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Selecting Aquifer Wells for Planned Gyroscopic Logging

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SUMMARY

Understanding the configuration of the eastern Snake River Plain aquifer's water table is made difficult, in part, due to borehole deviation in aquifer wells. A borehole has deviation if it is not vertical or straight. Deviation impairs the analysis of water table elevation measurements because it results in measurements that are greater than the true distance from the top of the well to the water table. Conceptual models of the water table configuration are important to environmental management decision-making at the INEEL; these models are based on measurements of depth to the water table taken from aquifer wells at or near the INEEL. When accurate data on the amount of deviation in any given borehole is acquired, then measurements of depth-to-water can be adjusted to reflect the true depth so more accurate conceptual models can be developed. Collection of additional borehole deviation data with gyroscopic logging is planned for selected wells to further our confidence in the quality of water level measurements.

Selection of wells for the planned logging is based on qualitative and quantitative screening criteria. An existing data set from magnetic deviation logs was useful in establishing these criteria however, are considered less accurate than gyroscopic deviation logs under certain conditions. Population distributions for 128 aquifer wells with magnetic deviation data were used to establish three quantitative screening thresholds. Qualitative criteria consisted of administrative controls, accessibility issues, and drilling methods. Qualitative criteria eliminated all but 116 of the 337 aquifer wells, in the vicinity of the INEEL, that were initially examined in this screening effort. Of these, 72 have associated magnetic deviation data; 44 do not. Twenty-five (25) of the 72 wells with magnetic deviation data have deviation greater than one of the three quantitative screening thresholds. These 25 are recommended for the planned gyroscopic borehole deviation surveying. Nineteen (19) of the 44 wells without magnetic deviation data were selected for the planned gyroscopic logging based on their location relative to facilities, site boundaries, and contaminant transport concerns. In total, 44 aquifer wells (25 with magnetic deviation data and 19 without) are recommended for planned gyroscopic logging.

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FIGURES

TABLES

ACRONYMS

bls	below land surface
CFA	Central Facilities Area
DOE	Department of Energy
DQO	Data Quality Objectives
INEEL	Idaho National Engineering and Environmental Laboratory
RWMC	Radioactive Waste Management Complex
TAN	Test Area North
USGS	United States Geological Survey
WAG	Waste Area Group

Selecting Aquifer Wells for Planned Gyroscopic Logging

1. INTRODUCTION

The Waste Area Group (WAG) 10 of the INEEL Environmental Restoration Department is responsible for the integration of groundwater data from individual WAGs for the purpose of identifying deficiencies. This is part of the Data Quality Objectives (DQO) process that supports the long-term monitoring goals and objectives expected by regulatory agencies for prudent stewardship of this U.S. Department of Energy (DOE) site.

Much of this data is collected directly from the regional aquifer beneath the INEEL. Aquifer wells completed in the eastern Snake River Plain aquifer beneath the INEEL are routinely monitored to better characterize groundwater quality, to study the potential for contaminant migration, and to provide input for the design of remedial activities. Knowledge of the surface of the aquifer, or water table, is used to infer general groundwater flow direction and magnitude, including preferential flowpaths; these, in turn, predominantly influence the location and sampling schedules for new monitoring wells.

Current water table configuration modeling is based on the behavior of water levels observed in aquifer wells. Nearly 200 aquifer wells at or near the INEEL are routinely measured for water levels, some only annually while others are measured more frequently. The measurement process is not without error. Measuring equipment can be unreliable, tapes or cables can stretch or kink, and human error can occur while reading the instruments or transcribing the collected data.

An additional systematic error in water level data can arise if the well was constructed in a manner other than truly vertical or perfectly straight. Deviation impairs the analysis of water table elevation measurements because it results in measurements that are greater than the true distance from the top of the well to the water table. However, the error can be removed if the degree of deviation is known. Procedures and equipment for detecting and assessing borehole deviation are commonplace in the well construction industry.

To enhance the integrity of collected water level data, WAG 10 is scheduled to conduct digital gyroscopic deviation logging of selected aquifer wells based on the criteria presented in this report. To minimize the work scope of the planned logging, wells to be surveyed were selected from an initial set of 337 aquifer wells. This report describes the selection process. The scope of the screening was limited to analyzing available deviation data and the factors contributing to borehole deviation, developing a screening process, and recommending a list of wells which should receive high priority for planned digital gyroscopic logging.

2. BACKGROUND

The INEEL includes approximately 900 square miles of southeastern Idaho desert located above the eastern Snake River Plain aquifer, one of the country's most pristine and abundant water resources. Water in this aquifer generally flows from northeast to southwest as determined by the configuration of the water table which slopes at an average gradient of 12 ft/mi (Lindholm, 1996). Beneath the INEEL, the water table is approximately 200 ft below land surface (bls) in the northern end of the Site and approximately 600 ft bls along the INEEL's southern boundary. Land surface topography also dips from northeast to southwest but at a more gradual rate.

In 1999, the water table elevation at the northeast INEEL boundary was 4670 ft above mean sea level. Some 50 miles to the southwest, along the southern boundary, the water table elevation was 4430 ft. This is an average gradient of 4.8 ft/mi, close to the average 4 ft/mi reported in other INEEL aquifer studies (Anderson, Kuntz, and Davis, 1999). Such a small hydraulic gradient can be difficult to detect with water levels collected from aquifer wells adjacent to each other. It can also be frustrating to map. Questionable contour maps of the aquifer potentiometric surface have been developed for groundwater modeling or monitoring evaluations in past studies at the INEEL.

The ideal undeviated borehole is both vertical (plumb) and straight (true). In some cases, the reported water table elevation has included error attributed to borehole deviation in aquifer wells (Wylie, 1993). Because the deviated borehole does not follow a straight line or is not vertical, additional measuring line is required to reach the aquifer, giving the false impression of a lower water table at this location. This is illustrated in Figure 1. In this report, inclination refers to the angle measured from vertical that an off-plumb well makes. Inclination azimuth describes the twisting or corkscrewing of an untrue borehole.

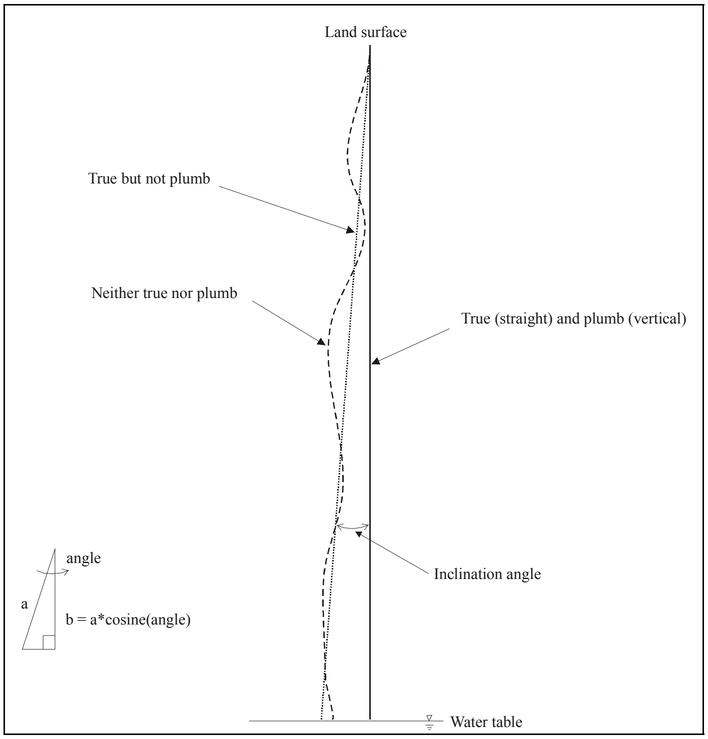


Figure 1. Borehole deviation description (from Driscoll, 1987).

Previous work identified error, attributed to borehole deviation, in water level measurements collected from aquifer monitoring wells located near the Central Facilities Area (CFA) landfills I and II (Wylie, 1993; Wylie and Hubbell, 1993). In that effort, photo gyroscopic equipment was used to log wells and the results provided a means of quantifying the degree of deviation. Readings of borehole inclination and inclination azimuth were recorded at discrete depths in each well, regression equations were fitted to the readings, and linear expressions were developed from which a unique correction factor can be found for any measured depth. In another study (Wylie, 1996), magnetic deviation data collected during borehole neutron-logging were similarly processed to develop quadratic-equation-based correction formulae.

There are over 340 aquifer wells at or near the INEEL. Principal details for 337 of these are provided in Appendix A. Almost all of these wells have associated water level information useful for developing aquifer configuration conceptual models. Gyroscopic logging is planned for a selected subset of these wells. Both qualitative and quantitative criteria were used to screen wells to find candidate wells for the planned gyroscopic logging. These criteria are described in Section 5.

3. DEVIATION LOGGING METHODS

The simplest deviation logging device consists of a single-shot device with a circular card mounted on a magnetic compass that is passed through drill pipe to record the borehole inclination and inclination azimuth at the hole bottom.

An improvement on this method, the magnetic multi-shot camera, measures multiple readings of direction and inclination at specific depths. A similar method using photo gyroscopic equipment was used by Strata Data Inc. at the INEEL in the 1993 CFA study (Wylie, 1993). The Strata Data equipment included a Humphrey gyroscope, Welnav inclinometer, and a multi-shot camera. The two inclination devices, a low-angle and a high-angle unit, were reported with ranges of 0 to 12 ±0.125 degrees and 0 to 34 degrees ±0.25 degrees, respectively (Wylie, 1993). The inclination azimuth reading was reported to have an accuracy of ±0.5 degrees. Twenty-six (26) aquifer wells at the INEEL were logged with this equipment.

The United States Geological Survey (USGS) routinely logs boreholes with a logging tool that contains magnetic deviation components. The tool is the multi-parameter model 9055, manufactured by the Century Geophysical Corporation of Tulsa, OK, which contains a 3-axis magnetometer for inclination azimuth and a 2-axis inclinometer for inclination angle. The tool reads inclinations from vertical ranging from 0 to 45 degrees with ±0.5-degree accuracy and has an inclination azimuth range of 0 to 360 ±2 degrees (Peterson, undated). Although its main function, as used by the USGS, is neutron measurement of formation moisture content, it also provides useful magnetic borehole deviation data. Additional information on this tool is presented in Appendix B. In all, about 130 INEEL aquifer wells have been logged with the 9055 tool during which magnetic deviation data were collected.

