 days**	**Mon 3/9/15**	**Wed 3/11/15**	
144	**0%**	**Architectural Design**	**3 days**	**3 days**	**Mon 3/9/15**	**Wed 3/11/15**	
145	**0%**	**Mechanical Design**	**16 days**	**12 days**	**Mon 3/9/15**	**Tue 3/24/15**	
146	**0%**	**Electrical Design**	**16 days**	**12 days**	**Mon 3/9/15**	**Tue 3/24/15**	
147	0%	50% package review (KAFB, USACE)	7 days	5 days	Wed 4/1/15	Tue 4/7/15	
148	0%	Incorporate Comments	7 days	5 days	Wed 4/8/15	Tue 4/14/15	
149	**0%**	**Final Design**	**21 days**	**15 days**	**Wed 4/1/15**	**Tue 4/21/15**	
150	**0%**	**Process Design**	**14 days**	**10 days**	**Wed 4/1/15**	**Tue 4/14/15**	
151	**0%**	**Civil Design**	**15 days**	**11 days**	**Wed 4/1/15**	**Wed 4/15/15**	
152	**0%**	**Structural Design**	**2 days**	**2 days**	**Wed 4/1/15**	**Thu 4/2/15**	
153	**0%**	**Architectural Design**	**2 days**	**2 days**	**Wed 4/1/15**	**Thu 4/2/15**	
154	**0%**	**Mechanical Design**	**21 days**	**15 days**	**Wed 4/1/15**	**Tue 4/21/15**	
155	**0%**	**Electrical Design**	**21 days**	**15 days**	**Wed 4/1/15**	**Tue 4/21/15**	
156	0%	Final package review (KAFB, USACE)	7 days	5 days	Wed 4/22/15	Tue 4/28/15	
157	0%	Incorporate Comments	7 days	5 days	Wed 4/29/15	Tue 5/5/15	
158	0%	Construction Scope Package for Bids	7 days	5 days	Wed 4/29/15	Tue 5/5/15	
159	**0%**	**Permits**	**21 days**	**15 days**	**Wed 4/22/15**	**Tue 5/12/15**	
160	0%	Environmental Impact Form	21 days	15 days	Wed 4/22/15	Tue 5/12/15	
161	0%	KAFB Dig Permit	14 days	10 days	Wed 4/22/15	Tue 5/5/15	
162	0%	Traffic Permit	14 days	10 days	Wed 4/22/15	Tue 5/5/15	
163	0%	Fugitive Dust Permit	9 days	7 days	Wed 4/22/15	Thu 4/30/15	
164	0%	SWPPP	21 days	15 days	Wed 4/22/15	Tue 5/12/15	
165	0%	Construction Debris Landfill	21 days	15 days	Wed 4/22/15	Tue 5/12/15	
166	**0%**	**Procurement for Construction Services**	**31 days**	**23 days**	**Wed 5/6/15**	**Fri 6/5/15**	
167	0%	Bid Package to Construction Bidders	3 days	3 days	Wed 5/6/15	Fri 5/8/15	
168	0%	Out for Bid	12 days	10 days	Mon 5/11/15	Fri 5/22/15	
169	0%	Contractor Site Walk	1 day	1 day	Mon 5/18/15	Mon 5/18/15	
170	0%	Review Bids	5 days	5 days	Mon 5/25/15	Fri 5/29/15	
171	0%	Award PO	5 days	5 days	Mon 6/1/15	Fri 6/5/15	
172	**0%**	**Construction**	**102 days**	**74 days**	**Mon 6/1/15**	**Thu 9/10/15**	
173	0%	Contractor Base Access	12 days	10 days	Mon 6/1/15	Fri 6/12/15	
174	0%	Construction Kick-Off Meeting	1 day	1 day	Mon 6/15/15	Mon 6/15/15	
175	0%	Construction Mobilization	2 days	2 days	Mon 6/15/15	Tue 6/16/15	
176	0%	Discharge Pipeline Construction	28 days	20 days	Wed 6/17/15	Tue 7/14/15	
177	**0%**	**Infiltration Gallery Construction**	**84 days**	**60 days**	**Wed 6/17/15**	**Tue 9/8/15**	**Final Duration determined by final design and PO award**
178	0%	Excavation	28 days	20 days	Wed 6/17/15	Tue 7/14/15	
179	0%	Grading	14 days	10 days	Wed 7/15/15	Tue 7/28/15	
180	0%	Distribution Manifold and Manhole	42 days	30 days	Wed 7/29/15	Tue 9/8/15	
181	0%	Construction Demobilization	2 days	2 days	Wed 9/9/15	Thu 9/10/15	
182	**11%**	**Treatment Plant**	**379 days**	**265 days**	**Fri 9/19/14**	**Fri 10/2/15**	
183	**6%**	**Geotechnical Report**	**155 days**	**105 days**	**Fri 9/19/14**	**Fri 2/20/15**	
184	100%	Geo-Tech Scope	1 day	1 day	Fri 9/19/14	Fri 9/19/14	
185	0%	Geo-Tech Testing and Report	19 days	15 days	Mon 2/2/15	Fri 2/20/15	
186	**100%**	**50% Design**	**25 days**	**15 days**	**Tue 12/23/14**	**Fri 1/16/15**	
187	**100%**	**Process Design**	**2 days**	**2 days**	**Tue 12/23/14**	**Wed 12/24/14**	
188	**100%**	**Civil Design**	**19 days**	**13 days**	**Mon 12/29/14**	**Fri 1/16/15**	
189	**100%**	**Structural Design**	**19 days**	**13 days**	**Mon 12/29/14**	**Fri 1/16/15**	
190	**100%**	**Architectural Design**	**19 days**	**13 days**	**Mon 12/29/14**	**Fri 1/16/15**	
191	**100%**	**Mechanical Design**	**19 days**	**13 days**	**Mon 12/29/14**	**Fri 1/16/15**	
192	**100%**	**Electrical Design**	**19 days**	**13 days**	**Mon 12/29/14**	**Fri 1/16/15**	



