To: Commission on the Seacoast Cancer Cluster Investigation c/o Andrew Hoffman, Case Manager, NHDES

From: James Soukup, PG, RG, LSP Principal Hydrogeologist Weston Solutions, Inc.

Cc: Skip Hull, USEPA

Date 13 May 2020

Re: Current Understanding of Bedrock Groundwater Flow in the Vicinity of the Coakley Landfill, North Hampton, New Hampshire NHDES Site # 198712001

Weston Solutions, Inc. (Weston®) has prepared this overview of groundwater flow conditions in the bedrock aquifer in the vicinity of the Coakley Landfill, located in North Hampton, NH, at the request of the New Hampshire Department of Environmental Services (NHDES) in an effort to clarify why continued monitoring of selected residential neighborhoods (i.e., September Drive area) is no longer required. The description of groundwater flow conditions and pathways presented in this report is based on the extensive deep bedrock data collected by the Coakley Landfill Group (CLG), as directed by the NHDES and United States Environmental Protection Agency (USEPA), as well as the knowledge and local experience of the author.

The Coakley Landfill is located within the towns of Greenland and North Hampton. The actual landfill covers approximately 27 acres. The Site is located about 400 to 800 feet west of Lafayette Road (U.S. Route 1), directly south of Breakfast Hill Road, and about 2.5 miles northeast of the center of the town of North Hampton as shown on **Figure 1**. The area around the landfill is characterized by a combination of undeveloped land, residential developments, and commercial businesses. Most of the commercial properties are located east of the landfill, along Lafayette Road (U.S. Route 1). The area immediately west of the landfill is undeveloped land, but residential neighborhoods are present further to the west, as well as to the north and south.

The local bedrock is composed mostly of the Rye Formation, which consists of various layers of metamorphosed sedimentary rocks (like phyllite, schist, gneiss, and quartzite). There is also an area of granite (Breakfast Hill Granite) and basalt bedrock in the vicinity of the landfill that extends to the northeast and southwest. The granite and basalt were once mined in the area of the landfill and a small quarry can still be seen today behind the Bethany Church off Breakfast Hill Road.

Groundwater movement in bedrock of the type found at the Coakley Landfill is through fractures, or ‘cracks’, in the rock. While most fractures are relatively small and only extend a few tens or hundreds of feet, larger ones do occur that can extend for several hundred feet or even more than a thousand feet. It is important to understand that fractures are ‘planar’ features, meaning that they have both length and width, like a sheet of paper. Most fractures are too small, too short, or too tight to allow much groundwater flow, so groundwater movement in bedrock is mostly restricted to the larger fractures that are called ‘hydraulically active’, meaning that they can transport groundwater. As an example, a typical 300-foot bedrock water supply well for a home may intersect 50 to 100 fractures (depending on the type of bedrock), but only 3 to 6 may contain flowing groundwater.

Because groundwater flow in bedrock is restricted to these 'hydraulically-active' fractures, it can only move in certain directions. To figure out where groundwater in bedrock is flowing, we must first understand how the fractures are oriented. The pattern of fractures in bedrock is not completely random, but instead is controlled by the properties of the rock and the forces that have acted on the rocks over the many thousands of years since they were formed. In New England, the primary forces that influenced fracture patterns in the bedrock were related to the closing of the proto-Atlantic Ocean about 440 million years ago. As a result, the primary 'strike' or alignment of bedrock fractures in New Hampshire (including the vicinity of the Coakley Landfill) is generally northeast to southwest (roughly parallel to the coastline). Note that this alignment will vary slightly based on local conditions. However, when bedrock cracks in response to such regional stresses, a second set of fractures develops that is roughly perpendicular to the primary direction. So in New Hampshire, this secondary set of fractures typically is oriented northwest to southeast. The secondary set of fractures is usually less well developed than the primary fractures, meaning they tend to be shorter and less frequent (more widely spaced apart). The secondary fractures typically extend only a few tens or a hundred feet, while the primary fractures can extend for several hundred feet or even more than a thousand feet.

