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-PROFESSIONALS-

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September 26, 2022

RE: Review and Commentary of Green Ridge Landfill Documents.

CCLA
Attn: Ms. Betty Myer
Via email: bjmeyers27@earthlink.net

Dear Ms. Myer,

I have completed the review of several of the technical documents associated with the permit application by Green Ridge. I did this with the aim of answering the attached "Questions for Geologist" that CCLA submitted to me addressing its concerns with the adequacy of the science conducted for the permit. Because my expertise is in geology, I focused on the *PTA Attachment XI Hydrogeologic and Geotechnical Report and* the *PTA Attachment VII Landfill Impact Statement.*

General Geology of Virginia

Before I attempt to answer the questions, please allow me to offer a brief primer in basic groundwater geology for the non-technical reader. Virginia is comprised of five geologic provinces; from west to east these are 1) the Appalachian Plateau, 2) the Valley and Ridge, 3) the Blue Ridge, 4) the Piedmont, and 5) the Coastal Plain. The Appalachian Plateau consists of horizontally stratified sedimentary rocks, primarily shale, sandstone, and limestone. These rocks started as unconsolidated sediments and then later were lithified. The Valley and Ridge Province also consists of sedimentary rocks, but these have been intensely folded and faulted. The province gets its name from the alternating valleys and ridges that result from the differential weathering of the rocks. The shales and limestones are much more susceptible to weathering than are the sandstones and conglomerates, so the valleys are generally comprised of limestone and shale while the ridges are comprised of sandstone and conglomerate.

The Blue Ridge Province is comprised of metamorphic rocks that also have been intensely folded and faulted. The word metamorphic comes from the Greek *meta* (change), and morph (form). All metamorphic rocks started as another rock type and then changed form into the new rock type. The theory is that sometime in antiquity the original rock was sedimentary, igneous (volcanic or otherwise originating from magma), or another metamorphic rock. Subsequently, the parent rock was subject to heat and pressure during mountain building events to the point of partial re-melting of the minerals before solidifying again. During this partial re-melting, different minerals can be formed from the parent materials, and those minerals tend to align themselves perpendicular to the direction of pressure being applied to it. As an example, picture pouring out a box of toothpicks on your kitchen counter. The toothpicks will be aligned randomly in all directions. If you take your open hands and place them on either side of the pile of toothpicks and bring your palms together, most of the toothpicks will be aligned with your palms, perpendicular to the direction of stress. The Piedmont shares most of the characteristics of the Blue Ridge but tends to be lower in elevation and the two provinces are separated by major faults. Cumberland County lies in the east-central portion of the Piedmont Province.

The mountains of the Valley and Ridge, Blue Ridge, and Piedmont are believed to have been built primarily from an ancient collision between the North American tectonic plate and the African tectonic plate. This collision between the two continental landmasses pushed up the earth's crust and caused the folding and faulting that is observed today. There are various types of faults, but a significant number of those in Virginia are thrust faults. These occurred when blocks of rock were pushed overtop of rocks to the west. In this way, older (deeper) rocks were thrust on top of younger rocks. Each of the boundaries between the provinces is marked by a major thrust fault or thrust fault system. Figure 1 provides a generalized geologic province map of Virginia and an idealized cross section illustrating this. The arrows on the cross-section illustrate the relative directions of movement on the fault.

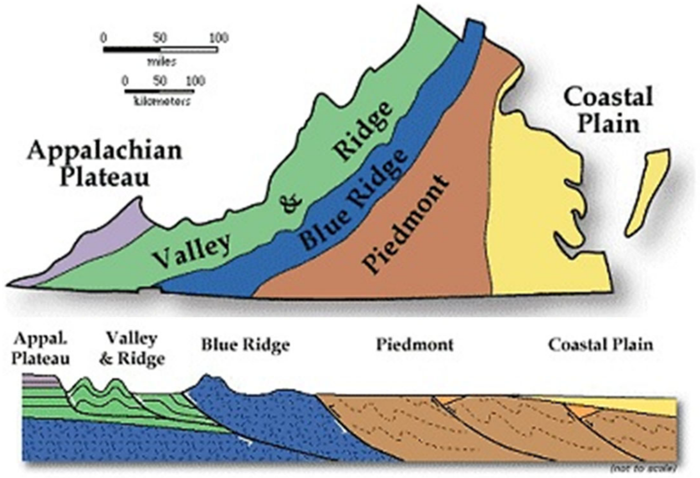

Figure 1. Generalized geologic province map and idealized cross-section of Virginia.

General Hydrogeologic Principles

Groundwater originates as precipitation. When rainfall or snow melt enters the ground, it percolates through the soil pores in what is called the unsaturated zone or vadose zone. In this zone, generally the upper part of the soil, the soil pores are filled with air and water. Eventually, the water reaches a depth where the pore space is primarily filled with water, and this is called the saturated zone. The boundary between the unsaturated and saturated zone is the water table. Once the water reaches the water table it will flow from high pressure to low pressure. This pressure is also called head or potential, so water is said to flow from high head to low head or high potential to low potential. The water table is therefore sometimes called the potentiometric surface.

As the water flows toward low potential, it will often discharge into a surface water body such as a pond or stream. Any perennial stream receives water not just from runoff but from groundwater discharging into its banks. This is depicted graphically in Figure 2.

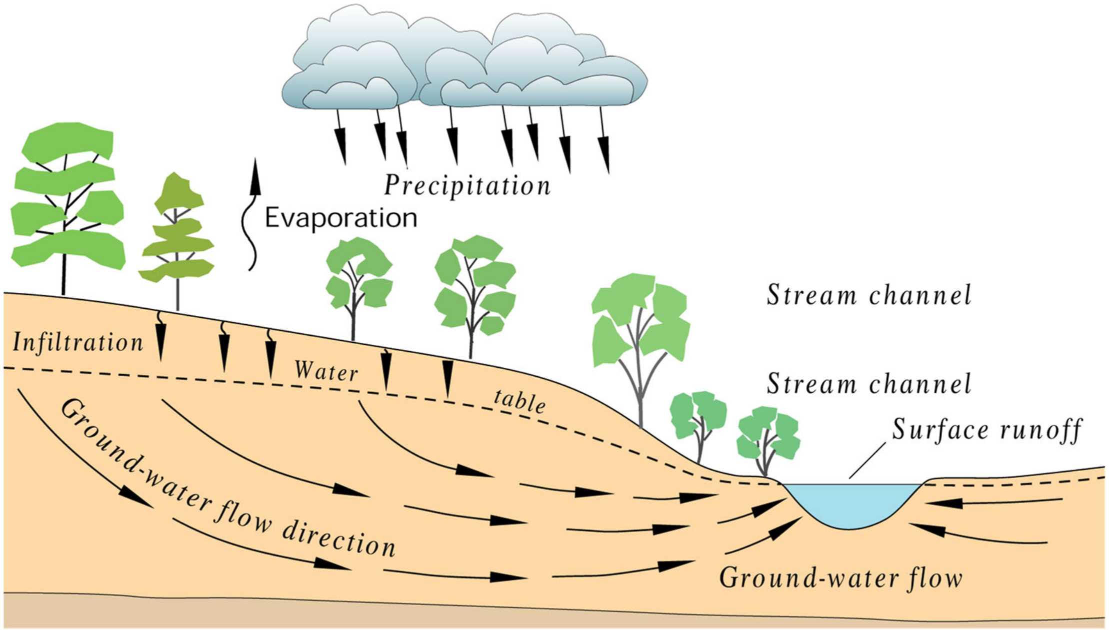

Figure 2. Generalized cross section illustrating groundwater movement.

The water table as described above is an example of an unconfined aquifer, that is to say that there is nothing that restricts groundwater movement from above. Often this aquifer will be confined from below by a barrier that restricts further downward movement, but the water table fluctuates freely in response to precipitation and changes in barometric pressure. To be considered a confined aquifer it must be confined from above but be open at some location where the aquifer is recharged. When a well is drilled into a confined aquifer, the water will rise in the well bore to an elevation that is determined by the elevation of the recharge area. If the elevation of the recharge area is higher than the top of the well, water may flow spontaneously out of the well. This is known as a flowing artesian well (Figure 3).

