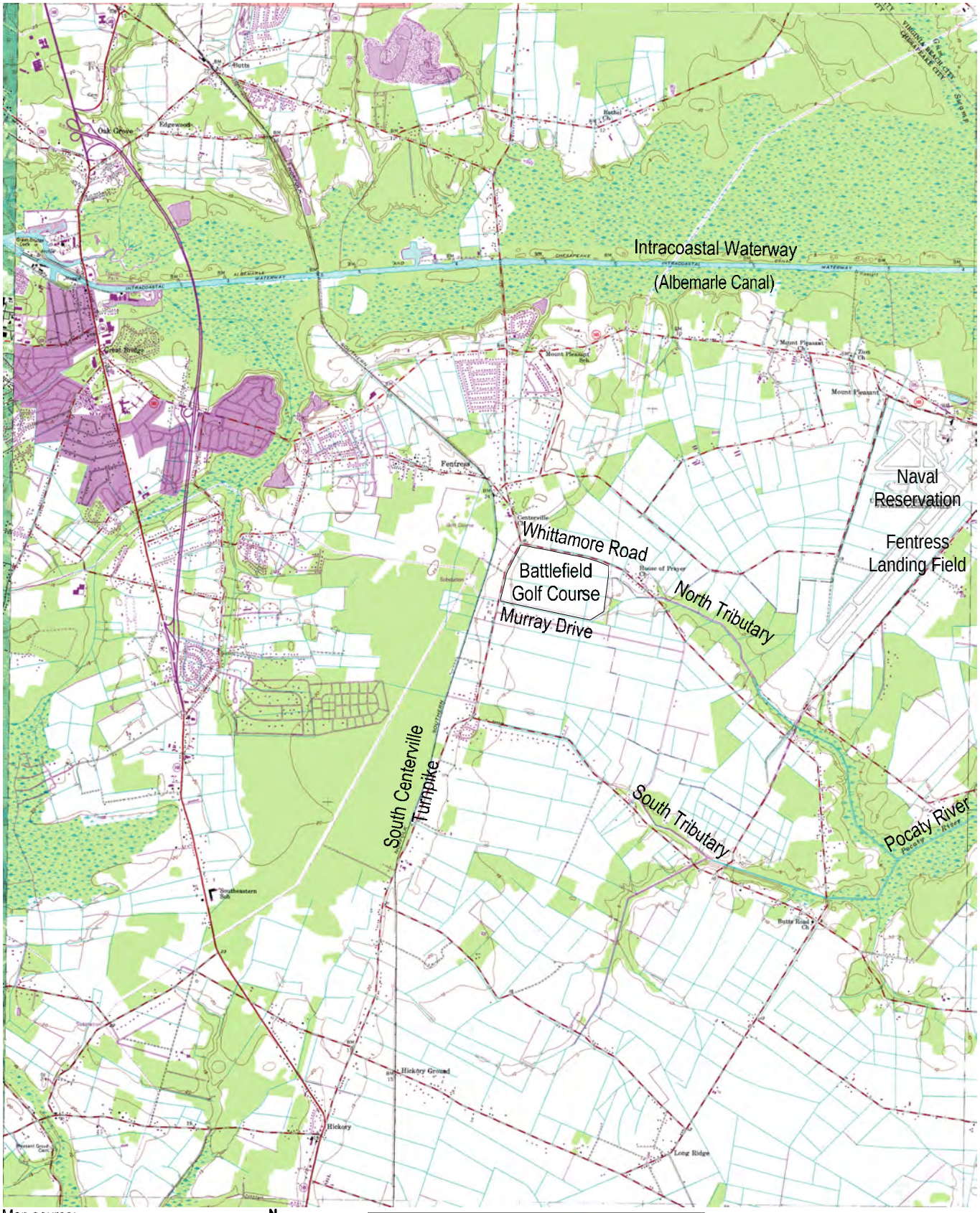
Figures

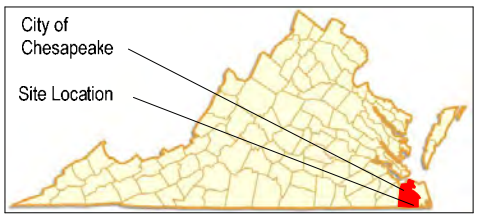


Map source:
Beartooth Mapping, Inc.,
10-16-03, Fentress (o36076f2).

N
W E
S

Scale in Miles

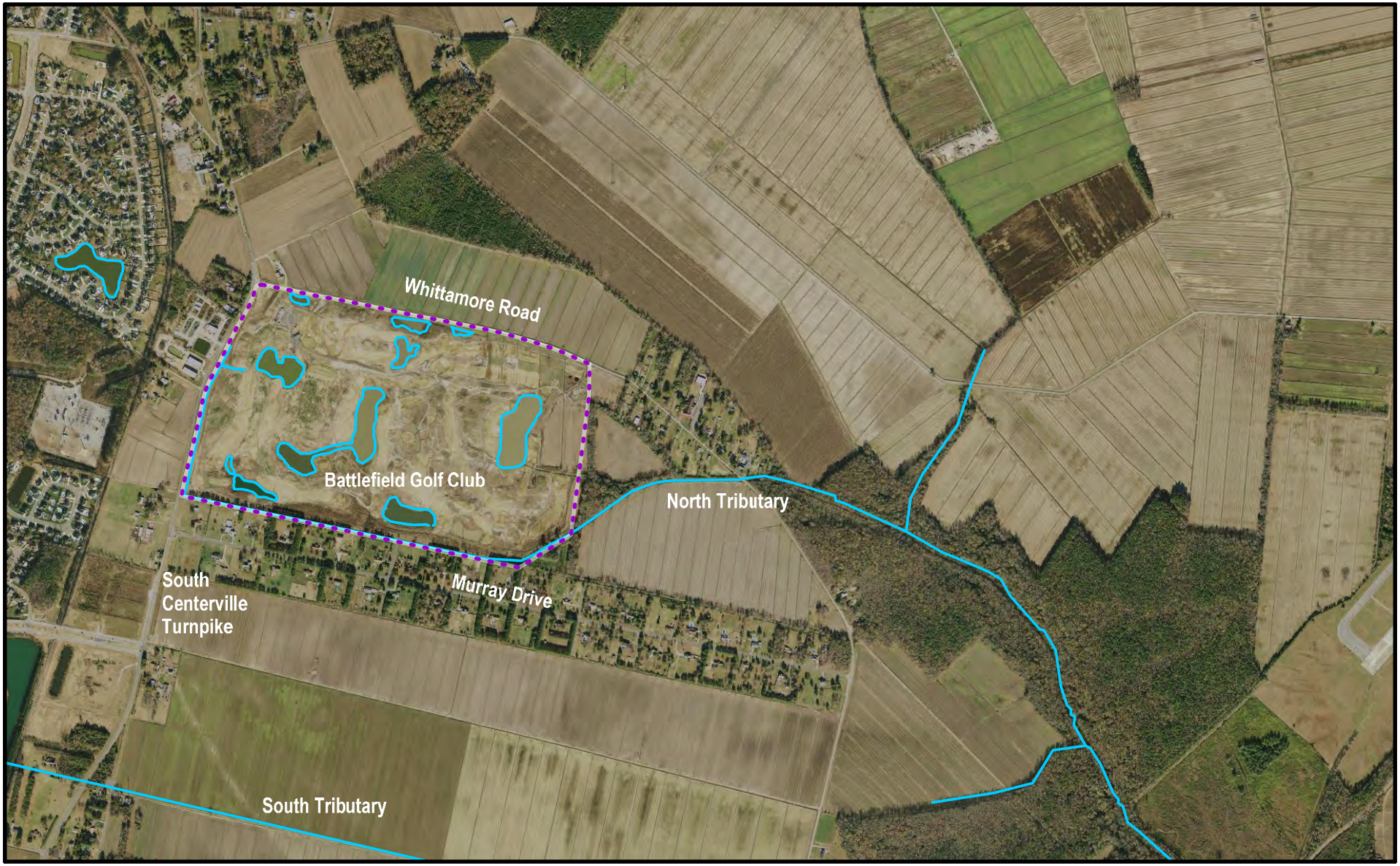
0 1



CDM

Figure 1-1
Site Location Map
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60059



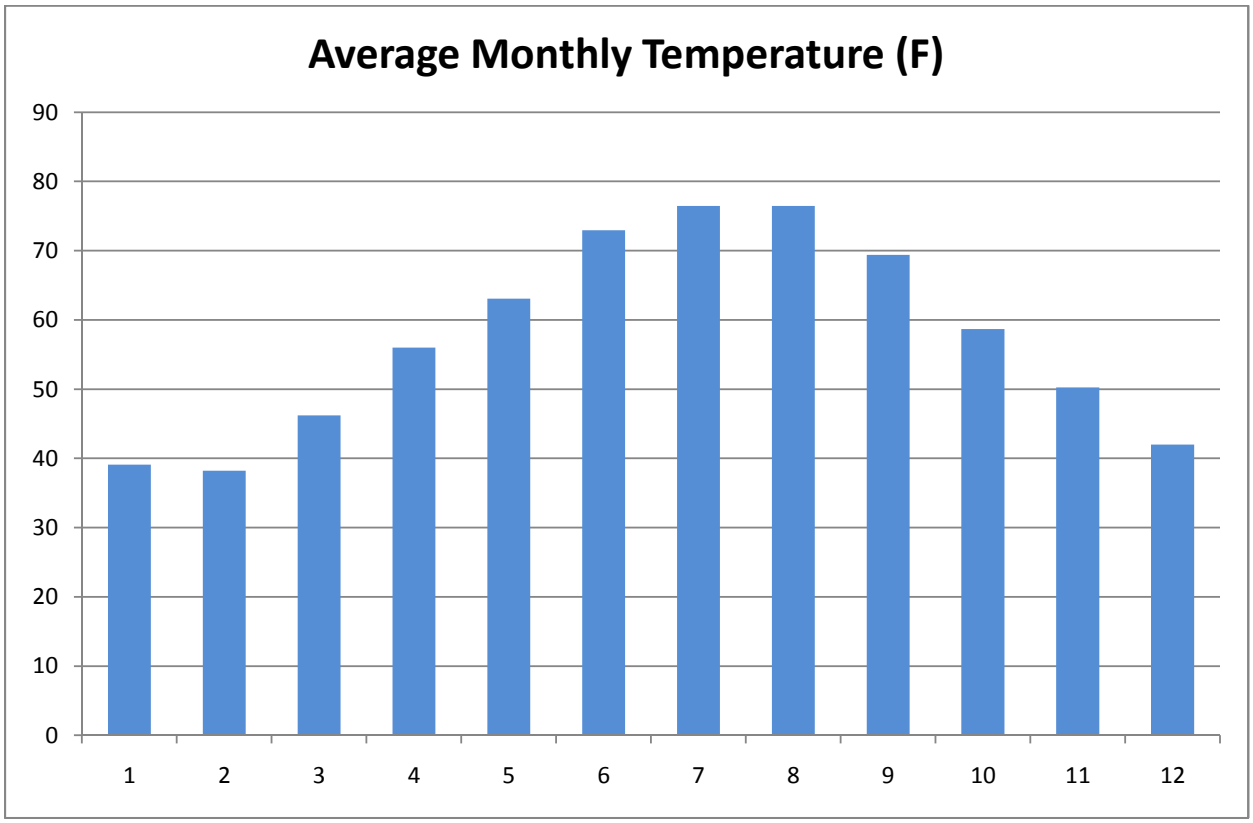
Base Map: TerraServer
Date: January 1, 2009

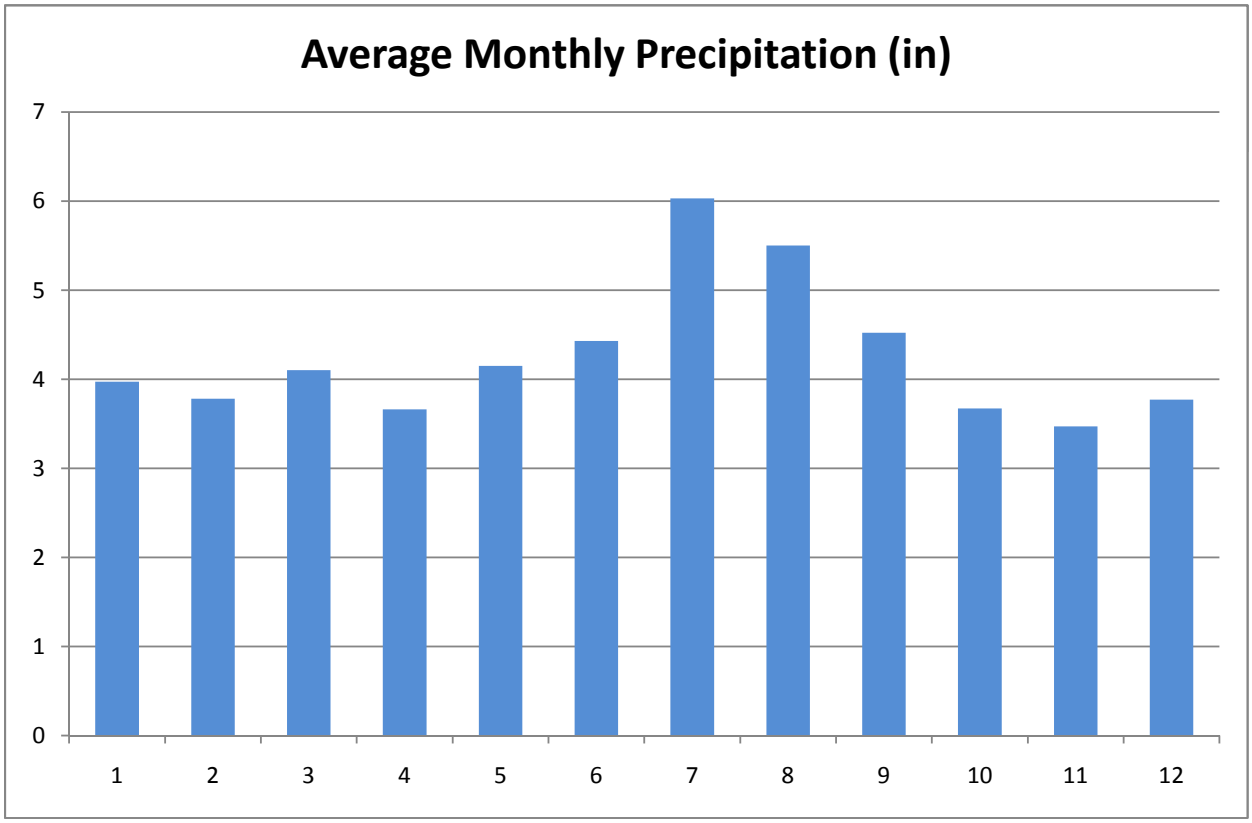
Scale in Feet
0 1400 2800 4200 5600

N
W E
S

CDM

Figure 1-2
Site Vicinity Map
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60060





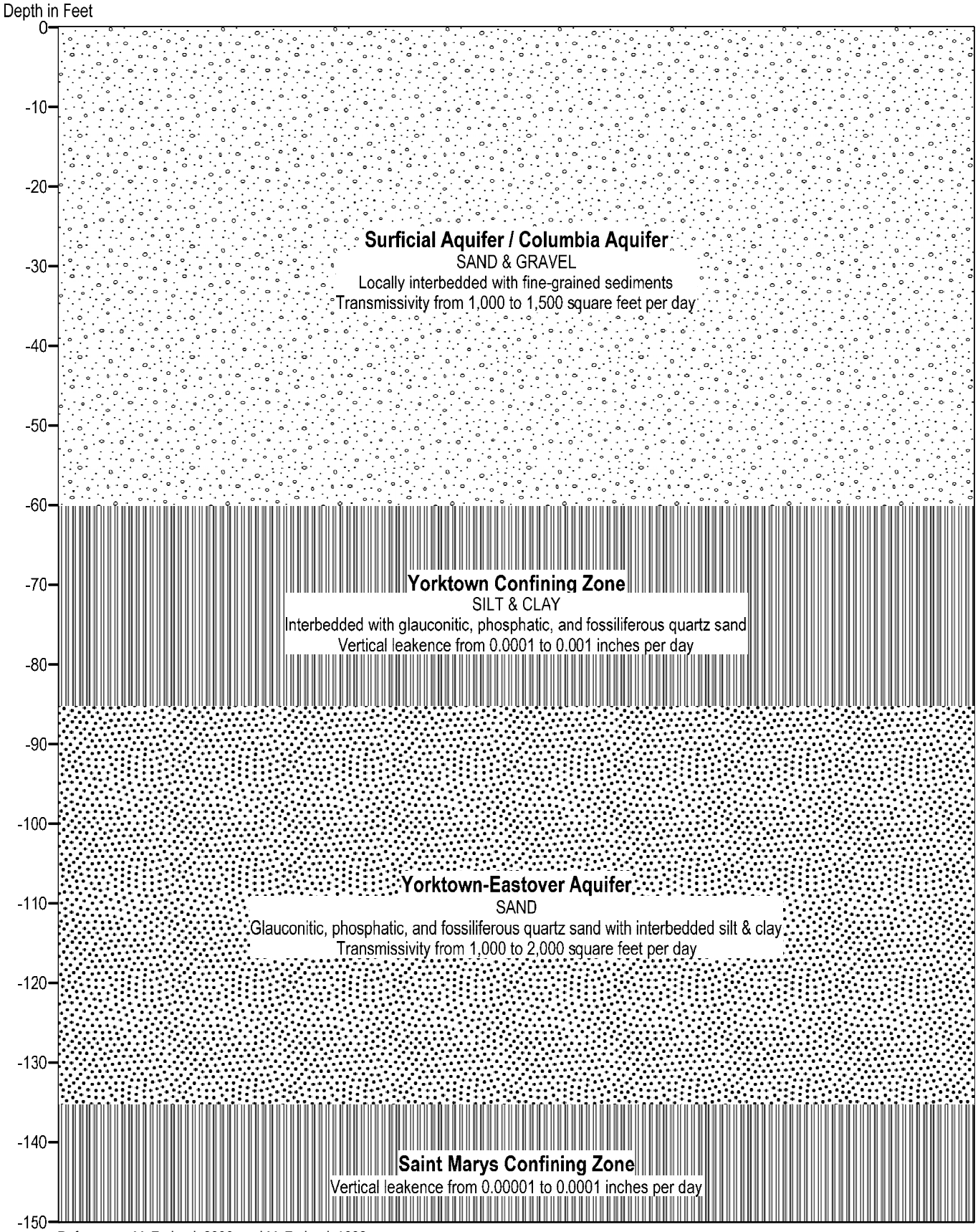
The Southeast Regional Climate Center, Historical Climate Summaries for Virginia, Wallaceton Lake Drummond, Virginia, http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?va8837, July 31, 2010.

Figure 1-3: Climate Data

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

CDM

60061

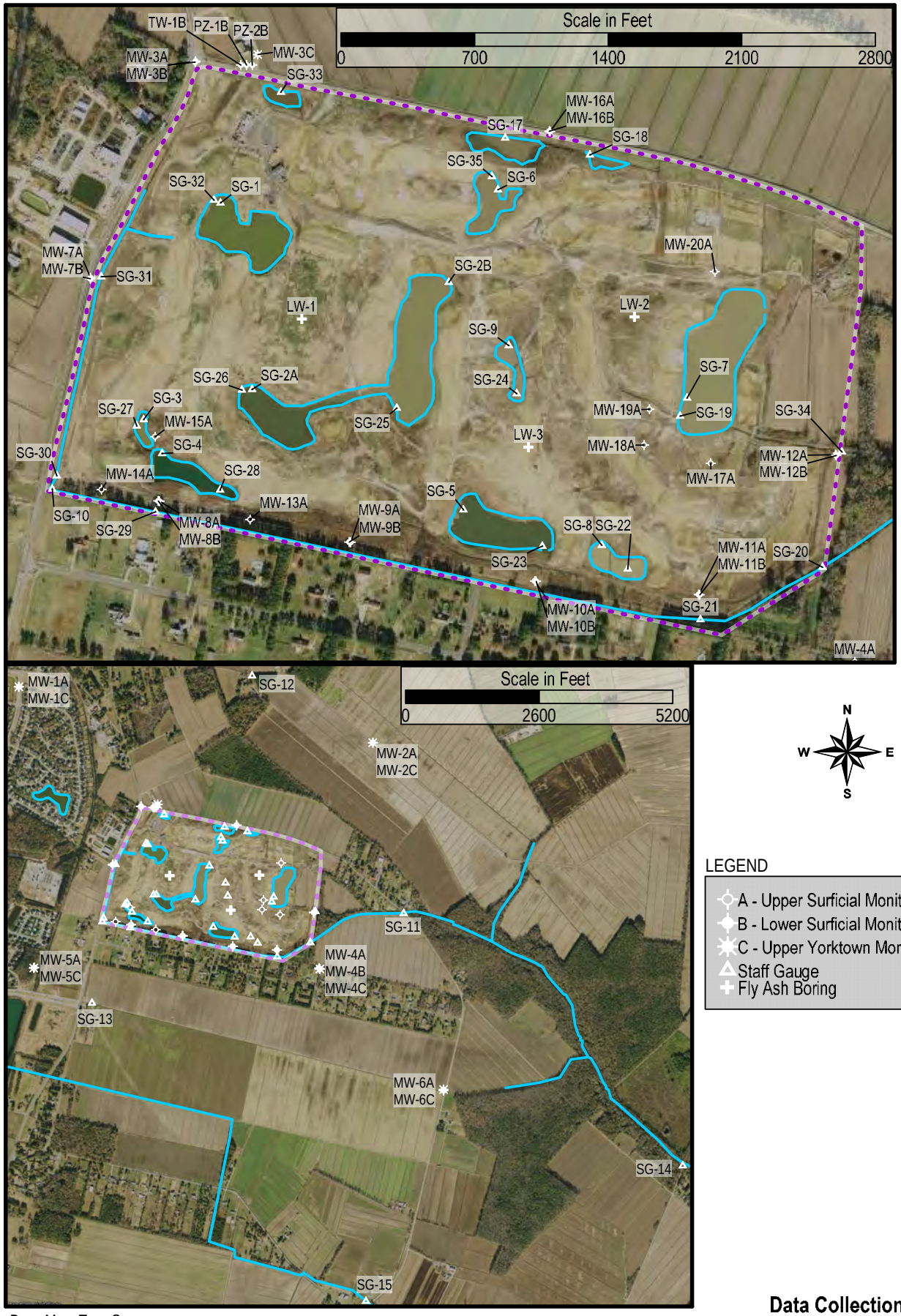


References: McFarland, 2006, and McFarland, 1998.

Figure 1-4
Generalized Hydrogeologic Section
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

CDM

60062



Base Map: TerraServer
Date: January 1, 2009

CDM

Figure 1-5
Data Collection Locations
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60063

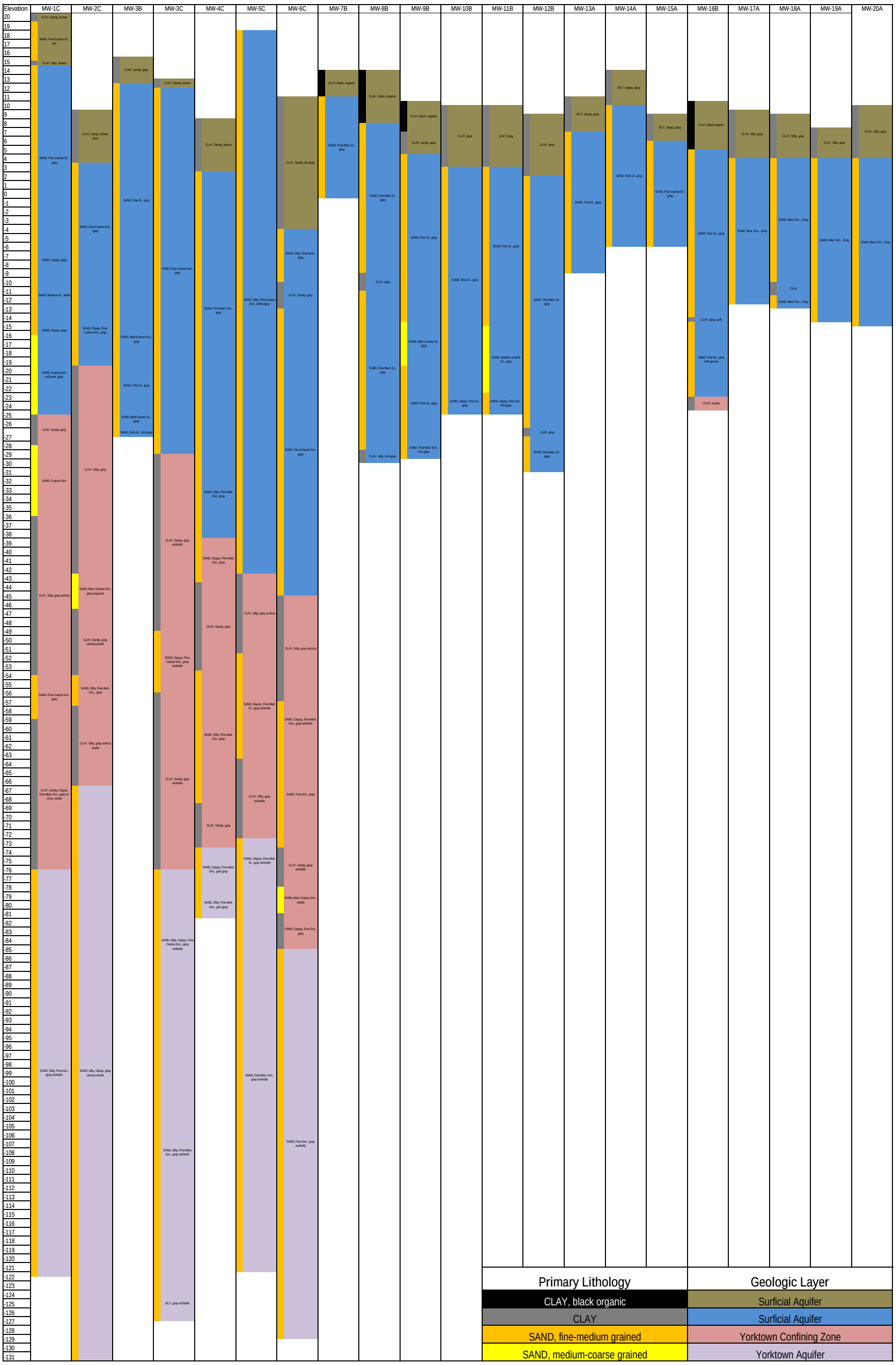


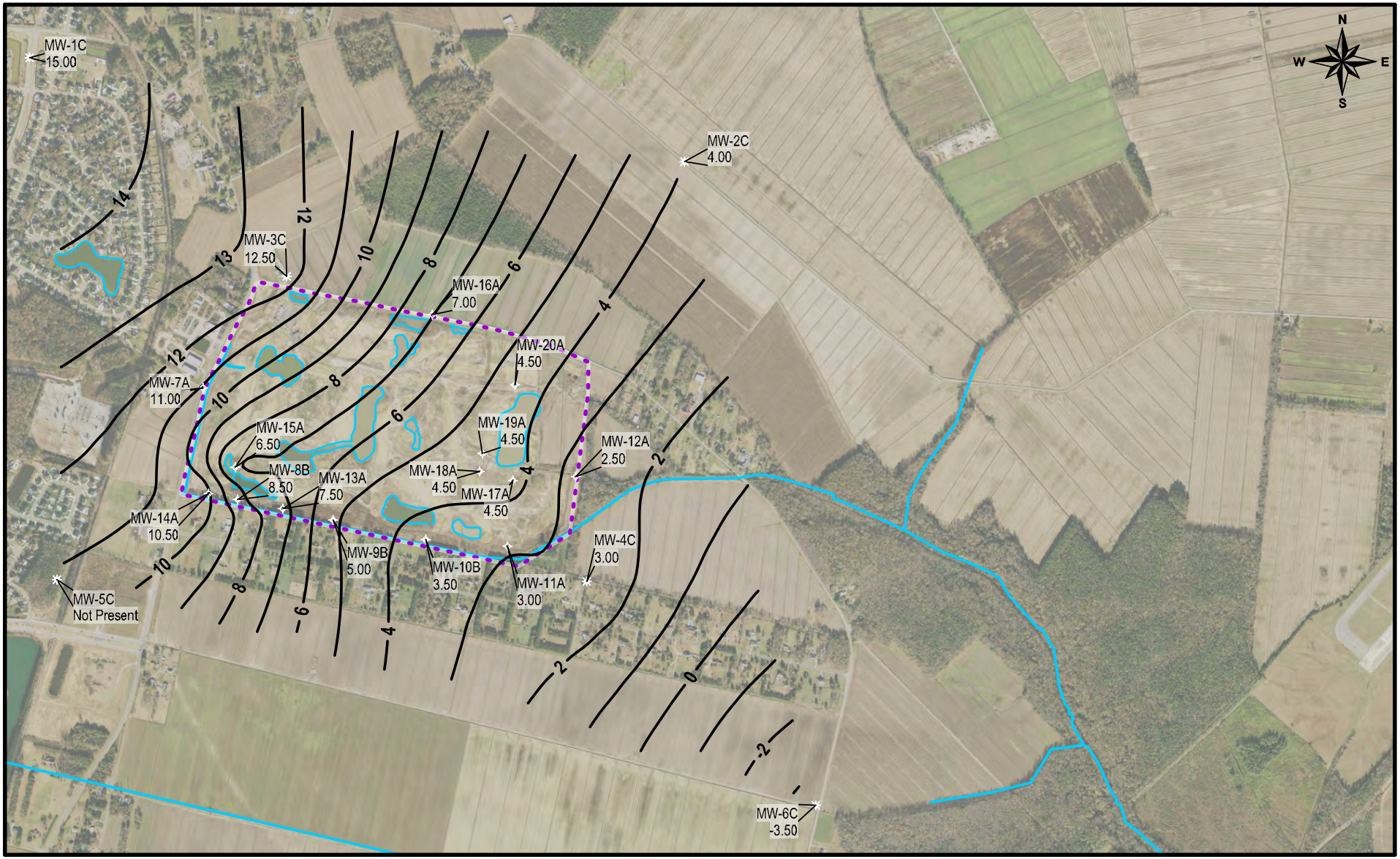
Figure 3-1: Boring Log Summary

Hydrogeologic Investigation and
Groundwater Modeling Report

Battlefield Golf Club

Chesapeake, Virginia

CDM



Base Map: TerraServer
Date: January 1, 2009

LEGEND

- A - Upper Surficial Monitoring Well
- B - Lower Surficial Monitoring Well
- C - Upper Yorktown Monitoring Well

