DOE/ID-22241
Prepared in cooperation with the U.S. Department of Energy

# Borehole Deviation and Correction Factor Data for Selected Wells in the Eastern Snake River Plain Aquifer at and near the Idaho National Laboratory, Idaho

Scientific Investigations Report 2016–5163

U.S. Department of the Interior
U.S. Geological Survey

**Cover:** Photographs showing setup for the gyroscopic logging tool at well site USGS 102, Idaho National Laboratory, Idaho. Photograph by Brian Twining, U.S. Geological Survey, September 2, 2015.

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SALLY JEWELL, Secretary

**U.S. Geological Survey**
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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# Contents



## Figures



## Tables

## Conversion Factors

U.S. customary units to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| gallon (gal) | 3.785 | liter (L) |
| | Flow rate | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| | Hydraulic conductivity | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| | Hydraulic gradient | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |
| | Transmissivity | |
| foot squared per day ($ft^2/d$) | 0.09290 | meter squared per day ($m^2/d$) |

## Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Elevation, as used in this report, refers to distance above the vertical datum.

## Supplemental Information

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day ($ft^2/d$), is used for convenience.

# Borehole Deviation and Correction Factor Data for Selected Wells in the Eastern Snake River Plain Aquifer at and near the Idaho National Laboratory, Idaho

By Brian V. Twining

## Abstract

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, has maintained a water-level monitoring program at the Idaho National Laboratory (INL) since 1949. The purpose of the program is to systematically measure and report water-level data to assess the eastern Snake River Plain aquifer and long term changes in groundwater recharge, discharge, movement, and storage. Water-level data are commonly used to generate potentiometric maps and used to infer increases and (or) decreases in the regional groundwater system. Well deviation is one component of water-level data that is often overlooked and is the result of the well construction and the well not being plumb. Depending on measured slant angle, where well deviation generally increases linearly with increasing slant angle, well deviation can suggest artificial anomalies in the water table. To remove the effects of well deviation, the USGS INL Project Office applies a correction factor to water-level data when a well deviation survey indicates a change in the reference elevation of greater than or equal to 0.2 ft.

Borehole well deviation survey data were considered for 177 wells completed within the eastern Snake River Plain aquifer, but not all wells had deviation survey data available. As of 2016, USGS INL Project Office database includes: 57 wells with gyroscopic survey data; 100 wells with magnetic deviation survey data; 11 wells with erroneous gyroscopic data that were excluded; and, 68 wells with no deviation survey data available. Of the 57 wells with gyroscopic deviation surveys, correction factors for 16 wells ranged from 0.20 to 6.07 ft and inclination angles (SANG) ranged from 1.6 to 16.0 degrees. Of the 100 wells with magnetic deviation surveys, a correction factor for 21 wells ranged from 0.20 to 5.78 ft and SANG ranged from 1.0 to 13.8 degrees, not including the wells that did not meet the correction factor criteria of greater than or equal to 0.20 ft.

Forty-seven wells had gyroscopic and magnetic deviation survey data for the same well. Datasets for both survey types were compared for the same well to determine whether magnetic survey data were consistent with gyroscopic survey data. Of those 47 wells, 96 percent showed similar correction factor estimates (≤ 0.20 ft) for both magnetic and gyroscopic well deviation surveys. A linear comparison of correction factor estimates for both magnetic and gyroscopic deviation well surveys for all 47 wells indicate good linear correlation, represented by an r-squared of 0.88. The correction factor difference between the gyroscopic and magnetic surveys for 45 of 47 wells ranged from 0.00 to 0.18 ft, not including USGS 57 and USGS 125. Wells USGS 57 and USGS 125 show a correction factor difference of 2.16 and 0.36 ft, respectively; however, review of the data files suggest erroneous SANG data for both magnetic deviation well surveys. The difference in magnetic and gyroscopic well deviation SANG measurements, for all wells, ranged from 0.0 to 0.9 degrees. These data indicate good agreement between SANG data measured using the magnetic deviation survey methods and SANG data measured using gyroscopic deviation survey methods, even for surveys collected years apart.

## Introduction

The Idaho National Laboratory (INL), operated by the U.S. Department of Energy (DOE), encompasses about 890 $mi^2$ of the eastern Snake River Plain (ESRP) in southeastern Idaho (fig. 1). The INL was established in 1949 to develop atomic energy, nuclear safety, defense programs, environmental research, and advanced energy concepts. Wastewater disposal sites at the Test Area North (TAN), the Naval Reactors Facility (NRF), the Advanced Test Reactor Complex (ATR Complex), and the Idaho Nuclear Technology and Engineering Center (INTEC) (fig. 1) have contributed radioactive- and chemical-waste contaminants to the ESRP aquifer. These sites incorporated various wastewater disposal methods, including lined evaporation ponds, unlined percolation (infiltration) ponds and ditches, drain fields, and injection wells. Waste materials buried in shallow pits and trenches within the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) have contributed contaminants to groundwater. The U.S. Geological Survey (USGS) routinely collects water-level data and water quality samples from monitor wells to describe the fate and transport of ESRP groundwater at the INL.

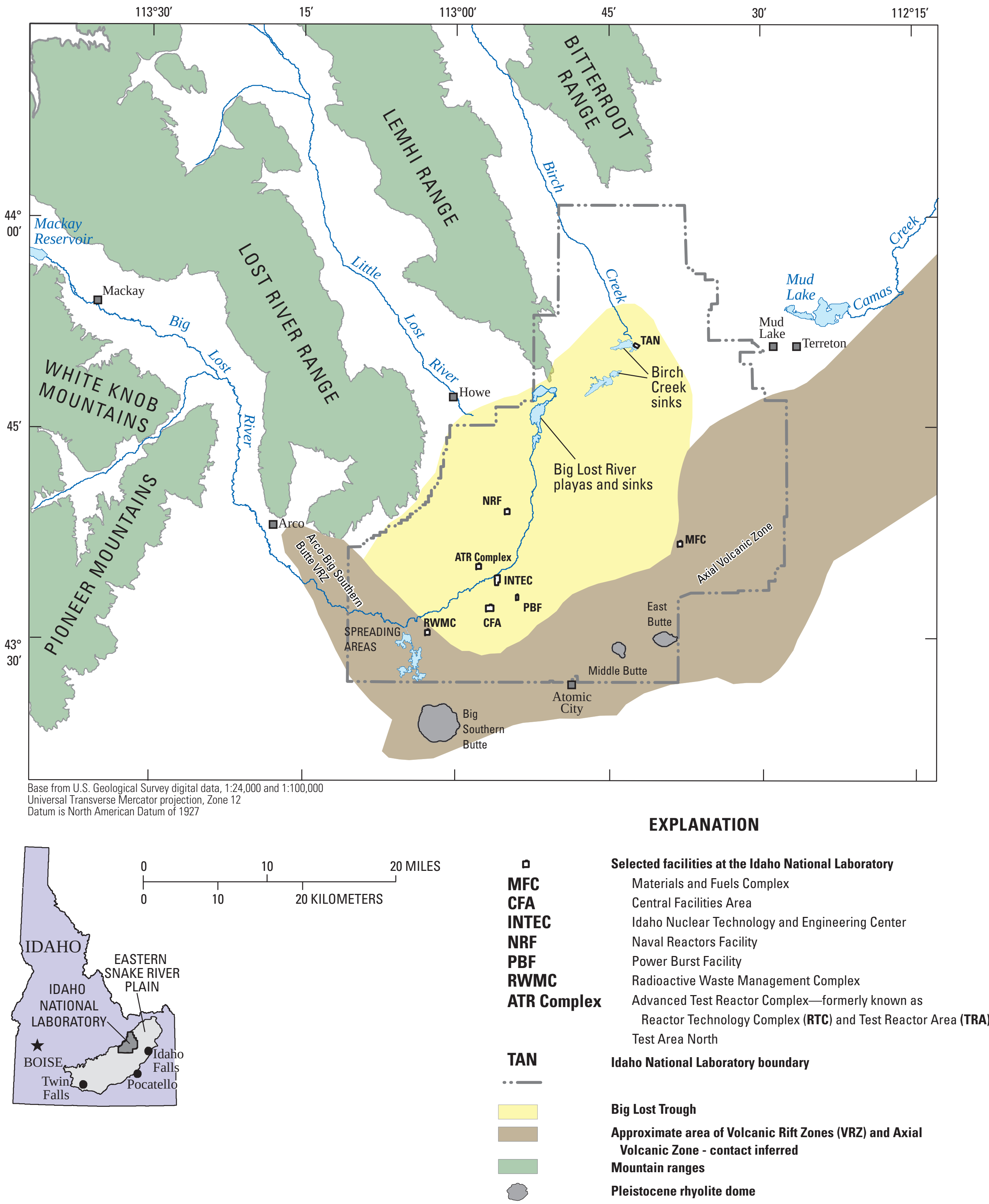


**Figure 1.** Location of selected facilities, Idaho National Laboratory, Idaho.

The USGS, in cooperation with the DOE, has maintained a water-level monitoring program at the INL since 1949 to systematically measure water levels to provide long-term information on groundwater recharge, discharge, movement, and storage for the ESRP aquifer (figs. 2 and 3). As of 2015, water levels from the ESRP aquifer were collected either continuously, monthly, quarterly, semi-annually, or annually at about 180 wells (Bartholomay and others, 2014, appendix B). Water-level data were obtained through discrete manual measurements using electric-tapes (e-tapes) and/or continuous data using loggers. The USGS has established procedures for the collection of water-level data and calibration of e-tapes to ensure accuracy of manual measurements (Bartholomay and others, 2014).

Across the INL, the average water table gradient is close to 4 ft/mi (Anderson and others, 1999). Many INL wells are located at and near facilities for the purpose of monitoring levels and water quality (figs. 2 and 3). Well deviation can increase the measured distance to a reference elevation and create anomalies in potentiometric maps when not corrected. Currently, the USGS INL Project Office assigns a correction factor based off of a reference depth measured below land surface, generally the water table, if the well deviation survey suggests the correction factor is equal to or greater than 0.20 ft (Twining and others, 2016).

The ideal borehole is vertical and straight with minimal deviation; however, drilling and construction often result in some deviation generally caused by density changes in rock or sediment, or both. To measure well deviation, wireline surveys are collected after the well is drilled or during routine well maintenance. The well deviation survey and post-processing software provide an assessment of the well path for various reference elevations, located at or near the water table, and are used to assign a correction factor based off of the survey information. Vertical wells are usually defined as wells with an inclination angle, or SANG, within 5 degrees or less of vertical; however, a well is not considered highly deviated until inclination is greater than 60 degrees (Farah, 2013). In this report, SANG refers to the inclination angle measured from vertical that an off plumb well makes; SANGB describes the azimuth angle which is a measure of the twisting or corkscrewing of an untrue borehole (fig. 4).

## Purpose and Scope

The purpose of this report is to evaluate borehole deviation survey data for water-level wells completed in the ESRP aquifer at or near the INL. This report examines all data available as of 2016, and will be used to adjust water-level data for wells with a correction factor of equal to or greater than 0.20 ft. Methods and procedures will be described for gyroscopic and magnetic deviation surveys. Deviation survey results will be described for both gyroscopic and magnetic deviation surveys. Additionally, gyroscopic and magnetic deviation survey results will be compared where both surveys are available for the same well. Correction factor data, plan view displays, and data tables for various reference depths will be presented for wells that require correction factors.

## Geohydrologic Setting

The study area is in the ESRP in Idaho, a relatively flat topographic depression, about 200 mi long and 50–70 mi wide (fig. 1). The INL lies within the west-central part of the ESRP. Streams, some ephemeral, originate in mountain ranges north and west of the study site and include the Big Lost River (BLR), the Little Lost River, Birch Creek, and Camas Creek. Streamflow-infiltration recharge fluctuates greatly in response to seasonality, such as spring snowmelt. Episodic recharge from the BLR channel, spreading areas, sinks, and playas represent a large transient stress within the ESRP aquifer at the INL (fig. 1). Episodic flood events can result in large pulses of surface-water infiltration near the southern boundary and have been shown to affect the saturated and unsaturated zones in this region (Nimmo and others, 2002).

The ESRP at the INL mostly consists of olivine tholeiitic basaltic lava flows (about 85 percent by volume) with lesser amounts of interbedded terrestrial sediments (Kuntz and others, 1992). Basaltic rocks and sedimentary deposits combine to form the ESRP aquifer. Significant landforms of the ESRP in the vicinity of the INL include (fig. 1): (1) rhyolite domes (Kuntz and others, 1994), (2) Big Lost Trough (Blair, 2002), (3) volcanic rift zones (VRZ), and (4) axial volcanic zone (AVZ). The Big Lost Trough (fig. 1) is bounded to the northwest by mountains and on the other sides by informally named VRZs—the AVZ extends northeast and southwest and the Arco-Big Southern Butte VRZ extends northwest and southeast. The VRZs, including the Arco-Big Southern Butte VRZ and AVZ, are areas of focused volcanism resulting in high concentrations of volcanic vents and fissures (Anderson and others, 1999, p. 13; Hughes and others, 1999, p. 145), which are the major sources of basaltic rocks on the plain.

The BLR has been a major source of sediment since late Pliocene time, resulting in a depocenter known as the Big Lost Trough (fig. 1; Geslin and others, 2002). Boreholes drilled in the Big Lost Trough generally encounter greater amounts by volume of interbedded sediment than boreholes drilled in and near the Arco-Big Southern Butte VRZ and AVZ (Anderson and others, 1999, fig. 9, table 2; Hughes and others, 2002; Welhan and others, 2007). Interbedded sediments penetrated by boreholes on the INL range in thickness from equal to or less than 1 ft to equal to or greater than 313 ft and are thickest in the northwestern part of the INL (Anderson and others, 1996; Welhan and others, 2007).

The ESRP aquifer is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 194).