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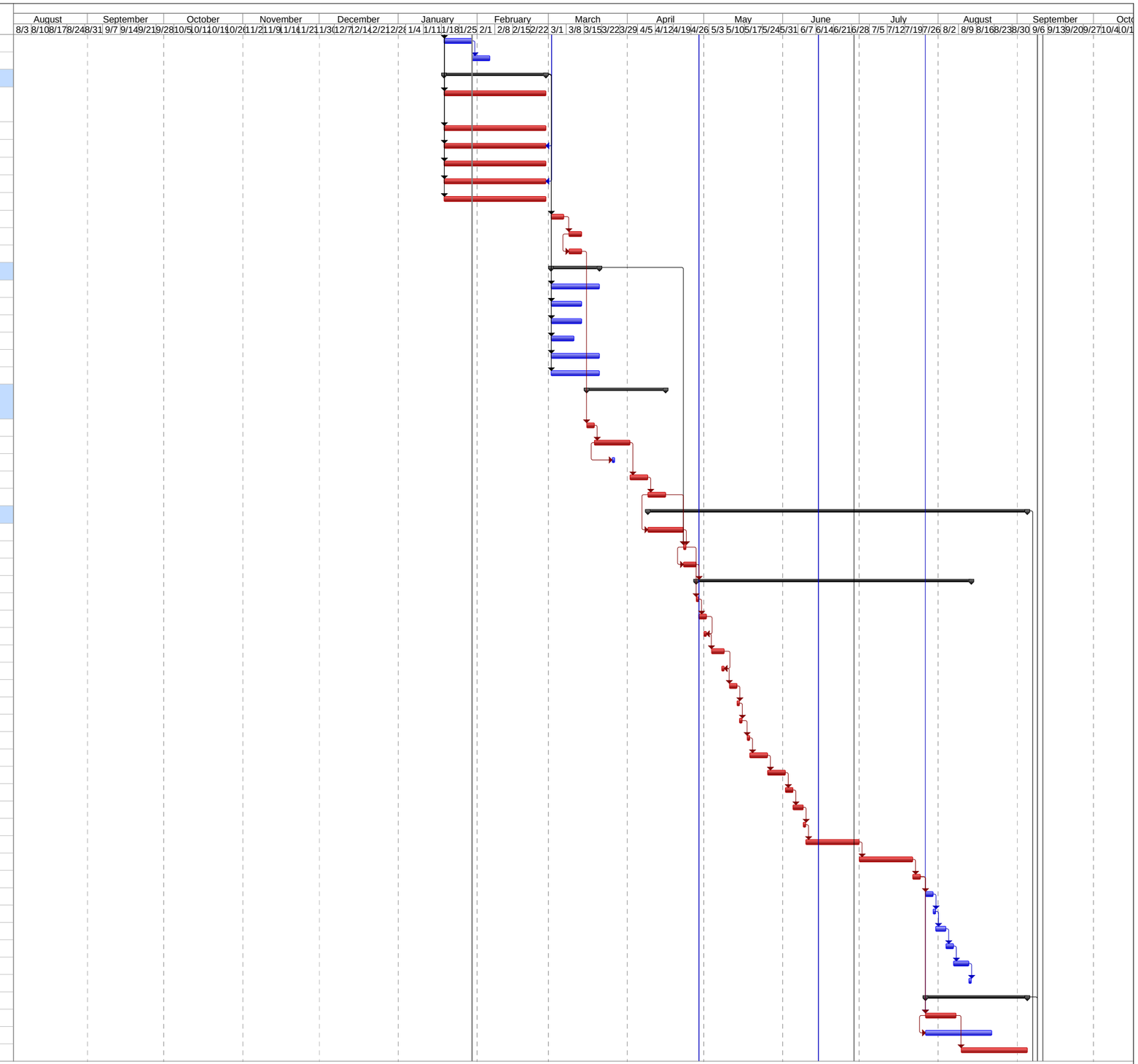
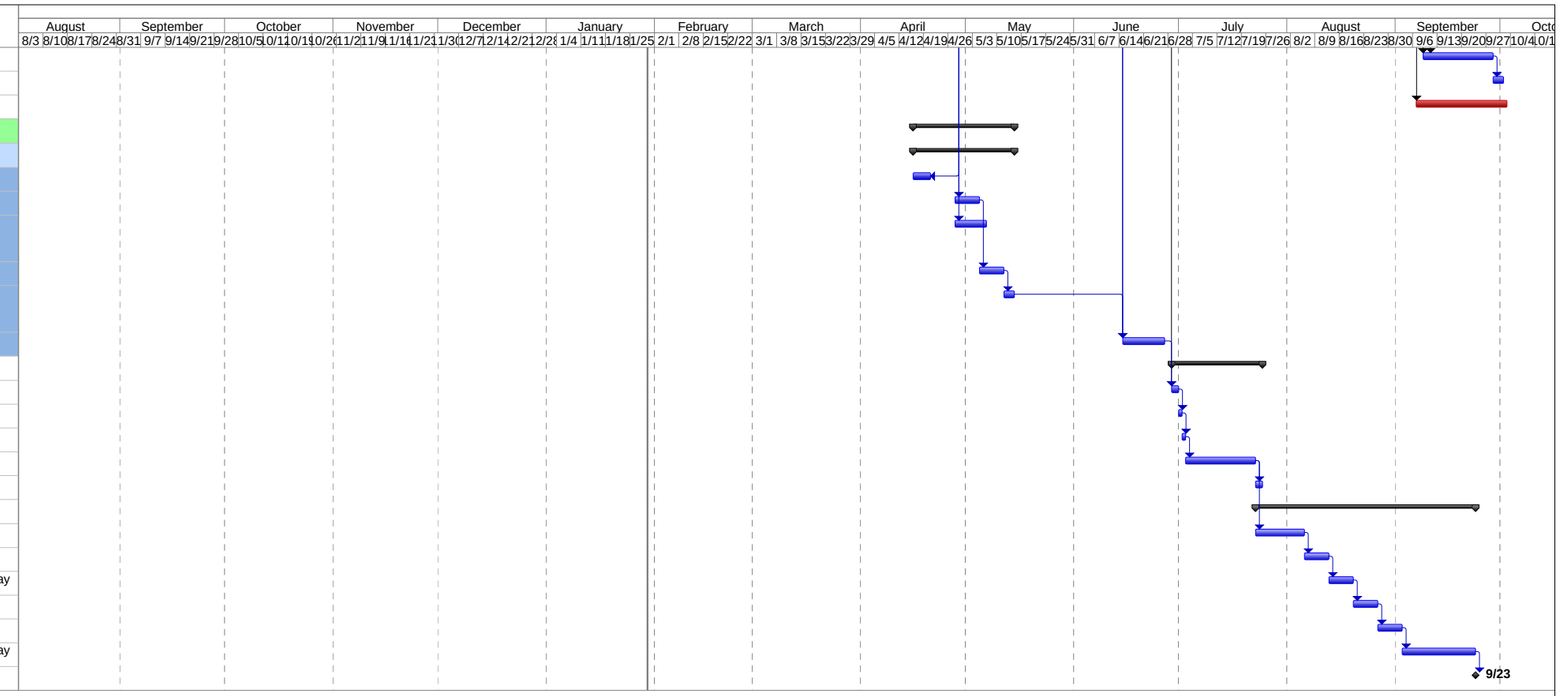
ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
193	0%	50% package review (KAFB, USACE)	11 days	9 days	Mon 1/19/15	Thu 1/29/15	
194	0%	Incorporate Comments	7 days	5 days	Fri 1/30/15	Thu 2/5/15	
195	**0%**	**Final Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
196	**0%**	**Process Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	**Received NTE Funding 1/20**
197	**0%**	**Civil Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
198	**0%**	**Structural Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
199	**0%**	**Architectural Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
200	**0%**	**Mechanical Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
201	**0%**	**Electrical Design**	**40 days**	**30 days**	**Mon 1/19/15**	**Fri 2/27/15**	
202	0%	Final package review (KAFB, USACE)	5 days	5 days	Mon 3/2/15	Fri 3/6/15	
203	0%	Incorporate Comments	5 days	5 days	Mon 3/9/15	Fri 3/13/15	
204	0%	Construction Scope Package for Bids	5 days	5 days	Mon 3/9/15	Fri 3/13/15	
205	**0%**	**Permits**	**19 days**	**15 days**	**Mon 3/2/15**	**Fri 3/20/15**	
206	0%	Environmental Impact Form	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
207	0%	KAFB Dig Permit	12 days	10 days	Mon 3/2/15	Fri 3/13/15	