Scale in Feet

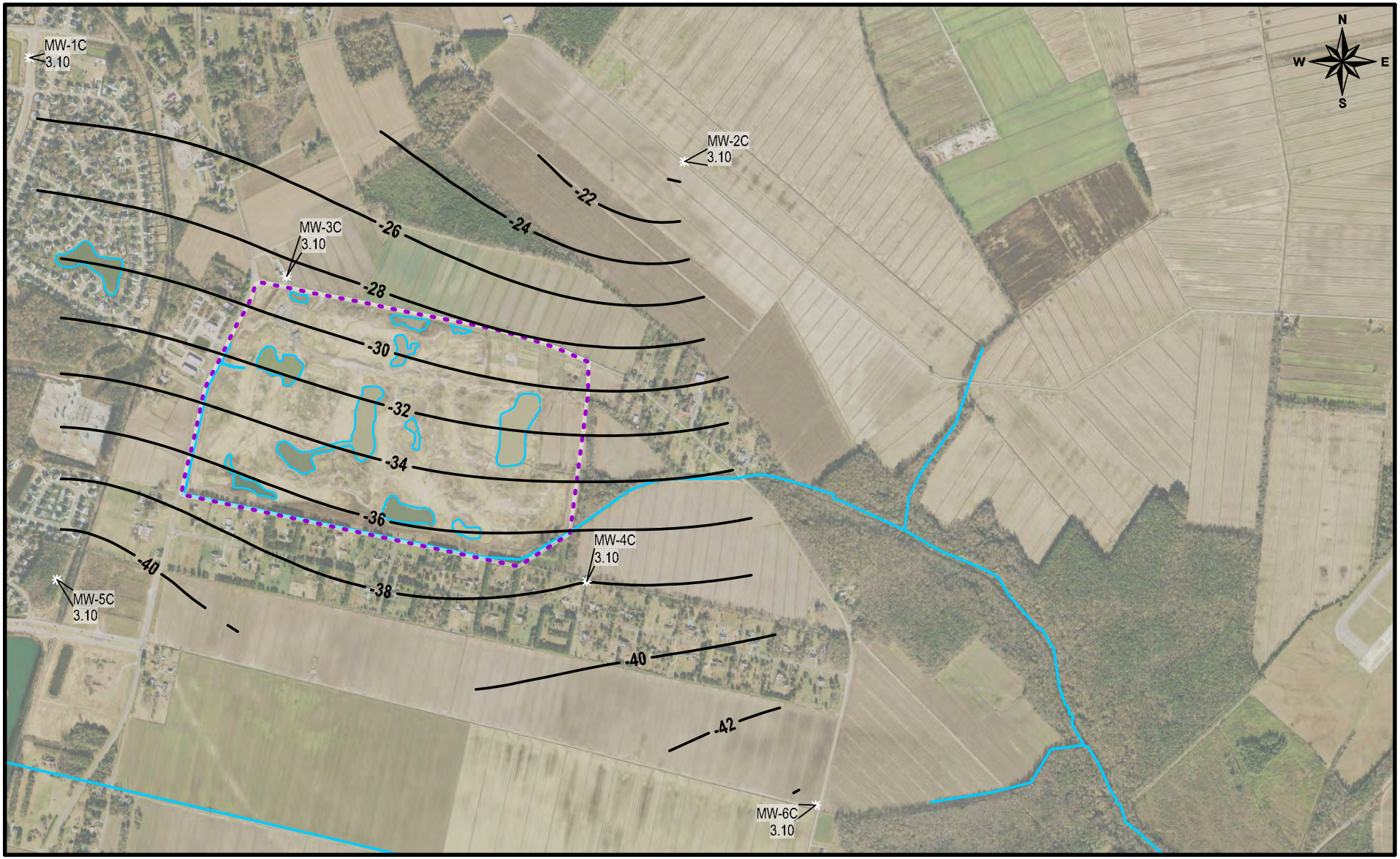
0 1400 2800 4200 5600

Structure contours drawn on the surface of the surficial aquifer sand zone are in feet NAVD88. Contour interval is 1 foot.

CDM

Figure 3-2: Surficial Aquifer Sand Zone Structure Contour Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60065



Base Map: TerraServer
Date: January 1, 2009

Scale in Feet

0 1400 2800 4200 5600

LEGEND

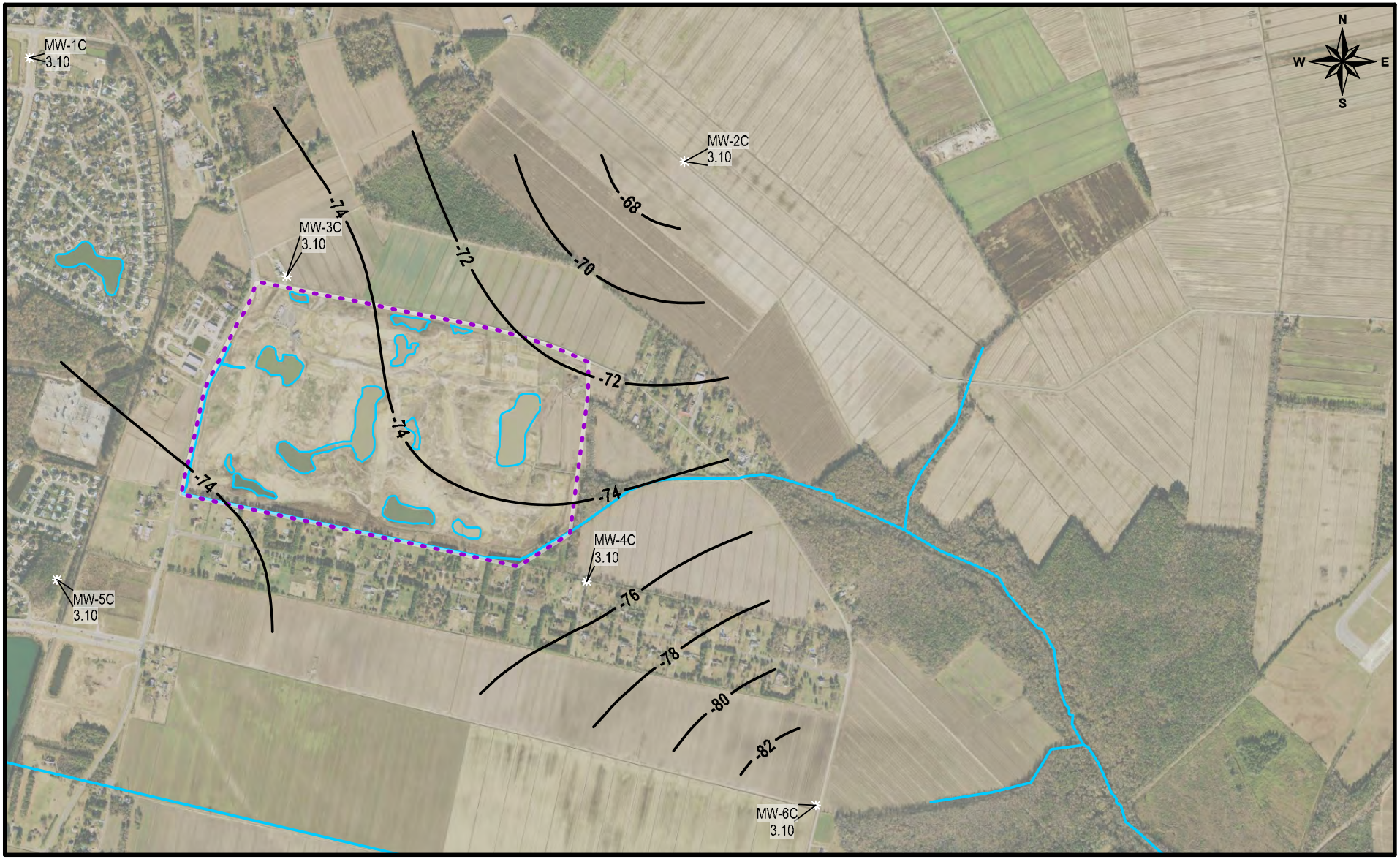
C - Upper Yorktown Monitoring Well

Structure contours drawn on the surface of the Yorktown confining zone are in feet NAVD88. Contour interval is 2 feet.

CDM

Figure 3-3: Yorktown Confining Zone Structure Contour Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60066



Base Map: TerraServer
Date: January 1, 2009

Scale in Feet

0 1400 2800 4200 5600

LEGEND

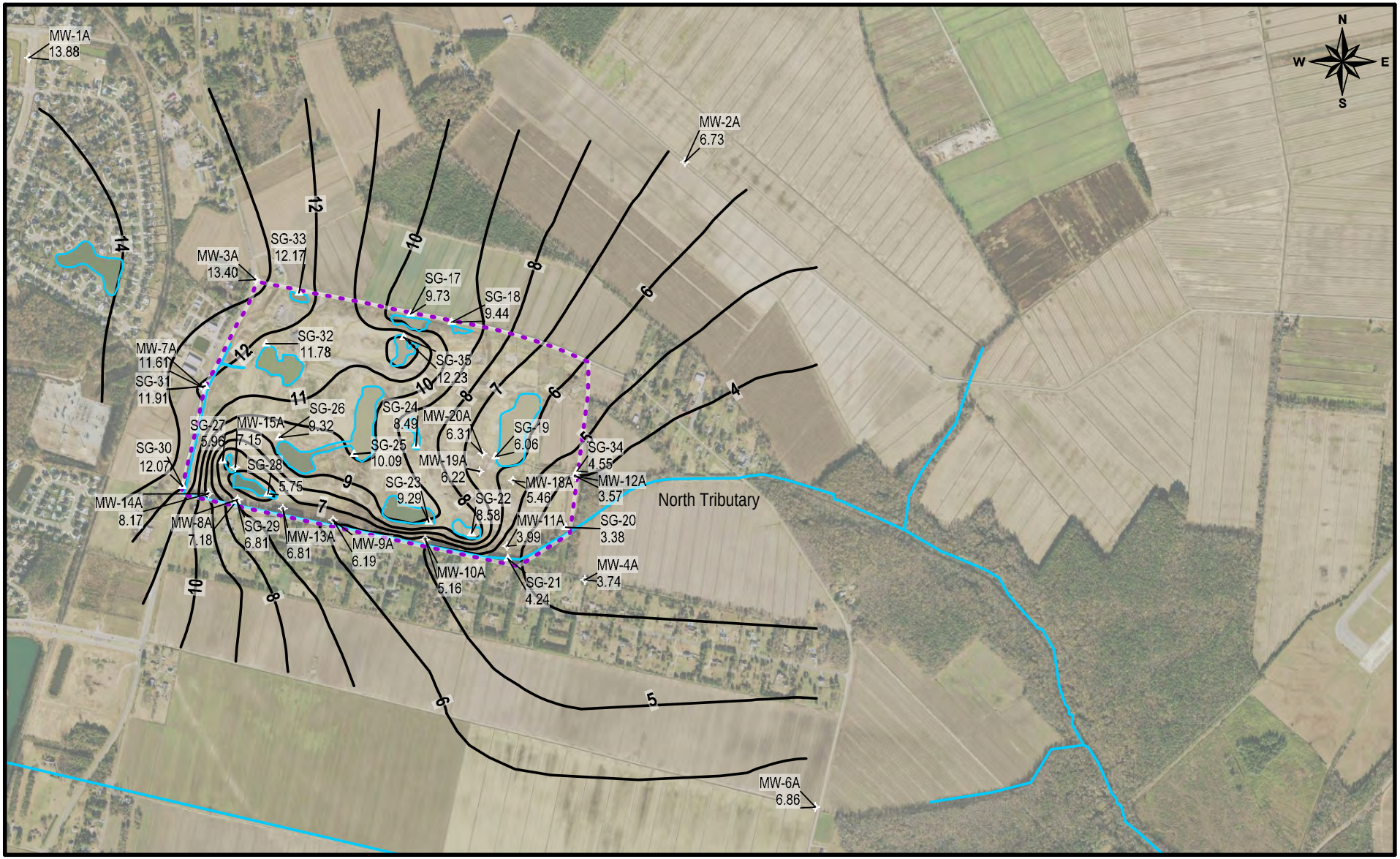
C - Upper Yorktown Monitoring Well

Structure contours drawn on the surface of the Yorktown aquifer are in feet NAVD88.
Contour interval is 2 feet.

CDM

Figure 3-4: Yorktown Aquifer Structure Contour Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60067



Base Map: TerraServer
Date: January 1, 2009

LEGEND

- A - Upper Surficial Monitoring Well
- Staff Gauge

Scale in Feet

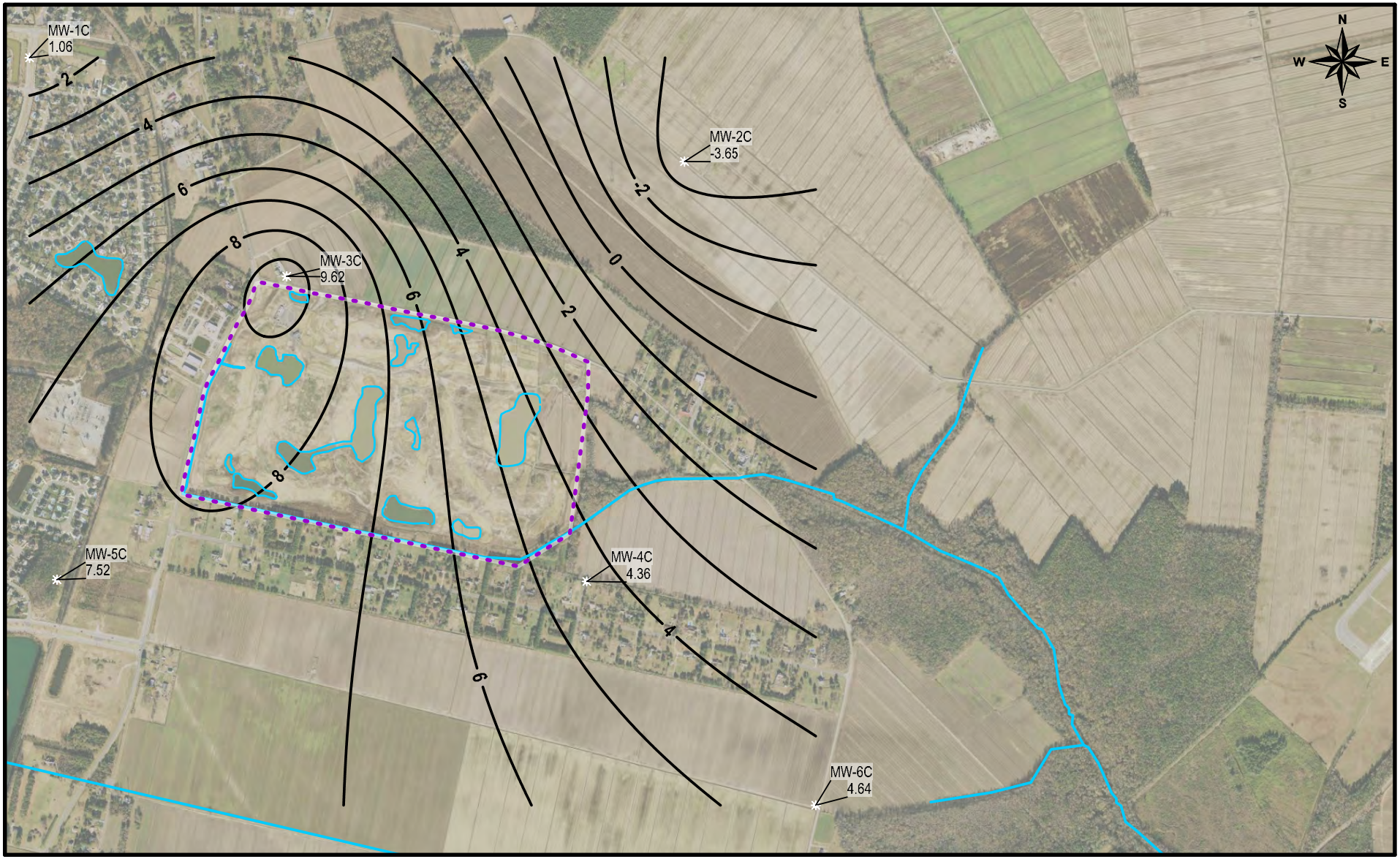
0 1400 2800 4200 5600

Potentiometric surface contours are in feet NAVD88.
Contour interval is 1 foot. Water levels from wells collected on 9/15/2009. Staff gauge levels estimated from previous dates.

CDM

Figure 3-5: Surficial Aquifer Potentiometric Surface Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60068



Base Map: TerraServer
Date: January 1, 2009

LEGEND

C - Yorktown Monitoring Well

Scale in Feet

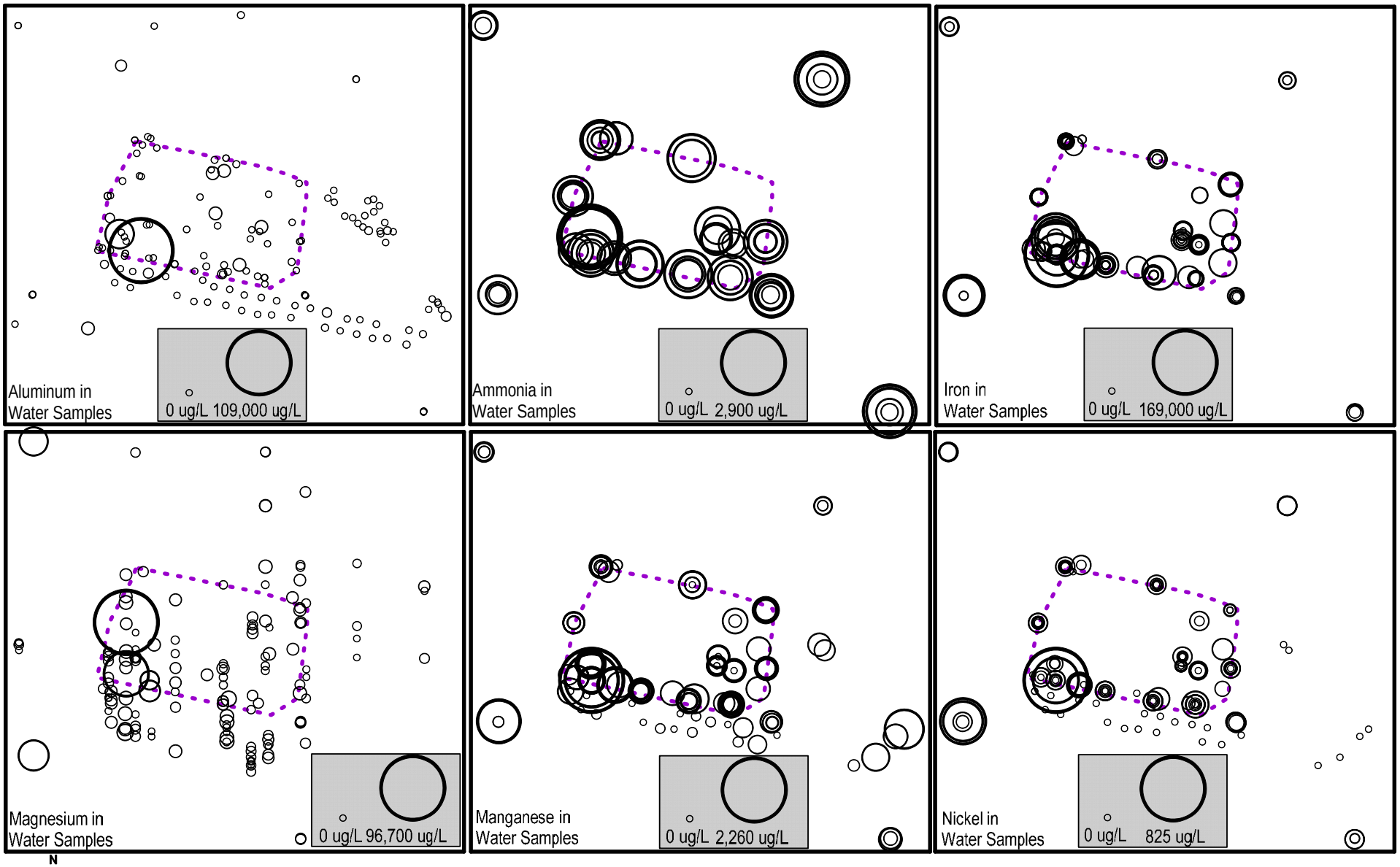
0 1400 2800 4200 5600

Potentiometric surface contours are in feet NAVD88.
Contour interval is 1 foot.
Water levels from wells collected on 9/15/2009.

CDM

Figure 3-6: Yorktown Aquifer Potentiometric Surface Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60069



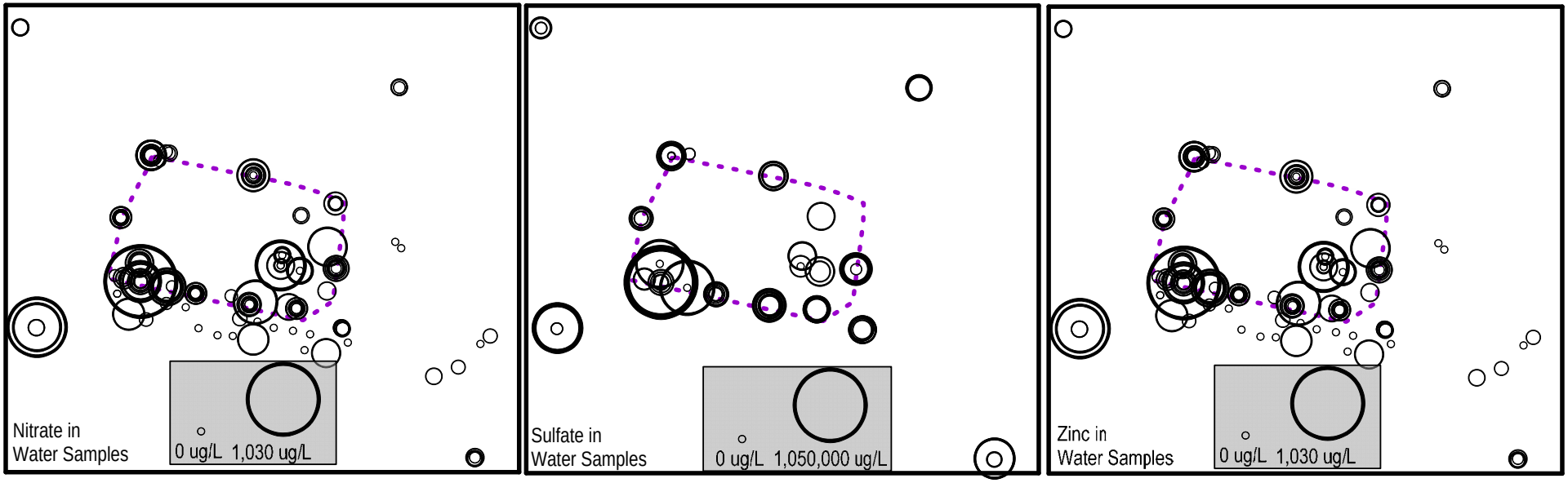
Scale in Feet

0 2000 4000 6000 8000

CDM

Figure 3-7: Constituent Distributions in Groundwater

Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60070



CDM

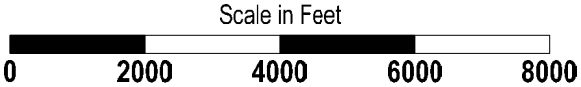


Figure 3-8: Constituent Distributions in Groundwater

Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60071

Legend

- Observation Point
- Pumped Well
- Site Boundary

Aquifer Performance Test, November 16-20, 2009
Base Map: TerraServer
Date: January 1, 2009

Figure 4-1
Aquifer Performance Test Well Locations
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