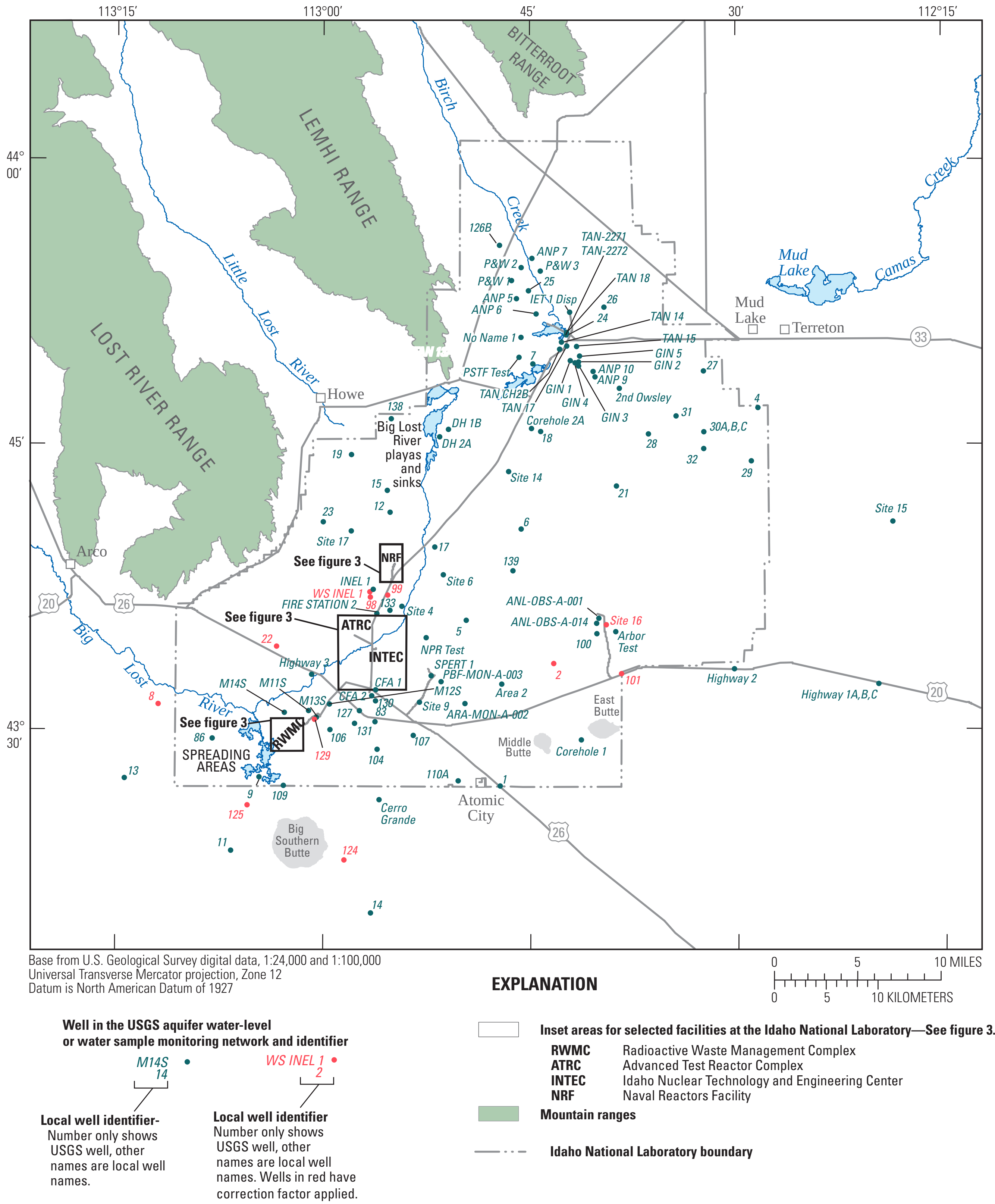


**Figure 2.** Location of wells used for water-level measurements and select wells that have a correction factor of greater than or equal to 0.20 ft, at and near the Idaho National Laboratory, Idaho.

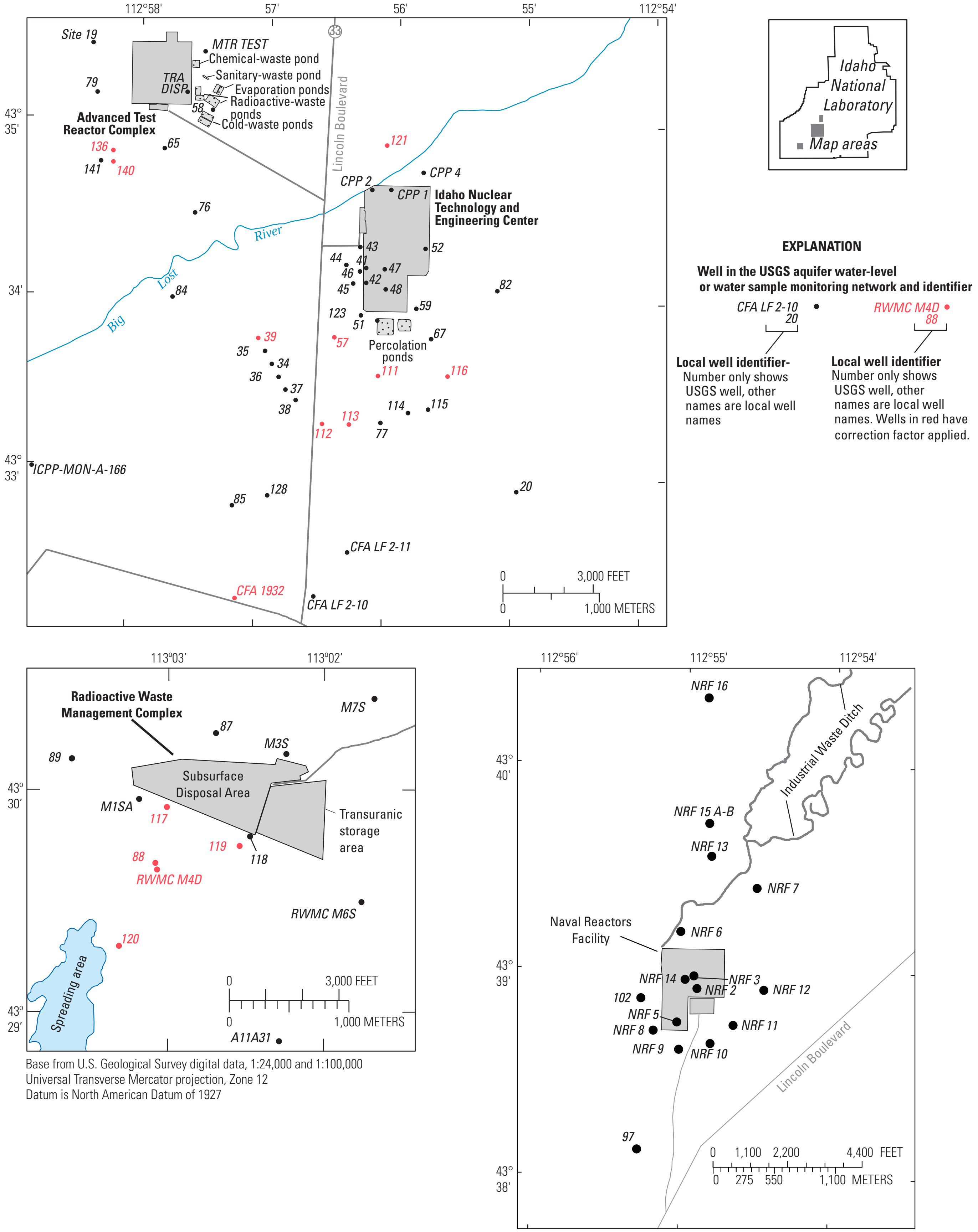


**Figure 3.** Location of wells used for water-level measurements and select wells that have a correction factor of greater than or equal to 0.20 ft near the Advanced Test Reactor Complex, the Idaho Nuclear Technology and Engineering Center, the Naval Reactors Facility, and the Radioactive Waste Management Complex, Idaho National Laboratory, Idaho.

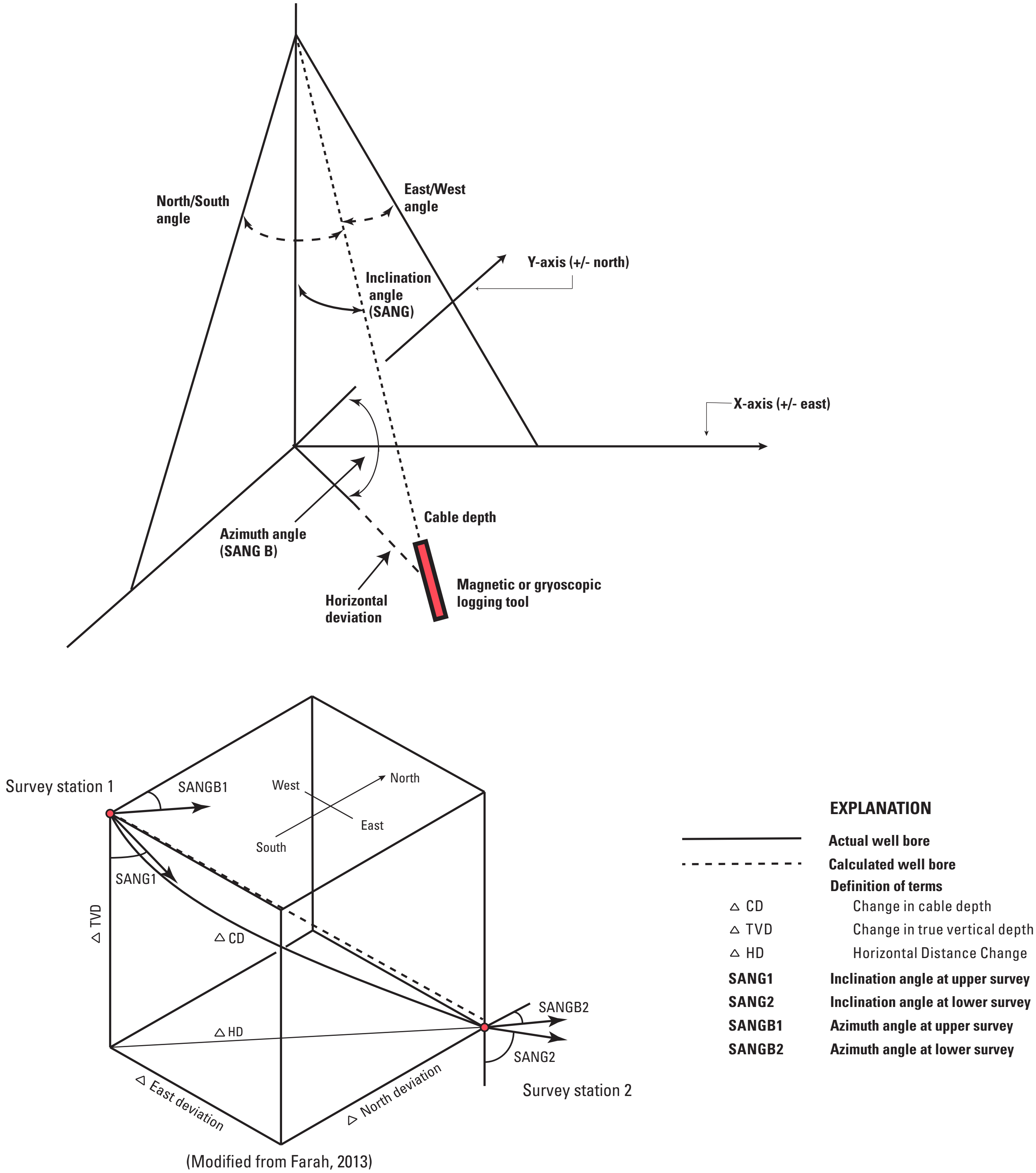


**Figure 4.** Deviation survey well path parameters and associated inclination angle and azimuth angle measurements.

Along the northwestern mountain front, surface-water and groundwater underflow enter the aquifer system from three tributary valleys—BLR, Little Lost River, and Birch Creek (fig. 1). Groundwater moves horizontally through basalt interflow zones and vertically through joints and fracture zones. Infiltration of surface water, groundwater pumping, geologic conditions, and seasonal flux of recharge and discharge locally affect the movement of groundwater in the aquifer (Garabedian, 1986). Recharge primarily is from the infiltration of applied irrigation water, streamflow, precipitation, and underflow from the tributary valleys to the plain.

Across the INL, borehole water-table elevation ranges from about 4,560 to 4,410 ft and groundwater generally flows in a southwestern direction (Davis and others, 2013, fig. 9). Depth to the water table ranges from about 200 ft below land surface (BLS) north of the INL to more than 900 ft BLS in the southeast. Aquifer thickness is variable and generally thins towards the mountain fronts and appears to thicken towards the southern boundary of the INL.

Wells completed within the ESRP aquifer, and open to less than 100 ft of the aquifer, can yield as much as 7,000 gal/min with only a few feet of drawdown (Whitehead, 1992). Ackerman (1991, p. 30) and Bartholomay and others (1997, table 3) reported a range of relative transmissivities for basalt in the upper part of the aquifer of 1.1–760,000 $ft^2/d$. The hydraulic gradient through the INL generally drives groundwater from northeast to southwest and ranges from 2 to 10 ft/mi, with an average of about 4 ft/mi (Davis and others, 2013). Calculated horizontal groundwater flow velocities ranging from 2 to 20 ft/d are based on the movement of various constituents in different areas of the aquifer beneath the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Busenberg and others, 2001). Localized tracer tests at the INL have shown vertical and horizontal transport rates as high as 60–150 ft/d (Nimmo and others, 2002; Duke and others, 2007).

## Previous Investigations

Numerous previous investigations on the hydrology and geology at the INL have been done by INL contractors, state agencies, and the USGS. The USGS provides a list of references and hyperlinks to published reports from its previous INL studies at the USGS INL Project Office Web page at: http://id.water.usgs.gov/INL/Pubs/index.html.

Water-level data for wells measured by the USGS INL Project Office have been published in numerous reports. Barraclough and others (1984) published data from selected wells from 1949 through 1982, Ott and others (1992) published data from selected wells from 1983 through 1990, and Bartholomay and Twining (2015) published water-level data for all wells currently monitored at the INL. Starting in mid-1990, the USGS water-level data became accessible where data could be pulled in tables and presentation-quality hydrographs through USGS Web pages. Water-level data from wells at the INL are available at: http://maps.waterdata.usgs.gov/mapper/index.html?SiteGroups=gw,act&MapCenterX=-112.84&MapCenterY=43.58&MapZoom=10.

# Methods

The USGS INL Project Office routinely collects magnetic deviation and gyroscopic deviation survey data after a well is drilled and (or) during well maintenance. Deviation survey data are available for many wells on the INL (table 1). The logging tools used for the magnetic survey collect other parameters that are not included in this report, but the tool used for the gyroscopic survey is dedicated for the collection of deviation surveys. The gyroscopic deviation survey requires a more involved setup and requires operators to follow procedures outlined in appendix A. It is common practice for the USGS INL Project Office to collect both magnetic and gyroscopic well deviation surveys on completion of a new well and (or) during well maintenance. Deviation data are continuously collected at regular spaced intervals (0.10 or 0.20 ft) and post-processing software, proprietary to Century™, is used to compute the well bore path using reference angles SANG and SANGB, referred to as the slant angle (inclination) and slant angle bearing (azimuth).

Three Century™ wireline logging tools were used to collect well deviation surveys, and include: model numbers 9055A (serial number [SN]-242); 9057A (SN-1077); 9095 (SN-1203). Both 9055A and 9057A tools are equipped with a three-axis magnetometer; and, the 9095 logging tool is equipped with a mechanical gyroscope for SANGB measurements (fig. 4). The wireline tools (9055A, 9057A, and 9095) use a similar two-axis accelerometer for SANG measurements (fig. 4). The primary disadvantage of the three-axis magnetometer, on the 9057A and 9055A logging tools, is that steel casing and (or) ferrous rocks are known to distort SANGB measurements, similar to a handheld compass near magnetic objects. The mechanical gyroscopic can be run under most borehole conditions and is currently the preferred survey at the INL after a well is drilled because it is not susceptible to ferrous material. Using the 9095 logging tool for a gyroscopic well deviation survey requires a known starting azimuth, station measurements, and tool leveling (appendix A). For wells that both gyroscopic and magnetic deviation surveys are available, the gyroscopic well deviation survey was used to estimate a correction factor.