Yet another method of borehole deviation logging uses the Century Geophysical digital gyroscopic tool, model 9095, used by the USGS at the INEEL. This tool is fully dedicated to borehole deviation detection. It is intended for logging within steel casings or open holes and can be used where magnetic rocks occur. The digital solid state design incorporates a continuous-reading Humphrey gyroscope that has a range and accuracy of 0 to 45 degrees from vertical ±0.5 degree and has an azimuth range of 0 to 360 ±2 degree (Century Geophysical Corp.). Additional information for this tool, is presented in Appendix B. Fourteen (14) aquifer wells at or near the INEEL have been logged using this tool. More gyroscopic logging in aquifer wells suspected of being deviated is scheduled for summer 2001.

Digital gyroscopic deviation logging (using the 9095) is time-consuming because the tool requires long startup and shutdown times (Peterson, undated). Magnetic deviation data, on the other hand, has been routinely collected when the USGS logs a well using the 9055 tool in its neutron moisture-detection capacity. Although the 9055 tool has an efficient rapid retrieval and real time application, the borehole deviation portion of this tool is not intended for use in wells with metal casings or in formations containing naturally magnetic material (Helm-Clark, 2001). Still, deviation data collected with this tool from 128 aquifer wells were available for this study.

4. 9055 DATA PROCESSING

Electronic copies of 1,585 logging files, including 500 magnetic deviation files, were obtained from the USGS. Many of these logs were not useful for this study because they were obtained from the same borehole or were from vadose zone wells. Of the 337 aquifer wells initially examined for screening, 130 were found to have associated magnetic deviation data files. Of these, 128 were useful for establishing screening criteria and screening aquifer wells.

Century Geophysical Corporation software (Log v.3.43, Display v.3.64), which includes a proprietary algorithm to calculate true depths from readings of inclination angle and bearing (azimuth), was used to process these 128 magnetic deviation files. The output includes true depth, cable (measured) depth, inclination angle, bearing (azimuth), and plan view plots showing the downhole trace relative to plumb. (The plan view plots for 128 aquifer wells can be found in Appendix C.) The output was included in a database of well information and corrected depths. This database was queried to find the difference between true and measured depths for each well. From these, correction factors were determined for the expected range of depths-to-water at each well.

In a borehole, deviation adds length to the distance that a measuring device must travel to reach a reference depth such as the aquifer water table. By subtracting the correction factor from the measured depth, the depth is reduced to reflect the actual vertical distance ("true depth"). This correction factor is obtained from the formula:

$$\text{True Vertical Depth} = \text{Measured Depth} - \text{Correction Factor}$$

$$\text{Correction Factor} = \text{Measured Depth} - \text{True Vertical Depth} \tag{1}$$

If a borehole is somehow drilled straight and plumb after an initial jog or dogleg, the required correction factor may be a constant. Otherwise, the correction factor increases with depth. Therefore, the worst case correction factor is best represented by the difference between true and measured depths at the historical maximum water table depth at each well.

The correction factors obtained from the Century Geophysical software processing of magnetic deviation data resemble the results obtained with other deviation data collection devices (i.e., photo or digital gyroscope devices). Correction factors for wells that were logged with the 9055 neutron tool and also with either the Strata Data photo gyroscopic device or the 9095 digital gyroscopic tool are presented in Table 1.

The results in Table 1 show an acceptable level of agreement between the 9055-derived corrections, calculated using the Century Geophysical software algorithm, and corrections obtained with other methods. Yet, in cases of large deviation, the 9055 tool underestimates the deviation. This is likely due to the lack of magnetometer control in metal-cased wells. At low levels of deviation, the 9055 and 9095 tools produce similar ranges of correction factors. At low inclination angles, both tools can hang plumb and yield readings that indicate a true and plumb borehole. At higher levels of deviation, the corkscrewing becomes significant and an accurate reading of inclination azimuth becomes important. The 9095 can provide a higher level of inclination azimuth accuracy because it is designed for use in metal-cased wells. The lack of azimuth control with the 9055 in metal-cased wells is evident from the incredible plan view plots in Appendix C, though some of these are probably the result of using the tool without casing centralizers.

Table 1. Comparison of correction factors developed from data collected with different logging devices.

Well Name	9055 Data Processed with Century Software Algorithm (ft)	9095 Digital Gyroscope (ft)	StrataData Photo Gyroscope[a] (ft)
ANL-OBS-A-001	0.04	0.04	—
TANT-MON-A-008	0.08	0.57	—
TANT-MON-A-009	0.04	0.03	—
TANT-MON-A-011	0.00	0.00	—
LF2-09	4.73	6.49	5.36
LF3-09	0.11	—	0.12
LF2-12	0.09	—	0.09
LF3-11	0.03	—	0.03
LF3-10	0.02	—	0.01
USGS-113	4.84	5.87	5.64
USGS-116	0.16	—	0.21
USGS-118	0.15	0.17	—
USGS-121	1.51	1.73	—
USGS-126b	0.46	0.42	—

a. photo gyroscope data from Wylie (1993).

Due to the questionable azimuth data, the USGS uses a different method for calculating the correction factor from magnetic deviation data. Their method is to ignore the inclination azimuth data and to rely only on the average inclination angle from land surface to water table. They use the cosine of this average angle and multiply it by the measured depth to obtain true depth. The correction factor formula then becomes:

$$\text{Correction Factor} = \text{Measured Depth} - [\text{Measured Depth} \times \text{Cosine (average inclination angle)}] \qquad (2)$$

The above formula was used in conjunction with 128 wells that have existing 9055 deviation data. The database of Century Geophysical software-processed results was used to find well-specific average inclination angles and to calculate correction factors with these angles at maximum depth-to-water.

It should be noted that these calculated correction factors are used in this report only to screen wells for planned deviation logging. They are not intended to correct existing or future sets of water level data. These factors have not been developed with the same rigor as the linear- or quadratic-equation-based corrections developed in earlier deviation analyses (Wylie, 1993; Wylie and Hubbell, 1993; Wylie, 1996).

5. SCREENING CRITERIA

Summary statistics for 128 wells with existing 9055 deviation data were used to develop correction factor-based screening criteria. Table 2 presents the statistics of depth-to-water, average inclination angle, and correction factors developed using the Century Geophysical software algorithm and also the correction factors based only on average inclination angle and maximum depth-to-water. Figure 2a is a histogram showing the distribution of inclination angles. The distribution is positively-skewed due to a few large outliers; the most frequent angles appear to be between 0.5 and 0.7 degrees. Figure 2b shows the distribution of correction factors based on average inclination angle and maximum depth-to-water; these are also positively-skewed with the mode occurring around 0.01 ft.

Drilling contracts now routinely require that the borehole inclination angle must be less than three degrees (Arnett, Brower, and Freiburger, 1993). Earlier wells, constructed without this contract requirement, may have more deviation. The inclination angle is a good indicator of borehole deviation, however, screening criteria based on inclination angle alone do not account for the borehole depth, which can strongly influence total deviation. For example, a shallow well (such as those at Test Area North [TAN]), even with a large inclination angle, may not require a large correction factor because the water level is relatively shallow. However, a deep well (such as those south of the Radioactive Waste Management Complex [RWMC]) will require a large correction factor even if the inclination angle is only slight.

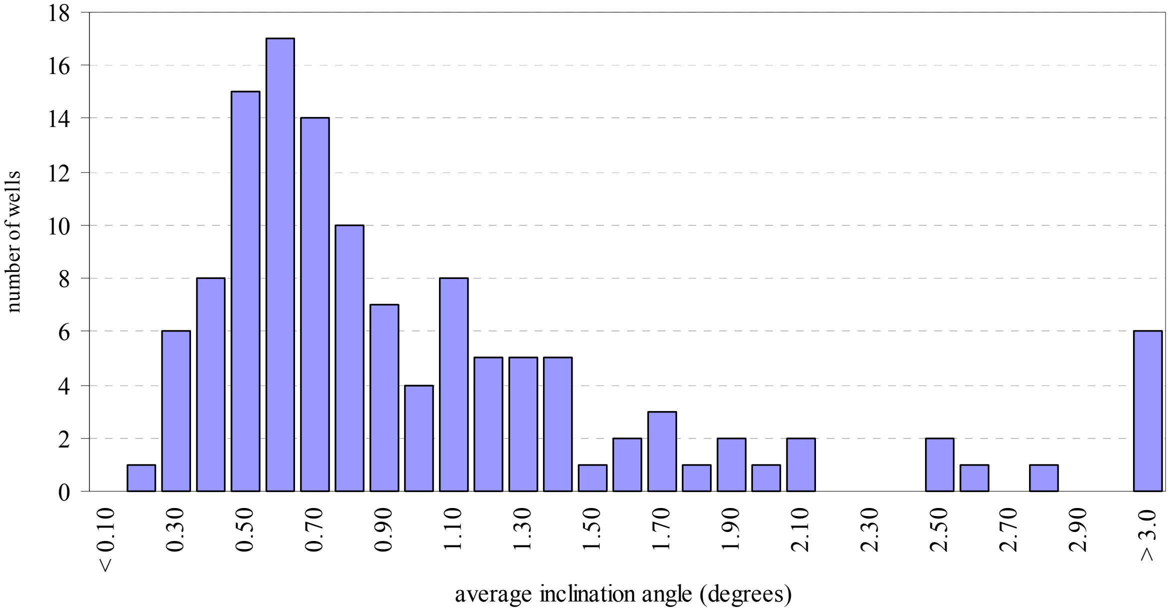
In their borehole deviation analyses, the USGS uses a threshold correction factor of 0.3 ft (Ackerman, 2001). If deviation data reveal a correction factor greater than this threshold, the USGS recommends correcting the depth-to-water measurements by the correction factor. They obtain this factor using equation (2) as described in Section 4. If the calculated correction factor is less than 0.3 ft, water levels are not corrected by USGS. The 0.3-ft level is consistent with recommended data evaluation guidelines presented in a previous water level validation study (Arnett, Brower, and Freiburger, 1993).

Table 2. Summary statistics for 128 wells with available magnetic deviation data.