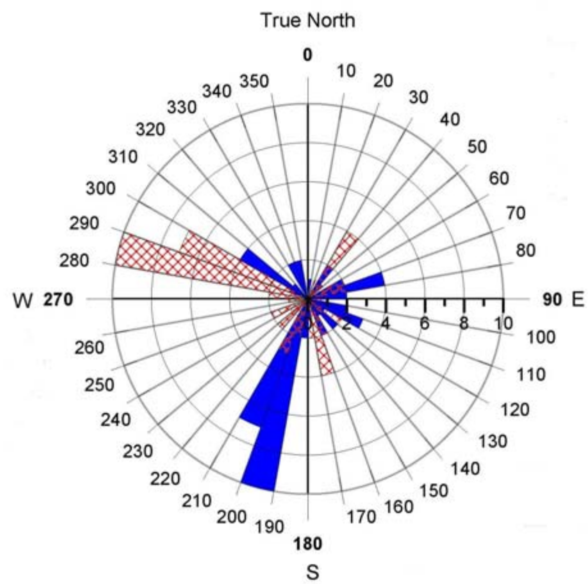
Numerous investigations have been conducted in the vicinity of the Coakley Landfill to investigate the fracture patterns in the bedrock to understand how the groundwater can move, and therefore where any contamination in groundwater leaving the landfill would likely go. These investigations have included lineament analysis, bedrock outcrop mapping, and drilling/logging of bedrock wells. Most of this investigation work is detailed in the November 25, 2019, *Deep Bedrock Investigation Interim Report* prepared by CES, Inc., on behalf of the CLG (www.epa.gov/superfund/coakley).

One method used by geologists to determine how groundwater moves through bedrock is conducting a 'lineament analysis'. Lineaments are linear features on the ground surface that can be identified from aerial photographs of an area. Sometimes these linear features on the ground surface correspond to larger bedrock fractures or other features like faults or contacts between different types of bedrock that can be used to infer the orientation of the primary and secondary fracture sets in the local bedrock. A lineament analysis is conducted by reviewing aerial photographs of the study area and drawing lines representing linear features that stand out. However, not all linear features identified during a lineament analysis are related to bedrock fractures, and a trained eye can often weed out those that are obviously related to man-made structures like roads, utilities, or rail lines. Lineament analyses are typically one of the first methods a geologist uses to assess fracture patterns because it can be done quickly and is cost-effective; but it is not as accurate as direct measurements of fractures in wells or on bedrock outcrops (bedrock exposed above ground surface).

Bedrock outcrop mapping is another method used to determine the orientation of fractures at a site. This method can be effective if bedrock is shallow and outcrops are present/exposed and distributed around the site. At Coakley, there are a number of outcrops in the vicinity of the landfill, including the quarry mentioned earlier. Mapping the outcrops consists of having a geologist examine the outcrop, identify the fractures present, and measure a representative number of the identified fractures. However, data collected from outcrops is most-representative of conditions in shallow bedrock and may not represent conditions in the deeper bedrock where most residential wells get their water.

The most accurate method of mapping bedrock fractures is the drilling and logging of bedrock wells. The USEPA and CLG have drilled numerous wells deep into the bedrock (100 feet to 300 feet deep) and then used special downhole geophysical tools to map (also called 'logging') all of the fractures and identify which ones are hydraulically-active (have groundwater flowing through them). The hydraulically-active fractures are then isolated and discrete groundwater samples are collected directly from these fractures and sent to a laboratory for testing. Results from the geophysical logging of the bedrock wells are used to create 'rose diagrams' that illustrate the pattern of fractures in each well.

An example of a rose diagram from a typical bedrock well at the Coakley Landfill is shown below:



The blue 'petals' on the above rose diagram show the alignment of the fractures measured in this well. You can see that most fractures in this example are trending northeast-southwest and represent the primary fracture set. Closer inspection of the diagram shows a few fractures that are oriented northwest-southeast, representing the secondary fracture set. The pink 'petals' represent the dip of the fractures, which is typically less important with regard to groundwater flow.