Well deviation survey post-processing and analysis was done using Century™ Display, version 3.64KT. The post-processing software computes the well path using a method referred to as “Average Angles” and continuous SANG and SANGB measurements (Brian Peterson, Century™ Geophysical Corp. LLC., written commun., June 8, 2015).

**Table 1.** Well sites monitored by the U.S. Geological Survey for water-level data and deviation survey information in 2016, at and near the Idaho National Laboratory, Idaho.

[Well location shown in figures 2 and 3. Deviation survey data collected using a Century™ wireline logging tool. During post-processing magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifer used to access well data from the USGS National Water Information System (NWIS, http://waterdata.usgs.gov/nwis). **Elevation** is referenced to survey to National Geodetic Vertical Datum of 1929. **Drill depth** refers to total depth of hole during construction. **Depth range to water** is the reported range of water level data available through NWIS and used to determine most current correction factor. **Gyroscopic** and **Magnetic** refer to deviation survey reference dates (mm-dd-yy). **Abbreviations**: BLS, below land surface; Err, file error; ft, feet; unk, data not available]

| Local name | Site identifier | Elevation (ft) | Drill depth (ft BLS) | Depth range to water | | Gyroscopic | Magnetic |
|---|---|---|---|---|---|---|---|
| | | | | (ft BLS) | (ft BLS) | | |
| ANP 5 | 435308112454101 | 4,872.18 | 383 | 284.43 | 315.27 | unk | 08-16-07 |
| ANP 6 | 435152112443101 | 4,794.43 | 295 | 206.69 | 241.12 | unk | 06-11-12 |
| ANP 7 | 435522112444201 | 4,934.64 | 433 | 345.45 | 373.93 | unk | 08-25-08 |
| ANP 9 | 434856112400001 | 4,786.14 | 321 | 214.72 | 245.24 | unk | unk |
| ANP 10 | 434909112400401 | 4,786.05 | 676 | 216.34 | 241.02 | unk | 05-28-08 |
| ANL OBSA-001 | 433545112394101 | 5,121.04 | 1,910 | 638.20 | 646.54 | unk | 07-14-94 |
| ANL MONA-014 | 433537112393801 | 5,118.08 | 682 | 635.02 | 645.34 | unk | 11-12-96 |
| ARA-MON-A-002 | 433054112492102 | 5,037.40 | 629 | 594.00 | 600.82 | Err | 06-28-94 |
| ARBOR TEST | 433509112384801 | 5,163.95 | 790 | 672.04 | 691.47 | unk | unk |
| AREA 2 | 433223112470201 | 5,128.60 | 876 | 664.47 | 682.37 | unk | unk |
| A11A31 | 432853113021701 | 5,065.56 | 675 | 638.50 | 647.16 | Err | unk |
| CERRO GRANDE | 432618112555501 | 4,979.30 | 563 | 527.36 | 562.84 | unk | unk |
| CFA 1932 | 433214112570101 | 4,938.08 | 525 | 490.52 | 494.06 | 01-11-05 | 01-11-05 |
| CFA LF 2-10 | 433216112563301 | 4,932.03 | 716 | 475.20 | 489.60 | Err | unk |
| CFA LF 2-11 | 433230112561701 | 4,928.37 | 499 | 470.20 | 485.88 | Err | unk |
| COREHOLE 1 | 432927112410101 | 5,370.00 | 2,000 | 929.71 | 943.61 | unk | 05-03-95 |
| COREHOLE 2A | 434558112444801 | 4,787.05 | 3,000 | 204.50 | 231.24 | Err | unk |
| CROSSROADS | 432128113092701 | 5,120.00 | 796 | 710.00 | 714.50 | 05-17-04 | unk |
| DH 1B | 434611112504301 | 4,792.12 | 400 | 246.89 | 299.89 | unk | 03-19-13 |
| DH 2A | 434547112512801 | 4,794.60 | 425 | 252.02 | 303.22 | unk | 03-19-13 |
| FIRE STATION 2 | 433548112562301 | 4,902.31 | 510 | 416.07 | 441.88 | 03-21-05 | 08-02-06 |
| GIN 1 | 434947112414301 | 4,786.73 | 364 | 207.72 | 232.78 | unk | unk |
| GIN 2 | 434949112413401 | 4,786.23 | 381 | 201.19 | 234.53 | unk | unk |
| GIN 3 | 434945112413101 | 4,786.24 | 386 | 202.63 | 231.81 | unk | unk |
| GIN 4 | 434949112413601 | 4,786.32 | 300 | 206.81 | 231.85 | unk | unk |
| GIN 5 | 434953112413301 | 4,786.63 | 285 | 206.98 | 231.97 | unk | unk |
| HWY 1A PIEZO 3 | 433218112191603 | 5,089.83 | 1,147 | 573.51 | 597.80 | unk | unk |
| HWY 1B PIEZO 2 | 433218112191602 | 5,089.83 | 982 | 573.26 | 596.47 | unk | unk |
| HWY 1C PIEZO 1 | 433218112191601 | 5,089.83 | 800 | 573.29 | 594.87 | unk | unk |
| HIGHWAY 2 | 433307112300001 | 5216.55 | 786 | 716.67 | 736.32 | 06-12-07 | 06-06-07 |
| ICPP-MON-A-166 | 433300112583301 | 4,956.12 | 527 | 505.05 | 511.75 | unk | unk |
| IET 1 DISP | 435153112420501 | 4,790.02 | 242 | 202.36 | 236.24 | unk | 05-01-08 |
| INEL 1 | 433717112563501 | 4,873.29 | 10,333 | 300.70 | 314.57 | unk | unk |
| MTR TEST | 433520112572601 | 4,916.47 | 588 | 447.52 | 471.42 | unk | 09-30-98 |
| NO NAME 1 | 435038112453401 | 4,784.30 | 550 | 198.78 | 231.91 | 02-17-15 | 02-17-15 |
| NPR TEST | 433449112523101 | 4,933.13 | 600 | 455.91 | 476.35 | unk | unk |
| NRF 2 | 433854112545401 | 4,849.73 | 528 | 359.60 | 388.19 | unk | unk |
| NRF 3 | 433858112545501 | 4,850.24 | 546 | 361.11 | 389.09 | unk | unk |
| NRF 5 | 433844112550201 | 4,851.00 | 367 | 398.40 | 400.79 | unk | unk |
| NRF 6 | 433910112550101 | 4,846.26 | 417 | 363.46 | 385.37 | unk | unk |
| NRF 7 | 433920112543601 | 4,842.67 | 415 | 360.38 | 381.12 | unk | 08-30-11 |
| NRF 8 | 433843112550901 | 4,853.23 | 415 | 369.19 | 391.07 | unk | 07-11-95 |
| NRF 9 | 433840112550201 | 4,853.45 | 420 | 370.29 | 392.25 | 12-02-14 | 07-14-95 |
| NRF 10 | 433841112545201 | 4,854.00 | 422 | 369.92 | 391.88 | unk | 07-11-95 |
| NRF 11 | 433847112544201 | 4,852.00 | 427 | 367.51 | 389.41 | unk | 07-25-95 |
| NRF 12 | 433855112543201 | 4,850.84 | 417 | 367.67 | 389.19 | unk | 07-28-95 |
| NRF 13 | 433928112545401 | 4,842.00 | 421 | 358.23 | 380.17 | unk | 11-20-06 |

**Table 1.** Well sites monitored by the U.S. Geological Survey for water-level data and deviation survey information in 2016, at and near the Idaho National Laboratory, Idaho.—Continued

| Local name | Site identifier | Elevation (ft) | Drill depth (ft BLS) | Depth range to water (ft BLS) | Depth range to water (ft BLS) | Gyroscopic | Magnetic |
|---|---|---|---|---|---|---|---|
| NRF 14 | 433856112545901 | 4,849.92 | 425 | 385.08 | 388.58 | unk | unk |
| NRF 15-A | 433942112545002 | 4,841.87 | 759 | 374.03 | 380.11 | 11-20-08 | 04-29-09 |
| NRF 15-B | 433942112545001 | 4,841.87 | 759 | 366.68 | 375.81 | 11-20-08 | 04-29-09 |
| NRF 16 | 434018112545101 | 4,827.54 | 425 | 358.33 | 362.28 | 08-31-09 | 08-27-09 |
| PSTF TEST | 434941112454201 | 4,786.35 | 322 | 200.77 | 234.32 | unk | unk |
| P&W 1 | 435416112460401 | 4,895.62 | 422 | 307.62 | 338.31 | unk | 08-28-06 |
| P&W 2 | 435419112453101 | 4,890.86 | 386 | 303.12 | 337.00 | unk | 06-01-11 |
| P&W 3 | 435443112435801 | 4,885.49 | 406 | 297.20 | 328.36 | 09-07-04 | unk |
| PBF-MON-A-003 | 433203112514201 | 4,959.26 | 545 | 522.20 | 524.39 | 06-24-03 | 10-26-94 |
| RWMC M1SA | 432956113030901 | 5,011.35 | 638 | 582.54 | 591.21 | unk | 08-14-92 |
| RWMC M3S | 433008113021801 | 5,016.34 | 632 | 585.31 | 595.62 | unk | 06-30-92 |
| RWMC M4D | 432939113030101 | 5,022.94 | 828 | 593.48 | 602.43 | unk | 08-20-92 |
| RWMC M6S | 432931113015001 | 5,066.06 | 697 | 637.00 | 645.83 | unk | 08-14-92 |
| RWMC M7S | 433023113014801 | 5,005.15 | 628 | 573.74 | 583.94 | unk | 08-20-92 |
| RWMC M11S | 433058113010401 | 4,994.19 | 624 | 564.14 | 571.38 | 05-22-02 | 05-22-02 |
| RWMC M12S | 433118112593401 | 4,975.23 | 572 | 533.46 | 542.84 | Err | 06-01-98 |
| RWMC M13S | 433037113002701 | 5,026.85 | 643 | 599.11 | 605.97 | Err | 06-13-02 |
| RWMC M14S | 433052113025001 | 5,032.46 | 634 | 591.29 | 611.49 | Err | 06-19-02 |
| SITE 6 | 433826112510701 | 4,836.17 | 523 | 346.42 | 372.38 | unk | unk |
| SITE 9 | 433123112530101 | 4,925.65 | 1,057 | 465.91 | 482.90 | unk | unk |
| SITE14 | 434334112463101 | 4,793.52 | 716 | 256.45 | 290.58 | unk | 04-22-08 |
| SITE15 | 434102112180701 | 4,939.32 | 1,000 | 402.48 | 431.33 | unk | 08-11-97 |
| SITE 16 | 433545112391501 | 5,121.23 | 758 | 630.97 | 646.49 | unk | 06-16-94 |
| SITE 17 | 434027112575701 | 4,880.47 | 600 | 381.15 | 414.29 | unk | unk |
| SITE 19 | 433522112582101 | 4,925.95 | 865 | 460.61 | 479.83 | unk | unk |
| SPERT-1 | 433252112520301 | 4,924.98 | 653 | 455.84 | 470.40 | unk | unk |
| TAN CH2 Piezo B | 435033112421702 | 4,790.88 | 1,090 | 213.43 | 238.77 | unk | unk |
| TAN 14 | 435039112423701 | 4,780.89 | 396 | 220.25 | 228.52 | unk | unk |
| TAN 15 | 435021112412701 | 4,786.89 | 252 | 225.43 | 234.07 | unk | unk |
| TAN 17 | 435034112421601 | 4,789.52 | 340 | 216.25 | 236.74 | unk | unk |
| TAN-2271 | 435053112423101 | 4,780.98 | 289 | 228.42 | 228.42 | 06-24-15 | 06-24-15 |
| TAN-2272 | 435053112423001 | 4,781.25 | 289 | 227.90 | 227.90 | 07-30-15 | 07-30-15 |
| TAN 18 | 435051112421401 | 4,802.96 | 516 | 226.01 | 250.56 | unk | 10-20-92 |
| TRA DISP | 433506112572301 | 4,922.63 | 1,267 | 457.64 | 476.76 | unk | unk |
| WS INEL 1 | 433716112563601 | 4,872.23 | 507 | 384.31 | 411.66 | 11-29-04 | unk |
| 2ND OWSLEY | 434819112380501 | 4,784.80 | 302 | 216.83 | 243.18 | unk | unk |
| USGS 1 | 432700112470801 | 5,022.34 | 630 | 582.10 | 595.44 | 03-29-11 | 06-23-05 |
| USGS 2 | 433320112432301 | 5,125.22 | 704 | 651.10 | 670.16 | 07-13-05 | 06-30-05 |
| USGS 4 | 434657112282201 | 4,790.73 | 553 | 252.00 | 281.06 | 03-12-14 | 03-12-14 |
| USGS 5 | 433543112493801 | 4,937.57 | 494 | 460.00 | 480.41 | unk | unk |
| USGS 6 | 434031112453701 | 4,898.55 | 620 | 406.61 | 426.87 | unk | unk |
| USGS 7 | 434915112443901 | 4,789.24 | 1,200 | 204.31 | 237.24 | unk | unk |
| USGS 8 | 433121113115801 | 5,194.94 | 812 | 750.70 | 774.04 | unk | 07-25-06 |
| USGS 9 | 432740113044501 | 5,030.32 | 654 | 595.00 | 614.05 | unk | unk |
| USGS 11 | 432336113064201 | 5,067.12 | 704 | 594.22 | 614.42 | 07-24-06 | 07-24-06 |
| USGS 12 | 434126112550701 | 4,819.00 | 563 | 308.24 | 346.52 | unk | unk |
| USGS 13 | 432731113143902 | 5,374.58 | 1,010 | 981.48 | 993.08 | unk | unk |
| USGS 14 | 432019112563201 | 5,132.88 | 751 | 709.80 | 721.84 | 07-11-06 | 07-11-06 |
| USGS 15 | 434234112551701 | 4,811.99 | 610 | 302.42 | 337.56 | unk | unk |
| USGS 17 | 433937112515401 | 4,833.44 | 498 | 342.25 | 370.43 | unk | unk |
| USGS 18 | 434540112440901 | 4,804.23 | 329 | 258.65 | 292.48 | unk | unk |
| USGS 19 | 434426112575701 | 4,800.06 | 399 | 251.05 | 283.61 | unk | 06-17-03 |
| USGS 20 | 433253112545901 | 4,915.11 | 658 | 453.14 | 472.03 | 11-18-02 | unk |

