Memo

To:	Mr. Dustin Armstrong (DEP)
From:	Timothy Uhler (GES) Frank DiGnazio, P.G. (GES)
cc:	Russ Devan, P.G. (DEP) Joshua Crooks (DEP)
Date:	January 7, 2022
Re:	Technical Memorandum GTAC 7-1-343 – Nockamixon TCE Site Nockamixon Township, Bucks County, Pennsylvania

Groundwater & Environmental Services, Inc. (GES) has prepared this Technical Memorandum on behalf of the Pennsylvania Department of Environmental Protection (DEP) for the Nockamixon TCE Site (Site), located in Nockamixon Township, Bucks County, Pennsylvania. The purpose of this Technical Memorandum is to: discuss the components and results of a fracture-trace study and surficial geophysical investigation conducted as part of recent site investigation activities; and to make recommendations for future work at the Site based on the new information obtained from these studies.

Background

The Site area includes multiple residential and commercial properties located along Durham Road, Easton Road, Cord Road, Mountain View Drive, Tower Road, Brennan Road, and Park Drive West in Nockamixon Township, Bucks County, Pennsylvania. The source of the groundwater contaminant plume has been identified as a former 77.2-acre farm (Schulberger Farm) located on Brennan Road. The Site area is rural and comprises undeveloped land, farmland, residences, and businesses. A school is located on Durham Road and a quarry is located east of Easton Road. Nockamixon State Park is located to the west and southwest, and the Revere Chemical NPL Site is located northeast of the Site. A Site Location Map is included as **Figure 1** and a Site Layout Map is included as **Figure 2**.

Groundwater contamination was initially discovered at the Site in 2002 when public water supply sampling was conducted at a restaurant located at the intersection of Durham Road and Easton Road by the Bucks County Health Department (BCHD). Laboratory data indicated that trichloroethene (TCE) was detected in the restaurant supply well. In subsequent potable well sampling conducted by the DEP, additional contaminated wells were identified on Durham Road, Easton Road, Cord Road, Mountain View Drive, Tower Road, Brennan Road, and Park Drive West. To date, more than 100 potable wells have been sampled, with 42 of those wells exceeding the Maximum Contaminant Level (MCL) of 5 micrograms per liter (µg/L) for TCE. In addition to

TCE, tetrachloroethene (PCE), 1,1-dichloroethene (1,1-DCE) have also been detected above their respective MCLs in at least one potable well. The DEP funded the installation of point-of-entry treatment (POET) systems for each of the residential private well water supplies with concentrations of contaminants which exceeded the MCLs.

Based upon groundwater sampling results, aerial photography analysis, and other investigations, the former Schulberger Farm has been identified as the source of contamination. The 77.2-acre Schulberger Farm, which was subdivided into eight parcels in 1978, housed drums of unknown contents which were removed from the Site in 1980. The source areas primarily include two drum storage areas: one in the northeast area of the former farm and one in the southwest. In addition to the drums, evidence suggests that other wastes may have been deposited or buried at the Site. Soil sampling, passive soil gas screening, and active soil gas screening investigations revealed elevated concentrations of chlorinated solvents in the areas where the former drums had been stored.

Site-Specific Geology and Hydrogeology

The local geologic and hydrogeologic conditions have been examined in a number of Site investigation activities and are described as follows.

Local Geologic Conditions

The work of previous consultants described the geology at the Site as comprising bedrock of the Triassic to Jurassic-aged Brunswick and Lockatong Formations overlain by unconsolidated soils. The unconsolidated overburden soils were identified as the Reaville channery silt loam, which is classified as farmland of statewide importance and is characterized as somewhat poorly drained with a very high potential for runoff.

Bedrock at the Site is relatively shallow, particularly in the vicinity of the former drum storage areas. Measured depths to bedrock (soil thicknesses) at the Site have been observed to range from one foot below ground surface (bgs) to 14.5 feet bgs, with an average of 5.8 feet bgs.

Based on a previous assessment completed by GES and included in the Conceptual Site Model (CSM) submitted with the Final Remedial Investigation Work Plan for the Site, the top of bedrock is observed to dip to the southwest in the northern project area in the vicinity of the suspected source areas and to the west further south in the project area. It should be noted that the northeast former drum storage area is located on the western edge of the bedrock high, and the southwest former drum storage area is located slightly down dip from the northeast drum storage area. A geologic map, published by the Pennsylvania Geological Survey was reviewed to assess bedrock structure in the area. Bedrock strike and dip measurements provided on this Pennsylvania Geological Survey map for the Site vicinity range from a north-south strike with a westerly dip direction to a northwest-southeast strike with a southwesterly dip direction, which are consistent with the observed structure contours for the Site vicinity. This bedrock structure appears to strongly influence groundwater flow and contaminant plume distributions in groundwater.

Local Hydrogeologic Conditions

Unconsolidated overburden soils do not contain a water-bearing zone. At times of heavy recharge, these materials are wet, as water slowly percolates and recharges the bedrock aquifer; however, there is no true overburden aquifer present at the Site. The water table only begins at a significant depth within the bedrock unit.

The Brunswick and Lockatong Formation aquifers have been described by Morin et. al (2000) in a study conducted on seven wells in nearby Lansdale, Pennsylvania, as follows:

The Brunswick Group and the underlying Lockatong Formation are composed of lithified Mesozoic sediments that constitute part of the Newark Basin in southeastern Pennsylvania. These fractured rocks form an important regional aquifer that consists of gradational sequences of shale, siltstone, and sandstone, with fluid transport occurring primarily in fractures.

Additionally, Inners (1980) describes development of secondary porosity features in these rock units in nearby Nockamixon State Park, in the following:

Joints, or naturally occurring, mostly planar fractures, are extremely well developed in the rocks underlying Nockamixon Park. Several distinct groups, consisting of near-vertical fractures that repeat at regular intervals, are present at most outcrops….. Generally, they are spaced less than 12 inches apart in the sedimentary rocks and hornfels and 12 to 48 inches apart in the diabase.

From this information, it is expected that groundwater flow in the bedrock aquifer will be dominated by movement through well-developed and regularly-spaced secondary porosity features, including movement along bedding plane partitions and through joint development. Given that this secondary porosity is well developed and regularly spaced, it is assumed that plume movement in the aquifer will behave similarly to a homogenous aquifer, but with the possibility for some deflections of plume movement associated with the orientation of the secondary porosity features. Irregular plume movement and distribution like what would be associated with a karst environment is not expected here.

Groundwater in the vicinity of the Site has been investigated through the installation of a series of bedrock monitoring wells at 12 locations. A number of the locations include nested well pairs to separate the upper and lower portion of the aquifer. Monitoring wells completed in the shallower upper zone of the bedrock aquifer have depths ranging from 119-196 feet bgs, with an average depth of 149 feet bgs. Monitoring wells completed in the deeper portion of the bedrock aquifer or left as open holes have depths ranging from 187-300 feet bgs, with an average depth of 250 feet bgs.

Additional details related to Site hydrogeology are included in the CSM included in the Final Remedial Investigation Work Plan prepared by GES and submitted to DEP on April 28, 2021.

Fracture Trace Study

To assist in positioning electrical resistivity imaging (ERI) profile locations, a fracture trace study was conducted in order to identify potential fractures trending through the Site. Fracture trace

involves the examination of remotely sensed data (e.g., aerial photographs), topographic maps, and other landform data to identify linear features on the surface that could be representative of subsurface secondary porosity features, such as fractures, faults, and joints that could influence groundwater flow. The fracture trace study for this Site consisted of a desktop study (macro-scale examination of the area using geological and topographic maps) and field verification of the desktop results.

Due to the relatively small scale of the Site and the necessity to strategically locate the ERI profile locations, the desktop study was conducted using Light Detection and Ranging (LiDAR) topographic contours as the primary means to identify potential linear features for field examination. Linear features identified through LiDAR appeared to follow the northwest bedrock strike direction and the southwest dip direction, suggesting that these linear features may be representative of fractures and joints in the underlying bedrock.

On May 25, 2021, GES conducted a site visit to locate and verify site features identified during the desktop study. GES located the anticipated features and collected global positioning system (GPS) data and orientation of these surface features. The suspected primary fracture feature from the source area and overall linear features orientations correlated with the contamination plume shape. Additionally, GES identified a surface water feature and wetland area to the southwest of the Site, and along the suspected primary fracture feature. This is likely an area of groundwater discharge to surface water. While conducting the desktop fracture trace analysis, GES did identify an additional potential surface feature to the northwest of the primary fracture feature; however, this property was not accessible during the site visit to inspect the area. These results were reviewed with the PADEP via teleconference on May 27, 2021. The presentation materials used to facilitate that teleconference are presented in **Attachment A** of this Technical Memorandum.

Surficial Geophysical Investigation

GES, along with our subcontractor Advanced Geological Services, Inc. (AGS), designed a surficial geophysical investigation and selected ERI profile locations based on the results of the fracture trace analysis. The ERI profiles were established in northeast-southwest and northwest-southeast trending orientations in an attempt to orthogonally intersect the linear Site features identified during the fracture-trace study. These orientations would best image any potential secondary porosity features formed along the primary bedrock strike and jointing directions and low for tracing their progression, if any, across the Site.

From June 24-30, 2021, GES performed oversight of the surficial geophysical investigation. ERI was completed along seven (7) profiles. The profiles were collected using a standard dipole-dipole configuration. The ERI profiles consisted of a series of electrodes spaced 10 to 15 feet apart. The profiles provided a maximum depth of investigation to between approximately 175 feet and 275 feet.

Resistivity methods measure the resistivity structure of subsurface materials using a direct current electrical source. A direct current signal is injected into the ground between two transmitting electrodes. The voltage is then measured between two receiving (potential) electrodes. The

measured voltage is converted into apparent resistivity using algorithms that take into account the geometry of the dipole-dipole electrode array.

Apparent resistivity is a function of the porosity, permeability, water content, and ionic makeup of the material. Consequently, soils or rocks that contain a high percentage of clay minerals, such as shale, and a high water content generally have a low apparent resistivity. On the other hand, a clean sand or sandstone with few free ions will have a relatively high apparent resistivity.

The results of the ERI profiles are included in the ERI Investigation Results Report prepared by AGS, Inc. (**Attachment B)**. Additional detail on the methodologies and the field implementation of ERI technology is summarized within the AGS report.

Evaluation of Fracture Trace Study and Surficial Geophysical Investigation

GES completed a thorough evaluation of all data collected during the fracture trace study and surficial geophysical investigation to determine bedrock structure and fracture depth and orientation. The ERI profiles corroborated the information obtained from the desktop and field fracture trace study activities. The orientations of the fractures in the bedrock on-site were confirmed to be consistent with the bedrock strike and jointing along dip directions previously identified (i.e., northwest to southeast and northeast to southwest).

Potential bedrock fracture zones (FRZ) identified during the ERI investigation are identified as FRZ-A through FRZ-H and interpolated as blue dashed lines connecting through the ERI profiles (ERI-1 through ERI-7) in Figure 1 of the AGS, Inc. ERI Investigation Results Report (**Attachment B**). GES imported these imaging results from ERI-1 through ERI-7 into a geographic information system (GIS) and conducted a thorough analysis of the new data with respect to the existing comprehensive Site conceptual model dataset (e.g., fracture trace results, groundwater plume results, bedrock surface mapping, etc.) to assess the location and scale of each of the fracture zones. The components and results of this GIS analysis were reviewed with PADEP representatives using the GIS system during an online interactive presentation on August 11, 2021. Based on the results of this analysis, it was determined that the most significant fracture features (FRZ-B and FRZ-C) are oriented northeast to southwest, which is consistent with the primary jointing/fracturing direction identified during the desktop and field fracture trace study. Given the expected interconnection of the primary joint/fracture sets, GES concluded that FRZ-B and FRZ-C are the two primary features that are likely transporting groundwater, which is consistent with the localized groundwater flow direction (to the southwest) and eventual downgradient location of the offsite surface water feature. Additionally, FRZ-B and FRZ-C are assumed to be the main connection between current impacted monitoring wells MW-1 and MW-2. GES is recommending rock coring activities aimed at targeting these primary features to assess any residual source material present in the bedrock and to obtain additional downhole geophysical data from the boreholes. More details regarding recommendations for additional Site investigation based on the ERI data are presented in the following.

Recommendations for Additional Remedial Investigation Activities

Based on the evaluation of the data obtained from the fracture trace study and surficial geophysical investigation, GES has prepared the following recommendations for additional remedial investigation activities. Please note that the majority of these recommendations were included in the Final Remedial Investigation Work Plan and Cost Estimate, but had not been fully quantified, as the intention was to conduct this initial Fracture Trace and ERI phase of the remedial investigation to assist in making more specific recommendations. Details related to specific methodologies and sampling requirements of the recommended activities specified here are included in the Final Remedial Investigation Work Plan and Sampling Analysis Plan.

Additional Site Inspection

As indicated above, GES identified an additional potential surface water feature located on the property at 338 Park Drive West, which is northwest of the confirmed surface water feature. DEP has coordinated access to this property to complete a site visit and inspection of the feature. The primary objective of this site visit will be to identify any surface water or wetland features present on the property. GES will conduct an additional site visit to 338 Park Drive West as part of this scope of work and costs are included under **Task 3040** in **Attachment C**. If possible, this site visit will be coupled with other potential site activities (e.g., bid walk with drilling subcontractor).

Surface Water Investigation and Sampling

Based on the results of the fracture trace study, GES is recommending collection of surface water samples from the surface water feature/wetland area to the southwest of the Site identified on **Figure 3**. As described above, an additional surface water feature, similar to what was identified to the southwest of the Site, was also identified during the desktop fracture trace study on the property at 338 Park Drive West, which will be examined as part of this next phase of proposed work. This potential location is also identified on **Figure 3**. If confirmed at this location, GES is also recommending collection of a surface water sample from this location. The surface water samples will be collected via disposable bailer and submitted for analysis of volatile organic compounds (VOCs), including 1,4-dioxane (1,4D), consistent with the Final Sampling and Analysis Plan / Quality Assurance Project Plan (SAP/QAPP) for the Site. This task was not originally proposed in the Final Remedial Investigation Work Plan and Cost Estimate, however, costs associated with surface water sampling are not included in the Cost Estimate. Per DEP request, the surface water samples will be collected during the site inspection activities at 338 Park Drive West and GES will assist DEP personnel with the surface water sample collection.