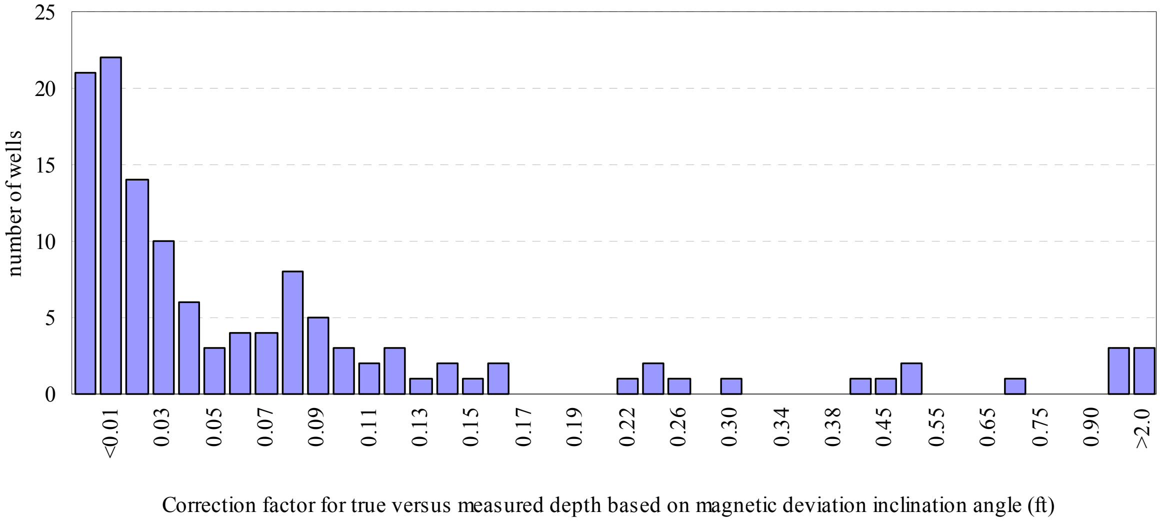
Average Depth-to-Water (ft)	Average of Inclination Angle (degrees)	Correction Factor from Average Depth-to-Water and Average Inclination Angle (ft)	Average of Correction Factors from Century Software-Algorithm (i.e., with Azimuth[a]) (ft)	Average of Individual Correction Factors Calculated from Well-Specific Max Water Depth and Inclination Angles (i.e., without Azimuth[b]) (ft)
441	1.09	441- [441 x cos(1.09)] = 0.08	0.214	0.198

a. Correction factor calculated using Century Geophysical Corporation software, which incorporates both inclination angle and inclination azimuth. Value is the average of 128 wells' difference between true and measured depths at their historically lowest water table level.

b. Correction factor calculated using only maximum depth-to-water and average inclination angle for each well (i.e., no inclination azimuth data). Value is the average of 128 correction factors calculated in this manner.



a.



b.

Figure 2. Histograms of magnetic deviation data: a. Average inclination angles for 128 aquifer wells; b. Correction factors for 128 aquifer wells based on average inclination angle and maximum depth-to-water.

The 9055 tool measures inclination within a 0.5-degree tolerance. To account for this accuracy limitation in this analysis, 0.5 degrees is added to the average inclination angle for each well. Therefore, the sum represents the maximum possible average inclination for each well, based on 9055-derived data. To determine the correction factor for each well, the cosine of the sum of 0.5 degrees and the average inclination angle is multiplied by the measured depth; this product is then subtracted from the measured depth. The new correction factor formula is:

$$\text{Correction Factor} = \text{Measured Depth} - [\text{Measured Depth} \times \text{Cosine (average inclination angle} + 0.5)] \quad (3)$$

Calculated correction factors for each well using this formula are listed in Tables D-6A and D-6B of Appendix D. In this analysis, the 0.3-ft correction factor is adopted as the highest quantitative screening criterion. Wells with existing magnetic deviation data that are found to have correction factors greater than 0.3 ft are given highest priority for planned gyroscopic deviation logging. The two other quantitative screening criteria used to assign medium and low priorities for planned gyroscopic logging are a 0.2-ft and 0.1-ft correction factor, respectively. The 0.2-ft correction factor criterion represents the average of correction factors obtained for 128 aquifer wells using either the Century Geophysical software or equation (3), with measured depths and average inclination angles. The 0.1-ft criterion is close to the group correction factor (0.08) obtained from the average depth-to-water (441 ft bls) and the average inclination angle (1.09 degrees) found from the set of 128 wells with magnetic deviation data.

Initially, a set of qualitative screening criteria was used to minimize the number of wells recommended for gyroscopic logging. These qualitative criteria include accessibility (abandoned wells, private offsite wells, and turbine-equipped production wells were screened out), administrative control (USGS-owned wells were screened out), and inferences between borehole deviation and drilling methods. Wells with existing gyroscopic deviation data, whether collected with the Strata Data device or the Century Geophysical 9095 tool, do not need to be logged with a gyroscopic tool again and therefore are excluded from further consideration.

Inferences, between borehole deviation and drilling methods, are based on the observation that drilling methods for construction of aquifer wells at or near the INEEL appear to affect borehole deviation. Table 3 presents the summarized inclination angle results for different drilling types used at the INEEL. The oldest INEEL aquifer wells, constructed between 1949 and 1963, were drilled using the cable-tool percussion method. This method is based on the repeated lifting and dropping of a heavy string of drilling tools that, due to cable twisting, rotate upon impact at the bottom of the hole allowing the bit to crush and cut through rock. While the force of gravity tends to make the drill bit cut a vertical hole, the varying hardness of differing subsurface materials can deflect the bit from a truly vertical course (Driscoll, 1987). However, 26 INEEL cable-tool drilled aquifer wells yielded an average inclination angle of only 0.88 degrees.

Air-rotary drilling uses compressed air to blow cuttings out the borehole in the annular space between the drill string and the borehole wall. This method typically uses a conventional rotating bit with pressure applied through the drill string to advance the bit. Too much pressure applied at the top of the drill stem will bend the drill pipe, causing the bit to cut off-center and produce a highly-deviated borehole (Driscoll, 1987). Analysis of magnetic deviation data from 35 aquifer wells, identified as being drilled with the conventional air-rotary and tri-cone bit method, yielded an average inclination angle of 1.80 degrees. This method was popular in the 1980s when the CFA landfill wells and other wells were drilled, and they have major borehole deviation. Wylie (1993) used whisker-and-box plots to demonstrate that the air-rotary method produced significantly more borehole deviation than the cable-tool method.

Table 3. Average inclination angles for different well drilling methods, from 128 INEEL aquifer wells.

Drill Method	Average of Inclination Angles (degrees)[a]	Number of Wells
Air-rotary	1.80	35
Coring	1.24	10
Cable tool	0.88	26
Downhole hammer	0.82	33
Reverse circulation	0.64	23
Unknown[b]	0.63	1

[a] Inclination angle readings are measured between a vertical line and the borehole. These are averaged between land surface and the deepest observed water measurement.

[b] Unknown method is from well ICPP-POT-A-012 which has a short 9055 file; results for this well may be inaccurate.

Several INEEL aquifer wells were core-drilled in support of geologic analyses of the vadose zone and aquifer matrix. The coring method uses a wire-line retrievable core-sampling barrel, which is lowered down the inside of the drill string and removed to collect the core sample. The set of 10 cored INEEL aquifer wells with magnetic deviation data produced the second highest average inclination of 1.24 degrees.

The downhole hammer method uses a pneumatic-percussion hammer and rotating bit. Like cable-tool drilling, the hammering allows the bit to crush through materials of contrasting hardness with little or no drift and produces a fairly straight and plumb hole. This is evidenced by the average inclination angle of 0.82 degrees for the set of 33 INEEL aquifer wells drilled with this method.

Reverse-circulation removes cuttings through the outer annular space between a double-walled drill stem and can be used with various bit types. The list of 23 INEEL aquifer wells constructed with reverse-circulation does not include any information regarding the type of bit used with this method, i.e., whether downhole hammer or tri-cone rotary bits were used. However, the low inclination angle average of 0.64 degrees for this set of wells suggests that a hammer bit was probably used.

The magnetic deviation data summarized in Table 3 suggest that drilling methods do affect borehole deviation. It appears that wells constructed with the air-rotary method are more likely to be deviated that those constructed with the cable-tool method, as identified in previous studies (Wylie, 1993). This is useful for screening out wells constructed with a certain drilling method (i.e., cable-tool or downhole hammer) but for which no screening deviation data exists. The consistency of these data also suggests that the 9055-derived inclination data can be used as a screening-criteria assessment of borehole deviation.

6. SCREENING RESULTS

Prior to assessing borehole deviation in wells with available 9055 magnetic deviation data, qualitative screening criteria were used to pare the list of 337 aquifer wells down to a more manageable list of 116 wells. A logic flowchart showing these qualitative criteria is presented in Figure 3. These criteria and the number of wells eliminated from further consideration for gyroscopic logging are:

- Existing gyroscopic deviation data. Wells that have been previously logged with either photo or digital gyroscopic deviation tools are considered finished with regard to gyroscopic logging needs. Twelve (12) INEEL aquifer wells have been surveyed with the digital gyroscope by the USGS, and 24 have been logged by the Strata Data Corporation of Wyoming using the photo gyroscope device. Two additional wells were logged with both methods. This step eliminated 38 aquifer wells, leaving 299.

- USGS-controlled wells. All aquifer wells at or near the INEEL that are under USGS administrative control were removed from further gyroscopic logging consideration. This eliminated 88 of the wells, leaving 211.

- Inaccessible wells. All aquifer wells deemed inaccessible (i.e., abandoned wells, private offsite wells, production wells equipped with turbine pumps) were removed from further gyroscopic logging consideration. This eliminated 45 aquifer wells, leaving 166.

- Drilling method. All aquifer wells constructed with the historically-plumb cable-tool drilling method were eliminated from further screening. This eliminated an additional 50 aquifer wells, leaving 116.

Of the 116 wells remaining after initial qualitative screening, 72 have 9055 logging magnetic deviation data while 44 are without. The 72 wells with available magnetic deviation data were then screened using correction factor criteria, derived from maximum water depths and average inclination angles, with quantitative screening criteria of 0.3, 0.2, and 0.1 ft. Table 4 presents the 25 wells that failed at least the lowest criteria. The location of these wells and their relative priority are shown in Figure 4. This includes 15 wells that fail the 0.1-ft screening criterion, 8 wells that fail the 0.2-ft criterion, and 2 wells that fail the 0.3-ft criterion.

