



# United States Department of the Interior

GEOLOGICAL SURVEY  
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Dear Darius:

This letter report concerns work performed by the U.S. Geological Survey (USGS) as part of the Area B investigation at the U.S. Naval Air Warfare Center (NAWC) Superfund site in Warminster, Bucks County, Pennsylvania, under Interagency Agreement Number DW14943510-01-1. Enclosed are analog and digital copies of the borehole geophysical logs run at the NAWC site.

## INTRODUCTION

Caliper, natural-gamma, single-point-resistance (electric), fluid-resistivity, and fluid-temperature logs and a borehole television survey were run by the USGS in all deep and some intermediate-depth boreholes at the NAWC site. Caliper logs were run in all shallow and intermediate-depth boreholes.

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. The tool is calibrated at land surface after each caliper log is run. Caliper logs are used to help correlate lithostratigraphy, to identify fractures and possible water-bearing openings, and to qualitatively correct other geophysical logs for changes in borehole diameter. Correlation of caliper logs with single-point-resistance, fluid-resistance, and fluid-temperature logs is used to identify fractures and water-producing and water-receiving zones.

Single-point-resistance logs record the electrical resistance between the borehole and an electrical ground at land surface. In general, resistance increases with grain size and decreases with borehole diameter, density of water-bearing fractures, and increasing dissolved-solids concentration of borehole fluid. A fluid-filled borehole is required for single-point-resistance logs, and they are run only for the saturated part of the formation below the casing. Single-point-resistance logs are used to correlate lithostratigraphy and may help to identify the location of water-bearing zones. Single-point-resistance logs run at the NAWC site were not helpful in locating water-bearing zones, but are excellent indicators of lithostratigraphy.

Natural-gamma logs, also called gamma-ray logs, record the natural gamma radiation emitted from rocks penetrated by the borehole. Gamma radiation can be measured through casing, but the gamma response is dampened. Uranium-238, thorium-232, and the progeny of their decay series and potassium-40 are the most common emitters of natural-gamma radiation. These radioactive elements may be concentrated in clay by adsorption and ion exchange, and, therefore, fine-grained sediments (mudstone-siltstone units) usually emit more gamma radiation than do quartz sand rocks (sandstone).

Fluid-resistivity logs measure the electrical resistance of fluid in the borehole. Resistivity is the reciprocal of fluid conductivity, and fluid-resistivity logs reflect changes in the dissolved-solids concentration of the borehole fluid. Fluid-resistivity logs are used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Water-producing and water-receiving zones usually are identified by sharp changes in resistivity, and intervals of borehole flow are identified by a low resistivity gradient between water-producing and water-receiving zones. However, most fluid-resistivity logs run at NAWC were run soon after drilling, and fluid-resistivity gradients in the boreholes may not have had sufficient time to stabilize.

Fluid-temperature logs provide a continuous record of the temperature of the fluid in the borehole. Temperature logs are used to identify water-producing and water-receiving zones and to determine intervals of vertical borehole flow. Intervals of vertical borehole flow are identified by little or no temperature gradient. Temperature logs from wells with no borehole flow generally show a decrease in fluid temperature with depth in the upper part of the borehole and an increase in fluid temperature with depth as a function of the geothermal gradient in the lower part of the borehole. However, most fluid-temperature logs run at NAWC were run soon after drilling, and fluid-temperature gradients in the boreholes may not have had sufficient time to stabilize.

In selected boreholes, the direction and rate of borehole-fluid movement was determined by injecting a slug of high-conductance fluid at a specific depth in the borehole and monitoring the movement of the slug with the fluid-resistivity tool. This is called the "brine-tracing" method of flow measurement. The lower limit of flow measurement is about 0.5 gallons per minute in a 6-inch diameter borehole.

The borehole television surveys were conducted by lowering a waterproof video camera with a fish-eye lens down the borehole and recording the results on videotape. The footage indicated on the borehole television surveys may not correspond exactly to those on the geophysical logs because of slippage of the television cable. Likewise, the same borehole feature may not be indicated at exactly the same depth during camera descent as during camera ascent.

## **BOREHOLE CLUSTER A**

### **BK-2530 (NAWC A-D)**

The caliper log confirms that the total depth of the borehole is 153 ft (feet) and that it is cased with 8-inch diameter casing to 11.5 ft bls (below land surface). The caliper log shows fracture zones at 12-45, 67-79, and 99-119 ft bls; major fractures are at 12, 24.5, 32, 40, 44, 68, and 70.5 ft bls. The fluid-resistivity and fluid-temperature logs indicate possible fluid-producing zones at approximately 24, 35, and 70 ft bls that correlate with fractures shown on the caliper log. A screen placed at 112-127 ft bls would include the only water-bearing zone reported during drilling.

