GEOTECHNICAL SPECIAL PUBLICATION NO. 183

Sinkholes

and the Engineering and Environmental Impacts of Karst

PROCEEDINGS OF THE
Eleventh Multidisciplinary Conference

EDITED BY
Lynn B. Yuhr
E. Calvin Alexander, Jr.
Barry F. Beck

ASCE

GEO INSTITUTE
of the American Society of Civil Engineers

GEOTECHNICAL SPECIAL PUBLICATION NO. 183

SINKHOLES AND THE ENGINEERING AND ENVIRONMENTAL IMPACTS OF KARST

PROCEEDINGS OF THE ELEVENTH MULTIDISCIPLINARY CONFERENCE

September 22–26, 2008
Tallahassee, Florida

SPONSORED BY
The Geo-Institute of the American Society of Civil Engineers

EDITED BY
Lynn B. Yuhr
Technos, Inc.

E. Calvin Alexander, Jr.
University of Minnesota

Barry F. Beck
P.E. LaMoreaux & Associates, Inc.

ASCE

GEO INSTITUTE
of the American Society of Civil Engineers

Published by the American Society of Civil Engineers

ALONG STRIKE MIGRATION AND DEGRADATION OF HALOGENATED HYDROCARBONS AT DEPTH THROUGH FRACTURED LIMESTONE

Gheorghe Ponta[1], and Lois D. George[2]

[1]P.E. LaMoreaux & Associates, Inc., 1009 23rd Avenue, Tuscaloosa, Alabama 35401, U.S.A., gponta@pela.com, [2]P.E. LaMoreaux & Associates, Inc., 1009 23rd Avenue, Tuscaloosa, Alabama 35401, U.S.A., lgeorge@pela.com

ABSTRACT

Since 1975, site operators have manufactured specialized equipment and assembled utility trucks at the now closed site. Several Environmental Site Assessments (ESAs) were completed from 1990 to 2004. A fuel underground storage tank was removed, shallow wells were installed, and halogenated hydrocarbon-contaminated soil was removed.

The hydrogeologic setting has been interpreted from subsurface data from prior investigations and data from corehole drilling and drilling and construction of 24 wells (monitoring wells, hereafter referred to as MW-11 through MW-25 including designations of shallow [S], intermediate [I], and deep [D]). Double cased monitoring wells were constructed to prevent interconnection of the water-bearing zones and downward migration of contaminants. The site is underlain by a Cambrian age formation, the Conasauga Formation, consisting predominantly of interbedded limestone and calcareous shale with an approximate thickness of 1,100 to 1,900 feet. Ground-water movement occurs along solutionally enlarged fractures of limited size and bedding planes. Interpretation of ground-water elevations indicate the direction of ground-water movement is generally toward the southeast, similar to the dip of the formation.

Ground-water analyses indicate that many wells have concentrations of halogenated hydrocarbons above Maximum Contaminant Levels. The distribution of the organic constituents in nested wells illustrates the source area in the vicinity of the site operational area in shallow wells and migration and degradation by-products (chemical and biological transformation) in deeper wells, along strike. The contaminated ground water encompasses most of the site and has also migrated to at least 225 feet below land surface.

SETTING

The site is located in the Birmingham-Big Canoe Valley Physiographic District of the Alabama Valley and Ridge Physiographic Section. Structure in the area is characterized by large thrust fault ramps and associated folding with the most prominent structural features including the Birmingham Anticlinorium, the Cahaba Synclinorium and the Coosa Synclinorium. Published mapping of geologic structure (Kidd, 1979), shows that the site is located approximately 0.25 miles southeast of the hinge of the Murphrees Valley Anticline. Measurements in the area indicate bedrock is dipping to the southeast between 8° and 23°. The beds strike N 25° E to N 30° E.

The site is underlain by the Cambrian age Conasauga Formation that has an estimated thickness of 1,100 to 1,900 feet. It consists mainly of interbedded limestone and calcareous shale (Butts, 1927). The lowermost exposed Conasauga consists mainly of thinly interbedded, medium- to dark-gray micritic limestone and dark-gray shale. The middle and upper Conasauga includes dark-gray, stylonodular, bioclastic, and oolitic limestone. The uppermost limestone is dolomitic in part. Fossils are observed mainly in the limestone and include brachiopods and trilobites. Soils consist of deep reddish-brown, sticky clay, and in some areas contain minor, very thin chips and rounded nodules of light yellowish-brown chert. The chert nodules can be fossiliferous (Rindsberg & Others, 2003).