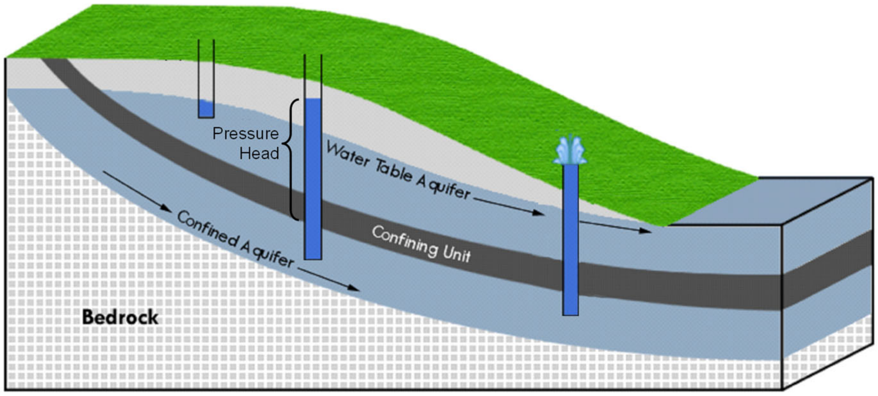

Figure 3. Generalized cross section illustrating unconfined and confined aquifers.

Answers to Questions

With this foundation laid, I will attempt to address the questions in order while also developing narrative in areas that I think are pertinent to your concerns.

I. Inadvisable Landfill Liner Installation in Bedrock

I concur that the landfill liner resting on bedrock poses an additional risk to groundwater, but the comparison to the Shoosmith landfill is not valid. The Shoosmith landfill proposed to deposit waste 200 feet below the water table. The proposed Green Ridge Landfill has only one observed incident where the water level in a monitoring well was above the proposed base grade (see Question IX on page 20).

That said, it is my opinion that the bedrock liner should not rest on bedrock and in fact some states such as New York prohibit contact of the landfill liner with bedrock. Their siting requirements state in 6 CRR-NY 363-5.1(a)(2), "Unconsolidated deposits: a minimum of 10 feet of unconsolidated deposits must exist beneath the proposed landfill site to minimize the migration of contaminants from the facility." The last part of this statement, "to minimize the migration of contaminants…" implies that having the liner directly on the bedrock would facilitate the migration of contaminants relative to having the liner on soil.

My main concern is what can happen to the liner during an earthquake. Virginia contains two zones that have a history of seismic activity, the Giles County Seismic Zone (GCSZ) and the Central Virginia Seismic Zone (CVSZ, Fig. 4). Both of these seismic zones have a history of significant earthquake activity, including the largest recorded earthquake in Virginia history (Mag 5.8) that took place in Louisa County in 2011 (Figure 5). Note that Cumberland County is primarily located in the hottest part of the zone, as well as most of the counties adjoining it.

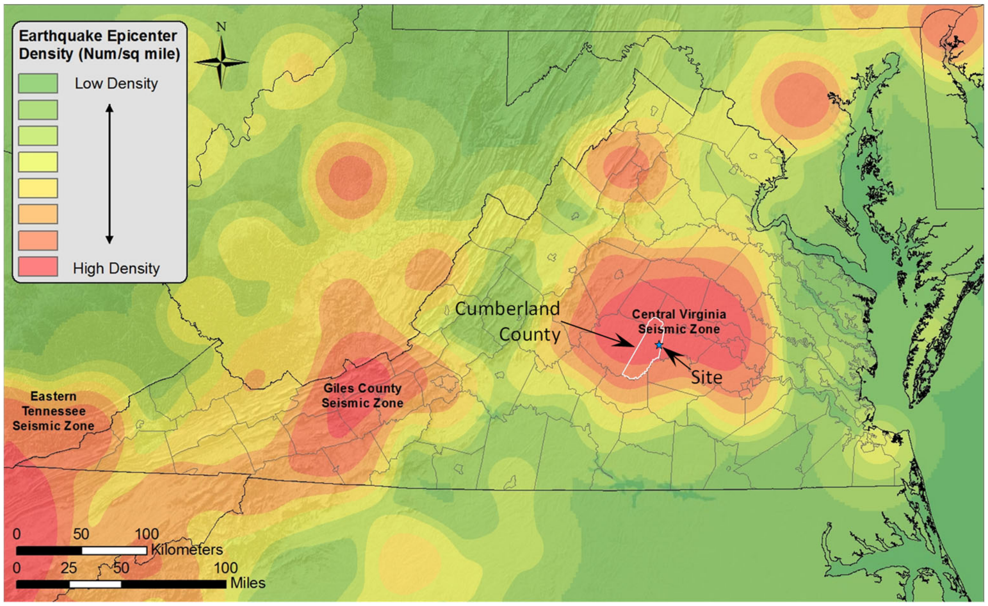

Figure 4. Virginia's seismic zones. After Whitt et al, 2017.

Figure 2 illustrates the location of the site relative to the mapped epicenters within the CVSZ.

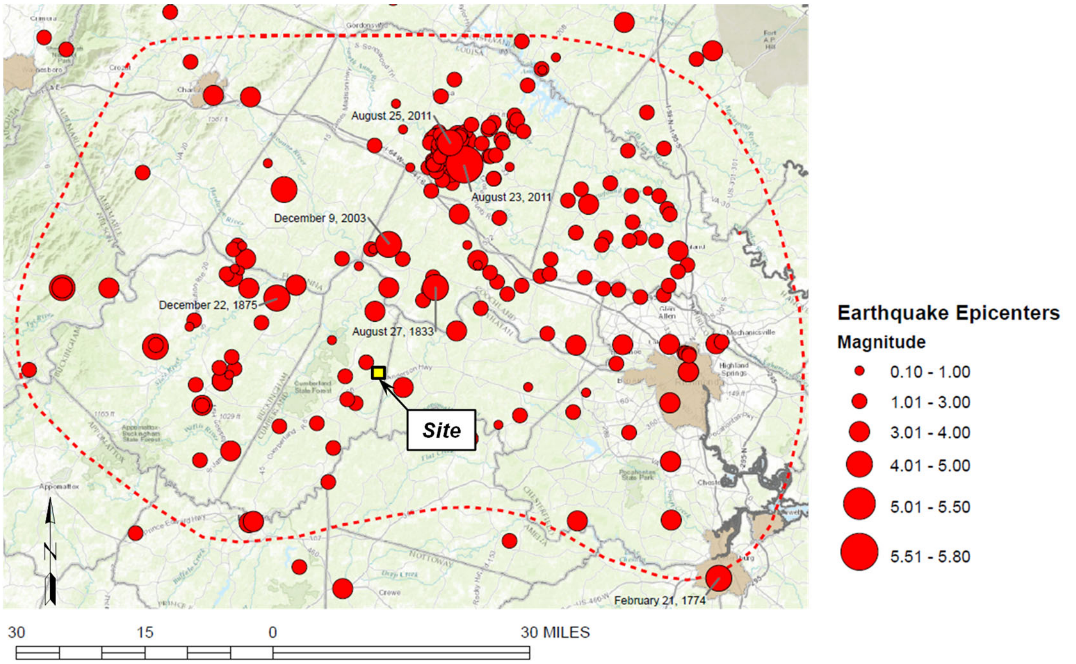

Figure 5. Mapped earthquake epicenters in the CVSZ. After Whitt et al, 2017.

So, what can happen to a landfill liner resting on rock with tons of waste atop it when the earth begins to shake? There will be a significant difference between the stiffness and density of the waste and that of the bedrock, which will result in disparate shaking of those two materials during an earthquate. Because the rock is very stiff, it will move back and forth very little, especially when compared to the waste. The waste will have very low stiffness, so it will experience far greater shaking. The disparate shaking of those two materials will likely put shearing stresses on the liner. With the liner in contact with the rock, it seems probable that this shearing will take place over rock points and edges, and that this will lead to tears and punctures. On the other hand, if the liner were to rest on a softer material such as compacted clay, the stiffness differential between the clay and the waste would be significantly lower. This will result in a lower difference in shaking and corresponding lower shear stress on the liner. Moreover, as the liner moves relative to the compacted clay beneath it, there will be no sharp edges save the occasional rocks or debris.

Failure of the landfill liner is only a matter of time because anything built by humans will eventually cease to work no matter how well crafted. Statistics on the life expectancy of landfill liners are not robust because landfill liners have only been in use for about 30 years, but Pivato (2011) puts it at only 10 to 30 years.

Question I had two more questions embedded in it so I will address those with a continuation of our numbering system.

I.a. Could the blasting that would be required to achieve the base grade create or expand fractures in the bedrock that would alter groundwater flow directions and volumes? Could the blasting cause private wells to dry up?

Any strong seismic activity has the potential to impact water supply wells finished in bedrock because these wells are supplied solely by water flowing through discreet fractures in the rock. And this seismic impact has the potential to diminish well yield and can also increase turbidity or otherwise affect groundwater quality. The primary mitigating factor is going to be distance. Those of you that are nearer the blasting have more risk of being impacted than those farther away.

