Emery & Garrett Groundwater, Inc.
56 Main Street • P.O. Box 1578
Meredith, New Hampshire 03253
(603) 279-4425 *Fax (603) 279-8717*

March 23, 2012

Mr. Paul Howard, Jr.
Director of Environmental Services
306 N. Main Street
Culpeper, VA 22701

Dear Paul,

Please find enclosed Emery & Garrett Groundwater, Inc.'s (EGGI's) summary report for the Phase II groundwater investigation conducted to identify additional exploratory test well targets in the vicinity of the Culpeper County Laurel Valley Landfill in Culpeper County, Virginia.

I hope you find the information contained herein responsive to your needs. If you have any questions concerning this material, please do not hesitate to contact me.

Best regards,

Kenneth C. Hardcastle, Ph.D., PG
Senior Structural Geologist

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56 Main St. • P.O. Box 1578
Meredith, New Hampshire 03253
(603) 279-4425 *www.eggi.com* *Fax (603) 279-8717*

GROUNDWATER INVESTIGATION TO ASSESS THE POTENTIAL TO DEVELOP A PUBLIC WATER SUPPLY SOURCE NEAR THE CULPEPER COUNTY LAUREL VALLEY LANDFILL

CULPEPER COUNTY, VIRGINIA

March 2012

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CULPEPER COUNTY, VIRGINIA
March 2012

I. INTRODUCTION

This report summarizes Emery & Garrett Groundwater, Inc.'s (EGGI's) Phase II groundwater investigation conducted in the Study Areas identified on Figures 1 and 2 near the Culpeper Landfill in Culpeper County, Virginia. This study is an expansion of previous investigations in the region by Emery & Garrett Groundwater, Inc. (EGGI, 1998 and 2008)[1]. The goal of this current investigation is to identify additional exploratory test well targets that could be developed as public drinking water supplies in the vicinity of the Culpeper County Laurel Valley Landfill.

The Phase I investigation of the Culpeper County Regional Study Area by EGGI in 1998 provided the hydrogeologic context for conducting Phase II investigations (geophysical surveys) of the selected areas near the Culpeper Landfill. EGGI and Culpeper County personnel sent property access request letters to property owners to gain permission to enter specific land parcels that were considered favorable for groundwater development. Those property owners that granted permission for groundwater surveys to be conducted were then evaluated using a variety of geophysical techniques. These geophysical surveys were carried out in order to locate the optimal exploratory test well sites (Figure 2). A total of fourteen (14) drilling targets have been identified for future investigation; these sites are ranked in order of priority, *relative to each other*, such that CCO-L1 is considered more favorable than CCO-L2, etc. (Figures 3 and 4).

Subsequent phases of this groundwater exploration and development program will include the following:

Phase III	Drilling of exploratory test wells at identified target sites
Phase IV	Conversion of highest yielding exploratory test wells to larger-diameter Production Wells
Phase V	Assessment of available long-term sustainable yields and groundwater quality
Phase VI	Preparation of a Final Hydrogeologic Report and Groundwater Use Management Plan

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[1]Six exploratory test well targets that were previously identified in Groundwater Water Development Zones CCO-17 and CCO-18 were re-evaluated and incorporated into the study presented herein.

II. PHASE II INVESTIGATION

A. Geophysical Methods/Introduction

Geologic contacts, fractures, faults, and other bedrock discontinuities are often the primary pathways for groundwater migration and storage in otherwise impermeable bedrock, such as that underlying the study area[2]. These geologic features commonly cause changes in the physical characteristics of bedrock that can be detected "remotely" using geophysical instruments.

Variations in the magnetic characteristics of rocks, caused by such geologic discontinuities, result in measurable deflections in the earth's magnetic field. Similarly, local variations in the electrical resistivity of the bedrock (and the overlying unconsolidated regolith) create measurable deviations in electromagnetic fields that propagate from VLF (Very Low Frequency) radio transmitters. Changes in bedrock resistivity can also be measured using electrical resistivity methods.[3]

The geophysical surveys performed on this project were conducted in two parts. The initial investigations included conducting a grid-work of magnetometer/VLF surveys. Key areas were then further investigated in more detail by conducting electrical resistivity surveys in order to specifically locate (pinpoint) exploratory test well drilling targets.