The Conasauga is an important source of ground water in Jefferson County. Hunter and Moser (1990) observed that zones of increased permeability and porosity occur along solution channels; however, water availability is not uniformly distributed. Wells completed in the regolith may produce small quantities of ground water while well yields of 300 gallons per minute (gpm) and spring yields of 3,400 gpm have been reported from the Formation. Most the ground water in the Conasauga occurs in the upper 300 feet of the Formation.

SITE INVESTIGATIONS

The investigations, completed in three stages, involved drilling and sampling of 25 soil borings and installation of 24 ground-water monitoring wells, collection of 73 soil samples, and stream sampling at three locations. Nine existing monitoring wells were also sampled. The soil and water samples were analyzed for a variety of constituents including volatile organic compounds, semi-volatile organic compounds, metals, and petroleum hydrocarbons.

During drilling the air in the breathing zone and work area was monitored with a photoionization detector (PID). No PID reading was recorded above 5 parts per million during drilling activities. Overburden and rock samples were also screened with a PID and the 73 soil samples were selected for chemical analyses.

During the drilling of each well, the overburden (soil) was sampled at the following intervals and described: 1) near-surface (below the vegetative root zone, or below pavement or gravel) and, 2) at the top of the zone of saturation or immediately above bedrock, whichever was shallowest.

A variety of drilling methods were used during installation of the 24 bedrock monitoring wells and 25 Geoprobe borings, including hollow-stem augers, mud rotary, air rotary, GeoProbe®, and coring. To minimize any potential cross-contamination during drilling and installation, each of the wells was "telescoped" utilizing multiple casings into the overburden, and then into the bedrock. Geophysical logging was completed to further correlate lithologic units, structural and bedrock features, and ground-water inflow. The deep wells were nested with two or more wells that are screened at different elevations in shallower water-bearing zones.

The Conasauga consists of medium dark gray to medium gray, finely crystalline limestone with minor quantities of interbedded dolomite, and shale. Bedding is generally 5 to 12 inches thick. The shale of the Conasauga usually occurs as thin beds/laminae separating carbonate units. As indicated by natural gamma logs, the clay content of the carbonates typically increases adjacent to the shale layers. At the site the limestone strike is N. 25° E. to N. 30° E., and the dip is 20° to 23° SE.

The Conasauga Formation weathers to a clay-rich residuum, which locally contains chert fragments. The thickness of the residuum varies over relatively short distances. The total variation in thickness of the residuum is from 2 feet to 29.6 feet at the site. The top of bedrock (Figure 1) dips gently towards the south (10 feet difference in elevation from the north and south part of the site), with two lows at BH-4 (29.6 feet BLS [below land surface]) and MW-3 (14.61 feet BLS).

Fragments of bedrock (limestones) are present throughout the residuum, close to the overburden/bedrock interface. The contact between the residuum and underlying Conasauga Formation is abrupt and no basal lag or gravel was encountered. No water-bearing horizons were penetrated in the residuum. Occasionally, limited water was intercepted at the top of the bedrock.

Small vugs containing calcite are common in the Conasauga Formation. Crystals within vugs may exhibit well-developed crystal facies. Some fractures have been filled by calcite. The healed fractures vary in thickness from less than 0.001 inches to 0.8 inches. Stylolites (stylolites are formed diagenetically by differential vertical movement under pressure, accompanied by solution) are common also in the Conasauga Formation.

The Conasauga Formation exhibits little or no intercrystalline porosity. Ground-water movement in the Conasauga Formation occurs along solutionally enlarged fractures of limited size (2-6 inches) and bedding planes. During drilling, some voids or cavities were penetrated, some of which were clay-filled. The extent of the cavities ranges from a few inches to 11 feet (MW-16: 18-29 feet BLS). The deepest soft zone was penetrated at MW-19DD: 185-190 feet BLS.