One thing that the nearest residents can do is request a pre-blast inspection of their homes in order to obtain a baseline for identifying any damages to the home. You can do a similar thing with your well, but you will need to bring in enough water to have your well inoperable for a day or two. My general approach is to pull the pump from the well and let it sit for a while until the water reachwa its static level. Then I measure the static water level in the well before running a pump test on the well for up to 24 hours if possible. By running such a test, we can measure some of the properties of the aquifer from which your well draws. We can measure the well's sustainable yield, and also get aquifer properties such as storage coefficient and saturated hydraulic conductivity. I would also collect water samples to test for things like coliform bacteria, nitrates, and other parameters. Again, this documents a baseline set of information about the quality and yield of your well prior to landfill operations. Thereby, in the event you think some changes have occurred in the future you have the documented evidence of pre-landfill conditions.

II. Inadequate Number of Bedrock Corings to Determine Ground Water Flow Direction.

III. Flawed Hydrogeologic Assumptions in Relation to Public Water Wells.

IV. Flawed Hydrogeologic Assumptions in Relation to Private Water Wells.

In my opinion, the hydrogeologic study performed by Draper Aden Associates (DAA) on behalf of Green Ridge ignores many important aspects of geology in the Blue Ridge and Piedmont Provinces (many researchers, including those that will be cited in this letter, treat the Blude Ridge and Piedmont provinces as a single groundwater region because of their similar geologic and hydrogeologic characteristics). First, it ignores the impact of the geologic structure on groundwater flow by making the statement, "No structural discontinuities that would affect groundwater flow were noted during the subsurface investigation (page 14 of the Hydrogeologic Report)." While this may be a true statement that they did not observe any obvious structural discontinuities, but structural features that affect groundwater flow are ubiquitous throughout the Blue Ridge and Piedmont Provinces. As I discussed previously, the rocks are intensely folded and faulted at both the macro and micro scales, and mineralogical banding is common. The boring logs describe the rocks as biotite gneiss. By its nature, biotite forms in small, flat, plates that align themselves together perpendicular to the principal stress direction. Therefore, these plates will often hinder groundwater movement perpendicular to the plates and facilitate groundwater movement parallel to the plates. Moreover, gneissic rocks often display separate bands of distinct mineralogy, and the contacts between these bands are also structural features that can affect groundwater flow. And these geologic structures are often retained as the rock weathers, such that weathered rock or saprolite described in the boring logs will exert a similar though lesser influence. This influence is called anisotropy, where the aquifer properties are different in one direction than another.

In addition to anisotropy, other common structural features such as fracture zones and faults often go undetected and unmapped. When I was an undergraduate, my structural geology professor said as we prepared for a mapping project, “If you can map in the eastern US you can map anywhere in the country”, referring to the thick soil cover and intense vegetation in the east that hide the rocks. Therefore, many structural features exist that go unidentified because they are hidden. Figure 6 illustrates a map of faults within the CVSZ (Whit et al., 2017). I realize that at this scale most of the text on this map is illegible, but what is clearly visible are the fault lines in black. Note that they are relatively parallel to each other and oriented northeast to southwest. This orientation is called “Appalachian strike” because most of the rocks and other structural features like faults in the Appalachian region are oriented as such. The term “strike” refers to the orientation of any line formed by the intersection of a fault, bed, or other planar feature and a horizontal plane.

Figure 7 contains a portion of the previous fault map at a larger scale illustrating the approximate location of the proposed landfill site relative to the mapped faults. Though there is no evidence that these faults are currently active, they were once active and will have fracture zones parallel to them, as well as fracture zones in other orientations depending on the principal directions of ancient tectonic stresses. My point is that it is possible that similar faults are present under the site that have gone unseen. It is highly likely that existing fracture zones associated with the known faults exist beneath the site as we will discuss later in this section. These faults and fracture zones are highly likely to be exerting influence on the local hydrogSeaton and Burbey came to the conclusion that not only do fault zones have an influence on local hydrogeology, but they may actually “dominate the flow characteristics of a region.” (2005).

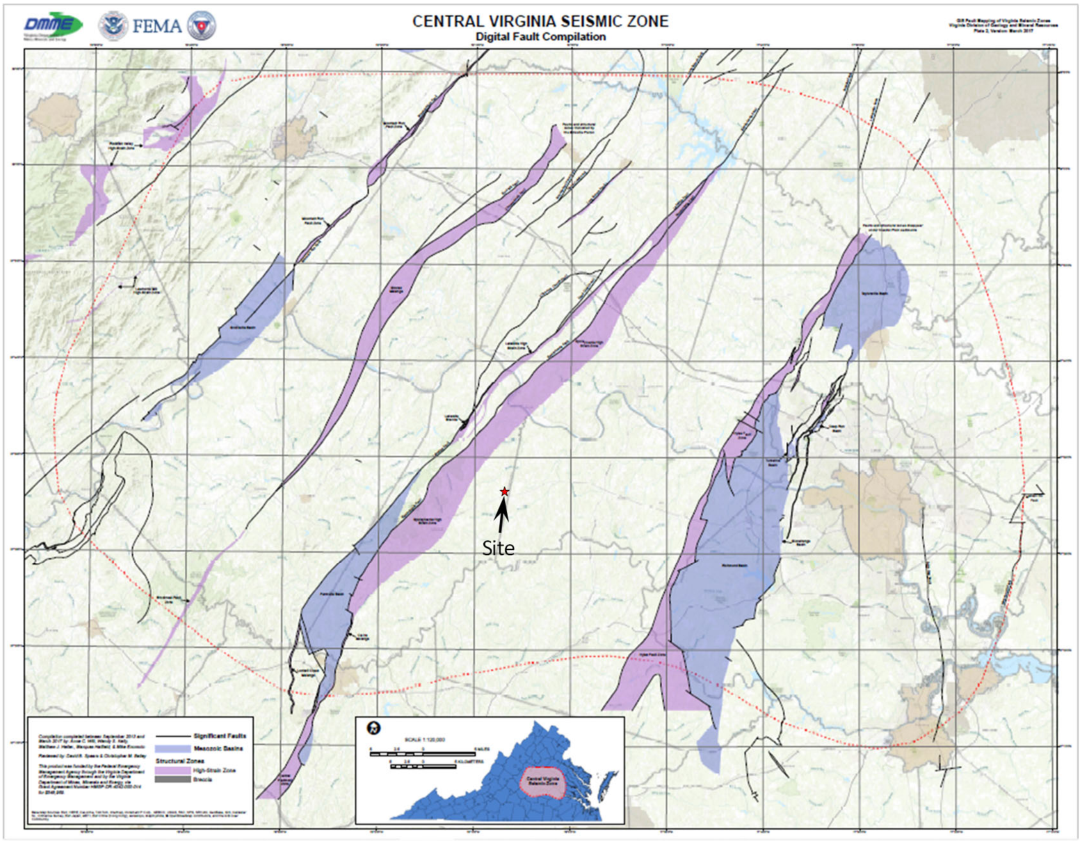

Figure 6. Mapped faults in the CVSZ. After Whitt et al, 2017.

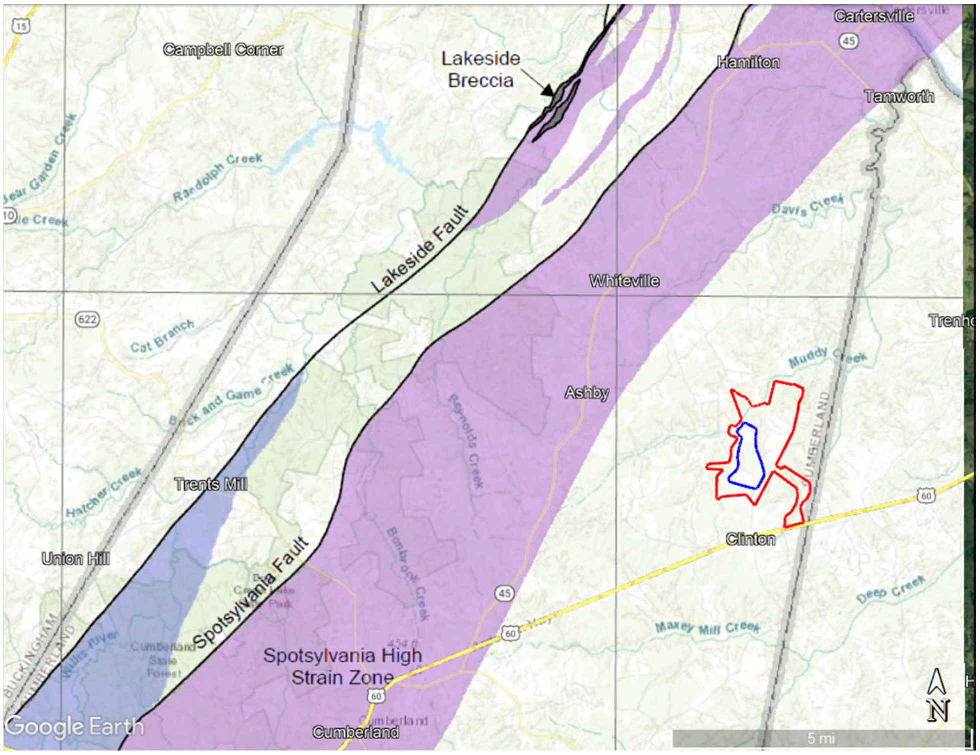

Figure 7. Approximate site location relative to locally mapped faults in the CVSZ. After Whitt et al, 2017.