Soil/Rock Core Boring Locations

GES recommends installation of two (2) soil boring/rock cores to assess soil and bedrock for the presence of source impacts. These soil/rock core boring locations are strategically placed based on the findings of the surficial geophysical investigation detailed above and the proposed locations can be found on Figure 3. Based on historical monitoring well analytical results, soil boring/rock core location RC-1 is estimated to be advanced to a depth of 150 feet bgs. Soil boring/rock core location RC-2 will be advanced deeper, and based on field observations and screening, may be

advanced to a maximum depth of 250 feet bgs. The data from these soil/rock core borings will be used to complete additional analytical assessment of the adsorbed COC impacts in the source area soils, and to identify potential NAPL within the unsaturated/saturated fractured bedrock. The soil/rock core borings will be advanced to investigate unconsolidated material, weathered bedrock, and competent bedrock conditions.

Hollow stem auger drilling, in conjunction with split-spoon sampling methods, will be used to assess overburden conditions at each location and PQ™ wireline tooling (3.375” diameter) will be utilized to advance the soil/rock core boring to the proposed terminal depth. The composition, color, texture, and moisture content of the soil/bedrock will be monitored as it is recovered and recorded on a subsurface log. The soil/rock boring locations will be sampled within the overburden at the interval of the highest PID reading or visual observation of impacts and the soil/bedrock interface. Additionally, rock core samples for chemical analysis will be collected during the soil/rock core boring installation at the interval where significant impacts and/or NAPL are identified in the fractured rock, and one sample will be collected from a competent interval of bedrock for comparative purposes. Up to four (4) rock samples from each rock core boring will be crushed and field preserved in methanol vials for analysis. GES will plan to collect one (1) unfractured/competent rock sample, and up to three (3) fractured rock samples. If any dense non-aqueous phase liquid (DNAPL) is encountered during advancement of the soil boring/rock cores, GES will cease the boring and discuss with DEP to collectively decide if additional coring is warranted or the location should be terminated.

Specific soil logging, screening, and sampling procedures are specified in the Final SAP/QAPP previously submitted to DEP along with the Final Remedial Investigation Work Plan. If any free product/NAPL is encountered in the overburden or bedrock during the soil/rock core boring installation activities, arrangements may be made with DEP to collect a sample for identification analysis. Additional physical property analysis may be completed to determine rippability of the shallow bedrock zone based on findings from the surficial geophysical investigation and initial observations during rock coring.

Rock coring will be performed upon encountering competent bedrock to define the rock surface and stratigraphy. Rock coring will be performed to a maximum depth determined from the findings of the surficial geophysical investigation. Following extraction of the core, at a minimum, the following information will be documented by GES’ field inspector:

- Total recovery
- Solid recovery
- Rock core descriptions
- Core photographs
- Presence of fractured zones
- Saturation
- Presence of NAPL

Note: Bedrock strike and true strike and dip orientations (not relative to bedding only) of joints and fractures will be determined using a downhole geophysical survey of each of the coring locations converted to monitoring well, as specified under Task 3040.

At the completion of each soil/rock core boring, the rock cores will be contained in core boxes and properly labeled. Additionally, the borehole will be marked accordingly for future downhole geophysical investigation and horizontal/vertical data will be collected via handheld global positioning system (GPS) device. After completion of the soil/rock boring and subsequent downhole geophysical investigation, the borehole will be properly abandoned (bottom grouted to surface and patched with topsoil) to prevent potential downward vertical migration. At this time, monitoring well installation activities are not recommended at the proposed soil/rock core boring locations; however, based on the results of this next phase of investigation, additional soil/rock core boring locations and/or monitoring wells may be recommended. GES will conduct the soil/rock core boring installation and survey as part of this scope of work and costs are included under **Tasks 3011**in **Attachment C.**

Investigation derived waste (IDW) generated during the soil/rock core boring installation activities will be disposed of according to the Final Remedial Investigation Work Plan and costs for this activity are included under **Task 3080** in **Attachment C**.

Downhole Geophysics

GES recommends completion of downhole geophysical logging after completion of the soil/rock core boring installation to evaluate the bedrock characteristics in the drilled locations to identify potential water-bearing fracture zones, confirm structural orientation of the fractures, and to characterize borehole conditions in terms of flow and lithology. The downhole geophysical logging will utilize the following tools:

- Three-Arm Caliper measuring variations in borehole diameter as a function of depth;
- Heat Pulse Flow Meter measuring vertical flow within the borehole;
- Fluid Temperature measuring changes in fluid temperature as a function of depth;
- Optical Televiewer providing an undistorted 360-degree view of the borehole;
- Acoustical Televiewer providing a 360-degree acoustical image of the borehole;
- Gamma Ray measuring radioactivity from geologic units encountered in the borehole;
- Fluid Resistivity providing fluid column dissolved solids data;
- Short and Long Normal Resistivity measuring electrical resistivity of current passing through bedrock material; and
- Sing Point Resistivity used to detect fractures in the borehole following variations in the resistivity of the bedrock.

Geophysical logging results will be evaluated to determine bedrock characteristics that will be incorporated into remedial option evaluation for source area groundwater. The costs for the downhole geophysical investigation activities are included under **Task 3040** in **Attachment B**.

Summary

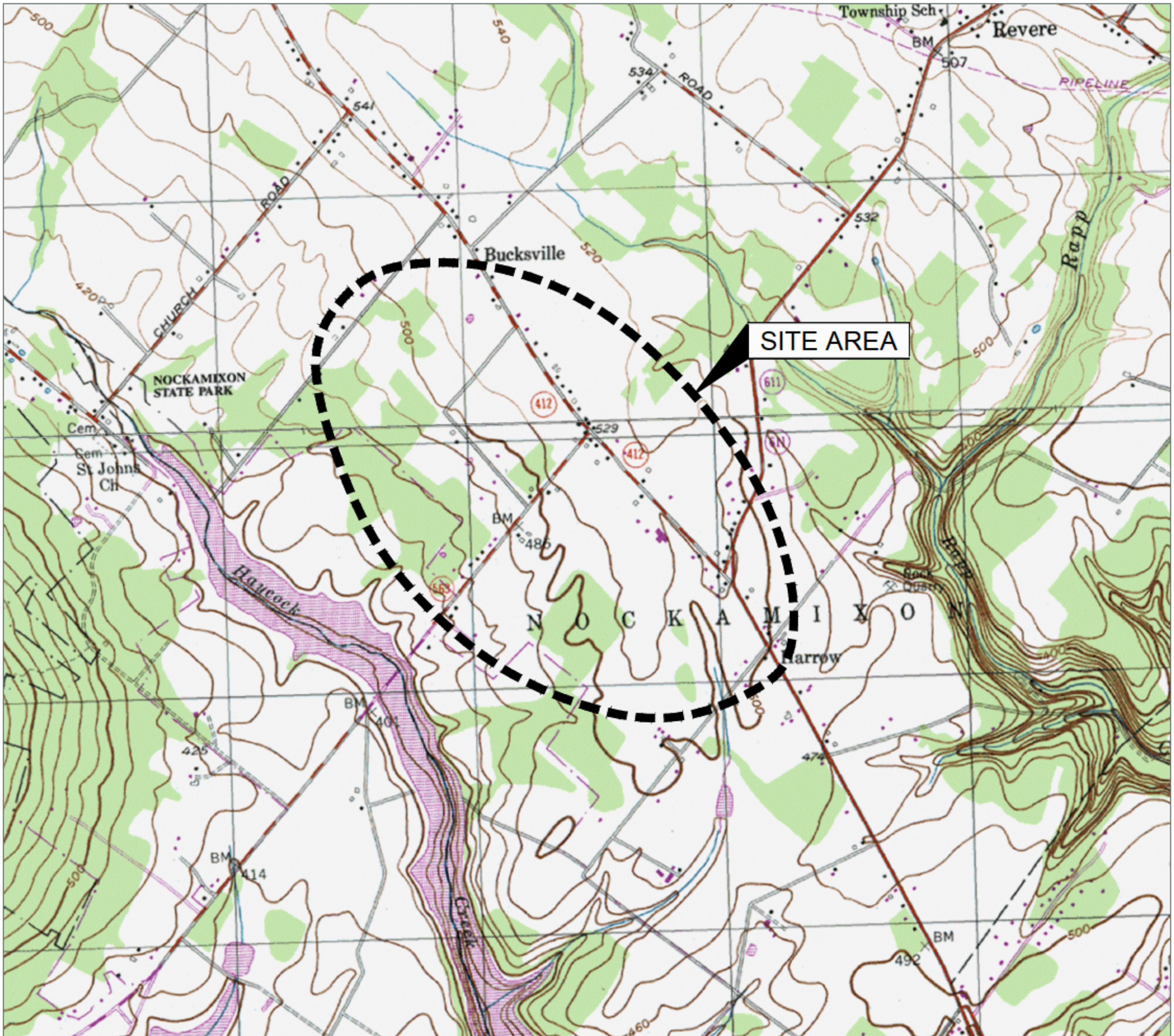
GES recommends the following activities as the next phase of remedial investigation at this Site. The cost estimate included as **Attachment C** covers these tasks as a change order to the original scope of work cost estimate for the Site. Please note that the cost estimate included in **Attachment C** will be submitted to DEP as a change order to the original Remedial Investigation Work Plan cost estimate under separate cover.

- Conduct a Site visit to confirm additional potential surface water feature/groundwater discharge location on 338 Park Drive West;
- Assist DEP with the collection of surface water sample(s) from up to two (2) surface water features/groundwater discharge locations;
- Install two (2) soil/rock core borings to depths ranging from 150 feet bgs to a maximum depth of 250 feet bgs;
- Collect up to eight (8) rock samples for chemical characterization (up to four from each boring);
- Collect samples for potential rippability analysis, to be performed by a geotechnical subcontracted laboratory;
- Conduct downhole geophysical investigation on the two (2) soil/rock core boring locations;
- Review and assess the analytical data obtained from soil/rock core borings and surface water;
- Determine if additional remedial investigation activities are warranted (e.g., additional soil/rock core borings, monitoring well installation, geophysics, etc.); and
- Prepare an additional cost estimate to complete any recommended additional remedial investigation activities or move forward with the Screening Evaluation and Feasibility Study.

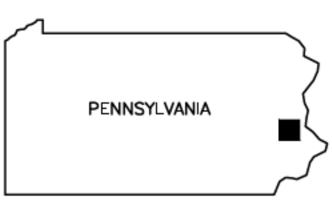
Please contact Tim Uhler at 610.458.1077 ext. 3071 or at TUhler@gesonline.com with any questions or comments regarding the information presented in this Technical Memorandum.

Figures

Figure 1 – Site Location Map



Source:
USGS 7.5 Minute Series
Topographic Quadrangle, 1997
Riegelsville, Pennsylvania
Bedminster, Pennsylvania
Contour Interval = 20'



QUADRANGLE LOCATION

Site Location Map

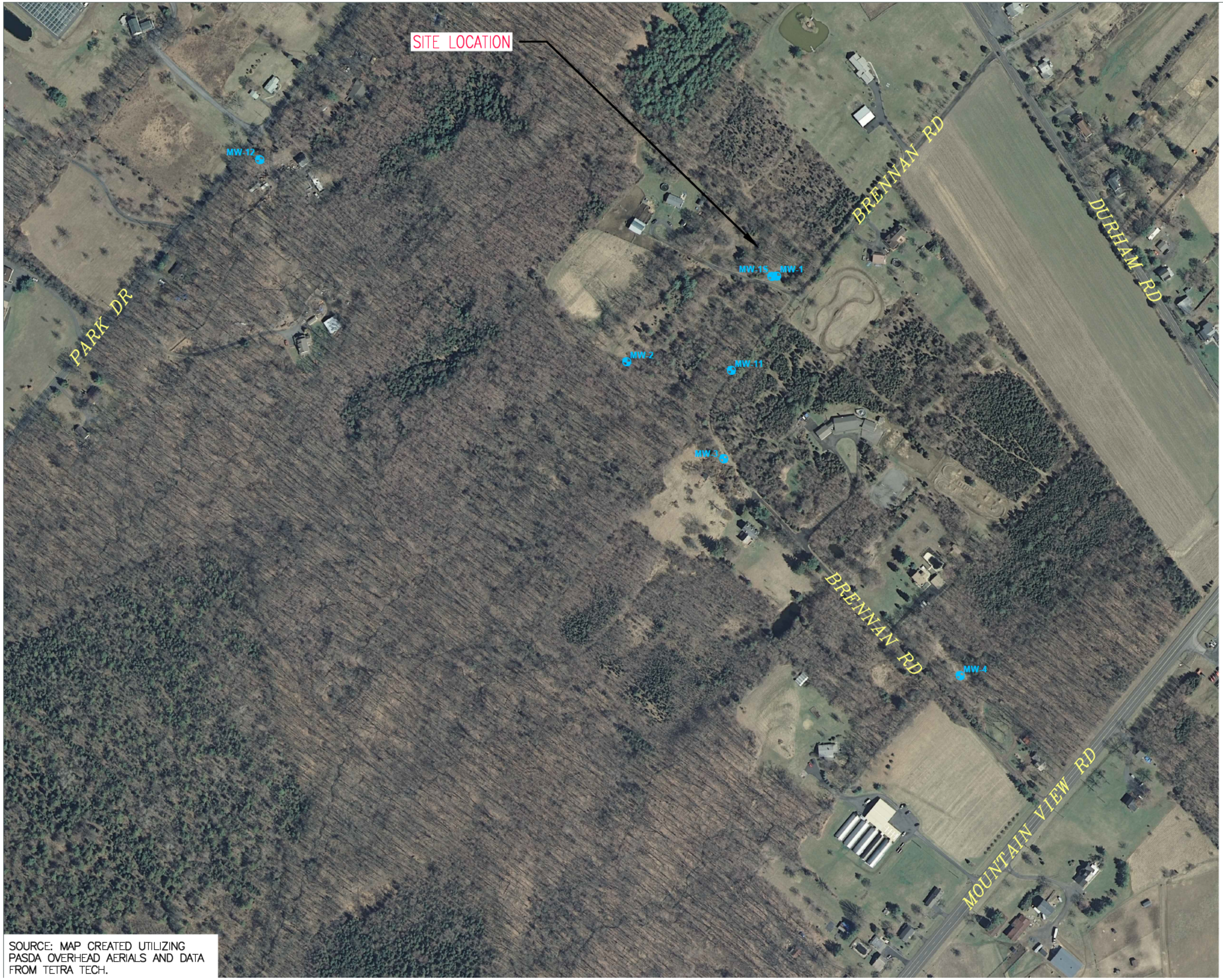
Pennsylvania Dept of Environmental Protection
Nockamixon TCE Site
84 Brennan Road, Nockamixon Township
Ottsville, Pennsylvania

Drawn T.P.	Date 08/27/21
Designed M.E.T.	Figure 1
Approved T.F.U.	

Scale In Feet
0 2,000

Groundwater & Environmental Services, Inc.

Figure 2 – Site Map



SOURCE: MAP CREATED UTILIZING PASDA OVERHEAD AERIALS AND DATA FROM TETRA TECH.