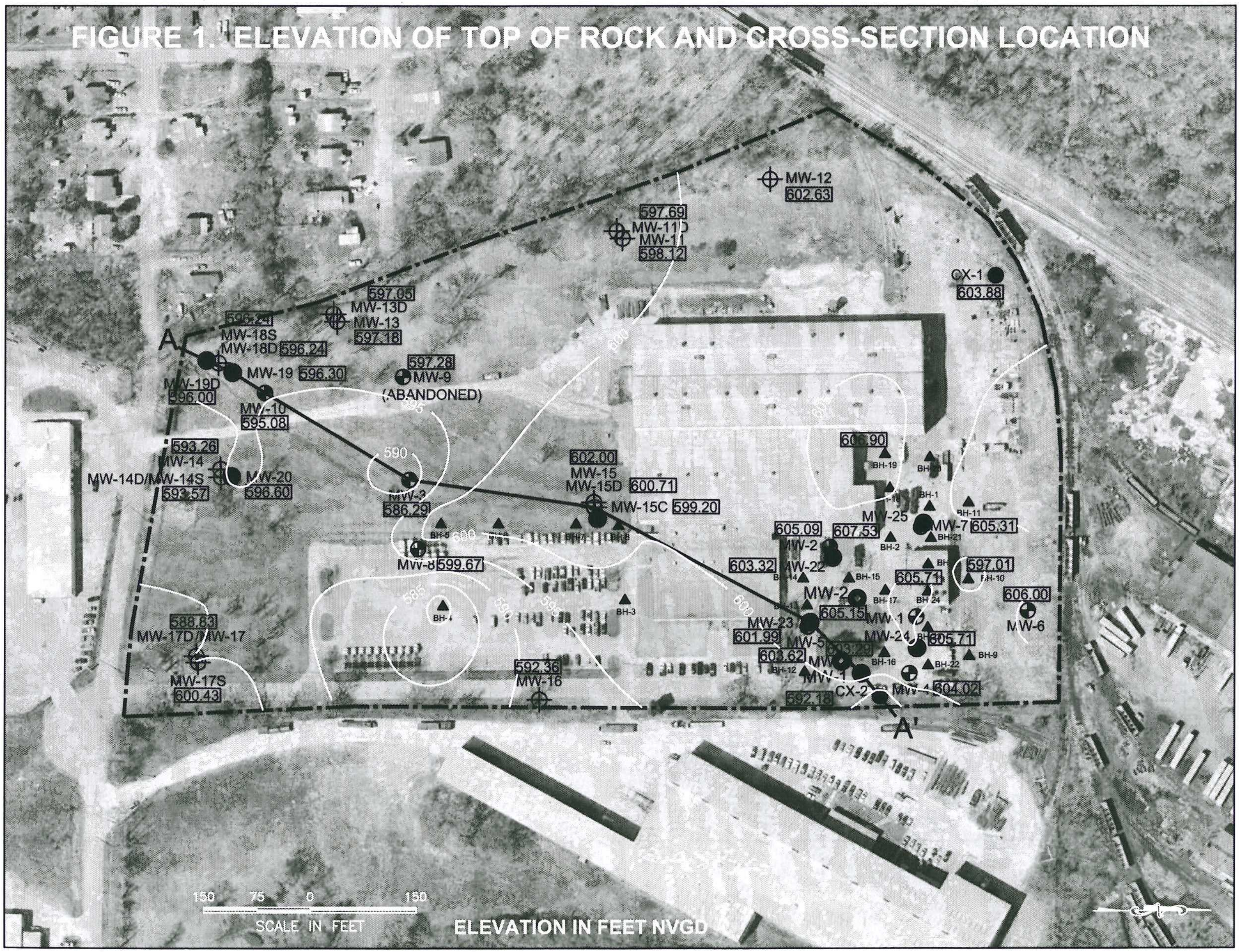


FIGURE 1. ELEVATION OF TOP OF ROCK AND CROSS-SECTION LOCATION

Slug tests were completed on eight wells (MW-8, MW-15, MW-15D, MW-18I, MW-19D, MW-19DD, MW-21D and MW-22D). Two tests were performed on each well, except for MW-15D, MW-19DD, and MW-21D where only one test was completed (slow water-level recovery to pre-test level). Water-level data was collected for the falling head portions of the test in each of the eight wells. Falling head tests were performed by inserting a slug rod of known volume to each well and recording the changes in water level (Test 1). After the water level returned to near its pre-test level, the test in each well was terminated. After pulling out the slug rod from the each well, the changes in water level to recovery to near its pre-test level were recorded (Test 2).