**Table 1.** Well sites monitored by the U.S. Geological Survey for water-level data and deviation survey information in 2016, at and near the Idaho National Laboratory, Idaho.—Continued

| Local name | Site identifier | Elevation (ft) | Drill depth (ft BLS) | Depth range to water | | Gyroscopic | Magnetic |
|---|---|---|---|---|---|---|---|
| | | | | (ft BLS) | (ft BLS) | | |
| USGS 21 | 434307112382601 | 4,838.70 | 405 | 324.56 | 346.37 | unk | unk |
| USGS 22 | 433422113031701 | 5,048.27 | 657 | 574.28 | 618.80 | 04-09-08 | 04-09-08 |
| USGS 23 | 434055112595901 | 4,884.20 | 457 | 382.76 | 416.88 | 03-15-07 | 03-21-07 |
| USGS 24 | 435053112420801 | 4,795.10 | 326 | 207.18 | 241.16 | unk | unk |
| USGS 25 | 435339112444601 | 4,848.47 | 320 | 260.12 | 294.47 | unk | unk |
| USGS 26 | 435212112394001 | 4,788.69 | 266 | 200.76 | 234.90 | unk | unk |
| USGS 27 | 434851112321801 | 4,783.90 | 312 | 218.35 | 244.33 | unk | 07-26-06 |
| USGS 28 | 434600112360101 | 4,771.48 | 334 | 225.24 | 249.50 | unk | unk |
| USGS 29 | 434407112285101 | 4,877.48 | 425 | 346.98 | 372.17 | unk | unk |
| USGS 30A | 434601112315403 | 4,793.87 | 725 | 250.09 | 275.71 | unk | unk |
| USGS 30B | 434601112315402 | 4,793.87 | 400 | 257.36 | 288.26 | unk | unk |
| USGS 30C | 434601112315401 | 4,793.87 | 300 | 259.39 | 287.72 | unk | unk |
| USGS 31 | 434625112342101 | 4,785.79 | 428 | 259.39 | 268.76 | unk | unk |
| USGS 32 | 434444112322101 | 4,812.02 | 392 | 282.61 | 306.85 | unk | unk |
| USGS 34 | 433334112565501 | 4,928.54 | 700 | 459.08 | 482.99 | unk | unk |
| USGS 35 | 433339112565801 | 4,928.97 | 579 | 463.65 | 484.71 | unk | unk |
| USGS 36 | 433330112565201 | 4,928.83 | 567 | 463.21 | 484.30 | unk | unk |
| USGS 37 | 433326112564801 | 4,928.54 | 572 | 462.93 | 483.99 | unk | unk |
| USGS 38 | 433322112564301 | 4,929.04 | 724 | 463.40 | 483.39 | 10-04-05 | 10-04-05 |
| USGS 39 | 433343112570001 | 4,930.55 | 492 | 465.09 | 485.66 | unk | 04-21-08 |
| USGS 41 | 433409112561301 | 4,916.26 | 666 | 448.59 | 471.07 | unk | unk |
| USGS 42 | 433404112561301 | 4,915.48 | 678 | 449.15 | 470.65 | unk | unk |
| USGS 43 | 433415112561501 | 4,915.48 | 564 | 447.55 | 470.41 | unk | 03-21-09 |
| USGS 44 | 433409112562101 | 4,917.73 | 650 | 449.77 | 471.26 | 04-19-05 | 09-16-91 |
| USGS 45 | 433402112561801 | 4,917.69 | 651 | 450.73 | 473.37 | unk | 06-21-93 |
| USGS 46 | 433407112561501 | 4,916.42 | 651 | 448.50 | 469.99 | 04-19-05 | 06-21-93 |
| USGS 47 | 433407112560301 | 4,915.63 | 651 | 446.82 | 469.29 | 04-20-05 | 06-07-93 |
| USGS 48 | 433401112560301 | 4,916.84 | 750 | 448.52 | 471.55 | 04-20-05 | 04-27-95 |
| USGS 51 | 433350112560601 | 4,916.91 | 647 | 451.34 | 470.44 | unk | 05-07-03 |
| USGS 52 | 433414112554201 | 4,909.44 | 602 | 443.92 | 464.17 | unk | 06-08-93 |
| USGS 57 | 433344112562601 | 4,922.23 | 582 | 458.14 | 477.84 | 10-31-07 | 10-31-07 |
| USGS 58 | 433500112572502 | 4,918.11 | 503 | 451.41 | 472.70 | unk | unk |
| USGS 59 | 433354112554701 | 4,912.88 | 587 | 447.64 | 467.74 | unk | 06-16-93 |
| USGS 65 | 433447112574501 | 4,924.75 | 498 | 459.23 | 476.46 | 10-16-03 | unk |
| USGS 67 | 433344112554101 | 4,913.34 | 694 | 448.23 | 468.50 | 10-16-03 | unk |
| USGS 76 | 433425112573201 | 4,029.74 | 718 | 465.24 | 484.91 | unk | unk |
| USGS 77 | 433315112560301 | 4,921.43 | 586 | 457.43 | 477.12 | unk | unk |
| USGS 79 | 433505112581901 | 4,930.50 | 702 | 465.42 | 485.40 | unk | unk |
| USGS 82 | 433401112551001 | 4,906.83 | 693 | 440.75 | 461.51 | unk | unk |
| USGS 83 | 433023112561501 | 4,941.11 | 752 | 492.88 | 506.97 | 09-30-08 | 09-30-08 |
| USGS 84 | 433356112574201 | 4,937.63 | 505 | 472.56 | 493.00 | 03-14-07 | 02-27-07 |
| USGS 85 | 433246112571201 | 4,938.99 | 614 | 474.20 | 494.68 | Err | unk |
| USGS 86 | 432935113080001 | 5,076.92 | 691 | 635.15 | 656.70 | 07-19-06 | 07-19-06 |
| USGS 87 | 433013113024201 | 5,017.85 | 673 | 575.12 | 595.95 | unk | unk |
| USGS 88 | 432940113030201 | 5,020.81 | 663 | 513.27 | 599.72 | 06-16-03 | 11-13-97 |
| USGS 89 | 433005113032801 | 5,030.24 | 637 | 580.03 | 608.60 | unk | 05-14-03 |
| USGS 97 | 433807112551501 | 4,858.49 | 510 | 367.76 | 397.16 | 03-23-06 | 03-23-06 |
| USGS 98 | 433657112563601 | 4,882.64 | 508 | 394.39 | 426.07 | 05-16-05 | 05-19-05 |
| USGS 99 | 433705112552101 | 4,871.55 | 440 | 382.70 | 410.18 | unk | 05-01-03 |
| USGS 100 | 433503112400701 | 5,157.94 | 750 | 669.86 | 688.15 | 01-26-94 | unk |
| USGS 101 | 433255112381801 | 5,251.16 | 865 | 763.44 | 781.68 | unk | 06-16-05 |
| USGS 102 | 433853112551601 | 4,850.28 | 440 | 367.08 | 387.82 | unk | 06-18-09 |
| USGS 104 | 432856112560801 | 4,987.64 | 700 | 549.07 | 563.31 | unk | 10-12-05 |

**Table 1.** Well sites monitored by the U.S. Geological Survey for water-level data and deviation survey information in 2016, at and near the Idaho National Laboratory, Idaho.—Continued

| Local name | Site identifier | Elevation (ft) | Drill depth (ft BLS) | Depth range to water | | Gyroscopic | Magnetic |
|---|---|---|---|---|---|---|---|
| | | | | (ft BLS) | (ft BLS) | | |
| USGS 106 | 432959112593101 | 5,015.30 | 760 | 576.63 | 594.85 | unk | 02-12-96 |
| USGS 107 | 432942112532801 | 4,917.50 | 690 | 473.59 | 487.88 | unk | unk |
| USGS 109 | 432701113025601 | 5,043.64 | 800 | 607.90 | 628.61 | 07-21-08 | 07-21-08 |
| USGS 110A | 432717112501502 | 4,999.46 | 644 | 563.14 | 571.88 | 10-11-05 | 10-11-05 |
| USGS 111 | 433331112560501 | 4,920.48 | 560 | 456.22 | 475.74 | 11-19-02 | unk |
| USGS 112 | 433314112563001 | 4,927.82 | 507 | 463.57 | 483.14 | 11-19-02 | unk |
| USGS 113 | 433314112561801 | 4,925.32 | 556 | 460.36 | 478.89 | 11-19-02 | 04-21-08 |
| USGS 114 | 433318112555001 | 4,920.04 | 560 | 456.46 | 475.84 | Err | unk |
| USGS 115 | 433320112554101 | 4,918.86 | 581 | 455.34 | 474.38 | Err | unk |
| USGS 116 | 433331112553201 | 4,916.05 | 572 | 451.72 | 471.32 | 04-13-10 | 04-22-98 |
| USGS 117 | 432955113025901 | 5,012.50 | 655 | 580.27 | 592.12 | unk | 03-12-96 |
| USGS 118 | 432947113023001 | 5,012.42 | 608 | 582.60 | 591.38 | 06-29-99 | 08-14-92 |
| USGS 119 | 432945113023401 | 5,031.84 | 705 | 599.75 | 611.48 | unk | 03-12-96 |
| USGS 120 | 432919113031501 | 5,040.43 | 705 | 610.62 | 621.40 | 03-20-07 | 03-06-96 |
| USGS 121 | 433450112560301 | 4,909.66 | 474 | 447.43 | 464.32 | 11-30-04 | 06-25-93 |
| USGS 123 | 433352112561401 | 4,919.26 | 514 | 457.65 | 475.03 | 09-01-04 | 06-25-93 |
| USGS 124 | 432307112583101 | 5,102.30 | 800 | 681.39 | 689.30 | unk | 10-22-93 |
| USGS 125 | 432602113052801 | 5,050.71 | 774 | 626.85 | 635.11 | 07-20-06 | 07-20-06 |
| USGS 126B | 435529112471401 | 4,989.25 | 472 | 409.50 | 436.37 | 11-02-04 | 08-13-97 |
| USGS 127 | 433058112572201 | 4,956.44 | 596 | 479.78 | 490.41 | 05-10-12 | 02-08-00 |
| USGS 128 | 433250112565601 | 4,934.92 | 615 | 603.58 | 605.83 | unk | 08-14-02 |
| USGS 129 | 433036113002701 | 5,026.19 | 779 | 481.12 | 487.17 | 09-19-05 | 05-29-02 |
| USGS 130 | 433130112562801 | 4,927.55 | 723 | 544.72 | 548.20 | 05-27-04 | 01-21-09 |
| USGS 131 | 433036112581601 | 4,977.30 | 808 | 544.72 | 548.26 | 07-14-10 | 10-17-05 |
| USGS 136 | 433447112581501 | 4,935.00 | 1,048 | 486.70 | 489.98 | 05-05-11 | 05-11-09 |
| USGS 138 | 434615112553501 | 4,798.79 | 325 | 185.03 | 201.35 | unk | 11-14-12 |
| USGS 139A | 433823112460402 | 4,950.69 | 788 | 476.31 | 479.14 | 11-25-13 | 11-25-13 |
| USGS 139B | 433823112460401 | 4,950.69 | 788 | 478.55 | 480.99 | 11-25-13 | 11-25-13 |
| USGS 140 | 433441112581201 | 4,936.51 | 546 | 489.96 | 491.35 | 07-23-13 | 07-08-13 |
| USGS 141 | 433441112581601 | 4,938.2 | 845 | 492.18 | 492.18 | 09-10-13 | 09-10-13 |

Both SANG and SANGB measurements were used to compute output files for true vertical depth (TVD), north deviation, east deviation, distance, and azimuth at continuous measurement points. Text output files were presented for select wells on 1-ft intervals where well deviation survey results suggest the correction factor exceeds 0.20 ft at reference elevation (tables 2 and 3; appendixes B and C). The listed TVD values use cable depth and continuous SANG data to compute true vertical depth change based off of measured inclination angles (tables 2 and 3). The north and east deviation are measured in degrees and computed using both SANG and SANGB data. The distance (in ft) is a measurement of how far the well path has moved from the initial starting point. The azimuth (in degrees) is a reference to the well path location shown on plan view displays (appendixes D and E).

**Table 2.** Magnetic deviation survey data for select monitor well sites at or near the 2016 water table, Idaho National Laboratory, Idaho.

[Location of wells is shown in figures 2 and 3. Survey performed using a Century™ 9057A or 9055A logging tools with magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifer used to access well data from the USGS National Water Information System (http://waterdata.usgs.gov/nwis). **CD** (cable depth) is reported from wireline depth. **TVD** (true vertical depth) is computed depth using average angles equation (eqn. 3). **CF** (correction factor) is computed (CD - TVD). **Northing**, **Easting**, **Distance**, and **Azimuth** are computed from the well path survey using SANG and SANGB data (appendixes B and C). **SANG** refers to inclination or slant angle. **SANGB** refers to azimuth or slant angle bearing from well survey **Abbreviations:** BLS, below land surface; CD, refers to cable depth; CF, refers to correction factor computed from CD-TVD; deg, degrees; ft, feet; TVD, refers to true verical depth; ≥, greater than or equal to]