The most detailed published geologic mapping of the area is the state-wide map at a very coarse scale of 1:500,000. Therefore, the accuracy of this map is commensurate with the scale (the most detailed published mapping usually uses a USGS 7½ minute topographic quadrangle as its base at a scale of 1:24,000). The geologic map reveals that most of the site is underlain by Pre-Cambrian Age porphyroblastic biotite gneiss, with possibly a little migmatitic paragneiss near the northwestern edge (Figure 5). Both of these rock types are formed under high grade metamorphism and are generally characterized by large mineral grains and alternating bands of similar mineralogy.

Even at 1:500,000 scale the geologic map reveals many diabase dikes in the vicinity of the site. These dikes are younger than the surrounding rocks because the dikes were formed when diabase magma pushed its way up into prominent fractures of the existing rocks. I will come back to this point later, but note that the orientation of most of the dikes in Figure 8 is somewhat west of north.

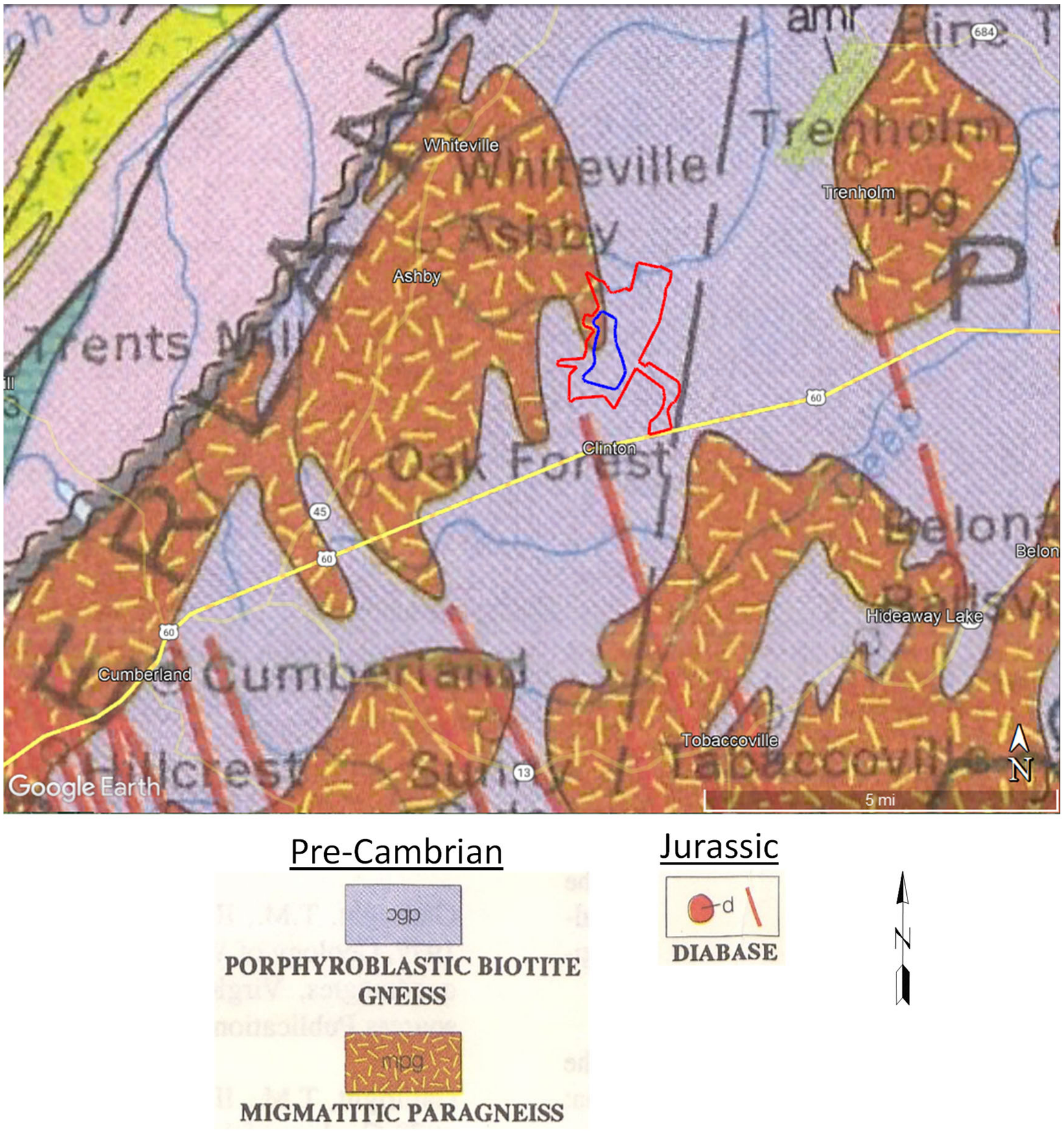

Figure 8. A portion of the published geologic map of the area.

One tool that geologists have used for generations to assess local geologic structure is called fracture trace analysis. But before delving into the fracture trace analysis, it would be beneficial to look at the general types of topographic drainage patterns, because it is from these patterns that we infer the underlying geologic conditions. There are many types of drainage patterns, but those in Virginia generally fall into three main categories or combinations thereof. These include dendritic, trellis, and in a sense rectangular drainage patterns (Figure 9).

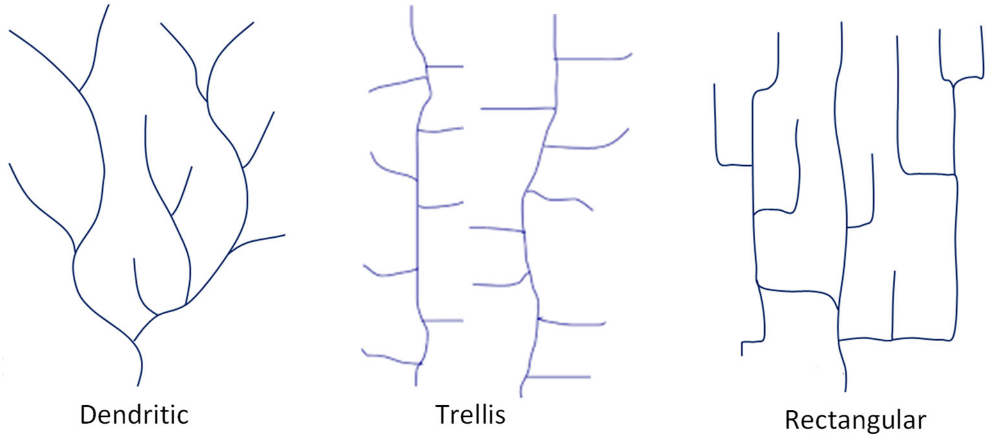

Figure 9. Sketches depicting generalized drainage patterns.

Dendritic patterns usually result from a uniform substrate, so they are common in parts of each of the Virginia provinces. Trellis patterns result from alternating resistant and weak rock, so it is particularly common in the Valley and Ridge. Truly rectangular drainage patterns are rare in Virginia because these occur in rock that is jointed at right angles. However, joint-controlled drainages are common in Virginia but rarely occur at right angles. Examination of the drainage patterns of the site and surrounding area reveals the strong influence of bedrock joints on the drainage, which display a high degree of angularity.

