APPENDIX H

Slug Test Results

H-1. Slug Testing

H-2. Field Verification of Test Procedures

H-3. Individual Slug Test Analyses Sheets

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
KAFB	Kirtland Air Force Base
PSI	pounds per square inch
QC	quality control
Shaw	Shaw Environmental & Infrastructure, Inc.
Ss	Specific Storage

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H-1. SLUG TESTING

Shaw Environmental & Infrastructure, Inc. (Shaw) is doing work to characterize a fuel plume originating from a spill at the Bulk Fuels Facility on Kirtland Air Force Base (AFB) in Albuquerque, New Mexico. Jet fuel which leaked from the facility has migrated through the vadose zone and into the aquifer approximately 500 feet below ground surface. Slug tests were performed in selected wells at Kirtland AFB and in adjacent neighborhoods to obtain detailed, site-specific information to aid in modeling the extent of light non-aqueous phase liquid, dissolved phase migration and groundwater flow velocities across the site. Figure H-1 shows the locations where slug tests were performed. The data can be used to obtain an estimate of the spatial variability of the hydraulic conductivity of the aquifer system at the site and to assist in the design of subsequent pumping tests.

Among the parameters derived from the aquifer tests are the following:

- Hydraulic conductivity
- Specific storage (Ss)
- General aquifer characteristics (i.e., does the aquifer occur under confined, unconfined, or other conditions, are boundaries observed, do water levels fluctuate over the testing period?)

These hydrologic data were derived from observation and interpretation of water-level responses to stresses applied to the aquifer system through the introduction of a “slug” into or withdrawal of the “slug” from the well. The test procedures, analytical methods, assumptions and results are described below. Table H-1 summarizes the results shown on the individual analyses sheets (Section H-3). Analyses sheets provide graphs of the water level data over time, well and test specifications, the analytical method, the test parameters and the straight-line or curve matching fit used to estimate hydraulic conductivity (K). The table summarizes the values from the different tests performed at each well and for different analyses performed on each test. The table also shows the single recommended value for each well selected from the results. Laboratory test data and the results of field logging from the screened interval are also summarized for comparison.

1.1 Testing Procedures and Test Nomenclature

A slug test is an aquifer test in which the water level in a well is “instantaneously” changed by removing, adding, or displacing a known volume of water. At Kirtland AFB, two procedures were used to accomplish this displacement, a mechanical slug and a pneumatic test. The procedures for the two methods are discussed separately in the following sections. Diagrams of the methods are provided in Figure H-2.

During the performance of the mechanical slug test, the response of a well to a rapid change in water level may vary between slug-in and slug-out testing if a significant section of unsaturated aquifer (dry screen length) occurs in the well. As noted by Bouwer (1989), the slug test was initially developed for rising water-level conditions (slug-out), and slug-in tests are potentially influenced by the re-saturation of the upper portion of the well. For this reason, the data are segregated according to the mode of water displacement (“in” or “out”). For the pneumatic tests, four tests were performed at each well with varying initial pressures, labeled as P1, P2, P3 and P4. Therefore, the individual tests are designated in the table and test sheets by the prefix Kirtland AFB, before the well name (e.g., 106030 followed by the test type (in/out or P1/P2/P3/P4) followed by the initials of the analytical method. Test KAFB106030IN-BR represents the Bouwer and Rice solution for the “in” test at Kirtland AFB well number 106030.

1.2 Mechanical Slug Tests

Mechanical slug tests were performed in wells screened across the water table. Shaw performed 36 injection or withdrawal tests in 18 wells to obtain an estimate of aquifer hydraulic conductivity in the tested wells. A known volume was added to or removed from (assumed instantaneously) each tested well using a steel slug lowered into the well on the free-line of a well development rig (Figure H-2). Two sizes of slug were used. A 2.4-inch-diameter, 9.8-foot-long slug was used in 4-inch-diameter wells. A 3.4-inch-diameter, 10.1-foot-long slug was used in 5-inch-diameter wells. For the “in” test, the slug was slowly lowered into the well casing until it was positioned just above the water table. When the testing equipment was positioned and the water level was stabilized, the slug was moved as rapidly as possible into the water until it was totally submerged. During the “out” test the slug was pulled from the water as rapidly as possible until it was suspended totally above the water.

Following the rapid lowering or withdrawal of the slug, the water-level response in the well was monitored over time. Because the tests require accurate, rapidly recorded water level data, Troll 700™ pressure transducers and data loggers were used to collect these data. The data logs are on file and can be provided if necessary. Logging was ended when water level returned to pre-test levels and stabilized.

1.3 Pneumatic Slug Tests

In the pneumatic slug test, the wellhead is sealed and air is pumped into the well (Figure H-2). The increased air pressure lowers the water level in the well. When the water level is stabilized at the desired level (pressure), the pressure is released at the well head through a large-diameter valve. The rapid release of the air pressure represents a removal of a “slug” of water the size of the casing radius and the differential of the water levels before and after the well is pressurized.

The pneumatic slug tests were performed in wells screened below the water table, where the well casing could maintain the pressure. Shaw performed 76 pneumatic slug tests in 19 wells to obtain an estimate of aquifer hydraulic conductivity in the tested wells.

As with the mechanical slug tests, Troll 700™ pressure transducers and data loggers were used to collect the water level recovery data. Butler et al. (2003) recommends placing the transducer close to the static water surface in the well to avoid having potentially inaccurate readings due to varying transducer depths in the well. Therefore, the transducers were all placed between 2.5 and 2.2 feet from the static water surface during the pneumatic tests. Four tests were performed in each well, P1 with a pressure increase of 0.6 to 0.7 pounds per square inch (PSI), P2 with an increase of 0.4 to 0.5 PSI, P3 with an increase of 0.2 PSI, and P4 with an increase of 0.7-0.8 PSI.

1.4 Data Analysis

The slug test data were analyzed in the following iterative fashion:

1. Basic assumptions used in the AQTESOLV software were defined and tested.
2. Multiple analyses were performed to determine the most appropriate analytical method for each test.
3. The data in Table H-1 were summarized and the results from all the tests were compared to determine the most appropriate value for each individual well.
4. The selected slug test conductivity data for the wells were compared to laboratory data and field descriptions from the boring logs to provide observations and conclusions regarding the hydrogeologic conditions.
5. Tests were repeated on four wells to field verify consistency of test procedures (Section H-2).

1.4.1 Defining and Testing the Analytical Assumptions

Initially, the following assumptions were used during the analyses:

- The aquifer is unconfined.
- Wells are partially penetrating with an aquifer thickness of at least 100 feet.
- The conductivity of the sand pack is similar (within an order of magnitude) to the conductivity of the surrounding materials.

- The wells are capable of producing an oscillatory water level change following the slug removal.
- Slug withdrawal or injection is instantaneous.

Each of these assumptions was tested during the analysis of the results and several assumptions were changed to reflect the observed conditions.

1.4.1.1 Confined vs Unconfined

Initially, the aquifer was assumed to respond as an unconfined aquifer because no confining layers were observed, and the aquifer material is porous. The unconfined nature of the aquifer (for purposes of the analytical methods) was questioned because the type curve matches performed using the KGS (Hyder et. al., 1994) method were a better fit using lower storativity values. These analyses calculated a vertical to horizontal (Kv/Kr) ratio of approximately 0.001. In addition, the laboratory analyses of Kv are generally lower than corresponding slug test analyses of Kh. Therefore, in most cases, it appeared the appropriate analytical methods may be those recommended for confined aquifers. The majority of the analyses performed used methods applicable to either confined or unconfined aquifers (Bouwer and Rice, Butler-Zhan, or KGS Solution).

1.4.1.2 Partial Penetration

The initial assumption was that the wells are partially penetrating and the aquifer thickness is at least 100 feet. Sensitivity analyses performed for the slug tests indicated that aquifer thickness was not a significant input for these analyses. The analytical methods used do not calculate transmissivity or specific yield and therefore, the aquifer thickness is not required for calculating the hydraulic conductivity or storativity. In the final solutions, sand pack thickness was used for aquifer thickness.