The Bouwer and Rice method (Schwartz and Zhang, 2003) of analysis was used to calculate a value for hydraulic conductivity (K) using the standard equation and input values: initial change in water level in the well, radius of the well casing, effective radius of the well, saturated thickness of the aquifer, length of well screen, and height of the water column in the well.

Values of hydraulic conductivity determined from the data collected fall within the expected range for limestone at the site. The water level in MW-22D failed to recover after approximately 21 hours. During the time this well was monitored, the water level in this well changed by less than 0.1 foot. The hydraulic conductivity of bedrock near well MW-22D is significantly low, indicating that this well did not penetrate fractures. The test documented the hydraulic conditions of the non-porous bedrock.

Values of hydraulic conductivity determined from these tests range from 1.99×10^{-3} cm/sec to 7.03×10^{-6} cm/sec.

ASSESSMENT OF RESULTS

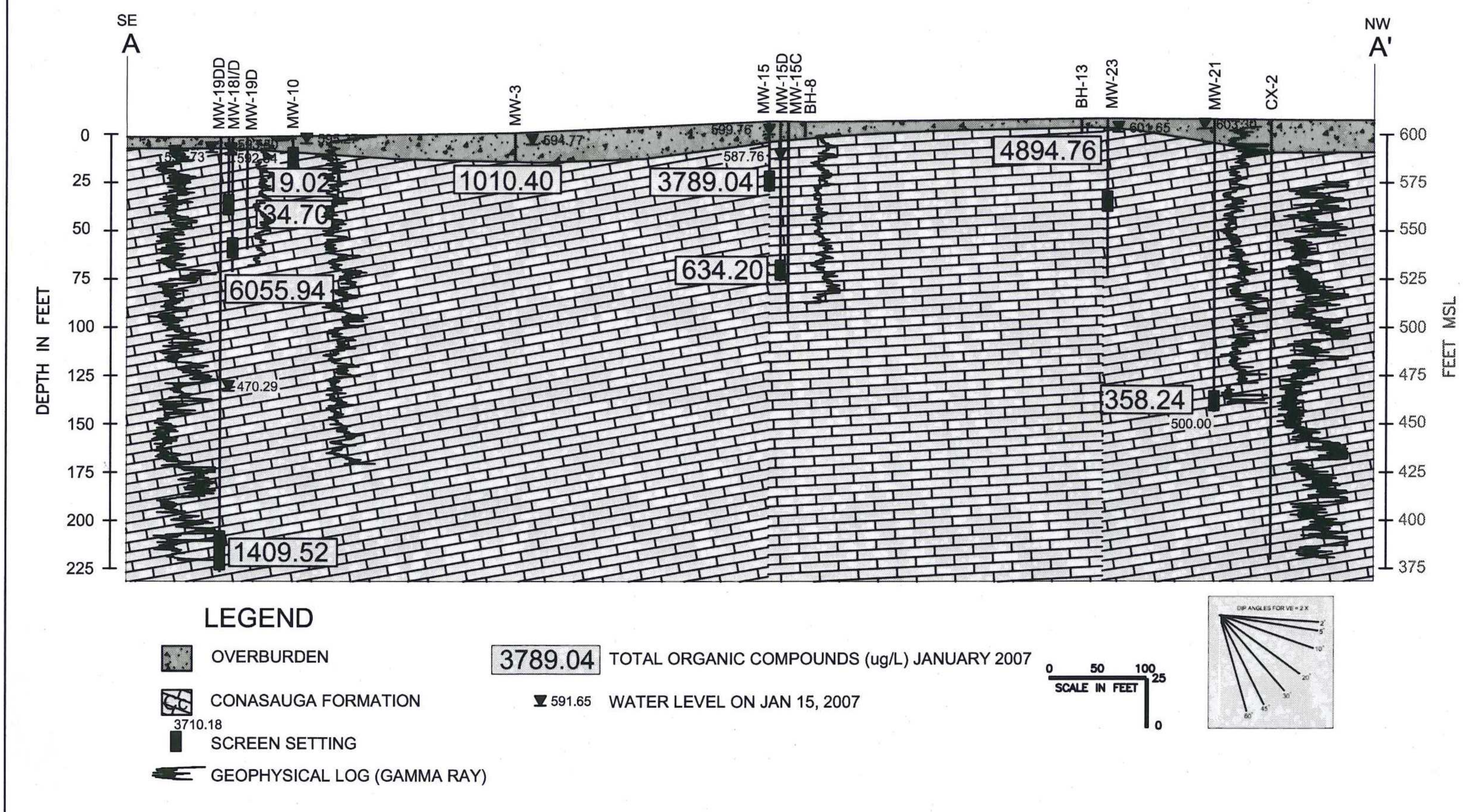
A total of 21 shallow wells and 12 deep wells have been installed at targeted intervals within the Conasauga. All of these monitoring wells (33 wells) provided geologic, water-quality and water-level data.. These data were used to generate cross sections, and to further define movement of ground water and supplement information on water quality characteristics of the Conasauga Formation (Figure 2).