CDM

60072

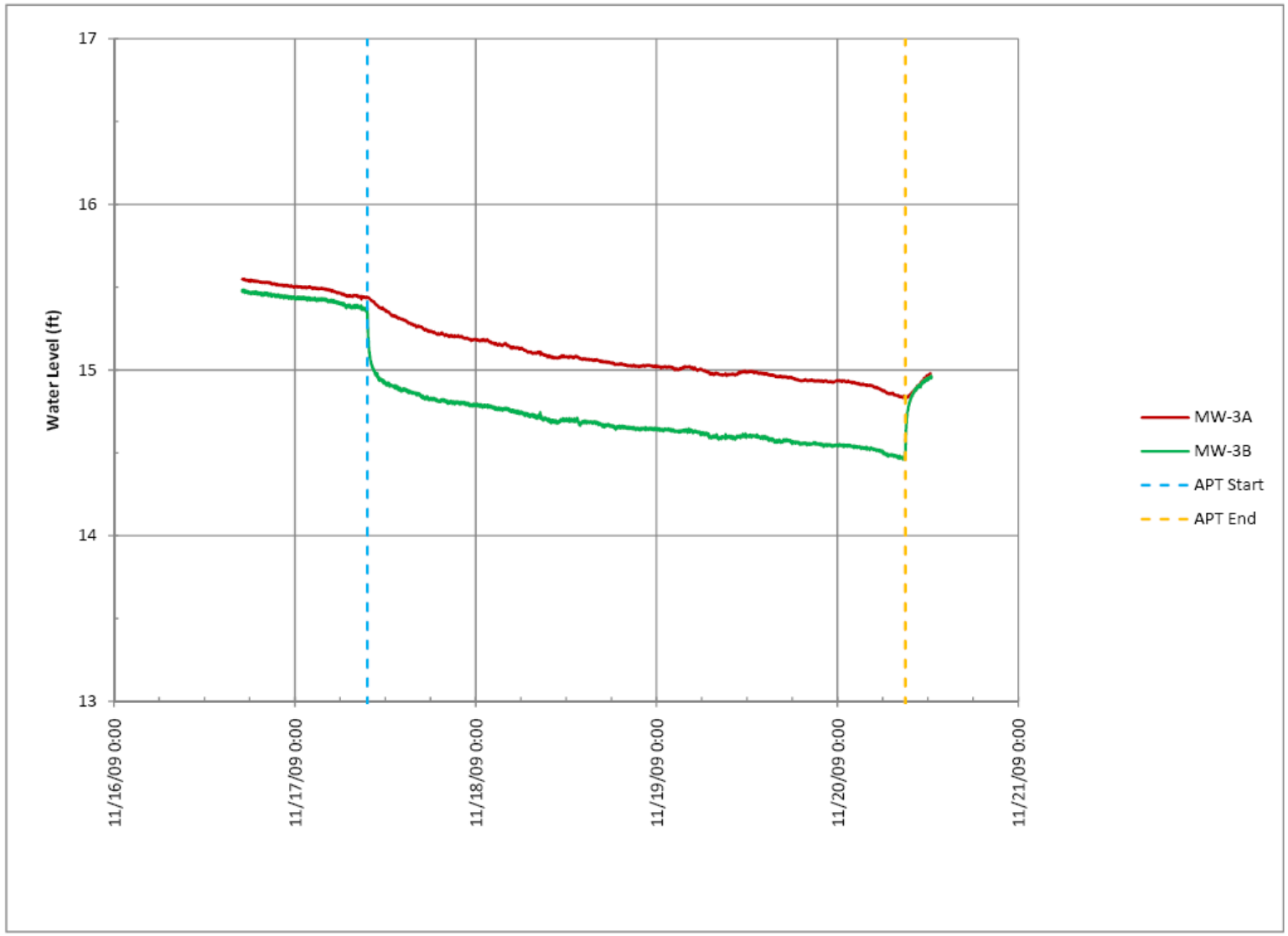


Figure 4-2
MW-3A/MW-3B Observed Water Levels
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60073

CDM

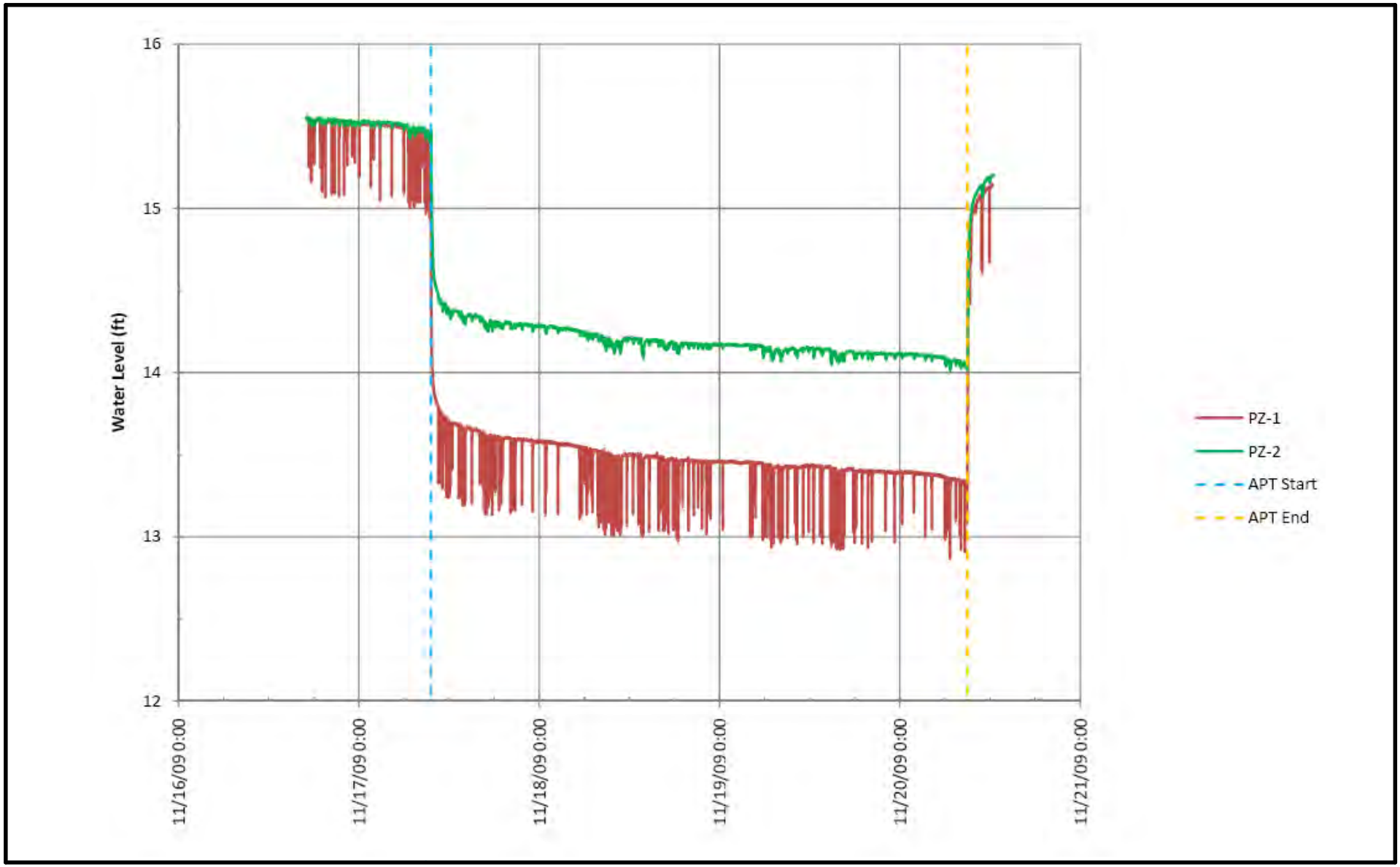


Figure 4-3
PZ-1/PZ-2 Observed Water Levels
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60074

CDM

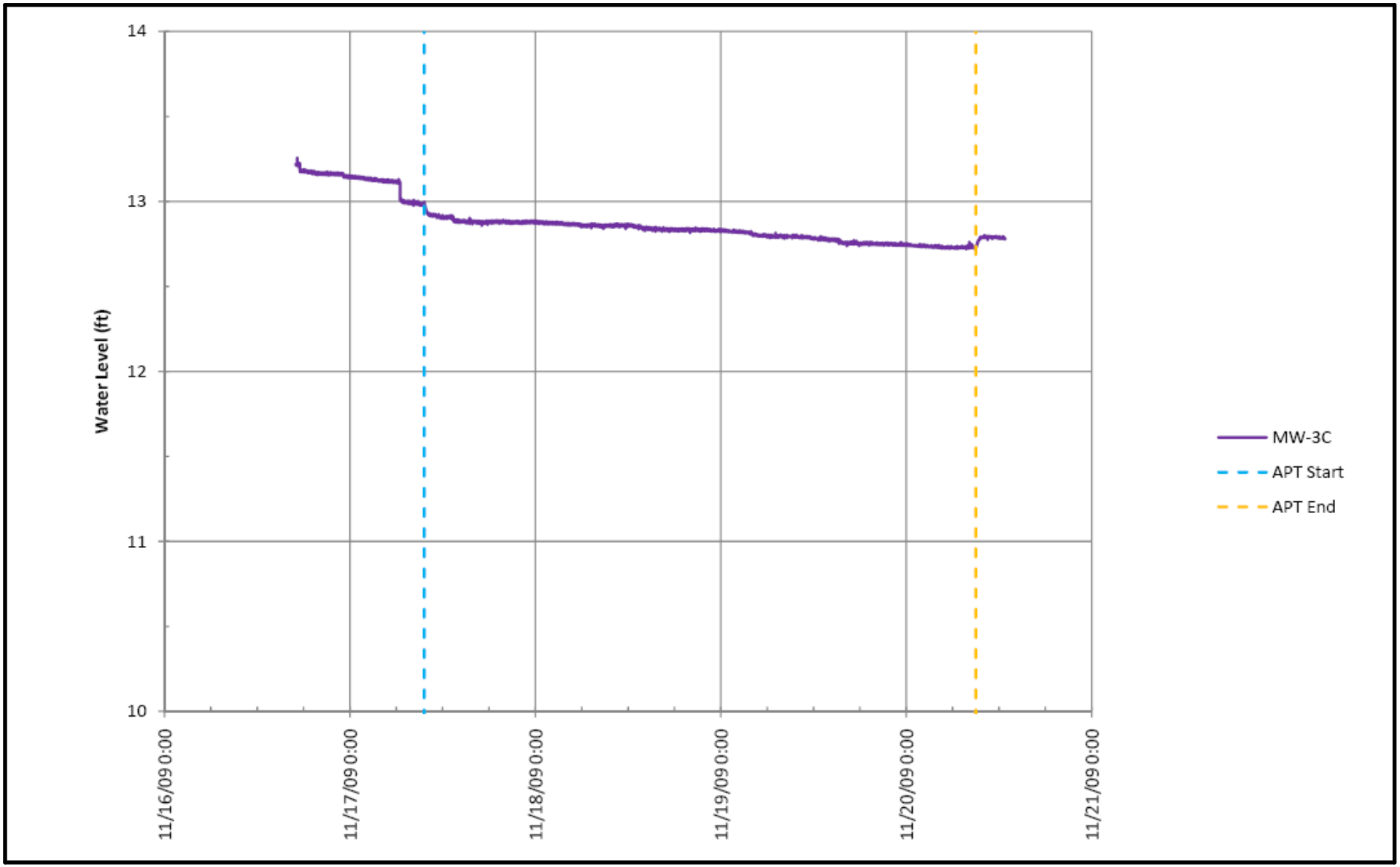


Figure 4-4
MW-3C Observed Water Levels
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60075

CDM

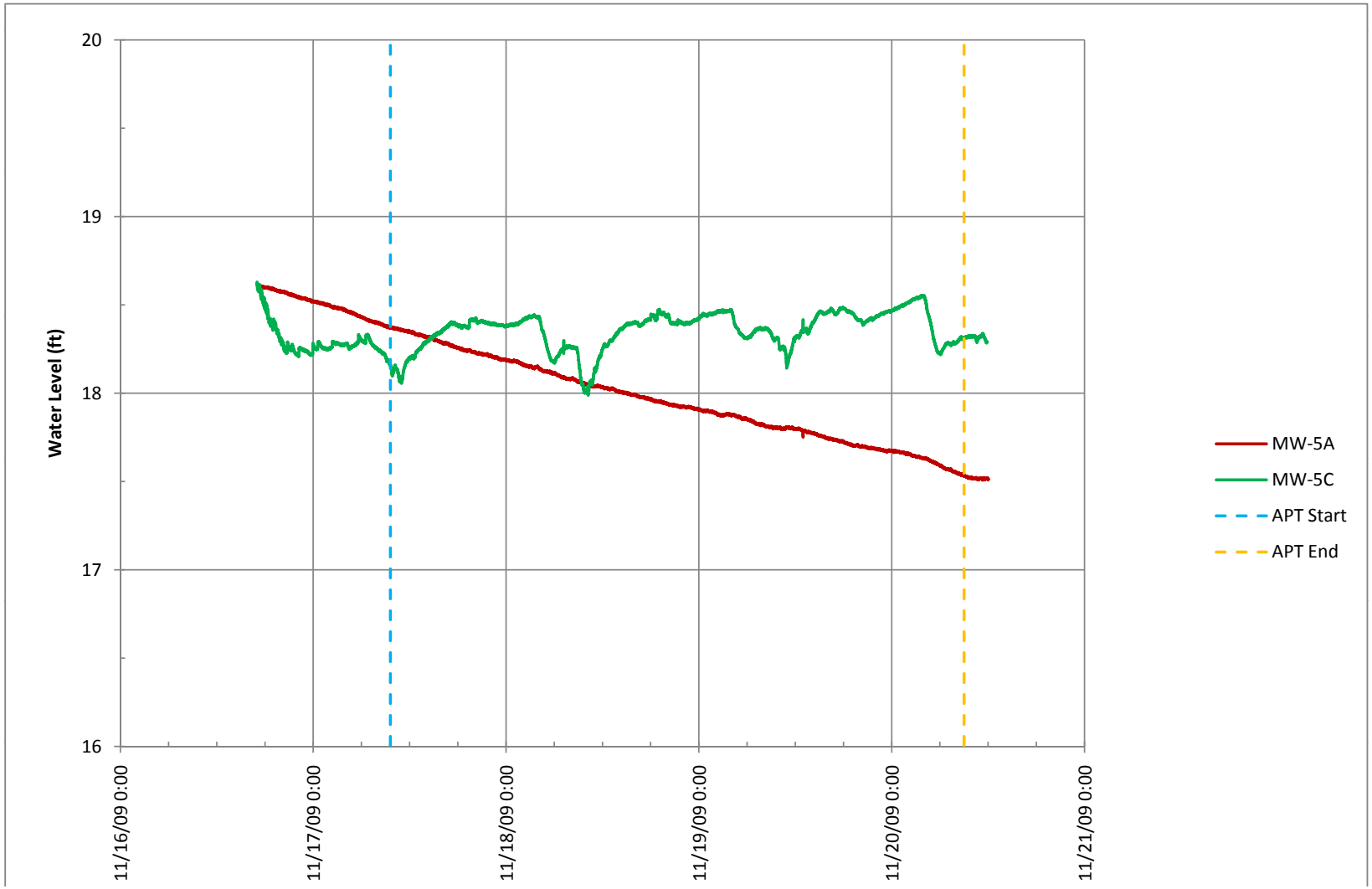


Figure 4-5
MW-5A/MW-5C Observed Water Levels
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60076

CDM

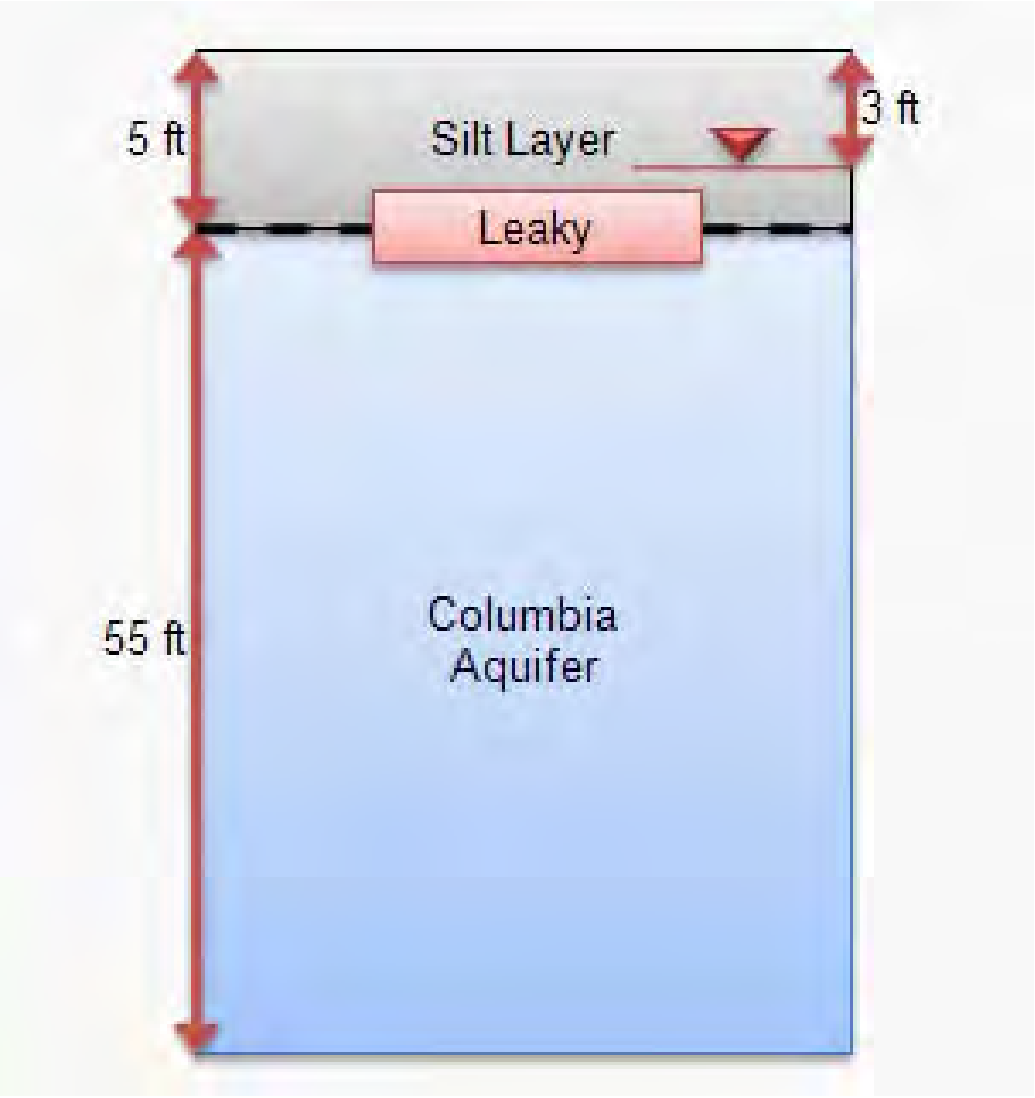


Figure 4-6
Aquifer System Cross-Section
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

CDM

60077

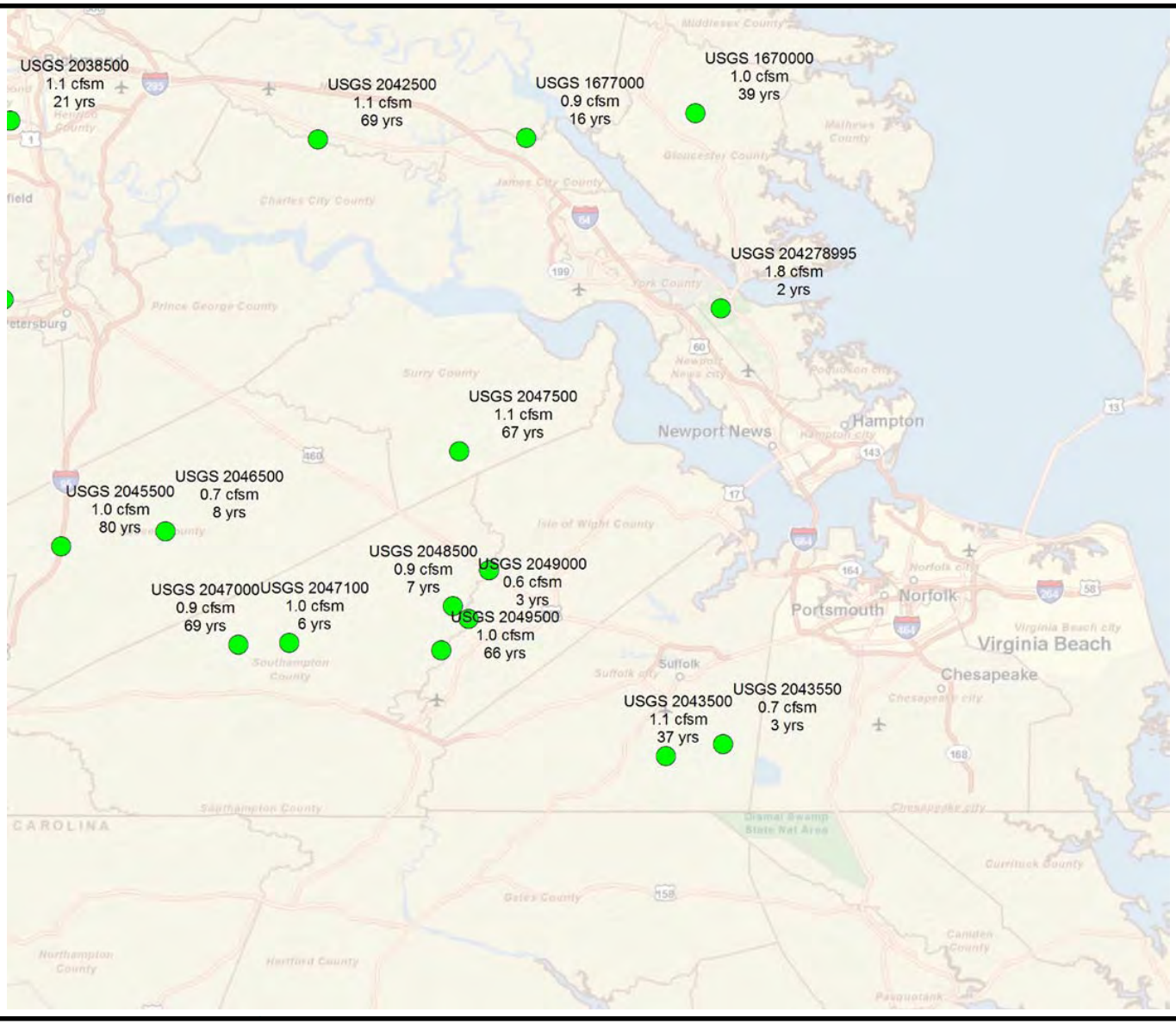
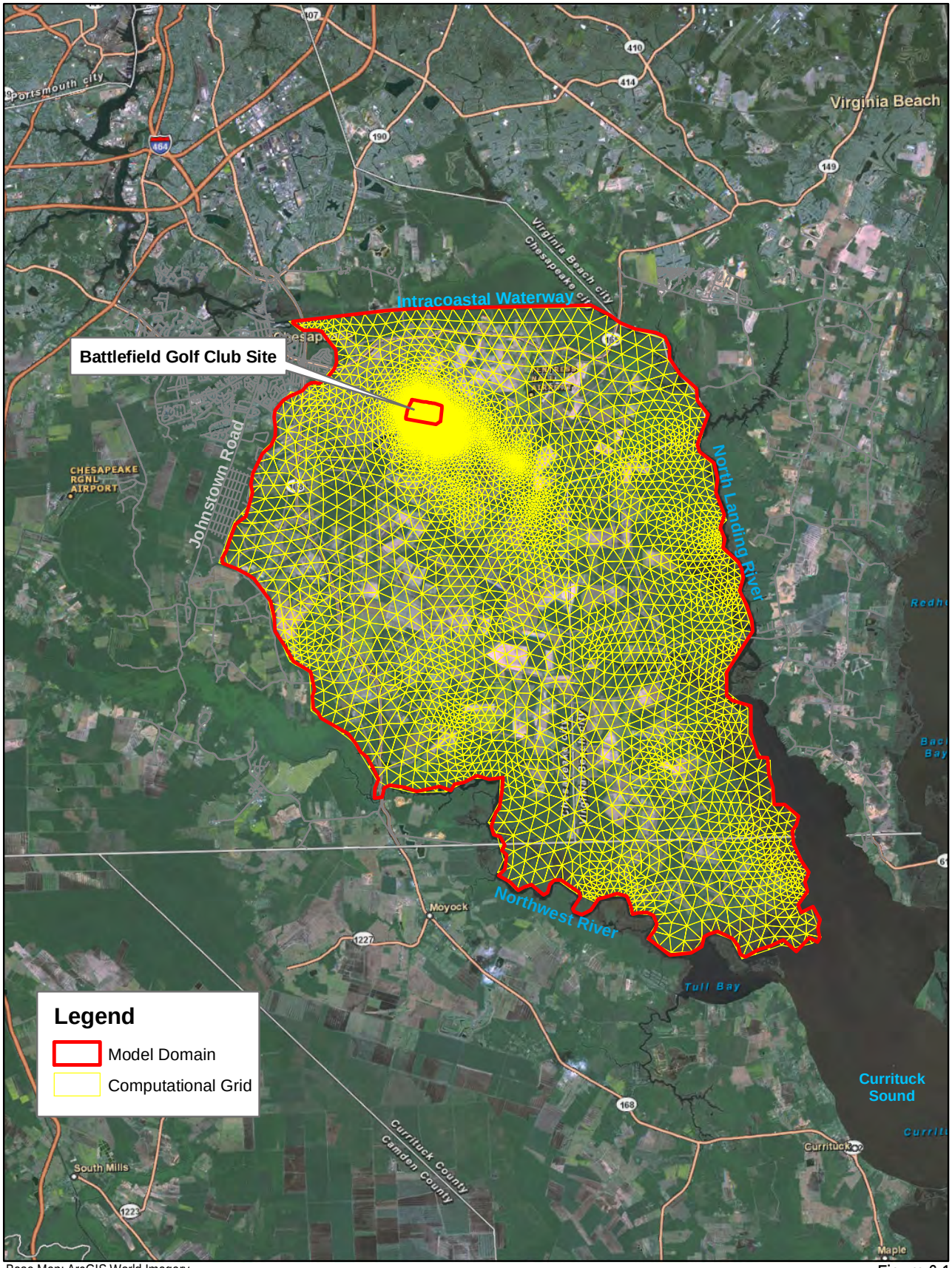


Figure 5-1
USGS Streamflow Gauge Average Streamflow Values
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60078

CDM



Base Map: ArcGIS World Imagery
Publication Date: June 2010

0 1.5 3 Miles

CDM

Figure 6-1
Model Domain and Computational Grid
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60079

Base Map: TerraServer
Date: January 1, 2009

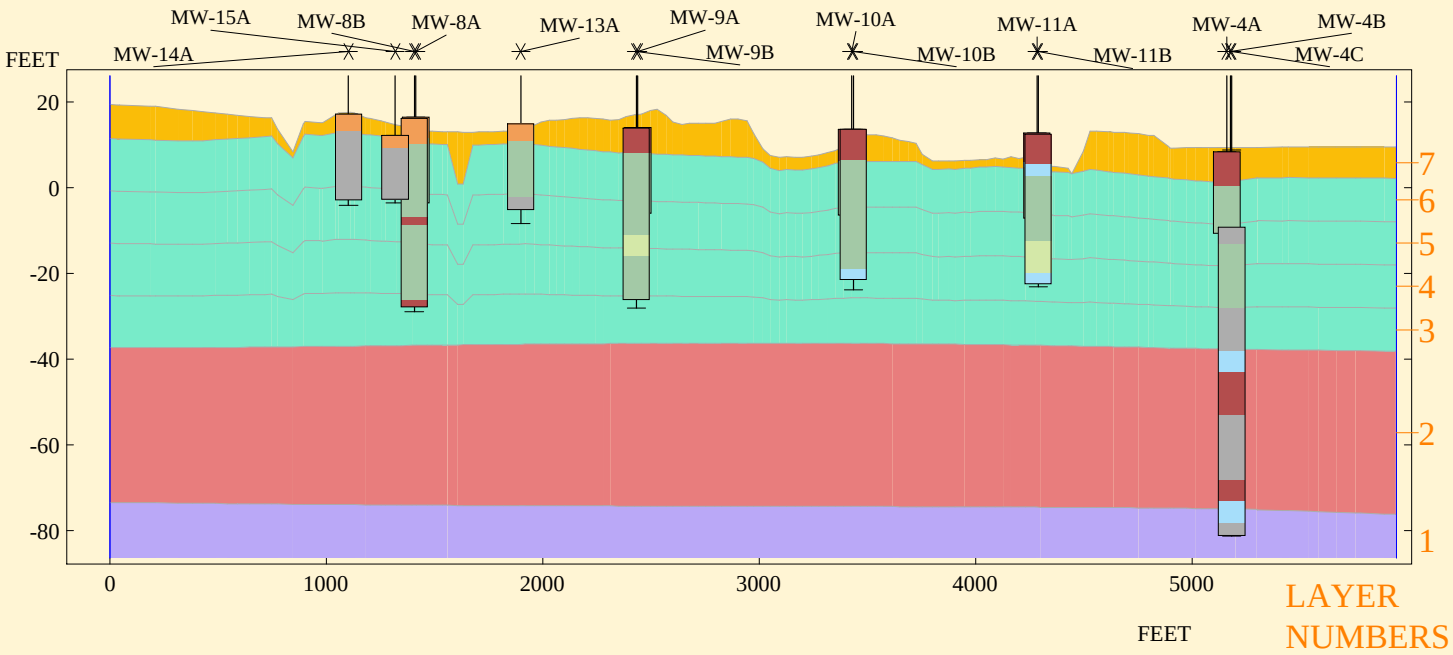
0 350 700 Feet

N
W E
S

CDM

Figure 6-2
On-Site Model Computational Grid
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60080



