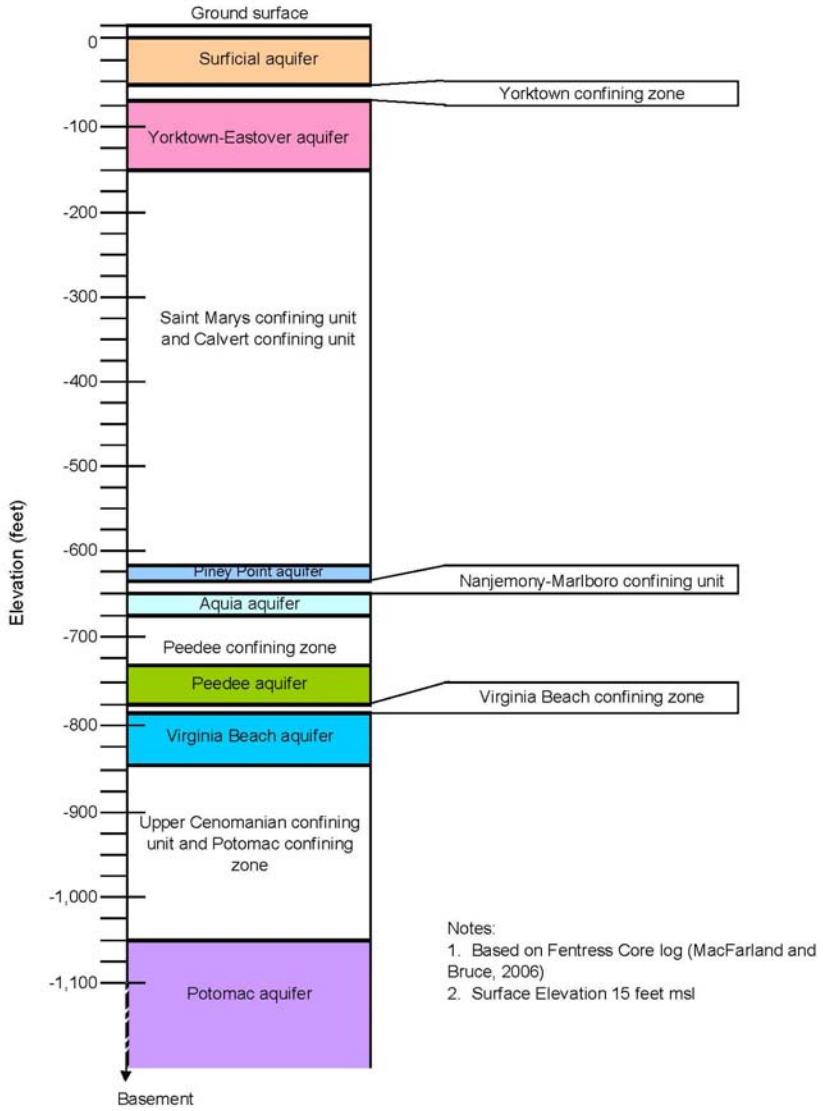
3.0 GROUNDWATER CONDITIONS

3.1 Regional Geology and Hydrogeology

The project area is located within the Coastal Plain Physiographic Province of Virginia. The Virginia Coastal Plain is "underlain by a seaward-dipping strata of unconsolidated to partially consolidated sediments of Cretaceous, Tertiary, and Quaternary age that unconformably overlie a basement of consolidated bedrock" (MacFarland and Bruce, 2006). This "wedge" of sediments extends from the Fall Line located near Richmond, VA and thickens to the east, and is estimated to reach a thickness in excess of 3,000 feet in the Chesapeake area.