208	0%	Traffic Permit	12 days	10 days	Mon 3/2/15	Fri 3/13/15	
209	0%	Fugitive Dust Permit	9 days	7 days	Mon 3/2/15	Tue 3/10/15	
210	0%	SWPPP	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
211	0%	Construction Debris Landfill	19 days	15 days	Mon 3/2/15	Fri 3/20/15	
212	**0%**	**Procurement for Construction Services**	**31 days**	**23 days**	**Mon 3/16/15**	**Wed 4/15/15**	
213	0%	Bid Package to Construction Bidders	3 days	3 days	Mon 3/16/15	Wed 3/18/15	
214	0%	Out for Bid	14 days	10 days	Thu 3/19/15	Wed 4/1/15	
215	0%	Contractor Site Walk	1 day	1 day	Thu 3/26/15	Thu 3/26/15	
216	0%	Review Bids	7 days	5 days	Thu 4/2/15	Wed 4/8/15	
217	0%	Award PO	7 days	5 days	Thu 4/9/15	Wed 4/15/15	
218	**0%**	**Construction**	**149 days**	**107 days**	**Thu 4/9/15**	**Fri 9/4/15**	
219	0%	Contractor Base Access	14 days	10 days	Thu 4/9/15	Wed 4/22/15	
220	0%	Construction Kick-Off Meeting	1 day	1 day	Thu 4/23/15	Thu 4/23/15	
221	0%	Construction Mobilization	5 days	3 days	Thu 4/23/15	Mon 4/27/15	
222	0%	Building Construction	108 days	78 days	Tue 4/28/15	Thu 8/13/15	
223	0%	Survey	1 day	1 day	Tue 4/28/15	Tue 4/28/15	
224	0%	Line Spotting	3 days	3 days	Wed 4/29/15	Fri 5/1/15	
225	0%	Proctor	1 day	1 day	Fri 5/1/15	Fri 5/1/15	
226	0%	Over Excavation	5 days	5 days	Mon 5/4/15	Fri 5/8/15	
227	0%	Compaction Testing	1 day	1 day	Fri 5/8/15	Fri 5/8/15	
228	0%	Foundation Excavation	3 days	3 days	Mon 5/11/15	Wed 5/13/15	