1.4.1.3 Sand Pack Effects

Initially the conductivity of the sand pack was assumed to be similar (within an order of magnitude) to the conductivity of the surrounding materials. As the testing proceeded and the KGS solution (which allows the use of "skin effects" in the calculation) was performed, skin effects were evident in some wells. The sand pack conductivity was estimated from some of the KGS analyses to be approximately 180 feet per day. Because the sand pack material installation techniques were identical in all the wells, the value estimated from the early KGS analyses was extrapolated to the other KGS solutions.

1.4.1.4 Oscillatory Water Level Changes

Slug tests performed in high hydraulic conductivity aquifers may produce oscillatory water level changes in the test well following the slug removal or injection. The hydraulic conductivities in the aquifer below Kirtland were initially assumed to be capable of these types of oscillatory response. Care was taken during the analyses to check for oscillatory water level changes and use analytical methods which were capable of addressing inertial effects (Butler and Zhan, 2004; Springer and Gelhar, 1991), if necessary. Most tests followed the classic smooth (non-oscillatory) water level change and were analyzed using techniques for those types of response.

1.4.1.5 Instantaneous Slug Withdrawal or Injection

Every effort was made to introduce the slugs or relieve the pressure in the well as quickly as possible during the slug tests. However, both processes, mechanical and pneumatic, took a small amount of time, usually 1 to 2 seconds. Lowering or raising the slug on the development rig free line could not be performed safely in less time. For the pneumatic tests, air was flowing from the well head one to two seconds after the valve was opened even with a two-inch ball valve installed on the well head to release the air pressure. Accordingly the very early time data is not considered to be accurate in most of the slug tests. Late time data (data collected more than 2 seconds after the introduction or withdrawal of the slug) was considered more reliable. A review of the results on the test sheets (Section H-3) demonstrates relatively good matches after the initial 2 seconds.

1.4.2 Performing Multiple Analyses

A number of analytical methods were available for the interpretation of slug test data. The interpretations were implemented using the AQTESOLV groundwater modeling software package (Dufield, 1999). Multiple analyses were performed using differing methodologies. After a review of the results, one test was selected as most representative. The tests performed are documented in the test sheets in Section H-3 and are summarized on Table H-1, which also shows the hydraulic conductivity selected for future use for each well.

1.4.2.1 Bouwer and Rice

The initial analysis of each test was performed using a straight line matching approach (Bouwer and Rice, 1976). The Bouwer and Rice interpretation was performed as a first approximation of the hydraulic conductivity. Although it was originally developed for unconfined aquifers, this method has also been shown to be reliable for confined aquifer conditions. Because the analysis was universally performed and can be used to provide a relative comparison between all the wells, the Bouwer and Rice interpretation is shown on Table H-1 for all wells.

1.4.2.2 Curve Matching Interpretations

Once the straight line Bouwer and Rice interpretation was completed, various curve matching interpretations were used and the results of the curve-matching analysis with the best fit was added to the summary table. Methods used were Butler-Zhan (2004) inertial (test well), KGS Model (1994) with skin, and Springer-Gelhar (1991) inertial. The aquifer did not clearly respond as either confined or unconfined. Therefore, analyses for both conditions were performed and the final result selected from the best fit.

Table H-1 shows the results for the Springer-Gelhar test and either the Butler-Zhan or KGS test results for all wells.

1.4.3 Comparison to Laboratory and Field Characterization Results

The slug test results compared to the laboratory test results for soils sampled within the same screened interval are shown on Figure H-3.

The slug test results compared to the characterization of the materials noted on the boring logs are summarized in a histogram on Figure H-4. The figure indicates that United Soil Classification System soil types as characterized in the boring logs are not easily correlated to conductivity ranges.

1.5 Results

The results of the tests and analyses are described in this section. Table H-1 summarizes the analyses. Graphs of the tests and analyses can be found in Section H-3 and Figure H-5 shows the spatial variability of hydraulic conductivities determined by slug testing.

1.5.1 General Observations and Conclusions

- The results of the slug tests are internally consistent within each well
- Slug tests are performed consistently, and slug test types yield results consistent with one another.
- The results of the slug tests are within the ranges expected for units ranging in grain size from silty sand to gravel.
- Some component of vertical anisotropy was observed in all the tests.
- Results that might indicate boundary conditions were not observed.
- At the scale of the well screen, a vertical distance of 5 to 15 feet, the soil type observed in the boring log and the hydraulic conductivity measured by the slug tests do not appear to have a strong correlation.

- Soil types which could be considered to create confining or semi-confining layers are not observed in either the slug or laboratory tests.

1.5.2 Specific Results

- The aquifer in the vicinity of the Kirtland AFB wells has a mean hydraulic conductivity of 72 feet/day with a minimum of 41 feet/day and a maximum of 127 feet/day.

- Average Ss of the aquifer is .001.

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H-2. FIELD VERIFICATION OF TEST PROCEDURES

Slug tests were repeated on four of the wells for quality control (QC) evaluation of the field methods. Two of the wells (KAFB 106032 and 106038) are shallow wells, and so the mechanical slug test method was used for both initial and QC tests. The other two wells (KAFB 106089 and KAFB 106096) are intermediate and deep respectively. On these, the pneumatic method was used for the initial tests and both the pneumatic and mechanical methods were used for the QC test. The data from these tests is found on Table H-1, and the individual test results are in Section H-3. The QC tests were run to confirm the assumptions that:

1. Slug tests are performed consistently and yield consistent results
2. Slug test types will yield results consistent with each other

2.1 Consistency within Tests

The difference was taken between the solutions for the initial and QC tests for all test and solution types in each of the four wells. These differences were all found to be within two standard deviations of the mean.

For each type of test (IN, OUT, P1, P2, P3), the differences in the solutions between initial and QC tests were within two standard deviations of the mean, with the “out” tests having the lowest mean and standard deviation.

Types of solutions (Bower-Rice, curve matching, and SG) were compared, and the differences between initial and QC tests were all within two standard deviations of the mean, with the curve matching (Butler-Zhang or KGS) having the lowest mean difference.

For each test, the solutions chosen for the initial and QC tests were within the same order of magnitude.

These results show that slug testing was performed consistently and yielded consistent data.

2.2 Consistency Between Methods

Both pneumatic and mechanical slug tests were performed on KAFB 106089 and 106096 to compare the two methods.

The conductivity values for each solution type (Bower-Rice, curve matching, and SG) were compared for each well, and found to all be within two standard deviations of the mean.

The chosen solutions for the initial test and both the QC-pneumatic and QC-mechanical tests were within the same order of magnitude for each well.

These results show that the two types of slug tests give comparable data, and it is acceptable to use whichever test is more appropriate for the circumstances.

2.3 References

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Bouwer, H., and R.C. Rice. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research 12, no. 3: 423–428.

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Hyder, Z. et. al. 1994. Slug tests in partially penetrating wells, Water Resources Research, vol. 30, no. 11, pp. 2945-2957.

Springer, R.K., and L.W. Gelhar. 1991. Characterization of large-scale aquifer heterogeneity in glacial outwash by analysis of slug tests with oscillatory response. USGS Water Resource Investigations Report 91-4034. Cape Cod, Massachusetts: USGS