The most recent published literature describes seven discrete aquifers and eight confining units that separate the aquifers in the vicinity of the project area. Each of these units is briefly discussed, from the deepest to the shallowest, in this section based on the interpretations presented in MacFarland and Bruce (2006) of lithologic and geophysical logs obtained from the Fentress Core. Figure 2 illustrates the location of the Fentress test wells/core. As the study area is located approximately two miles to the west (up dip) of this core hole, the actual depths will be somewhat shallower (+/- 10 to 20 feet) and the units will typically be thinner (+/- 10 feet). Figure 3 presents a stratigraphic cross-section of these units based on the Fentress Core.

Figure 3
General Hydrogeologic Section



The Potomac aquifer is the deepest aquifer in the area and directly overlies the bedrock. Historically, this aquifer was divided into three separate aquifers, termed the Lower, Middle, and Upper Potomac aquifers (Meng and Harsh, 1988). However, recent studies have concluded that the confining units described in previous studies are probably not present, and for purposes of this study, the Potomac aquifer is defined as a single aquifer as described by MacFarland and Bruce (2006).

The top of the Potomac aquifer is encountered at a depth of approximately 1,065 feet below ground surface (bgs), and extends to depths in excess of 3,000 feet. Because of its large lateral extent and coarse grained sediments, this aquifer is one of the predominantly used aquifers in the Virginia Coastal Plain. Capable of providing large quantities of groundwater, its depth and the brackish nature of its water quality in the eastern portion of

URS

Legend

- Site Boundary
- Past Samples
- Fentress Test Wells

N
W E
S

0 500 1,000 2,000 3,000 4,000 Feet

Figure 2
Past Sample Locations
Battlefield Golf Club
Chesapeake, Virginia

G: Projects\Battlefield_Golf_Club\GIS\Projects\Samples.mxd

the state limit its use to major water supply systems for industrial and municipal use, and the water must be treated to achieve potable water quality.

The Potomac Aquifer is overlain by the Potomac confining zone and the Upper Cenomanian confining unit that form a 200-foot thick sequence of fine grained sandy and silty clays. These confining beds are overlain by the Virginia Beach aquifer which is comprised of well-sorted sands. Extending from depths of approximately 800 feet to 855 feet bgs, this aquifer also has relatively poor water quality owing to its brackish nature, and water supplies obtained from this unit require treatment to achieve potable water quality.

The Virginia Beach confining zone overlies the Virginia Beach aquifer and is approximately 15 feet thick. The Peedee aquifer overlies the Virginia Beach confining zone and extends from depths of approximately 755 to 790 feet bgs. Owing to its depth, and limited areal extent in just the southern portions of Chesapeake and Virginia Beach, the Peedee aquifer it is considered to be unused as a source of groundwater in Virginia. It also is considered to contain brackish water; thus requiring treatment prior to use as a potable water source.

The Peedee confining zone overlies the Peedee aquifer, and is approximately 60 feet thick. The Aquia aquifer overlies the Peedee confining zone and extends from depths of approximately 665 to 690 feet bgs. The Aquia aquifer is a widespread aquifer in the Virginia Coastal Plain, and is comprised of medium- to coarse-grained sand. Due to its relative thinness, the Aquia aquifer is not a major water supply source, and wells installed into this aquifer typically do not produce quantities of water needed for large industrial, commercial, or municipal use in the area. This aquifer also contains brackish water, requiring the need for treatment prior to potable use.

The Nanjemony-Marlboro confining unit overlies the Aquia aquifer and is approximately 15 feet thick. The Piney Point aquifer overlies the Nanjemony-Marlboro confining unit, and extends from depths of approximately 630 to 650 feet bgs. A laterally extensive aquifer, it is a moderately used aquifer that provides water to small towns and can be used for low-density residential development. However, south of the James River, the Piney Point aquifer is not considered to be a productive groundwater source.