### **BK-2531 (NAWC A-I)**

The caliper log confirms that the total depth of the borehole is 103 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows major fractures at 12.5, 35-40, 72.5, and 88.5 ft bls. These fractures (except for the fracture at 12.5 ft bls) correlate with fluid-producing zones indicated by the fluid-resistivity and fluid-temperature logs. The slope of the temperature gradient on the fluid-temperature log does not indicate vertical borehole flow. A screen placed at 70-90 ft bls would include fluid-producing zones at 72.5 and 88.5 ft bls indicated by the fluid logs.

### **BOREHOLE CLUSTER B**

#### **BK-2533 (NAWC B-D)**

The caliper log confirms that the total depth of the borehole is 153 ft and that it is cased with 8-inch diameter casing to 9 ft bls. The caliper log shows highly fractured zones at 99-104 and 115-138 ft bls. The borehole television survey showed that the zone from 119.2 to 135.2 ft bls was an unstable siltstone-mudstone unit; the borehole television survey was run only to 135.2 ft bls because the borehole was filled to that depth with material caved from this zone. The fluid-resistivity and fluid-temperature logs indicate possible fluid-producing zones at approximately 28, 38, 45, and 120 ft bls. A screen placed at 115-135 ft bls would include the fluid-producing zone at 120 ft bls indicated by the fluid logs. The borehole television survey showed a large zone of vertical fractures at 115.6-130.3 ft bls.

#### **BK-2533 (NAWC B-I)**

The caliper log confirms that the total depth of the borehole is 103 ft and that it is cased with 8-inch diameter casing to 13.5 ft bls. The caliper shows major fractures at 21, 39, 47.5, 70, 71, and 74 ft bls. The fluid-resistivity log indicates possible fluid-producing zones at approximately 22, 40, and 49 ft bls, which correlate with major fractures. The fluid-temperature log indicates possible fluid-producing zones at approximately 21, 25, 30, and 48 ft bls. A screen placed at 87-97 ft bls would include the water-bearing zones at 88 and 96 ft bls reported during drilling.

### **BOREHOLE CLUSTER C**

#### **BK-2536 (NAWC C-D)**

The caliper log confirms that the total depth of the borehole is 161 ft and that it is cased with 8-inch diameter casing to 7 ft bls. The caliper log shows major fractures at 18-21, 26-28, 70, and 150 ft bls. The fluid-resistivity log shows possible fluid-producing zones at approximately 22, 25, 34, and 135 ft bls. The fluid-temperature log shows possible fluid-producing zones at approximately 23 and 33 ft bls. A screen placed at 120-135 ft bls would include the fluid-producing zone indicated by the fluid-resistivity log at 135 ft bls and the water-bearing zone at 130 ft bls reported during drilling. The borehole television survey showed small, horizontal fractures at 128.3 and 128.6 ft bls and small, steeply dipping fractures at 120.7-125.5 and 130-130.5 ft bls.

#### **BK-2537 (NAWC C-I)**

The caliper log confirms that the total depth of the borehole is 101 ft and that it is cased with 8-inch diameter casing to 7.5 ft bls. The caliper log shows a large fracture at 26 ft bls and fracture zones at 22-30, 38-42, 62-69, and 78-93 ft bls. A screen placed at 80-95 ft bls would include the fracture zone shown on the caliper log at 78-93 ft bls and the water-bearing zone at 84-86 ft bls reported during drilling.

## **BOREHOLE CLUSTER D**

### **BK-2539 (D-D)**

The caliper log confirms that the total depth of the borehole is 178 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows fracture zones at 12-20, 21-30, 35-47 ft bls. Major fractures below 50 ft bls are at 63.5, 75.5, 115.5, 134, and 141.5 ft bls.