Ground-water contour maps were generated using water levels measured in existing wells. The maps indicate that the direction of ground-water movement is generally towards the south (Figure 3).

Based on the soil and ground-water analytical data, some of the areas (sandblasting operations located at northeastern portion of property and the floor drain and storm water drainage system) yielded samples with analytical results that were below appropriate regulatory standards and, thus, there is no further need for investigation or remediation in those areas.

Contour maps of Total Organic Hydrocarbons in shallow and deep wells show the vertical and horizontal migration/degradation of the constituents (Figures 4 and 5).

FIGURE 2. GEOLOGIC CROSS-SECTION A-A'



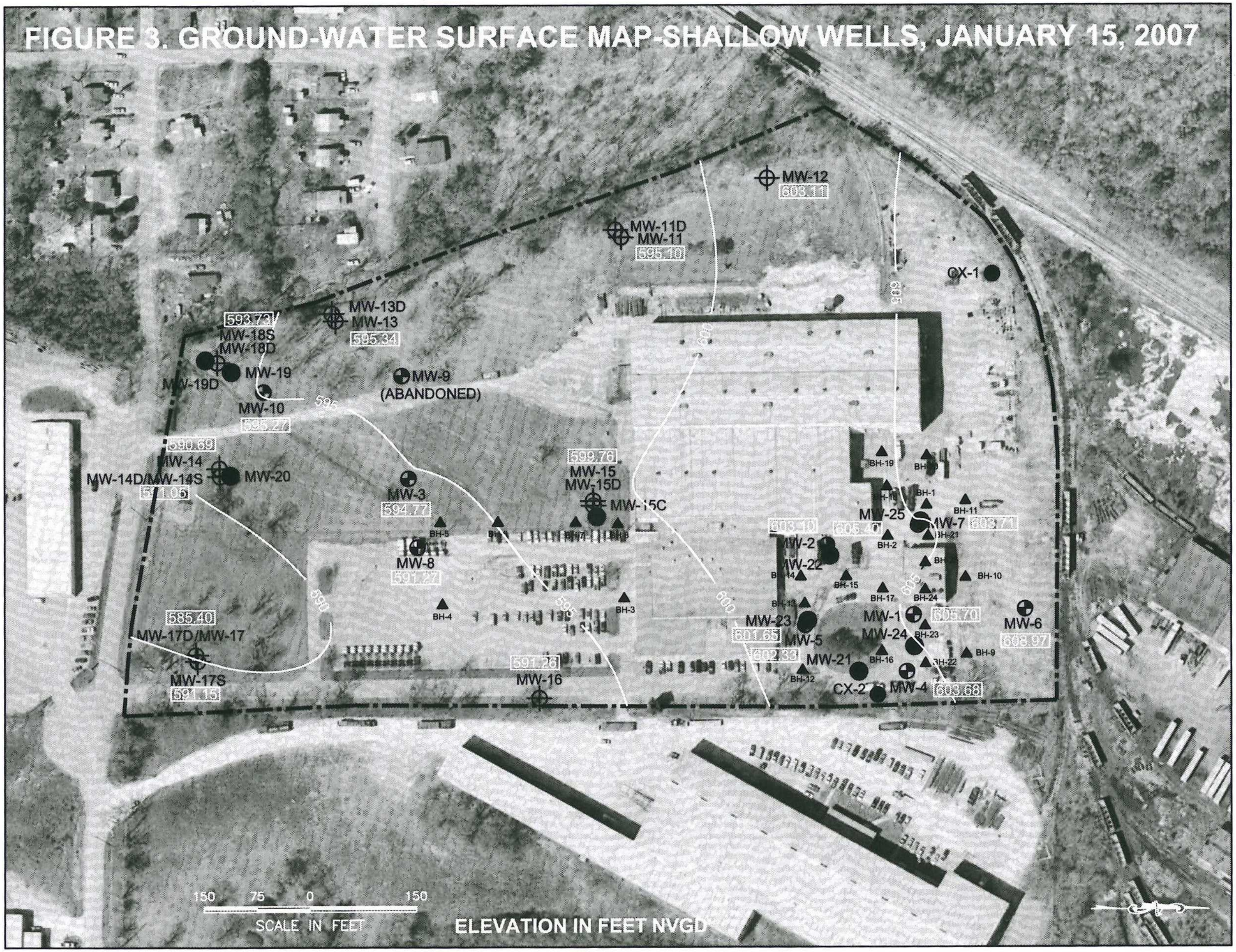


FIGURE 3. GROUND-WATER SURFACE MAP-SHALLOW WELLS, JANUARY 15, 2007
MW-12
603.11
MW-11D
MW-11
595.10
CX-1
593.73
MW-13D
MW-13
595.34
MW-18S
MW-18D
MW-19D
MW-19
MW-9
(ABANDONED)
MW-10
595.27
590.69
MW-14
MW-14D/MW-14S
MW-20
MW-3
594.77
599.76
MW-15
MW-15D
MW-15C
MW-8
591.27
MW-25
MW-7
603.71
603.10
605.40
MW-2
MW-22
MW-23
601.65
MW-5
602.33
MW-1
605.70
MW-24
MW-21
MW-6
608.97
CX-2
MW-4
603.68
585.40
MW-17D/MW-17
MW-17S
591.15
591.26
MW-16
595
590
600
605
150 75 0 150
SCALE IN FEET
ELEVATION IN FEET NVGD