The Calvert confining unit overlies the Piney Point aquifer and is approximately 15 feet thick. This unit is overlain by the Saint Mary's confining unit that measures approximately 425 feet thick. Together these two units comprise an extensive confining unit that separates the underlying Piney Point aquifer from the Yorktown-Eastover aquifer. The Yorktown-Eastover aquifer extends from depths of approximately 85 to 185 feet bgs. A laterally extensive aquifer across the Virginia Coastal Plain, this aquifer is heavily used as a groundwater supply source. With interbedded fossiliferous sands, water-supply well yields range from 10 to 300 gallons per minute (gpm), and average nearly 90 gpm (Siudyla, et al., 1981) with larger production wells located along the eastern shore of Virginia producing up to 300 gpm.

Water quality of the Yorktown-Eastover aquifer is typically good, although salinity is reported to increase with depth, particularly if wells are drilled into the finer grained and less productive Calvert confining unit that underlies the aquifer. Iron may also be present in local areas, and poses taste and staining issues.

The Yorktown confining zone overlies the Yorktown-Eastover aquifer and is approximately 15 feet thick. Based on the amount of silt and clay present, this unit varies laterally and in certain locations where coarser sediments are present, it does not serve as a confining unit between the Yorktown-Eastover aquifer and the Surficial aquifer.

Formerly referred to as the Columbia aquifer, the Surficial aquifer lies above the Yorktown confining zone and is an unconfined, water table aquifer that exists within sands that are interbedded with laterally discontinuous silts and clays. Extending to a depth of approximately 70 feet bgs, the Surficial aquifer serves as a water supply source of shallow water, although sustained well yields are typically less than 25 gpm. As a result of its existence as a water table aquifer, it is continuously recharged as fresh water infiltrates from precipitation. In general, the water quality is good, although iron, manganese, and sulfate may pose taste and discoloration issues locally, and because the aquifer is not confined, it may be subject to degradation from pollution.

3.2 Study Area Geology and Hydrogeology

To supplement the published literature and gain a greater understanding of the study area, hydrogeological data gathered during previous investigations at the Battlefield Golf Club were reviewed, and residential well records were obtained from the City of Chesapeake Health Department. In addition, two monitoring wells (MW-1 and MW-2) were installed as part of this study as detailed in Appendix F to gain an understanding of the local stratigraphy and hydrogeologic relationship between the Surficial aquifer and the underlying Yorktown-Eastover aquifer. Figure 4 depicts the locations of the two wells.

Based on the lithologic logs from the wells installed at the end of Bonney Road (see Appendix F) as part of this study, the Surficial aquifer was found to extend to a depth of 52 feet bgs where lean clays indicative of the Yorktown confining zone were encountered. These clays extended for 10 feet, and then sands indicative of the Yorktown-Eastover aquifer were encountered.

As part of this study, two undisturbed tube samples were collected from the Yorktown confining zone and vertical permeability tests indicate hydraulic conductivities of 8.3×10^{-7} centimeters per second (cm/sec) from the 55-57 feet bgs sample and 1.7×10^{-6} cm/sec from the 60-62 feet bgs sample. Appendix F contains the testing results.

Water level measurements were obtained from wells MW-1 and MW-2 installed as part of this study from December 10, 2008 through January 15, 2009 (see Appendix F). Well MW-1 was installed into the Yorktown-Eastover aquifer and well MW-2 was installed into the Surficial aquifer. The portion of the Yorktown-Eastover aquifer screened in well MW-

URS

Legend

- Golf Club Boundary
- Monitoring Well
- Residential Well Samples

N
W E
S

0 250 500 1,000 1,500 Feet

Figure 4
Residential Sampling Locations
Chesapeake, Virginia

G: Projects\Battlefield_Golf_Club\GIS\Projects\GolfClub.mxd

1 was comprised of lean clays, clayey sand, and silty sand, and was not a productive water bearing zone. Consequently, during well development, the well was pumped dry, and the water level recovery was very slow. This is evidenced by the water levels recorded in well MW-1 which slowly rose over the monitoring period.