| Local Name | Site identifier | CD (ft BLS) | TVD (ft BLS) | CF (ft) | CF (≥ 0.2 ft) | North deviation (ft) | East deviation (ft) | Distance (ft) | Azimuth (deg) | SANG (deg) | SANGB (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ANP 5 | 435308112454101 | 315.00 | 314.99 | 0.01 | No | -0.31 | -0.35 | 0.5 | 229.1 | 0.4 | 253.9 |
| ANP 6 | 435152112443101 | 241.00 | 241.00 | 0.00 | No | -0.23 | -0.08 | 0.2 | 198.3 | 0.5 | 200.2 |
| ANP 7 | 435522112444201 | 374.00 | 373.95 | 0.05 | No | -1.95 | 0.02 | 2 | 179.5 | 1.1 | 150.2 |
| ANP 10 | 434856112400001 | 241.00 | 241.00 | 0.00 | No | 0.01 | -0.05 | 0 | 287.6 | 0.1 | 216.0 |
| [1]ANL-OBS-A-001 | 434909112400401 | 644.00 | 643.95 | 0.05 | No | 0.36 | 4.86 | 4.9 | 85.7 | 0.6 | 121.4 |
| ANL-MON-A-014 | 433537112393801 | 645.00 | 644.81 | 0.19 | No | 11.34 | -3.94 | 12 | 340.8 | 1.4 | 356.0 |
| ARA-MON-A-002 | 433054112492102 | 601.00 | 600.96 | 0.04 | No | 1.28 | 0.99 | 1.6 | 37.7 | 0.4 | 337.0 |
| CFA 1932 | 433214112570101 | 494.00 | 493.80 | 0.20 | Yes | -3.52 | -10.71 | 11.3 | 251.8 | 2.6 | 291.5 |
| COREHOLE 1 | 432927112410101 | 943.00 | 942.87 | 0.13 | No | -0.42 | 0.03 | 0.4 | 175.9 | 0.2 | 247.1 |
| DH-1B | 434611112504301 | 300.00 | 299.95 | 0.05 | No | -0.83 | -0.04 | 0.8 | 183.0 | 0.9 | 288.7 |
| DH-2A | 434547112512801 | 303.00 | 302.97 | 0.03 | No | 0.25 | 0.94 | 1 | 75.2 | 0.7 | 52.1 |
| FIRE STATION 2 | 433548112562301 | 442.00 | 441.98 | 0.02 | No | 1.98 | -2.64 | 3.3 | 206.8 | 0.9 | 277.5 |
| HIGHWAY 2 | 433307112300001 | 736.00 | 735.91 | 0.09 | No | -2.82 | -0.8 | 2.9 | 196.3 | 0.6 | 180.2 |
| IET 1 DISP | 435153112420501 | 236.00 | 236.00 | 0.00 | No | -0.06 | 0.01 | 0.1 | 172.5 | 0.2 | 249.9 |
| MTR TEST | 433520112572601 | 471.00 | 470.98 | 0.02 | No | -1.68 | 0.62 | 1.8 | 159.7 | 1.1 | 179.6 |
| NO NoME 1 | 435038112453401 | 232.00 | 232.00 | 0.00 | No | 0.01 | -0.02 | 0 | 285.0 | 0.2 | 355.6 |
| NRF 7 | 433920112543601 | 381.00 | 380.97 | 0.03 | No | -0.36 | -0.96 | 1 | 249.7 | 1.5 | 303.1 |
| NRF 8 | 433843112550901 | 391.00 | 390.98 | 0.02 | No | 0.92 | 0.76 | 1.2 | 39.6 | 0.2 | 211.6 |
| NRF 9 | 433840112550201 | 392.00 | 391.90 | 0.10 | No | 1.66 | -1.22 | 2.1 | 323.5 | 0.8 | 304.6 |
| [1]NRF 10 | 433841112545201 | 287.00 | 286.99 | 0.01 | No | 0.5 | -0.78 | 0.9 | 302.8 | 1.3 | 303.7 |
| NRF 11 | 433847112544201 | 389.00 | 388.99 | 0.01 | No | 0.62 | -0.3 | 0.7 | 334.0 | 0.7 | 321.0 |
| NRF 12 | 433855112543201 | 389.00 | 388.97 | 0.03 | No | -0.79 | 0.23 | 0.8 | 163.7 | 0.7 | 146.3 |
| NRF 13 | 433928112545401 | 380.00 | 379.99 | 0.01 | No | 0.83 | -0.19 | 0.9 | 346.9 | 0.9 | 346.3 |
| NRF 15A | 433942112545002 | 380.00 | 379.98 | 0.02 | No | 0.24 | 0.37 | 0.4 | 56.4 | 0.7 | 19.0 |
| NRF 15B | 433942112545001 | 376.00 | 375.98 | 0.02 | No | 0.2 | 0.34 | 0.4 | 59.7 | 0.8 | 355.2 |
| NRF 16 | 434018112545101 | 362.00 | 361.83 | 0.17 | No | 0.21 | 3.73 | 3.7 | 86.7 | 1.7 | 27.0 |
| P&W 1 | 435416112460401 | 338.00 | 337.99 | 0.01 | No | -0.29 | -0.17 | 0.3 | 211.2 | 1.1 | 138.7 |
| P&W 2 | 435419112453101 | 337.00 | 337.00 | 0.00 | No | -0.26 | 0.34 | 0.4 | 127.2 | 0.4 | 324.7 |
| PBF-MON-A-003 | 433203112514201 | 524.00 | 523.97 | 0.03 | No | 0.54 | 0.04 | 0.5 | 4.7 | 0.4 | 254.2 |
| RWMC M1SA | 432956113030901 | 591.00 | 590.86 | 0.14 | No | -10.3 | 2.35 | 10.6 | 167.1 | 1.6 | 202.1 |
| RWMC M3S | 433008113021801 | 596.00 | 595.86 | 0.14 | No | 8.67 | -0.01 | 8.7 | 359.9 | 1.7 | 0.6 |
| RWMC M4D | 432939113030101 | 602.00 | 601.62 | 0.38 | Yes | -3.83 | -18.37 | 18.8 | 258.2 | 3.0 | 268.8 |
| RWMC M6S | 432931113015001 | 646.00 | 645.98 | 0.02 | No | -3.13 | 0.13 | 3.1 | 177.6 | 0.3 | 168.5 |
| RWMC M7S | 433023113014801 | 600.00 | 599.87 | 0.13 | No | 5.83 | -9.52 | 11.2 | 301.5 | 1.6 | 325.2 |
| RWMC M11S | 433058113010401 | 571.00 | 570.97 | 0.03 | No | -3.93 | -0.71 | 4 | 190.2 | 1 | 229.9 |
| RWMC M12S | 433118112593401 | 543.00 | 542.96 | 0.04 | No | 4.97 | 0.01 | 5 | 0.1 | 0.7 | 346.8 |
| RWMC M13S | 433037113002701 | 606.00 | 605.99 | 0.01 | No | 1.21 | -0.65 | 1.4 | 331.6 | 0.2 | 321.9 |
| RWMC M14S | 433052113025001 | 611.00 | 610.98 | 0.02 | No | 0.62 | 4.19 | 4.2 | 81.5 | 0.5 | 24 |
| SITE-14 | 434334112463101 | 291.00 | 290.99 | 0.01 | No | -0.11 | -0.07 | 0.1 | 212.6 | 0.2 | 47.5 |
| SITE-15 | 434102112180701 | 431.00 | 430.91 | 0.09 | No | -5.96 | -0.05 | 6 | 180.5 | 1.2 | 33.3 |
| [1]SITE-16 | 433545112391501 | 640.00 | 639.68 | 0.32 | Yes | 9.31 | -6.3 | 11.2 | 325.8 | 3.9 | 287.9 |
| TAN 18 | 435051112421401 | 250.00 | 249.84 | 0.16 | No | -1.07 | -1.84 | 2.1 | 239.9 | 2.9 | 271.2 |
| TAN-2271 | 435053112423101 | 228.00 | 227.90 | 0.10 | No | 0.89 | 1.67 | 1.9 | 62 | 1.4 | 313.1 |
| TAN-2272 | 435053112423001 | 228.00 | 228.00 | 0.00 | No | -0.31 | 0.1 | 0.3 | 162.3 | 0.4 | 230.3 |
| USGS 1 | 432700112470801 | 595.00 | 594.85 | 0.15 | No | 2.76 | | 2.9 | 340.1 | 1.6 | 40.7 |
| USGS 2 | 433320112432301 | 670.00 | 669.75 | 0.25 | Yes | -4.35 | -1.71 | 4.7 | 201.5 | 1.2 | 226.2 |
| USGS 4 | 434657112282201 | 281.00 | 280.97 | 0.03 | No | 0.22 | 0.08 | 0.2 | 20 | 1.3 | 259.7 |
| USGS 8 | 433121113115801 | 774.00 | 773.11 | 0.89 | Yes | 1.64 | -15.67 | 15.8 | 276 | 4.1 | 334.2 |
| USGS 11 | 432336113064201 | 614.00 | 613.94 | 0.06 | No | -0.24 | -2.34 | 2.4 | 264.1 | 1.8 | 206.9 |

**Table 2.** Magnetic deviation survey data for select monitor well sites at or near the 2016 water table, Idaho National Laboratory, Idaho.—Continued

| Local Name | Site identifier | CD (ft BLS) | TVD (ft BLS) | CF (ft) | CF (≥ 0.2 ft) | North deviation (ft) | East deviation (ft) | Distance (ft) | Azimuth (deg) | SANG (deg) | SANGB (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| USGS 14 | 432019112563201 | 722.00 | 721.98 | 0.02 | No | -0.53 | -2.2 | 2.3 | 256.3 | 0.2 | 11.3 |
| USGS 19 | 434426112575701 | 284.00 | 283.98 | 0.02 | No | 0.47 | 0.85 | 1 | 61 | 1.1 | 4.1 |
| USGS 22 | 433422113031701 | 619.00 | 618.79 | 0.21 | Yes | 11.47 | 0.5 | 11.5 | 2.5 | 2.7 | 352.5 |
| USGS 23 | 434055112595901 | 417.00 | 416.83 | 0.17 | No | -1.8 | 0.24 | 1.8 | 172.4 | 1.5 | 232.4 |
| USGS 27 | 434851112321801 | 244.00 | 244.00 | 0.00 | No | -0.31 | 0.19 | 0.4 | 149.1 | 0.6 | 243.8 |
| USGS 38 | 433322112564301 | 483.00 | 482.98 | 0.02 | No | -0.07 | 0.16 | 0.2 | 114.3 | 0.4 | 289.6 |
| USGS 39 | 433343112570001 | 486.00 | 485.76 | 0.24 | Yes | 5.11 | 3.35 | 6.1 | 33.2 | 1.7 | 9.8 |
| USGS 43 | 433415112561501 | 470.00 | 469.82 | 0.18 | No | -9.63 | -3.54 | 10.3 | 200.2 | 1.3 | 110.7 |
| USGS 44 | 433409112562101 | 471.00 | 471.00 | 0.00 | No | -0.2 | -0.14 | 0.2 | 215.1 | 0.1 | 198.2 |
| USGS 45 | 433402112561801 | 473.00 | 472.96 | 0.04 | No | 1.67 | -0.65 | 1.8 | 338.8 | 0.7 | 34.5 |
| USGS 46 | 433407112561501 | 470.00 | 469.97 | 0.03 | No | 0.92 | 0.1 | 0.9 | 7.1 | 0.5 | 242.4 |
| USGS 47 | 433407112560301 | 469.00 | 468.96 | 0.04 | No | 0.92 | 0.46 | 1 | 26.4 | 0.4 | 326.1 |
| USGS 48 | 433401112560301 | 472.00 | 471.98 | 0.02 | No | 0.51 | 0.11 | 0.5 | 11.7 | 1 | 88.5 |
| USGS 51 | 433350112560601 | 470.00 | 469.97 | 0.03 | No | -1.41 | 0.11 | 1.4 | 175.6 | 0.2 | 332.5 |
| USGS 52 | 433414112554201 | 464.00 | 463.82 | 0.18 | No | 2.89 | 2.32 | 3.7 | 38.8 | 1.6 | 21.6 |
| [1]USGS 57 | 433344112562601 | 474.00 | 471.73 | 2.27 | Yes | 0.24 | -3.46 | 3.5 | 273.9 | 1 | 317.4 |
| USGS 59 | 433354112554701 | 467.00 | 466.84 | 0.16 | No | -1.89 | -0.89 | 2.1 | 205.1 | 1.3 | 29.6 |
| USGS 83 | 433023112561501 | 507.00 | 506.98 | 0.02 | No | -0.88 | -0.74 | 1.2 | 219.9 | 0.4 | 228.9 |
| USGS 84 | 433356112574201 | 493.00 | 492.99 | 0.01 | No | -0.2 | -0.13 | 0.2 | 212.4 | 0.4 | 239.9 |
| USGS 86 | 432935113080001 | 657.00 | 656.92 | 0.08 | No | -0.19 | 5.33 | 5.3 | 92.1 | 0.2 | 4.4 |
| USGS 88 | 432940113030201 | 600.00 | 599.69 | 0.31 | Yes | 1.41 | -1.38 | 2 | 315.6 | 2.9 | 204.3 |
| USGS 89 | 433005113032801 | 609.00 | 608.97 | 0.03 | No | -0.39 | -0.69 | 0.8 | 240.4 | 0.4 | 151.2 |
| USGS 97 | 433807112551501 | 397.00 | 396.94 | 0.06 | No | -0.04 | -0.47 | 0.5 | 365.1 | 0.4 | 222.1 |
| USGS 98 | 433657112563601 | 426.00 | 423.65 | 2.35 | Yes | 18.79 | -7.29 | 20.2 | 338.8 | 7.4 | 88.9 |
| USGS 99 | 433705112552101 | 410.00 | 409.79 | 0.21 | Yes | -1.64 | -0.68 | 1.8 | 202.7 | 2.4 | 336 |
| USGS 101 | 433255112381801 | 781.00 | 780.38 | 0.62 | Yes | 0.29 | -5.89 | 5.9 | 272.9 | 4.3 | 338.9 |
| USGS 102 | 433853112551601 | 387.00 | 386.83 | 0.17 | No | 1.47 | 2.14 | 2.6 | 55.5 | 2 | 219.5 |
| USGS 104 | 432856112560801 | 563.00 | 562.81 | 0.19 | No | 0.16 | 3.92 | 3.9 | 87.6 | 3.3 | 158.9 |
| USGS 106 | 432959112593101 | 595.00 | 594.95 | 0.05 | No | -1.3 | -1.27 | 1.8 | 224.3 | 0.7 | 293.1 |
| USGS 109 | 432701113025601 | 629.00 | 628.90 | 0.10 | No | -2.98 | 2.37 | 3.8 | 141.5 | 1 | 290.8 |
| USGS 110A | 432717112501502 | 572.00 | 571.95 | 0.05 | No | -0.13 | -0.22 | 0.3 | 239 | 1.2 | 5.3 |
| USGS 113 | 433314112561801 | 479.00 | 473.22 | 5.78 | Yes | 35.86 | -4.61 | 36.2 | 352.7 | 13.8 | 6.3 |
| USGS 116 | 433331112553201 | 471.00 | 470.83 | 0.17 | No | 1.31 | -3.14 | 3.4 | 292.6 | 3.2 | 287 |
| USGS 117 | 432955113025901 | 591.00 | 589.91 | 1.09 | Yes | -3.24 | -6.64 | 7.4 | 244 | 8.2 | 293.5 |
| [1]USGS 118 | 432947113023001 | 555.00 | 554.85 | 0.15 | No | 1.17 | 7.51 | 7.6 | 81.1 | 1.6 | 82.9 |
| USGS 119 | 432945113023401 | 611.00 | 610.13 | 0.87 | Yes | -4.62 | -10.83 | 11.8 | 246.9 | 4.7 | 239.4 |
| USGS 120 | 432919113031501 | 621.00 | 620.14 | 0.86 | Yes | 4.71 | -4.47 | 6.5 | 316.5 | 5 | 153.8 |
| USGS 121 | 433450112560301 | 464.00 | 462.49 | 1.51 | Yes | 3.5 | 1.08 | 3.7 | 17.1 | 2.5 | 282.5 |
| USGS 123 | 433352112561401 | 473.00 | 472.91 | 0.09 | No | -0.34 | 0.05 | 0.3 | 171.9 | 1.9 | 208.6 |
| USGS 124 | 432307112583101 | 689.00 | 687.75 | 1.25 | Yes | 10.02 | -6.28 | 11.8 | 327.9 | 3.8 | 151.9 |
| USGS 125 | 432602113052801 | 635.00 | 634.81 | 0.19 | No | 3.09 | -2.86 | 4.2 | 317.2 | 1.4 | 178.1 |
| [1]USGS 126B | 435529112471401 | 413.00 | 412.97 | 0.03 | No | 0 | 0.13 | 0.1 | 91.7 | 0.6 | 232 |
| USGS 127 | 433058112572201 | 490.00 | 489.90 | 0.10 | No | -0.35 | 0.01 | 0.4 | 178.6 | 1.4 | 100.4 |
| USGS 128 | 433250112565601 | 606.00 | 605.96 | 0.04 | No | -1.56 | 0.84 | 1.8 | 151.7 | 1.4 | 201.9 |
| USGS 129 | 433036113002701 | 487.00 | 486.59 | 0.41 | Yes | -6.55 | -0.09 | 6.6 | 180.8 | 2.7 | 302.7 |
| USGS 130 | 433130112562801 | 548.00 | 547.90 | 0.10 | No | 0.88 | 1.08 | 1.4 | 50.7 | 1.3 | 48 |
| USGS 131 | 433036112581601 | 548.00 | 547.95 | 0.05 | No | -0.06 | -0.54 | 0.5 | 264.2 | 0.7 | 227.1 |
| USGS 136 | 433447112581501 | 490.00 | 489.78 | 0.22 | Yes | 2.6 | 2.13 | 3.4 | 39.3 | 2.3 | 15.3 |
| USGS 138 | 434615112553501 | 201.00 | 201.00 | 0.00 | No | -0.21 | 0.01 | 0.2 | 176.5 | 0.3 | 82.9 |
| USGS 139A | 433823112460402 | 479.00 | 478.97 | 0.03 | No | 0.22 | -0.49 | 0.5 | 294.4 | 1 | 315.6 |
| USGS 139B | 433823112460401 | 480.00 | 479.97 | 0.03 | No | 0.22 | -0.5 | 0.5 | 293.6 | 1 | 210.7 |
| USGS 140 | 433441112581201 | 491.00 | 490.75 | 0.25 | Yes | 1.73 | 1.14 | 2.1 | 33.3 | 1.3 | 83.1 |
| USGS 141 | 433441112581601 | 492.00 | 491.99 | 0.01 | No | 0.03 | -0.51 | 0.5 | 273.3 | 0.1 | 254.2 |

[1]Measurement taken at the lowest survey depth and above the water table.