MATERIALS CROSS-SECTION AA

- Surficial Silt-Clay
- Surficial Aquifer
- Yorktown Aquitard
- Yorktown-Eastover Aquifer

WELL LOG LEGEND

- SW
- CH
- ML
- SC
- SM
- SP
- CL

- Monitoring
- LAND SURFACE
- TOP OF SCREEN
- BOTTOM OF SCREEN

PROJECTED 500 FT

CROSS SECTION AA

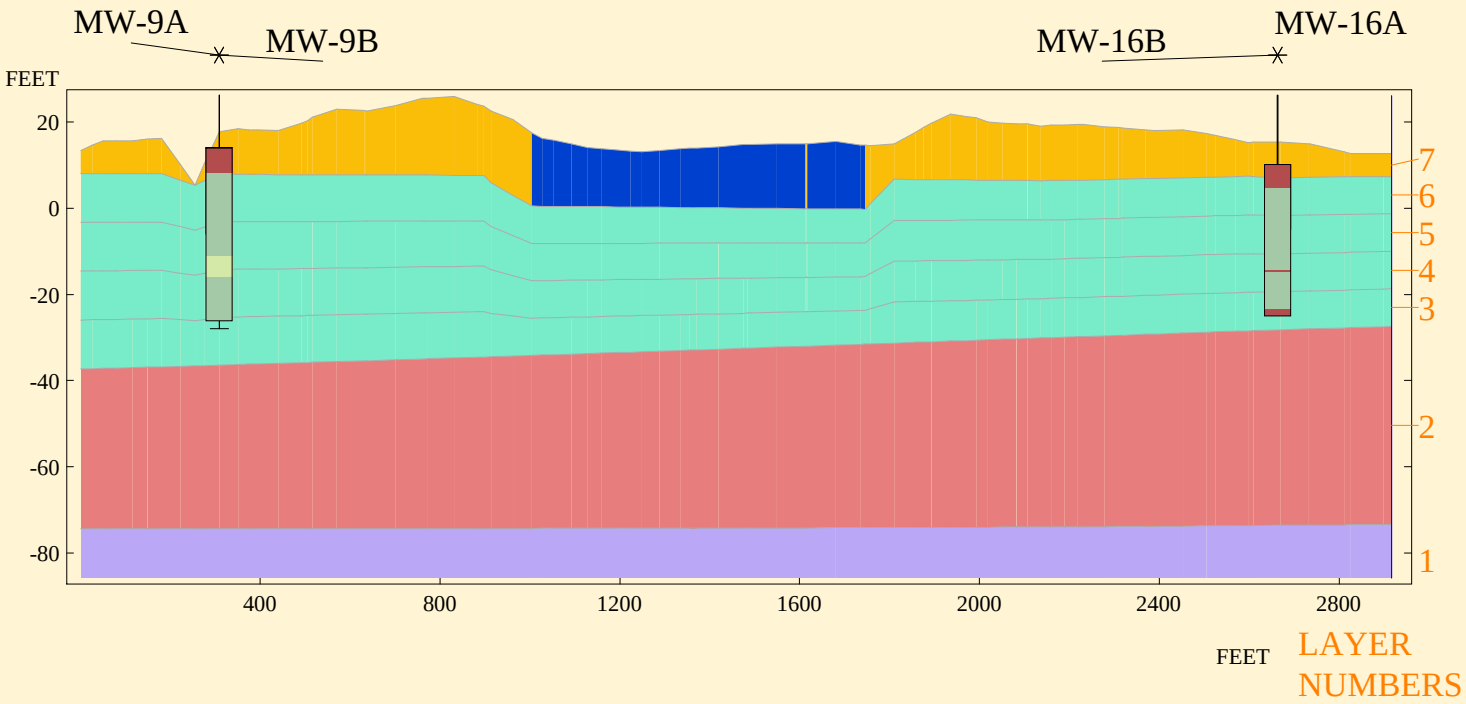
Aug 4 10 sav/build10f.sav

CDM

Cross-Section AA East-West
Draft Groundwater Model Report
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-3

60081



CROSS SECTION BB

MATERIALS CROSS-SECTION BB
- Pond
- Surficial Silt-Clay
- Surficial Aquifer
- Yorktown Aquitard
- Yorktown-Eastover Aquifer

WELL LOG LEGEND
- ML
- SW
- SP
- CH
- CL

- Monitoring
- LAND SURFACE
- TOP OF SCREEN
- BOTTOM OF SCREEN

PROJECTED 500 FT

Aug 4 10 sav/build10f.sav

CDM

Cross-Section BB North-South
Draft Groundwater Model Report
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-4

60082

http://www.cityofchesapeake.net/services/citizen_info/battlefieldgolfclub/index.shtml#SiteTestReports
Base Map: TerraServer
Date: January 1, 2009

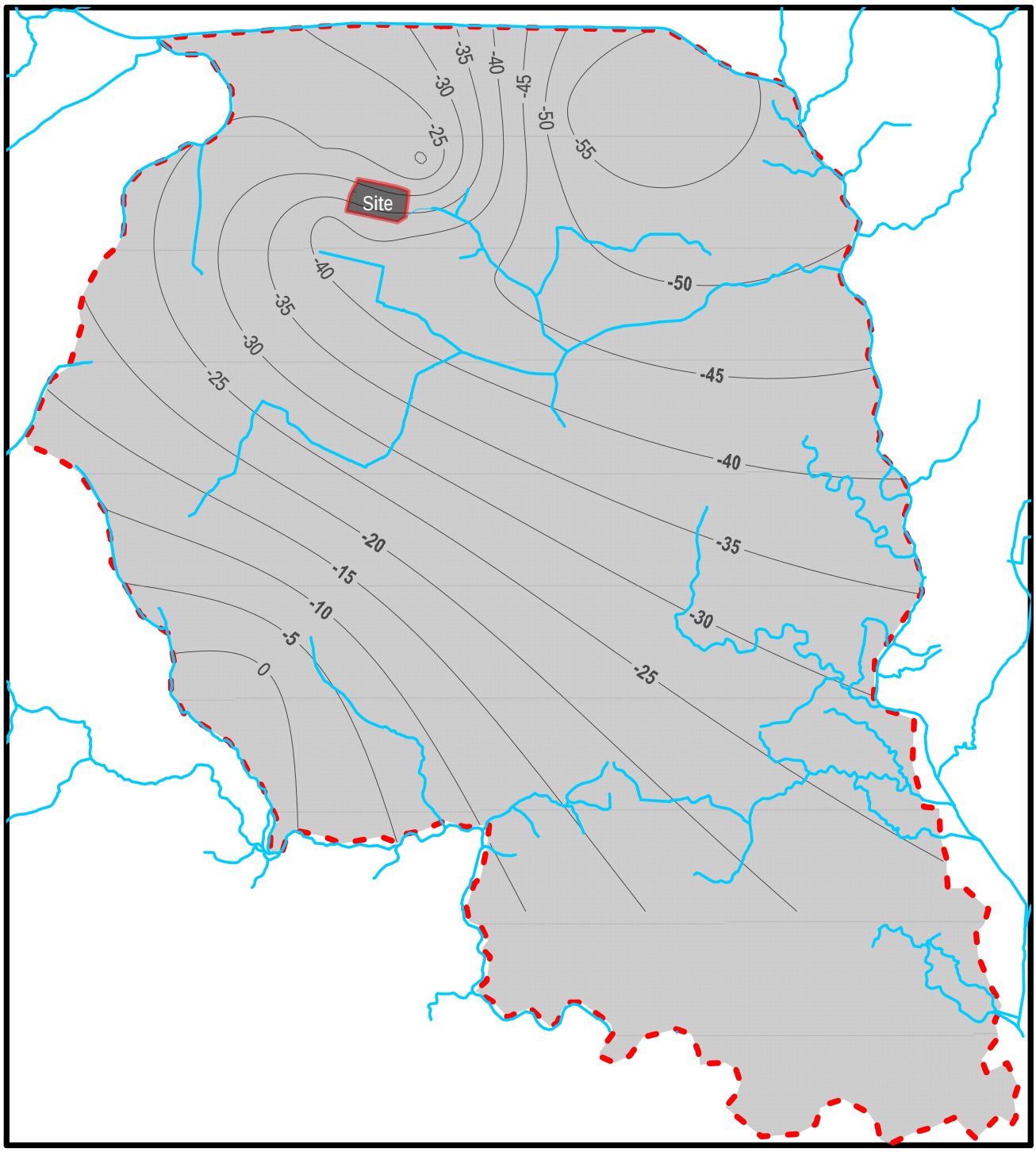
0 275 550 1,100 Feet

N W E S

CDM

Figure 6-5
Land Surface Elevations
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60083



Structure contours drawn on the base of the surficial aquifer are in feet NAVD88.
Contour interval is 5 feet.

Model Domain

Stream/River

N
W
E
S

Scale in Feet

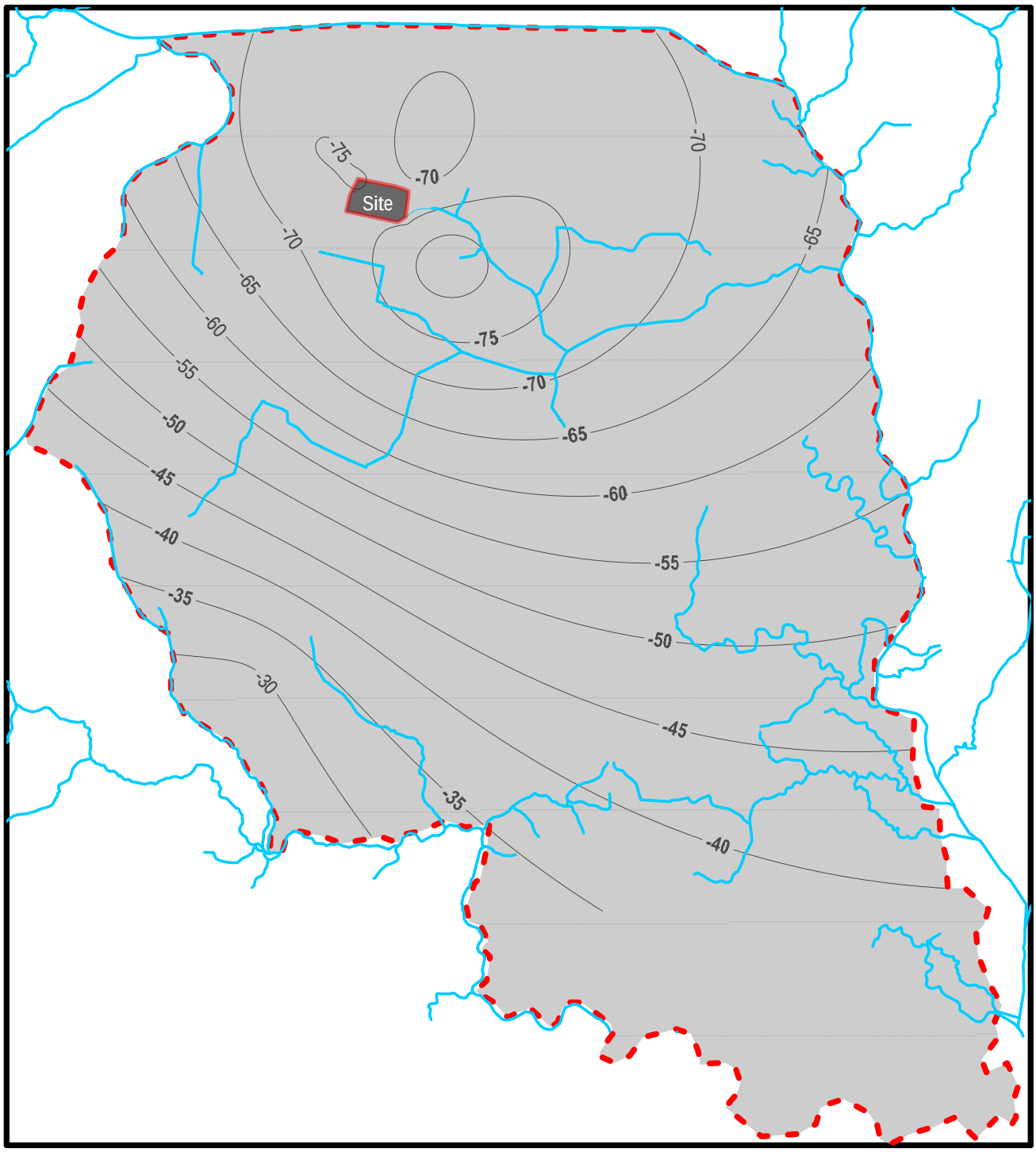
0 10000 20000 30000 40000

CDM

Figure 6-6: Surficial Aquifer Base Elevation Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60084



Structure contours drawn on the base of the Yorktown confining zone in feet NAVD88. Contour interval is 5 feet.

Model Domain

Stream/River

N
W E
S

Scale in Feet

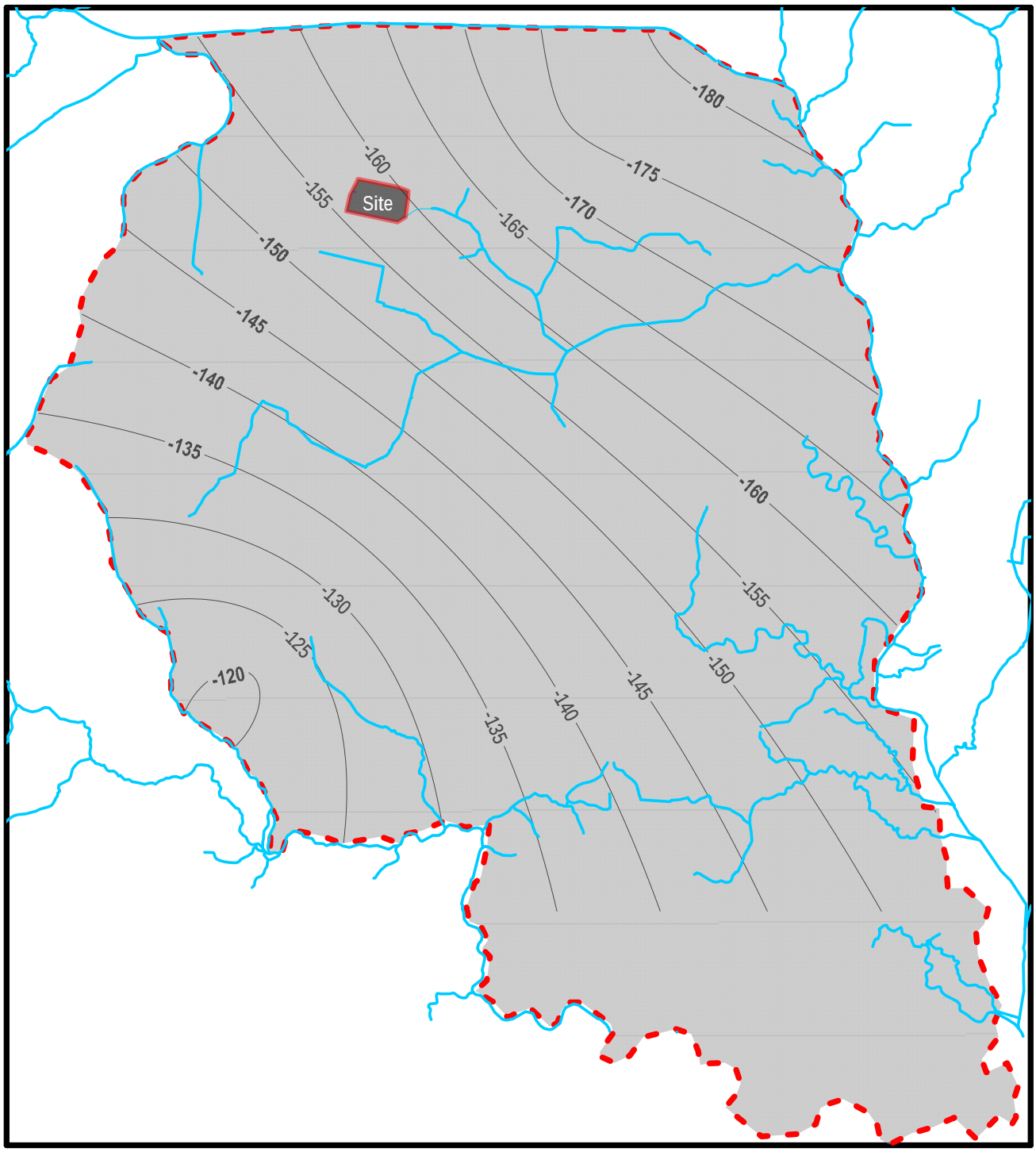
0 10000 20000 30000 40000

CDM

Figure 6-7: Yorktown Confining Zone Base Elevation Map

Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60085



Structure contours drawn on the base of the
Yorktown aquifer in feet NAVD88.
Contour interval is 5 feet.

Model Domain

Stream/River

N
W E
S

Scale in Feet

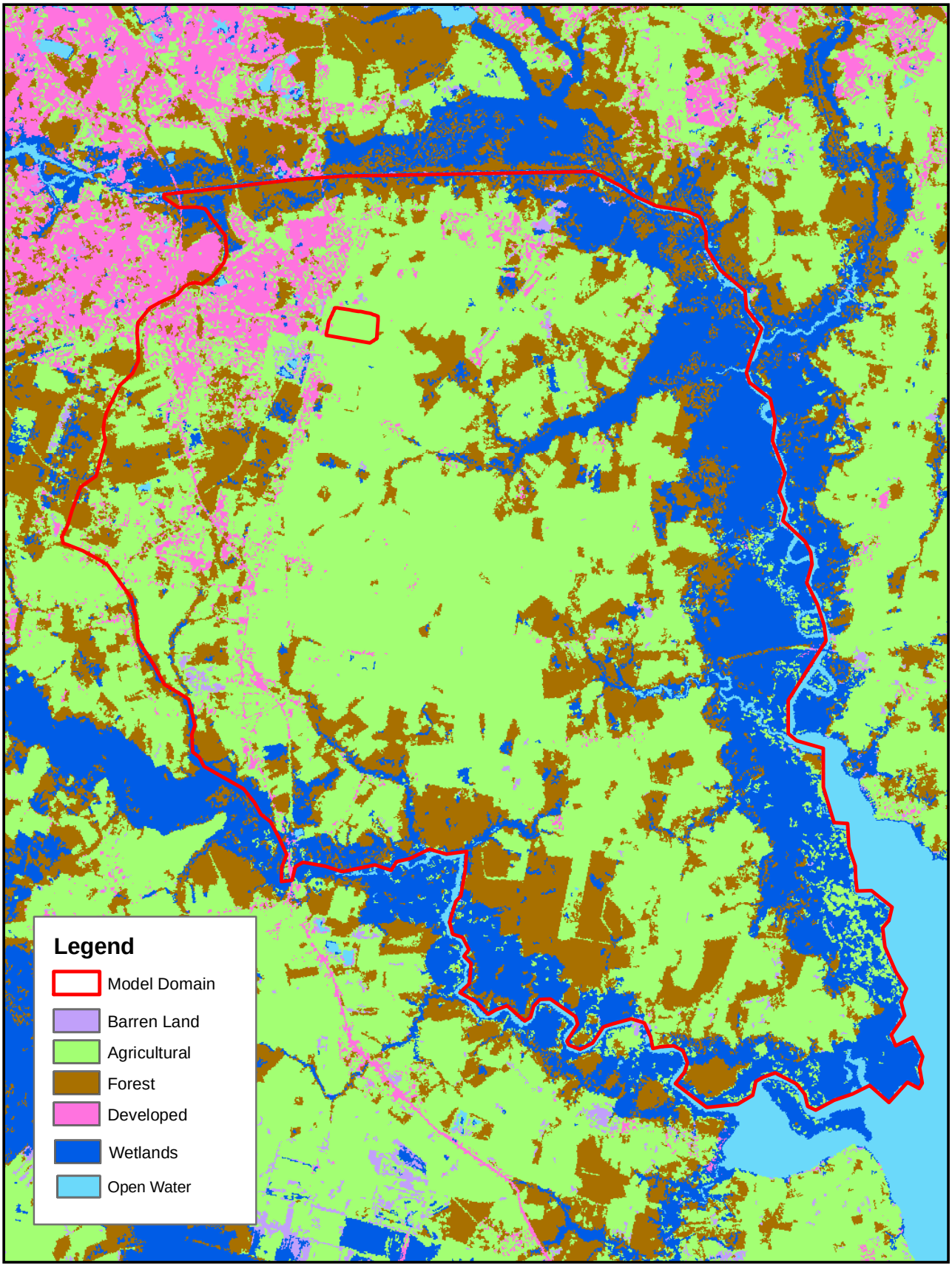
0 10000 20000 30000 40000

CDM

Figure 6-8: Yorktown Aquifer Base Elevation Map

Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60086



National Land Cover Database 2001

0 5,500 11,000 22,000 Feet

N W E S

Figure 6-9
Land Use
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

CDM

60087

Base Map: ArcGIS World Imagery
Publication Date: June 2010

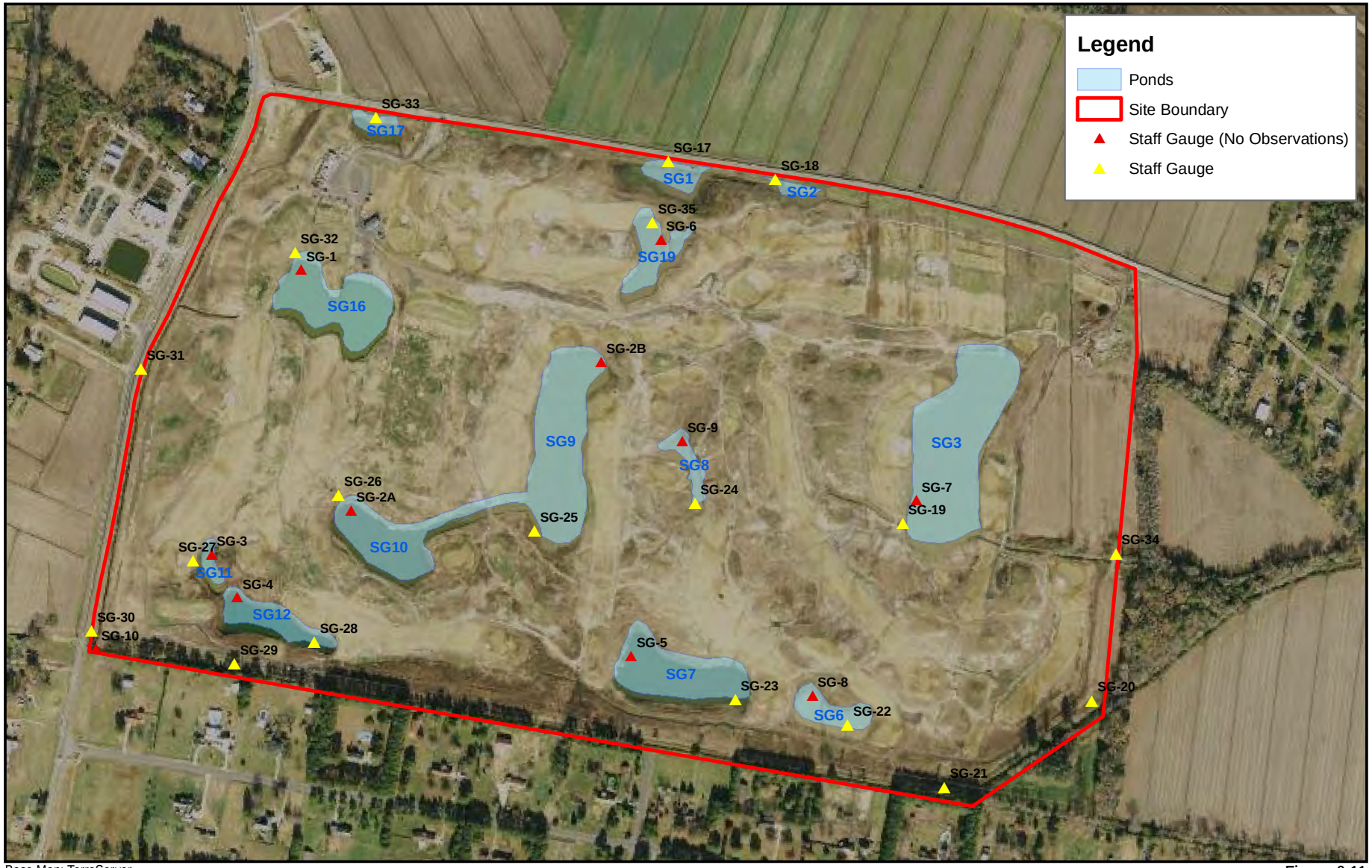
0 675 1,350 2,700 Feet

N W E S

CDM

Figure 6-10
Drainage Ditches
Hydrogeologic Investigation and Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60088