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APPENDIX H

Figures

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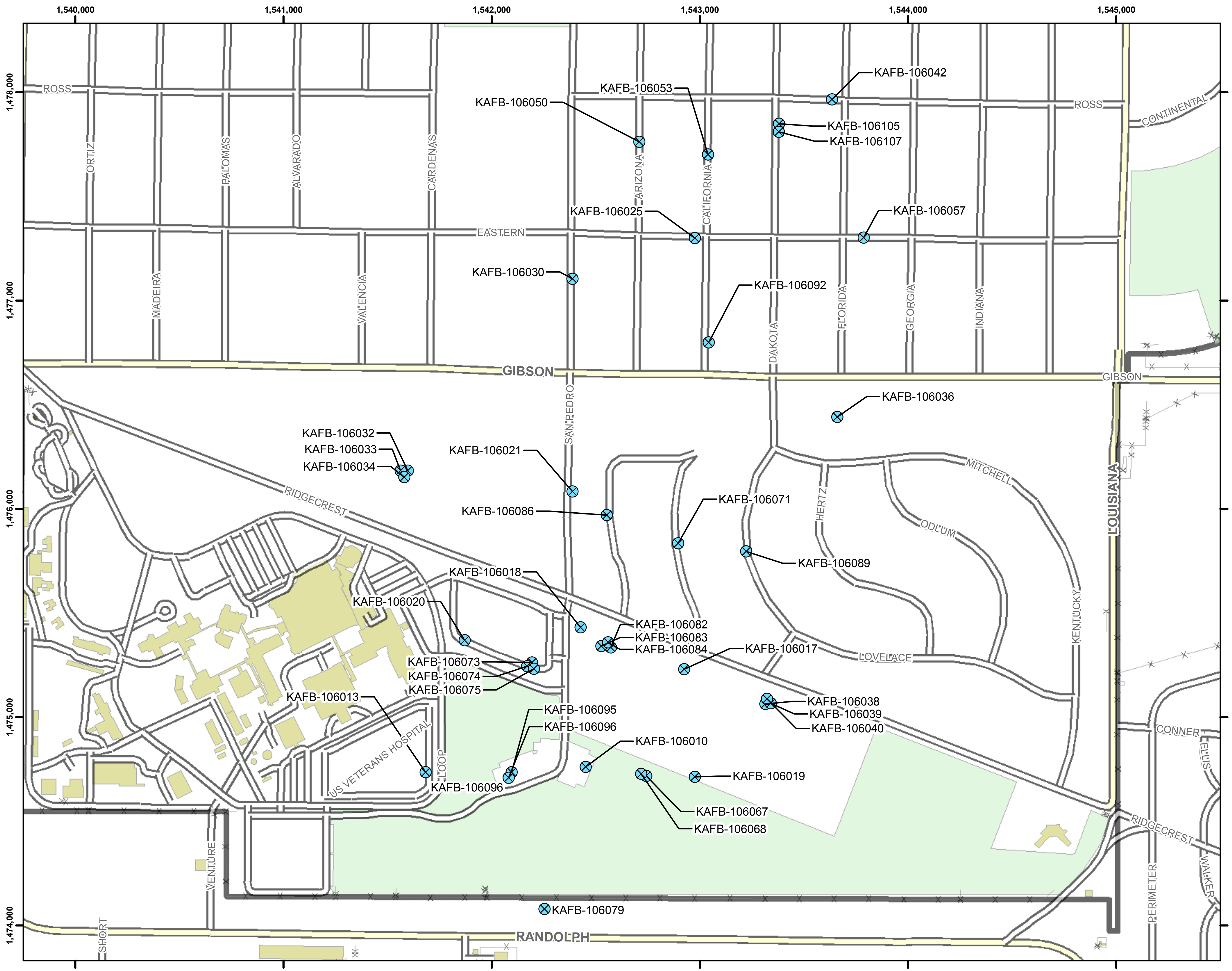

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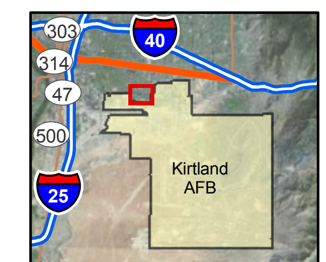
Legend

- Slug Test Locations
- Fence
- Interstate
- Major Road
- Road
- Structure
- Runway
- Park
- Installation Boundary



SITE LOCATION

Revision Date: 11/14/11

N

0 250 500 1,000

Feet

1 inch = 500 feet

Projection : NAD83 State Plane New Mexico Central FIPS3002 Feet

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FIGURE H-1

SLUG TEST LOCATIONS

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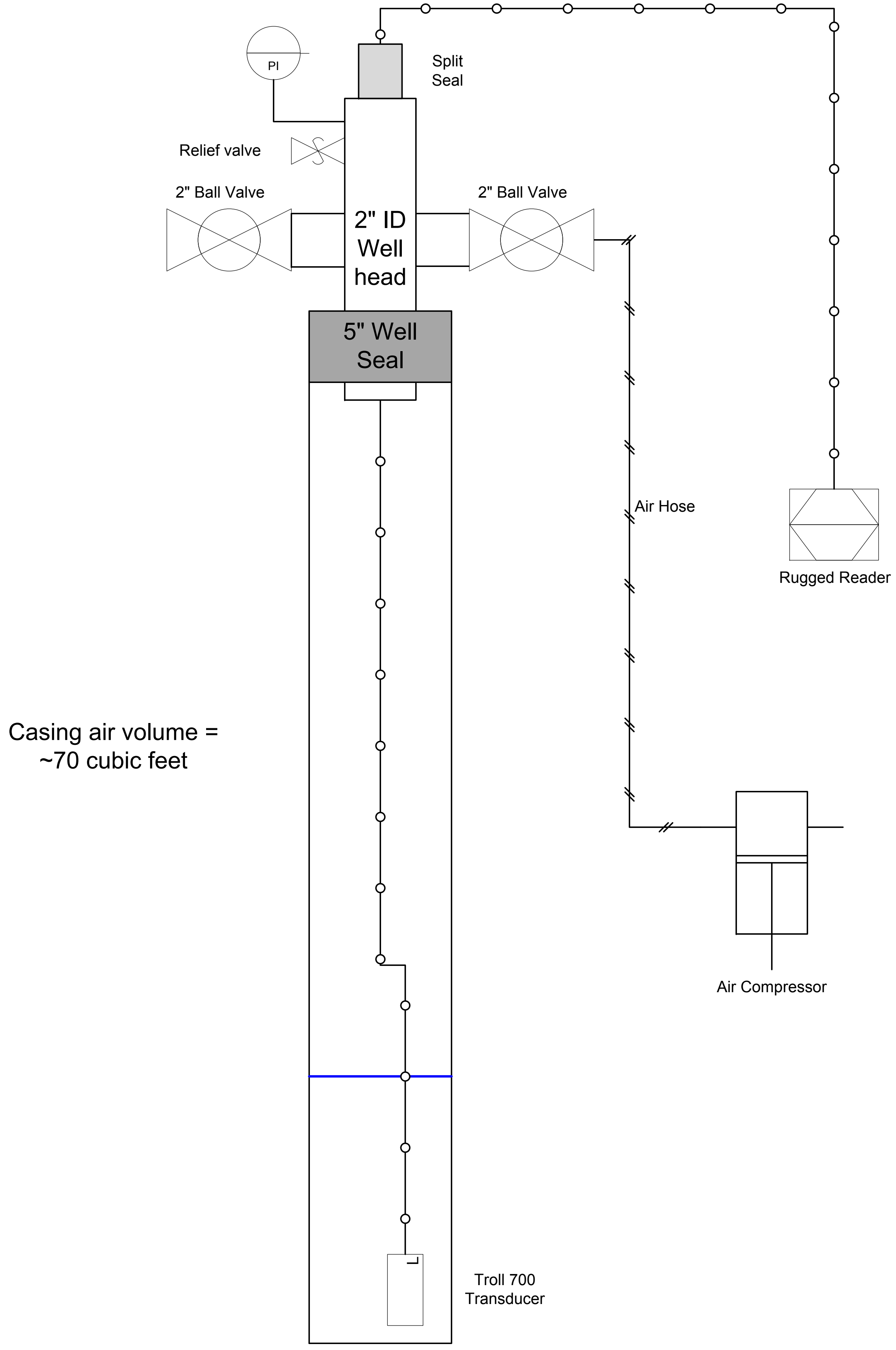
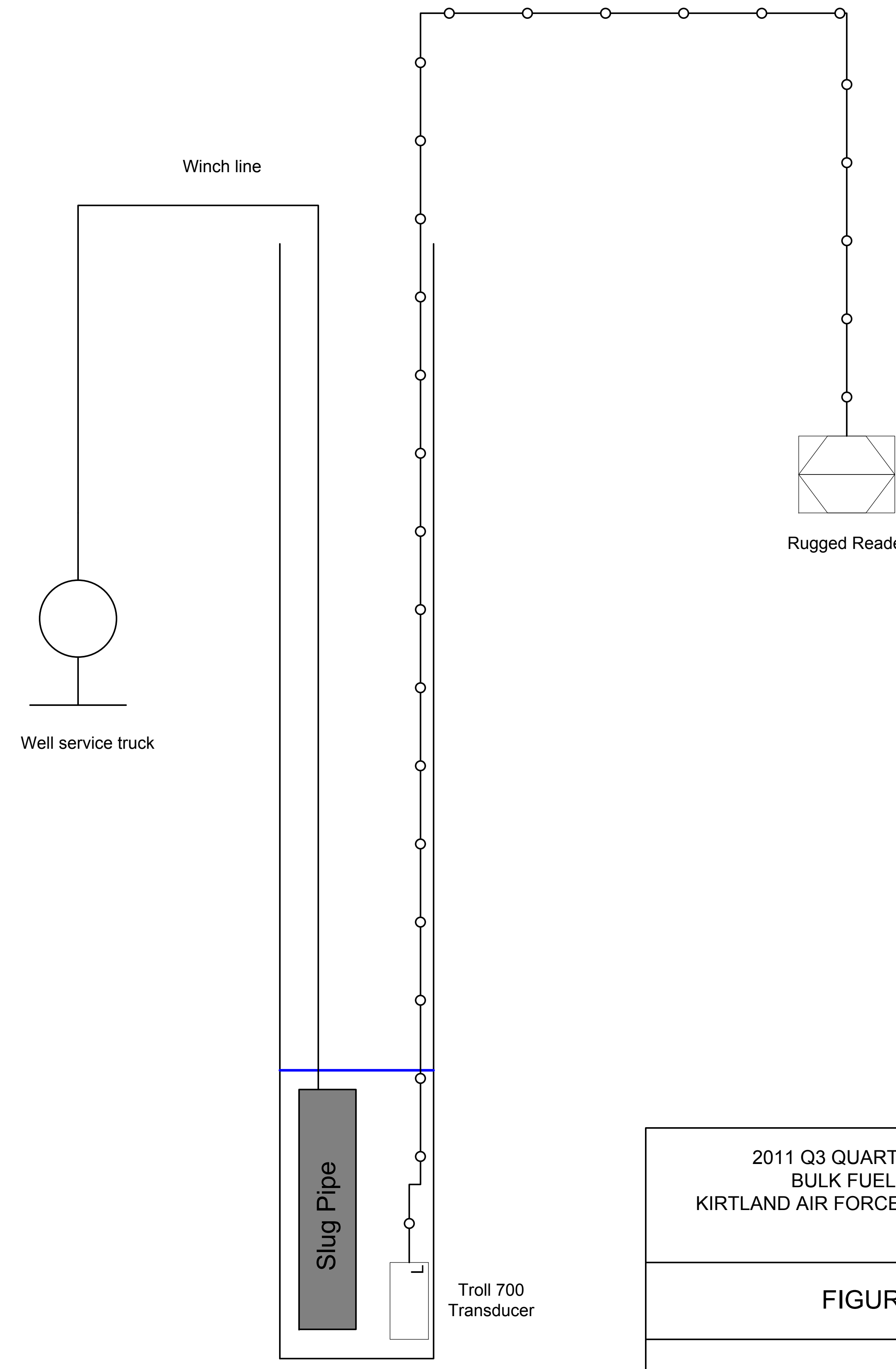