**Table 3.** Gyroscopic deviation survey data for select monitor well sites at or near the 2016 water table, Idaho National Laboratory, Idaho.

[Location of wells is shown in figures 2 and 3. Survey performed using a Century™ 9095 logging tool with magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifer used to access well data from the USGS National Water Information System (http://waterdata.usgs.gov/nwis). **CD** (cable depth) is reported from wireline depth. **TVD** (true vertical depth) is computed depth using average angles equation (eqn. 3). **CF** (correction factor) is computed (CD - TVD). **Northing**, **Easting**, **Distance**, and **Azimuth** are computed from the well path survey using SANG and SANGB data (appendixes B and C). **SANG** refers to inclination or slant angle. **SANGB** refers to azimuth or slant angle bearing from well survey **Abbreviations:** BLS, below land surface; ft, feet; deg, degrees; CD, refers to cable depth; CF, refers to correction factor computed from CD-TVD; TVD, refers to true verical depth; ≥, greater than or equal to]

| Local name | Site identifier | CD (ft BLS) | TVD (ft BLS) | CF (ft) | CF (≥ 0.2 ft) | North deviation (ft) | East deviation (ft) | Distance (ft) | Azimuth (deg) | SANG (deg) | SANGB (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CFA 1932 | 433214112570101 | 494.00 | 493.75 | 0.25 | Yes | -3.8 | -11.2 | 11.8 | 251.5 | 2.5 | 289.2 |
| CROSSROADS | 432128113092701 | 714.00 | 713.87 | 0.13 | No | 10.4 | -1.5 | 10.5 | 357.1 | 0.7 | 318.9 |
| FIRE STATION 2 | 433548112562301 | 442.00 | 442.00 | 0.00 | No | 0.5 | 0.0 | 0.5 | 4.0 | 0.4 | 293.4 |
| HIGHWAY 2 | 433307112300001 | 736.00 | 735.91 | 0.09 | No | -5.3 | 0.2 | 5.3 | 178.0 | 0.7 | 25.2 |
| NO NAME 1 | 435038112453401 | 232.00 | 232.00 | 0.00 | No | -0.5 | 0.3 | 0.5 | 149.3 | 0.3 | 132.3 |
| NRF 9 | 433840112550201 | 392.00 | 391.90 | 0.10 | No | 4.8 | -6.5 | 8.0 | 306.6 | 1.0 | 307.4 |
| NRF 15A | 433942112545002 | 380.00 | 379.98 | 0.02 | No | 2.6 | 2.9 | 3.9 | 47.7 | 0.8 | 60.7 |
| NRF 15B | 433942112545001 | 376.00 | 375.98 | 0.02 | No | 2.6 | 2.8 | 3.8 | 47.5 | 0.8 | 63.1 |
| NRF 16 | 434018112545101 | 362.00 | 361.83 | 0.17 | No | 2.5 | 10.4 | 10.7 | 76.4 | 1.5 | 76.3 |
| P&W 3 | 435443112435801 | 328.00 | 327.98 | 0.02 | No | 1.7 | 0.6 | 1.8 | 20.3 | 1.2 | 93.8 |
| PBF-MON-A-003 | 433203112514201 | 524.00 | 523.94 | 0.06 | No | 2.0 | -0.7 | 2.1 | 342.0 | 0.4 | 228.5 |
| RWMC M11S | 433058113010401 | 571.00 | 570.96 | 0.04 | No | 1.1 | 1.4 | 1.8 | 50.1 | 1.4 | 37.8 |
| TAN-2271 | 435053112423101 | 228.00 | 227.90 | 0.10 | No | 3.2 | 5.9 | 6.7 | 61.1 | 1.7 | 59.6 |
| TAN-2272 | 435053112423001 | 228.00 | 227.99 | 0.01 | No | -1.0 | 0.9 | 1.3 | 135.5 | 0.4 | 171.3 |
| WS INEL 1 | 433716112563601 | 411.00 | 410.80 | 0.20 | Yes | 2.3 | 12.0 | 12.2 | 79.2 | 2.0 | 121.4 |
| USGS 1 | 432700112470801 | 595.00 | 594.84 | 0.16 | No | 6.4 | 10.4 | 12.2 | 58.4 | 1.7 | 50.7 |
| USGS 2 | 433320112432301 | 670.40 | 670.14 | 0.26 | Yes | 14.3 | -6.1 | 15.5 | 336.7 | 1.7 | 336.9 |
| USGS 4 | 434657112282201 | 281.00 | 280.96 | 0.04 | No | 2.8 | -0.8 | 2.9 | 343.2 | 2.2 | 29.0 |
| USGS 11 | 432336113064201 | 614.00 | 613.93 | 0.07 | No | 5.5 | 0.1 | 5.5 | 0.9 | 1.7 | 20.1 |
| USGS 14 | 432019112563201 | 723.00 | 722.97 | 0.03 | No | 1.0 | -1.2 | 1.6 | 308.9 | 0.3 | 125.6 |
| USGS 20 | 433253112545901 | 472.00 | 471.93 | 0.07 | No | 3.4 | -6.1 | 7.0 | 299.3 | 2.3 | 310.1 |
| USGS 22 | 433422113031701 | 618.20 | 617.97 | 0.23 | Yes | -1.8 | -11.9 | 12.0 | 261.5 | 2.7 | 260.5 |
| USGS 23 | 434055112595901 | 416.00 | 415.81 | 0.19 | No | 6.0 | -7.6 | 9.6 | 308.1 | 1.1 | 15.3 |
| USGS 38 | 433322112564301 | 484.00 | 483.98 | 0.02 | No | 3.6 | -1.6 | 3.9 | 336.2 | 0.7 | 306.8 |
| USGS 44 | 433409112562101 | 471.00 | 470.99 | 0.01 | No | -1.0 | 0.7 | 1.2 | 142.3 | 0.3 | 130.8 |
| USGS 46 | 433407112561501 | 470.00 | 469.99 | 0.01 | No | -1.1 | -0.2 | 1.1 | 192.5 | 0.5 | 212.1 |
| USGS 47 | 433407112560301 | 469.00 | 468.98 | 0.02 | No | -0.7 | -2.4 | 2.5 | 253.7 | 0.7 | 242.2 |
| USGS 48 | 433401112560301 | 472.00 | 471.98 | 0.02 | No | 3.0 | -0.6 | 3.1 | 348.0 | 0.2 | 356.3 |
| USGS 57 | 433344112562601 | 477.00 | 476.89 | 0.11 | No | -7.8 | -2.5 | 8.1 | 197.6 | 1.2 | 196.9 |
| USGS 65 | 433447112574501 | 476.00 | 475.89 | 0.11 | No | 9.1 | -0.3 | 9.1 | 358.3 | 0.6 | 0.9 |
| USGS 67 | 433344112554101 | 469.00 | 468.98 | 0.02 | No | -2.2 | 1.6 | 2.7 | 144.2 | 0.2 | 40.7 |
| USGS 83 | 433023112561501 | 507.00 | 506.99 | 0.01 | No | -1.7 | -0.8 | 1.9 | 206.1 | 0.3 | 277.0 |
| [1]USGS 84 | 433356112574201 | 486.00 | 485.99 | 0.01 | No | -1.7 | 1.0 | 1.9 | 149.7 | 0.6 | 12.3 |
| USGS 86 | 432935113080001 | 656.00 | 655.85 | 0.15 | No | 5.6 | -0.4 | 5.6 | 355.8 | 0.3 | 203.8 |
| USGS 88 | 432940113030201 | 599.00 | 598.63 | 0.37 | Yes | 5.7 | -18.0 | 18.9 | 287.5 | 2.8 | 277.7 |
| USGS 97 | 433807112551501 | 397.00 | 396.94 | 0.06 | No | 4.9 | -3.1 | 5.8 | 327.6 | 0.2 | 276.1 |
| USGS 98 | 433657112563601 | 426.00 | 423.47 | 2.53 | Yes | -7.7 | 42.4 | 43.1 | 100.3 | 7.4 | 89.4 |
| [1]USGS 100 | 433503112400701 | 669.00 | 668.91 | 0.09 | No | -0.7 | 4.6 | 4.7 | 98.2 | 1.2 | 273.9 |
| USGS 109 | 432701113025601 | 628.00 | 627.87 | 0.13 | No | -8.1 | -6.7 | 10.5 | 219.8 | 1.4 | 191.7 |
| USGS 110A | 432717112501502 | 572.00 | 571.95 | 0.05 | No | -1.0 | -6.4 | 6.5 | 261.0 | 1.3 | 277.2 |
| USGS 111 | 433331112560501 | 475.00 | 468.93 | 6.07 | Yes | 14.1 | -47.9 | 49.9 | 286.4 | 16.0 | 263.9 |
| USGS 112 | 433314112563001 | 483.00 | 480.19 | 2.81 | Yes | 35.6 | -27.7 | 45.1 | 322.2 | 10.4 | 346.6 |
| USGS 113 | 433314112561801 | 478.00 | 472.27 | 5.73 | Yes | 58.4 | 9.8 | 59.2 | 9.5 | 13.7 | 7.0 |
| USGS 116 | 433331112553201 | 471.00 | 470.79 | 0.21 | Yes | 8.8 | -6.7 | 11.0 | 322.8 | 3.4 | 284.9 |
| USGS 118 | 432947113023001 | 555.00 | 554.84 | 0.16 | No | -2.9 | 12.6 | 12.9 | 102.8 | 0.9 | 127.5 |

**Table 3.** Gyroscopic deviation survey data for select monitor well sites at or near the 2016 water table, Idaho National Laboratory, Idaho.—Continued

| Local name | Site identifier | CD (ft BLS) | TVD (ft BLS) | CF (ft) | CF (≥ 0.2 ft) | North deviation (ft) | East deviation (ft) | Distance (ft) | Azimuth (deg) | SANG (deg) | SANGB (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| USGS 120 | 432919113031501 | 621.00 | 620.09 | 0.91 | Yes | -21.8 | 12.5 | 25.1 | 150.2 | 5.5 | 132.6 |
| USGS 121 | 433450112560301 | 464.00 | 462.32 | 1.68 | Yes | 3.0 | -35.7 | 35.8 | 274.8 | 3.2 | 301.3 |
| [1]USGS 123 | 433352112561401 | 473.00 | 472.94 | 0.06 | No | 1.4 | -1.5 | 2.0 | 313.3 | 1.1 | 305.9 |
| USGS 125 | 432602113052801 | 635.00 | 634.45 | 0.55 | Yes | 2.2 | -11.9 | 12.1 | 280.6 | 1.6 | 243.3 |
| USGS 126B | 435529112471401 | 436.00 | 435.96 | 0.04 | No | -0.9 | -1.9 | 2.0 | 245.5 | 0.5 | 125.1 |
| USGS 127 | 433058112572201 | 491.00 | 490.88 | 0.12 | No | -10.0 | 0.2 | 10.0 | 178.8 | 1.4 | 185.2 |
| USGS 129 | 433036113002701 | 487.00 | 486.53 | 0.47 | Yes | -20.8 | -2.4 | 20.9 | 186.7 | 2.7 | 183.2 |
| USGS 130 | 433130112562801 | 548.00 | 547.89 | 0.11 | No | 4.2 | 2.1 | 4.7 | 26.6 | 1.6 | 49.6 |
| USGS 131 | 433036112581601 | 548.00 | 547.95 | 0.05 | No | -4.2 | -5.8 | 7.1 | 234.5 | 0.4 | 220.3 |
| USGS 136 | 433447112581501 | 489.00 | 488.78 | 0.22 | Yes | 6.8 | 12.5 | 14.2 | 61.3 | 1.7 | 72.6 |
| USGS 139A | 433823112460402 | 479.00 | 478.97 | 0.03 | No | -2.0 | -4.2 | 4.7 | 245.0 | 0.7 | 240.8 |
| USGS 139B | 433823112460401 | 481.00 | 480.97 | 0.03 | No | -2.0 | -4.3 | 4.7 | 245.0 | 0.7 | 224.1 |
| USGS 140 | 433441112581201 | 491.00 | 490.74 | 0.26 | Yes | -6.5 | 14.0 | 15.5 | 114.9 | 1.7 | 94.9 |
| USGS 141 | 433441112581601 | 492.00 | 491.98 | 0.02 | No | 1.4 | 2.0 | 2.4 | 55.8 | 0.2 | 16.1 |

[1]Measurement taken at the lowest survey depth and above the water table.

The “Average Angle” method uses average of station SANG and station SANGB measurements at the upper and lower survey stations (eqns. 1, 2, and 3). The Century™ post-processing software performs continuous computation for all measurement points; therefore, erroneous data points can be difficult to recognize without close review of the text output files. The well bore path and TVD can be calculated using trigonometric equations that include (Sperry-Sun, 2001):

$$\Delta \text{North} = \Delta \text{CD} \times \sin\left(\frac{\text{SANG1} + \text{SANG2}}{2}\right) \times \cos\left(\frac{\text{SANGB1} + \text{SANGB2}}{2}\right) \quad (1)$$

$$\Delta \text{East} = \Delta \text{CD} \times \sin\left(\frac{\text{SANG1} + \text{SANG2}}{2}\right) \times \sin\left(\frac{\text{SANGB1} + \text{SANGB2}}{2}\right) \quad (2)$$

$$\Delta \text{TVD} = \Delta \text{CD} \times \cos\left(\frac{\text{SANG1} + \text{SANG2}}{2}\right) \quad (3)$$

where:

$\Delta$CD is the cable depth change measured between upper and lower survey (ft);

$\Delta$TVD is the true vertical depth change measured between upper and lower survey (ft);

SANG1 is the inclination angle at upper survey point (degrees);

SANG2 is the inclination angle at lower survey point (degrees);

SANGB1 is the azimuth direction at upper survey point (degrees); and

SANGB2 is the azimuth direction at lower survey point (degrees).