1) Magnetometer/VLF

A SCINTREX ENVI MAG/VLF instrument equipped with a magnetometer and VLF receiver was used in this study to measure the earth's magnetic field and the VLF electromagnetic field. ***Magnetic and VLF measurements were obtained along approximately 94,400 feet (≈17.8 miles) of survey lines*** (Figure 2; Appendix A). The earth's magnetic field and the electromagnetic fields associated with the VLF stations were measured along these survey lines at 10 pace (approximately 28 feet) intervals.

2) Electrical Resistivity Surveys

Electrical resistivity surveys were conducted using automated ABEM resistivity equipment. ***Approximately 26,200 feet (~5 miles) of electrical resistivity surveys were conducted.*** The locations of these resistivity surveys are shown on Figure 2; profiles of the data are provided in Appendices B and C. This geophysical method involves the measurement of induced electrical flow through subsurface materials, which serves to define the depth to bedrock and type of subsurface material (e.g., unconsolidated sediment, saprolite, bedrock). Electrical resistivity measurements of the subsurface materials were taken along the survey lines using arrays of 41 or more stainless steel electrodes spaced at ten-meter intervals. The gradient and dipole-dipole

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[2] Please refer to EGGI's 1998 Phase I report for further details on the hydrogeologic conditions of the study areas.
[3] Publications written by Telford, et al., 1983, Wright, 1988, and Loke and Barker, 1996 contain detailed descriptions of magnetic, VLF, and resistivity geophysical methods.

methods of collecting electrical resistivity data used in this study resulted in the collection of as many as 984 resistivity measurements for *each* completed survey line.

These resistivity data were analyzed using computer-modeling software. The results of the analyses are displayed in color contoured cross-sectional resistivity models of the subsurface areas investigated (Appendices B and C). The higher resistivity values displayed in the models (typically shown as green to purple-red color contour intervals) represent competent bedrock. The lower resistivity values (usually shown as blue colored contour intervals) have electrical resistivity values typical of saturated unconsolidated sediments, saprolite (bedrock weathering residuum) or fractured bedrock.

B. Findings of the Magnetometer and VLF Surveys

Analysis of the magnetic field measurements collected during this survey shows that the magnetic field generally ranged between 51,000 and 52,000 gammas (the unit used to express the strength of the earth's magnetic field).

Several magnetic anomalies were detected which helped direct the detailed geophysical (electrical resistivity) surveys and aided in the identification of specific exploratory test well sites (Appendix A). For example, survey line L150 shows a distinct change from steady magnetic signals to those that are more erratic, indicating a change in subsurface conditions. Exploratory test well site CCO-L4 is located to intercept potentially disrupted bedrock indicated by this change in magnetic signature.

Analysis of the VLF survey data resulted in the identification of several potential bedrock discontinuities that are considered likely candidates for enhanced groundwater flow (Appendix A). The VLF surveys also provided guidance for where electrical resistivity surveys should be carried out.

C. Findings of the ABEM Resistivity Surveys

The color contoured cross-sections of the modeled resistivity data show that the electrical resistivities of the geologic materials below the project site range from approximately 50 to >15,000 ohmmeters. Exploratory test well targets were identified at the transition between less resistive materials (such as unconsolidated sediments, weathered bedrock, or fracture zones) and competent bedrock (Appendices B and C).

A few of the geophysical data profiles delineate discrete regions within the bedrock that are relatively conductive, suggesting the presence of moderately transmissive fracture features. Exploratory test wells are located to intercept disrupted bedrock, and layers of bedrock have contrasting characteristics, as revealed through the profiles of electrical resistivity data (Appendices B and C). For example, proposed exploratory test well CCO-L2 was selected to intercept a distinct, vertical to steeply dipping bedrock structure interpreted to be a fracture zone, as seen on the profile of data for survey line R3G and R3D.