Based on the water levels measured in these two wells, and the reduced rate of recovery of the water level in well MW-1, it appears that the potentiometric surface of groundwater in the Yorktown-Eastover aquifer is approximately 1.5 feet lower than the water level in the Surficial aquifer. Using the mid-point of the screened intervals (40 feet bgs at MW-2 and 85 feet bgs in MW-1), a downward vertical gradient of approximately 0.03 ft/ft is calculated. This gradient indicates that the Yorktown confining zone retards the vertical migration of groundwater from the Surficial aquifer downward into the Yorktown-Eastover aquifer at the location of these wells as would be expected given the low vertical permeability of the lean clays encountered between the Surficial and Yorktown-Eastover aquifers, mentioned above.

While at the location of wells MW-1 and MW-2, the Yorktown confining zone appears to act as a confining unit, this unit is typically not extensively mappable as a confining unit, and when present, is usually leaky (T. Scott Bruce, DEQ, personal communication, 2008). A review of lithologic logs obtained from residential wells in the area obtained did not identify the Yorktown confining zone as being present, although the quality of the logs, which are typically made from soil cuttings observed during drilling, may not be an accurate representation of the stratigraphy in the area.

Based on the data obtained, it is concluded that, where present, the Yorktown confining zone may serve to retard the migration of groundwater from the Surficial aquifer downward into the Yorktown-Eastover aquifer. However, leakage through the Yorktown Confining zone occurs, albeit slowly, and if this confining zone is not present or has a higher sand content, groundwater in the Surficial aquifer will migrate into the underlying Yorktown-Eastover aquifer.

3.3 Project Area Groundwater Use

The properties within the study area utilize private water supply wells for domestic and small business use. Groundwater is also used for feeding livestock. The upper two aquifers, the Surficial and the partially confined Yorktown-Eastover Aquifer, are the major sources for the local water supply wells. Water levels obtained from wells installed at the Battlefield Golf Club as reported by Kimley-Horn and Associates (2008) indicate that groundwater flow in the unconfined Surficial aquifer is toward the southeast, away from the homes and businesses located west of South Centerville Turnpike.

To avoid potential contamination that potentially may occur in the future in the Surficial aquifer, the Yorktown-Eastover aquifer will be considered the main groundwater source for any proposed well installation, private or community systems. For the purpose of this study it has been assumed that all individual supply wells are capable of producing 400 gallons per day to be consistent with the Virginia “Waterworks Regulations”.

3.4 Existing Well Groundwater Quality

3.4.1 Well Information

Well records were located for 29 wells in the region at the City of Chesapeake Health Department. Among them, well yield information is available for 14 of the wells. Well information is summarized in Table 1 of Appendix G.

The average well yield is 19 gpm and the average well depth is 71 ft bgs. The screen interval data was reviewed to evaluate which wells withdraw water in the unconfined Surficial water table aquifer and which wells withdraw from the uppermost partially confined aquifer (Yorktown-Eastover aquifer). A small majority of the 29 wells with supporting data are believed to utilize water from the Surficial aquifer based on the recorded screen intervals. The remainder of the wells are advanced to deeper depths and resumed to be part of the Yorktown-Eastover aquifer.

3.4.2 Existing Well Water Quality Data

Past groundwater quality data for local water supply wells is summarized in Table 2 of Appendix G.

November and December 2001 Groundwater Tests

In November and December 2001, prior to the commencement of Battlefield Golf Course construction, 43 groundwater samples were taken from 40 homes in the region (Stokes Environmental Associates, Ltd., 2002). Sampling locations are indicated in Figure 4. Tests were conducted for the following elements:

- Primary contaminants: antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), cyanide (CN), fluoride (F), mercury (Hg), lead (Pb), selenium (Se), thallium (Tl)
- Secondary contaminants: iron (Fe), manganese (Mn), silver (Ag), zinc (Zn)
- Other unregulated elements: nickel (Ni)