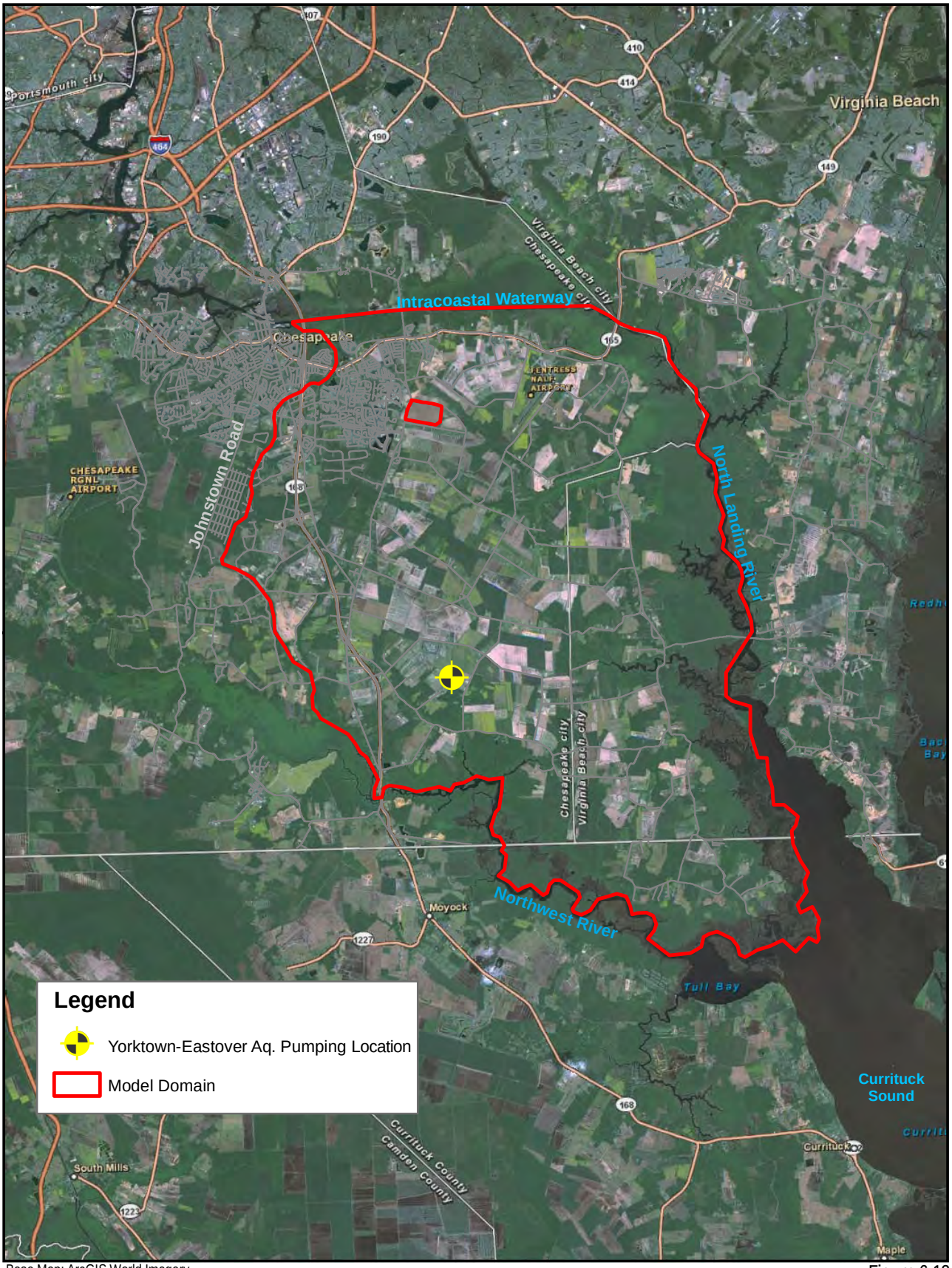
Base Map: TerraServer
Date: January 1, 2009

0 275 550 1,100 Feet

CDM

Figure 6-11
Golf Course Ponds and Staff Gauge Locations
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60089



Base Map: ArcGIS World Imagery
Publication Date: June 2010

0 1.5 3 Miles

CDM

Figure 6-12
Yorktown-Eastover Aquifer Pumping Location
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

60090

Legend

- Observation Point
- Pumped Well
- Site Boundary

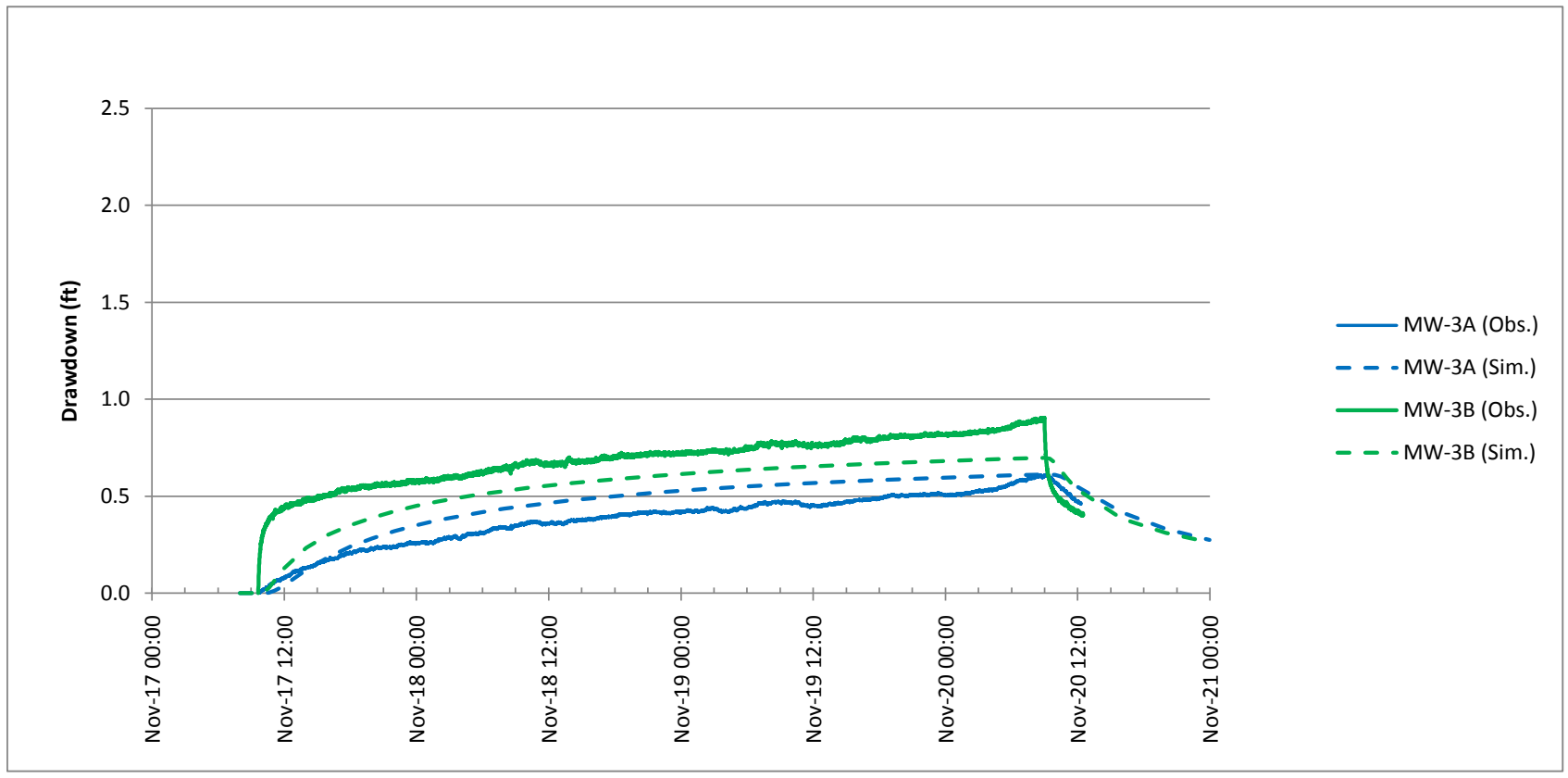
Aquifer Performance Test, November 16-20, 2009
Base Map: TerraServer
Date: January 1, 2009

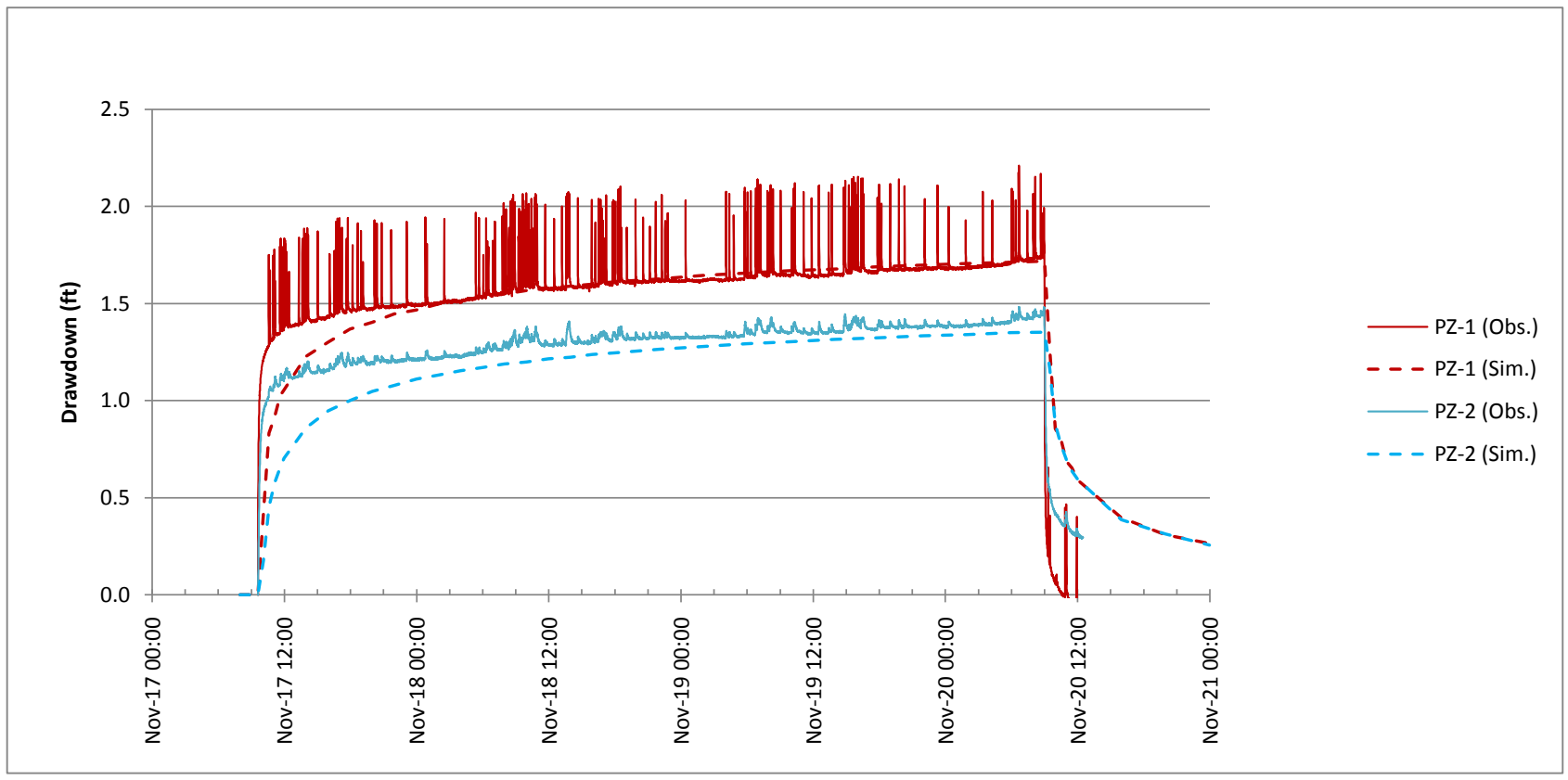
Figure 6-13
Aquifer Performance Test Well Locations
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia

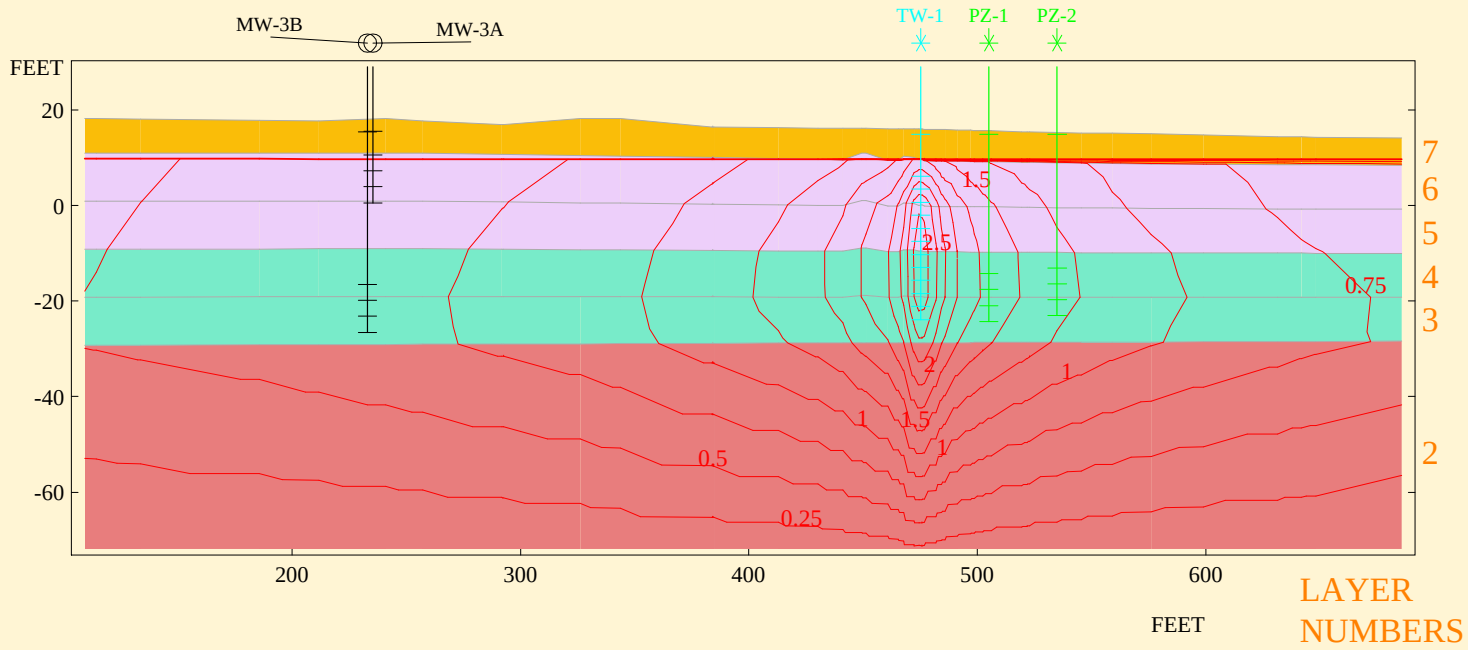
CDM

60091

Figure 6-14
Aquifer Performance Test Simulated and Observed Drawdowns







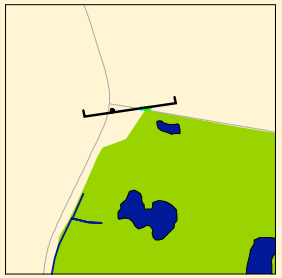
MATERIALS CROSS-SECTION CC

- Surficial Silt-Clay
- Upper Surficial Aquifer
- Lower Surficial Aquifer
- Yorktown Aquitard
- Yorktown-Eastover Aquifer

— Drawdown

- OBSERVATION WELL
- PUMPING WELL
- INJECTION WELL
- GROUND SURFACE
- TOP OF SCREEN
- BOTTOM OF SCREEN
- PROJECTED 100 FT

CROSS SECTION CC



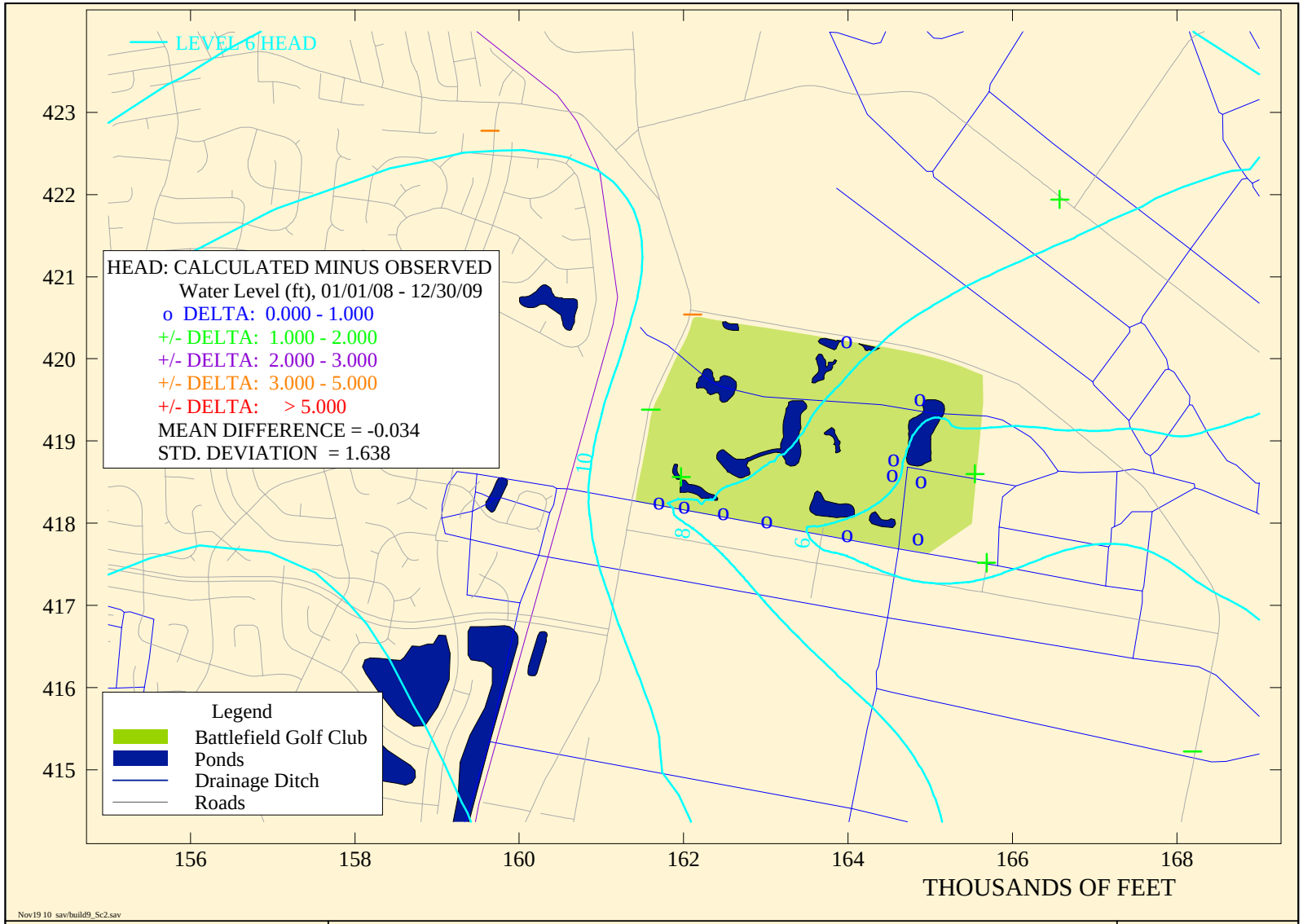
Aug 4 10 sav/build9f.sav

CDM

Aquifer Performance Test Drawdown
Aquifer Performance Test Model
Battlefield Golf Course
Chesapeake, VA

FIGURE 6-15

60093



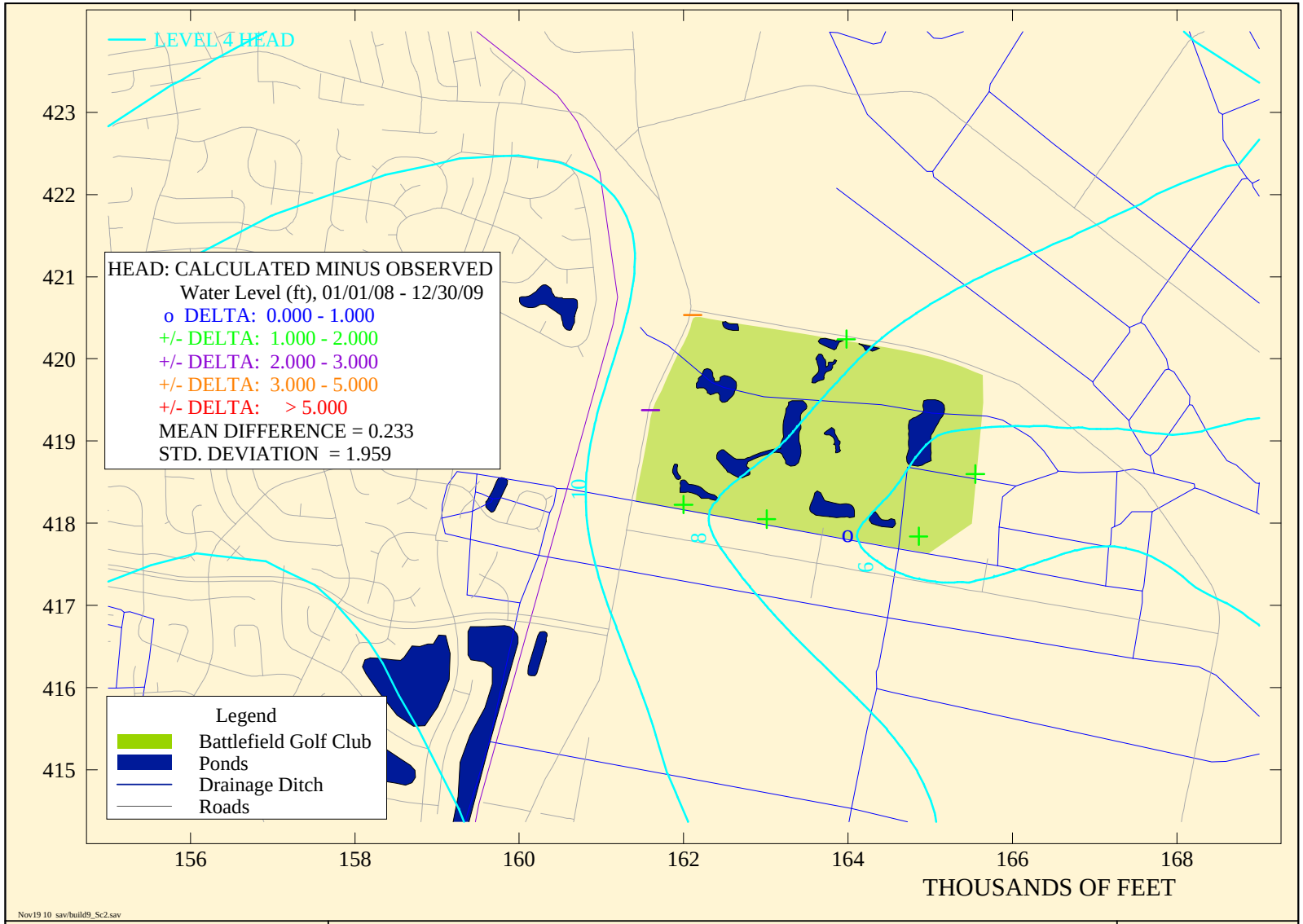
Nov19 10 sav/build9_Sc2.sav

CDM

Upper Surficial Aquifer - A Wells - Sim. Heads and Cal. Results
Aquifer Performance Test Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-16

60094

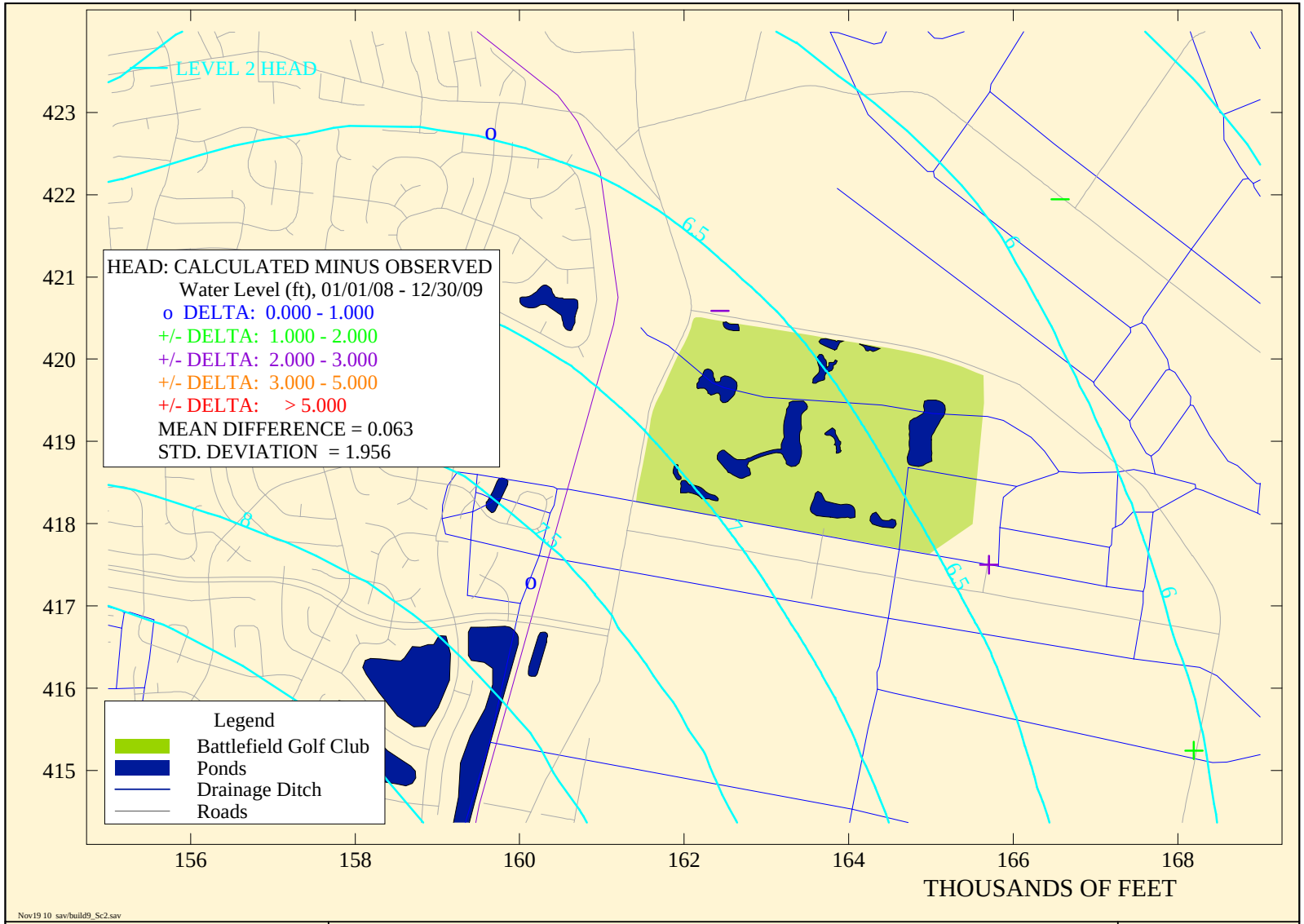


CDM

Lower Surficial Aquifer - B Wells - Sim. Heads and Cal. Results
Aquifer Performance Test Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-17