The 44 remaining wells, which have no previous magnetic deviation data and were not screened out with qualitative criteria, were ranked for planned gyroscopic logging based on their location relative to facilities and areas of contaminant transport concern. Nineteen (19) wells are considered high-priority with regard to gyroscopic logging; 25 are now considered non-priority.

Wells outside the boundaries of WAG-specific facilities are considered to be within WAG 10 administrative-control domain; these are given a higher priority since they are unlikely to be logged for deviation by any other WAG. Wells downgradient of individual facilities are the most important wells with regard to regulatory groundwater standards compliance and therefore receive a higher ranking. The monitoring wells near the southern INEEL boundaries are the last line of monitoring before groundwater in the eastern Snake River Plain aquifer leaves the vicinity of the INEEL; as a result, these wells are given a higher priority. Deeper wells are also a higher priority because they are more sensitive to inclination angle; i.e., a slight inclination will cause their required correction to be greater than shallower wells with the same amount of inclination. High priority wells that have no existing deviation data are listed in Table 5 and are shown relative to INEEL facilities and site boundaries in Figure 5. Appendix D contains tables delineating the screening process that produced Tables 4 and 5.

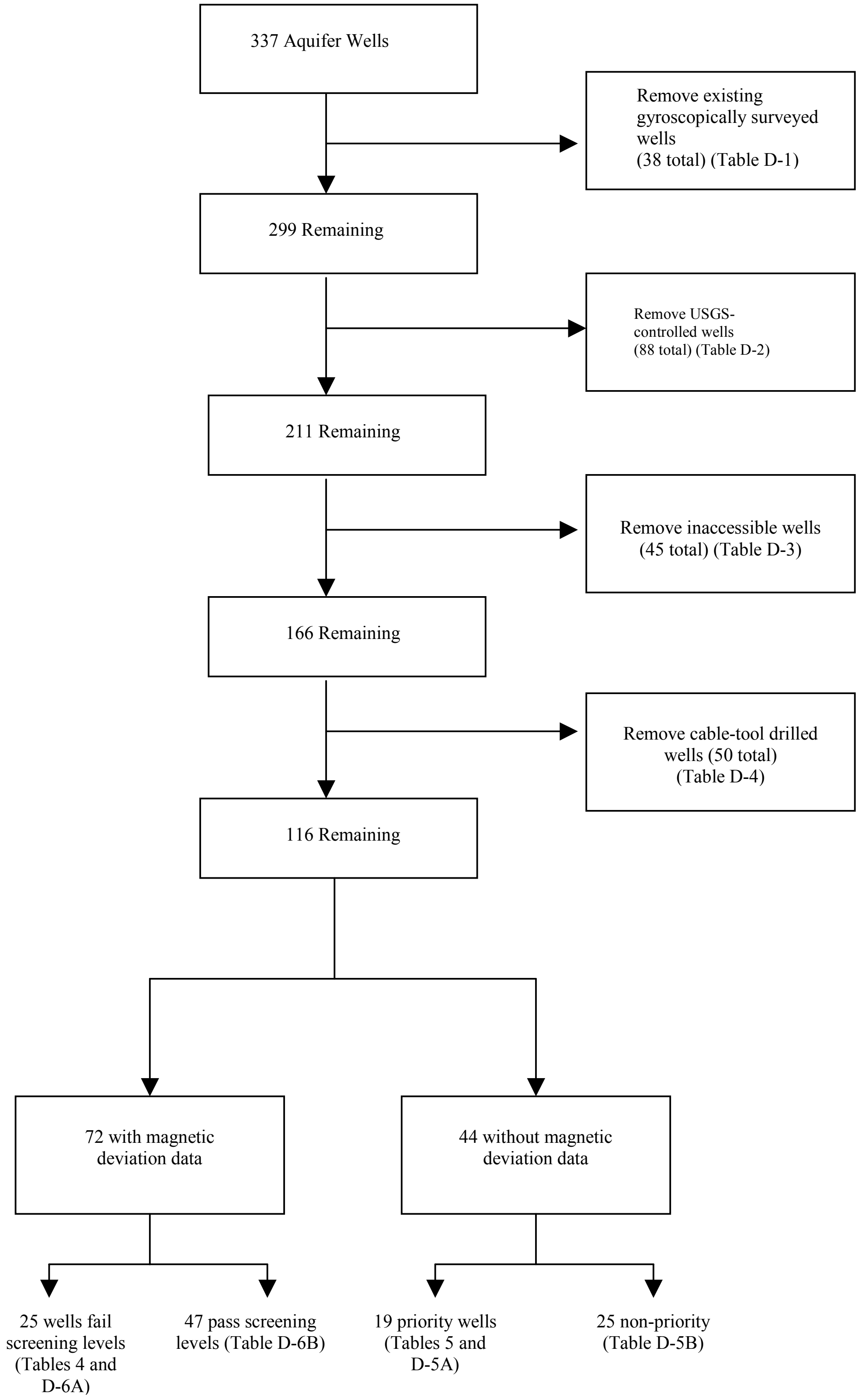


Figure 3. Flow chart showing qualitative and quantitative screening.

Table 4. Aquifer well priority for planned gyroscopic logging based on quantitative screening levels.

Priority	Well ID	Well Name	Facility	Drilling Method	Maximum Depth-to-Water (ft)	Average Inclination Angle (degrees)	Correction Factor (ft)[a]
high	767	M4D	RWMC	Hammer	599	1.85	0.50
high	1003	ARA-MON-A-001	ARA	Hammer	596	1.66	0.42
medium	765	M1SA	RWMC	Hammer	596	1.14	0.24
medium	96	Corehole 1	south Site	Corehole	938	0.81	0.24
medium	906	RWMC-MON-A-013	RWMC	Hammer	641	1.05	0.24
medium	769	M7S	RWMC	Hammer	580	1.11	0.23
medium	797	TAN-23A	TSF	Air-rotary	211	2.13	0.22
medium	766	M3S	RWMC	Hammer	592	1.01	0.21
medium	1305	STF-MON-A-003	STF/OMRE	Hammer	499	1.14	0.20
medium	790	TAN-18	TSF	Air-rotary	226	1.90	0.20
low	1306	STF-MON-A-004	STF/OMRE	Hammer	506	1.08	0.19
low	968	ANL-MON-A-012	ANL	NF [b]	648	0.88	0.19
low	1092	ICPP-MON-A-022	ICPP	Reverse-circulation	453	1.09	0.17
low	1076	ARA-COR-A-005	ARA	Rotary cored	597	0.88	0.17
low	1080	NRF-MON-A-009	NRF	Hammer	381	1.22	0.17
low	1095	PBF-MON-A-005	PBF	Hammer	512	0.92	0.16
low	1008	TANT-MON-A-028	TAN-TSF	Air-Rotary	207	1.66	0.15
low	1132	RWMC-MON-A-66	RWMC	Hammer	601	0.77	0.15
low	1101	TANT-MON-A-005	TAN-TSF	Reverse-circulation	207	1.64	0.14
low	1006	ARA-MON-A-03A	ARA	Hammer	608	0.65	0.12
low	1314	TANT-MON-A-047	TAN	Air-Rotary	215	1.33	0.11
low	1004	ARA-MON-A-002	ARA	Hammer	594	0.59	0.11
low	1117	TANT-MON-A-024	TAN-TSF	Reverse-circulation	203	1.31	0.10
low	1087	PBF-MON-A-003	PBF	Hammer	521	0.62	0.10
low	1007	ARA-MON-A-004	ARA	Hammer	617	0.52	0.10

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a. These correction factors are developed from average inclination angle and maximum depth-to-water using trigonometry.

b. NF = Not found

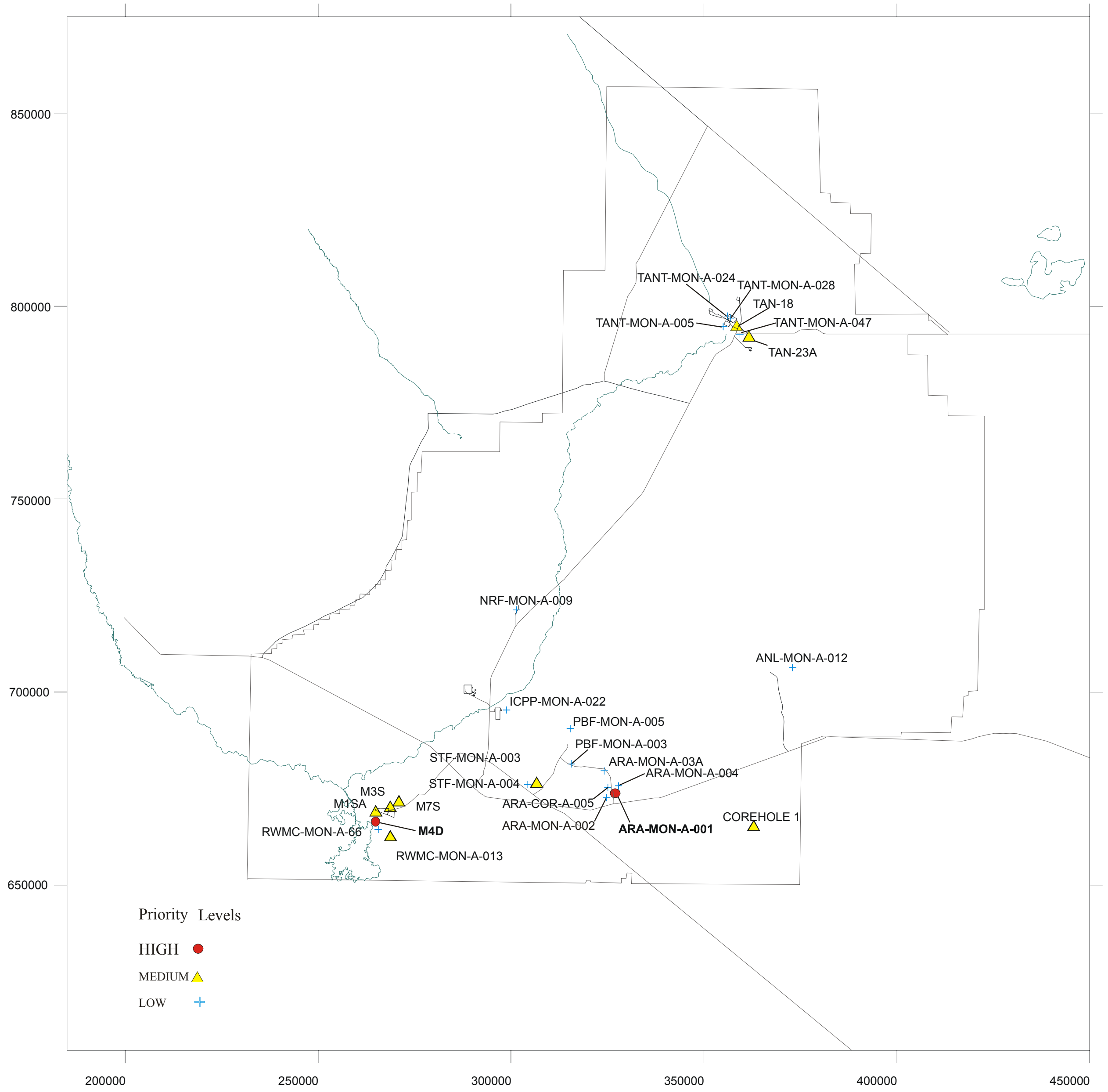

Figure 4. Location of wells that are high-priority for planned gyroscopic logging following application of three quantitative screening levels for borehole deviation.