LEGEND

MONITORING WELL

Site Map

Pennsylvania Dept of Environmental Protection
Nockamixon TCE Site
84 Brennan Road, Nockamixon Township
Ottsville, Pennsylvania

Drawn T.P.
Designed T.F.U.
Approved T.F.U.

Date 09/20/21
Figure 2

Scale In Feet
0 300

GES
Groundwater & Environmental Services, Inc.

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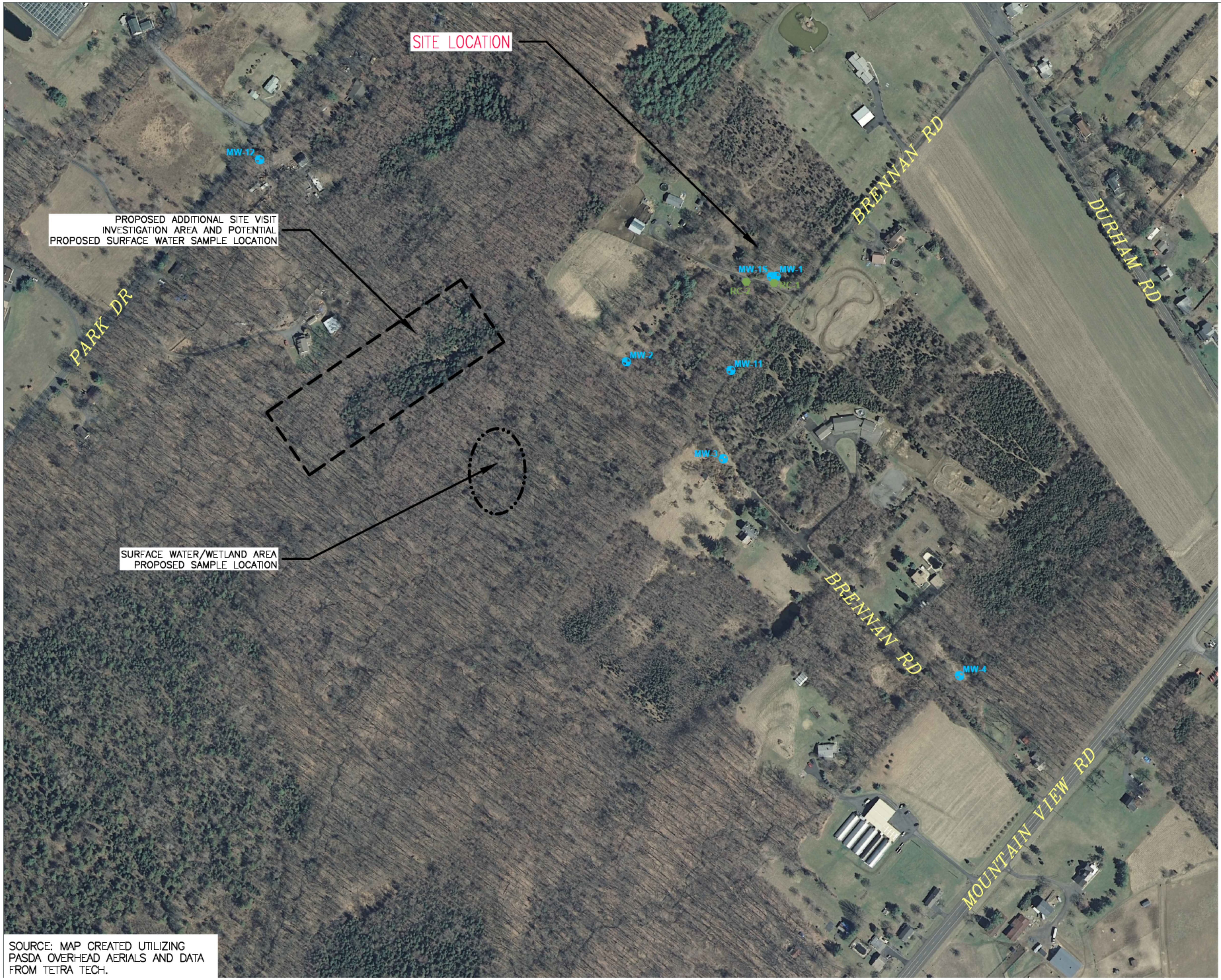
Figure 3 – Proposed Soil/Rock Core Boring Location Map



LEGEND

- MONITORING WELL
- PROPOSED SOIL/ROCK CORE BORING LOCATION

Proposed Soil/Rock Core Boring Location Map
Pennsylvania Dept of Environmental Protection Nockamixon TCE Site 84 Brennan Road, Nockamixon Township Ottsville, Pennsylvania
Drawn T.P. · Designed T.F.U. · Approved T.F.U. · Date 10/07/21 · Figure 3

Scale In Feet
0 300

Groundwater & Environmental Services, Inc.

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Attachment A – Fracture Trace Desktop and Field Results

GTAC-Nockamixon TCE Site - Fracture Trace Study Results

- Prepared for: Pennsylvania Department of Environmental Protection (PADEP)
- Prepared by: Groundwater & Environmental Services, Inc. (GES)

May 27, 2021

Fracture Trace Study Purpose

- During preparation of the Site Investigation Work Plan, GES developed a Conceptual Site Model (CSM) for the Nockamixon TCE Site.
- This CSM identified an impacted fractured bedrock aquifer, where groundwater flow and contaminant fate and transport are likely control by the fracture fabric within the bedrock.
- To more-effectively locate proposed rock core sampling locations and additional well installation locations in the fractured rock, a surface geophysical survey will be conducted.
- To assist in positioning surface geophysical survey line locations, a fracture trace study was conducted in attempt to identify potential fractures trending though the Site, which should be examined with the geophysical survey.
- The Fracture Trace study included a desktop study and field verification of the desktop results.

Fracture Trace Study Components

- Fracture Trace involves examination of remotely sensed data (e.g., aerial photographs), topographic maps, and other landform data to identify linear features on the surface that could be representative of subsurface secondary porosity features, such as, fractures, faults and joints that could influence groundwater flow.
- Historically, the fracture trace study included the use of stereoscopic image analysis to produce a 3D effect which is helpful in identifying the linear features.
- For the Nockamixon TCE Site study, a macro-scale examination of the area was done using geological and topographic maps.
- Given the very small scale of the Site and the desire to strategically locate geophysical investigation lines, a small detailed scale study was conducted using LiDAR topographic contours as the primary means to identify potential linear features for field examination.
- The LIDAR contours provide a high resolution view of the topographic surface, which cannot be matched on the small scale Site area by any other data analysis means.

Figure 1 – Bedrock Geology in Site Vicinity

- A significant bedrock fold exists in the vicinity of the Site.
- The Site is locate on the north structural fold limb , where bedrock strikes to the Northwest and dips to the Southwest.

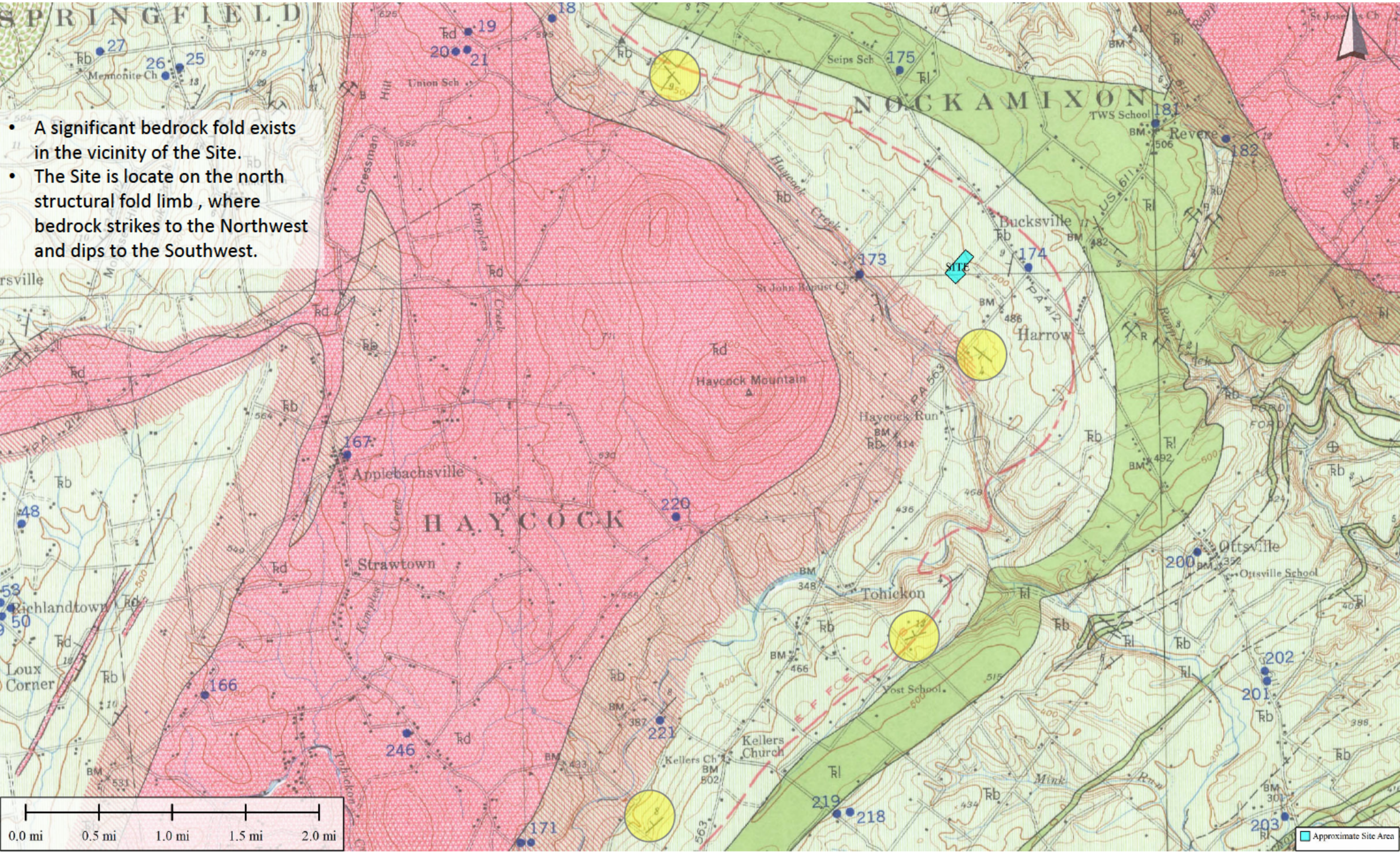
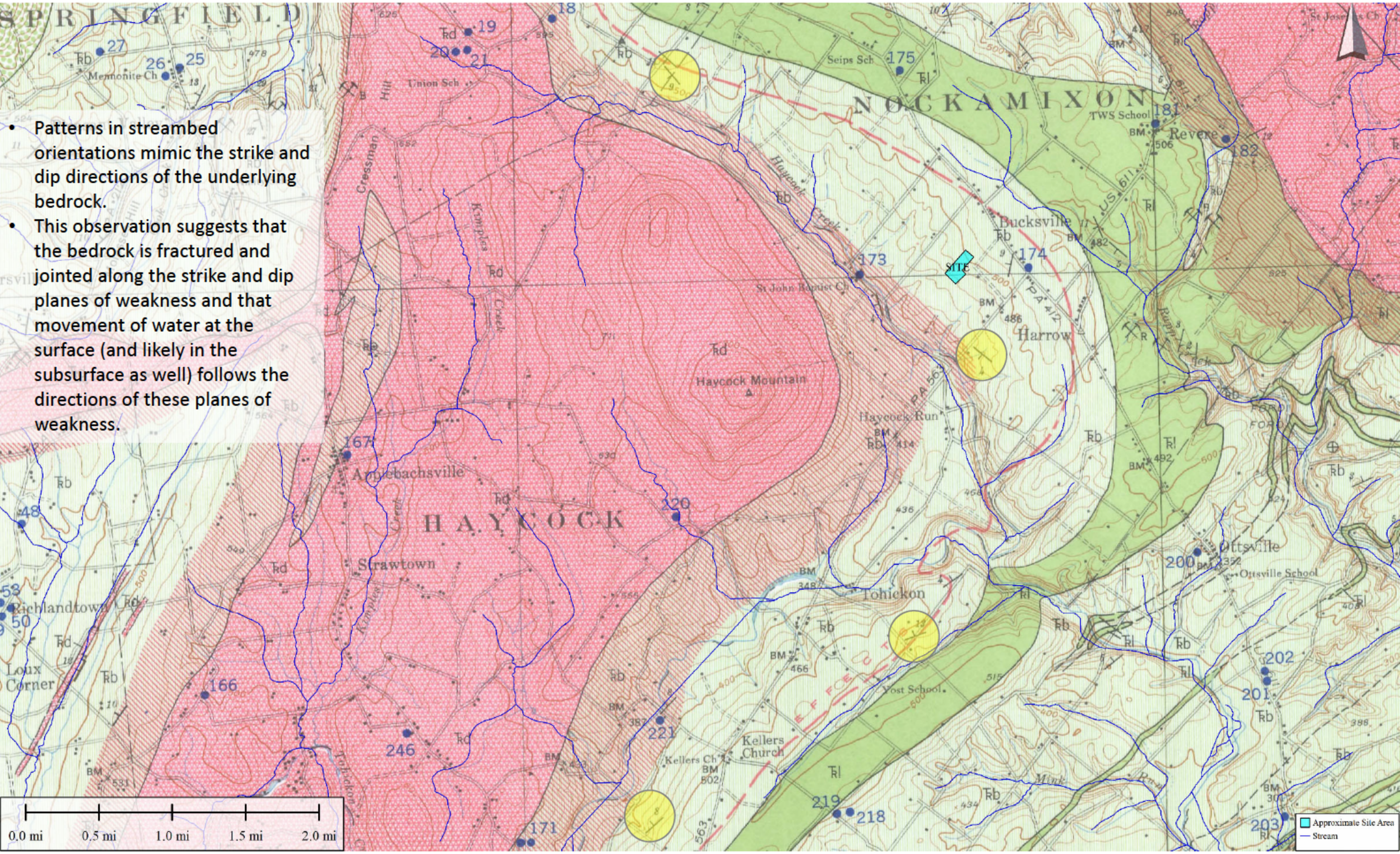


Figure 2 – Bedrock Geology with Chapter 93 Stream GIS Layer



- Patterns in streambed orientations mimic the strike and dip directions of the underlying bedrock.
- This observation suggests that the bedrock is fractured and jointed along the strike and dip planes of weakness and that movement of water at the surface (and likely in the subsurface as well) follows the directions of these planes of weakness.