60095

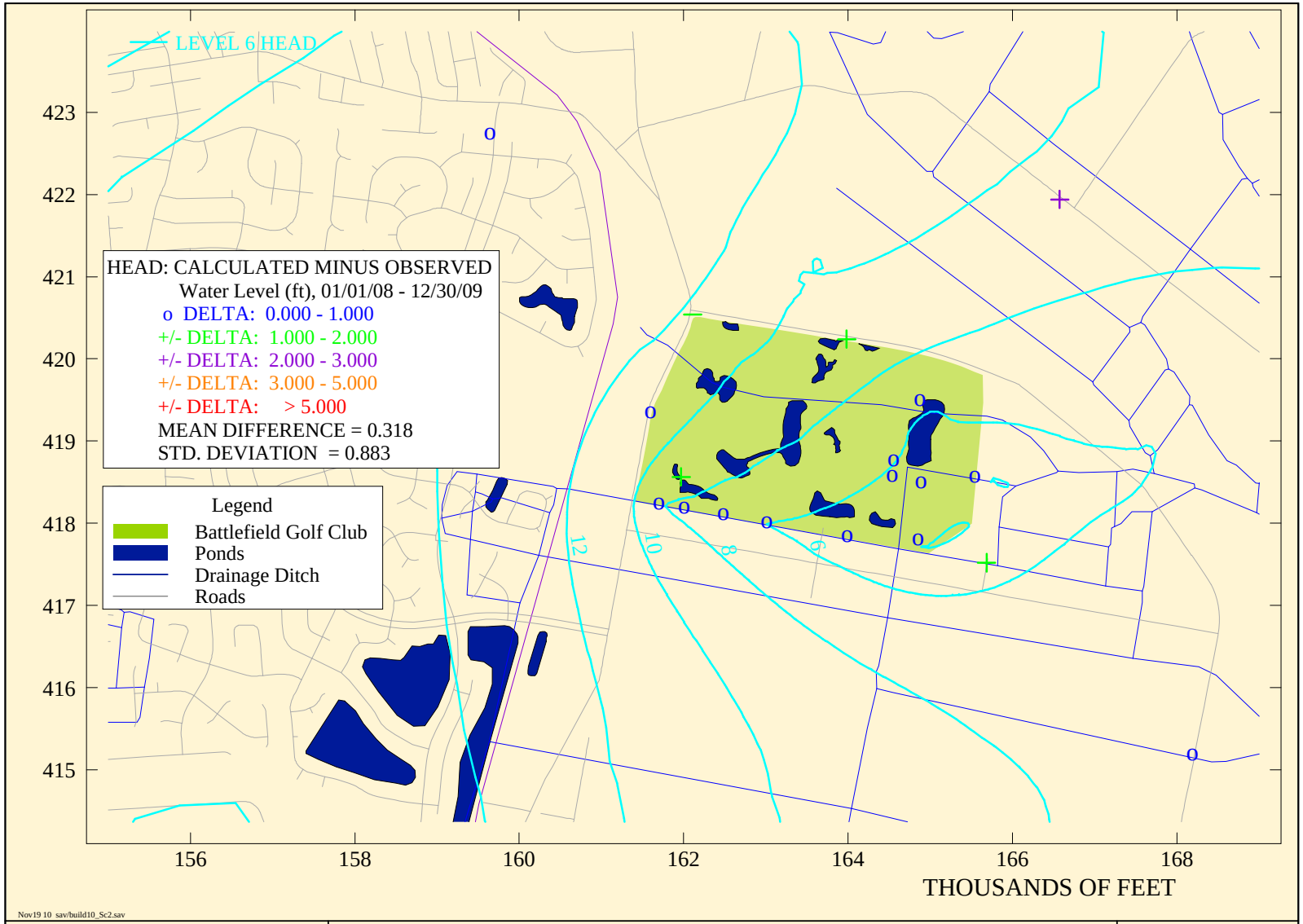


CDM

Upper Yorktown-Eastover Aquifer - C Wells - Sim. Heads and Cal. Results
Aquifer Performance Test Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-18

60096



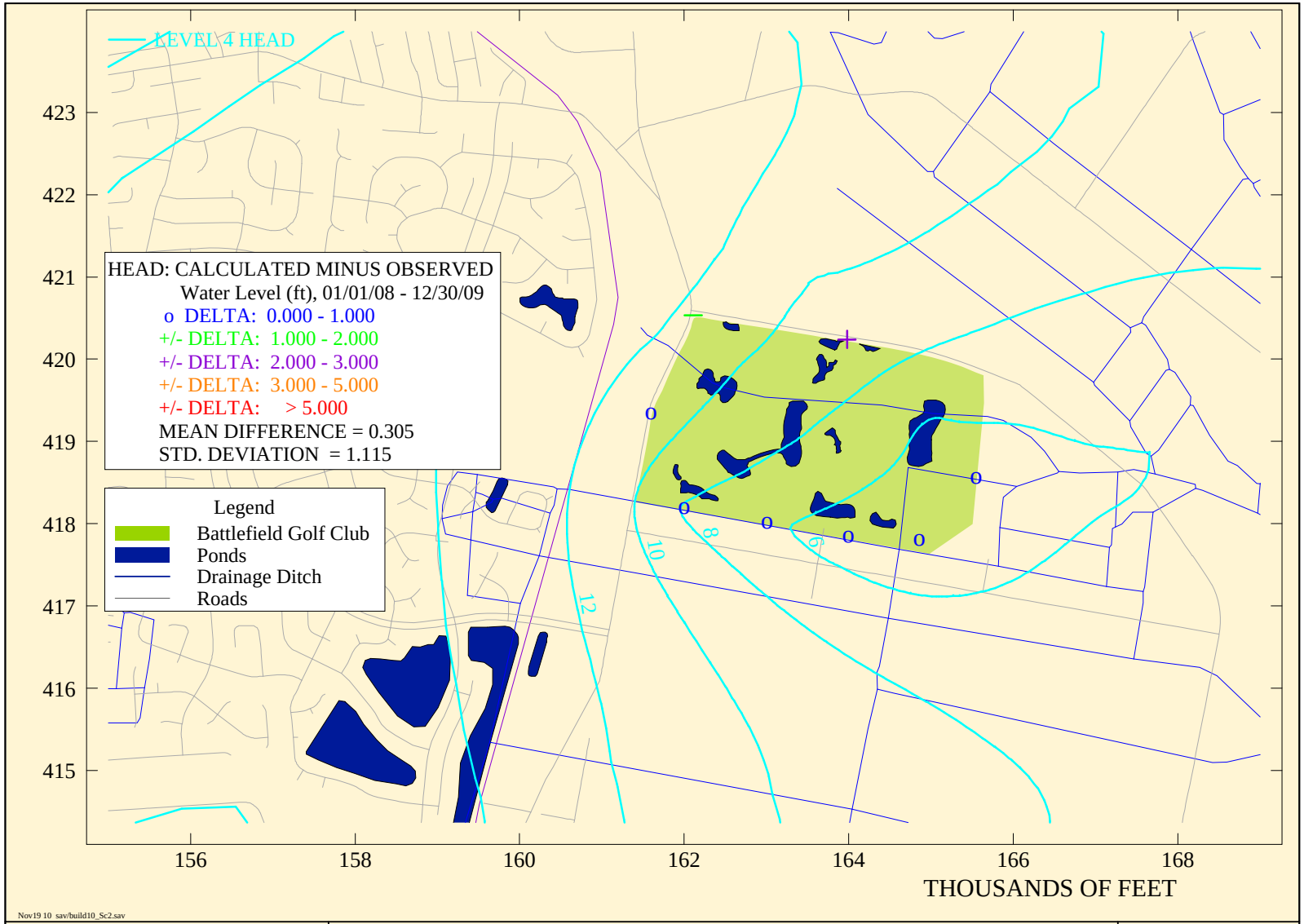
Nov19 10 sav/build10_Sc2.sav

CDM

Upper Surficial Aquifer - A Wells - Sim. Heads and Cal. Results
High Flow Calibration Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-19

60097

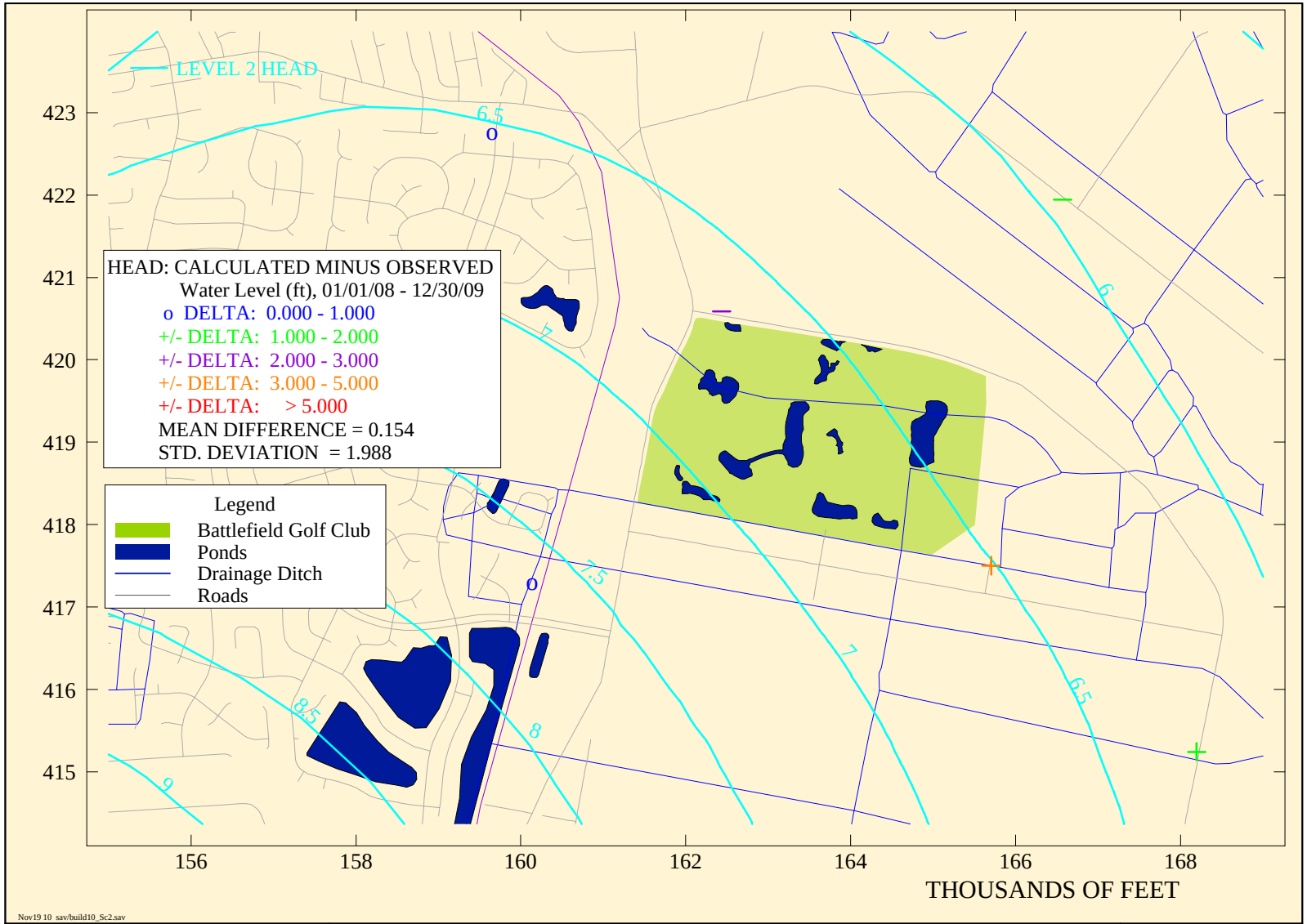


CDM

Lower Surficial Aquifer - B Wells - Sim. Heads and Cal. Results
High Flow Calibration Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-20

60098

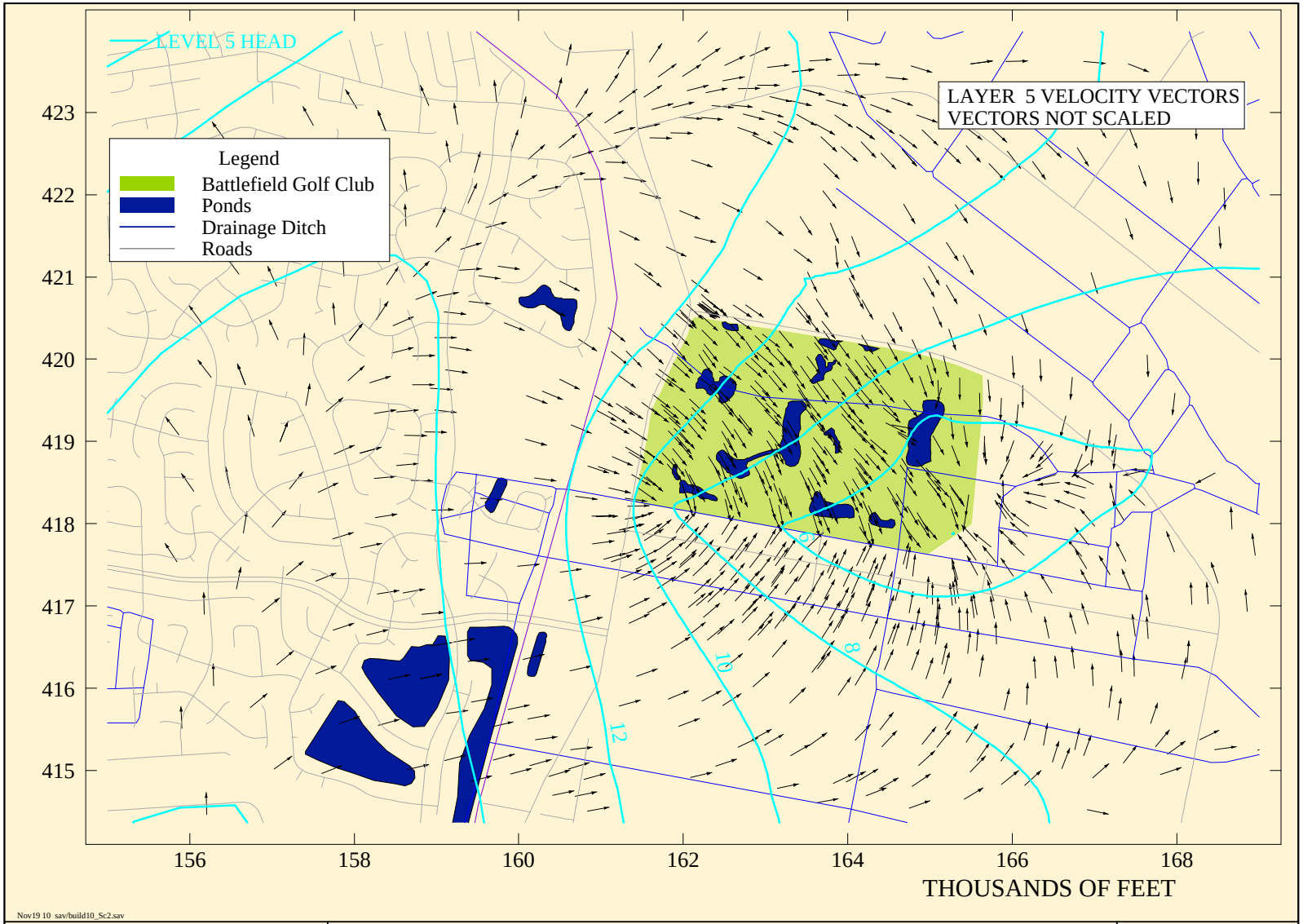


CDM

Upper Yorktown-Eastover Aquifer - C Wells - Sim. Heads and Cal. Results
High Flow Calibration Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-21

60099

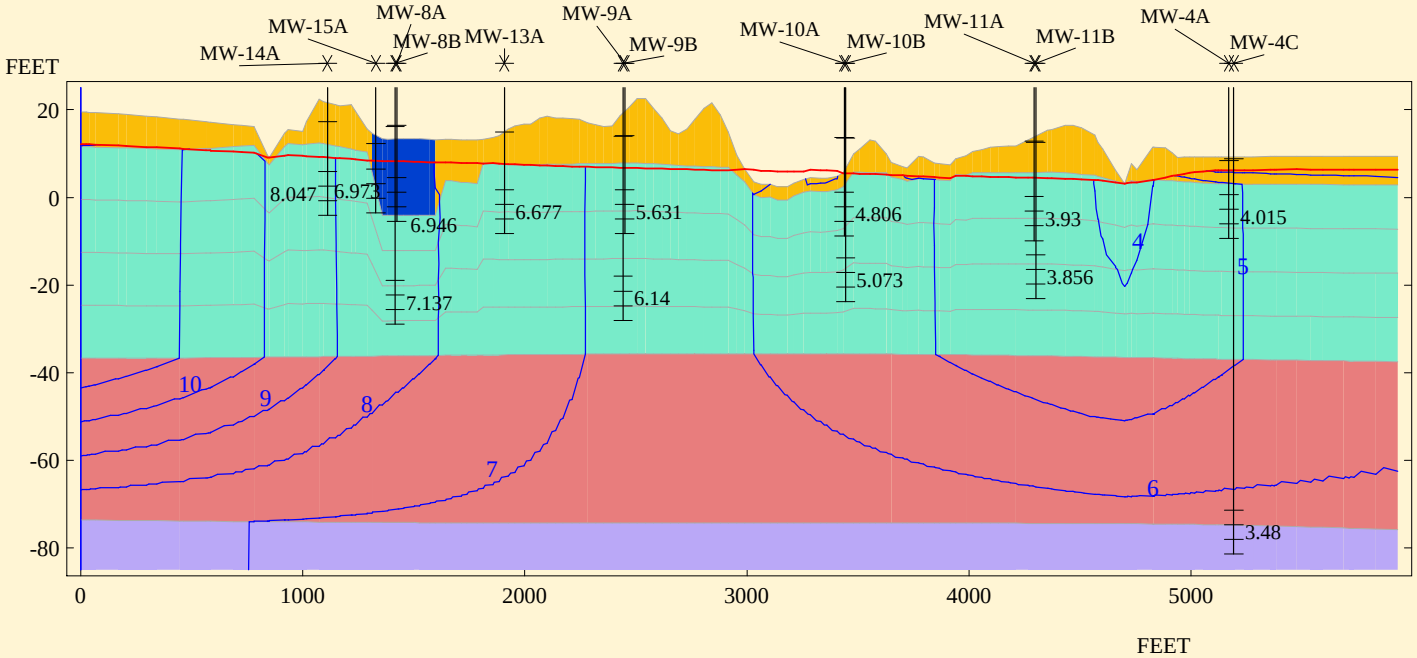


CDM

Upper Surficial Aquifer Groundwater Flow Vectors
High Flow Calibration Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-22

60100



— HEAD

MATERIALS CROSS-SECTION AA

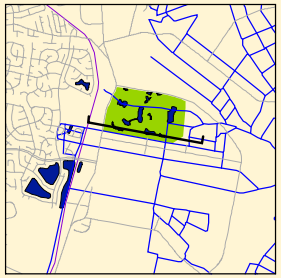
- Pond
- Surficial Silt-Clay
- Surficial Aquifer
- Yorktown Aquitard
- Yorktown-Eastover Aquifer

Water Level (ft)
01/01/08 - 12/30/09

- Monitoring
- GROUND SURFACE
- TOP OF SCREEN
- BOTTOM OF SCREEN

PROJECTED 500 FT

CROSS SECTION AA



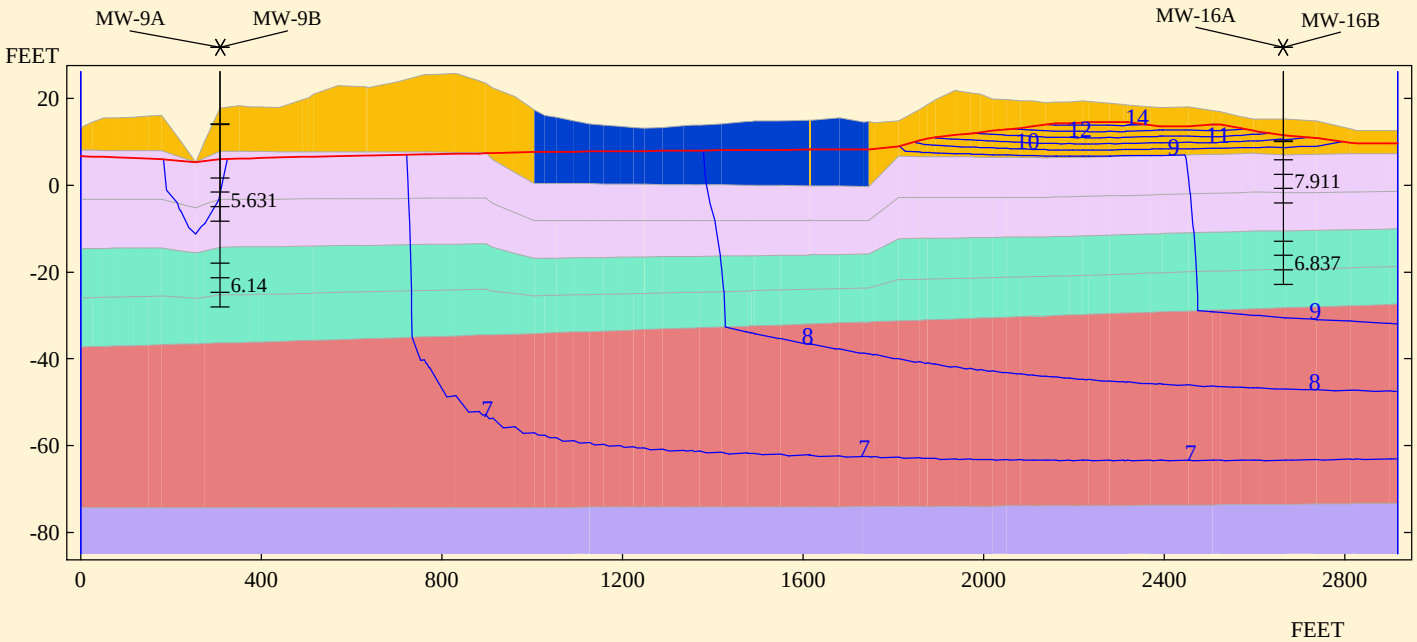
Nov19 10 sav/build10_Sc2.sav

CDM

Simulated Head Contours - East-West Cross-Section
High Flow Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-23

60101



— HEAD

MATERIALS CROSS-SECTION BB

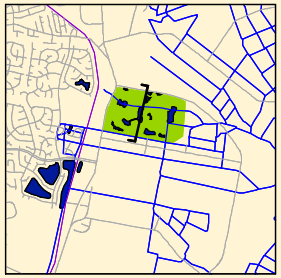
- Pond
- Surficial Silt-Clay
- Upper Surficial Aquifer
- Lower Surficial Aquifer
- Yorktown Aquitard
- Yorktown-Eastover Aquifer

Water Level (ft)
01/01/08 - 12/30/09

- Monitoring
- GROUND SURFACE
- TOP OF SCREEN
- BOTTOM OF SCREEN

PROJECTED 500 FT

CROSS SECTION BB



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CDM

Simulated Head Contours - North-South Cross-Section
High Flow Model
Battlefield Golf Course
Chesapeake, VA

FIGURE
6-24

60102

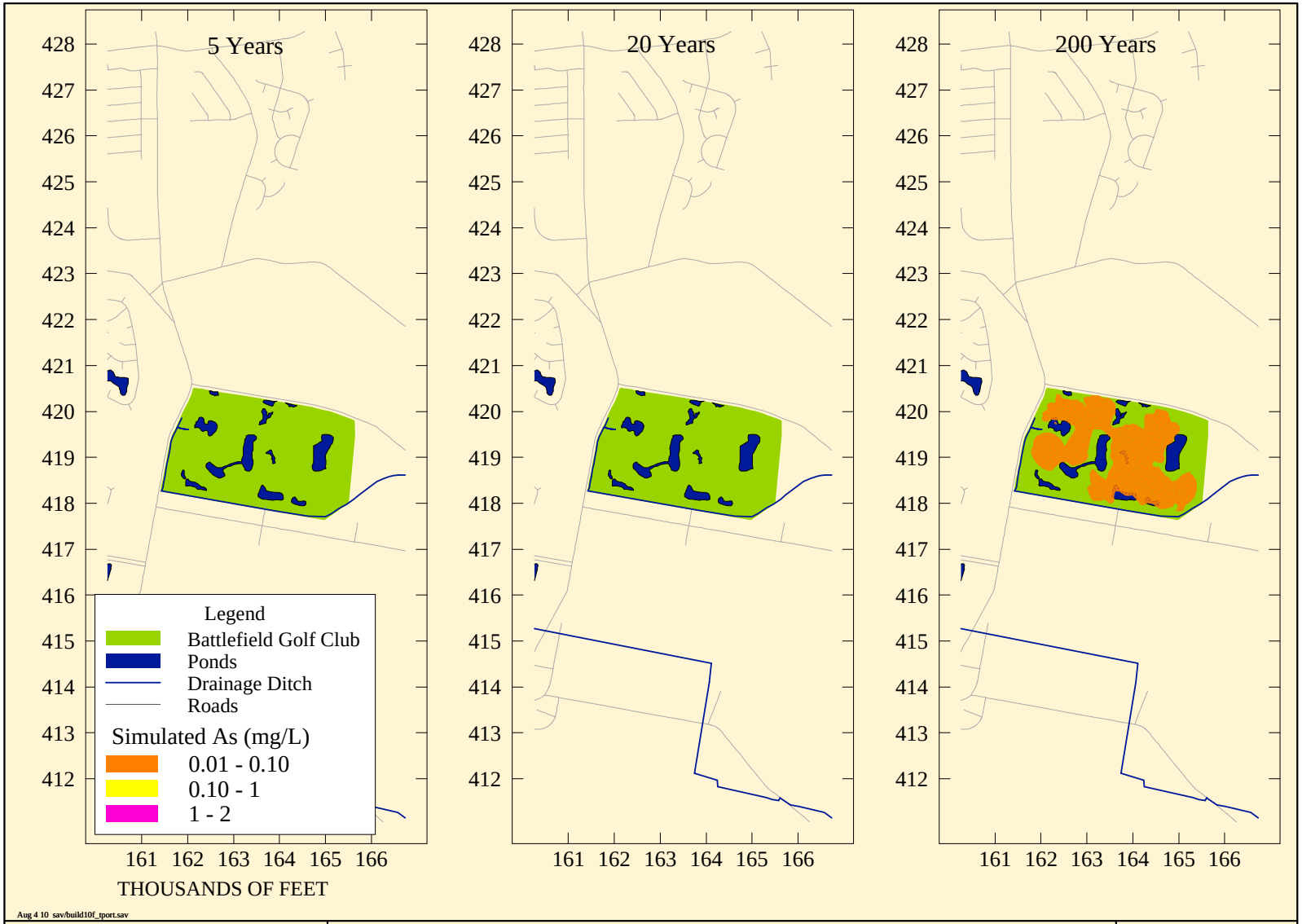
Base Map: TerraServer
Date: January 1, 2009

0 275 550 1,100 Feet

N W E S

CDM

Figure 7-1
Ash Fill Emplacement Area
Hydrogeologic Investigation and
Groundwater Modeling Report
Battlefield Golf Club
Chesapeake, Virginia
60103



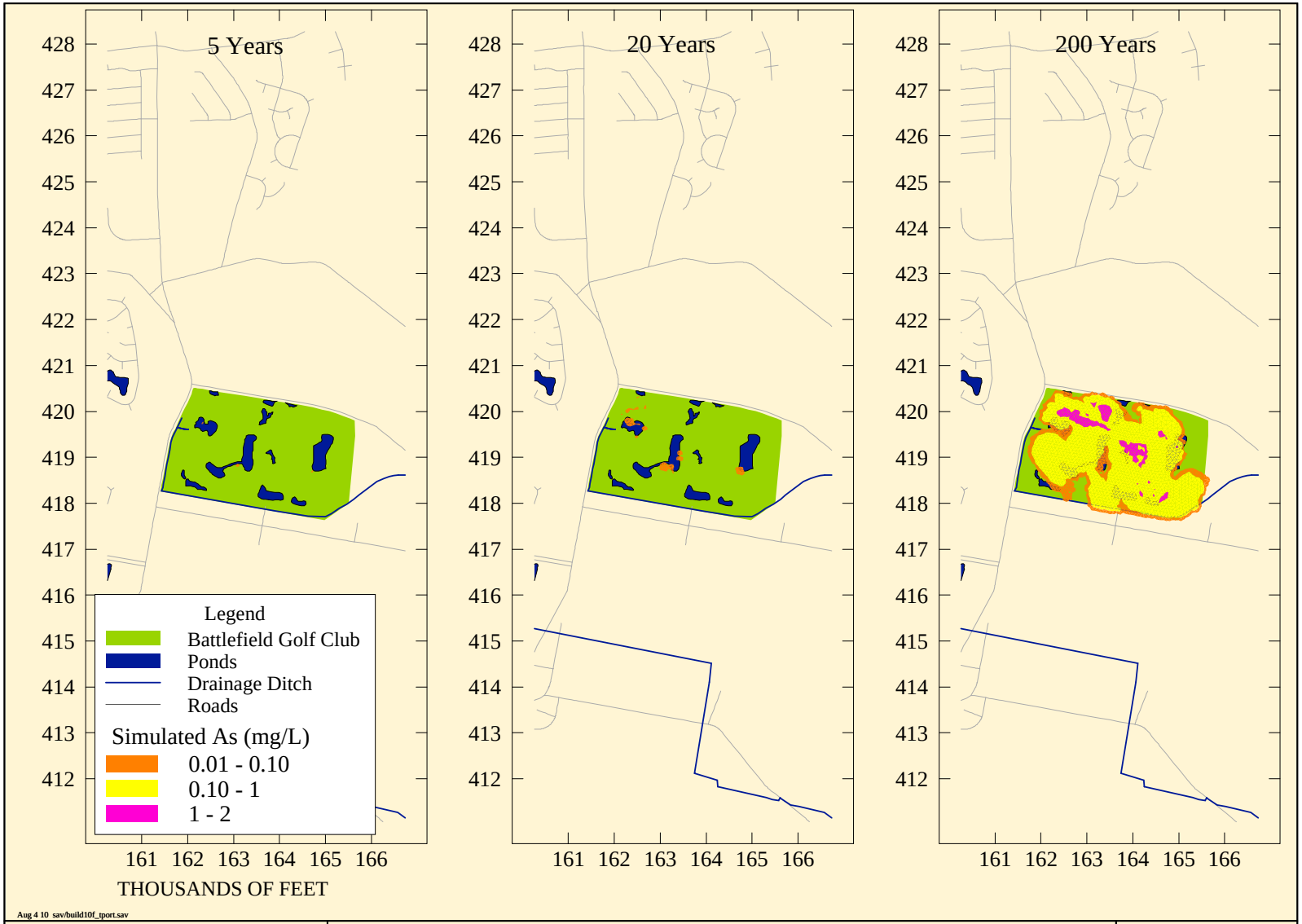
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 20 L/Kg, R = 87
Leachate Infiltration Rate of 15.8 inches/year
Mass Loading from TCLP Analysis