D. Results of the Geophysical Surveys

Analysis of the geophysical data generated during this investigation, combined with exploratory targets identified during previous work efforts, resulted in the identification of fourteen (14) exploratory test well sites in the area of the Laurel Valley Landfill. The locations of all of the geophysical survey lines and the selected exploratory well sites are presented on Figures 2, 3 and 4. Detailed geophysical profiles developed from each survey line are found in Appendices A and B. The proposed sites are ranked according to their relative favorability, such that CCO-L1 is considered more favorable for groundwater development than CCO-L2, etc. In addition, EGGI has further subdivided the fourteen (14) proposed exploratory test well targets into two groups, **Primary, and Secondary**. The **Primary** targets consist of proposed test Wells CCO-L1, CCO-L2, CCO-L3, CCO-L4, CCO-17A, and CCO-17B; the **Secondary** targets consist of proposed test Wells CCO-L5, CCO-L6, CCO-L7, CCO-L8, CCO-17C, CCO-17D, CCO-18A, and CCO-18B. Please be aware that the proposed priority of exploratory test well targets is subject to be changed based on the results of the initial drilling program.

III. CONCLUSIONS/RECOMMENDATIONS

Based upon the hydrogeologic data collected to date, EGGI recommends that this groundwater exploration program proceed to Phase III (exploratory test well drilling). The hydrogeologic conditions of the project site, as defined by Phase I and II investigations, served to identify a total of fourteen (14) exploratory test well drilling sites (Table I and Figures 3 and 4).

A relative ranking of the proposed exploratory test well sites identified in all areas investigated, is as follows:

1) **Primary Exploratory Test Well Sites**
   Exploratory test well sites CCO-L1, CCO-L2, CCO-L3, CCO-L4, CCO-17A, and CCO-17B

2) **Secondary Exploratory Test Well Sites**
   CCO-L5, CCO-L6, CCO-L7, CCO-L8, CCO-17C, CCO-17D, and CCO-18A, and CCO-18B.

We recommend that the **Primary** test well sites be drilled first during an initial exploratory drilling program. Throughout the exploratory drilling program (Phase III), preliminary yields will be measured using the drill rig by airlifting water from the borehole.[4] Test wells yielding the greatest quantities of water with the highest quality should be given further consideration for conversion to production wells (Phase IV).

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[4] Airlift tests involve using the drill rig to "airlift" water out of the well during the drilling process, such that a preliminary measurement can be made of the well's yield.

It is very difficult, if not impossible, to predict the ultimate yields of wells targeted for drilling or even the total capacity of a selected groundwater development zone to produce water prior to subsurface investigation (i.e., test well drilling, and/or long-term pumping yield tests). The study areas investigated near the Culpeper Landfill are not considered highly favorable relative to other areas in the region (EGGI, 2008). However, based upon our combined experiences and the hydrogeological data we have collected and evaluated to date, we believe that the potential exists for the development of 100-150+ gallons per minute (150,000-225,000 gallons per day) of groundwater from fractured bedrock aquifers in the Study Areas investigated (Figure 1).

If the exploratory drilling program is successful, the estimated sustainable yield and quality of any well or well field (and associated off-site impacts) will need to be determined with the aid of properly conducted long-term pumping tests (Phase V). At the conclusion of the groundwater testing program, a Final Hydrogeologic Report and Groundwater Use Operations Plan (Phase VI) will be prepared that will describe the volume of water that is recommended for long-term withdrawal from each well.

IV. LIMITATIONS

EGGI has collected and evaluated the available technical data according to professionally accepted scientific standards. The conclusions and recommendations provided herein represent EGGI's professional opinion based upon the hydrogeologic data collected and do not constitute a warranty written or implied.

V. REFERENCES

EGGI, 1998, Groundwater Exploration and Development – Results of Phase I Investigation, Proposed Culpeper County Water Service Area.