I performed a fracture trace analysis for the site and surrounding area using shaded relief mapping constructed from publicly available LIDAR data. Fracture trace analysis uses local topography to infer the orientations of underlying fracture zones. The premise is that fracture zones in rocks present more surface area to weathering, so they will often be expressed in the topography as relatively long, straight, topographic draws. Examining the shaded relief map in Figure 10 we see drainage patterns at various scales with the most prominent represented by Muddy Creek and Maple Swamp Creek. Evidence of fracture-controlled drainage is clear in Maple Swamp Creek, which is comprised of only two segments that are very straight. We can also see that the tributaries and drainages into Maple Swamp Creek are also characterized by very straight topographic draws. At first glance Muddy Creek gives the opposite impression, an impression more of a meandering stream. However, on close examination we can see that this apparent meandering is actually the stream intersecting joints at various angles as it makes its way downstream. Figure 11 is the shaded relief map with my interpreted fracture traces superimposed as the white dashed lines.

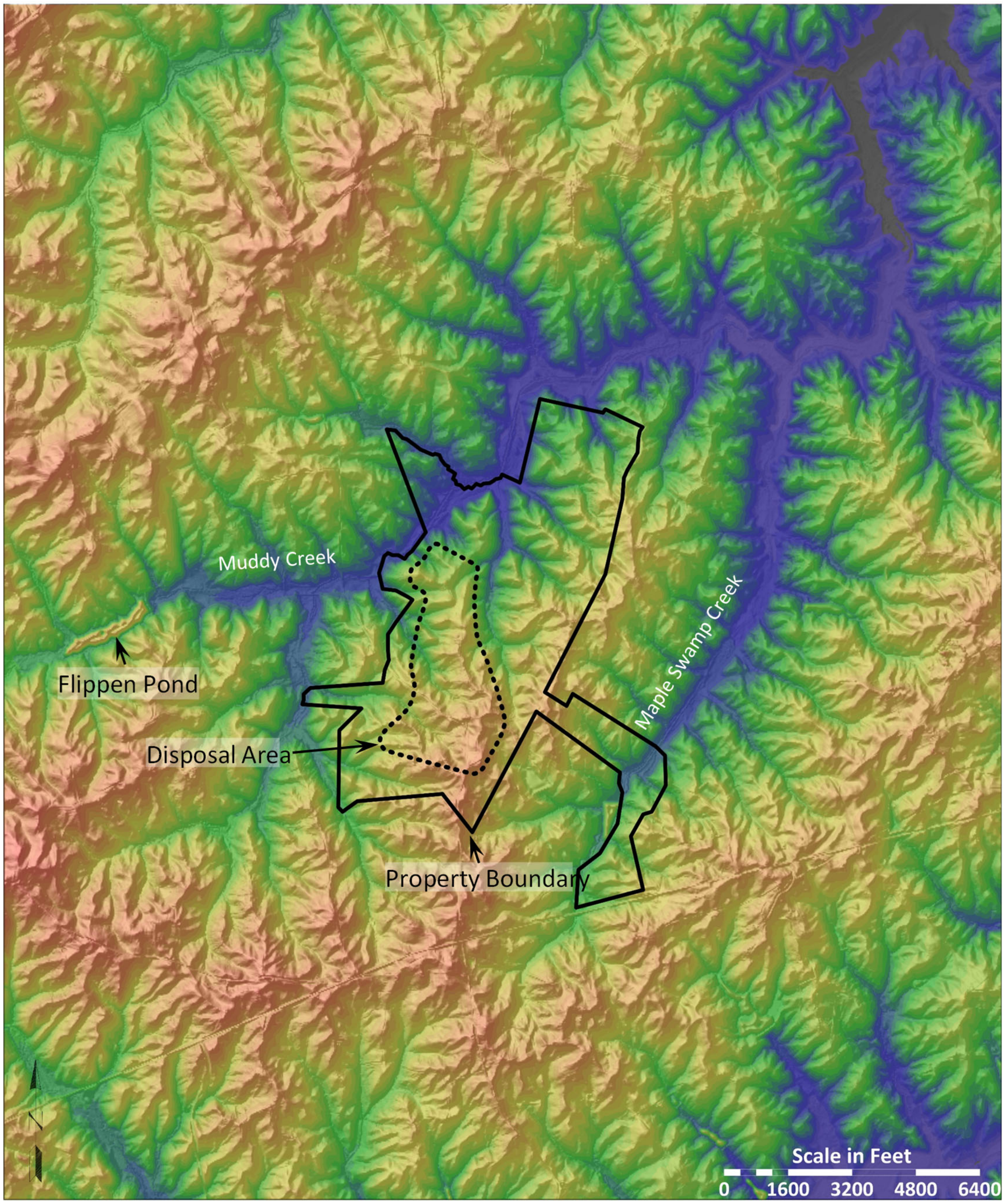

Figure 10. Shaded relief map of the site and surrounding area.

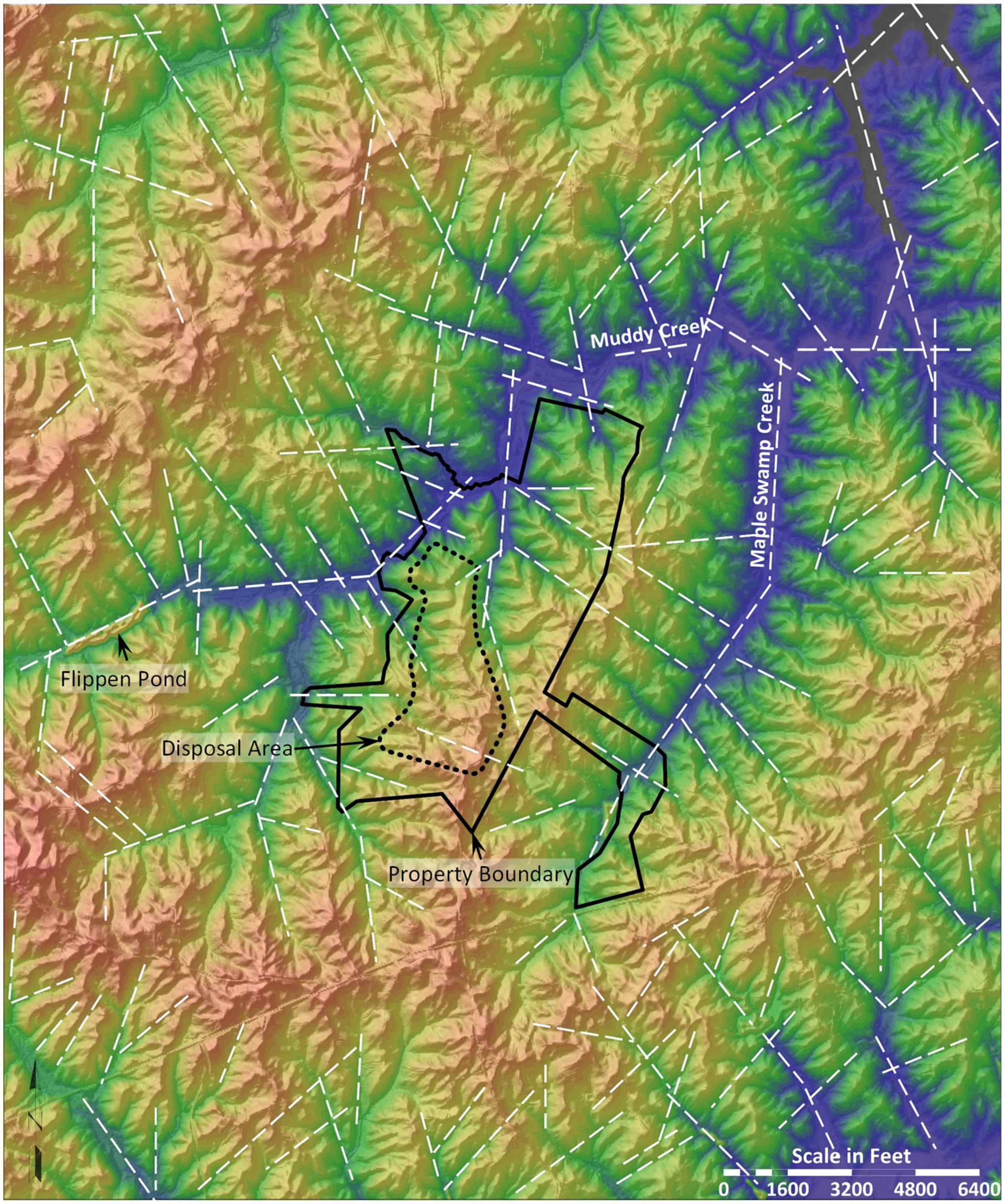

Figure 11. Shaded relief map depicted the site and local fracture traces.