229	0%	Foundation FTG Forming	1 day	1 day	Thu 5/14/15	Thu 5/14/15	
230	0%	Foundation Rebar	1 day	1 day	Fri 5/15/15	Fri 5/15/15	
231	0%	Foundation Placement	1 day	1 day	Mon 5/18/15	Mon 5/18/15	
232	0%	Electrical UG	7 days	5 days	Tue 5/19/15	Mon 5/25/15	
233	0%	Plumbing UG	7 days	5 days	Tue 5/26/15	Mon 6/1/15	
234	0%	SOG Fine Grade	3 days	3 days	Tue 6/2/15	Thu 6/4/15	
235	0%	SOG Rebar	4 days	2 days	Fri 6/5/15	Mon 6/8/15	
236	0%	SOG Placement	1 day	1 day	Tue 6/9/15	Tue 6/9/15	
237	0%	CMU Block Install	21 days	15 days	Wed 6/10/15	Tue 6/30/15	
238	0%	Steel Erection	21 days	15 days	Wed 7/1/15	Tue 7/21/15	
239	0%	Roof Decking Install	3 days	3 days	Wed 7/22/15	Fri 7/24/15	
240	0%	TPO Install	3 days	3 days	Mon 7/27/15	Wed 7/29/15	
241	0%	MD Door Install	1 day	1 day	Thu 7/30/15	Thu 7/30/15	
242	0%	OH Door Install	4 days	2 days	Fri 7/31/15	Mon 8/3/15	
243	0%	Exterior CMU Painting	3 days	3 days	Tue 8/4/15	Thu 8/6/15	
244	0%	Canopy Standing Seam Roof Install	6 days	4 days	Fri 8/7/15	Wed 8/12/15	
245	0%	Gutter/Down Spout Install	1 day	1 day	Thu 8/13/15	Thu 8/13/15	
246	0%	GWTS Equipment Installation	40 days	30 days	Mon 7/27/15	Fri 9/4/15	
247	0%	Set Tanks, Vessels, & Pump Skids	12 days	10 days	Mon 7/27/15	Fri 8/7/15	
248	0%	Piping and Pipe Support Install	26 days	20 days	Mon 7/27/15	Fri 8/21/15	
249	0%	Electrical Connections	26 days	20 days	Mon 8/10/15	Fri 9/4/15	