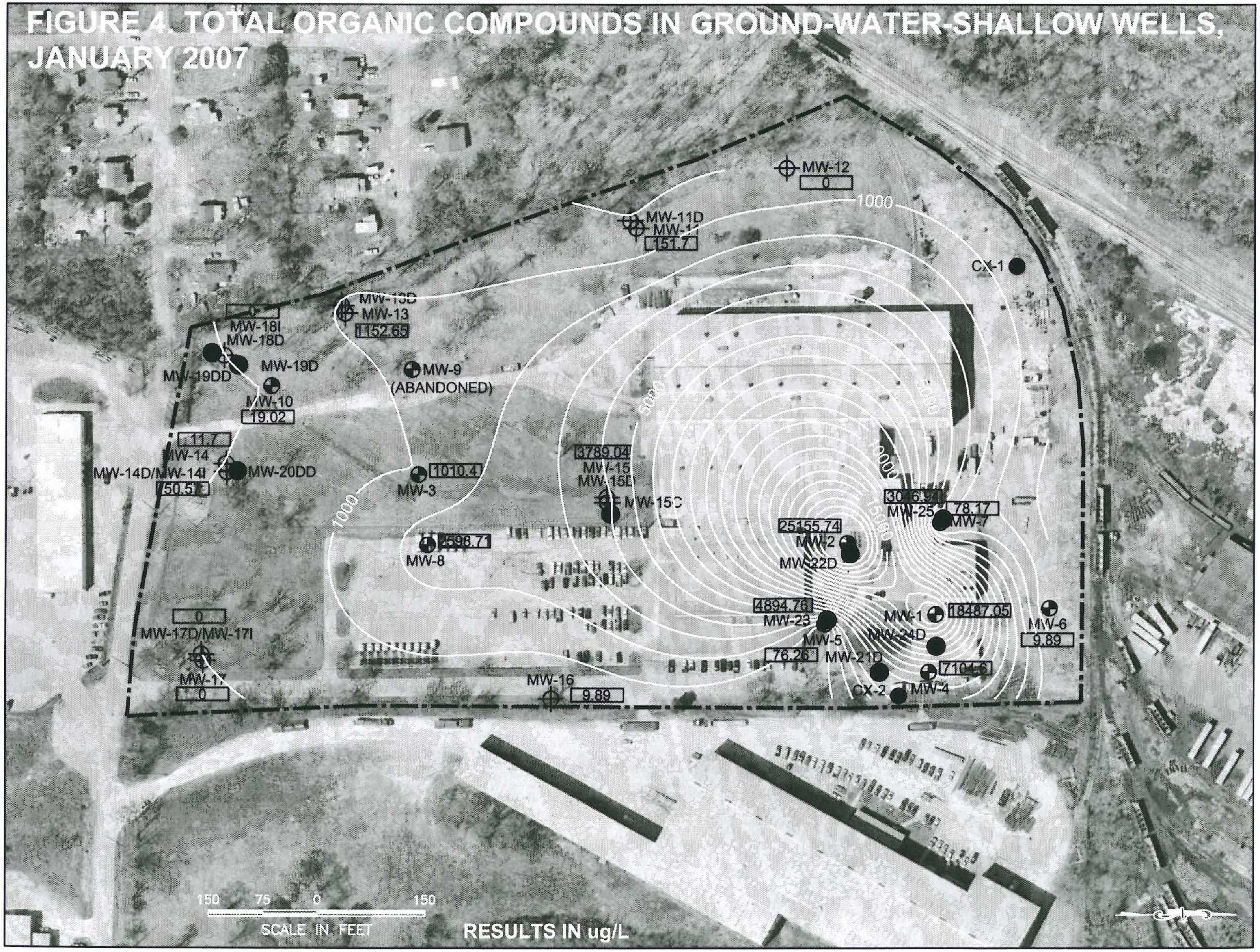