Figure 3 – PAMAP LiDAR Digital Elevation Model (DEM) in Site Vicinity

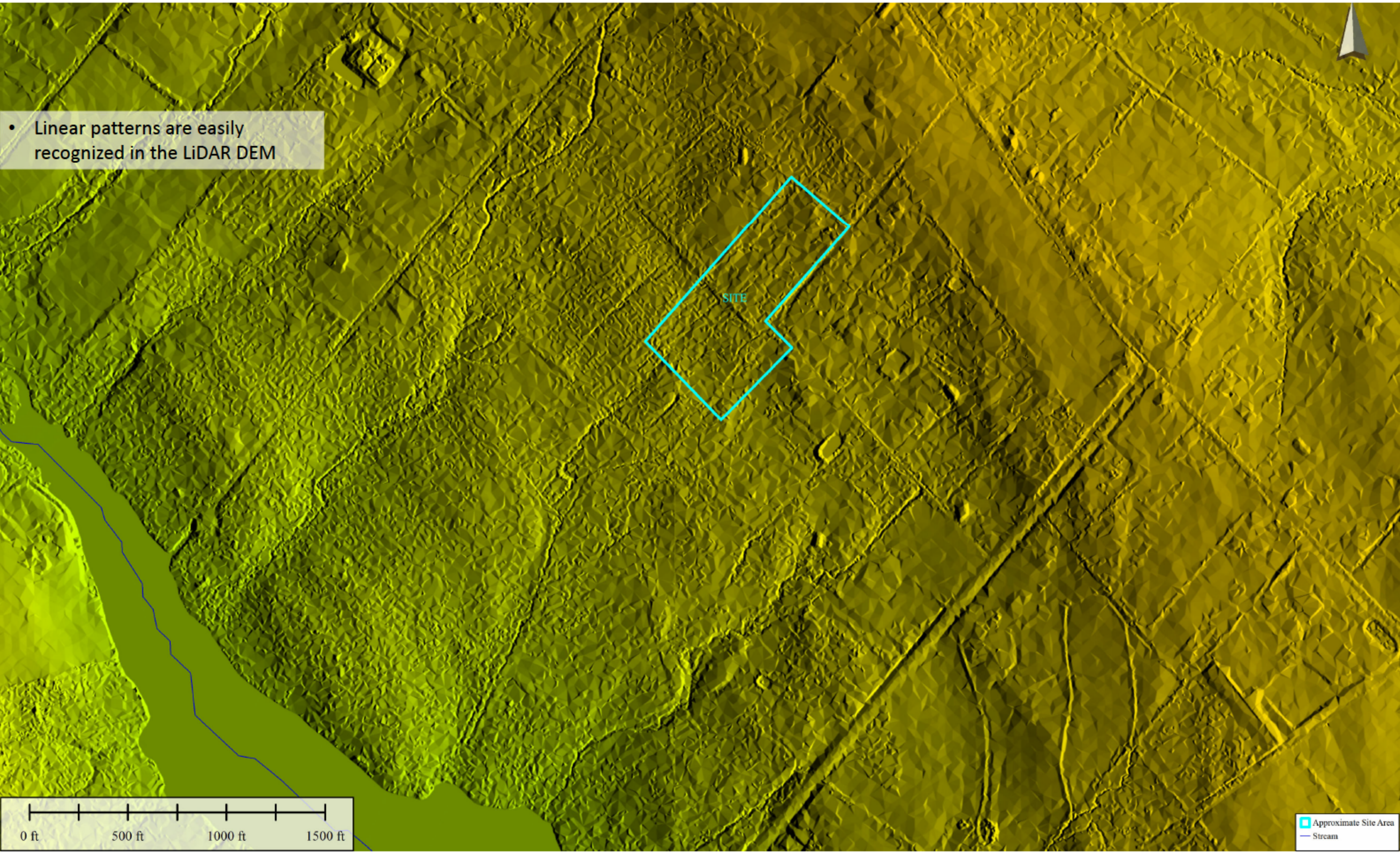
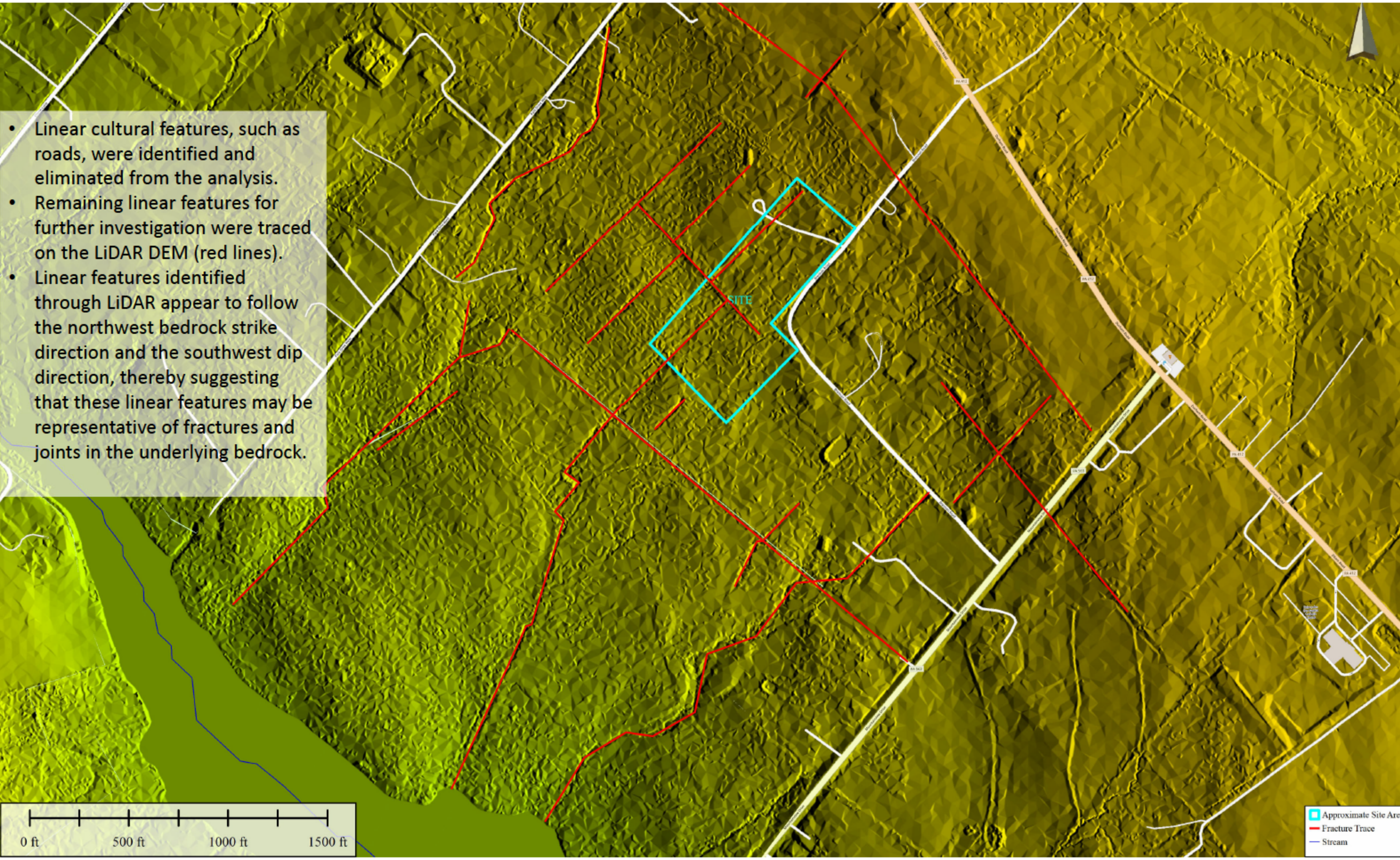


Figure 4 – Fracture Trace of Features Identified from LiDAR DEM



- Linear cultural features, such as roads, were identified and eliminated from the analysis.
- Remaining linear features for further investigation were traced on the LiDAR DEM (red lines).
- Linear features identified through LiDAR appear to follow the northwest bedrock strike direction and the southwest dip direction, thereby suggesting that these linear features may be representative of fractures and joints in the underlying bedrock.

Figure 5 – PAMAP LiDAR DEM with 2-Foot Interval Contour Lines in Site Vicinity

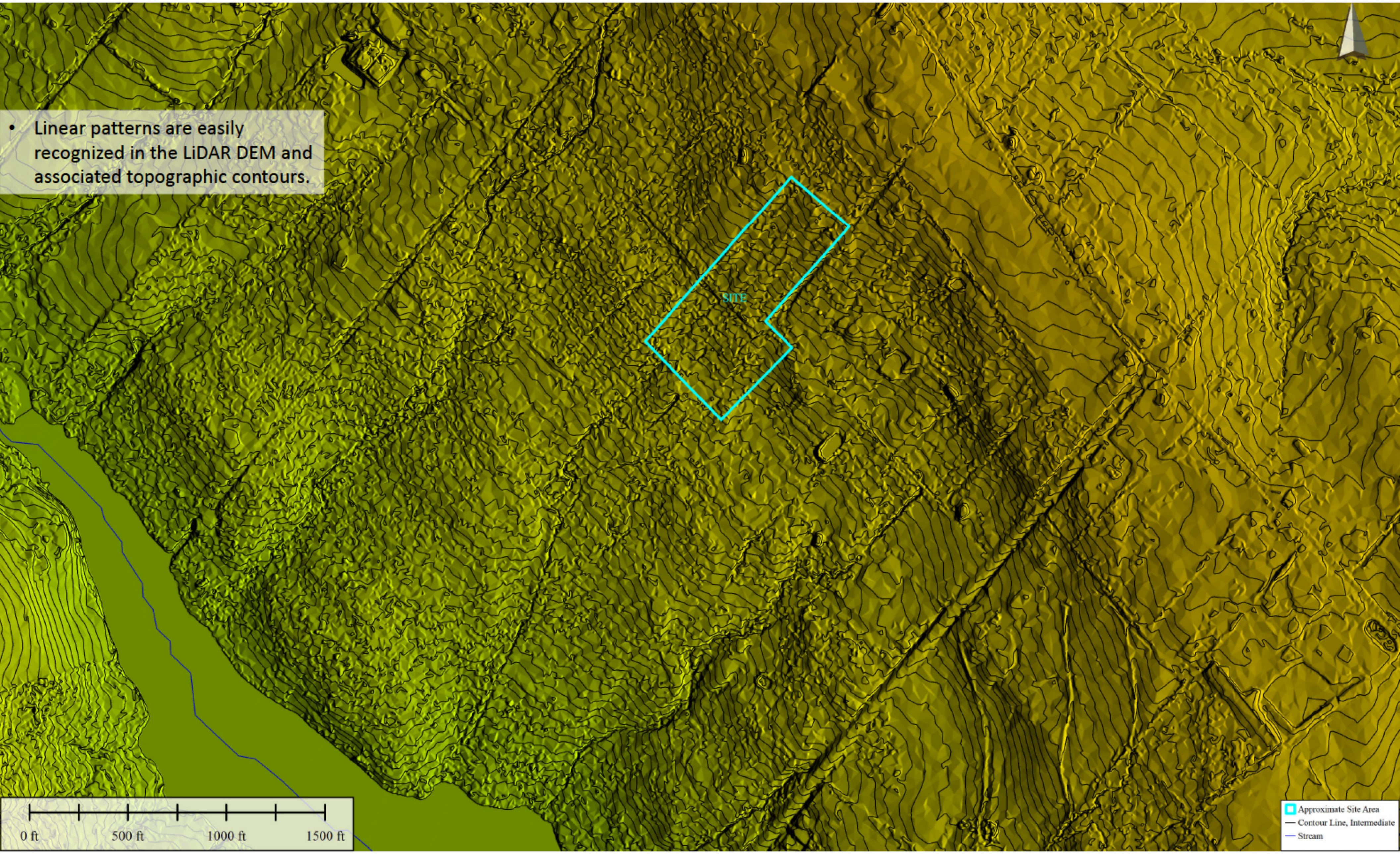
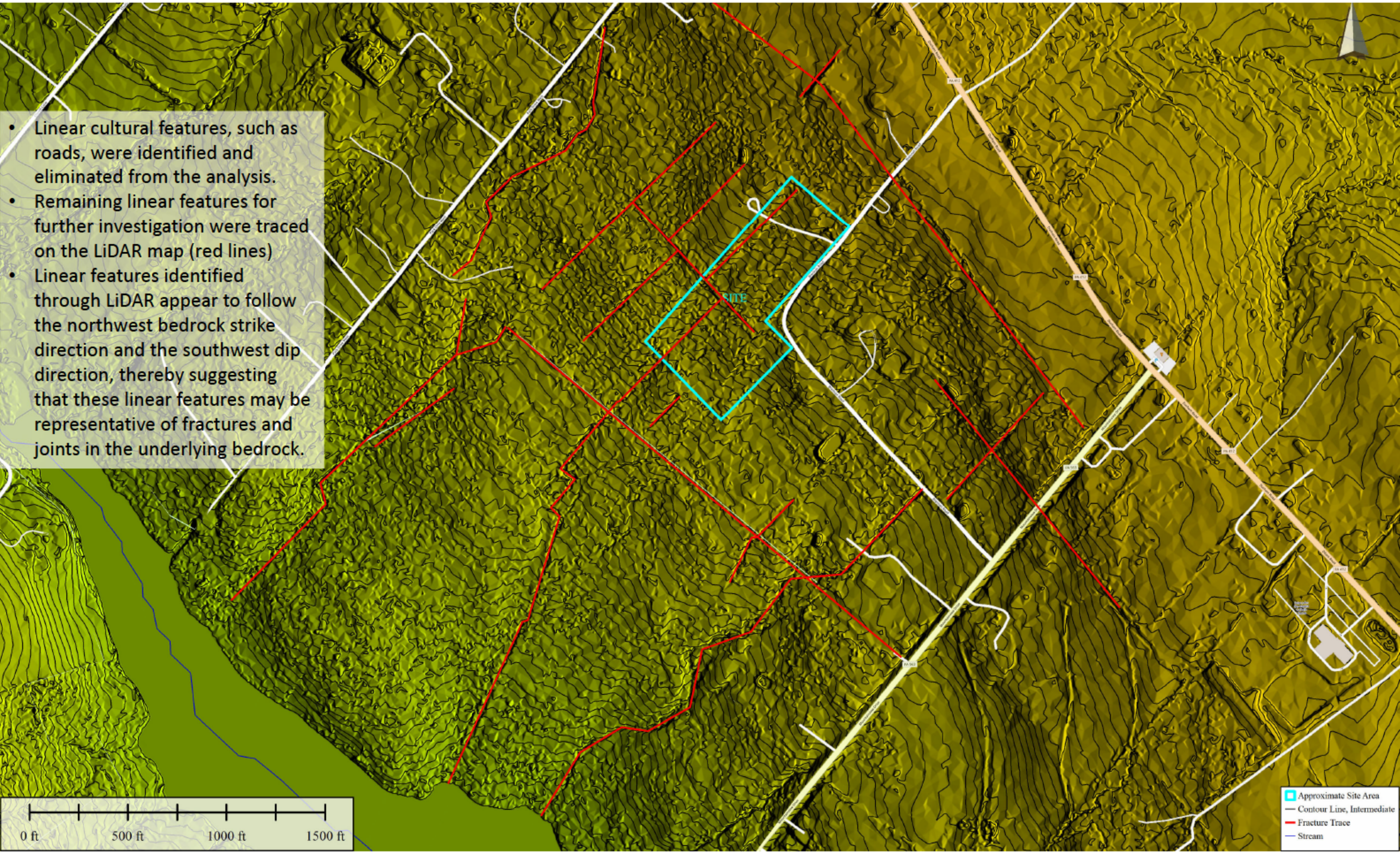


Figure 6 – Fracture Trace of Linear Features Identified from PAMAP LiDAR DEM and Contours



- Linear cultural features, such as roads, were identified and eliminated from the analysis.
- Remaining linear features for further investigation were traced on the LiDAR map (red lines)
- Linear features identified through LiDAR appear to follow the northwest bedrock strike direction and the southwest dip direction, thereby suggesting that these linear features may be representative of fractures and joints in the underlying bedrock.