The test results indicate naturally elevated iron and manganese levels in the local groundwater, can be used as the baseline water quality data, and are summarized with respect to SDWA levels as indicated below:

Constituent	Detected	Above Regulatory Limit	Comments
Antimony (Sb)	No		
Arsenic (As)		No	Found at isolated locations
Barium (Ba)	No		
Beryllium (Be)		No	Found at isolated locations
Cadmium (Cd)		No	Found at 20 locations
Chromium (Cr)		No	Found at 5 locations
Copper (Cu)		2 Locations Above Primary Limit (1.30 mg/L)	Found at 9 locations
Cyanide (Cn)	No		
Fluoride (F)		No	Found at 29 locations
Iron (Fe)		16 Locations Above Secondary Limit (0.30 mg/L)	Found at 24 locations
Lead (Pb)		No	Found at 17 locations
Manganese (Mn)		9 Locations Above Secondary Limit (0.05 mg/L)	Found at 11 locations
Mercury (Hg)		No	Found at isolated locations
Nickel (Ni)	No		
Selenium (Se)	No		
Silver (Ag)		No	Found at isolated locations
Thallium (Tl)		1 Location Above Primary Limit (0.002 mg/L)	Found at 11 locations
Zinc (ZN)		No	Found at 7 locations

April and May 2008 Groundwater Tests

In April and May 2008, 89 samples were drawn from 81 homes in the region and were tested for the presence of the following ten elements.

- Primary contaminants: arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), selenium (Se)
- Secondary contaminants: silver (Ag)
- Other unregulated elements: boron (B), vanadium (V)

Test results reflect the following:

Constituent	Detected	Above Regulatory Limit	Comments
Arsenic (As)	No		
Barium (Ba)		No	Found at 53 locations. Compared with the baseline data, the higher detectible rate was likely due to the lower detectible limit of the current test method.
Boron (B)		3 Locations Above World Health Organization (WHO) recommended limit (0.50 mg/L)	Found at nearly all the tested homes
Cadmium (Cd)		No	Found at 12 locations
Chromium (Cr)		No	Found at 1 location
Lead (Pb)		3 Locations Above "Action Level" (0.015 mg/L)	Found at 37 locations
Mercury (Hg)	No		
Selenium (Se)	No		
Silver (Ag)	No		
Vanadium (V)	No		
Zinc (Zn)		No	Found at 7 locations

July 2008 Groundwater Tests

In July 2008, the City retested the 24 homes along Murray Drive and Whittamore Road. Besides the ten elements originally tested in April 2008, four new elements were added in this round of tests. They were cobalt (Co), nickel (Ni), zinc (Zn) and manganese (Mn). Of these, manganese (Mn) and zinc (Zn) are regulated as secondary contaminants. Nickel (Ni), zinc (Zn) and manganese (Mn) were the elements in the baseline test.

According to the City's documentation, test results reflect the following:

Constituent	Detected	Above Regulatory Limit	Comments
Arsenic (As)	No		
Barium (Ba)		No	Found at 9 locations
Boron (B)		2 Locations Above World Health Organization (WHO) recommended limit (0.50 mg/L)	Found at all the tested locations
Cadmium (Cd)	No		
Chromium (Cr)	No		
Cobalt (Co)	No		
Lead (Pb)		1 Location Above "Action Level" (0.015 mg/L)	Found at 5 locations
Manganese (Mn)		At least 7 Secondary Limit (0.05 mg/L)	Found at 15 locations
Mercury (Hg)	No		
Nickel (Ni)	No		
Selenium (Se)		No	Found at 3 locations
Silver (Ag)	No		
Vanadium (V)	No		
Zinc (Zn)		No	Found at 10 locations

Based on the analysis on the past water quality tests, the existing water supply wells in the region have naturally high levels of iron and manganese, both of which are regulated as "secondary" contaminants. Approximately 40% of the wells exceed the secondary limit for iron, and 30% exceed the secondary limit for manganese. The elevated iron and manganese level were also observed by the local residents on the homeowner questionnaire. Boron was detected in local groundwater supply during the 2008 tests. The most recent test shows approximately 10% of the 24 tested wells had a boron level above the WHO recommended limit.