Pneumatic Slug Test Setup



Solid Slug, Slug Test Setup

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FIGURE H-2

SLUG TEST SETUPS

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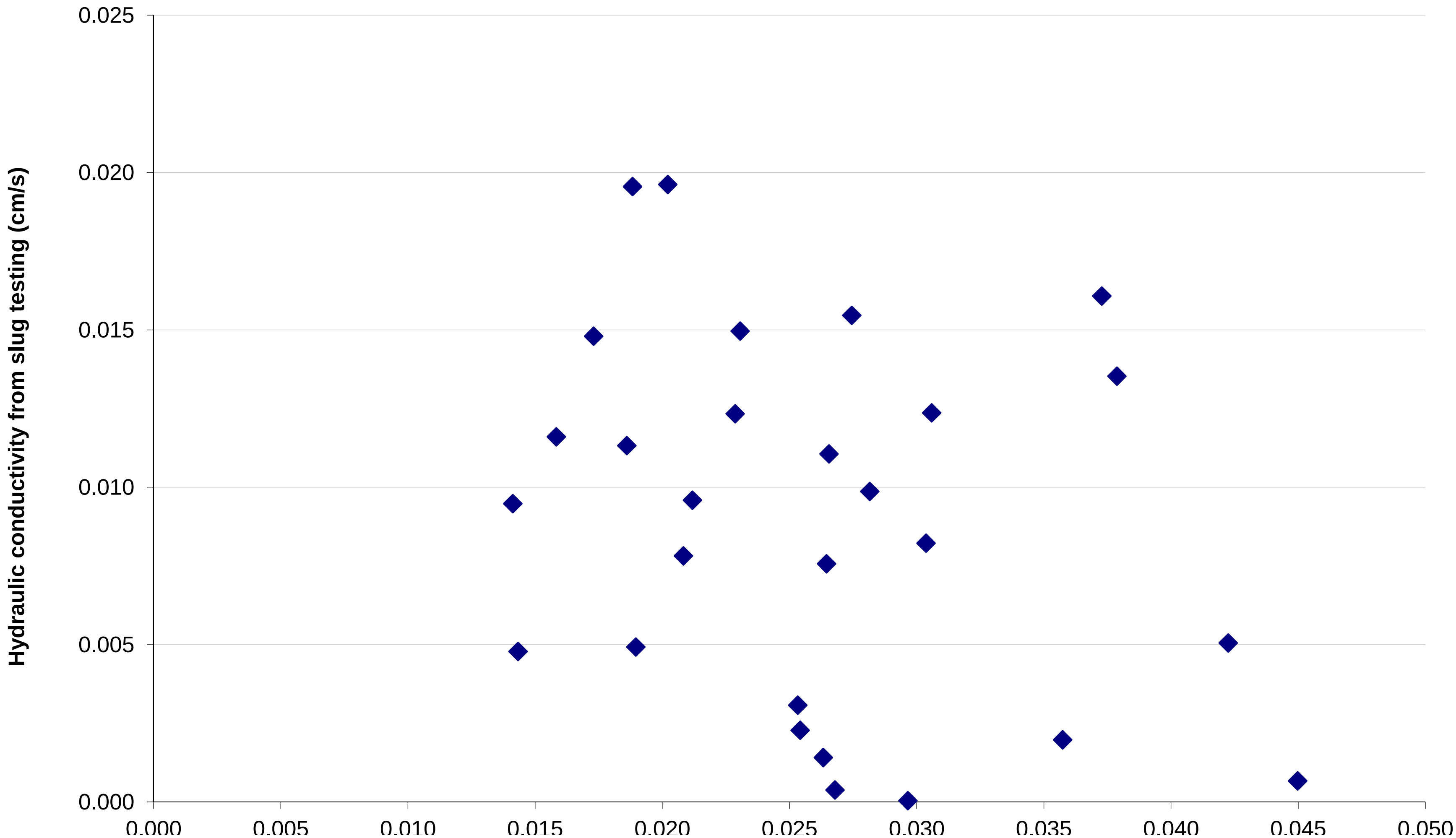
Figure H-3
Hydraulic conductivities from slug testing vs hydraulic conductivities from lab analysis