Figure 7 – Current Aerial Photograph of Site Vicinity

Figure 8 – LiDAR-Identified Linear Features Overlain on Current Aerial Photograph

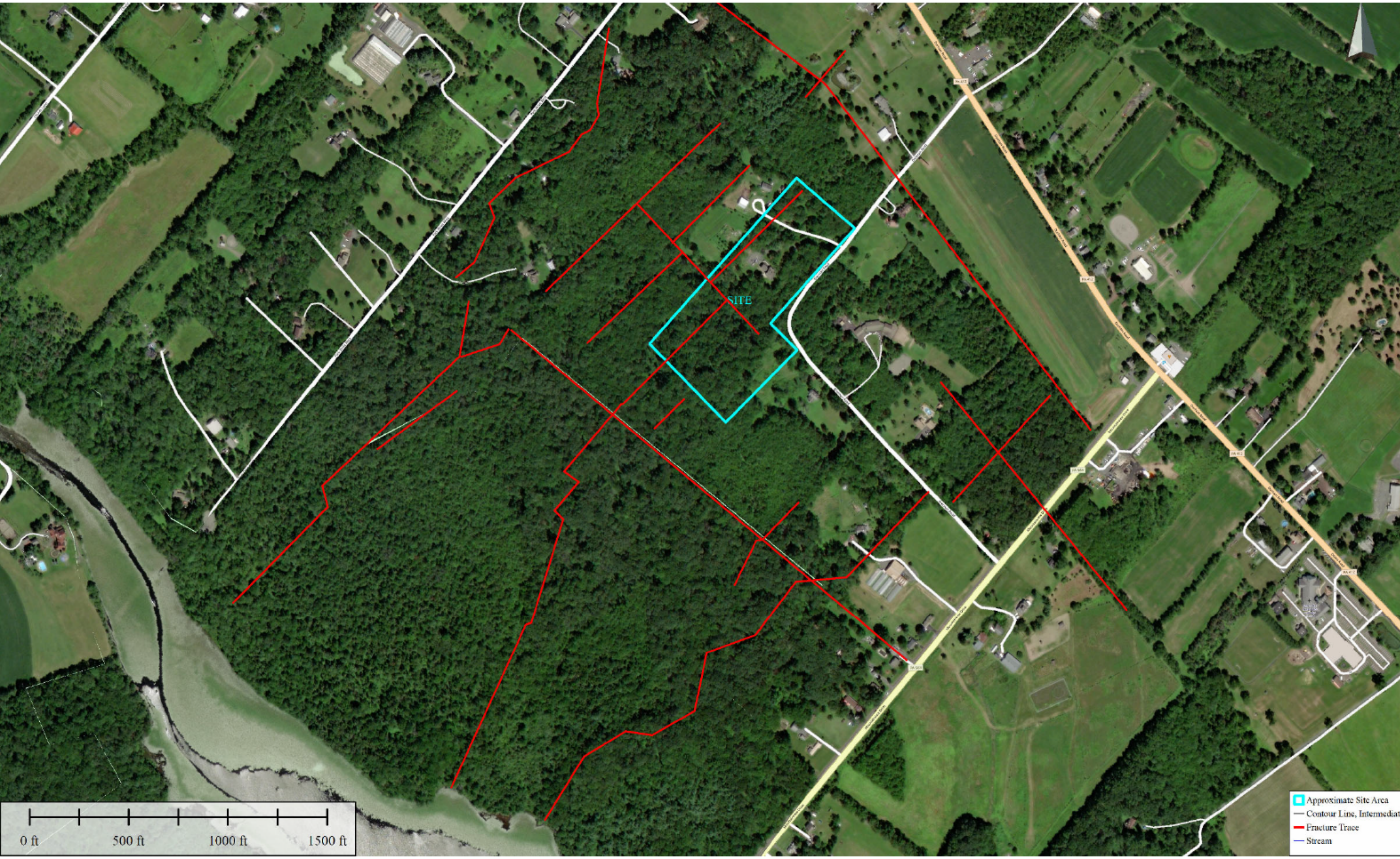
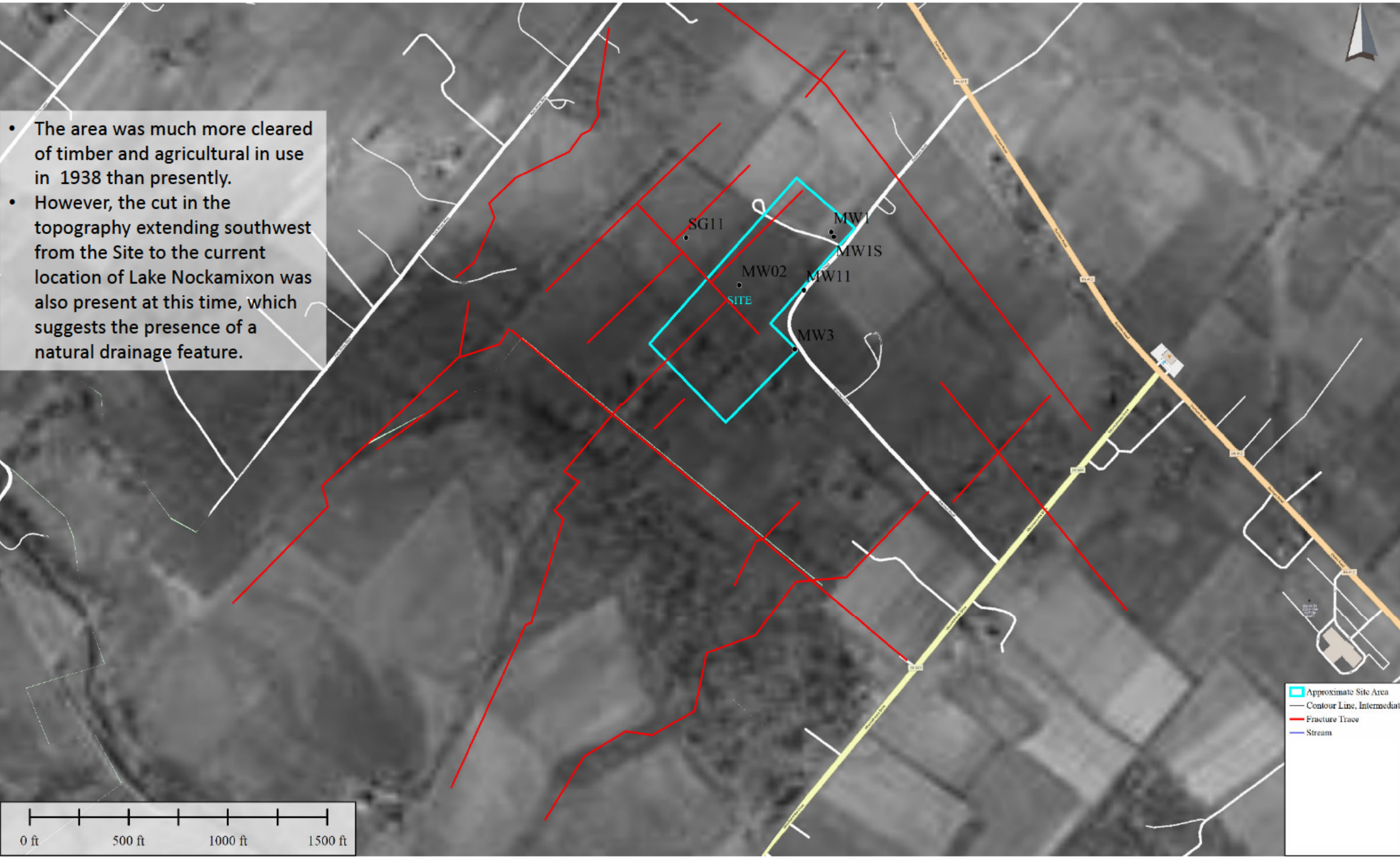


Figure 9 – Historic 1938 Aerial Photograph of Site Vicinity (from PennPilot)

- The area was much more cleared of timber and agricultural in use in 1938 than presently.
- However, the cut in the topography extending southwest from the Site to the current location of Lake Nockamixon was also present at this time, which suggests the presence of a natural drainage feature.

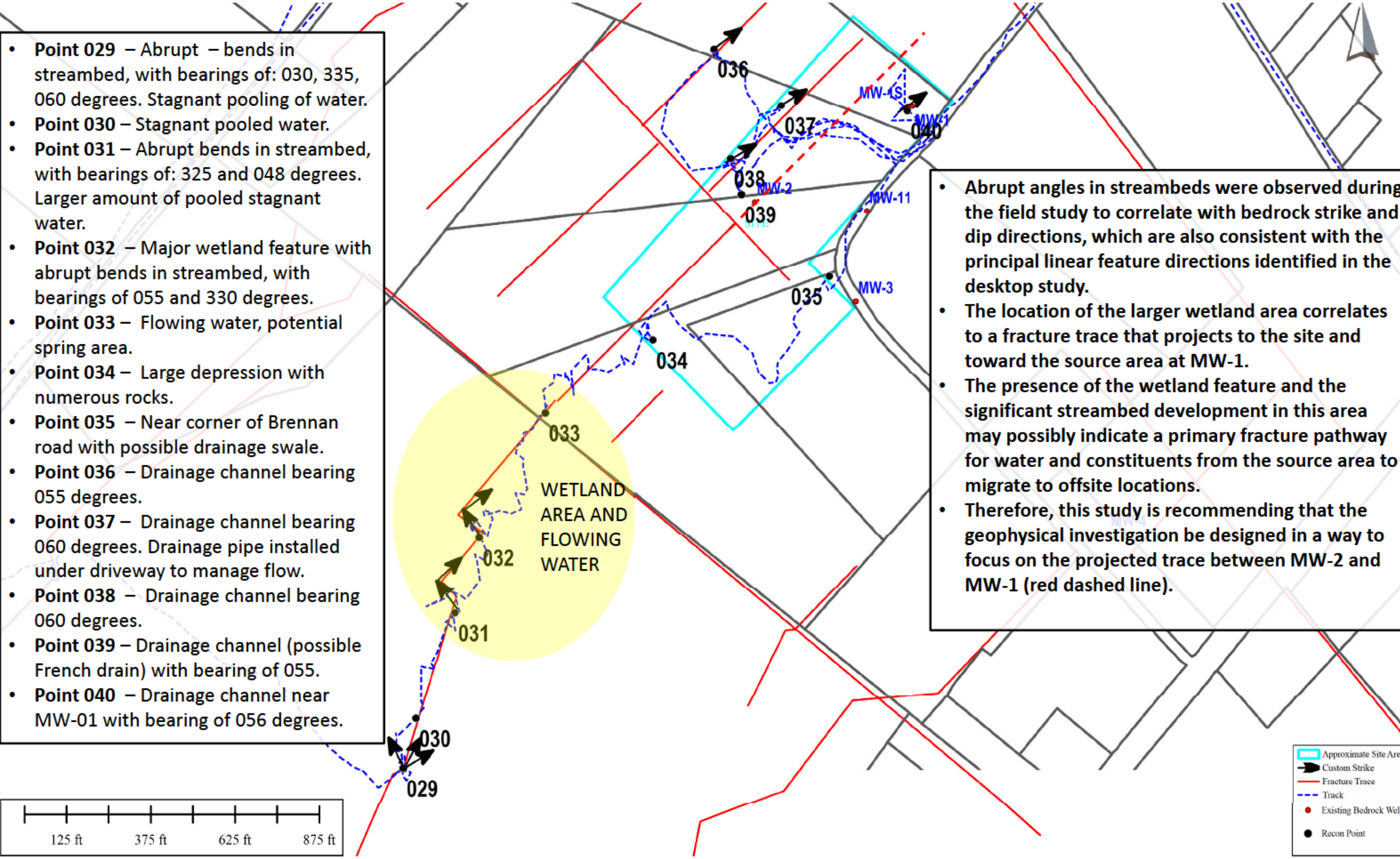
Figure 10 – LiDAR-Identified Linear Features Overlain on Historic 1938 Aerial Photograph



- The area was much more cleared of timber and agricultural in use in 1938 than presently.
- However, the cut in the topography extending southwest from the Site to the current location of Lake Nockamixon was also present at this time, which suggests the presence of a natural drainage feature.

Figure 11 – Field Verification of Linear Features

- **Point 029** – Abrupt – bends in streambed, with bearings of: 030, 335, 060 degrees. Stagnant pooling of water.
- **Point 030** – Stagnant pooled water.
- **Point 031** – Abrupt bends in streambed, with bearings of: 325 and 048 degrees. Larger amount of pooled stagnant water.
- **Point 032** – Major wetland feature with abrupt bends in streambed, with bearings of 055 and 330 degrees.
- **Point 033** – Flowing water, potential spring area.
- **Point 034** – Large depression with numerous rocks.
- **Point 035** – Near corner of Brennan road with possible drainage swale.
- **Point 036** – Drainage channel bearing 055 degrees.
- **Point 037** – Drainage channel bearing 060 degrees. Drainage pipe installed under driveway to manage flow.
- **Point 038** – Drainage channel bearing 060 degrees.
- **Point 039** – Drainage channel (possible French drain) with bearing of 055.
- **Point 040** – Drainage channel near MW-01 with bearing of 056 degrees.