December 2008 Well Water Quality Data

Following the contact of selected homeowners by URS, water samples were collected on December 23, 2008 from two residences on Murray Drive:

- Sample A (Yorktown-Eastover aquifer well – 80 ft deep, screened from 67ft – 80ft)
- Sample B (Surficial aquifer well – 50 ft deep, screened from 40ft – 50 ft)

The results of the analytical tests are included in Appendix F. In summary, the water quality meets the primary drinking water regulations at both locations. However, the shallower well on Murray Drive exceeded the secondary drinking water criteria for iron, manganese, and aluminum, while the deeper well on Murray Drive met all primary and secondary drinking water criteria.

3.5 Background Well Water Quality Data

The aquifer water quality data was obtained from DEQ and has been evaluated to determine the appropriate aquifer to be utilized as the community potable water supply.

This data comes from a set of observation wells (Fentress Test Wells) installed approximately 2.5 miles to the east/northeast of the project area as illustrated in Figure 2. The information for 12 observation wells is summarized in Table 1.

Table 1 DEQ Observation Wells Summary

Well Name	Screen Interval (Elev MSL)	Aquifer
91-A / 61B 2	-77 to -82	Yorktown Eastover
91-B / 61B 5	-1,025 to -1,045	Potomac (top)
91-C / 61B 6	-745 to -765	Peedee
91-D / 61B 7	- 2 to -7	Surficial/Columbia
91-E / 61B 12	-1,806 to -1,816	Potomac
91-F / 61B 13	-1,365 to -1,365	Potomac
91-G / 61B 14	-1,078 to -1,088	Potomac (top)
91-H / 61B 15	-744 to -754	Peedee
91-J / 61B 16	-665 to -675	Aquia
91-K / 61B 17	-73 to -83	Yorktown Eastover
91-L / 61B 18	-42 to -52	Surficial/Columbia
91-M / 61B 19	5 to -5	Surficial/Columbia

Based on the screen interval data, three wells (91-D, -L and -M) are believed to be supplied by the Surficial aquifer. The water quality data for these wells is summarized in Table 2 along with the regulatory limits of the contaminants. Water in this uppermost aquifer appeared to have high levels of iron (Fe) and manganese (Mn), which exceeded the secondary drinking water standard. Two wells had a pH value of 5.7, which is also outside the secondary criteria range.

Table 2 Surficial Aquifer Water Quality

Parameter	Units	Secondary MCL	91-D	91-L	91-M
pH	std. units	6.5-8.5	5.7	6.5	5.7
HCO_3^-	mg/L		90	90	90
CO_3^{2-}	mg/L		0.0	0.0	0.0
Alkalinity	mg/L as $CaCO_3$		74	74	74
ANC	mg/L		64	116	62
Hardness	mg/L as $CaCO_3$		72	87	38
Ca^{2+}	mg/L		11.5	27.0	6.2
Mg^{2+}	mg/L		10.4	4.8	5.4
Na^+	mg/L		17.9	21.0	17.0
K^+	mg/L		1.1	3.3	1.1
Cl^-	mg/L	250	24.0	18.0	17.0
SO_4^{2-}	mg/L	250	12.0	11.0	15.0
SiO_2	mg/L		20.0	44.0	19.0
Fe_T	mg/L	0.30	12.0	5.0	13.0
Mn_T	mg/L	0.05	0.24	0.14	0.24
Al_T	mg/L	0.05- 0.20	0.020	0.020	0.020
TDS	mg/L	500	159	191	134
Specific Conductance	µS/cm		325	278	208
B – Boron*	mg/L		0.04	0.05	0.02

* Boron -WHO recommended limit of 0.5 mg/L.