Bedrock fracture data from each of these three methods, as well as information from other published sources such as USGS publications, are plotted on a site map and evaluated to assess site-wide trends and develop a holistic conceptual model for groundwater flow. The attached **Figure 2** was excerpted from the *Deep Bedrock Investigation Interim Report* and presents the bedrock fracture data collected to date at the Coakley Landfill. The mapped lineaments are shown as light blue lines and rose diagrams for bedrock wells that have been logged to date are plotted. Note that rose diagrams for the mapped bedrock outcrops are not shown on **Figure 2**, but they show a similar pattern as observed in the monitoring wells.

Evaluation of the data plotted on **Figure 2** shows that the anticipated primary northeast-southwest and secondary northwest-southeast fracture sets are both evident at the Coakley Site. There are a large number of lineaments that are aligned with the primary northeast-southwest fracture set represented in the rose diagrams. There are fewer lineaments that align with the secondary fracture set (northwest-southeast) and only two rose diagrams that have prominent secondary fractures (MW-22D and MW-24); which is consistent with the lower frequency of these fractures.

In addition to the two sets of fractures described above, there is another feature at Coakley that has a significant impact on groundwater flow in bedrock. There is a large, linear depression (often referred to as a 'trough') in the bedrock surface that runs roughly northeast-southwest along Berrys Brook and Little River west of the landfill and is coincident with the mapped lineaments in this area. This trough in the bedrock surface was likely cut by the glaciers that covered this area during the last ice age. Glaciers will exploit weak spots in the underlying bedrock and gouge out loose or more highly-fractured rock. Such troughs or depressions in the bedrock surface are often associated with a zone of closely-spaced fractures that can represent a groundwater flow pathway. Such is the case at the Coakley Site.

Taken together, these data were used to identify groundwater flow pathways which govern migration of contaminants from the landfill. Three predominant groundwater pathways have been identified at the Coakley site (see **Figure 3**), and are listed in roughly the order of importance with the most significant pathway listed first:

1. North and south along the trough in the bedrock surface (red arrows)
2. Northeast and southwest along the primary fracture set (green arrows)
3. Northwest and southeast along the secondary fracture set (yellow arrows)

These pathways align with the groundwater impacts that have been measured at the Site, including historical concentrations of volatile organic compounds (VOCs) as well as current observations of 1,4-dioxane, arsenic, manganese, and per- and polyfluoroalkyl substances (PFAS). This line of evidence provides a greater level of confidence that the interpretation of the bedrock structures (fractures and trough) and resulting groundwater flow pathways is correct.

With multiple lines of evidence supporting the understanding of how groundwater can move through the bedrock, we can then assess which private wells might be situated along the bedrock flow paths from the landfill. **Figure 4** shows the area around the Coakley Landfill with the bedrock flow pathways from **Figure 3** added. From **Figure 4**, it is possible to identify the different areas and streets that could be impacted by contamination from the landfill, as well as those that are not aligned with bedrock pathways. This is explained below.

For the most significant groundwater flow pathway associated with the bedrock trough structure, the residence and golf course on Breakfast Hill Road near where the rail trail crosses are the most likely receptors to be impacted to the north, and in fact both of those locations have concentrations of site contaminants detected. Both of these wells have had treatment systems installed by CLG. Testing of the water supply wells in that area is performed twice a year by the CLG. Southward along this pathway, the area where the rail trail crosses North Road is also an area that could be impacted, and in fact historical results from monitoring well GZ-130 (shown on **Figures 2 and 3**) showed VOC contamination from the landfill had reached that location, although recent sampling results suggest that impacts from the landfill may no longer extend out that far. More testing is planned for that area.

For the primary fracture set (the next most significant bedrock pathway), the area to the northeast has the potential to be impacted, although ongoing testing of monitoring wells and private wells do not show impacts beyond elevated manganese. Although PFAS compounds have been detected in some of these wells, levels have consistently been low, and 1,4 dioxane has not been detected. Groundwater conditions to the northeast may also be impacted by contaminants from the Rye Landfill, which complicates interpretation of the data.