After processing, select magnetic and gyroscopic well deviation text files were reviewed to check for erroneous SANG measurements. For example, gyroscopic and magnetic well deviation survey SANG measurements were compared near a common reference depth specified in table 4. When the inclination difference ($\Delta$SANG) was greater than 0.5 degrees the well deviation data was reviewed for anomalies in SANG measurements (table 4, appendixes B and C). Only 5 of 48 wells had a $\Delta$SANG greater than 0.5 degrees and no wells show $\Delta$SANG greater than 1 degree. The $\Delta$SANG data show reasonable agreement based on the level of accuracy of the wireline probes, where the two-axis accelerometer has a stated accuracy of ±0.5 degrees for all three probes (Century™ Geophysical , LLC Web page: http://www.century-geo.com/, accessed July 14, 2016). Upon review, most erroneous SANG measurements were discovered near changes in casing diameter and (or) entering or exiting an open borehole; casing diameter change can result in bumping or jarring the logging tool during down- and up-hole measurements. Bumping the logging tool can cause the tool to swing and show artificial change in SANG data that could not be explained otherwise.

**Table 4.** Comparison between magnetic and gyroscopic deviation data for select monitor well sites, Idaho National Laboratory, Idaho.

[Well location shown in figures 2 and 3. Deviation survey performed using a Century™ wireline logging tools with magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifer used to access well data from the USGS National Water Information System (http://waterdata.usgs.gov/nwis). **CF DTW** (correction factor depth to water) refers to reference elevation used to select correction factor. **Gyro CF** (gyroscopic devation survey correction factor) and **Mag CF** (magnetic devation survey correction factor) refers to correction factor results from tables 2 and 3. ΔCF refers to correction factor difference between gryoscopic and magnetic deviation surveys. **Gyro SANG** and **Mag SANG** refer to inclination values taken from tables 2 and 3. **ΔSANG** refers to difference between inclination angle (SANG) of gyroscopic and magnetic devation surveys. **Abbreviations:** BLS, below land surface; CF, correction factor; ΔCF, correction factor difference; deg, degrees; ft, feet; Gyro, gyroscopic; Mag, magnetic]

| Local name | Site identifier | CF DTW (ft BLS) | Gyro CF (ft) | Mag CF (ft) | CF (ft) | Gyro SANG (deg) | Mag SANG (deg) | ΔSANG (deg) |
|---|---|---|---|---|---|---|---|---|
| CFA 1932 | 433214112570101 | 494 | 0.25 | 0.20 | 0.05 | 2.5 | 2.6 | 0.1 |
| FIRE STATION 2 | 433548112562301 | 442 | 0.00 | 0.02 | 0.02 | 0.4 | 0.9 | 0.5 |
| HIGHWAY 2 | 433307112300001 | 736 | 0.09 | 0.09 | 0.00 | 0.7 | 0.6 | 0.1 |
| NO NAME 1 | 435038112453401 | 232 | 0.00 | 0.00 | 0.00 | 0.3 | 0.2 | 0.1 |
| NRF 9 | 433840112550201 | 392 | 0.10 | 0.10 | 0.00 | 1.0 | 0.8 | 0.2 |
| [1]NRF 15-A/B | 433942112545002 | 380 | 0.02 | 0.02 | 0.00 | 0.8 | 0.7 | 0.1 |
| NRF 16 | 434018112545101 | 362 | 0.17 | 0.17 | 0.00 | 1.5 | 1.7 | 0.2 |
| PBF-MON-A-003 | 433203112514201 | 524 | 0.06 | 0.03 | 0.03 | 0.4 | 0.4 | 0.0 |
| RWMC M11S | 433058113010401 | 571 | 0.04 | 0.03 | 0.01 | 1.4 | 1.0 | 0.4 |
| TAN-2271 | 435053112423101 | 228 | 0.10 | 0.10 | 0.00 | 1.7 | 1.4 | 0.3 |
| TAN-2272 | 435053112423001 | 228 | 0.01 | 0.00 | 0.01 | 0.4 | 0.4 | 0.0 |
| USGS 1 | 432700112470801 | 595 | 0.16 | 0.15 | 0.01 | 1.7 | 1.6 | 0.1 |
| USGS 2 | 433320112432301 | 670 | 0.26 | 0.25 | 0.01 | 1.7 | 1.2 | 0.5 |
| USGS 4 | 434657112282201 | 281 | 0.04 | 0.03 | 0.01 | 2.2 | 1.3 | 0.9 |
| USGS 11 | 432336113064201 | 614 | 0.07 | 0.06 | 0.01 | 1.7 | 1.8 | 0.1 |
| USGS 14 | 432019112563201 | 722 | 0.03 | 0.02 | 0.01 | 0.3 | 0.2 | 0.1 |
| USGS 22 | 433422113031701 | 619 | 0.23 | 0.21 | 0.02 | 2.3 | 2.7 | 0.4 |
| USGS 23 | 434055112595901 | 417 | 0.19 | 0.17 | 0.02 | 1.1 | 1.5 | 0.4 |
| USGS 38 | 433322112564301 | 483 | 0.02 | 0.02 | 0.00 | 0.7 | 0.4 | 0.3 |
| USGS 44 | 433409112562101 | 471 | 0.01 | 0.00 | 0.01 | 0.3 | 0.1 | 0.2 |
| USGS 46 | 433407112561501 | 470 | 0.01 | 0.03 | 0.02 | 0.5 | 0.5 | 0.0 |
| USGS 47 | 433407112560301 | 469 | 0.02 | 0.04 | 0.02 | 0.7 | 0.4 | 0.3 |
| USGS 48 | 433401112560301 | 472 | 0.02 | 0.02 | 0.00 | 0.2 | 1.0 | 0.8 |
| USGS 57 | 433344112562601 | 478 | 0.11 | 2.27 | 2.16 | 1.2 | 1.0 | 0.2 |
| USGS 83 | 433023112561501 | 507 | 0.01 | 0.02 | 0.01 | 0.3 | 0.4 | 0.1 |
| USGS 84 | 433356112574201 | 486* | 0.01 | 0.01 | 0.00 | 0.3 | 0.4 | 0.1 |
| USGS 86 | 432935113080001 | 657 | 0.15 | 0.08 | 0.07 | 0.6 | 0.2 | 0.4 |
| USGS 88 | 432940113030201 | 600 | 0.37 | 0.31 | 0.06 | 2.8 | 2.9 | 0.1 |
| USGS 97 | 433807112551501 | 397 | 0.06 | 0.06 | 0.00 | 2.8 | 2.8 | 0.0 |
| USGS 98 | 433657112563601 | 426 | 2.53 | 2.35 | 0.18 | 7.4 | 7.4 | 0.0 |
| USGS 109 | 432701113025601 | 629 | 0.13 | 0.10 | 0.03 | 1.4 | 1.0 | 0.4 |
| USGS 110A | 432717112501502 | 572 | 0.05 | 0.05 | 0.00 | 1.3 | 1.2 | 0.1 |
| USGS 113 | 433314112561801 | 479 | 5.73 | 5.78 | 0.05 | 13.7 | 13.8 | 0.1 |
| USGS 116 | 433331112553201 | 471 | 0.21 | 0.17 | 0.04 | 3.4 | 3.2 | 0.2 |
| USGS 118 | 432947113023001 | 555 | 0.16 | 0.15 | 0.01 | 0.9 | 1.6 | 0.7 |
| USGS 120 | 432919113031501 | 621 | 0.91 | 0.86 | 0.05 | 5.5 | 5.0 | 0.5 |
| USGS 121 | 433450112560301 | 464 | 1.68 | 1.51 | 0.17 | 3.2 | 2.5 | 0.7 |
| USGS 123 | 433352112561401 | 473* | 0.06 | 0.09 | 0.03 | 1.9 | 2.3 | 0.4 |
| USGS 125 | 432602113052801 | 635 | 0.55 | 0.19 | 0.36 | 1.6 | 1.4 | 0.2 |
| USGS 126B | 435529112471401 | 412* | 0.04 | 0.03 | 0.01 | 0.5 | 0.6 | 0.1 |
| USGS 127 | 433058112572201 | 490 | 0.12 | 0.10 | 0.02 | 1.4 | 1.4 | 0.0 |
| USGS 129 | 433036113002701 | 487 | 0.47 | 0.41 | 0.06 | 2.7 | 2.7 | 0.0 |
| USGS 130 | 433130112562801 | 548 | 0.11 | 0.10 | 0.01 | 1.6 | 1.3 | 0.3 |
| USGS 131 | 433036112581601 | 548 | 0.05 | 0.05 | 0.00 | 0.4 | 0.7 | 0.3 |
| USGS 136 | 433447112581501 | 490 | 0.22 | 0.22 | 0.00 | 1.7 | 2.3 | 0.6 |
| USGS 139A | 433823112460401 | 479 | 0.03 | 0.03 | 0.00 | 0.7 | 1.0 | 0.3 |
| USGS 140 | 433441112581201 | 491 | 0.26 | 0.25 | 0.01 | 1.7 | 1.3 | 0.4 |
| USGS 141 | 433441112581601 | 492 | 0.02 | 0.01 | 0.01 | 0.2 | 0.1 | 0.1 |

[1]Measurement taken at the lowest survey depth and above the water table.

Both magnetic and gyroscopic well deviation tools are susceptible to bumping unless centralizers are set properly.

Gyroscopic and magnetic deviation surveys were used to estimate a correction factor for each surveyed well. To estimate a well correction factor, the cable depth and TVD were subtracted (eqn. 4) based off of a reference elevation at or near the 2014 water table (Bartholomay and Twining, 2015). By subtracting the correction factor, the reference depth (cable depth) is reduced to reflect TVD (eqn. 5). If the reference elevation changes, through increases and (or) decreases in the water levels, a revised correction factor might be considered based off of data tables presented in appendixes B and C. Wells that are not considered vertical (SANG ≥ 5 degrees) should have the correction factor examined on a more frequent basis. For example, well USGS 111 has a SANG of 16 degrees and a correction factor of 6.07 ft; whereas, well USGS 116 has a SANG of 3.4 degrees and the correction factor is 0.21 ft (table 3). The correction factor and TVD can be obtained from the formulas:

$$CF = CD - TVD \tag{4}$$

$$TVD = CD - CF \tag{5}$$

where:

CF is the correction factor (ft);

CD is the measured depth or cable depth (ft); and

TVD is the true vertical depth (ft).

# Results and Discussion

Gyroscopic and magnetic well deviation survey data was considered for 177 well locations that were constructed within the regional ESRP aquifer. Out of the wells considered for this study, 100 wells had magnetic deviation survey data available and 57 wells had gyroscopic deviation surveys; two wells (NRF 15A/B and USGS 139A/B) were piezometer wells and counted as a single well but listed separately in tables (tables 2 and 3). Gyroscopic deviation surveys for 11 wells could not be used because of file errors and were excluded from this dataset as noted in table 1. Wells with incomplete well deviation surveys, partial surveys, also were excluded from the discussion.

Well deviation surveys were completed using Century™ wireline logging tools between calendar years 1991 and 2015 (table 1). Prior to 2002, USGS INL Project Office wireline logging tool calibration records were not documented; after 2002, wireline logging tool calibrations were done annually and records were documented. During retrieval of geophysical log information, if multiple well deviation surveys were available, the most recent well deviation survey was generally selected. The USGS INL Project Office currently archives wireline geophysical data through the “USGS Log Archiver” database, accessed at: http://logarchiver.usgs.gov/ (last accessed July 14, 2016). The database Web page lists current USGS policies for storage and retrieval of geophysical log information. Logs are also available upon request of the USGS INL Project Office.

A threshold correction factor of 0.20 ft was determined based on stated accuracy of magnetic and gyroscopic logging equipment, human error, and well casing diameter variation in reported wells. When a deviation survey suggests a correction factor is equal to or greater than 0.20 ft, the correction factor is applied to manual water-level measurements based off of reference elevations listed in appendixes B and C. If correction factor is less than 0.20 ft, one is not applied. The 0.20 ft correction factor is consistent with recommended data evaluation guidelines for wells at the INL (Arnett and others, 1993).

Until recently, centralizers were not used during gyroscopic deviation measurements; however, in 2015, the USGS started using centralizers for gyroscopic measurements (appendix A). Change in well casing diameter can result in SANG data variation during a well deviation survey, especially if the tool is bumped during logging. When a logging tool is run without centralizers, the logging tool often travels along one side of the well casing and is subject to bumping into obstructions. Centralizers help limit the amount of bumping on the tool during logging in and out of the borehole and seems to improve gyroscopic deviation surveys (appendix A). No attempts have been made to run centralizers on magnetic deviation tools (9057A and 9055A). Only a few wells have gyroscopic deviation surveys performed with centralizers; therefore, no comparison was made between gyroscopic deviation surveys run with and without centralizers.

## Magnetic and Gyroscopic Well Deviation Survey Results

Magnetic and (or) gyroscopic deviation survey data were collected at 110 of 177 monitor wells examined at the INL (table 1). Wells screened to multiple locations (piezometer wells) were considered single wells; however, correction factor data for piezometer wells were examined at separate reference elevations and noted as two entries in the tables. Deviation analysis was not done for perched aquifer wells not part the regional ESRP aquifer. Based off of available well deviation survey data for INL related wells, 100 wells had magnetic surveys (table 2), 57 wells had gyroscopic surveys (table 3), 48 wells had both magnetic and gyroscopic data (table 4), and deviation data was not available for 68 wells (table 1).

Magnetic well deviation surveys were analyzed for 100 wells and 21 wells had a correction factor that meet or exceed the 0.20 ft criteria (table 2). Of the 21 wells, magnetic well deviation survey data suggest correction factors ranging from 0.20 to 5.78 ft and inclination angles (SANG) range from 1.0 to 13.8 degrees, not including the wells that did not meet the correction factor criteria. Only three magnetic deviation surveys have inclination angles (SANG) that exceed 5 degrees. About 21 percent of wells with magnetic well deviation surveys available, meet or exceed the correction factor criteria of 0.20 ft.

Gyroscopic well deviation surveys were completed and analyzed for 57 wells; 16 wells have a correction factor that meets or exceeds the 0.20 ft criteria (table 3). Of the 16 wells, gyroscopic well deviation survey results suggest correction factors ranged from 0.20 to 6.07 ft and SANG ranged from 1.6 to 16.0 degrees; and 5 gyroscopic deviation surveys have SANG that exceed 5 degrees (table 3). About 27 percent of wells with gyroscopic deviation surveys available, meet or exceed the correction factor criteria of 0.20 ft.

Well path plan-view projections were presented for select wells where the deviation correction factor exceeds 0.20 ft (tables 2 and 3; appendixes D and E). The plan-view projection uses inclination and azimuth data to display well-path trajectory with depth. The well-path projection can be used to assay whether magnetic surveys are reasonable. For example, well USGS 121 displays an irregular well path on the magnetic deviation survey; however, the gyroscopic deviation survey displays a straight line (appendixes D and E). The magnetic survey well-path projection suggests that well USGS 121 data is likely effected by ferrous well casing and (or) rocks with high ferrous content, based off of the irregularity of the projected well path. The gyroscopic and magnetic well deviation survey results for USGS 121 indicate slightly different correction factors; where the gyroscopic well deviation survey correction factor is 1.68 ft at a reference elevation of 464 ft BLS and the magnetic well deviation survey correction factor is 1.51 ft at this same depth (table 4). Well USGS 121 also shows a ΔSANG value of 0.7 degrees, and was one of five surveys that the ΔSANG values exceeded a 0.5 degree difference between magnetic and gyroscopic surveys (table 4). Well USGS 121 is one example of a deviation survey where the gyroscopic well deviation survey was used and the magnetic deviation survey was not, when considering the correction factor results.