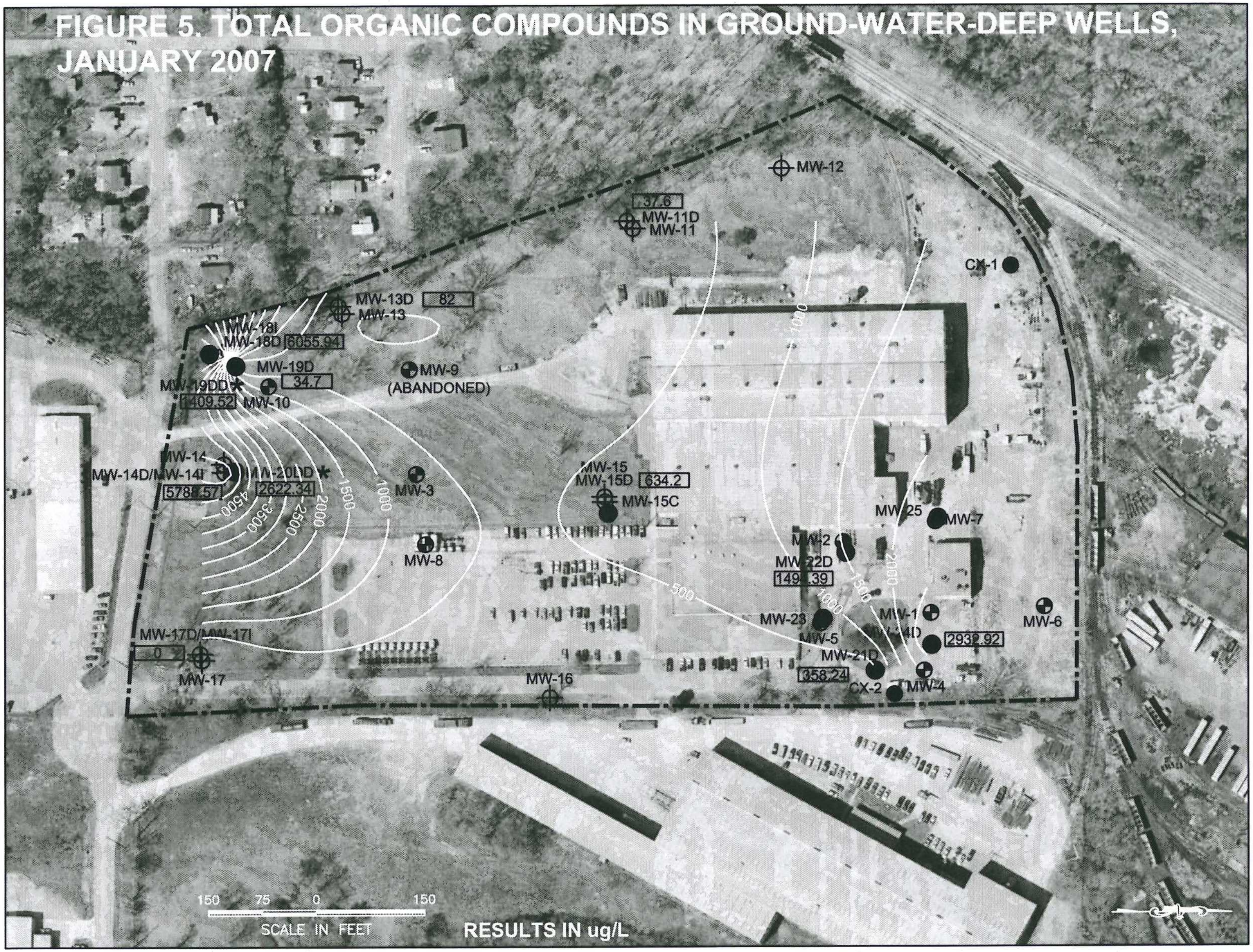