The southern end of the primary fracture set pathway merges with the southern end of the bedrock trough pathway described above and those two can be considered a single southern pathway. Private wells and monitoring wells along the southern pathway that are currently monitored show low levels (below standards) of PFAS compounds and no 1,4 dioxane, although manganese and arsenic are elevated.

The final pathway to be considered is the set of secondary fractures that are oriented northwest-southeast. As mentioned above, the secondary fractures are typically shorter and less frequent than the primary set, and as a result they represent a much less significant pathway for contamination to migrate away from the landfill. The eastern side of this pathway passes beneath Lafayette Road (U.S. Route 1), where all of the businesses are served by town water so there are no receptors. Monitoring wells on the east side of the landfill do show low-level impacts although existing monitoring well GZ-109 on the east side of Lafayette Road does not show any impacts, suggesting that migration to the east of Lafayette Road is likely limited. Additional investigations are planned for this area. The western side of this bedrock pathway extends beneath Berrys Brook and the associated wetlands, towards the Ridgecrest/Skyview Drive area. Groundwater tests from bedrock monitoring wells located along this pathway (MW-21D and MW-22D) have not detected any impacts from the landfill. Also, extensive testing of residential wells in that neighborhood have not identified any exceedances of the drinking water standards. Monitoring of select residential wells in that area continues to be performed twice a year by the CLG.

Sampling of residential wells within neighborhoods that are not aligned with any of the three groundwater pathways is no longer required. Before the bedrock study had been performed and the groundwater pathways confirmed, it was prudent to sample residential wells in all directions from the site. However, extensive investigations have been performed and multiple lines of evidence have been developed that inform the current understanding of the site. Residential neighborhoods located more than a mile northwest of the Coakley Landfill, including September Drive, the northern end of Falls Way, and the western end of Breakfast Hill Road, are not located along mapped bedrock groundwater flow pathways connected to the Site. As a result, further monitoring of those neighborhoods as part of the investigation into the Coakley Landfill is not justified.