EGGI, 2008, Culpeper Study Areas A and B Groundwater Investigation - Selection Of Proposed Exploratory Test Well Sites (Results Of Phase II – Geophysical Surveys), Culpeper County, Virginia.

Loke M.H. and Barker, R.D., 1996, Rapid least squares inversion of apparent resistivity pseudosections by a quasi-Newton method, Geophysical Prospecting, 44, 131-152.

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1983, Applied Geophysics, Cambridge University Press, Cambridge, England, 860 pg.

Wright, J.L., 1988, VLF Interpretation Manual, EDA Instruments, Inc., Toronto, Canada.

FIGURES

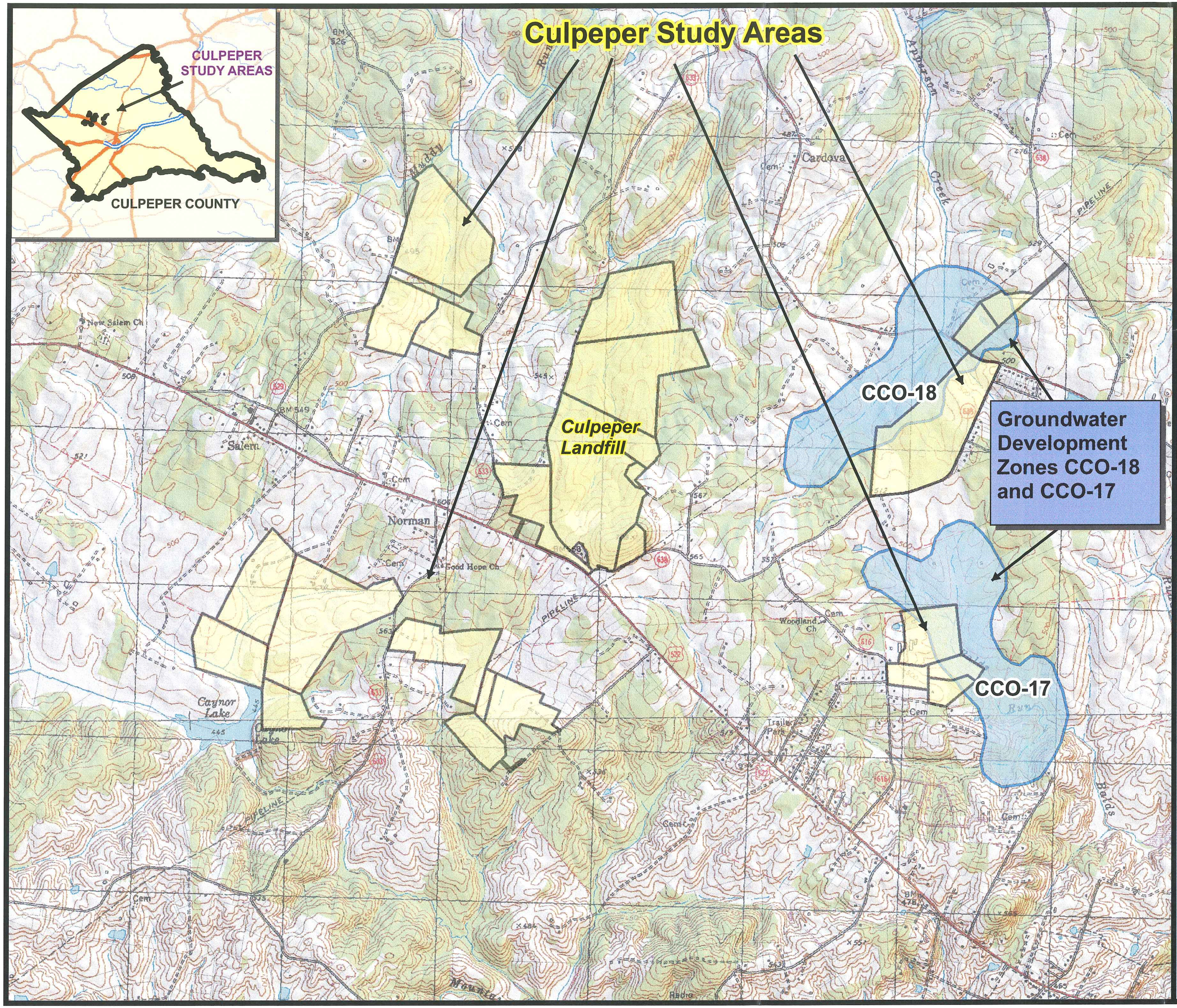

FIGURE 1

Topographic Setting of the Study Areas near the Culpeper Landfill Culpeper County, Virginia

Legend

- Land Parcels Where Access for Conducting Geophysical Surveys was Granted
- Previously Identified Groundwater Development Zones (2008)

N

Scale is 1:24,000

0 0.25 0.5 1 Miles

0 0.25 0.5 1 Kilometers

FIGURE 1

Emery & Garrett Groundwater, Inc.

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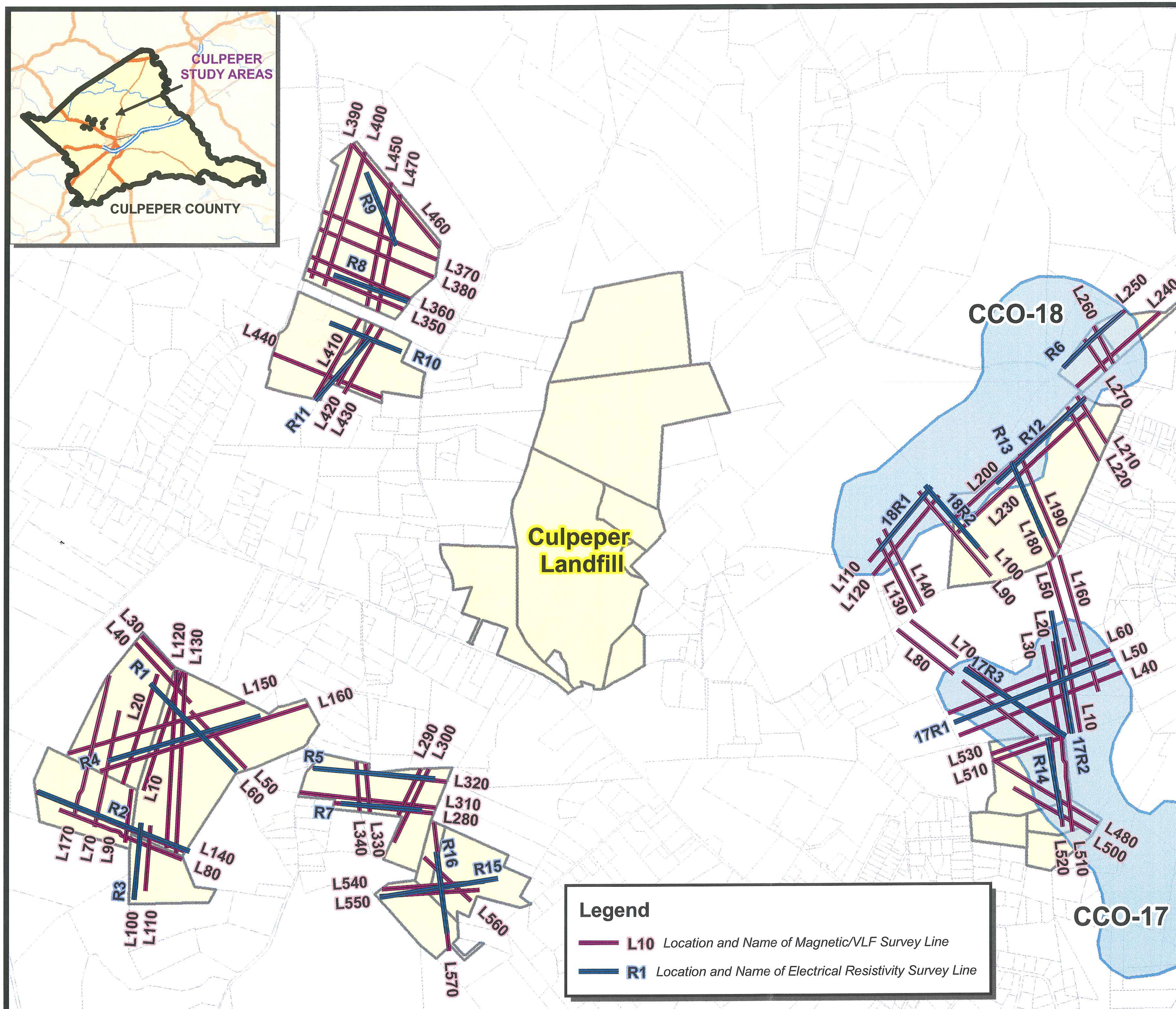