Table 5. Aquifer well priority for planned gyroscopic logging based on location, contaminant issues, and casing material.

Priority	Well ID	Well Name	Facility	Drilling Method	Casing Summary (top-bottom, ft)	Maximum Depth-to-Water (ft)
High	1340	TANT-MON-A-054	TAN	Hammer	carbon steel	NF[b]
High	1341	TANT-MON-A-055	TAN	Hammer	carbon steel	NF[b]
High	1342	TANT-MON-A-056	TAN	Hammer	carbon steel	NF[b]
High	1343	TANT-MON-A-057	TAN	Hammer	carbon steel	NF[b]
High	1344	TANT-MON-A-058	TAN	Hammer	carbon steel	NF[b]
High	97	Corehole 2A	mid Site	NF[b]	carbon steel	214
High	719	ANL-M11	ANL	Air-rotary	carbon steel NF[b]	635
Medium	1143	ANL-MON-A-014	ANL	Hammer	stainless	637
Medium	186	INEL-1[a]	mid Site	Air-rotary	carbon steel	309
Medium	239	NPR Test	mid Site	Air-rotary	carbon steel	468
Medium	101	CPP-04	ICPP	NF[b]	carbon steel	582
Medium	360	TRA Disposal	TRA	NF[b]	carbon steel	469
Medium	731	TRA-07	TRA	Air-rotary	stainless	476
Low	163	GIN-05	WRRTF	Air-rotary	carbon steel	213
Low	595	Water supply INEL-1[a]	mid Site	Air-rotary	carbon steel	402
Low	1351	ICPP-MON-A-165	INTEC	Hammer	carbon steel and stainless	NF[b]
Low	1352	ICPP-MON-A-166	INTEC	Hammer	carbon steel and stainless	NF[b]
Low	1383	ICPP-MON-A-167	INTEC	Hammer	carbon steel and stainless	NF[b]
Low	1186	ICPP-POT-A-012	ICPP	NF[b]	NF[b]	445

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a. Although wells INEL-1 and Water Supply for INEL-1 are closely located, the significantly deeper INEL-1 apparently taps more confined conditions resulting in the anomaly of high water table measurements.

b. NF = Not found.

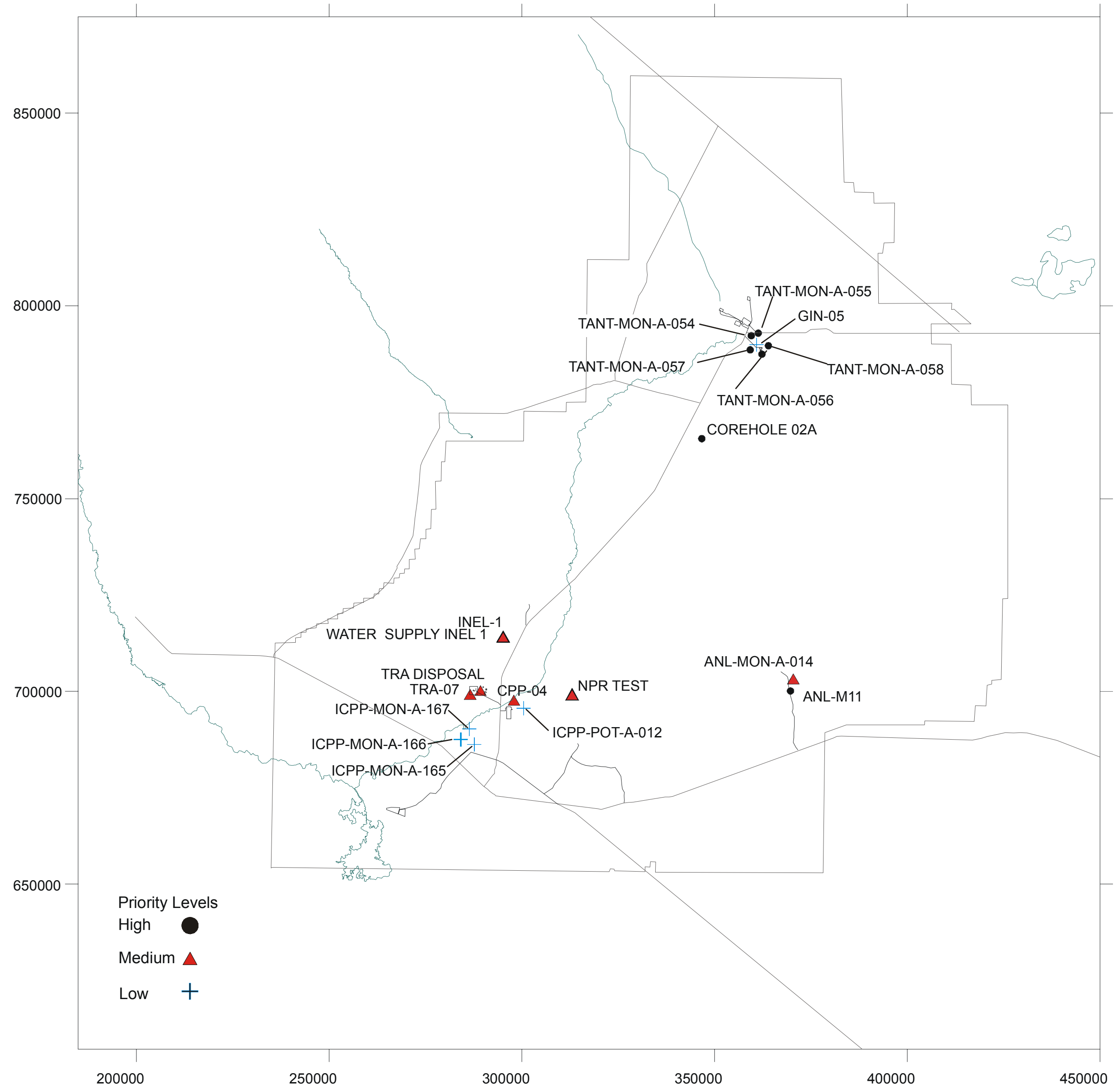

Figure 5. Location of wells that are high-priority for planned gyroscopic logging based on location, contaminant issues, and casing material.

7. CONCLUSIONS AND RECOMMENDATIONS

Scientists at the INEEL maintain information regarding more than 340 aquifer wells located at or near the INEEL. The INEEL lacks an adequate data set of accurate borehole deviation logs for these aquifer wells (only 38 aquifer wells have been logged with either photo or digital gyroscope tools). Past aquifer water table configuration concepts may be inaccurate, in part because of misleading water level information collected from deviated aquifer wells. This study is part of an effort to create a larger database of gyroscopic borehole deviation data on INEEL aquifer wells, which could then be used to better conceptualize aquifer water table configuration.

Logging to assess borehole deviation using the Century Geophysical model 9095 digital gyroscope is planned, because gyroscopic deviation data produces more accurate and reliable results (true versus measured depths) from highly-deviated wells than magnetic logging deviation data. However, the digital gyroscopic logging tool (model 9095), used by the USGS, requires long startup and shutdown times. For that reason, consideration should be given first to logging wells deemed sensitive with regard to borehole deviation. The goal of this study is to prioritize aquifer wells for gyroscopic deviation logging, based on both qualitative and quantitative information.

Qualitative screening criteria were established to initially screen aquifer wells from further consideration for planned gyroscopic logging. These include criteria based on well administrative control, accessibility, drilling methods, and the existence of previous gyroscopic borehole deviation logs. These criteria eliminated 221 of 337 aquifer wells from planned gyroscopic logging.

Quantitative screening criteria, based on magnetic borehole deviation data collected with the Century Geophysical 9055 tool, were then applied to the remaining 116 wells. The quantitative screening criteria were derived from a set of data from 128 wells that have existing magnetic borehole deviation data. In highly-deviated boreholes (i.e., those with approximately 1-ft difference or more between true depth and measured depth at the water table), the magnetic deviation tool underestimates deviation, relative to photo or digital gyroscope tools. Still, data indicates the 9055 tool has an acceptable level of accuracy at lower inclination angles.

In choosing the quantitative screening criteria, it was noted that the USGS uses a 0.3-ft threshold for correction factors (difference between measured and true depths) as determined from magnetic deviation data. Below this threshold, they do not correct water level data. This study adopted the 0.3-ft correction factor as the highest quantitative screening criterion for use with wells that have existing magnetic deviation data. Two other quantitative screening criteria levels were also employed in this study: 0.2-ft and 0.1-ft correction factors. These are based on observed population distribution of correction factors generated from borehole magnetic deviation data for the 128 wells.

Of the 116 aquifer wells remaining after the initial qualitative screening, 72 have associated magnetic deviation data; 44 do not. Of the 72 wells with magnetic deviation data, 25 have greater deviation (based on magnetic deviation data) than one of the three quantitative screening levels (correction factors of 0.3-, 0.2-, or 0.1-ft). These are recommended for planned gyroscopic logging. Of the 44 wells that do not have existing magnetic deviation data, 19 were selected for planned gyroscopic logging, based on location relative to facilities, contaminant transport concerns, and site boundaries. In total, 44 aquifer wells (25 with magnetic deviation data and 19 without) are recommended for planned gyroscopic logging. These are listed in Tables 4 and 5 in the body of this report and also in Tables D-5A and D-6A of Appendix D.