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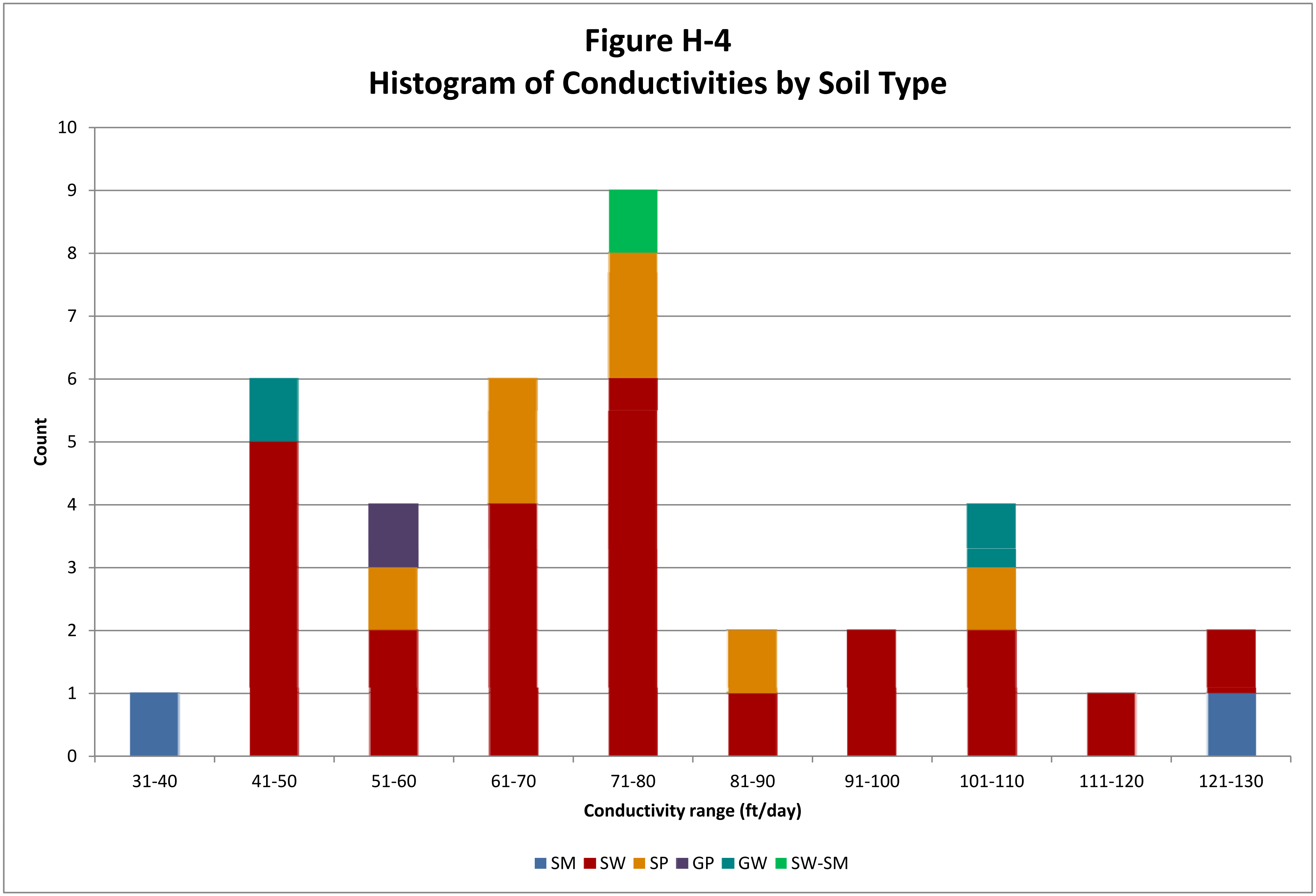
Figure H-4
Histogram of Conductivities by Soil Type
Count
0
1
2
3
4
5
6
7
8
9
10
31-40
41-50
51-60
61-70
71-80
81-90
91-100
101-110
111-120
121-130
Conductivity range (ft/day)
SM
SW
SP
GP
GW
SW-SM

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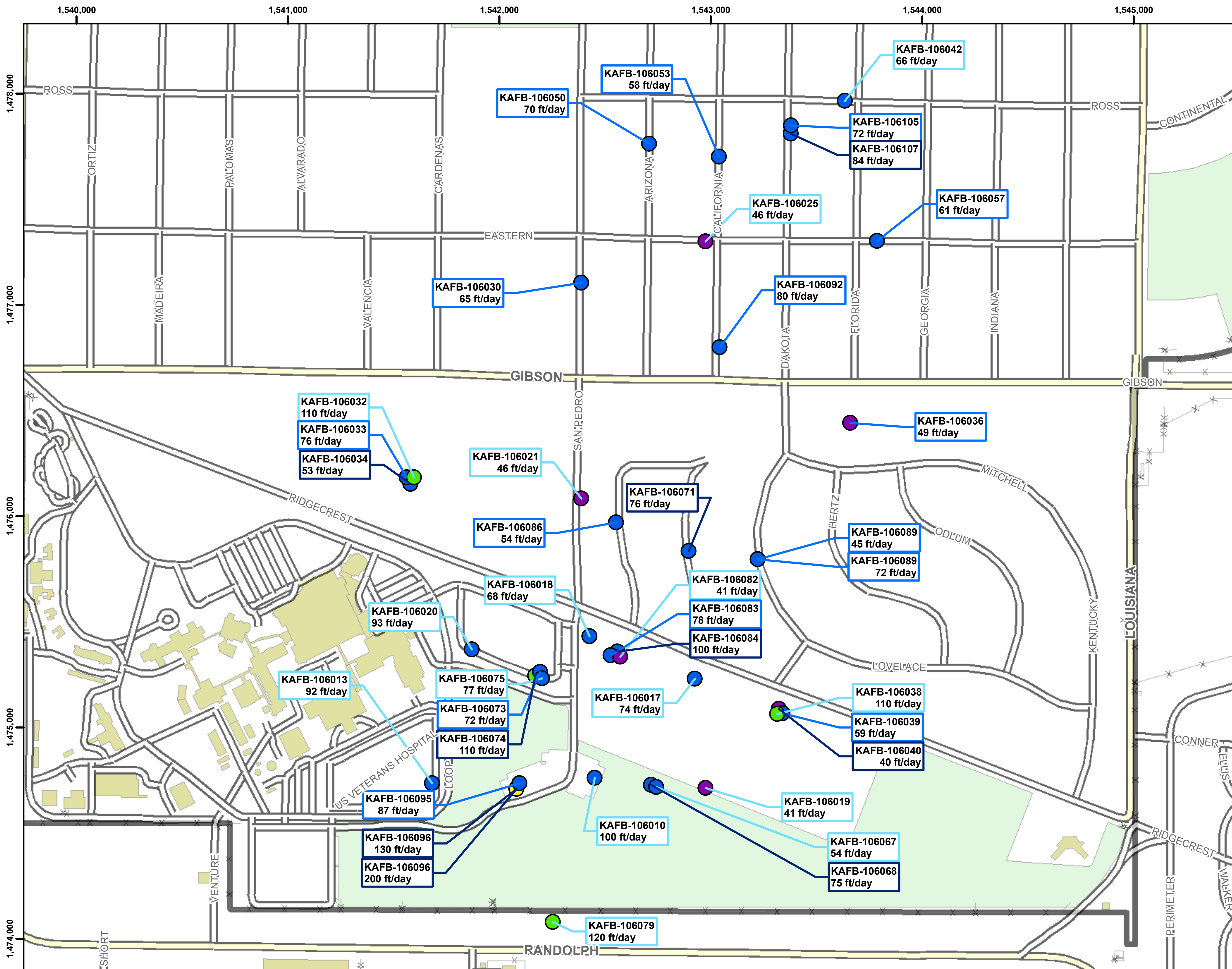
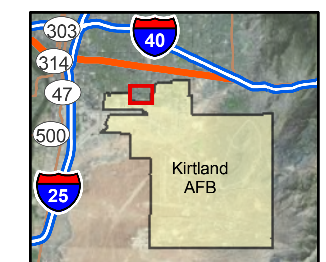


Legend

Hydraulic Conductivity (ft/day)

- 40 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- Fence
- Interstate
- Major Road
- Road
- Structure
- Runway
- Park
- Installation Boundary
- Well Screened in Shallow Zone of Aquifer
- Well Screened in Intermediate Zone of Aquifer
- Well Screened in Deep Zone of Aquifer



SITE LOCATION

N

Revision Date: 11/16/11

0 250 500 1,000
Feet
1 inch = 500 feet

Projection : NAD83 State Plane New Mexico Central FIPS3002 Feet

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FIGURE H-5

SPATIAL VARIABILITY OF
HYDRAULIC CONDUCTIVITY

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APPENDIX H

Tables

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Table H-1. Summary of Slug Test Results