FIGURE 2

Geophysical Surveys Completed in the Study Areas near the Culpeper Landfill Culpeper County, Virginia

Culpeper Study Areas

- Land Parcels Where Access for Conducting Geophysical Surveys was Granted
- Previously Identified Groundwater Development Zones (2008)

N

Scale is 1:18,000

0 750 1,500 3,000 Feet

0 150 300 600 Meters

FIGURE 2

Emery & Garrett Groundwater, Inc.

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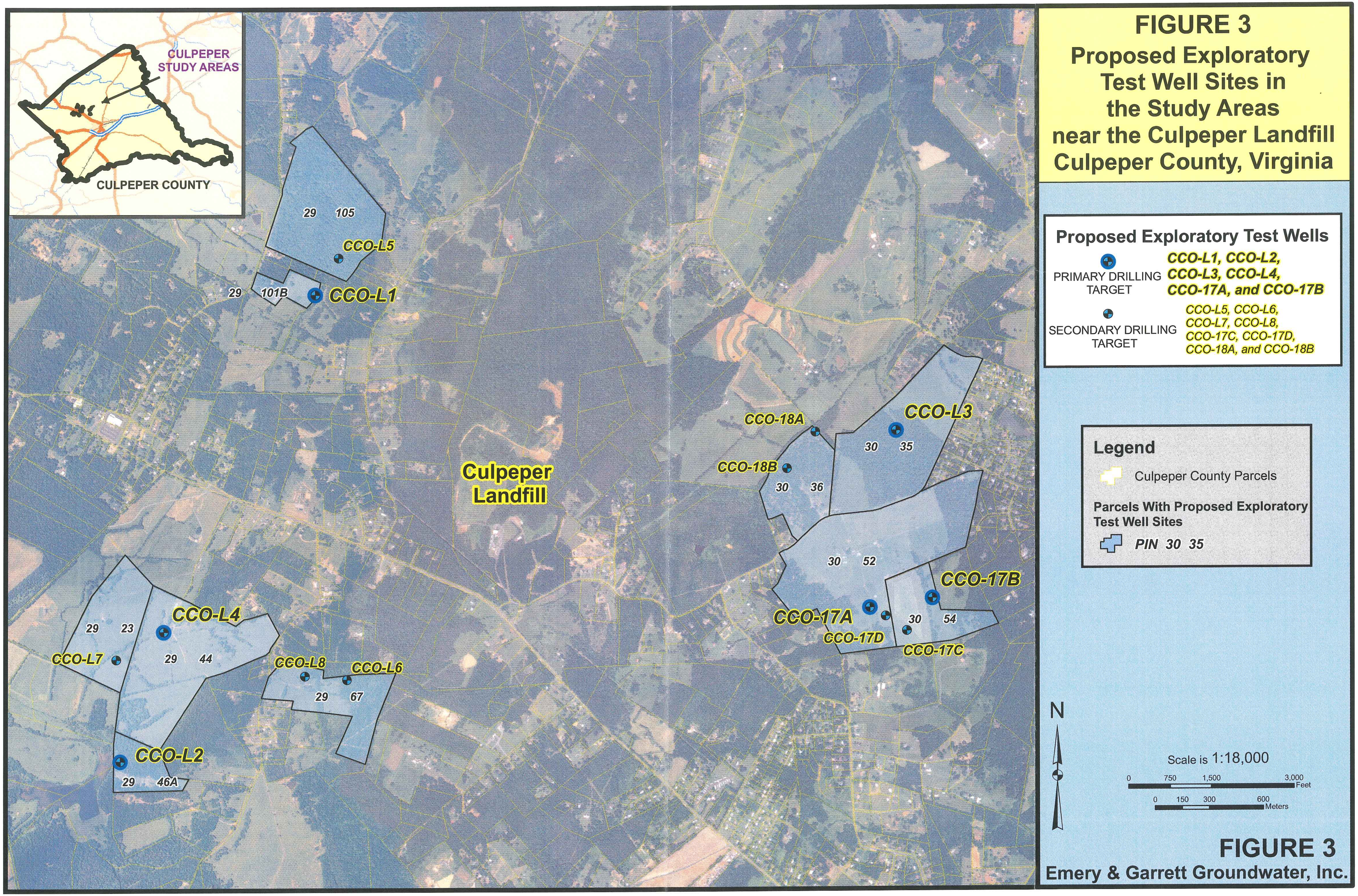