The fluid-resistivity and fluid-temperature logs indicate fluid-producing zones at approximately 27 and 37 ft bls and a fluid-receiving zone at approximately 114 ft bls. The borehole television survey showed large, steeply dipping fractures at 26.1-29.8 and 36.5-44.5 ft bls and a large, horizontal fracture at 114.6-115 ft bls. The borehole television survey also showed movement of particles in the borehole fluid caused by fluid flowing into the borehole at 26.8 and 37.3 ft bls. The absence of a temperature gradient on the fluid-temperature log from approximately 40 to 115 ft bls indicates a zone of vertical borehole flow. Below 115 ft bls, the fluid-temperature log shows an inverse temperature gradient, indicating no vertical borehole flow. The fluid-resistivity log shows a sharp increase in total dissolved solids concentration at 141 ft bls; this is probably caused by soluble minerals, such as gypsum or anhydrite, in the siltstone-mudstone unit at this depth.

Slugs of high conductance fluid were injected at 50 and 115 ft bls. The slug injected at 50 ft bls moved downward at 10 gal/min (gallons per minute). The slug injected at 155 ft bls did not move, indicating no borehole flow.

A screen placed at 105-120 ft bls would include the fluid-receiving zone indicated by the fluid-temperature log at 114 ft bls.

### **BK-2540 (NAWC D-I)**

The caliper log confirms that the total depth of the borehole is 101 ft and that it is cased with 8-inch diameter casing to 11 ft bls. The caliper log shows that the formation is highly fractured from 12-31 ft bls. A screen placed at 50-70 ft bls would include the water-bearing zone at 67 ft bls reported during drilling. However, this leaves only 15 ft of unscreened aquifer between screened intervals in boreholes BK-2540 (D-I) and BK-2541 (D-S).

### **BK-2541 (NAWC D-S)**

The caliper log confirms that the total depth of the borehole is 35 ft and that it is cased with 8-inch diameter casing to 11 ft bls. The caliper log shows that the formation is highly fractured from 13 to 34 ft bls. A screen placed at 20-35 ft bls would include the water-bearing zones at 22-27 ft bls (yielding 15 gal/min) reported during drilling.

## **BOREHOLE CLUSTER E**

### **BK-2543 (NAWC ED-2)**

The caliper log confirms that the total depth of the borehole is 202 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows major fractures at 12 and 24.5 ft bls and numerous smaller fractures. The fluid-resistivity log indicates possible fluid-producing zones at approximately 25-35 and 193 ft bls. The fluid-temperature log indicates a fluid-producing zone at approximately 189 ft bls. The caliper log shows a fracture at 193.5 ft bls. The fluid-temperature log does not indicate vertical borehole flow. A screen placed at 180-200 ft bls would include the fracture shown on the caliper log at 193.5 ft bls and the fluid-producing zone indicated by the fluid logs. The borehole television survey shows a large, steeply dipping fracture at 186.8-188.3 ft bls and a large, horizontal fracture at 192.8-193 ft bls.

#### **BK-2542 (NAWC E-D)**

The caliper log confirms that the total depth of the borehole is 152.5 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows major fractures at 20.5, 23.5, 35, 73.5, and 121 ft bls. Immediately after drilling and prior to geophysical logging, approximately 3-4 gal/min of water was cascading from a fracture at 13-14 ft bls. The fluid-temperature log indicates possible fluid-producing zones at approximately 55, 73, 80, 88, and 107 ft bls. No water-bearing zones were reported below 97 ft bls during drilling. A screen placed at 70-85 ft bls would include the large fracture shown on the caliper log at 73.5 ft bls and possible fluid-producing zones indicated by the fluid-temperature log at 73 and 80 ft bls.

#### **BK-2544 (NAWC E-S)**

The caliper log confirms that the total depth of the borehole is 53 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows that the formation is highly fractured throughout the entire open-hole interval. A screen placed at 40-50 ft bls would include the water-bearing zones at 30-31 ft bls reported during drilling.

### **BOREHOLE CLUSTER F**

#### **BK-2545 (NAWC F-D)**

The caliper log confirms that the total depth of the borehole is 152 ft and that it is cased with 8-inch diameter casing to 13 ft bls. The caliper log shows a fracture zone at 18-22 ft bls; the borehole television survey showed that this is a wash-out zone in a siltstone-mudstone unit. The caliper log also showed major fractures at 26.5, 43, 47.5, and 92.5 ft bls. Fractures shown on the caliper log generally correspond to siltstone-mudstone units. The fluid-resistivity log indicates a possible fluid-producing zone at 60-75 ft bls. The fluid-temperature log does not indicate vertical borehole flow. A screen placed at 135-153 ft bls would include the only water-bearing zone (140 ft bls) reported during drilling. The borehole television survey shows a steeply dipping fracture from 138.8 to 143.6 ft bls.