- **Abrupt angles in streambeds were observed during the field study to correlate with bedrock strike and dip directions, which are also consistent with the principal linear feature directions identified in the desktop study.**
- **The location of the larger wetland area correlates to a fracture trace that projects to the site and toward the source area at MW-1.**
- **The presence of the wetland feature and the significant streambed development in this area may possibly indicate a primary fracture pathway for water and constituents from the source area to migrate to offsite locations.**
- **Therefore, this study is recommending that the geophysical investigation be designed in a way to focus on the projected trace between MW-2 and MW-1 (red dashed line).**

Figure 12 – Correlation of Field-Verified Linear Features and TCE Plume Shape

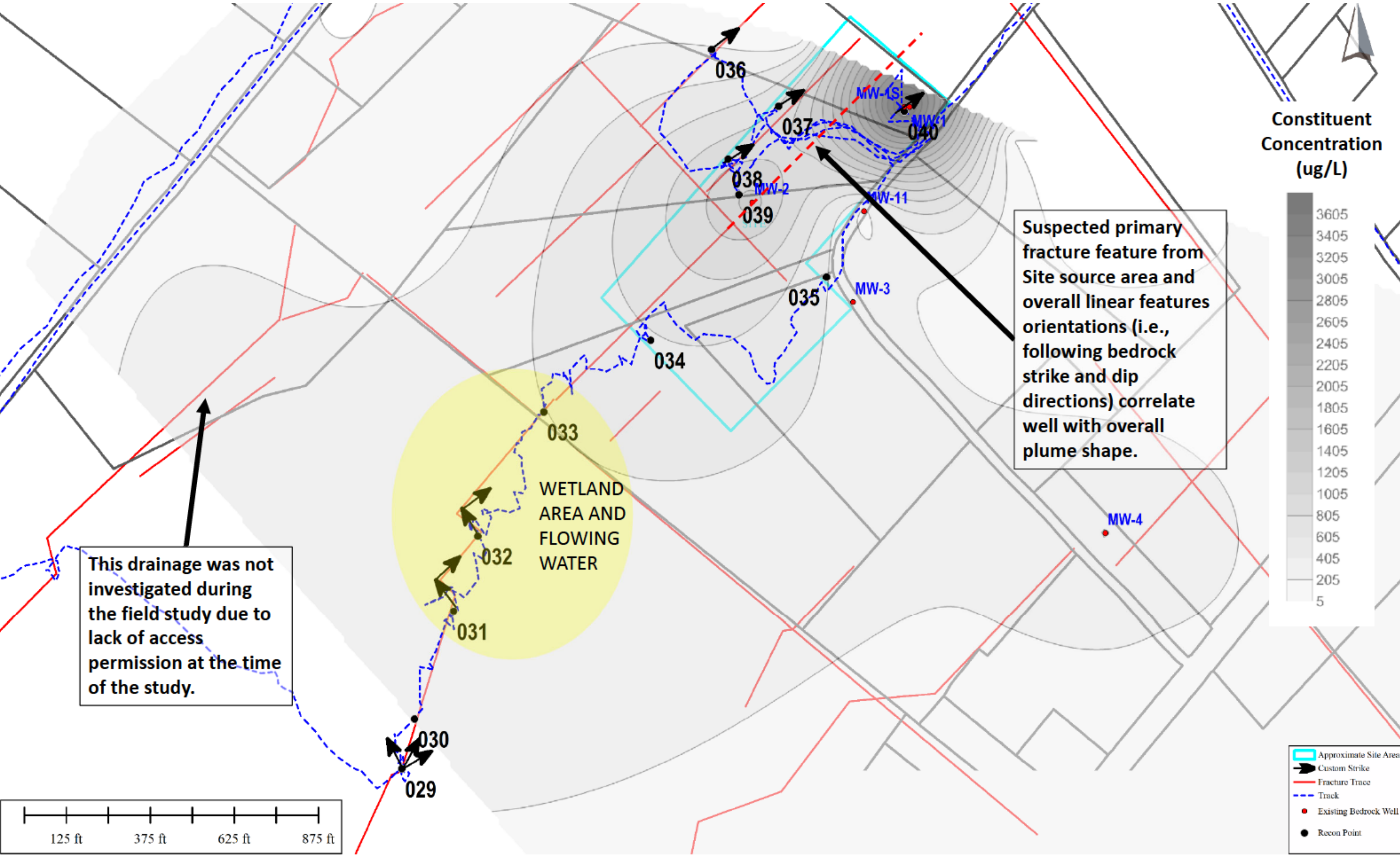


Figure 13 – Correlation of Field-Verified Linear Features and PCE Plume Shape

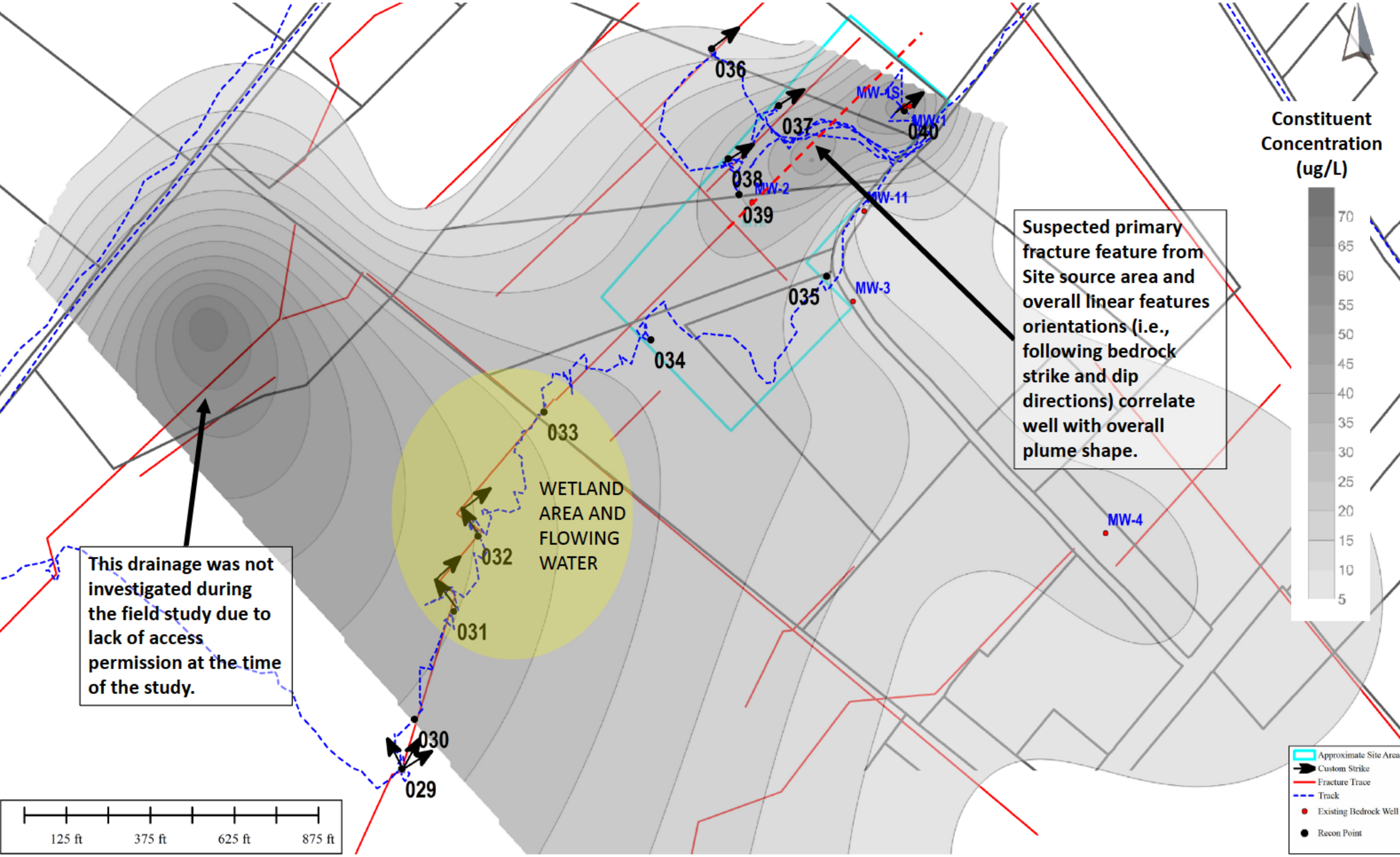
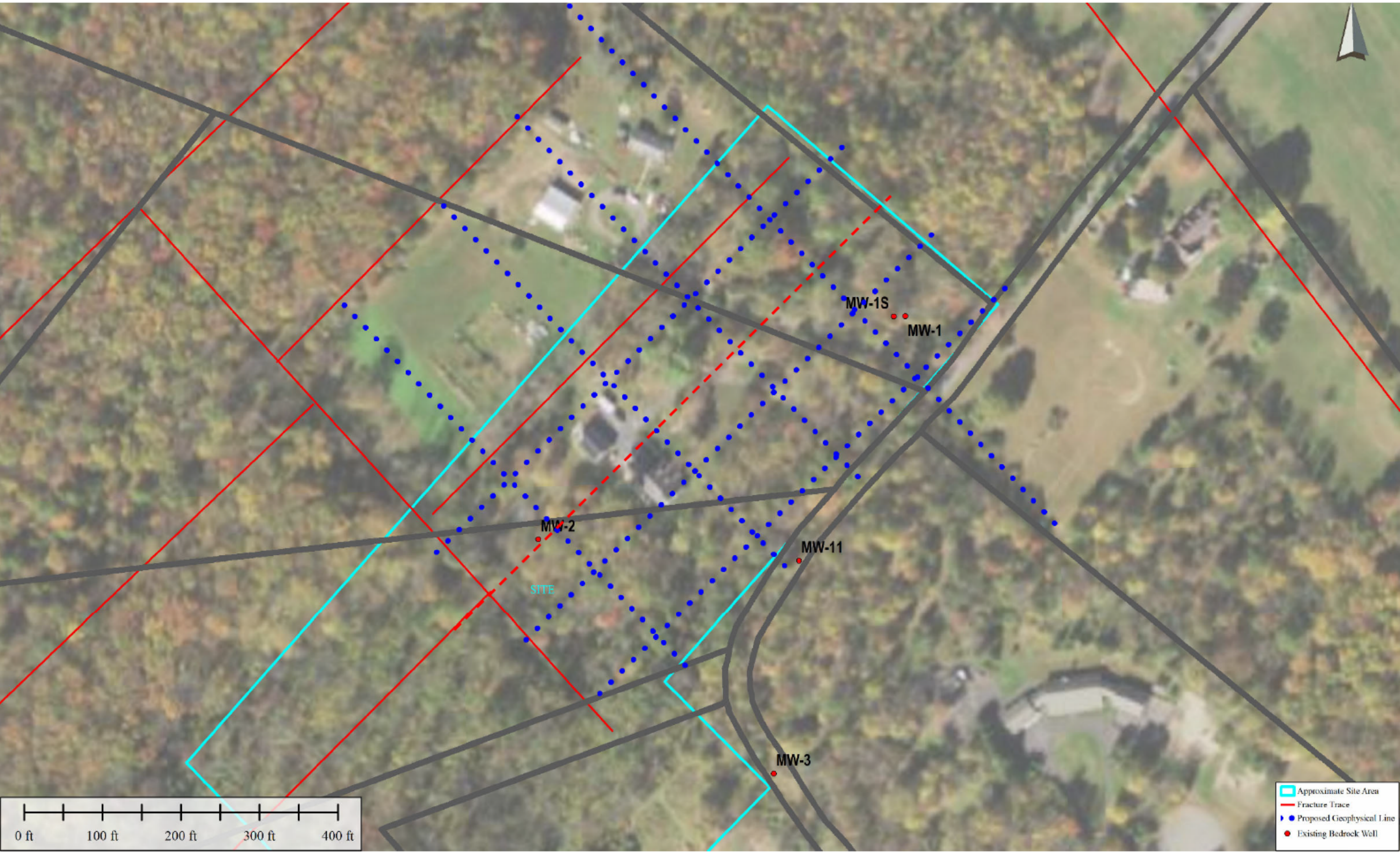


Figure 14 – Proposed Geophysical Lines and Orientation



Attachment B – Advanced Geological Services, Inc. Electrical Resistivity Imaging Investigation Report

ADVANCED GEOLOGICAL SERVICES
P.O. Box 348
280½ East Main Street
Chillicothe, OH 45601
Offices in PA and CA

July 26, 2021
Reference: 21-183-1

Mr. Timothy Uhler
Groundwater & Environmental Services, Inc.
440 Creamery Way, Suite 500
Exton, PA 19341

Subject: Electrical Resistivity Imaging Investigation Results
GTAC - Nockamixon TCE Site
Nockamixon Township, Bucks County, Pennsylvania

Dear Mr. Uhler:

Advanced Geological Services (AGS) presents this letter report to Groundwater & Environmental Services, Inc. (GES) summarizing the geophysical work completed at GTAC – Nockamixon TCE Site in Nockamixon Township, Bucks County, Pennsylvania. Resistivity data acquisition was completed by AGS on June 24 through June 30, 2021.

The objective of the investigation was to use the electrical resistivity imaging (ERI) method to to identify potential bedrock fractures and and other geologic features that could influence groundwater flow. Previous fracture trace analysis completed by GES indicates that primary fractures within the survey area generally trend either southwest to northeast, or southeast to northwest.

Methods

The ERI method is used to distinguish variations in the electrical resistivity of earth materials. Resistivity is an intrinsic characteristic of an earth material that measured in units of ohm-meters (ohm-m). Generally, within shale/siltstone regimes, unweathered and unsaturated rock will have a moderate to relatively high electrical resistivity, whereas fractured or weathered rock and water saturated shale/siltstone will have low electrical resistivity.

Electrical Resistivity Imaging (ERI)

Electrical resistivity imaging (ERI) profiles were completed along seven transects selected by GES. Four ERI profiles were oriented in the northwest to southeast direction, and three ERI profiles were oriented in the southwest to northeast direction. The orientations and locations of the ERI profiles were selected by GES to intersect the primary bedrock fracture orientations of this site.

Each ERI transect consisted of a series of electrodes spaced 10 apart. The total number of electrodes used in any given transect depended upon the available space. Transect lengths varied in total length from 550 feet to 830 feet. The maximum achievable depth of investigation is a function of total transect length, and varied from approximately 120 feet to approximately 190 feet below ground surface.

Resistivity methods measure the resistivity structure of subsurface materials using a direct current electrical source. A direct current signal is injected into the ground between two transmitting electrodes. The voltage is then measured between two receiving (potential) electrodes. The measured voltage is converted into apparent resistivity using algorithms that take into account the geometry of the dipole-dipole electrode array.

Apparent resistivity is a function of the porosity, permeability, water content, and ionic make up of the material. Consequently, soils or rocks that contain a high percentage of clay minerals, such as shale, and a high water content generally have a low apparent resistivity. On the other hand, a clean sand or sandstone with few free ions will have a relatively high apparent resistivity.