Of the 337 aquifer wells included in this analysis, 85 are not recommended for digital gyroscopic logging because a) they passed the quantitative screening levels for magnetic deviation logged wells

(47 wells, Table D-6B), or b) because they already have existing photo or digital gyroscopic survey data (38 wells, Table D-1). The wells presented in Figure 6 which have acceptable magnetic deviation results are limited to INEEL-administered wells; however, the set of wells with gyroscopic survey data include both INEEL-administered and USGS-controlled wells. Appendix E of this report is reserved for revisions containing newly processed magnetic deviation data and acquired gyroscopic survey data.

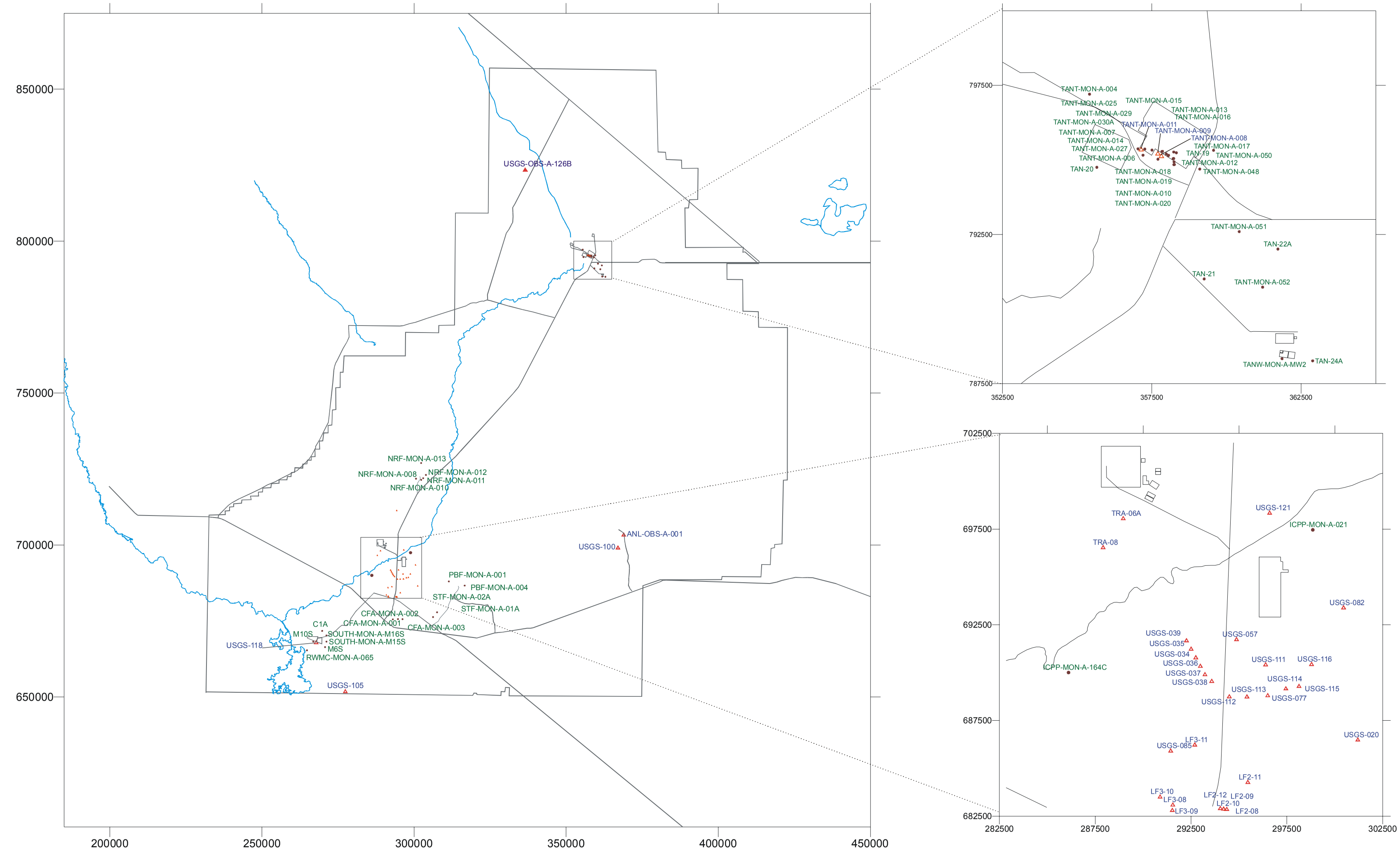

Figure 6. Spatial distribution of wells with existing gyroscopic survey data and wells with magnetic deviation data that pass quantitative screening levels.

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Appendix A

Principal Information for 337 Aquifer Wells Initially Considered for Planned Gyroscopic Logging

Table A-1. Principal information for 337 aquifer wells initially considered for planned gyroscopic logging.