Well ID No.	Test Type	Bouwer and Rice (ft/day)	Type Curve Analysis Type	Type Curve Analysis (K ft/day)	Type Curve Analysis (S_s ft^{-1})	Type Curve Analysis (Kv/Kh)	Springer and Gelhar (K ft/day)	Selected Value (K ft/day)	Selected Value (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K ft/day)	Material Screened	Dominant USCS in Screened Interval	Casing Radius (ft)	Boring Radius (ft)	Screen Length (ft)	Aquifer Thickness (ft)	Water Column Height (ft)	Initial Height (ft)	Selection Rationale
KAFB 10610	IN	137	KGS	103	6.3E-04	4.E-02	138	104	3.6E-02			3 ft - No recovery 8 ft - Well graded SAND with gravel (SW)	SW	0.167	0.417	20.86 (BOS 508)	31.86	23.36	2.4	Best fit to OUT-SG, similar to other out values and IN-KGS which are also good fits
	OUT	117	BZ	102	1.5E-05	1.E+00	104												2.8	
KAFB 10613	IN	172	KGS	120	6.0E-03	1.E-03	124	92	3.2E-02			15 ft - Well graded SAND (SW)	SW	0.167	0.417	14.66 (BOS 512)	19.66	19.66	3.7	Best fit to OUT-KGS, similar to other out solutions which are also decent fits
	OUT	78	KGS	92	3.8E-05	1.E-01	81												1.8	
KAFB 10617	IN	147	BZ	137	1.2E-05	4.E-03	106	74	2.6E-02			3 ft - Well graded SAND with gravel (SW) 4 ft - Well graded SAND (SW) 1.8 ft - Well graded GRAVEL (GW) 5.2 ft - Well graded SAND (SW) 7 ft - Well graded GRAVEL with sand (GW)	SW	0.167	0.417	20.95 (BOS 507)	28.95	25.95	3.6	Best fit to OUT-SG, same value as OUT-BR
	OUT	74	BZ	92	1.4E-05	1.E-01	74												2.1	
KAFB 10618	IN	51	KGS	137	7.9E-05	1.E-01	133	68	2.4E-02			3 ft - Well graded SAND with gravel (SW) 5 ft - Well graded silty gravelly SAND (SW-SC) 16 ft - Well graded SAND (SW)	SW	0.167	0.417	24.18 (BOS 501)	43.18	29.18	3.8	Best fit to OUT-KGS
	OUT	54	KGS	68	2.8E-05	1.E-02	59												2.0	
KAFB 10619	IN	57	BZ	99	7.9E-07	1.E-01	69	41	1.4E-02			5 ft - Well graded SAND with gravel (SW) 10 ft - Well graded GRAVEL with sand (GW) 8 ft - Well graded SAND with gravel (SW)	SW	0.167	0.417	22.68 (BOS 518)	29.68	27.68	1.5	Best fit to data
	OUT	26	KGS	41	1.0E-05	1.E-02	48												1.4	
KAFB 10620	IN	145	KGS	132	9.0E-04	1.E-02	116	93	3.3E-02			21 ft - Well graded SAND (SW)	SW	0.167	0.417	21.12 (BOS 507)	38.12	26.12	4.8	Best fit to OUT-KGS, similar to OUT-SG, also a good fit
	OUT	141	KGS	93	1.9E-04	1.E-01	95												2.7	
KAFB 10621	IN	129	KGS	78	1.6E-04	9.E-02	77	46	1.6E-02			1 ft - Well graded SAND with gravel (SW) 20 ft - Well graded SAND (SW) 3 ft - Well graded SAND with gravel (SW)	SW	0.167	0.417	24.03 (BOS 483)	36.03	29.03	3.5	Best fit to OUT-BR, similar to value for OUT-SG
	OUT	46	KGS	30	2.7E-04	1.E-02	45												1.8	
KAFB 10625	IN	75	KGS	55	2.3E-03	1.E-01	81	46	1.6E-02			10 ft - Well graded SAND (SW) 10 ft - Well graded SAND with gravel (SW)	SW	0.167	0.417	19.95 (BOS 507)	34.95	24.95	4.1	Best fit to OUT-KGS
	OUT	46	KGS	46	1.5E-04	1.E-01	55												2.7	
KAFB 106030	P1	63	BZ	63	3.1E-04	1.E-01	80	65	2.3E-02	1.23E-02	35	5 ft - Well graded SAND (SW) 6 ft - Poorly graded SAND (SP) 4 ft - Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 585)	35	33.92	2.5	Best fit to P4-KGS, similar values to all solutions, very close to P2, P3-KGS and P4-SG
	P2	66	KGS	71	5.8E-05	1.E-01	77												2.4	
	P3	63	KGS	70	1.8E-04	1.E-01	86												2.2	
	P4	62	KGS	65	7.9E-05	1.E-01	75												2.5	
KAFB 106032	IN	139	KGS	96	2.4E-02	1.E-01	185	108	3.8E-02	1.35E-02	38	14 ft - Poorly graded SAND (SP)	SP	0.198	0.417	13.58 (BOS 476)	30.58	18.08	10.1	Best fit to OUT-KGS, similar to values for IN-KGS, OUT-BR and OUT-KGS, which are also decent fits
	OUT	80	KGS	108	1.7E-04	1.E-01	104												10.6	
	QC-IN	133	KGS	57	2.3E-02	1.E-04	108												6.1	
	QC-OUT	87	KGS	108	5.4E-05	1.E-04	81												5.5	
KAFB 106033	P1	74	KGS	76	3.8E-04	1.E-01	102	76	2.7E-02	1.11E-02	31	15 ft - Poorly graded SAND (SP)	SP	0.198	0.417	15 (BOS 492)	45	34.00	2.4	Best fit to P1-KGS, similar to values from other tests
	P2	77	KGS	66	8.1E-04	1.E-01	105												2.4	
	P3	79	KGS	83	3.4E-04	1.E-01	111												2.1	
	P4	75	KGS	68	5.1E-04	1.E-01	95												2.5	
KAFB 106034	P1	60	KGS	53	1.2E-04	1.E-01	84	53	1.9E-02	1.13E-02	32	3 ft - Poorly graded SAND (SP) 10 ft -Well graded SAND with Gravel (SW) 2 ft - Poorly graded SAND (SP)	SW	0.198	0.417	15 (BOS 517)	30.5	59.05	2.6	Best fit to P1-KGS, similar to values for other good-fit tests
	P2	61	KGS	50	2.5E-04	1.E-01	93												2.6	
	P3	59	KGS	60	7.9E-05	1.E-01	92												2.4	
	P4	55	KGS	54	1.7E-05	1.E-01	75												2.6	