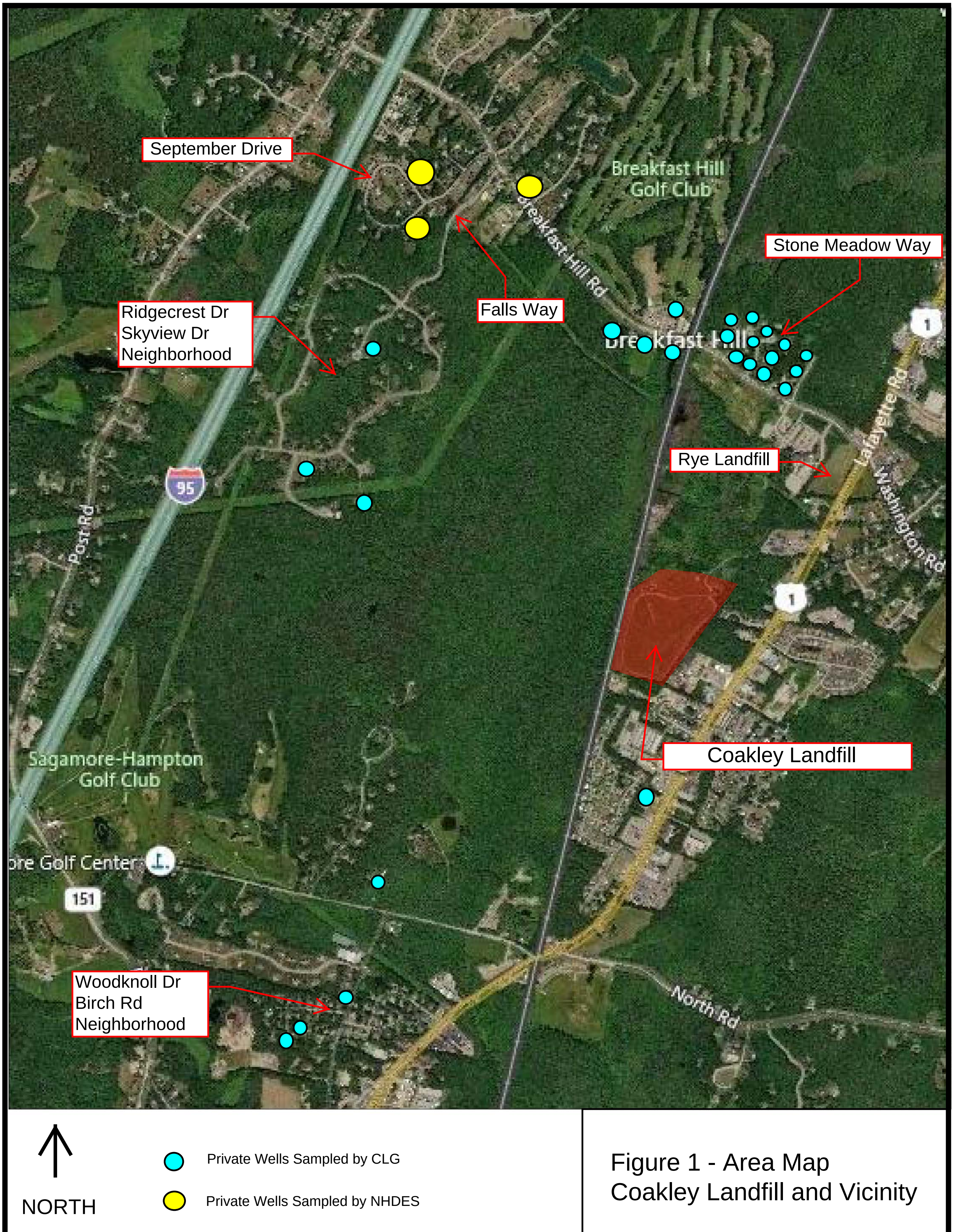
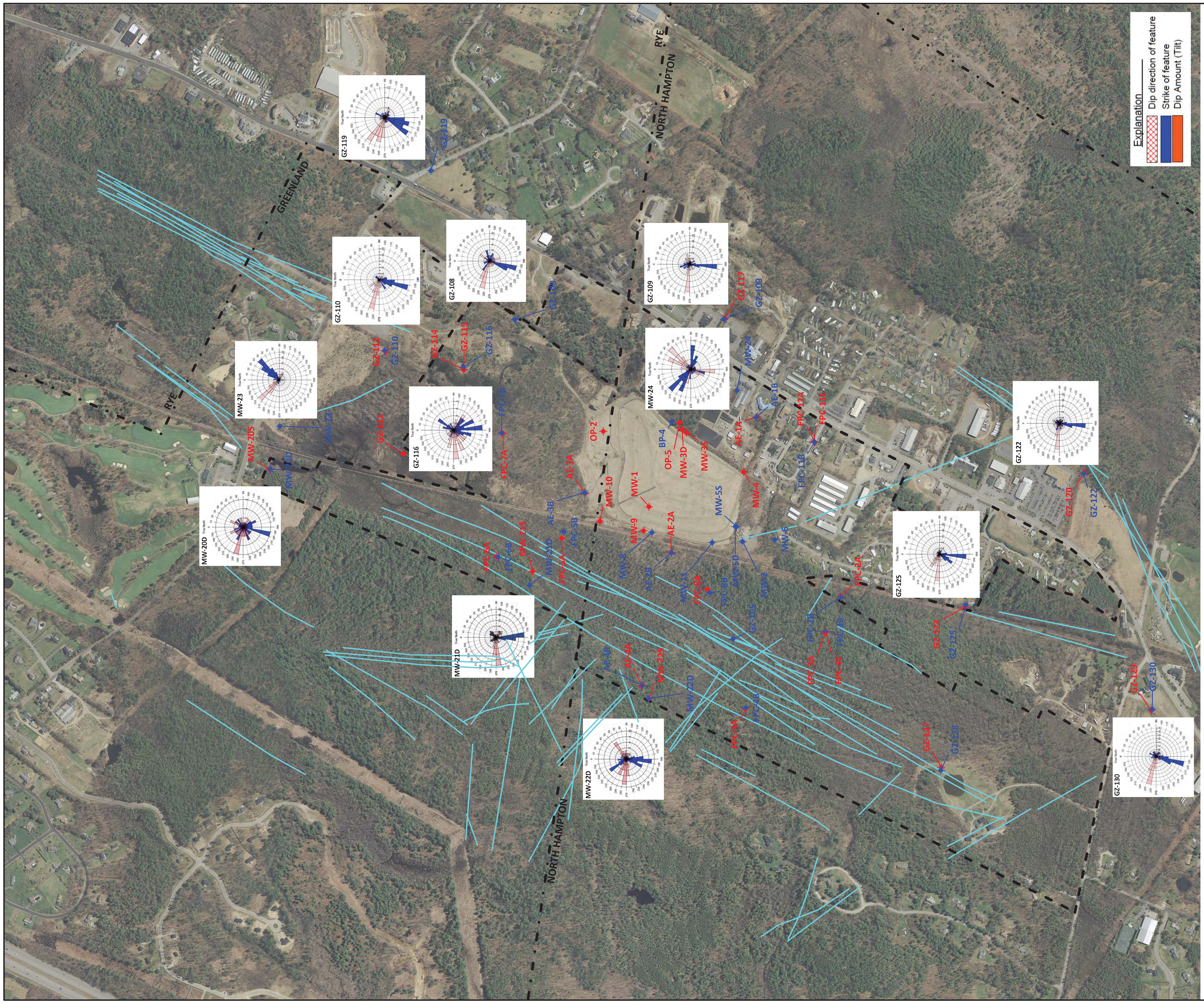