Surface resistivity data were collected using a SuperSting R8 resistivity meter that has integrated 8-channel rapid sampling capabilities. The SuperSting resistivity meter is manufactured by Advances Geosciences, Inc. of Austin Texas. The SuperSting resistivity meter is a self contained battery operated instrument that is capable of monitoring data quality using predetermined statistical parameters, numerical stacking of measured data to increase the signal to noise ratio, spontaneous potential cancellation, and data storage for downloading to a PC.

The 8-channel rapid sampling controller and electrode system used in this investigation consists of the integrated switching system, specially designed cables and up to 84 electrodes, although the total number of electrodes used depended upon the available space. This automatic switching system was pre-programmed to collect data using a dipole-dipole configuration. The "a" spacing, or distance between electrodes, was set to 10 feet. Upon completion of the electrode array set-up, an electrode test was conducted to ensure that all electrodes were correctly attached and that the resistance between the ground and the electrode was within acceptable range. If resistance of a given electrode was abnormally high, the electrode to ground resistance was decreased by wetting the electrode and adjacent soil with water. Upon completion of the electrode test, the resistivity meter was set to automatically sample the dipole-dipole array.

ERI data were analyzed using the commercially available computer program RES2dINV inversion and modeling software. This program mathematically inverts model resistivities and then calculates forward apparent resistivity pseudosection values. The calculated pseudosection apparent resistivities are compared to the observed apparent resistivities. The resistivity model is optimized by an iterative inversion routine until the calculated error is below a pre-determined level, or the percentage change between the previous model and the newly calculated model is below a pre-determined level, or a maximum specified number of iterations have been completed. The resulting model presents resistivity as a function of depth rather than as a function of dipole spacing as is standard for pseudosection presentation.

Results and Discussion

Seven ERI transects, ERI-1 to ERI-7, were completed during this investigation. Locations of the ERI transects are shown on Figure 1, and modeled ERI profiles are shown on Figures 2, 3, and 4. Transects ERI-1 through ERI-4 were oriented northwest to southeast, and ERI-5 through ERI-7 were oriented southwest to northeast, approximately perpendicular to ERI-1 Through ERI-4.

Overall, the resistivity data was of good quality along all transects. Generally the resistivity profiles indicate three distinct horizontal layers, as follows:

1. A shallow low resistivity layer extending from the ground surface to a depth of approximately 10(±) feet caused by the near surface soil and upper weathered bedrock.
2. A high resistivity layer of unsaturated shale/siltstone that extends to a depth of approximately 60 feet.
3. A deeper layer of low resistivity likely indicating the presence of water saturated bedrock.

Near vertical features showing a minor to major decrease in resistivity within, or cross-cutting the horizontal layering can indicate the presence of a potential near vertical bedrock fracture zone. Several potential fracture zones were identified and correlated across the geophysical survey area. It is not possible to accurately determine fracture dip angle from these ERI models. Results from the northwest to southeast oriented profiles, and the southwest to northeast oriented ERI profiles will be discussed briefly below.

Northwest to Southeast Oriented Profiles; ERI-1, ERI-2, ERI-3, and ERI-4

Locations of northwest to southeast ERI profiles and interpreted fracture zones are shown on Figure 1. The individual ERI model profiles are shown on Figure 2 and 3. Five potential fracture zones were identified from northwest to southeast oriented profiles. Potential fractures FRZ-A through FRZ-E are shown on Figure 1 and on the individual ERI model profiles. These fracture zones are oriented southwest to northeast, approximately perpendicular to the resistivity transects. The most prominent southwest to northeast fracture zone is FRZ-A which can be identified in all ERI northwest to southeast profiles, and being most prominent in profile ERI-3.

Fracture zone FRZ-D is also identifiable in profiles ERI-1 through ERI-4. Fracture FRZ-E is located beyond the southeast ends of ERI-2 and ERI-3, but can be identified in profiles ERI-1 and ERI-2.

Fracture zones FRZ-B and FRZ-C can be recognized in both profiles ERI-2 and ERI-3, but are not easily recognized in ERI-1 and ERI-4. It is possible that fractures FRZ-B and FRZ-C are either discontinuous or change in character (e.g. width, aperture, tightness) as they cross the site.

Southwest to Northeast Oriented Profiles; ERI-5, ERI-6, and ERI-7

Three potential fracture zones were identified passing through profiles ERI-5, ERI-6, and ERI-7, the most prominent being FRZ-H (Figures 1 and 6). Fracture zones FRZ-F and FRZ-G are oriented approximately northwest to southeast, whereas fracture FRZ-H is oriented slight more

towards a north-northwest direction. The orientation of FRZ-H suggests that it could intersect FRZ-G at a location located to the southeast of the site.

<u>*Summary Discussion*</u>

Seven ERI profiles were completed in an approximate grid pattern within the survey area to identify potential bedrock fractures. Resistivity models show the presence of a horizontal low resistivity starting at a depth of approximately 60 feet below the ground surface and continuing to the base of the ERI models. This low resistivity layer is interpreted to be the likely the water saturated bedrock.

Several fracture zones were identified from the modeled ERI profiles and were correlated across the site. Most of the fracture zones were identified from features within the upper 60 to 80 feet of the the profiles, above the interpreted water saturated layer. Given the nature of the fractures occurring in the shale/siltstone bedrock, it is reasonable to assume the fracture zone features identified within the upper 60 to 80 feet penetrate deeper into the formation. If this information is to used to assist with the siting of future wells, it is suggested that locations near the intersection of identified fracture zones be targeted for the highest probability to intersect permeable fractures.

Closing

All geophysical data and field notes collected as a part of this investigation will be retained at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past results of similar surveys although it is possible that some variation could exist at this site. Intrusive field activities, such as soil borings and/or rock coring, may be needed to further investigate and confirm the presence or absence of identified and interpreted features. Due to the nature of geophysical data, no guarantees can be made or implied regarding the presence or absence of additional objects or targets beyond those identified.

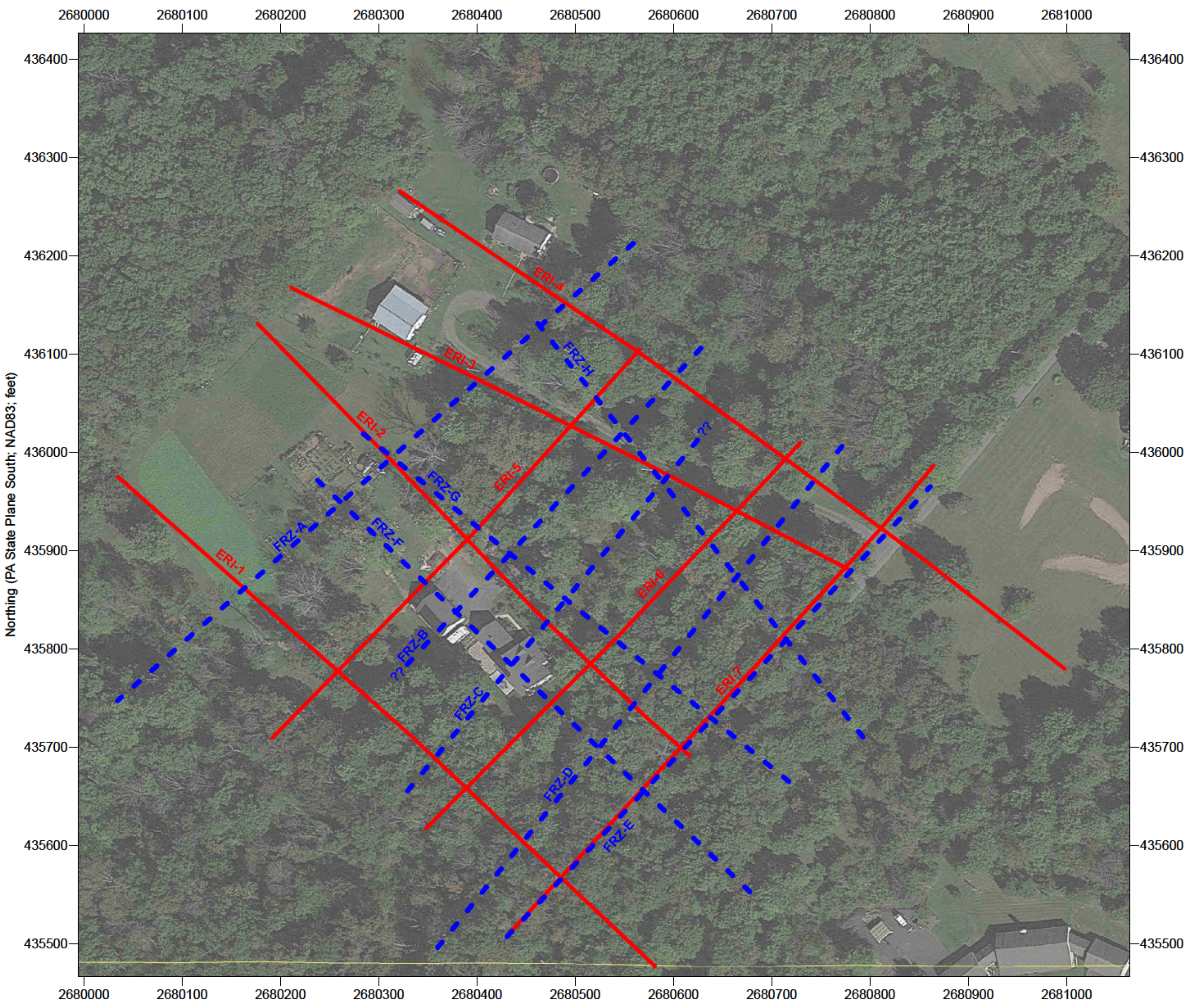
If you have any questions regarding the results of this field investigation, please contact me at 610-722-5500. It was a pleasure working with you on this project and we look forward to being able to provide you with sub-surface imaging services in the future.

Sincerely,

Martin Young
Project Geophysicist

Donald Jagel, P.G.
Principal Geophysicist

attachment: Figures 1 through 4



AERIAL PHOTO FROM GOOGLE EARTH

Legend

ERI-1 — Electrical Resistivity Imaging Profile

FRZ-A — Potential Bedrock Fracture Zone Interpreted from ERI Models

0 60 120 180 240 360

GRAPHIC SCALE IN FEET

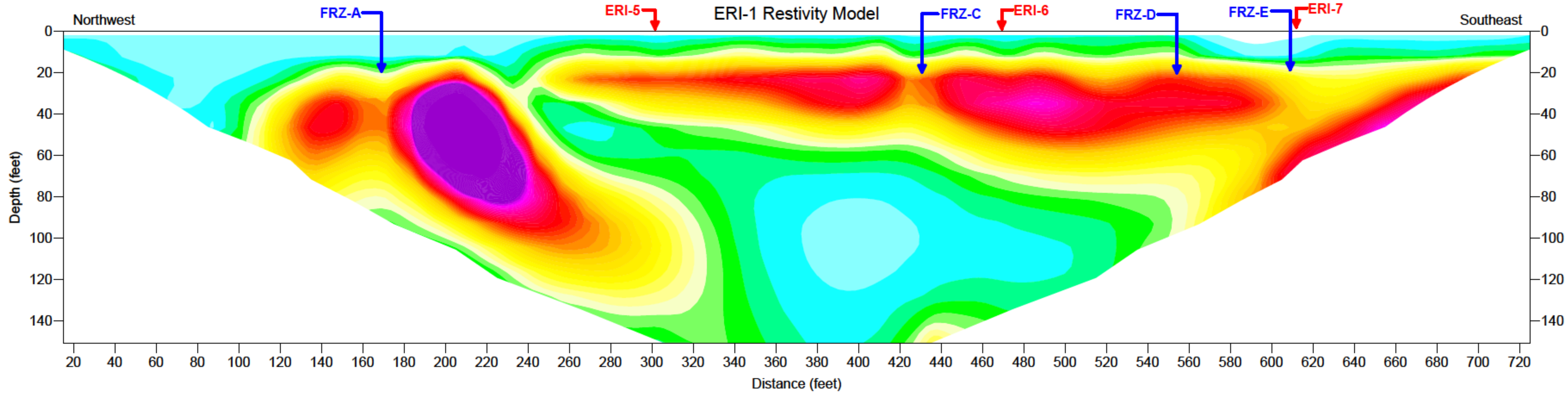
NOTES:

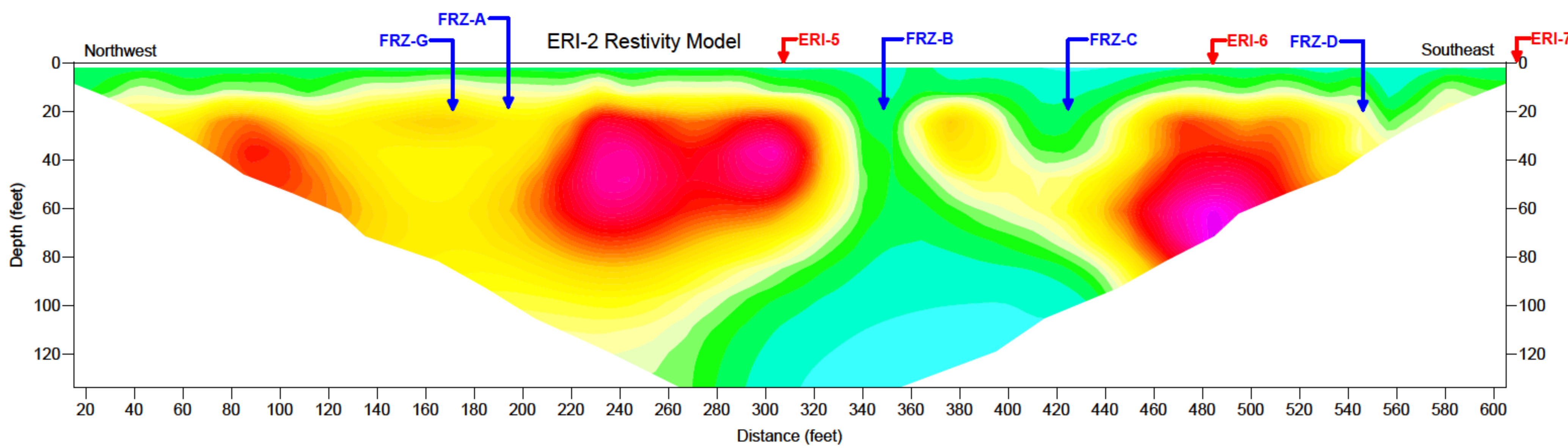
1) ERI data were collected along transects to determine geologic conditions, and identify potential water bearing features. Data were collected using an AGI Super Sting R8 resistivity meter. A dipole-dipole electrode configuration was used with electrode spacing set at 10 feet.
Data were modeled using RES2DINV. See report text for details and discussion.