Table H-1. Summary of Slug Test Results

Well ID No.	Test Type	Bouwer and Rice (ft/day)	Type Curve Analysis Type	Type Curve Analysis (K ft/day)	Type Curve Analysis (S_s ft^{-1})	Type Curve Analysis (Kv/Kh)	Springer and Gelhar (K ft/day)	Selected Value (K ft/day)	Selected Value (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K ft/day)	Material Screened	Dominant USCS in Screened Interval	Casing Radius (ft)	Boring Radius (ft)	Screen Length (ft)	Aquifer Thickness (ft)	Water Column Height (ft)	Initial Height (ft)	Selection Rationale
KAFB 106036	P1	33	BZ	47	1.5E-05	1.E-07	69	49	1.7E-02	1.48E-02	42	3 ft - Well graded SAND (SW) 5 ft - Well graded SAND with gravel (SW) 7 ft - Well graded SAND (SW)	SW	0.198	0.417	5 (BOS 49	33	35	2.4	Best fit to data, similar to other good fit solutions
	P2	67	BZ	49	2.5E-05	1.E-07	73												2.5	
	P3	70	BZ	49	5.8E-05	1.E-07	89												2.4	
	P4	60	BZ	43	3.9E-05	1.E-07	67												2.5	
KAFB 106038	QC-IN	99	KGS	99	1.2E-03	1.E-03	136	113	4.0E-02			5 ft - Well graded SAND (SW) 8 ft - Well graded SAND with gravel (SW)	SW	0.198	0.417	5 (BOS 50	23	18	5.6	Best fit to data.
	QC-OUT	118	KGS	98	1.7E-04	1.E-03	119												6.7	
	IN	80	KGS	116	5.2E-04	1.E-01	78												5.0	
	OUT	95	KGS	113	5.2E-04	1.E-02	103												7.9	
KAFB 106039	IN	42	BZ	48	2.1E-04	1.E-06	52	59	2.1E-02	7.82E-03	22	2 ft - Poorly graded SAND (SP) 5 ft - No recovery 5 ft - Well graded GRAVEL with sand (GW) 3 ft - Poorly graded SAND (SP)	SP	0.198	0.417	5 (BOS 52	32	36.00	6.4	Best fit to data.
	OUT	32	BZ	59	2.8E-07	1.E-09	46												4.9	
KAFB 106040	IN	39	BZ	45	2.2E-04	1.E-06	52	40	1.4E-02	9.48E-03	27	4 ft - Silty SAND with gravel (SM) 5 ft - Silty SAND (SM) 5 ft - No recovery 1 ft - Poorly graded GRAVEL with sand (GP)	SM	0.198	0.417	5 (BOS 54	35	60	6.6	Best fit to data, similar to other values
	OUT	47	BZ	40	1.5E-04	1.E-07	56												7.3	
KAFB 106042	IN	107	KGS	56	1.6E-02	1.E-01	145	66	2.3E-02	1.50E-02	42	10 ft - Poorly graded SAND (SP) 4 ft - Well graded SAND (SW)	SP	0.198	0.417	14.1 (BOS 483)	31.1	19.63	10.9	Best fit to OUT-KGS, and similar value to OUT-BR which is the next best fit
	OUT	62	KGS	66	5.7E-04	1.E-01	97												7.2	
KAFB 106050	P1	49	KGS	81	1.1E-03	1.E-01	83	87	3.0E-02	8.22E-03	23	6 ft - Well graded SAND (SW) 5 ft - Poorly graded SAND (SP) 4 - ft Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 489)	23	34.57	2.4	Best fit to P3-KGS, similar values to other good-fit solutions
	P2	53	KGS	104	1.0E-03	1.E-01	81												2.4	
	P3	56	KGS	87	1.5E-03	1.E-01	82												2.1	
	P4	49	KGS	80	1.5E-03	1.E-01	84												2.5	
KAFB 106053	P1	57	KGS	50	1.3E-04	1.E-01	69	58	2.0E-02	1.96E-02	56	6 ft - Well graded SAND (SW) 6 ft - Poorly graded GRAVEL with Sand (GP) 3 ft - Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 493)	40	34.43	2.5	Best fit to P4KGS, same as P3KGS, similar to other good-fit solutions
	P2	53	KGS	59	3.6E-05	1.E-01	68												2.4	
	P3	54	KGS	58	8.3E-05	1.E-01	73												2.1	
	P4	51	KGS	58	4.7E-05	1.E-01	69												2.5	
KAFB 106057	P1	56	KGS	56	5.2E-05	1.E-01	68	61	2.1E-02	9.59E-03	27	15 ft - Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 480)	38	33.56	2.5	Best fit to P3-KGS, same as P3BR, similar to other good-fit solutions
	P2	58	KGS	63	4.3E-05	1.E-01	72												2.5	
	P3	61	KGS	61	6.5E-05	1.E-01	76												2.3	
	P4	54	KGS	60	1.6E-05	1.E-01	64												2.5	
KAFB 106067	IN	119	KGS	124	1.0E-03	6.E-01	134	54	1.9E-02	4.93E-03	14	14 ft - Poorly graded SAND (SP)	SP	0.198	0.417	13.44 (BOS 590)	28.44	18.44	13.00	The difference between the results could be caused by higher conductivity at the top of the screen
	OUT	40	KGS	54	2.5E-04	2.E-01	54												8.09	
KAFB 106068	P1	78	KGS	57	2.2E-04	1.E-01	100	75	2.6E-02	1.41E-03	4	2 ft - Poorly graded SAND (SP) 7 ft - Clayey SAND (SC) 6 ft - Poorly graded SAND (SP)	SP	0.198	0.417	15 (BOS 595)	28	109.80	2.3	Best fit to P3-KGS, similar to values from other KGS and BR solutions, which are also decent fits
	P2	76	KGS	60	2.5E-04	1.E-01	104												2.3	
	P3	79	KGS	75	5.6E-04	1.E-01	110												2.3	
	P4	73	KGS	63	3.5E-05	1.E-01	85												2.4	
KAFB 106071	P1	90	KGS	73	1.0E-05	1.E-01	91	76	2.6E-02	7.57E-03	21	7 ft - Poorly graded GRAVEL (GP) 5 ft - Well graded SAND with Gravel (SW) 3 ft - Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 563)	37	102.68	2.4	Best fit to P2-KGS, similar to values from all other solutions, which are also decent fits
	P2	89	KGS	76	3.5E-05	1.E-01	94												2.4	
	P3	89	KGS	86	4.5E-05	1.E-01	110												2.5	
	P4	78	KGS	65	7.3E-06	1.E-01	93												2.5	

Table H-1. Summary of Slug Test Results

Well ID No.	Test Type	Bouwer and Rice (ft/day)	Type Curve Analysis Type	Type Curve Analysis (K ft/day)	Type Curve Analysis (S_s ft^{-1})	Type Curve Analysis (Kv/Kh)	Springer and Gelhar (K ft/day)	Selected Value (K ft/day)	Selected Value (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K ft/day)	Material Screened	Dominant USCS in Screened Interval	Casing Radius (ft)	Boring Radius (ft)	Screen Length (ft)	Aquifer Thickness (ft)	Water Column Height (ft)	Initial Height (ft)	Selection Rationale
KAFB 106073	P1	72	KGS	70	7.9E-05	1.E-01	89	72	2.5E-02	3.08E-03	9	6 ft - Well graded GRAVEL (GW) 9 ft - Well graded SAND (SW)	SW	0.198	0.417	15 (BOS 515)	33	36.13	2.4	Best fit to P4-KGS, same as P3-KGS, and similar values to all KGS and BR solutions, which are also decent fits
	P2	65	KGS	65	2.2E-04	1.E-01	90												2.4	
	P3	64	KGS	72	8.8E-05	1.E-01	88												2.1	
	P4	67	KGS	72	7.9E-05	1.E-01	89												2.5	
KAFB 106074	P1	89	BZ	129	1.0E-05	1.E-02	145	107	3.7E-02	1.61E-02	46	8 ft - Well graded GRAVEL (GW) 0.5 ft - Well graded SAND (SW) 2.5 ft - Well graded GRAVEL (GW) 4 ft - Well graded SAND (SW)	GW	0.198	0.417	15 (BOS 585)	56	104.67	2.5	Best fit to P2-KGS, very close to P3BR, P3KGS, and similar to other good fit solutions
	P2	97	KGS	107	7.9E-05	1.E-01	154												2.5	
	P3	106	KGS	106	2.5E-04	5.E-02	178												2.5	
	P4	85	KGS	100	7.2E-05	1.E-02	129												2.6	
KAFB 106075	IN	126	KGS	167	1.3E-04	1.E-01	122	77	2.7E-02	3.82E-04	1	12 ft - Well graded SAND with Silt (SW-SM) 5 ft - Poorly graded SAND (SP)	SW-SM	0.198	0.417	15.2 (BOS 500)	32	20.20	9.0	Best fit to OUT-KGS
	OUT	38	KGS	77	2.5E-05	2.E-02	72												7.5	
KAFB 106079	IN	201	KGS	121	1.4E-02	9.E-03	205	121	4.2E-02	5.05E-03	14	6 ft - Poorly graded SAND (SP) 6 ft - Well graded SAND with Gravel (SW)	SW	0.198	0.417	12 (BOS 504)	29.34	16.80	8.3	Best fit to OUT-KGS
	OUT	109	KGS	121	1.0E-03	3.E-01	146												6.5	
KAFB 106082	IN	38	KGS	38	1.2E-02	1.E-01	92	41	1.4E-02	4.78E-03	14	1 ft - No recovery 5 ft - Well graded GRAVEL with Sand (GW) 5 ft - Well graded SAND with Gravel (SW) 2 ft - Well graded SAND with silt (SW-SM)	SW	0.198	0.417	13 (BOS 492)	21.31	17.84	6.5	Best fit to OUT-BR, similar to other good fit solutions
	OUT	38	KGS	41	1.6E-04	1.E-01	51												6.4	
KAFB 106083	P1	72	KGS	72	6.3E-04	1.E-01	100	78	2.7E-02	1.55E-02	44	9 ft - Well graded SAND (SW) 6 ft - Silty SAND (SM)	SW	0.198	0.417	15 (BOS 510)	42	36.70	2.3	Best fit to P2-KGS, similar to values from P1 through P3 BR and KGS values, which are also decent fits.
	P2	75	KGS	78	3.1E-04	1.E-01	96												2.2	
	P3	82	KGS	79	6.3E-04	1.E-01	104												2.0	
	P4	71	KGS	68	3.4E-04	1.E-01	85												2.3	
KAFB 106084	P1	71	BZ	106	4.0E-05	1.E-02	120	102	3.6E-02	1.98E-03	6	9 ft - Well graded SAND with Gravel (SW) 5 ft - Well graded SAND (SW) 1 ft - Well graded GRAVEL with Sand (GW)	SW	0.198	0.417	15 (BOS 581)	29	107.95	2.4	KGS
	P2	82	BZ	102	1.8E-04	2.E-02	169												2.4	
	P3	102	BZ	102	7.2E-05	1.E-01	183												2.4	
	P4	65	KGS	95	1.1E-04	1.E-02	148												2.4	
KAFB 106086	IN	90	KGS	66	7.0E-04	1.E-01	92	54	1.9E-02	1.96E-02	55	4 ft - Well graded SAND (SW) 11 ft - Poorly graded GRAVEL with Sand (GP)	GP	0.198	0.417	15 (BOS 491)	44	34.60	8.2	Best fit to OUT-KGS, same as OUT-BR and similar to IN-KGS, both of which are also decent fits
	OUT	54	KGS	54	7.0E-04	1.E-01	94												6.7	
KAFB 106089	P1	51	KGS	45	2.0E-04	1.E-01	60	45	1.6E-02	1.16E-02	33	8 ft - Well graded GRAVEL with Sand (GW), 5 ft - Well graded SAND (SW), 2 ft - Well graded GRAVEL (GW)	GW	0.198	0.417	15 (BOS 497)	35	33.00	2.3	Best fit to P1-KGS, similar to values from all other tests, which are also decent fits
	P2	44	KGS	50	2.9E-04	1.E-01	53												2.4	
	P3	54	KGS	65	5.1E-04	1.E-01	61												2.2	
	P4	46	KGS	47	1.7E-05	1.E-01	47												2.4	
	QC-P1	106	BZ	56	1.2E-04	1.E-06	121												2.4	Best fit to data
	QC-P2	107	BZ	67	7.0E-05	1.E-06	123												2.4	
	QC-P3	106	BZ	72	7.0E-05	1.E-06	128												2.3	
	QC-P4	109	BZ	61	7.8E-05	1.E-06	114												2.5	
	QC-IN	128	BZ	74	5.0E-04	1.E-05	140												6.4	
	QC-OUT	117	BZ	68	5.0E-04	1.E-06	129												6.2	