#### **BK-2546 (NAWC F-I)**

The caliper log confirms that the total depth of the borehole is 102 ft and that it is cased with 8-inch diameter casing to 13 ft bls. The caliper log shows a highly fractured zone at 12-22 ft bls and major fractures at 48, 63.5, 81.5, and 98 ft bls. A screen placed at 80-100 ft bls would include the major fractures shown on the caliper log at 81.5 and 98 ft bls and water-bearing zones at 84 and 95-98 ft bls reported during drilling.

#### **BK-2547 (NAWC F-S)**

The caliper log confirms that the total depth of the borehole is 52 ft and that it is cased with 8-inch diameter casing to 12.5 ft bls. The caliper log shows a major fracture at 36 ft bls that was reported to yield 2 gal/min during drilling. A screen placed at 30-50 ft bls would include the major fracture at 36 ft bls shown on the caliper log and the water-bearing zones at 37 and 47 ft bls reported during drilling.

## **BOREHOLE CLUSTER G**

### **BK-2548 (NAWC G-D)**

The caliper log confirms that the total depth of the borehole is 202 ft and that it is cased with 8-inch diameter casing to 10.5 ft bls. The caliper log shows a fracture zone at 10-22 ft bls. The caliper log and borehole television survey showed major fractures at 51, 67.5, 78.5, 99-100, and 148 ft bls. Water was cascading from fractures at 10.5-16 ft bls during the borehole television survey. The fluid-resistivity log indicates a fluid-producing fracture at approximately 152 ft bls, which corresponds to a water-bearing zone at 147-153 ft bls reported during drilling. A screen placed at 145-160 ft bls would include the major fracture shown on the caliper log at 148 ft bls and the water-bearing zones between 145 and 160 ft bls reported during drilling. The borehole television survey shows four horizontal fractures between 147 and 160 ft bls.

### **BK-2549 (NAWC G-I)**

The caliper log confirms that the total depth of the borehole is 103 ft and that it is cased with 8-inch diameter casing to 10 ft bls. The caliper log shows a fracture zone at 10-22 ft bls and a major fracture at 76.5 ft bls. The fluid-resistivity log shows a decreasing total dissolved solids concentration from approximately 32 to 70 ft bls and an increasing total dissolved solids concentration from 70 to 101 ft bls. The fluid-temperature log shows a change in slope at approximately 41 ft bls. A screen placed at 65-80 ft bls would include the major fracture shown on the caliper log at 76.5 ft bls and the possible fluid-producing zone at 70 ft bls indicated by the fluid-resistivity log.

### **BK-2550 (NAWC G-S)**

The caliper log confirms that the total depth of the borehole is 44.5 ft and that it is cased with 8-inch diameter casing to 9 ft bls. The caliper log shows that the formation is highly fractured from 9 to 22 ft bls and shows a major fracture at 34.5 ft bls that was reported to yield 4-5 gal/min during drilling. A screen placed at 30-45 ft bls would include the major fracture shown on the caliper log at 34.5 ft bls.

## **BOREHOLE CLUSTER H**

### **BK-2551 (NAWC H-D)**

The caliper log confirms that the total depth of the borehole is 178 ft and that it is cased with 8-inch diameter casing to 13 ft bls. The caliper log and borehole television survey showed major fractures at 37.5, 49.5, 65.5-67.0, 82.1, and 175 ft bls. The borehole television survey showed that the zone from 142 to 147 ft bls is a wash-out zone in a siltstone-mudstone unit. The borehole television survey also showed water cascading from fractures at 23.1-27.2 ft bls. The fluid-resistivity and fluid-temperature logs showed possible water-producing zones at approximately 46, 67, 75, 84, and 104 ft bls. A screen placed at 157-178 ft bls would include the major horizontal fracture at 175 ft bls and minor horizontal fractures at 158, 159.5, 167.5, and 173 ft bls shown on the caliper log.

### **BK-2552 (NAWC H-I)**

The caliper log confirms that the total depth of the borehole is 78 ft and that it is cased with 8-inch diameter casing to 12 ft bls. The caliper log shows major fractures at 12, 29, 35-36, 46, and 51 ft bls and a fracture zone from 60-68 ft bls. A screen placed at 60-75 ft bls would include the fracture zone shown on the caliper log from 60-68 ft bls. However, this leaves only 15 ft of unscreened aquifer between screened intervals in boreholes BK-2552 (H-I) and BK-2553 (H-S).