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
1	01S27E14DCC1		Offsite	not found	not found	not found	989	1012	no		inaccessible (D-3)
2	04N26E32CBB1		Offsite	not found	not found	not found	not found	not found	no		inaccessible (D-3)
58	ACRE I WELL		ARA	Abandoned	not found	2" steel (galvanized)	not found	not found	no		inaccessible (D-3)
69	ANP-01		TSF	Active	cable tool	steel (0-200); uncased? (200-355)?	202	220	no		cable-tool (D-4)
70	ANP-02		TSF	Active	cable tool	steel (-5-235)	207	221	no		cable-tool (D-4)
71	ANP-03		TSF	Active	cable tool	steel (-2-180)	182	201	no		cable-tool (D-4)
72	ANP-04	IET-DISP	IET	Active	cable tool	steel (-2-324)	202	215	no		cable-tool (D-4)
73	ANP-05		TAN	Active	cable tool	steel (-2-296)	284	296	no		cable-tool (D-4)
74	ANP-06		TAN	Active	cable tool	steel (-2-211)	206	221	no		cable-tool (D-4)
75	ANP-07		TAN	Active	cable tool	steel (-2-354)	345	357	no		cable-tool (D-4)
76	ANP-08		WRRTF	Active	cable tool	steel (-2-233)	not found	not found	no		cable-tool (D-4)
77	ANP-09		TAN	Active	cable tool	steel (-2-237)	214	228	no		cable-tool (D-4)
78	ANP-10		TAN	Active	cable tool	steel (-2-552)	216	224	no		cable-tool (D-4)
79	APOLLO WELL		Offsite	not found	not found	not found	not found	not found	no		inaccessible (D-3)
80	ARA-1	ARA2 Product-ion	ARA	Inactive	cable tool	steel (-2-618)	603	608	YES		cable-tool (D-4)
81	ARA-3		ARA	Inactive	cable tool	steel (-2-978)	592	593	YES		cable-tool (D-4)
82	ARBOR TEST		ANL	Active	cable tool	steel (-2-680)	672	683	no		cable-tool (D-4)
83	ARCHER		Offsite	not found	not found	not found	230	246	no		inaccessible (D-3)
84	ARCO TEST		Offsite	not found	not found	not found	578	610	no		inaccessible (D-3)
85	ATOMIC CITY		Offsite	not found	cable tool	steel (0-35)	587	589	no		inaccessible (D-3)
88	BADGING FACILITY WELL		South site	Active	air rotary	steel (-1-482)	not found	not found	no		inaccessible (D-3)
91	CCC WELL 3		Offsite	not found	cable tool	steel (0-437)	not found	not found	no		inaccessible (D-3)
92	CERRO GR&E		Offsite	not found	cable tool	steel (0-?)	527	558	no		inaccessible (D-3)
93	CFA-1		CFA	Active	cable tool	steel (6-444)	467	480	YES		cable-tool (D-4)
94	CFA-2		CFA	Active	cable tool	steel (6-521)	469	521	no		cable-tool (D-4)
96	COREHOLE 1		South site	Active	cored	not found (0-836)	929	938	YES		magdev failed screening (D-6A)
97	COREHOLE 2A		Mid-site	Active	continuously cored	steel (-1-1936)	204	214	no		non-magdev high-priority (D-5A)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
98	CPP-01		ICPP/INTEC	Active	cable tool	steel (-1-460)	443	456	YES		cable-tool (D-4)
99	CPP-02		ICPP/INTEC	Active	cable tool	steel (0-458)	444	456	no		cable-tool (D-4)
101	CPP-04		ICPP	Active	not found (drilled 1983)	steel (7-450)	not found	not found	no		non-magdev high-priority (D-5A)
132	CROSS ROADS		Offsite	Inactive; backfilled to 563	not found	8" (0-746); 6" (746-796); built circa 1976 assume steel	582	582	no		inaccessible (D-3)
147	DH-1B		Mid-site	Active	air rotary	steel (-1-380)	246	286	no		USGS (D-2)
148	DH-2A		Mid-site	Active	air rotary	steel (-1-415)	252	284	no		USGS (D-2)
149	EBR-1		EBR	Active	cable tool	steel (8-600)	576	596	no		cable-tool (D-4)
150	EBR-II #1		ANL	Active	cable tool	steel (0-645)	632	633	no		cable-tool (D-4)
151	EBR-II #2		ANL	Active	cable tool	steel (-2-650)	not found	not found	no		cable-tool (D-4)
153	EOCR PRODUCTION WELL		South site	Inactive	cable tool	wrought iron (-2-1052)	484	485	no		inaccessible (D-3)
154	FET-1		CTF	Active	cable tool	steel (-2-230)	199	202	no		cable-tool (D-4)
155	FET-2		CTF	Active	cable tool	steel (-2-209)	200	202	no		cable-tool (D-4)
156	FET-3		CTF	Active	cable tool	steel (-2-175)	194	206	no		cable-tool (D-4)
157	FINGER'S BUTTE BLM		Offsite	not found	cable tool	steel (0-994)	not found	not found	no		inaccessible (D-3)
158	FIRE STATION WELL		WAG 10	Active	cable tool	steel (-2-427)	416	421	no		cable-tool (D-4)
159	GIN-01		WRRTF	Active	cable tool	steel (-1-48)	207	214	no		cable-tool (D-4)
160	GIN-02		WRRTF	Active	cable tool	steel (-2-43)	201	212	no		cable-tool (D-4)
161	GIN-03		WRRTF	Active	cable tool	steel (-2-176)	206	213	no		cable-tool (D-4)
162	GIN-04		WRRTF	Active	cable tool	steel (-2-41)	206	213	no		cable-tool (D-4)
163	GIN-05		WRRTF	Active	hydraulic rotary	steel (-2-30)	206	213	no		non-magdev high-priority (D-5A)
179	GRAZING-1		Offsite	not found	cable tool	steel (0-172)	162	172	no		inaccessible (D-3)
180	GRAZING-2		Offsite	not found	cable tool	steel (6-371)	350	363	no		inaccessible (D-3)
181	HANSEN		Offsite	not found	cable tool	steel (0-100)	88	120	no		inaccessible (D-3)
182	HIGHWAY 1(A),1(B),1(C)		Offsite	not found	cable tool	steel (0-1297) (-1-917) (-1-651)	573	587	no		cable-tool (D-4)
183	HIGHWAY 2		Offsite	Active	cable tool	steel (-2-741)	716	728	no		cable-tool (D-4)
184	HIGHWAY 3		South site	Active	cable tool	steel (-1-680)	537	539	no		cable-tool (D-4)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
185	IDAHO FISH & GAME		Offsite	not found	cable tool	steel (2-66)	29	65	no		inaccessible (D-3)
186	INEL-1		Mid-site	Active	rotary	steel (0-6796)	304	309	no		non-magdev high-priority (D-5A)
187	LEO ROGER'S 1		Offsite	Active	cable tool	steel (0-20)	not found	not found	no		cable-tool (D-4)
188	LEO ROGER'S 2		Offsite	not found	cable tool	steel (0-20)	not found	not found	no		inaccessible (D-3)
196	LF2-08		CFA	Active	air rotary	steel (-2-445)	472	481	no	photogyro	gyro (D-1)
197	LF2-09		CFA	Active	rotary	steel (-2-464)	475	484	YES	digital gyro	gyro (D-1)
198	LF2-10		CFA	Active	air rotary	steel (-1-676); stainless (452-725)	475	483	no	photogyro	gyro (D-1)
199	LF2-11		CFA	Active	air rotary	steel (-2-460)	466	475	no	photogyro	gyro (D-1)
207	LF3-08		CFA	Active	air rotary	steel (-2-460)	482	492	no	photogyro	gyro (D-1)
208	LIND & BOTT		Offsite	not found	not found	not found	90	129	no		inaccessible (D-3)
230	MINIDOKA WATER SYSTEM		Offsite	not found	not found	not found	not found	not found	no		inaccessible (D-3)
231	MTR TEST		TRA	Active	cable tool	steel (-1-447)	447	468	YES		cable-tool (D-4)
232	MUD-LAKE		Offsite	not found	not found	not found	not found	not found	no		inaccessible (D-3)
236	NO NAME 01		TAN	Active	cable tool	steel (-2-265)	198	213	no		cable-tool (D-4)
237	NO OWN 01		Offsite	not found	not found	not found	not found	not found	no		inaccessible (D-3)
238	NO OWN 24		Offsite	Inactive	augering	steel (-2-52)	13	31	no		inaccessible (D-3)
239	NPR TEST		South site	Active	air rotary	steel (-2-504)	455	468	no		non-magdev high-priority (D-5A)
240	NRF-1		NRF	Active	cable tool	steel (0-394)	359	366	no		cable-tool (D-4)
241	NRF-2		NRF	Active	cable tool	steel (-1-373)	359	367	no		cable-tool (D-4)
242	NRF-3		NRF	Active	cable tool	steel (-2-481)	361	372	no		cable-tool (D-4)
243	NRF-S5G		NRF	Inactive	rotary dry hole rig	18" (0-597); not found (894-1194)			no		inaccessible (D-3)
244	NRF-S5G TEST WELL		NRF	Backfilled	not found	not found (370-394)	425	440	no		inaccessible (D-3)
245	NTP-AREA 2		ARA	Active	cable tool	steel (-5-676)	664	673	no		cable-tool (D-4)
246	OMRE		South site	inactive	cable tool	steel (0-920)	480	498	no		cable-tool (D-4)
247	OWSLEY WELL 2		TAN	Active	cable tool	steel (4-252)	216	227	no		cable-tool (D-4)
248	P&W-1		TAN	Active	cable tool	steel (-2-322)	307	319	no		cable-tool (D-4)
249	P&W-2		TAN	Active	cable tool	steel (-2-313)	303	317	no		cable-tool (D-4)
250	P&W-3		TAN	Active	cable tool	wrought iron (-2-322)	297	309	no		cable-tool (D-4)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
253	PARK BELL		Offsite	not found	air rotary	steel (-1-40)	18	33	no		inaccessible (D-3)
256	PSTF TEST		TAN	Active	cable tool	steel (-2-190)	200	215	no		cable-tool (D-4)
266	QUAKING ASPEN BUTTE		Offsite	Active	air rotary	steel (0-1036)	759	766	no		inaccessible (D-3)
267	RIFLE RANGE WELL		South site	Active	air rotary	steel (-1-600)	not found	not found	no		inaccessible (D-3)
268	RWMC PRODUCTION		RWMC	Active	cable tool	steel (0-590)	565	565	YES		inaccessible (D-3)
269	SIMPLOT 1		Offsite	not found	cable tool	steel (-1-106)	115	127	no		inaccessible (D-3)
270	SIMPLOT 2		Offsite	not found	cable tool	steel (0-23)	313	324	no		inaccessible (D-3)
272	SITE 01 WATER		Offsite	not found	cable tool	steel (-2-1030)	656	986	no		USGS (D-2)
273	SITE-04		South site	Active	cable tool	steel (-2-416)	395	397	no		USGS (D-2)
274	SITE-06		Mid-site	Active	cable tool	steel (0-366)	346	363	no		USGS (D-2)
275	SITE-09		South site	Active	cable tool	steel (-2-1000)	465	476	no		USGS (D-2)
276	SITE-14		Mid-site	Active	cable tool	steel (-2-535)	256	277	no		USGS (D-2)
277	SITE-16		ANL	Active	cable tool	wrought iron (-2-655)	631	639	YES		USGS (D-2)
278	SITE-17		Mid-site	Active	cable tool	steel (-2-15)	381	404	no		USGS (D-2)
279	SITE-19		TRA	Active	cable tool	steel (0-781)	460	473	no		USGS (D-2)
280	SPERT-1		PBF	Active	cable tool	steel (-3-482)	455	471	no		cable-tool (D-4)
281	SPERT-2		PBF	Active	cable tool	steel (-2-950)	463	463	no		cable-tool (D-4)
285	SWEET SAGE		Offsite	not found	cable tool	steel (-1-100)	51	84	no		inaccessible (D-3)
336	T. SMITH		Offsite	not found	not found	not found	334	340	no		inaccessible (D-3)
337	TCH-1	TAN-CH2 MON. 1	TAN-TSF	Inactive	auger/core	pvc (-2-389)	211	211	no		inaccessible (D-3)
338	TAN DRAINAGE DISP. 01		TSF	Active	not found	steel (4-206)	not found	not found	no		non-magdev, non-exempt (D-5B)
339	TAN DRAINAGE DISP. 02		TSF	Active	not found	steel (4-262)	not found	not found	no		non-magdev, non-exempt (D-5B)
340	TAN DRAINAGE DISP. 03		CTF	Active	not found	steel (32-302)	not found	not found	no		non-magdev, non-exempt (D-5B)
342	TAN-03		TSF	Active	air rotary	steel (-4-231)	not found	not found	no		non-magdev, non-exempt (D-5B)
343	TAN-04		TSF	Active	air rotary	steel (0-214)	222	225	no		non-magdev, non-exempt (D-5B)
344	TAN-05		TSF	Active	air rotary	steel (-4-282)	222	225	no		non-magdev, non-exempt (D-5B)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
345	TAN-08		TSF	Active	air rotary	steel (-2-229)	213	218	no		non-magdev, non-exempt (D-5B)
346	TAN-09		TSF	Active	air rotary	steel (-5-300)	201	204	no		non-magdev, non-exempt (D-5B)
347	TAN-10		TSF	Active; Damaged	air rotary	steel (-3-214)	not found	not found	no		inaccessible (D-3)
348	TAN-10A		TSF	Active	rotary	steel (3-216)	201	204	no		non-magdev, non-exempt (D-5B)
349	TAN-11		TSF	Active	air rotary	steel (-2-290)	200	204	no		non-magdev, non-exempt (D-5B)
356	TRA-01		TRA	Active	cable tool	wrought iron (-1-481)	450	460	no		cable-tool (D-4)
357	TRA-02		TRA	Inactive	cable tool	steel (-2-490)	452	482	no		cable-tool (D-4)
358	TRA-03		TRA	Active	cable tool	steel (-3-470)	452	457	no		cable-tool (D-4)
359	TRA-04		TRA	Active	cable tool	steel (0-900)	not found	not found	no		cable-tool (D-4)
360	TRA DISPOSAL		TRA	Active	cable tool & air rotary?	steel (-2-928)	433	469	no		non-magdev high-priority (D-5A)
449	USBLM 1		Offsite	not found	cable tool	steel (0-41)	2	43	no		USGS (D-2)
450	USGS-001		South site	Active	cable tool	steel (-1-600)	582	591	YES		USGS (D-2)
451	USGS-002		South site	Active	cable tool	steel (-2-675)	651	662	no		USGS (D-2)
453	USGS-004		Mid-site	Active	cable tool	steel (-2-285)	252	268	no		USGS (D-2)
454	USGS-005		South site	Active	cable tool	steel (-1-475)	460	472	no		USGS (D-2)
455	USGS-006		Mid-site	Active	cable tool	steel (-2-532)	406	418	no		USGS (D-2)
456	USGS-007		TAN	Active	cable tool	steel (-1-760)	204	221	no		USGS (D-2)
457	USGS-008		Offsite	Active	cable tool	steel (-2-782)	750	770	no		USGS (D-2)
458	USGS-009		South site	Active	cable tool	steel (-1-620)	594	610	YES		USGS (D-2)
459	USGS-010A		Offsite	Active	cable tool	not found	not found	not found	no		USGS (D-2)
460	USGS-011		Offsite	Active	cable tool	steel (-2-673)	645	655	no		USGS (D-2)
461	USGS-012		Mid-site	Active	cable tool	steel (-1-388); steel (335-587)	308	336	no		USGS (D-2)
462	USGS-013		Offsite	Active	cable tool	6" (0-998) circa yr 1951; assume steel	981	989	no		USGS (D-2)
463	USGS-014		Offsite	Active	cable tool	steel (-1-752)	709	719	no		USGS (D-2)
464	USGS-015		Mid-site	Active	cable tool	steel (-1-540) (1127-1229)	302	334	no		USGS (D-2)
465	USGS-016		Offsite	Active	cable tool	steel (-2-739)	683	691	no		USGS (D-2)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)
466	USGS-017		Mid-site	Active	cable tool	steel (-2-406)	342	360	no		USGS (D-2)
467	USGS-018		Mid-site	Active	cable tool	steel (-2-255)	258	277	no		USGS (D-2)
468	USGS-019		Mid-site	Active	cable tool	steel (-2-285)	251	281	no		USGS (D-2)
469	USGS-020		ICPP	Active	cable tool	steel (-2-404) (552-676)	453	465	no	photogyro	gyro (D-1)
470	USGS-021		Mid-site	Active	cable tool	steel (-1-405)	324	338	no		USGS (D-2)
471	USGS-022		South site	Active	cable tool	steel (-2-619)	510	642	no		USGS (D-2)
472	USGS-023		Mid-site	Active	cable tool	steel (-1-410)	382	407	no		USGS (D-2)
473	USGS-024		TSF	Active	cable tool	steel (-2-255)	207	275	no		USGS (D-2)
474	USGS-025		TAN	Active	cable tool	steel (-4-285)	220	275	no		USGS (D-2)
475	USGS-026		TAN	Active	cable tool	steel (-1-232)	200	215	no		USGS (D-2)
476	USGS-027		NORTH	Active	cable tool	steel (-2-250)	218	230	no		USGS (D-2)
477	USGS-028		Mid-site	Active	cable tool	steel (0-254)	225	236	no		USGS (D-2)
478	USGS-029		Mid-site	Active	cable tool	steel (-2-328)	346	360	no		USGS (D-2)
479	USGS-030A		Mid-site	Active	cable tool	steel (-2-725)	250	263	no		USGS (D-2)
479	USGS-030B		Mid-site	Active	cable tool	steel (-2-400)	257	274	no		USGS (D-2)
479	USGS-030C		Mid-site	Active	cable tool	steel (-2-357)	259	276	no		USGS (D-2)
480	USGS-031		Mid-site	Active	cable tool	steel (-1-270)	250	260	no		USGS (D-2)
481	USGS-032		Mid-site	Active	cable tool	steel (-3-306)	282	294	no		USGS (D-2)
483	USGS-034		ICPP	Active	cable tool	steel (-1-700)	459	476	no	photogyro	gyro (D-1)
484	USGS-035		ICPP	Active	cable tool	steel (-2-143)	463	477	no	photogyro	gyro (D-1)
485	USGS-036		ICPP	Active	cable tool	steel (-1-430)	447	477	no	photogyro	gyro (D-1)
486	USGS-037		ICPP	Active	cable tool	steel (-2-507)	462	476	no	photogyro	gyro (D-1)
487	USGS-038		ICPP	Active	cable tool	steel (-1-678)	463	478	no	photogyro	gyro (D-1)
488	USGS-039		ICPP	Active	cable tool	steel (-1-48)	465	479	no	photogyro	gyro (D-1)
489	USGS-040		ICPP	Active	cable tool	steel (-2-447)	446	463	YES		USGS (D-2)
490	USGS-041		ICPP	Active	cable tool	steel (-2-428)	448	463	YES		USGS (D-2)
491	USGS-042		ICPP	Active	cable tool	steel (-2-453)	449	464	YES		USGS (D-2)
492	USGS-043		ICPP	Active	cable tool	steel (-2-451)	447	462	YES		USGS (D-2)
493	USGS-044		ICPP	Active	cable tool	wrought iron (-2-461)	449	464	YES		USGS (D-2)
494	USGS-045		ICPP	Active	cable tool	steel (-2-461)	450	466	YES		USGS (D-2)
495	USGS-046		ICPP	Active	cable tool	steel (-2-461)	448	463	YES		USGS (D-2)
496	USGS-047		ICPP	Active	cable tool	steel (-1-458)	446	461	YES		USGS (D-2)