From the fracture trace analysis I created a rose diagram (Figure 12). The rose diagram is constructed from measurements of the orientations of the fracture traces. These orientations are then plotted graphically on a radial diagram that illustrates the clusters of fracture traces with similar orientations. On the radial diagram, the horizontal axis represents the frequency or number of occurrences of the orientations represented by the bars. The circular axis represents the orientations of the traces in degrees.

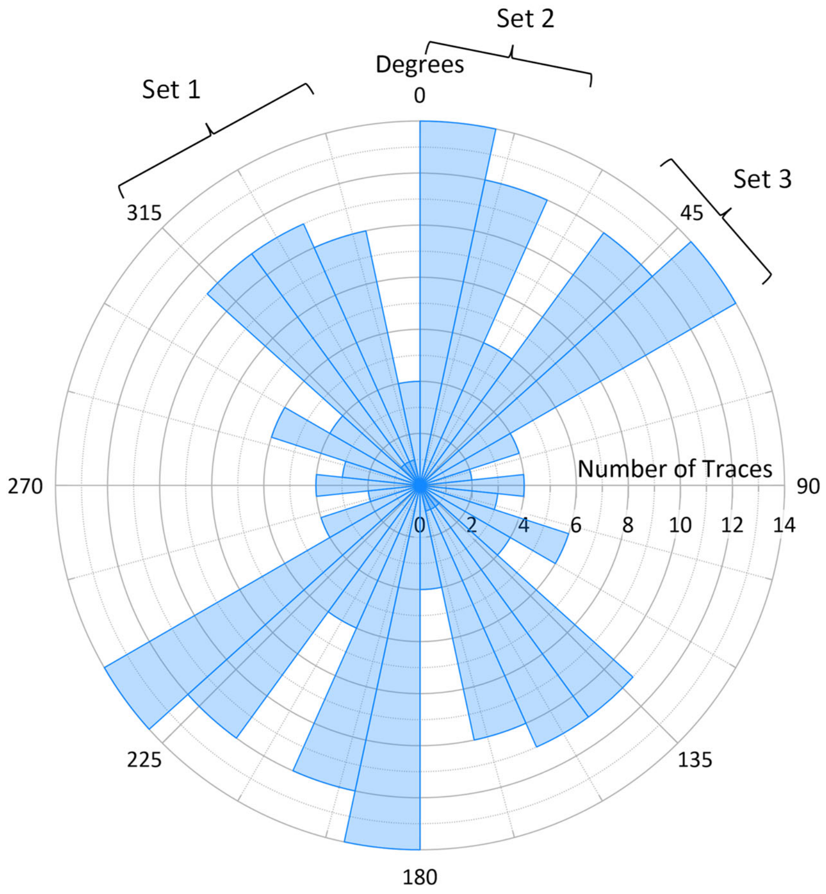

Figure 12. Rose diagram of the fracture traces illustrated three clusters or sets.

The rose diagram reveals three major groupings or “sets” of fracture traces, which I have numbered randomly in Figure 12. Set 1 centers on a bearing of about 330 degrees, Set 2 on a bearing of about 15 degrees, and Set 3 on a bearing of about 50 degrees. Note that the diagram is symmetrical about the horizontal axis and that those clusters on the top half are mirrored on the bottom half.

This analysis suggests that groundwater movement in fractured bedrock will be facilitated in the general directions of these fracture trace sets. This is not to say that groundwater cannot move along other fractures in other directions, but that there will be a propensity for groundwater and dissolved contaminants to move along major fracture zones. It is noteworthy that many of these fracture traces pass through the landfill property and into the proposed disposal area.

As discussed, Maple Swamp Creek and Muddy Creek are two major stream systems that bracket the site, with Maple Swamp Creek approximately paralleling its eastern boundary and Muddy Creek on its north-western and northern sides. Maple Swamp Creek appears to exploit two long fracture traces, one from Set 3 (upstream) and one from Set 2 (downstream). Expanding on my earlier observation that Muddy Creek does not actually meander much but rather intercepts fractures at various orientations, examine Muddy Creek on Figure 11 in the area of Flippen Pond. Flippen Pond was built on a stream segment that appears to be a fracture zone in Set 3. It then turns due east, which is not a dominant fracture orientation. It then turns northeast as it passes through the site in what is likely Set 3 again. It turns east again where it is coincident with the property boundary, then turns almost due north in what is probably Set 2. You can continue to follow those zig-zagging straight stream segments until it leaves the northeastern corner of Figure 11, with most of those stream segments being consistent with one of the three fracture sets. Contaminants released into a fracture trace are likely to experience a similar travel path. Contaminated groundwater will move down-gradient until it meets an intersecting fracture where some of the contaminants are dispersed into that fracture trace, and this will repeat as it makes its way down-gradient.

Note that Set 3 has a similar orientation to that of the faults on Figure 7. I measured many of the fault orientations and found that the average bearing is 342 degrees, which falls in the upper half of Set 1. It is possible that these fractures were formed in association with the faulting.

Moreover, note how similar the orientations of the diabase dikes in Figure 8 are to the orientation of Set 1 in Figure 12. I measured the orientations of the diabase dikes to have an average bearing of 342 degrees, which is within the range of Set 1. It is possible the diabase dikes were formed by exploiting some of the fracture zones in Set 1, and there may be diabase dikes that exploited fractures under the site that have gone unmapped. This is important because it has long been common knowledge to hydrogeologists that drilling a water supply well next to a diabase dike is very likely to result in a high production well because of the bedrock fracturing associated with the dike. These dikes facilitate groundwater movement along their edges.

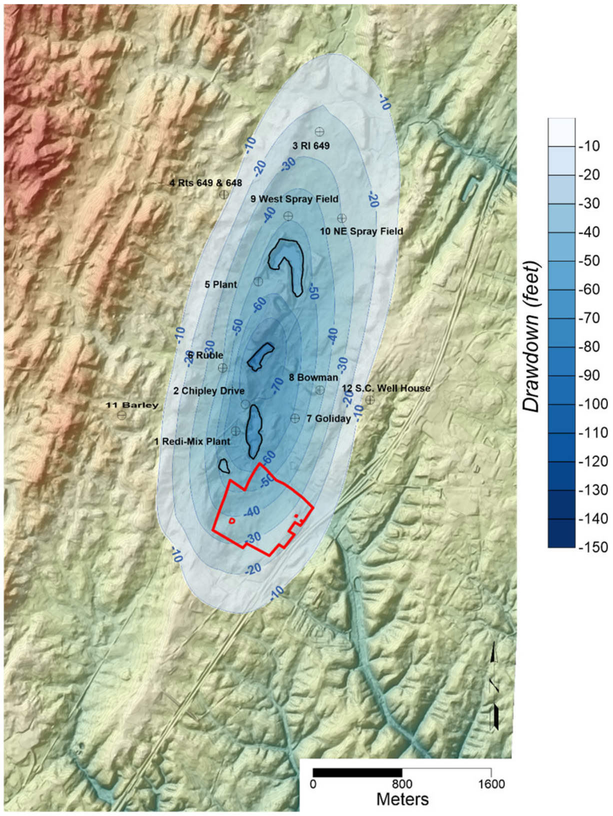

Figure 13. Shaded relief map and cone of depression from a previous project.

The influence of bedrock structure on groundwater movement is illustrated by a project on which Dr. Seaton and I had worked many years ago. This site was in the Valley and Ridge Province which is a different geology than that of the Blue Ridge and Piedmont, but all of these provinces exhibit Appalachian strike and the associated structural influence on groundwater. In this case we supported the plaintiff in a case over the withdrawal of water from three abandoned quarries in the northern Shenandoah Valley. The withdrawal of millions of gallons a day from the quarries was causing a large cone of depression in the water table (Figure 13), which resulted in streams going dry and the triggering of cover-collapse sinkholes. Note that the cone of depression is 3 miles long in the northeast-southwest direction but only 1.2 miles wide perpendicular to that. This is because water moves much more easily along the strike of the rocks than perpendicular to it.

The DAA Hydrogeologic and Geotechnical Report describes having performed slug tests in some of the monitoring wells to obtain the hydraulic conductivity of the aquifer. Hydraulic Conductivity is an aquifer property that describes how readily the aquifer facilitates the movement of groundwater. High values of hydraulic conductivity, expressed by the symbol K, suggests that water moves more readily through the aquifer than if the value for K is small. However, the slug test is less reliable than a pump test for measuring the aquifer hydraulic conductivity, and a pump test with two or more observation wells is necessary to determine the anisotropy of the aquifer. It is my opinion that the hydrogeology of the landfill site has not been characterized without a pump test that evaluates the anisotropy of the aquifer. Moreover, on a site this large with numerous groundwater wells on its borders, two or more pumping test would be appropriate.