The correction factor results for 25 wells that meet or exceed the 0.20 ft threshold are shown in table 5. Sixteen gyroscopic and nine magnetic well deviation surveys meet or exceed the correction factor criteria of 0.20 ft. The correction factors ranged between 0.20 and 6.07 ft (table 5). As expected, wells that exhibit the highest SANG measurements resulted in the highest correction factors (tables 2, 3, and 4). Data tables and plan-view well path displays for wells that require correction factors are included in appendixes B–E.

## Quality Assurance

The procedures used for gyroscopic deviation survey logging are included in appendix A; no procedures are available for magnetic deviation survey logging. During 2002, procedures for the collection of gyroscopic deviation surveys were updated (table 1). Since about 2003, procedures have been in place to improve consistency in the data collection and processing of gyroscopic deviation surveys, resulting in fewer file errors. The gyroscopic deviation survey logging tool is very susceptible to file errors if outlined procedures are not followed step-by-step (appendix A).

Equipment calibration is done annually and records are kept on file with the USGS INL Project Office. The stated accuracy for Century™ magnetic logging tools, include: SANG ±0.5 degrees and SANGB ±2.0 degrees. The stated accuracy for Century™ Geophysical mechanical gyroscopic logging tool include: SANG ±0.5 degrees and SANGB ±1.0 degrees. For more complete descriptions of the tools and sensors available visit the USGS INL Project Office website at: http://id.water.usgs.gov/INL/.

Repeat measurements, collected from the same well at different times, were not performed during this study. Attempts were made to review magnetic and gyroscopic data for correction factor and SANG data differences where available. No attempts were made to examine SANGB data where the three-axis magnetometer measurements are susceptible to ferrous material, as displayed in plan-view displays (appendix D).

Correction factor and SANG measurements were examined at 47 well locations that both magnetic and gyroscopic deviation surveys were done (table 4). Only two wells, USGS 57 and USGS 125, suggest a correction factor difference of 0.20 ft or greater. Examination of the two wells suggest erroneous data related to magnetic SANG and (or) SANGB measurements. For example, USGS 57 shows erroneous inclination data where SANG increases significantly over a short distance (1.9 –64.6 degrees from 240 to 241 ft BLS). The computation for TVD, using average angles method, averages each SANG measurements with depth; therefore, a large increase in SANG, even over one measurement, would result in an artificially high correction factor. USGS 57 had multiple elevated SANG measurements that could not be resolved at random depths so the magnetic deviation survey was not used. Review of USGS 125 suggest ferrous casing and (or) rock resulted in random SANGB measurements as observed in plan-view of the well path (appendix D). Additionally, SANG measurements reflect elevated increase and (or) decrease near changes in casing diameter based on the completion diagram; however, these measurements could not be discounted and were kept in the dataset.

**Table 5.** Correction factor results for 25 monitor wells, at or near the Idaho National Laboratory, that meet or exceed the 0.20 ft threshold at a set reference elevation.

[Location of wells is shown in figures 2 and 3. Survey performed using Century Geophysical Corporation™ 9095, 9057A, and 9055A logging tool with magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifer used to access well data from the USGS National Water Information System (http://waterdata.usgs.gov/nwis). **CD** (cable depth) refers to wireline depth. **TVD** (true vertical depth) is computed depth using average angles method (eqn 3). **Correction factor** is the difference of CD -TVD. **Survey type** refers to type of survey used to estimate correction factor. **Abbreviations:** BLS, below land surface; ft, feet; Gyro, gyroscopic survey; Mag, magnetic survey]

| Local name | Site Identifier | CD (ft BLS) | TVD (ft BLS) | Correction factor (ft) | Survey type (Mag or Gyro) |
|---|---|---|---|---|---|
| CFA 1932 | 433214112570101 | 494.00 | 493.75 | 0.25 | Gyro |
| RWMC M4D | 432939113030101 | 602.00 | 601.62 | 0.38 | Mag |
| [1]SITE-16 | 433545112391501 | 640.00 | 639.68 | 0.32 | Mag |
| WS INEL 1 | 433716112563601 | 411.00 | 410.80 | 0.20 | Gyro |
| USGS 2 | 433320112432301 | 670.40 | 670.14 | 0.26 | Gyro |
| USGS 8 | 433121113115801 | 774.00 | 773.11 | 0.89 | Mag |
| USGS 22 | 433422113031701 | 618.20 | 617.97 | 0.23 | Gyro |
| USGS 39 | 433343112570001 | 486.00 | 485.76 | 0.24 | Mag |
| USGS 88 | 432940113030201 | 599.00 | 598.63 | 0.37 | Gyro |
| USGS 98 | 433657112563601 | 426.00 | 423.47 | 2.53 | Gyro |
| USGS 99 | 433705112552101 | 410.00 | 409.79 | 0.21 | Mag |
| USGS 101 | 433255112381801 | 781.00 | 780.38 | 0.62 | Mag |
| USGS 111 | 433331112560501 | 475.00 | 468.93 | 6.07 | Gyro |
| USGS 112 | 433314112563001 | 483.00 | 480.19 | 2.81 | Gyro |
| USGS 113 | 433314112561801 | 478.00 | 472.27 | 5.73 | Gyro |
| USGS 116 | 433331112553201 | 471.00 | 470.79 | 0.21 | Gyro |
| USGS 117 | 432955113025901 | 591.00 | 589.91 | 1.09 | Mag |
| USGS 119 | 432945113023401 | 611.00 | 610.13 | 0.87 | Mag |
| USGS 120 | 432919113031501 | 621.00 | 620.09 | 0.91 | Gyro |
| USGS 121 | 433450112560301 | 464.00 | 462.32 | 1.68 | Gyro |
| USGS 124 | 432307112583101 | 689.00 | 687.75 | 1.25 | Mag |
| USGS 125 | 432602113052801 | 635.00 | 634.45 | 0.55 | Gyro |
| USGS 129 | 433036113002701 | 487.00 | 486.53 | 0.47 | Gyro |
| USGS 136 | 433447112581501 | 489.00 | 488.78 | 0.22 | Gyro |
| USGS 140 | 433441112581201 | 491.00 | 490.74 | 0.26 | Gyro |

[1]Measurement taken at the lowest survey depth and above the water table.

About 96 percent of the wells examined show similar correction factor results for both magnetic and gyroscopic well deviation surveys (table 4, fig. 5). A comparison chart for all magnetic as opposed to gyroscopic correction factor results suggest wells show excellent correlation with an r-squared of 0.88 (fig. 5). The difference in estimated correction factors (ΔCF) for 45 of 47 wells ranged from 0.00 to 0.18 ft, not including USGS 57 and USGS 125. The ΔSANG measurements for all 47 wells ranged from 0.0 to 0.9 degrees, which is reasonable for wireline logging tools run without the use of centralizers. Only five wells show ΔSANG of greater than or equal to 0.5 degrees between magnetic and gyroscopic wells surveys (table 4). This data suggests good agreement between SANG measured using the magnetic deviation survey methods and SANG measured using gyroscopic deviation survey methods, even for surveys collected years apart.

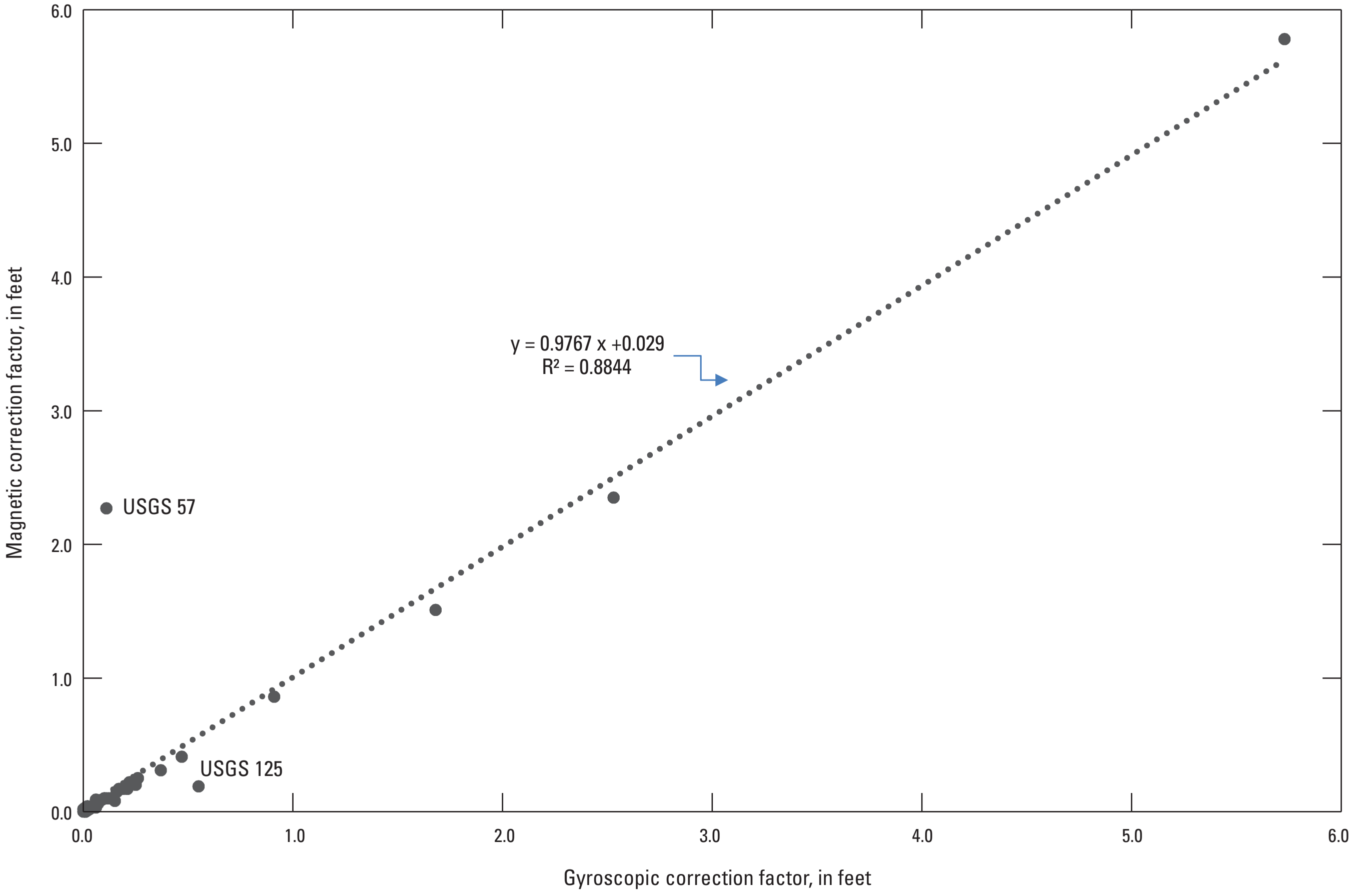


**Figure 5.** Comparison between magnetic and gyroscopic correction factors for 47 wells with both surveys, Idaho National Laboratory, Idaho.

## Summary

The U.S. Geological Survey (USGS) in cooperation with the U.S. Department of Energy has maintained a water-level monitoring program at the Idaho National Laboratory (INL) since 1949. The purpose of the program to systematically measure and report water-level data to provide long term information on the eastern Snake River Plain aquifer which can affect groundwater recharge, discharge, movement, and storage. Well-deviation data should be considered when mapping water table elevation data because it can affect the reference elevation (water level) by several tenths of feet to several feet on potentiometric maps.

The USGS INL project office applies a correction factor to water level data when a well deviation survey suggests a correction factor of equal to or greater than 0.20 ft. Gyroscopic and magnetic well deviation survey results were examined for all wells for which the USGS INL project office collects data; however, wells that are completed to the perched system, above the regional aquifer, were not considered. The 0.20 ft correction factor criteria is based on uncertainty related running tools without centralizers, changes in casing diameter, tool uncertainty, calibration, and human error.

Borehole well deviation survey data was considered for 177 wells completed within the eastern Snake River Plain aquifer, but not all wells had deviation survey data available. As of 2016, USGS INL Project Office database includes: 57 wells with gyroscopic survey data; 100 wells with magnetic deviation survey data; 11 wells show erroneous gyroscopic data that were excluded; and, 68 wells did not have deviation survey data available.

Of the 57 wells with gyroscopic well surveys, 16 wells had correction factors that ranged from 0.20 to 6.07 ft and inclination angle (SANG) ranged from 1.6 to 16.0 degrees. Five gyroscopic deviation surveys had SANG that exceeded 5 degrees and were not considered vertical. Forty-one wells with gyroscopic deviation surveys did not require a correction factor to be applied. About 27 percent of wells with gyroscopic deviation surveys available, met or exceeded the correction factor criteria of 0.20 ft.

Magnetic well deviation surveys were analyzed for 100 wells; however, of these 100 wells, 21 wells had a correction factor that met or exceeded the 0.20 ft criteria. Magnetic well deviation survey data for the 21 wells produced correction factors that ranged from 0.20 to 5.78 ft and SANG ranged from 1.0 to 13.8 degrees, not including the wells that did not meet the correction factor criteria. Of the 21 wells, only 7 of 21 magnetic deviation surveys were used in the final correction factor table, where 14 wells had both magnetic and gyroscopic deviation surveys, but only the gyroscopic deviation survey was used. Data from 3 of 21 magnetic deviation surveys suggest the SANG exceeds 5 degrees and are not considered vertical. There were 79 wells with magnetic deviation surveys did not require a correction factor to be applied. About 21 percent of those wells with magnetic well deviation surveys available meet or exceed the correction factor criteria of 0.20 ft.

There were 47 wells that had both gyroscopic and magnetic deviation surveys done for the same well, some at different dates. Of these 47 wells, 96 percent had similar correction factors for both magnetic and gyroscopic well deviation results and show good linear correlation represented by an r-squared of 0.88. The difference in estimated correction factors for 45 of 47 wells ranged from 0.00 to 0.18 ft, not including USGS 57 and USGS 125. The difference in SANG measurements, for all wells, ranged from 0.0 to 0.9 degrees and is reasonable for wireline logging tools run without the use of centralizers. This data suggests good agreement between SANG measured using the magnetic deviation survey methods and SANG measured using gyroscopic deviation survey methods, even for surveys collected years apart.

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# Appendixes

Appendixes A–E are .PDF and .TXT files available for download at https://doi.org/10.3133/sir20165163.

## Appendix A. Setup and Operation of the 9095 Gyroscopic Logging Tool

## Appendix B. Magnetic Deviation Data for Selected Wells, Idaho National Laboratory, Idaho

## Appendix C. Gyroscopic Deviation Data for Selected Wells, Idaho National Laboratory, Idaho

## Appendix D. Magnetic Deviation Plan View of Selected Wells, Idaho National Laboratory, Idaho

## Appendix E. Gyroscopic Deviation Plan View of Selected Wells, Idaho National Laboratory, Idaho

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