Project: Groundwater Treatment Syste
Date: Fri 1/30/15

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Critical | Critical Split | Progress | Deadline

ID	% Compl	Task Name	Calendar	Duration	Start	Finish	Notes
250	0%	Commissioning	20 days	14 days	Wed 9/9/15	Mon 9/28/15	
251	0%	Construction Demobilization	3 days	3 days	Tue 9/29/15	Thu 10/1/15	
252	0%	As-Built Drawings	26 days	20 days	Mon 9/7/15	Fri 10/2/15	
253	**0%**	**Temporary Treatment System**	**29 days**	**21 days**	**Thu 4/16/15**	**Thu 5/14/15**	
254	**0%**	**Treatment System Construction**	**29 days**	**21 days**	**Thu 4/16/15**	**Thu 5/14/15**	
255	0%	Site Prep	5 days	3 days	Thu 4/16/15	Mon 4/20/15	
256	0%	Set Tanks, Vessels, & Pump Skids	7 days	5 days	Tue 4/28/15	Mon 5/4/15	
257	0%	Aboveground Discharge Piping & Sprinklers	9 days	7 days	Tue 4/28/15	Wed 5/6/15	
258	0%	Piping and Pipe Support Install	7 days	5 days	Tue 5/5/15	Mon 5/11/15	
259	0%	Electrical Connections at Treatment System	3 days	3 days	Tue 5/12/15	Thu 5/14/15	
260	0%	Commissioning/Initial Start-up	12 days	10 days	Mon 6/15/15	Fri 6/26/15	
261	**0%**	**Aquifer Testing**	**26 days**	**20 days**	**Mon 6/29/15**	**Fri 7/24/15**	
262	0%	Mobilization for aquifer testing	2 days	2 days	Mon 6/29/15	Tue 6/30/15	
263	0%	Well KAFB-106228 step-testing	1 day	1 day	Wed 7/1/15	Wed 7/1/15	
264	0%	Recovery period following well KAFB-106228 step-testing	1 day	1 day	Thu 7/2/15	Thu 7/2/15	
265	0%	Well KAFB-106228 drawdown/recovery aquifer testing	20 days	14 days	Fri 7/3/15	Wed 7/22/15	
266	0%	Demobilization for aquifer testing activities	2 days	2 days	Thu 7/23/15	Fri 7/24/15	
267	**0%**	**Aquifer Testing Report**	**63 days**	**45 days**	**Thu 7/23/15**	**Wed 9/23/15**	
268	0%	Prepare Draft Aquifer Testing Report	14 days	10 days	Thu 7/23/15	Wed 8/5/15	
269	0%	USACE and KAFB review of Draft Aquifer Testing Report	7 days	5 days	Thu 8/6/15	Wed 8/12/15	Up from 1 day
270	0%	NMED Review of "Look Ahead" Aquifer Testing Report	7 days	5 days	Thu 8/13/15	Wed 8/19/15	Down from 10 day
271	0%	Prepare Final Aquifer Testing Report	7 days	5 days	Thu 8/20/15	Wed 8/26/15	
272	0%	Commander signature for offical submital	7 days	5 days	Thu 8/27/15	Wed 9/2/15	
273	0%	NMED review of Final Aquifer Testing Report	21 days	15 days	Thu 9/3/15	Wed 9/23/15	Down from 20 day
274	0%	NMED approval of Final Aquifer Testing Report	0 days	0 days	Wed 9/23/15	Wed 9/23/15	