Figure 1 - Area Map
Coakley Landfill and Vicinity



LEGEND

- GZ-117 OVERBURDEN GROUNDWATER MONITORING WELL
- GZ-108 BEDROCK GROUNDWATER MONITORING WELL
- GROUNDWATER MANAGEMENT ZONE BOUNDARY
- TOWN LINE
- PHOTOLINEAMENT LOCATIONS (BCI GEONETICS, 1986)

NOTES

1. THIS SITE PLAN IS BASED ON EXISTING SAMPLING LOCATIONS AS PER THE COAKLEY LANDFILL SUPERFUND SITE REVISED SAMPLING AND ANALYSIS PLAN DATED JULY 18, 2018.
2. GMZ BOUNDARY IS BASED UPON "GMZ BOUNDARY PLAN" DATED MAY 9, 2008 INCLUDED IN THE 2008 GMP APPLICATION PREPARED BY HANCOCK ASSOCIATES AND 2013 GMZ EXPANSION AREA ESTABLISHED BY THE 2013 GMP DATED JANUARY 7, 2014.
3. GIS DATA CURTESY OF NEW HAPSHIRE ONLINE GRANIT DATABASE.
4. MAP IS PROJECTED USING THE NEW HAMPSHIRE STATE PLANE PROJECTION, US FEET AND REFERENCES THE NORTH AMERICAN VERTICAL DATUM OF 1983.