It also seems that DAA is relying on an outdated conceptual model of groundwater in the Blue Ridge and Piedmont when they make the statement on page 14 of the *PTA Attachment XI Hydrogeological and Geotechnical Report* that “Flow of groundwater in bedrock primarily occurs in the upper weathered portions, and not the underlying, less weathered and more competent portions.” This statement fits very well with previous conceptualization of groundwater in the Piedmont as put forward by early researchers such LeGrand (1967) and Heath (1984). However, this conceptual model has been convincingly challenged in recent years by researchers such as Seaton and Burbey (2000, 2002, 2005). I met Dr. Seaton when we were both working for a consulting firm in Blacksburg during his PhD work at Virginia Tech in the 1990s. He subsequently became a partner in my first consulting company, ATS International, and his most recent publication on this topic in 2005 was submitted under its auspice. We put his knowledge to good use in our consulting business to successfully find water where others had failed. We saw the conclusions of his research proven many times over in our consulting by adding resistivity imaging techniques to traditional geologic methods.

Previous, outdated conceptual models of groundwater flow in the Piedmont and Blue Ridge had the majority of flow taking place in the soil and weathered rock called saprolite (just as DAA describes). In this model, the rock becomes less fractured with depth, so groundwater potential also decreases with depth. Figure 14 is based on Heath (1984) which represents this concept three different ways. The middle column is a cutaway of the earth revealing the downward transition from soil to weathered rock to fractured rock, with the fracture density and length decreasing with depth. The graphic to the left of it is a schematic diagram of the fractures intersecting the well bore and how those fractures provide less water with depth, and a similar one to the right depicting most of the storage of the aquifer being the weathered rock and shallow bedrock and diminishing markedly with depth.

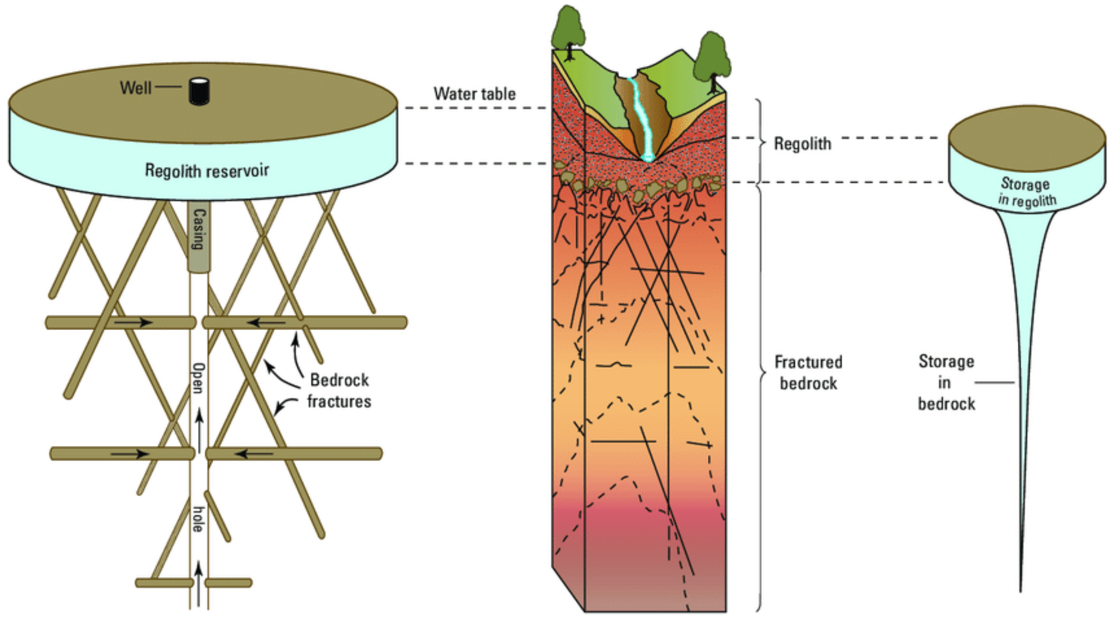

Figure 14. Schematic diagram of the previous conceptual model. After Heath, 1984.

The results of Seaton and Burbey's research, as well as a plethora of projects on which I have consulted, provide convincing evidence that this shallow soil and saprolite aquifer does exist ubiquitously in the Blue Ridge and Piedmont, but it overlies deeper, fractured rock aquifers that are intermittently connected to it.

To elaborate on this point, I must first introduce a geophysical technique called resistivity imaging, as this method figures prominently in Dr. Seaton's research and in our subsequent consulting. Resistivity is simply the property of a material to resist or inhibit the flow of electric current. Resistivity imaging operates by inducing an electric current into a series of metal stakes called electrodes, and measuring the potential field created by that current. After processing the data, we get a cross-sectional image of the earth resistivities from which we can infer geologic conditions.

The primary factors that affect resistivity are moisture and material grain size. Moisture facilitates the flow of electric current, so an increase in moisture will cause a decrease in resistivity. Soil almost always has more moisture than rock, because the rock only contains the moisture in discrete fractures. Therefore, rock tends to have a much higher resistivity than soil.

The material grain size affects the resistivity in that fine-grained materials such as clay or shale tend to have lower resistivities than coarse-grained materials such as sand or sandstone. With these principles in mind please refer to the resistivity section in Figure 15. The resistivities in this cross-section are contoured and given a color scale with the low resistivities in the cool, blue colors and the high resistivities in the warmer red colors. You can see that there is a distinct layer of low resistivities around 100 ohm-meters or less. Then below that the resistivities increase abruptly to several hundred ohm-meters. This transition from low to high resistivities usually marks the soil-bedrock interface, and in this case we had a boring that encountered bedrock precisely at this transition.

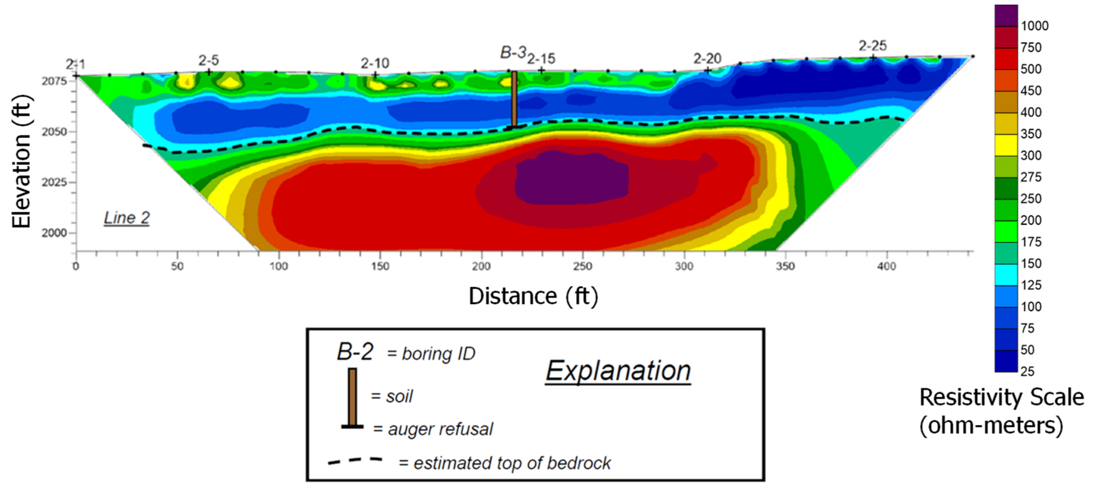

Figure 15. An example resistivity section from another project.

Going back to the conceptual model of groundwater in the Blue Ridge and Piedmont (these provinces are so similar that they are often treated as one hydrogeologic province), if the model proposed by Heath and LeGrand were true, then most or all resistivity sections collected in the Blue Ridge and Piedmont would look just like this one and the one in Figure 16, with groundwater flow taking place in the soil and uppermost regions of the rock because deeper fractures containing moisture are not prevalent.