Table A-1. (continued).

Well ID	Well Name	Alias	Facility	Status	Drilling Method	Casing Summary[a] (depths start-stop)	Minimum Depth-to-Water[b] (ft)	Maximum Depth-to-Water[b] (ft)	Magnetic Deviation Data Available?	Other Deviation Data	Screening Results (Appendix D table)	
497	USGS-048		ICPP	Active	cable tool	steel (-2-462)	448	464	YES		USGS (D-2)	
498	USGS-049		ICPP	Inactive	cable tool	6" (-2-459) circa yr 1960; assume steel	448	457	YES		USGS (D-2)	
500	USGS-051		ICPP	Active	cable tool	steel (-2-475)	451	464	no		USGS (D-2)	
501	USGS-052		ICPP	Active	cable tool	steel (0-450)	444	456	YES		USGS (D-2)	
506	USGS-057		ICPP	Active	cable tool	steel (-2-474)	458	666	no	photogyro	gyro (D-1)	
507	USGS-058		TRA	Active	cable tool	steel (-2-218)	451	465	no		USGS (D-2)	
508	USGS-059		ICPP	Active	cable tool	6.67" (-2-464) in year 1960; assume steel	447	460	YES		USGS (D-2)	
514	USGS-065		TRA	Active	cable tool	steel (-1-327)	459	470	no		USGS (D-2)	
516	USGS-067		ICPP	Active	cable tool	steel (-2-450)	448	461	no		USGS (D-2)	
525	USGS-076		TRA	Active	cable tool	8" steel (0-268); unk 6"	465□477□no	477□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
526□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□ca	cable tool□steel	steel (-2-	457□469□no	469□no□pho	no□photogy	photogyro□g	gyro (D-	□
528□US	USGS-	□TRA□Activ	TRA□Acti	Active□ca	cable tool□6"	6" unk (0-281) in year 1962;	465□478□no	478□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
531□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□ca	cable tool□steel	steel (-2-	440□454□no	454□no□pho	no□photogy	photogyro□g	gyro (D-	□
532□US	USGS-083□□South	□South	South	Active□ca	cable tool□steel	steel (-2-	492□502□Y	502□YES□□	YES□□US	□USGS (D-	USGS (D-	□
533□US	USGS-	□TRA□Activ	TRA□Acti	Active□ca	cable tool□steel	steel (-2-	472□485□Y	485□YES□□	YES□□US	□USGS (D-	USGS (D-	□
534□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□ca	cable tool□steel	steel (-2-	474□487□no	487□no□pho	no□photogy	photogyro□g	gyro (D-	□
535□US	USGS-086□□South	□South	South	Active□ca	cable tool□steel	steel (0-	635□653□Y	653□YES□□	YES□□US	□USGS (D-	USGS (D-	□
536□US	USGS-	□RWMC□A	RWMC□A	Active□ca	cable tool□steel	steel (-2-	575□592□no	592□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
537□US	USGS-	□RWMC□A	RWMC□A	Active□ca	cable tool□steel	steel (-2-	513□594□Y	594□YES□□	YES□□US	□USGS (D-	USGS (D-	□
538□US	USGS-	□RWMC□A	RWMC□A	Active□ca	cable tool□steel	steel (-2-	580□607□Y	607□YES□□	YES□□US	□USGS (D-	USGS (D-	□
539□US	USGS-	□RWMC□A	RWMC□A	Active□ca	cable tool□steel	steel (-1-	569□586□no	586□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
546□US	USGS-	□NRF□Activ	NRF□Acti	Active□air	air rotary□steel	steel (-1-	367□387□no	387□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
547□US	USGS-098□□Mid-	□Mid-	Mid-	Active□air	air rotary□steel	steel (-1-	396□417□no	417□no□digi	no□digital	digital	gyro (D-	□
548□US	USGS-099□□Mid-	□Mid-	Mid-	Active□air	air rotary□steel	steel (-2-	382□401□no	401□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
549□US	USGS-	□ANL□Acti	ANL□Acti	Active□air	air rotary□steel	steel (-1-	669□680□no	680□no□digi	no□digital	digital	gyro (D-	□
550□US	USGS-101□□South	□South	South	Active□air	air rotary□steel	steel (-1-	763□774□Y	774□YES□□	YES□□US	□USGS (D-	USGS (D-	□
551□US	USGS-	□NRF□Activ	NRF□Acti	Active□air	air rotary□steel	steel (-2-	367□378□no	378□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
552□US	USGS-103□□South	□South	South	Active□air	air rotary□steel	steel (0-	574□586□no	586□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
553□US	USGS-104□□South	□South	South	Active□air	air rotary□steel	steel (0-	454□559□Y	559□YES□□	YES□□US	□USGS (D-	USGS (D-	□
554□US	USGS-105□□South	□South	South	Active□air	air rotary□steel	steel (0-	658□673□no	673□no□digi	no□digital	digital	gyro (D-	□
555□US	USGS-106□□South	□South	South	Active□air	air rotary□steel	steel (-2-	576□591□Y	591□YES□□	YES□□US	□USGS (D-	USGS (D-	□
556□US	USGS-107□□South	□South	South	Active□air	air rotary□steel	steel (0-	473□482□no	482□no□□U	no□□USGS	□USGS (D-	USGS (D-	□
557□US	USGS-108□□South	□South	South	Active□air	air rotary□steel	steel (0-	598□611□Y	611□YES□□	YES□□US	□USGS (D-	USGS (D-	□
558□US	USGS-109□□South	□South	South	Active□air	air rotary□steel	steel (0-	607□623□Y	623□YES□□	YES□□US	□USGS (D-	USGS (D-	□
559□US	USGS-110a□□South	□South	South	Active□air	air rotary□steel	steel (0-	562□571□Y	571□YES□□	YES□□US	□USGS (D-	USGS (D-	□
560□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□air	air rotary□steel	steel (-2-	460□570□no	570□no□pho	no□photogy	photogyro□g	gyro (D-	□
561□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□hy	hydraulic	steel (-2-	465□478□Y	478□YES□p	YES□photo	photogyro□g	gyro (D-	□
562□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□hy	hydraulic	steel (-2-	462□479□Y	479□YES□di	YES□digital	digital	gyro (D-	□
563□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□hy	hydraulic	steel (-2-	459□471□no	471□no□pho	no□photogy	photogyro□g	gyro (D-	□
564□US	USGS-	□ICPP□Acti	ICPP□Acti	Active□air	air rotary□							