COAKLEY LANDFILL SUPERFUND SITE

NEW HAMPSHIRE

GRAPHIC SCALE
1 INCH = 400 FEET

0 FT 400 FT 800 FT 1200 FT 1600 FT

CES INC
Engineers • Environmental Scientists • Surveyors

PROJECT TITLE
COAKLEY LANDFILL SUPERFUND SITE
NORTH HAMPTON AND GREENLAND, NEW HAMPSHIRE

SHEET TITLE
Figure 2 - Fracture Data and Mapped Lineaments

REV.	DESCRIPTION	DATE	DRAWN BY	CHECKED BY
R1				
R2				
R3				
R4				
R5				
R6				
R7				

ISSUE STATUS
FOR DISCUSSION PURPOSES ONLY

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DATE 2020-03-24	
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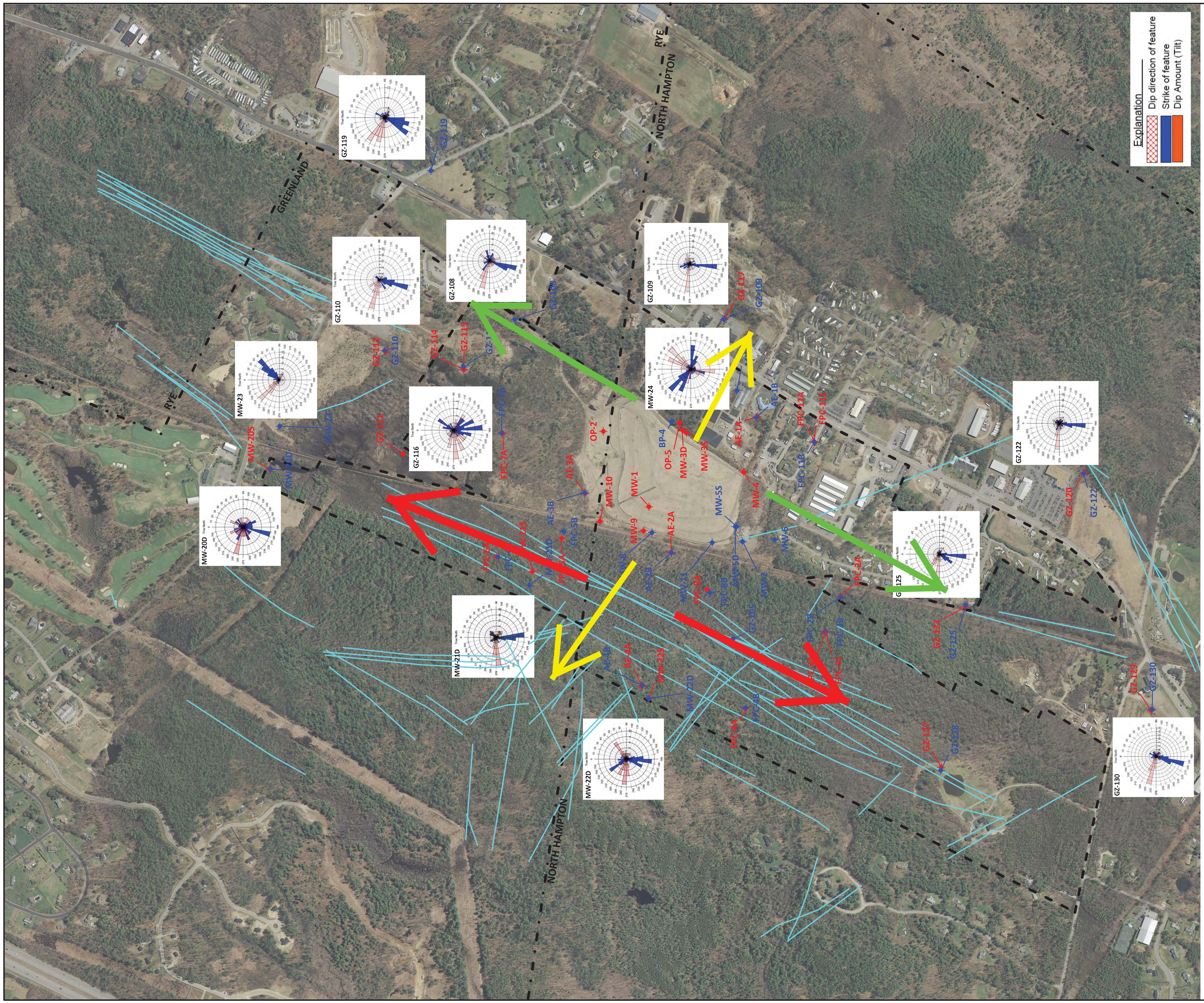
JOB NUMBER	
DRAWING NUMBER	



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- Bedrock Trough Flow Pathway
- Primary Fracture Flow Pathway
- Secondary Fracture Flow Pathway

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SHEET TITLE
Figure 3 - Deep Bedrock Flow Pathways