Table H-1. Summary of Slug Test Results

Well ID No.	Test Type	Bouwer and Rice (ft/day)	Type Curve Analysis Type	Type Curve Analysis (K ft/day)	Type Curve Analysis (S_s ft^{-1})	Type Curve Analysis (Kv/Kh)	Springer and Gelhar (K ft/day)	Selected Value (K ft/day)	Selected Value (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K cm/sec)	Geotechnical Laboratory Vertical Hydraulic Conductivity - Kv (K ft/day)	Material Screened	Dominant USCS in Screened Interval	Casing Radius (ft)	Boring Radius (ft)	Screen Length (ft)	Aquifer Thickness (ft)	Water Column Height (ft)	Initial Height (ft)	Selection Rationale
KAFB 106092	P1	57	BZ	70	4.7E-05	1.E-01	69	80	2.8E-02	9.87E-03	28	11 ft - Well graded SAND with Gravel (SW) 4 ft - Poorly graded SAND with Silt (SP-SM)	SW	0.198	0.417	15 (BOS 487)	46	34.23	2.3	Best fit to BZ. Matches SG
	P2	62	BZ	74	1.1E-04	1.E-01	82												2.3	
	P3	70	BZ	80	5.8E-05	1.E-01	80												2.1	
	P4	53	KGS	69	9.0E-06	6.E-02	64												2.4	
KAFB 106095	P1	85	KGS	86	9.8E-05	1.E-01	106	87	3.1E-02	1.24E-02	35	11 ft - Well graded SAND with Gravel (SW) 4 ft - Poorly graded SAND with Clay (SP-SC)	SW	0.198	0.417	15 (BOS 519)	33	35.38	2.2	Best fit to KSG. Matches P1
	P2	80	KGS	87	1.8E-04	1.E-01	106												2.1	
	P3	87	BZ	120	2.7E-05	1.E-02	112												1.9	
	P4	87	KGS	108	4.0E-04	4.E-02	102												2.3	
KAFB 106096	P1	114	KGS	119	1.3E-06	1.E-01	133	129	4.5E-02	6.71E-04	2	3 ft - Silty SAND with Gravel (SM) 5 ft - Well graded SAND with Gravel (SW) 5 ft - Well graded SAND with Silt (SW-SM) 2 ft - Poorly graded SAND with Silt (SP-SM)	SM	0.198	0.417	15 (BOS 592)	43	107.00	2.5	Best fit to P2KGS, matches P3BZ and P4SG, similar values to other good fit solutions
	P2	123	KGS	129	1.0E-05	1.E-01	137												2.5	
	P3	126	BZ	129	1.0E-05	2.E-02	158												2.5	
	P4	116	KGS	120	2.6E-06	1.E-01	129												2.6	
	QC-P1	173	BZ	133	2.3E-05	1.E-03	200												2.4	Best fit to data
	QC-P2	193	BZ	186	6.2E-07	1.E-04	186												2.4	
	QC-P3	209	BZ	199	6.2E-07	1.E-04	242												2.4	
	QC-P4	192	BZ	190	7.8E-08	1.E-04	199												2.4	
	QC-IN	252	BZ	252	7.8E-08	1.E-04	252												8.5	
	QC-OUT	250	BZ	196	2.4E-07	1.E-04	225												5.7	
KAFB 106105	P1	93	BZ	72	2.7E-05	1.E-05	104	72	2.5E-02	4.20E-05	0.12	1 ft - No recovery 5 ft - Well graded SAND with Gravel (SW) 5 ft - Lean CLAY (CL) 4 ft - Poorly graded GRAVEL with Sand (GP)	SW	0.198	0.417	5 (BOS 49	37	34	2.4	Best fit to data, similar to other BZ values which are also good fits
	P2	105	BZ	83	1.1E-05	1.E-05	115												2.3	
	P3	97	BZ	66	1.6E-04	1.E-04	109												2.1	
	P4	85	BZ	67	5.6E-05	1.E-04	102												2.4	
KAFB 106107	P1	130	BZ	76	9.7E-04	1.E-06	93	84	3.0E-02	2.28E-03	6	5 ft - Poorly graded SAND with gravel (SP) 10 ft - Poorly graded SAND (SP)	SP	0.198	0.417	5 (BOS 52	31	61	2.5	Best fit to data, similar to other BZ values which are also good fits
	P2	141	BZ	81	1.1E-03	1.E-06	93												2.4	
	P3	90	BZ	78	1.5E-03	1.E-06	88												2.3	
	P4	93	BZ	84	5.2E-04	1.E-06	93												2.5	
MINIMUM		**26**		**30**	**7.8E-08**	**1.E-09**	**45**	**40**	**0.00E+00**	**4.20E-05**	**0.00E+00**									
MAXIMUM		**252**		**252**	**2.4E-02**	**1.E+00**	**252**	**129**	**4.50E-02**	**1.96E-02**	**56**									
AVERAGE		**79**		**78**	**0.0E+00**	**6.E-03**	**96**	**71**	**2.01E-02**	**5.55E-03**	**16**									

Notes: 3OS = Bottom of scree BZ = Butler and Zhan KGS = KGS Model BR = Bouwer and Rice SG = Springer and Gelhar