FIGURE 3
Proposed Exploratory Test Well Sites in the Study Areas near the Culpeper Landfill Culpeper County, Virginia

FIGURE 3
Emery & Garrett Groundwater, Inc.

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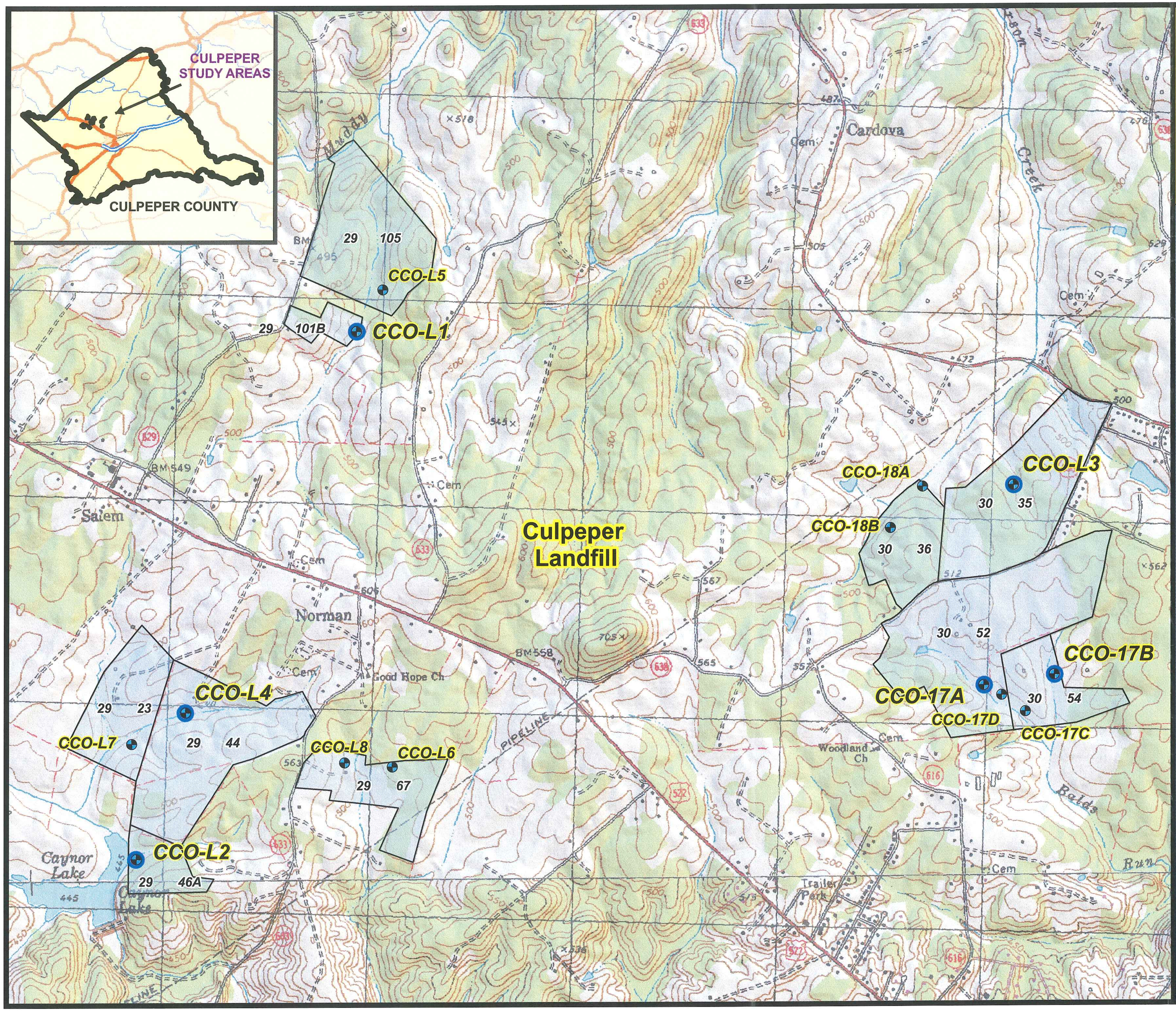