FIGURE 4. TOTAL ORGANIC COMPOUNDS IN GROUND-WATER-SHALLOW WELLS, JANUARY 2007
MW-12
0
1000
MW-11D
MW-11
151.7
CX-1
MW-13D
MW-13
1152.65
0
MW-18I
MW-18D
MW-19DD
MW-19D
MW-9
(ABANDONED)
MW-10
19.02
5000
11.7
MW-14
MW-14D/MW-14I
50.57
MW-20DD
1010.4
MW-3
3789.04
MW-15
MW-15D
MW-15C
1000
2598.71
MW-8
25155.74
MW-2
MW-22D
MW-25
78.17
MW-7
15000
0
MW-17D/MW-17I
MW-17
0
4894.76
MW-23
MW-5
76.26
MW-21D
MW-1
18487.05
MW-24D
MW-6
9.89
7104.6
CX-2
MW-4
MW-16
9.89
150 75 0 150
SCALE IN FEET
RESULTS IN ug/L

FIGURE 5. TOTAL ORGANIC COMPOUNDS IN GROUND-WATER-DEEP WELLS, JANUARY 2007



Ground-water analyses indicate that many wells have concentrations of halogenated hydrocarbons above Maximum Contaminant Levels. The distribution of the organic constituents illustrates the source area in the vicinity of the facility operational area in shallow wells and migration and degradation by-products (chemical and biological transformation) in deeper wells, down strike.

The direction of ground-water movement is generally to the south/southeast, consistent with the bedrock dip. Drilling conditions, geophysical logging and in-situ hydrologic tests indicate that the Conasauga Formation is comprised of beds of non-porous limestone with ground-water occurrence and movement along secondary features (bedding, fractures, and very limited karst). Ground-water quality data, from multiple and iterative rounds of sampling, indicate that the migration of halogenated hydrocarbons has occurred along strike. The contaminated ground water encompasses most of the site and has migrated downward to at least 225 feet BLS.

The owner of the site intends to return the entire property to productive use. It is believed that the facility can be used for commercial/industrial purposes with no effects to future operations during the remedial design and any corrective action activities.

REFERENCES

Butts, C., 1927, Bessemer-Vandiver folio, Alabama (Description of the Bessemer and Vandiver quadrangles): U.S. Geological Survey, Geologic Atlas of the United States, folio 221, 22p., 10pl.

Hunter, J. A., and Moser, P.H., 1990, Ground-Water Availability in Jefferson County, Alabama, Special Map 224, Geological Survey of Alabama.

Kidd, 1979, Areal Geology of Jefferson County, Alabama: Geological Survey of Alabama, Atlas 15.

Rindsberg, A. K., Ward, W. E., Osborne, W. E., and Irvin, G. D, 2003, Geology of the Irondale 7.5 – Minute Quadrangle, Jefferson County, Alabama, Quadrangle Series Map 26, Geological Survey of Alabama.

Schwartz, Franklin W. and Zhang, Hubao, 2003, Fundamentals of Ground Water, John Wiley & Sons, Inc.