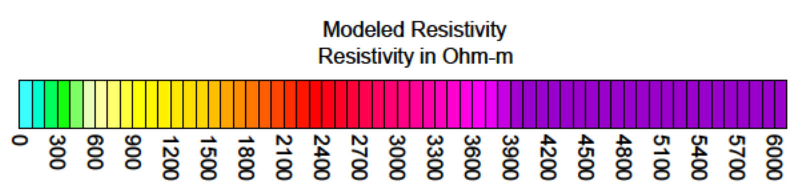
2) Feature locations were determined using a sub-meter GPS instrument (GIS quality), are for illustrative purposes only, and were not surveyed by licensed surveyor.

3) The items shown on this figure may not be all inclusive. AGS does not warrant the fact that additional buried features/utilities may be present which could not be identified by AGS personnel during this investigation.

ADVANCED GEOLOGICAL SERVICES 3 MYSTIC LANE MALVERN, PA 19355 (610) 722-5500	Electrical Resistivity Imaging Survey Line Location Plot LOCATION: GTAC Nockamixon TCE Site Nockamixon, Pennsylvania	
AGS PROJECT #: 21-183-1	CLIENT: Groundwater & Environmental Services ADVANCED GEOLOGICAL SERVICES, INC.	1
DATE: June 30, 2021	DRAWN BY: M. Young APPROVED BY: DJ	







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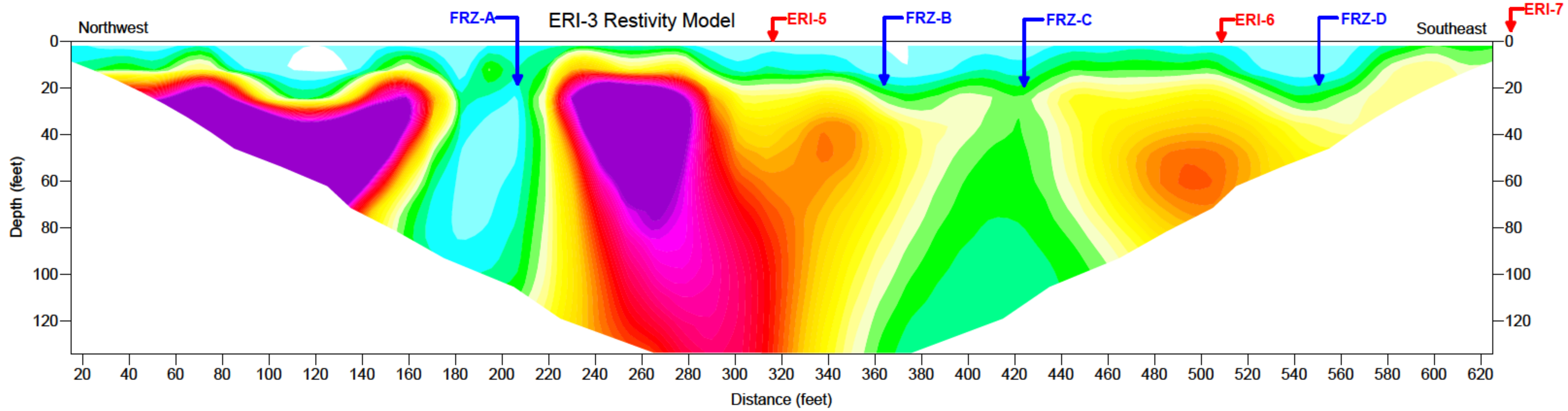
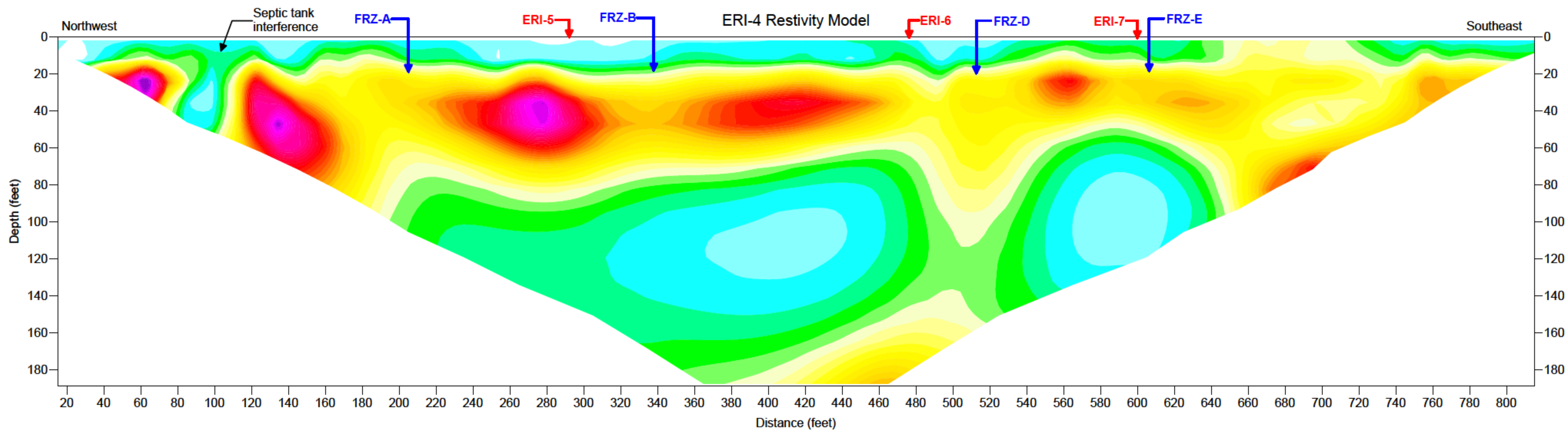
ADVANCED GEOLOGICAL SERVICES
3 MYSTIC LANE
MALVERN, PA 19355
(610) 722-5500

	Electrical Resistivity Imaging Survey ERI Profiles 1 & 2
	LOCATION: GTAC Nockamixon TCE Site Nockamixon, Pennsylvania
	CLIENT: Groundwater & Environmental Services
AGS PROJECT #: 21-183-1	ADVANCED GEOLOGICAL SERVICES, INC.
DATE: June 30, 2021	DRAWN BY: M. Young / APPROVED BY: DJ

2





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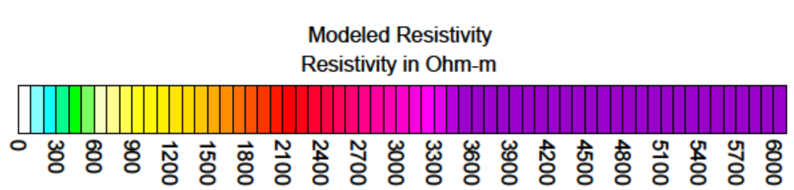


ADVANCED GEOLOGICAL SERVICES
3 MYSTIC LANE
MALVERN, PA 19355
(610) 722-5500

Electrical Resistivity Imaging Survey
ERI Profiles 3 & 4

LOCATION: GTAC Nockamixon TCE Site
Nockamixon, Pennsylvania

CLIENT: Groundwater & Environmental Services

AGS PROJECT #: 21-183-1

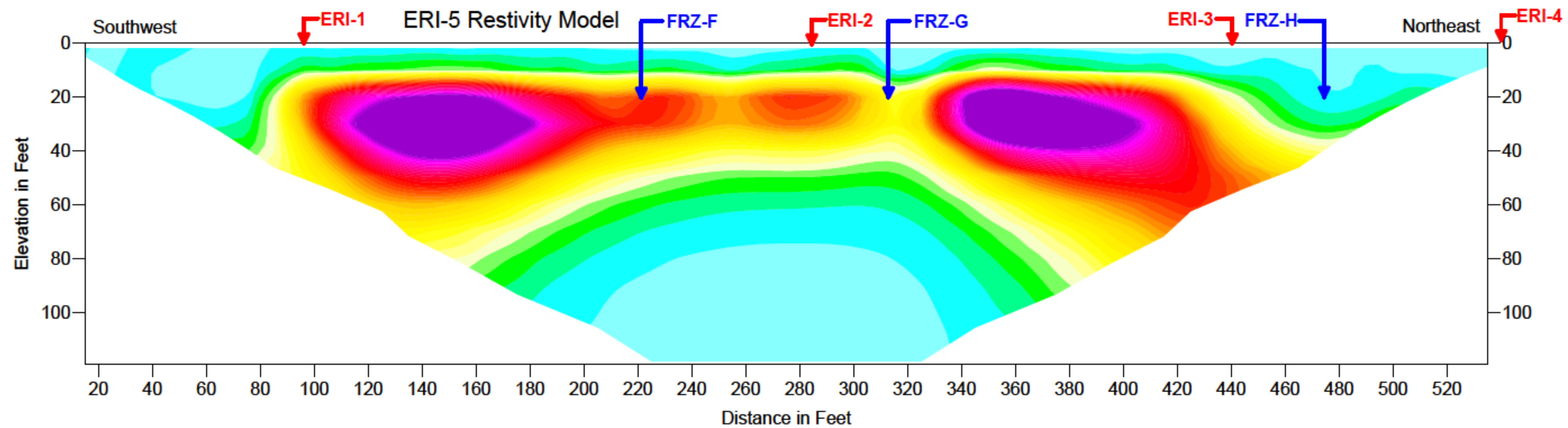
ADVANCED GEOLOGICAL SERVICES, INC.

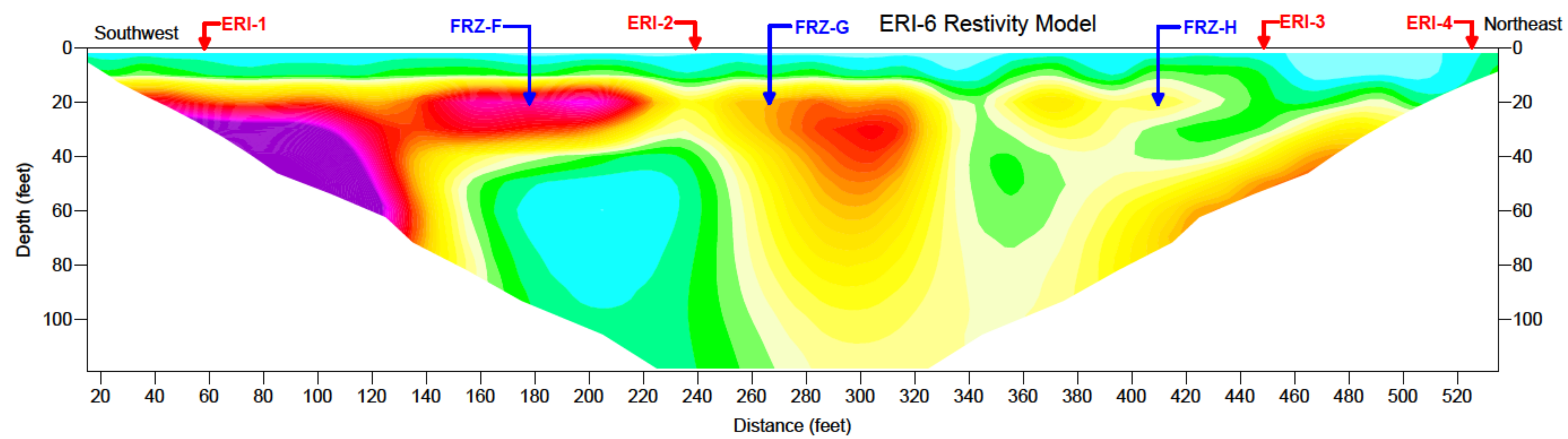
DATE: June 30, 2021

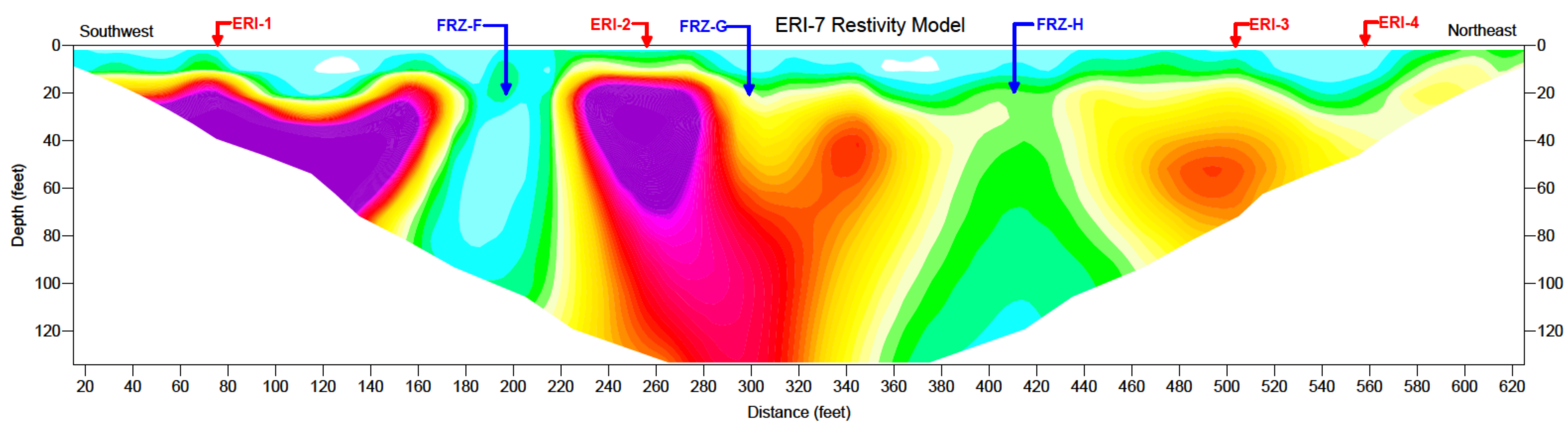
DRAWN BY: M. Young

APPROVED BY: DJ

3







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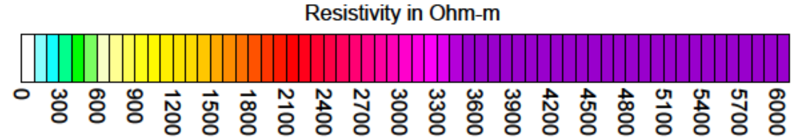
Modeled Resistivity

Resistivity in Ohm-m



ADVANCED GEOLOGICAL SERVICES 3 MYSTIC LANE MALVERN, PA 19355 (610) 722-5500	Electrical Resistivity Imaging Survey ERI Profiles 5, 6, & 7		
	LOCATION: GTAC Nockamixon TCE Site Nockamixon, Pennsylvania		
	CLIENT: Groundwater & Environmental Services		4
AGS PROJECT #: 21-183-1	ADVANCED GEOLOGICAL SERVICES, INC.		
DATE: June 30, 2021	DRAWN BY: M. Young	APPROVED BY: DJ	

Attachment C – Cost Estimate