### **BK-2553 (NAWC H-S)**

The caliper log confirms that the total depth of the borehole is 53 ft and that it is cased with 8-inch diameter casing to 12.5 ft bls. The caliper log shows that the formation is highly fractured. A screen placed at 25-45 ft bls would include the only water-bearing zone (at 45 ft bls) reported during drilling; this water-bearing zone, which yielded about 1 gal/min, went dry after pumping for approximately 40 minutes.

## **BOREHOLE CLUSTER I**

### **BK-2554 (NAWC I-D)**

The caliper log confirms that the total depth of the borehole is 202 ft and that it is cased with 8-inch diameter casing to 11 ft bls. The caliper log shows large fracture zones at 14-35 and 140-147 ft bls and large fractures at 43 and 58 ft bls. The borehole television survey showed water cascading from fractures at 17.8-19.7 ft bls. The fluid-resistivity and fluid-temperature logs indicate possible fluid-producing zones, which correlate with fractures shown on the caliper log, at approximately 30 and 138-159 ft bls. The temperature log does not indicate vertical borehole flow. A screen placed at 135-158 ft bls would include the major fracture at 140-147 ft bls shown on the caliper log and the possible fluid-producing zone between 138 and 159 ft bls indicated by the fluid logs. The borehole television survey showed that the fracture at 140-147 ft bls is a very large, steeply dipping fracture.

### **BK-2555 (NAWC I-I)**

The caliper log confirms that the total depth of the borehole is 102 ft and that it is cased with 8-inch diameter casing to 9 ft below land-surface. This borehole yields less than 2 gal/min. The caliper log shows fractures at 14.5, 16.5, 23-32, 45, and 90.5 ft bls. The fluid-resistivity log shows possible fluid-producing zones at approximately 24, 32, 40, 53, and 61 ft bls. The fluid-temperature log indicates a possible fluid-producing zone at 32 ft bls. A screen placed at 60-75 ft bls would include the possible fluid-producing zone indicated by the fluid-resistivity log at 61 ft.

### **BK-2556 (NAWC I-S)**

The caliper log confirms that the total depth of the borehole is 52 ft and that it is cased with 8-inch diameter casing to 8.5 ft below land-surface. The caliper log shows that the formation is highly; large fractures are at 34 and 38 ft bls. A screen placed at 35-50 ft bls would include water-bearing zones reported at 39 and 48 ft bls during drilling.

## **BOREHOLE CLUSTER J**

### **BK-2557 (NAWC J-D)**

The caliper log confirms that the total depth of the borehole is 252 ft and that it is cased with 8-inch diameter casing to 11 ft below land-surface. The caliper log shows large fractures at 12, 31, 36, 41-46, 51, and 84.5 ft bls plus numerous smaller fractures.

The fluid-resistivity log indicates a fluid-production zone at approximately 30-35 ft bls. The fluid-temperature log indicates a fluid-producing zone at approximately 35 ft bls and a fluid-receiving zone at approximately 95 ft bls. A slug of high conductance fluid injected at 50 ft bls moved downward at approximately 4.8 gal/min.

A screen placed at 225-240 ft bls would include the fractures shown on the caliper log at 226.5 and 234 ft bls. The borehole television survey showed that the fracture at 226.5 ft bls (225.3 ft bls on the borehole television survey) is a steeply dipping fracture and that the fracture at 234 ft bls (233.5 ft bls on the borehole television survey) is a horizontal fracture.

**BK-2558 (NAWC J-I)**

The caliper log confirms that the total depth of the borehole is 111 ft and that it is cased with 8-inch diameter casing to 11.5 ft bls. The caliper log shows a highly fractured zone from 27 to 54 ft bls and major fractures at 72 and 87 ft bls. The fluid-resistivity log indicates fluid-producing zones at approximately 25-31 and 88 ft bls. The fluid-temperature log indicates a fluid-producing zone at 85 ft bls. A screen placed at 83-98 ft bls would include the large fracture shown on the caliper log at 87 ft bls and the fluid-producing zone indicated by the fluid logs that corresponds to this fracture.

**BK-2559 (NAWC J-S)**

The caliper log confirms that the total depth of the borehole is 53 ft and that it is cased with 8-inch diameter casing to 11 ft bls. The caliper log shows a large fracture zone from 28-36 ft bls. A screen placed at 28-38 ft bls would include the large fracture shown on the caliper log from 28-36 ft bls.

Sincerely,



Ronald A. Sloto  
Supervisory Hydrologist

cc: M. Snoparski  
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