Project: Groundwater Treatment Syste
Date: Fri 1/30/15

Task | Milestone | Project Summary | External Milestone | Inactive Milestone | Manual Task | Manual Summary Rollup | Start-only | Critical | Progress
Split | Summary | External Tasks | Inactive Task | Inactive Summary | Duration-only | Manual Summary | Finish-only | Critical Split | Deadline

EDB Interim Measure Implementation Plan

The Air Force wants to reconfirm to the New Mexico Environment Department (NMED) our continued commitment to developing a robust and sustainable remediation plan for the Kirtland Air Force Base (AFB) Bulk Fuels Facility (BFF). The cohesive approach that we are actively developing in concert with NMED and other stakeholders will address all phases of the jet-fuel contamination including the dissolved-phase ethylene dibromide (EDB) plume and the residual contamination in the source area and BFF vadose zone. The Air Force's goal is to ensure that the remedial actions we deploy are, and will remain, protective of the citizens of Albuquerque, their drinking water resource, and the environment.

As you know, the Air Force and NMED have been working diligently over the past 6 months to develop a well-planned and robust interim measure for the dissolved-phase EDB plume. The Air Force presented the approach in the August 1, 2014 work plan, which NMED approved on August 20, 2014. The Air Force began to implement the work plan by submitting the drilling permit application to the New Mexico Office of the State Engineer (NMOSE) on September 26, 2014. Additionally, NMED requested drilling progress to be provided weekly as a condition in the NMED approval letter. The Air Force determined that more frequent updates were warranted and started submitting daily drilling summary reports on December 3, 2014, the day that the drillers were on site preparing to drill the first wells in the interim measures work plan. The Air Force will continue to submit daily updates throughout the drilling operations to meet the drilling reporting requirement as specified in the NOV Attachment A.

The Air Force is submitting this EDB Interim Measure Implementation Plan to provide the information that NMED requested in the January 15, 2015 NOV letter. The plan below is structured in accordance with the requested elements to facilitate the review and ensure that the plan meets the NMED-specified requirements.

Element 1: 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.

A detailed schedule has been prepared to show the completion dates for all of the actions described in the subject work plan, the October 9, 2014 Work Plan Addendum 1, and the post-NOV letter January 26, 2015 Work Plan Addendum 2. The work plan and the two addenda have received NMED's approval. The schedule is provided as Attachment 1 to this implementation plan.

Element 2: An aquifer pilot-test work plan for the hydraulic testing of extraction well 106228.

A work plan titled "Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan" has been prepared in accordance with the EPA "Suggested Operating Procedures for Aquifer

Pumping Tests" and the work plan included procedures that were followed during previous aquifer tests at the BFF and that have been approved by NMED. A copy of the draft work plan is provided as Attachment 2 to this implementation plan.

Element 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.

Descriptions of the remaining actions and milestones and the Air Force's commitments to provide the associated work plans and reports are described under the sub-elements below.

Sub-Element 3.a: Additional aquifer performance testing.

Work plans for additional aquifer performance testing will be developed in conjunction with NMED during the planning for installation of the additional extraction wells in calendar years (CY) 2015 - 2016.

Sub-Element 3.b: Aquifer test reports for extraction well 106228 and other tested wells.