FIGURE
7-2

60104



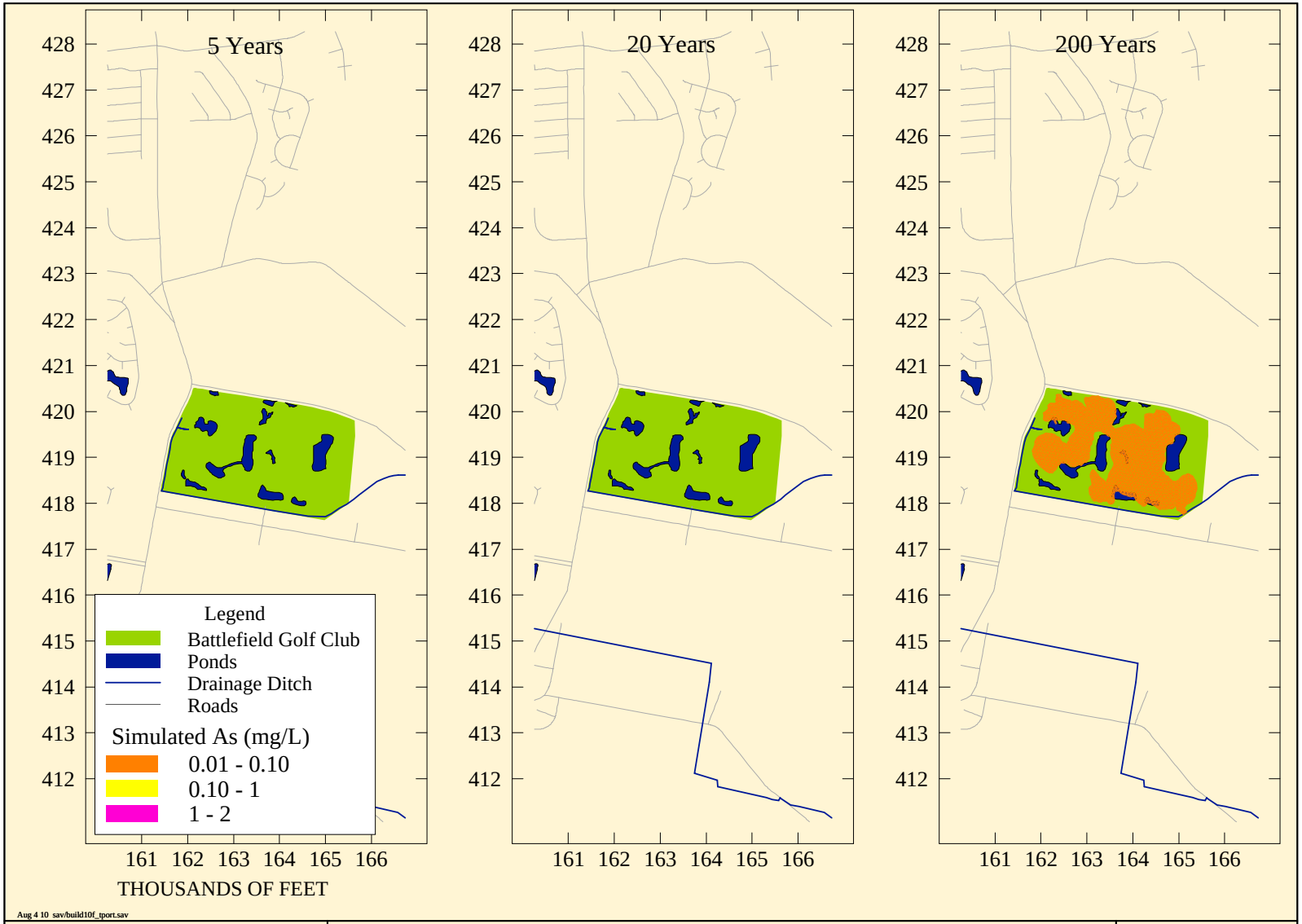
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 20 L/Kg, R = 87
Leachate Infiltration Rate of 15.8 inches/year
Mass Loading from Fly Ash As Composition (by Weight)

FIGURE
7-3

60105



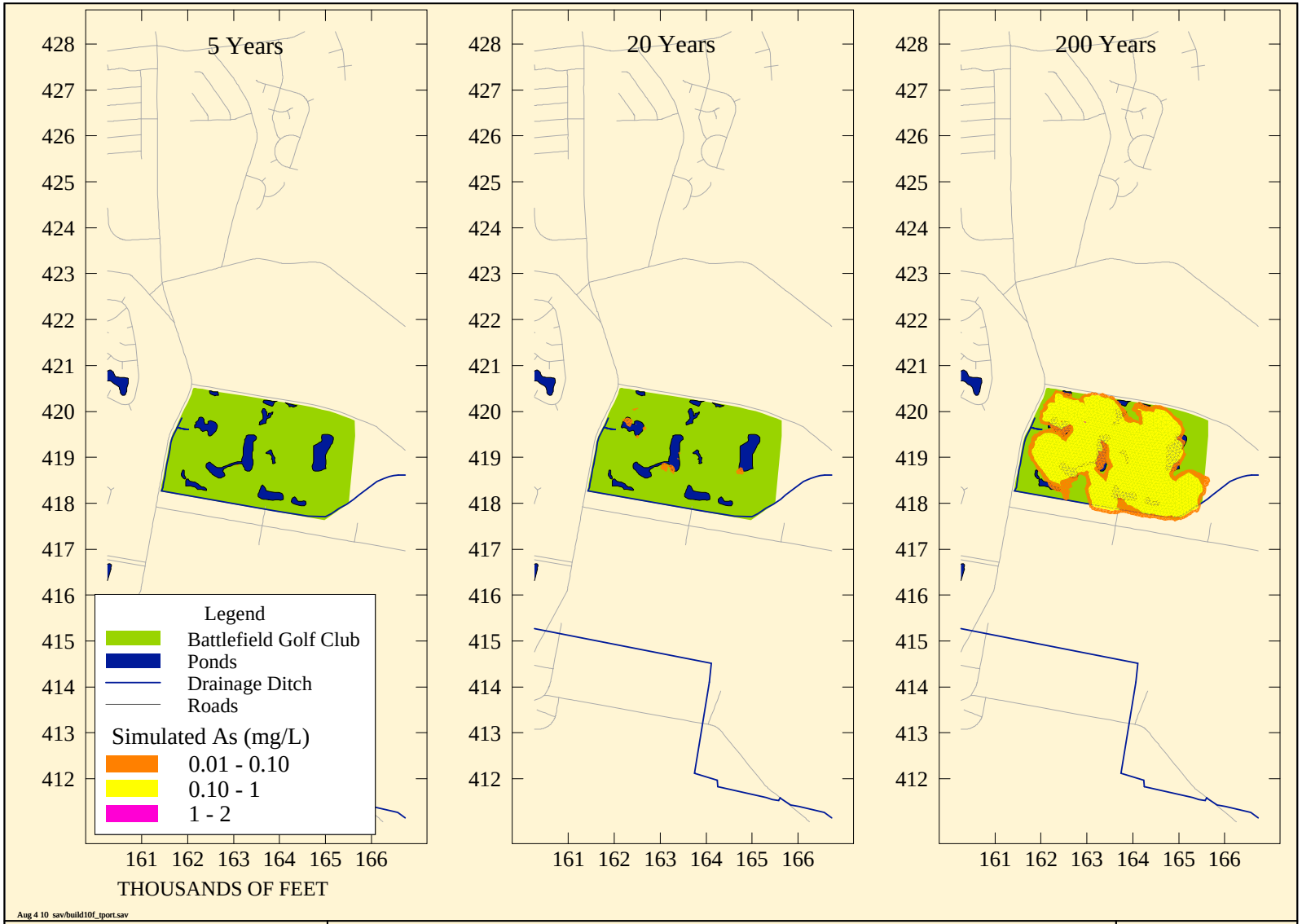
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 30 L/Kg, R = 131
Leachate Infiltration Rate of 15.8 inches/year
Mass Loading from TCLP Analysis

FIGURE
7-4

60106



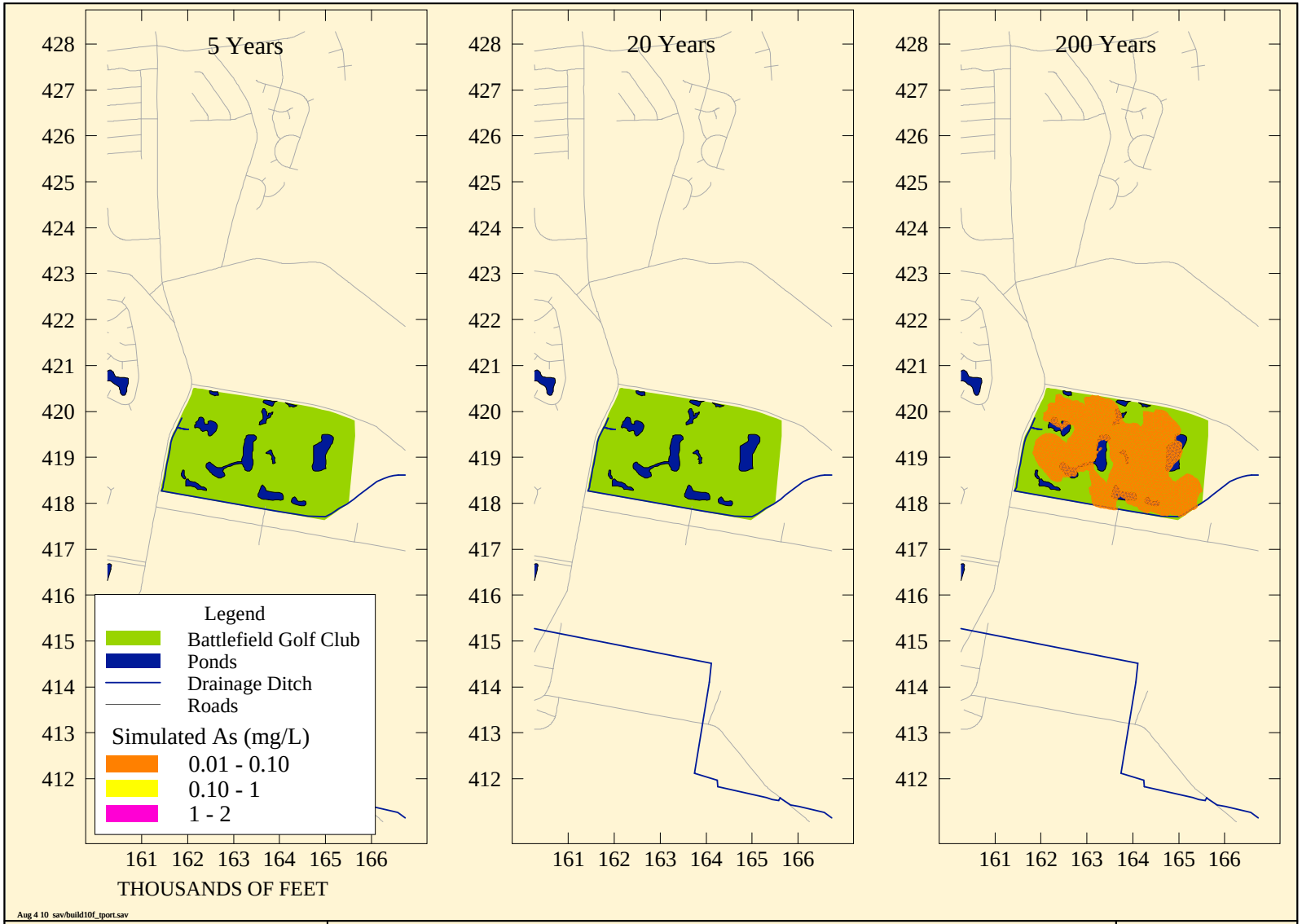
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 30 L/Kg, R = 131
Leachate Infiltration Rate of 15.8 inches/year
Mass Loading from Fly Ash As Composition (by Weight)

FIGURE
7-5

60107



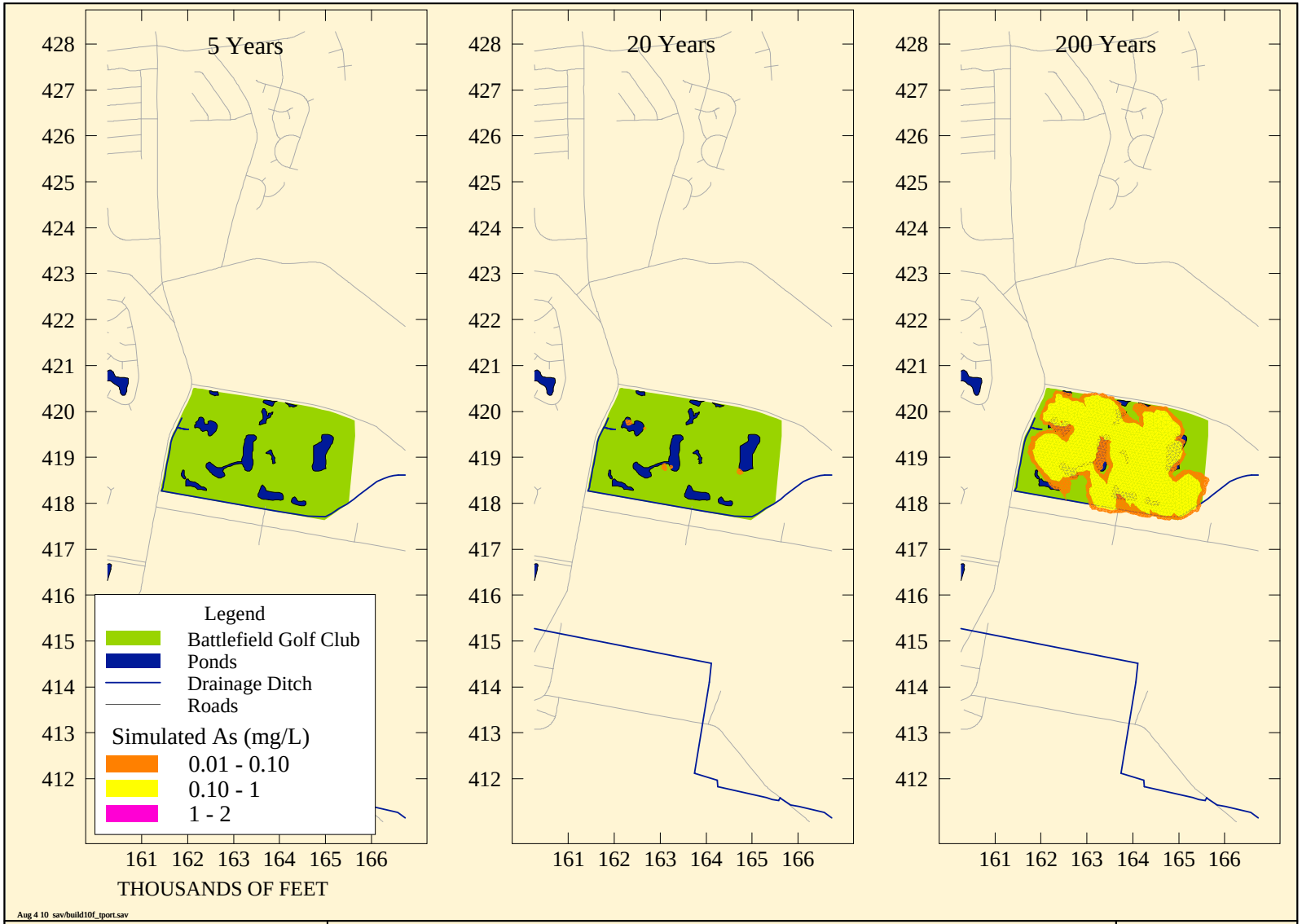
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 20 L/Kg, R = 87
Leachate Infiltration Rate of 7.5 inches/year
Mass Loading from TCLP Analysis

FIGURE
7-6

60108



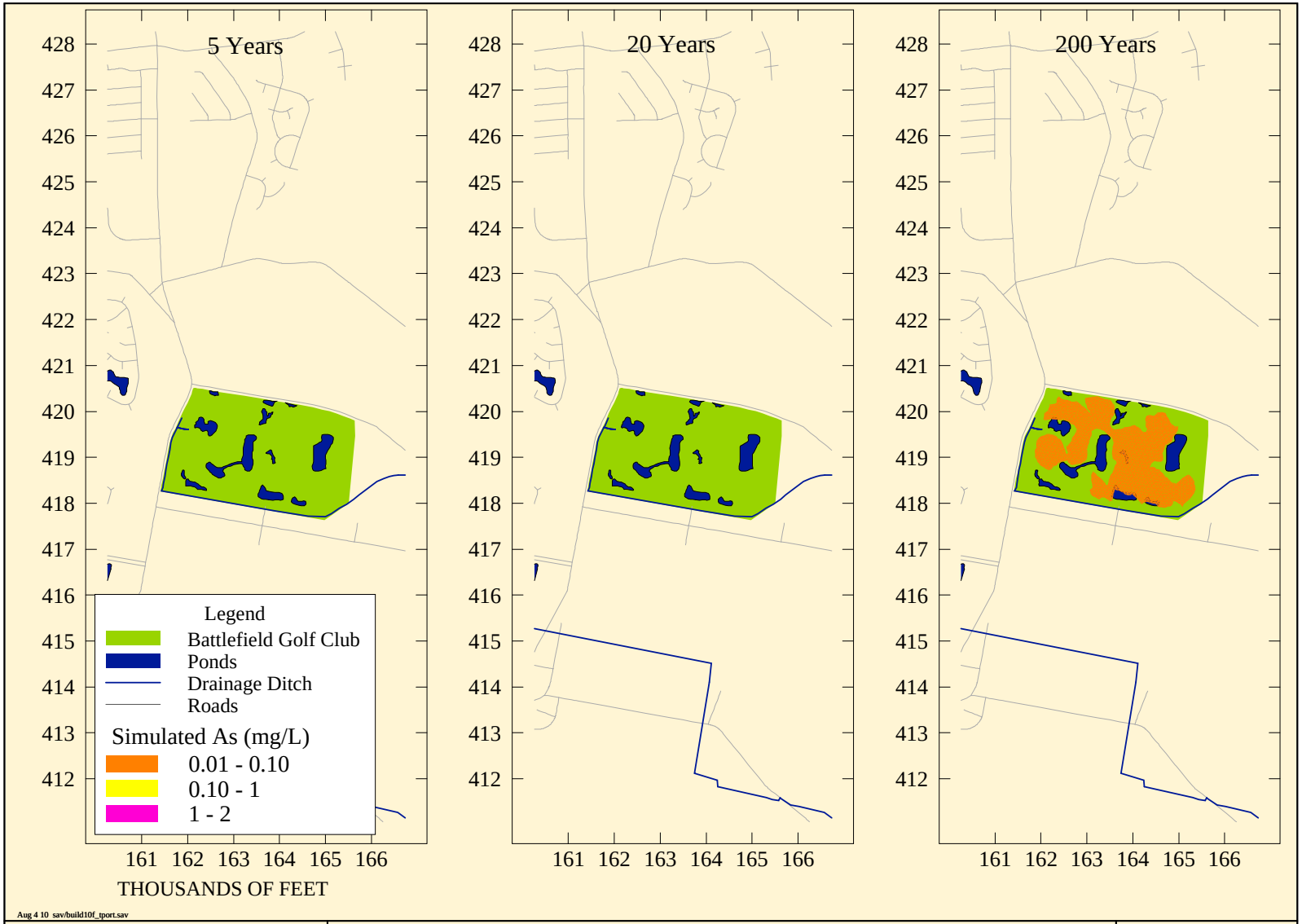
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 20 L/Kg, R = 87
Leachate Infiltration Rate of 7.5 inches/year
Mass Loading from Fly Ash As Composition (by Weight)

FIGURE
7-7

60109



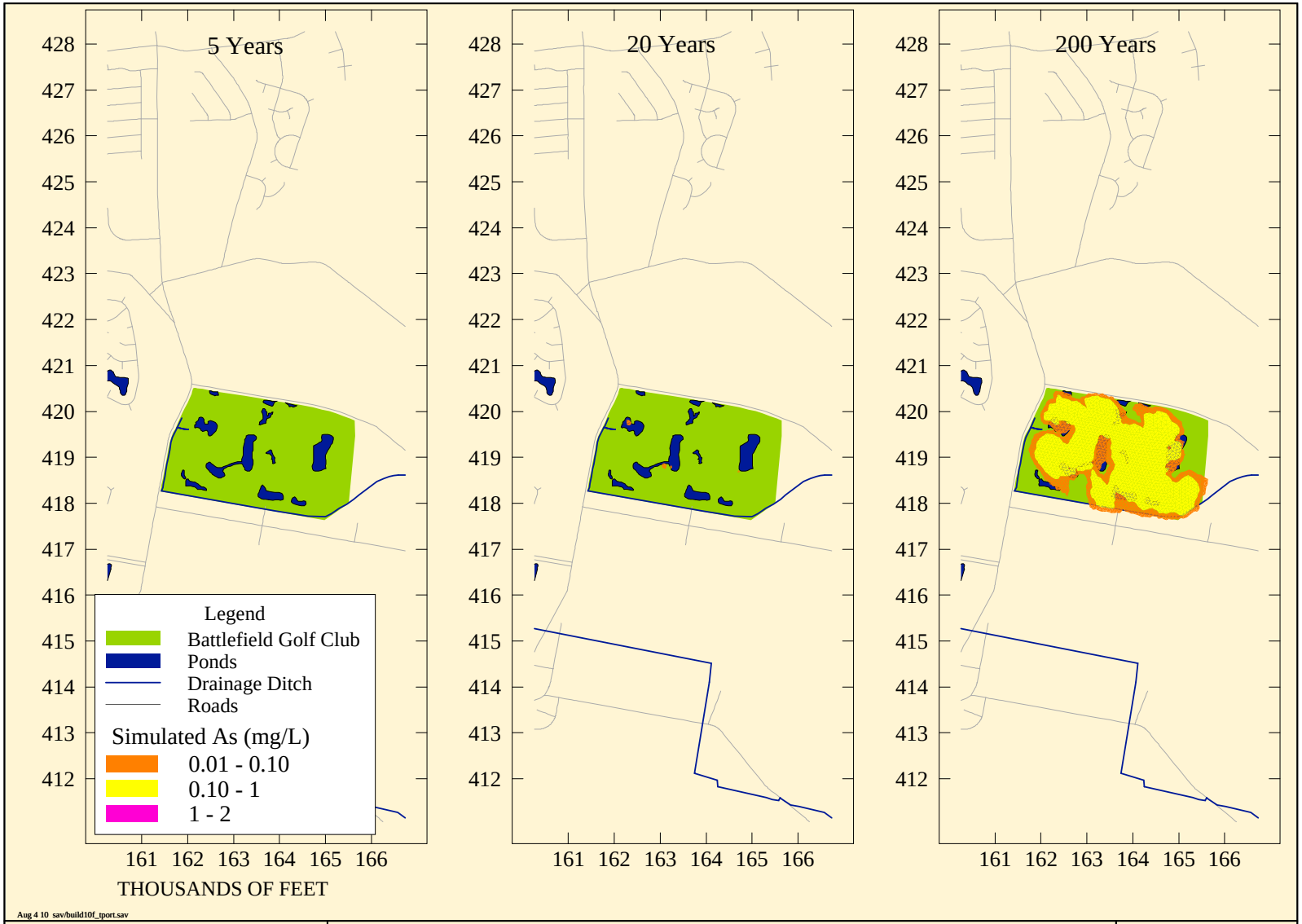
Aug 4 10 sav/build10f_tport.sav

CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 30 L/Kg, R = 131
Leachate Infiltration Rate of 7.5 inches/year
Mass Loading from TCLP Analysis

FIGURE
7-8

60110



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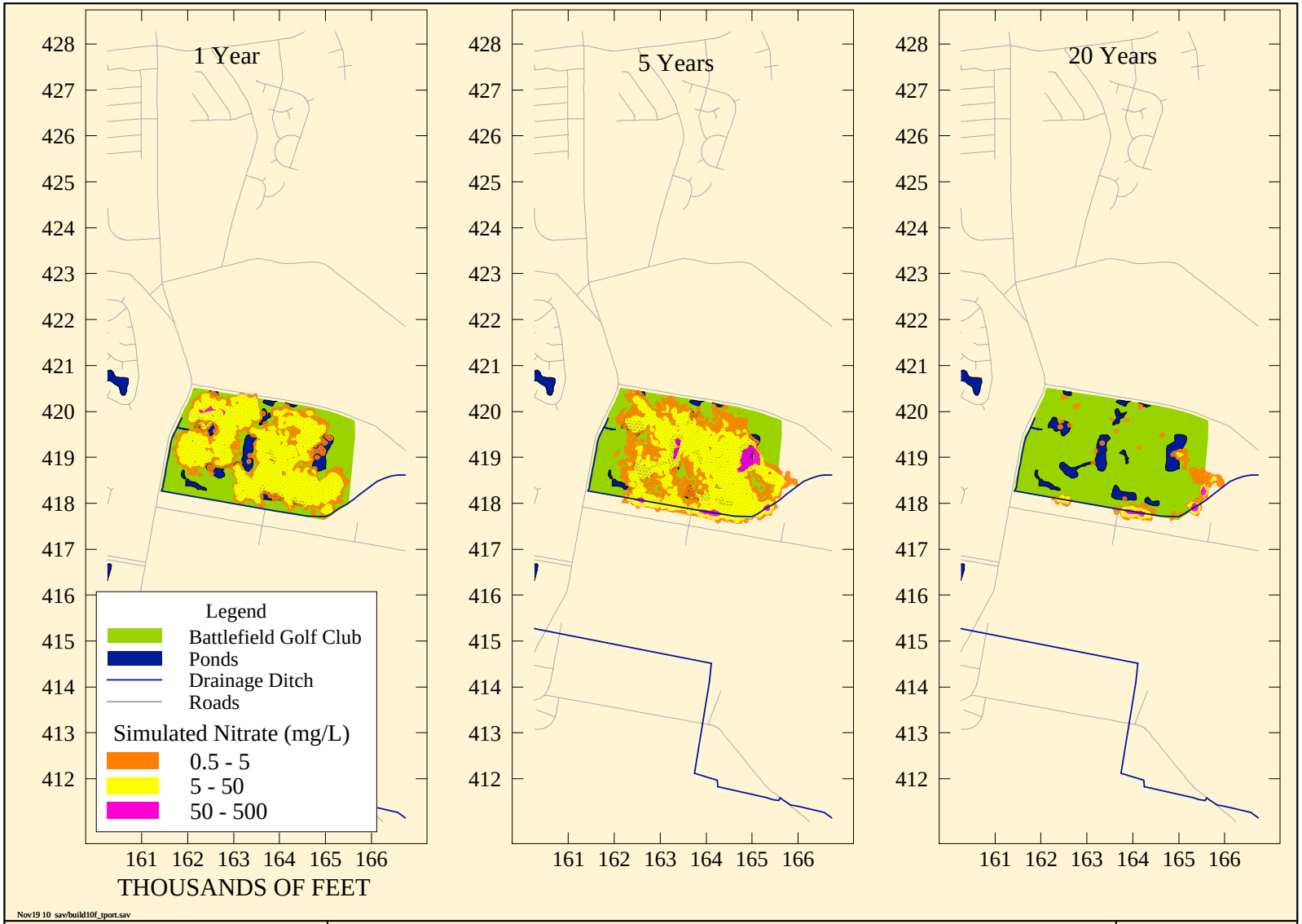
CDM