ISSUE STATUS
FOR DISCUSSION PURPOSES ONLY

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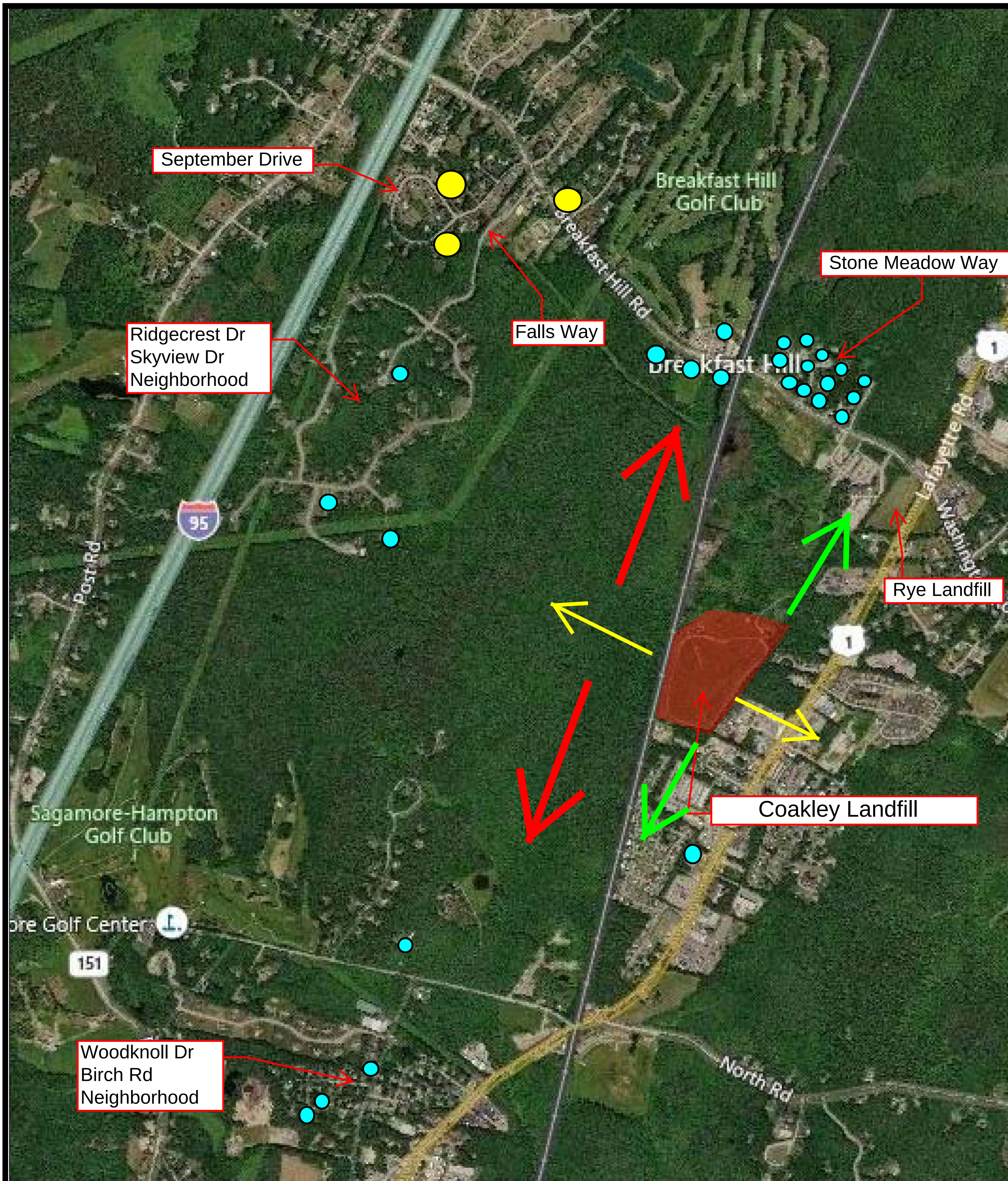

NORTH

Private Wells Sampled by CLG

Private Wells Sampled by NHDES

Figure 4 - Area Map with Flow Paths
Coakley Landfill and Vicinity