A draft aquifer test report for extraction well KAFB-106228 will be submitted within 42 days of the aquifer test completion, as described in the "Groundwater Extraction Well KAFB-106228 Aquifer Pilot-Test Work Plan" see Attachment 2. Additional aquifer test reports will be submitted after aquifer tests are completed on future extraction wells.

Sub-Element 3.c: Computer modeling of groundwater flow paths, travel times and extraction-well capture zones as necessary to locate and design additional extraction wells.

The Hydrogeology and Modeling Working Groups determined that groundwater modeling will be used to evaluate groundwater flow paths, travel times, and extraction-well capture zones. Preliminary model simulations will be run to show the effectiveness for positioning wells and identifying potential extraction well locations. The Modeling Working Group will use this information to locate and design additional extraction wells for CY 2015. Modeling will be recalibrated using data from the KAFB-106228 aquifer test and this recalibrated model will then be used to refine the future locations and design of the additional extraction wells for CY 2016. The placements and designs of the extraction wells will be finalized through the Modeling Working Group.

Sub-Element 3.d: Drilling and construction of additional monitoring wells, if necessary, to define the horizontal and vertical extent of EDB contamination.

Following the installation and sampling of the five new groundwater-monitoring-well clusters (KAFB-106213 to KAFB-106227) and the probe well (KAFB-106212), the Air Force will submit completion reports. Additionally, the monitoring data from these new wells will be

reviewed with NMED and determine whether and where additional monitoring wells may be necessary to define the horizontal and vertical extent of dissolved-phase contamination.

Sub-Element 3.e: Drilling and construction of additional monitoring wells, if necessary, to conduct aquifer performance testing.

The need for additional monitoring wells for aquifer testing on the future extraction wells will be dependent on the locations of the extraction wells, as determined under Sub-Element 3.c, and the proximity of those wells to existing monitoring wells. Upon finalizing the extraction well locations, the need for additional monitoring wells to effectively observe the aquifer response to pumping will be discussed with NMED and Hydrogeology Working Group prior to preparing the aquifer performance work plans described in Sub-Element 3.a.

Sub-Element 3.f: Drilling and construction of up to seven additional extraction wells, anticipated to include three wells in 2015 and four wells in 2016.

The Air Force is committed to install three additional extraction wells in the portion of the dissolved-phase EDB plume that is down gradient of extraction well KAFB-106228 within CY 2015. Up to four more extraction wells are planned to be installed in portions of the dissolved-phase of the EDB plume that is up gradient from extraction well KAFB-106228 during CY 2016. The number of, and locations for, the additional extraction wells will be based on the model simulations using the models for CY 2015 and the recalibrated models for CY 2016. The results and subsequent extraction well work plans will be developed in conjunction with NMED and the Hydrogeology and Modeling Working Groups.

Sub-Element 3.g: Modifications, if necessary, to the collection, treatment and disposal system for extraction water.

The "temporary" collection, treatment and disposal system for the extracted groundwater will be operational by June 30, 2015 and the "permanent" system will be operational in the CY 2015 as described in the August 1, 2014 Groundwater Extraction Pilot Implementation and Additional Plume Characterization Work Plan, and the subsequent addenda. Both systems are designed to ensure that the extracted water is treated to meet or exceed discharge criteria as defined in the discharge permit approved by NMED's Ground Water Quality Bureau and will be monitored to verify that performance. Any modifications required to achieve the discharge criteria will be evaluated in conjunction with NMED and if required implemented under a NMED-approved work plan.

Sub-Element 3.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 Hydrogeology Working Group reviewed, discussed, and formulated recommendations to optimize the current quarterly groundwater monitoring program on February 17-18, 2015. The

recommendations focus on incorporating the data quality objective (DQO) process to ensure that the data collected are sufficient and necessary to monitor the effectiveness of the interim measure, inform remediation process optimization decisions, and to ensure protection of the drinking water supply wells. The Working Group is continuing their discussions and will develop the final set of groundwater monitoring program optimization recommendations. Once the recommendations are finalized, the Air Force will prepare a proposal detailing the recommended quarterly groundwater monitoring program modifications. The proposal will be submitted to NMED by May 30, 2015 for review and approval. Upon approval, the modifications will immediately be incorporated into the groundwater monitoring program.

Attachment 1: Interim Measure Implementation Schedule

Attachment 2: Draft Groundwater Extraction Well KAFB-106228 Aquifer Testing Work Plan