FIGURE 4

Proposed Exploratory Test Well Sites in the Study Areas near the Culpeper Landfill Culpeper County, Virginia

Proposed Exploratory Test Wells

PRIMARY DRILLING TARGET	CCO-L1, CCO-L2, CCO-L3, CCO-L4, CCO-17A, and CCO-17B
SECONDARY DRILLING TARGET	CCO-L5, CCO-L6, CCO-L7, CCO-L8, CCO-17C, CCO-17D, CCO-18A, and CCO-18B

Legend

Parcels With Proposed Exploratory Test Well Sites

PIN 30 35

Scale is 1:18,000

0 750 1,500 3,000 Feet

0 150 300 600 Meters

FIGURE 4

Emery & Garrett Groundwater, Inc.

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TABLE

Emery & Garrett Groundwater, Inc.

TABLE I
PROPOSED EXPLORATORY TEST WELLS
GROUNDWATER INVESTIGATION TO ASSESS THE POTENTIAL TO DEVELOP A PUBLIC WATER SUPPLY SOURCE NEAR THE CULPEPER COUNTY LANDFILL
CULPEPER COUNTY, VIRGINIA

Well ID	PIN	Owner Name
CCO-L1	**29 101B**	**BOFINGER, CHARLENE**
CCO-L2	**29 46A**	**TROY, JOSEPH N JR TEE ET AL**
CCO-L3	**30 35**	**HILL, JAMES MALCOLM ET UX**
CCO-L4	**29 44**	**SETTLE, DOROTHY KEITH ET AL**
CCO-L5	29 105	LARSEN, NORMAN L TEE ET AL
CCO-L6	29 67	BEATEY, DONALD L
CCO-L7	29 23	BYLER, DANIEL S ET UX
CCO-L8	29 67	BEATEY, DONALD L
CCO-17A	**30 52**	**HILL, JAMES MALCOLM ET UX**
CCO-17B	**30 54**	**HILL, JAMES MALCOLM ET UX**
CCO-17C	30 54	HILL, JAMES MALCOLM ET UX
CCO-17D	30 52	HILL, JAMES MALCOLM ET UX
CCO-18A	30 36	HILL, JAMES MALCOLM ET UX
CCO-18B	30 36	HILL, JAMES MALCOLM ET UX
PRIMARY Drilling Targets are Highlighted		