Simulated Arsenic (mg/L) in Upper Columbia Aquifer
High Flow Model, Kd = 30 L/Kg, R = 131
Leachate Infiltration Rate of 7.5 inches/year
Mass Loading from Fly Ash As Composition (by Weight)

FIGURE
7-9

60111



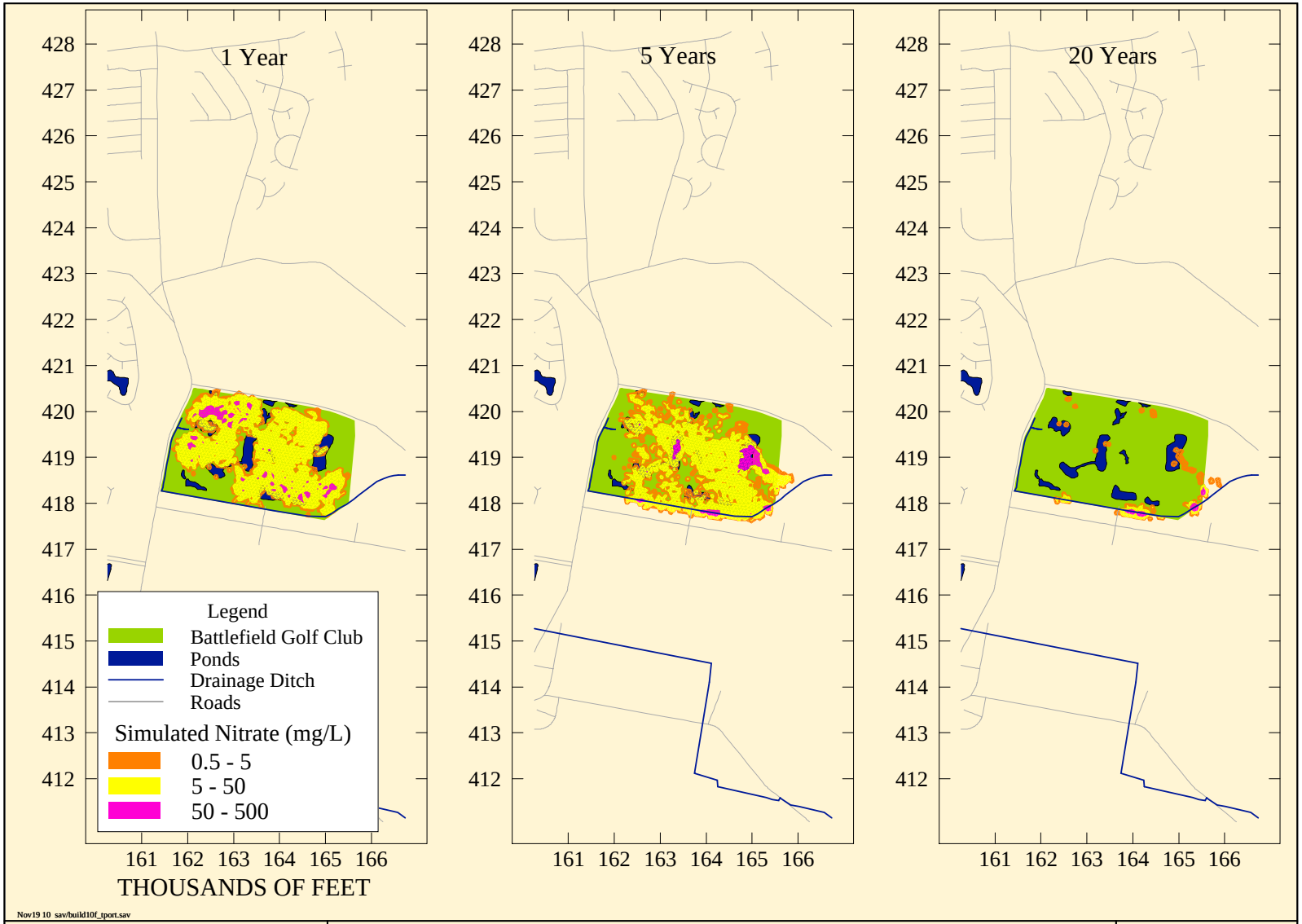
Nov19 10 sav/build10f_tport.sav

CDM

Simulated Nitrate (mg/L) in Upper Surficial Aquifer
High Flow Model
Leachate Infiltration Rate of 7.5 inches/year
Nitrate Method #1 (Kd)

FIGURE
7-10

60112



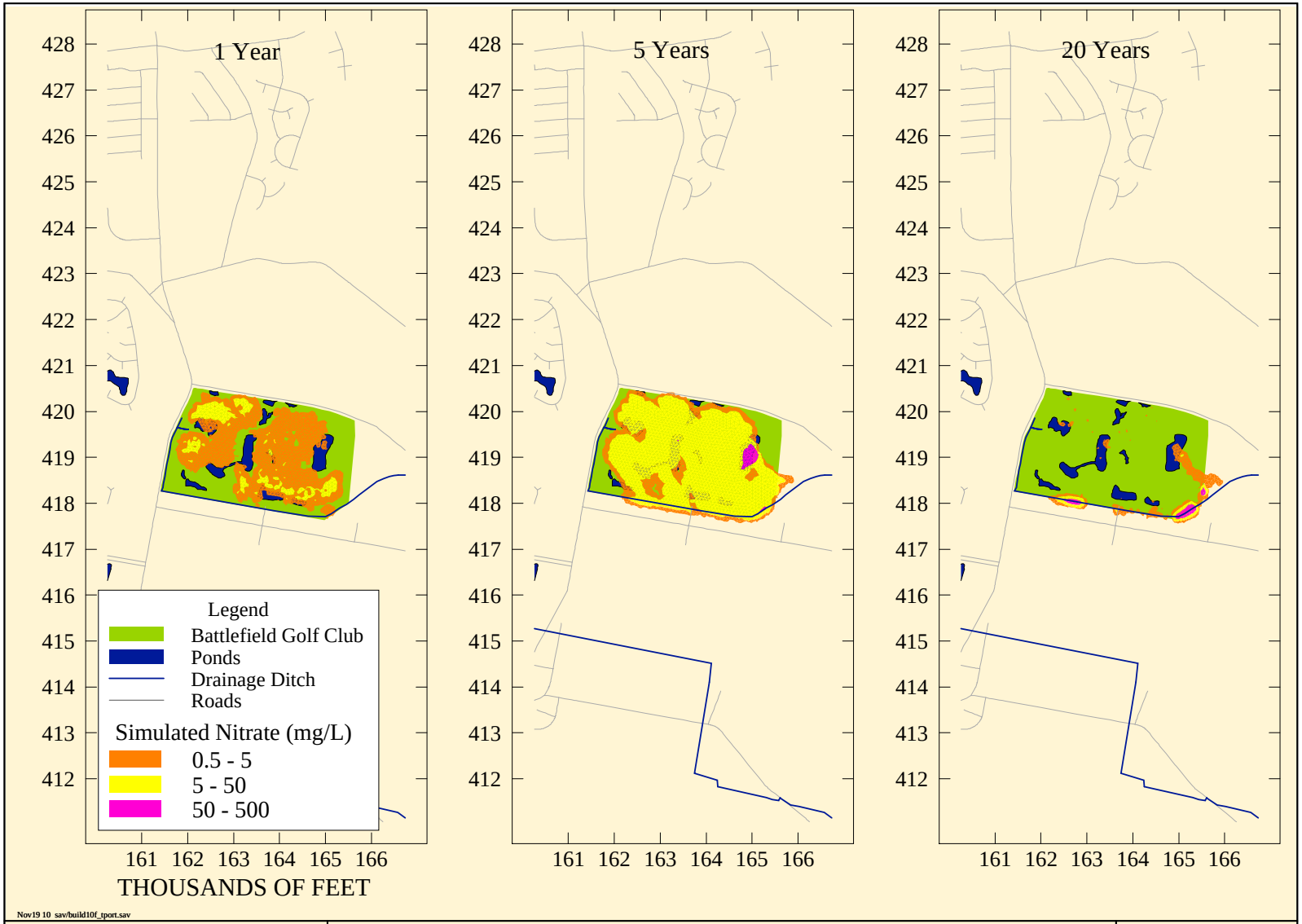
Nov19 10 sav/build10f_tport.sav

CDM

Simulated Nitrate (mg/L) in Upper Surficial Aquifer
High Flow Model
Leachate Infiltration Rate of 15.8 inches/year
Nitrate Method #1 (Kd)

FIGURE
7-11

60113



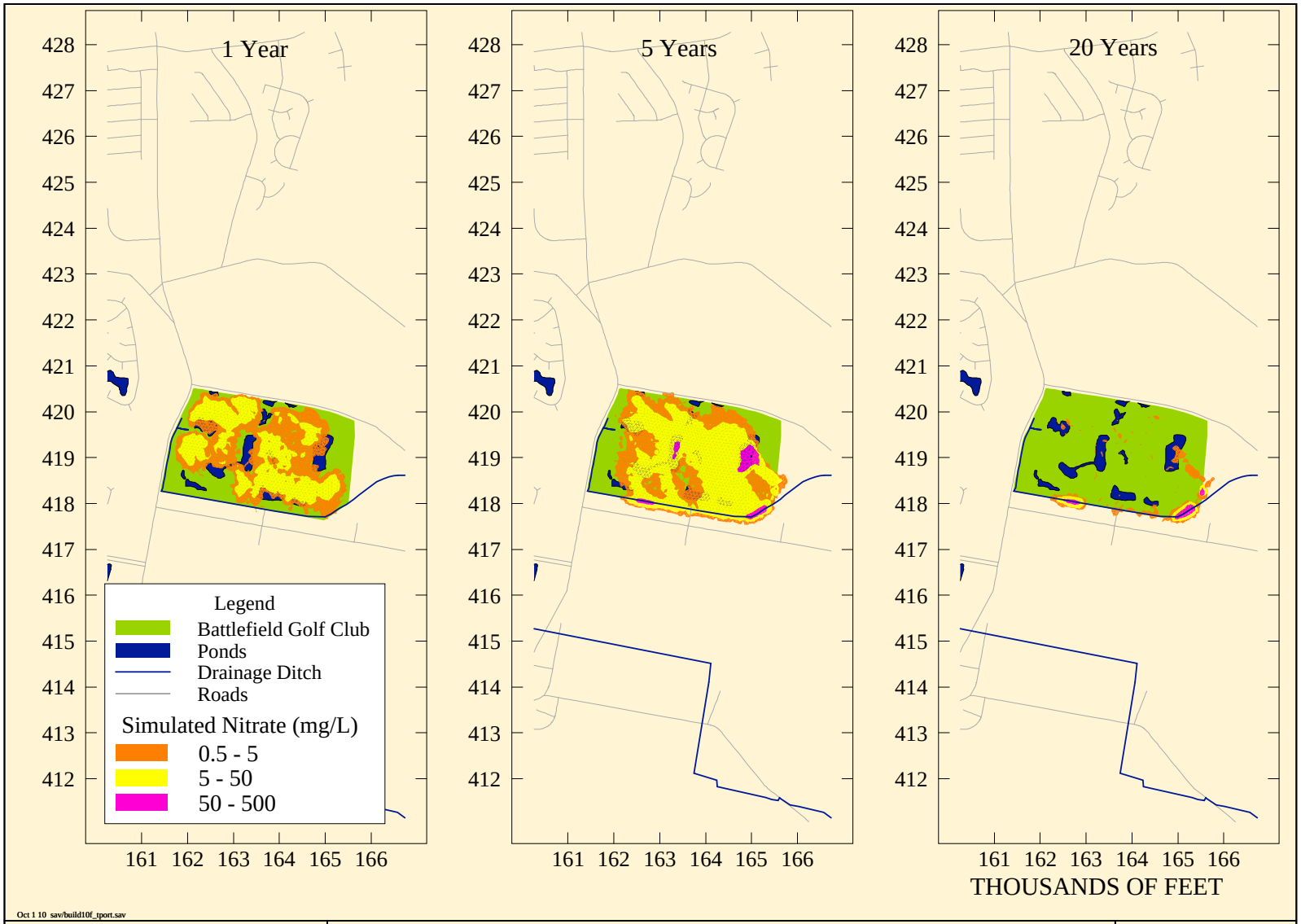
Nov19 10 sav/build10f_tport.sav

CDM

Simulated Nitrate (mg/L) in Upper Surficial Aquifer
High Flow Model
Leachate Infiltration Rate of 7.5 inches/year
Nitrate Method #2 (Pore Volume)

FIGURE
7-12

60114



CDM

Simulated Nitrate (mg/L) in Upper Surficial Aquifer
High Flow Model
Leachate Infiltration Rate of 15.8 inches/year
Nitrate Method #2 (Pore Volume)

FIGURE
7-13

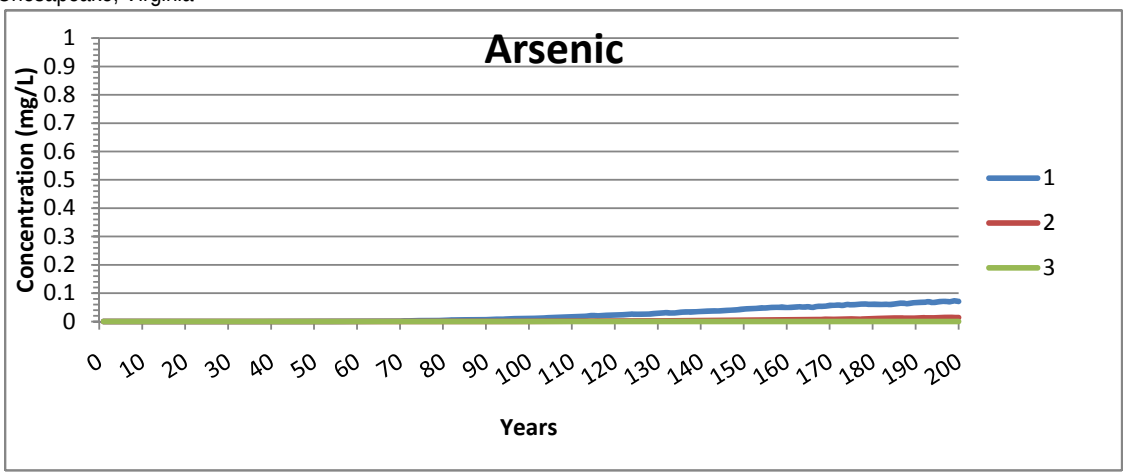
60115

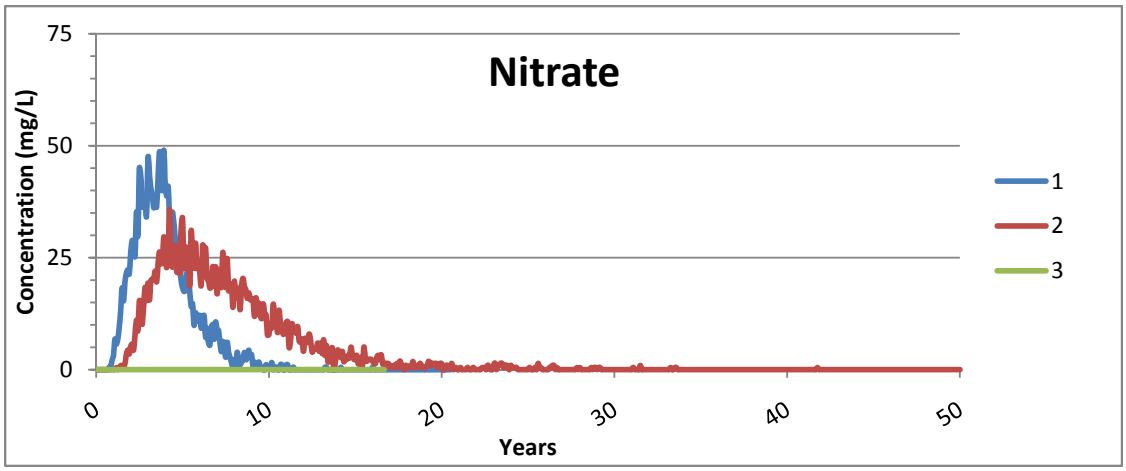
Figure 7-14: Time History of Simulated Constituent Concentrations at Three Locations in the Surficial Aquifer

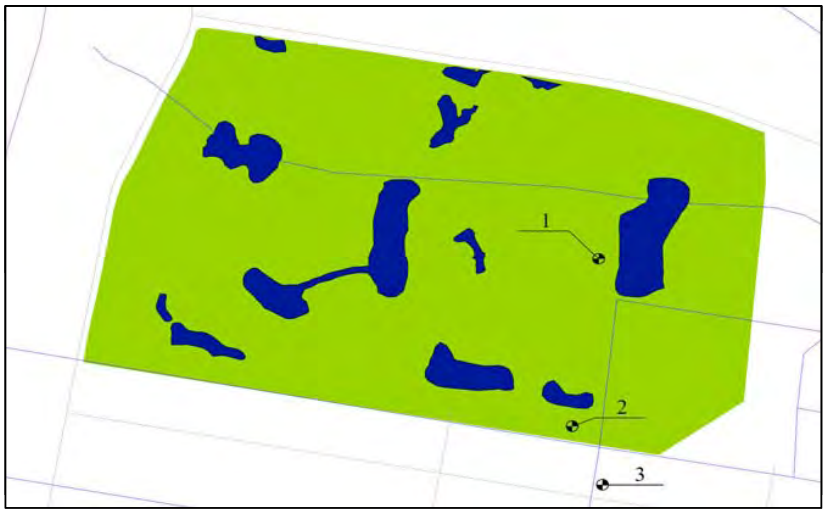
Hydrogeologic Investigation and Groundwater Modeling Report

Battlefield Golf Club

Chesapeake, Virginia







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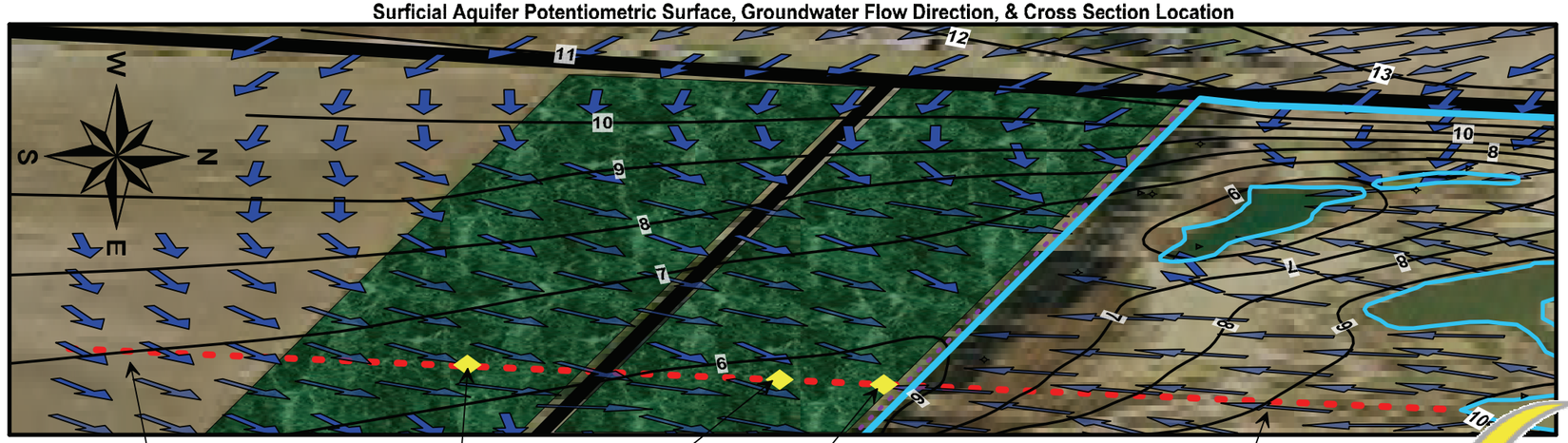
Diagramatic Illustration for Demonstrative Purposes

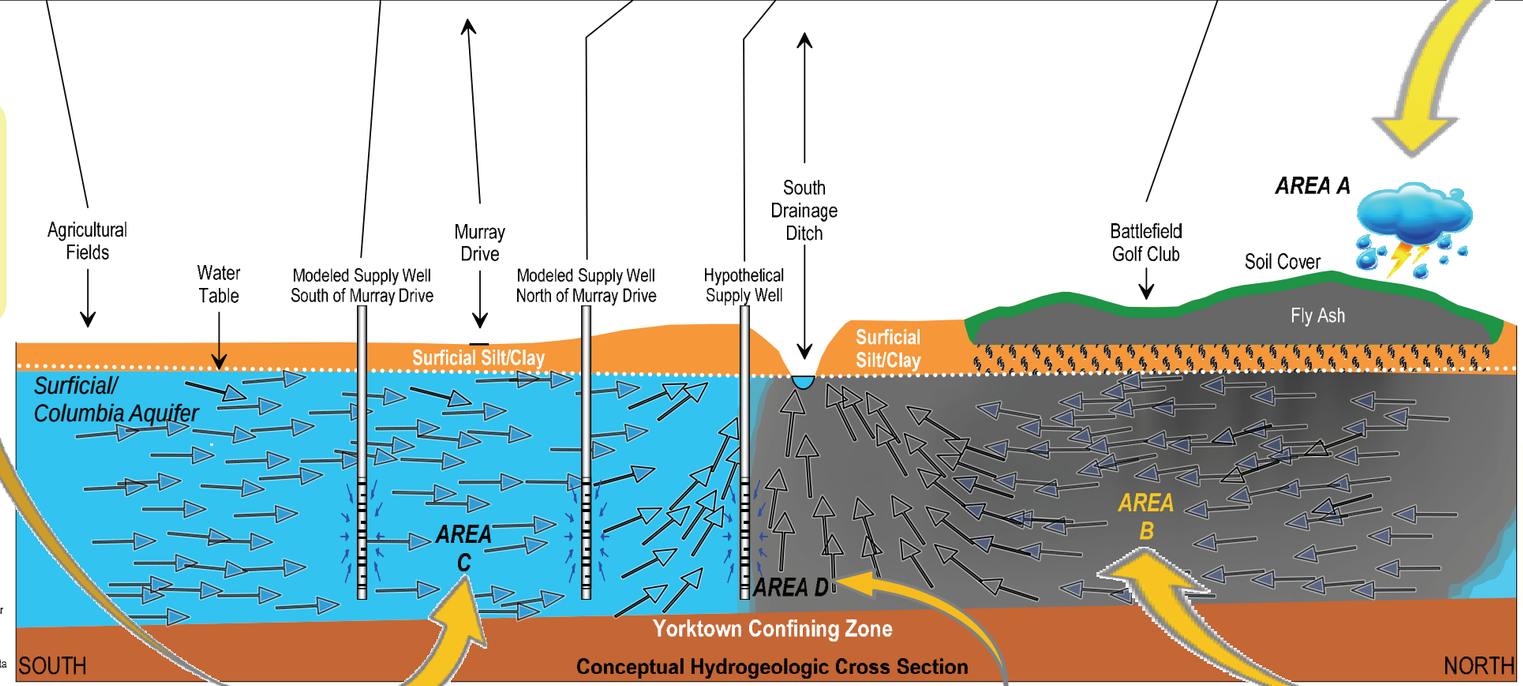
The **Surficial Aquifer**, or **Columbia aquifer**, is used for water supply by some residential wells in the site vicinity. Deeper supply wells also exist in the underlying **Yorktown Eastover aquifer** , which is confined from above by the low permeability **Yorktown Confining Zone**. The regional groundwater flow direction is to the southeast and toward the Atlantic Ocean. In the site vicinity, the hydrogeologic investigation found that the localized **Surficial Aquifer** groundwater flowed toward the south drainage ditch and discharged into the ditch. This finding was based on the water table surface elevation mapping and water levels measured in the south drainage ditch. Variables that can effect whether groundwater discharge to the ditch continues include the ditch channel being deep enough to penetrate below the water table and the continued flow of the discharged groundwater downstream. Infilling of the channel, flow restrictions, and/or damming of the ditch could allow groundwater to flow beyond the ditch.

Surficial Aquifer Potentiometric Surface, Groundwater Flow Direction, & Cross Section Location



In **Area C**, the groundwater model simulations completed for this report and the well pumping assumptions indicate that the migrating constituents would not reach residential supply wells on the south side of Murray Drive. The model assumed that all residential wells were located in the approximate center of the individual properties and the assumed residential supply flow rate was approximately 650 gallons per day. The model simulations for the residential wells on the north side of Murray Drive likewise indicated that the constituents would not reach these supply wells if located in the center of the properties.

In **Area A**, rainfall and irrigation water can infiltrate the soil cover into the fly ash where constituents can leach and migrate through the silt/clay into the aquifer below. Over time, a plume in groundwater can result. Variables that influence the rate and magnitude of plume development include: annual rainfall; soil cover thickness and permeability; plant root zone depth and evapotranspiration rates; the leachability of constituents from the fly ash; and the quantity of total constituents available for leaching. Erosion or thinning of the soil cover and/or sparse vegetation over the cover could increase the constituent loading to groundwater.



Conceptual Hydrogeologic Cross Section

In **Area B**, constituents are assumed to leach into groundwater and migrate with the ambient flow to the south and toward the south drainage ditch. Variables that effect the constituent concentrations along the migration path in groundwater include aquifer parameters (i.e., hydraulic conductivity, hydraulic gradient, and effective porosity) and the constituent migration characteristics such as dispersion and diffusion.

In **Area D**, it is possible for a theoretical vertical plane extended downward from the ditch channel to the base of the aquifer to act as a "fence line" that constituents do not cross. However, it is equally possible for the constituents in groundwater to migrate to points immediately south of the ditch prior to discharging to the ditch. As a result, a hypothetical supply well under undetermined combinations of closer distances to the drainage ditch, increased well pumping rates, and small-scale variations in constituent migration paths, could withdraw groundwater containing constituents derived from the fly ash.

NOTE: This conceptual hydrogeologic model was prepared to describe in a qualitative manner the potential for constituent leaching from fly ash and migration in groundwater based on the findings, assumptions, and modeling limitations described in detail in this report. This conceptual hydrogeologic model is too generalized to support quantitative conclusions. Responsible quantitative conclusions must consider the full range of acceptable quantified data and assumptions detailed in this report.

Figure 8-1
Conceptual Hydrogeologic Model
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Battlefield Golf Club
Chesapeake, Virginia

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