There are two wells, 91-A and -K, with screen interval between -73 feet (MSL) and -83 feet (MSL). These wells are believed to be supplied by the Yorktown-Eastover aquifer. The water quality data, shown in Table 3, indicate high levels of hardness, chloride (Cl), iron (Fe) and total dissolved solids (TDS), and slightly elevated levels of boron (B). Water with a hardness of 250 mg/L (as $CaCO_3$) is usually considered as very hard. The levels of chloride, iron and TDS were above the secondary limits.

Table 3 Yorktown-Eastover Aquifer Water Quality

Parameter	Units	Secondary MCL	91-A	91-K
pH	std. units	6.5-8.5	7.4	7.3
HCO_3^-	mg/L		331	
CO_3^{2-}	mg/L		0	
Alkalinity	mg/L as $CaCO_3$		271	282
ANC	mg/L		291	276
Hardness	mg/L as $CaCO_3$		250	240
Ca^{2+}	mg/L		57.4	54.0
Mg^{2+}	mg/L		26.3	26.0
Na^+	mg/L		210	240
K^+	mg/L		22.8	21.0
Cl^-	mg/L	250	358	340
SO_4^{2-}	mg/L	250		20.0
SiO_2	mg/L		42.4	36.0
Fe_T	mg/L	0.30	5.00	1.00
Mn_T	mg/L	0.05	0.05	0.012
Al_T	mg/L	0.05 - 0.20	0.02	0.01
TDS	mg/L	500	1,070	905
Specific Conductance	µS/cm		1620	1620
B – Boron*	mg/L		0.47	0.32

* Boron -WHO recommended limit of 0.50 mg/L.

The DEQ data set also include two wells which advance deeply into the Upper Potomac aquifer with a screen interval between -1,025 feet (MSL) and -1,088 feet (MSL). The water quality in this aquifer shows decreases in both hardness and iron. However, significantly higher levels of chlorides and TDS in the Upper Potomac make the Yorktown-Eastover aquifer more appealing as a community potable water supply.

All background DEQ water quality summary information can be found in Appendix H.

3.6 Battlefield Golf Course Groundwater Quality

Kimley-Horn and Associates, Inc installed three monitoring wells at the Battlefield Golf Course on May 15, 2008. Groundwater samples were taken and tested in May, July and August 2008. Meanwhile, groundwater samples were also taken from three monitoring wells located outside of the golf course in July. All the test results are summarized in Appendix I.

Table 2A in Appendix I demonstrates the metal analysis for three onsite monitoring wells. Below is a list of the constituents exceeding the drinking water standards:

- Aluminum (Al) – average at approximately 56.0 mg/L (above the secondary limit of 0.20 mg/L)
- Arsenic (As) – average at approximately 0.053 mg/L (above the secondary limit of 0.010 mg/L)
- Chromium (Cr) – average at approximately 0.126 mg/L (slightly above the primary limit of 0.10 mg/L)
- Iron (Fe) – average at approximately 101.80 mg/L (above the secondary limit of 0.30 mg/L)
- Lead (Pb) – average at approximately 0.047 mg/L (above the "action level" of 0.015 mg/L)
- Manganese (Mn) – average at approximately 0.784 mg/L (above the secondary limit of 0.050 mg/L)

Table 2B in Appendix I summarizes the metal analysis for the three offsite monitoring wells. Except for one offsite monitoring well having a high level of beryllium (Be), the results indicate lower levels of constituents in the offsite groundwater samples than those from the golf course groundwater samples. However, the levels of aluminum, iron and manganese at all offsite locations and the level of lead at two offsite locations still exceeded the drinking water standards.

Table 3A in Appendix I shows that the groundwater samples taken from the golf course met the secondary drinking water criteria for the classical chemical parameters, chloride (Cl), fluoride (F), sulfate (SO_4), and total dissolved solids (TDS).