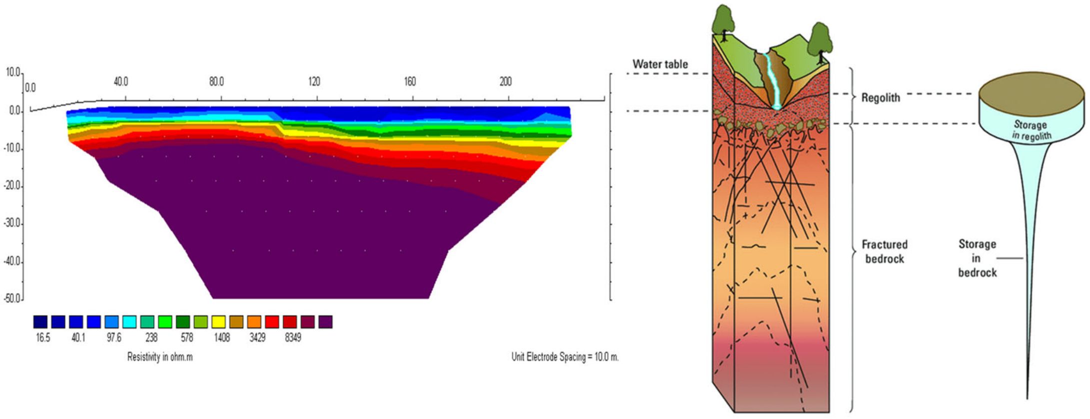

Figure 16. An example resistivity section from another project compared to Heath's model.

But Seaton and Burbey's research and my consulting experience do not bear this out. In fact, many resistivity sections in the Blue Ridge and Piedmont contained significant low-resistivity features within the bedrock that we interpret as water-bearing fracture zones. We used this interpretation many times to find high-production water wells, or to identify locations for monitoring wells to intercept contaminated groundwater flowing through fractures. Figure 17 contains several resistivity sections from such work along with the geologic province and yield of the well drilled into it.

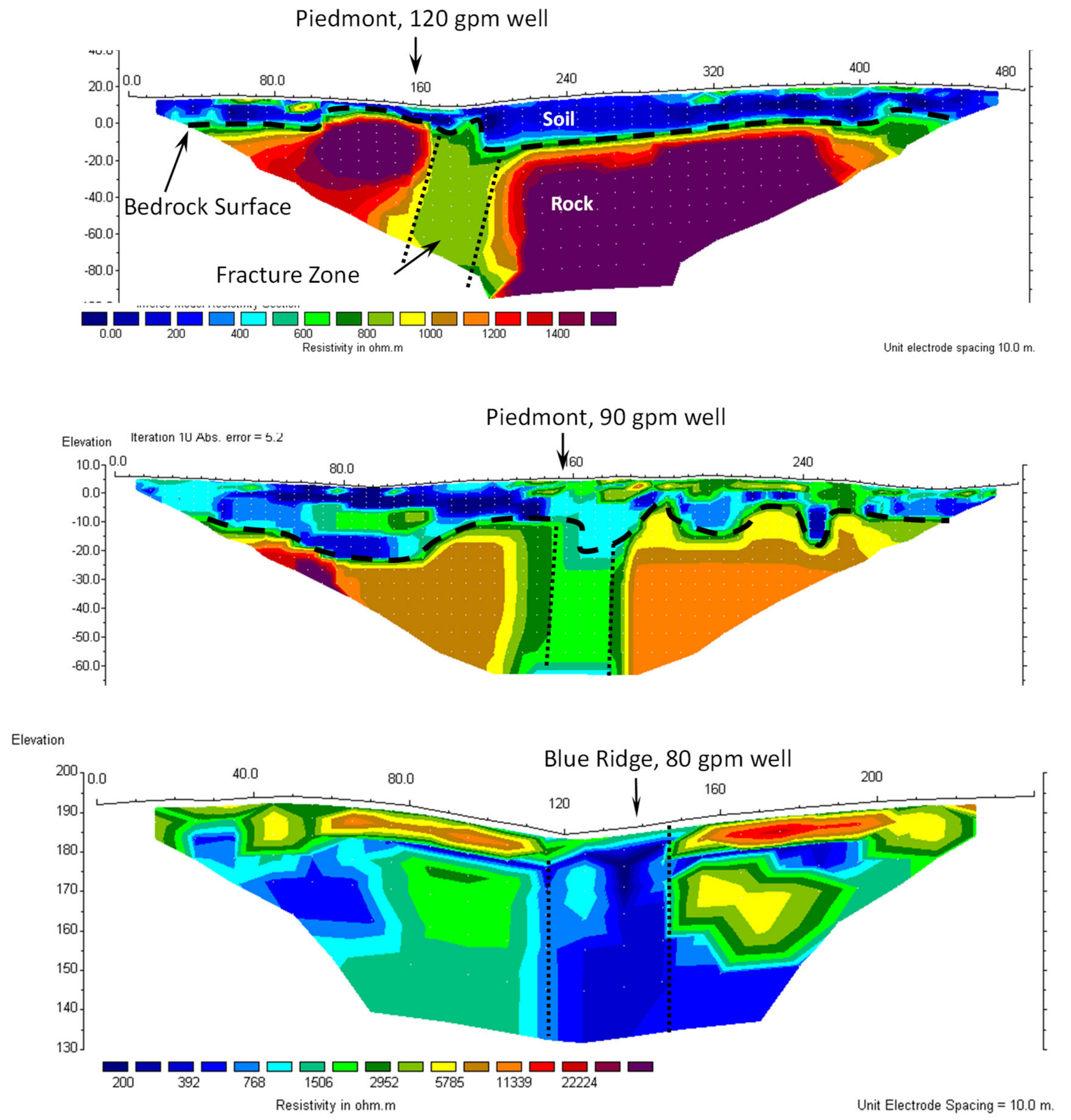

Figure 17. Example resistivity sections illustrating fracture zones in crystalline rocks.

Contrary to the previously accepted aquifer model, modern research and my consulting experience bears out the conceptual model as put forth by Seaton and Burbey (2001), in which two or more distinct aquifers exist in the crystalline rocks of the Blue Ridge and Piedmont. A shallow water table aquifer exists in the soil, weathered rock, and shallow bedrock fractures, but deeper fractured rock aquifers exist at depth that are associated with ancient faulting and tectonic stresses. These two aquifers are separated by low-permeability rock with low fracture density which confines the lower aquifer, and the two aquifers are intermittently connected through breach zones in the confining unit. This conceptual model is encapsulated in Figure 18. It should be noted that though this diagram depicts the breach zone as occurring in a topography low area, they are not necessarily associated with any topographic features.

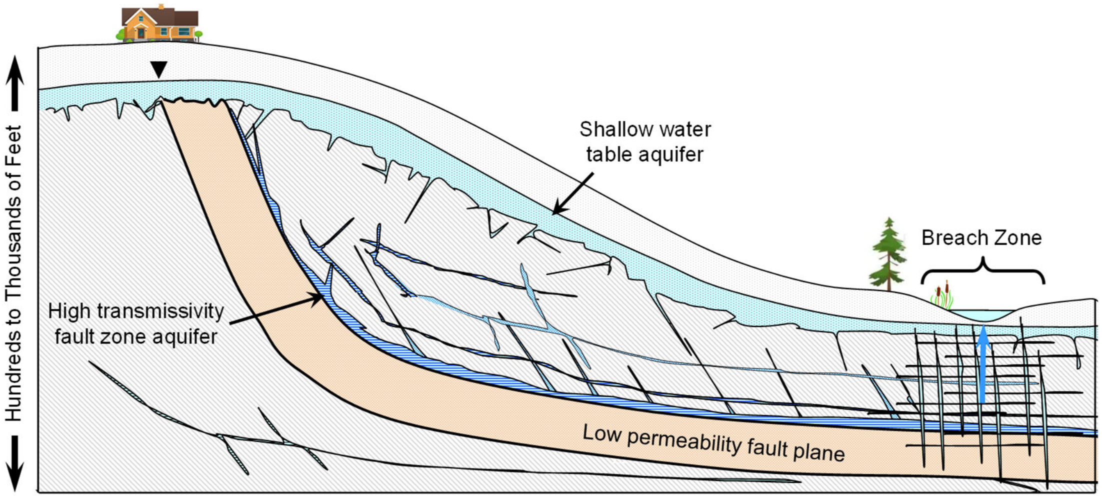

Figure 18. Conceptual model of groundwater in the Blue Ridge and Piedmont. After Seaton and Burbey, 2001.

This is precisely what is described by DAA in the *PTA Attachment VII Landfill Impact Statement* when documenting the well construction information for the domestic wells in the area. Some of the well completion information describes confined conditions where the well encounters water-bearing fractures at depth under enough pressure to cause the water to rise to a level well above those fractures and sometimes even up into the well casing. DAA makes the statement that the confining conditions are “protecting” the lower aquifer from which some of the wells are deriving their water, implying that this somehow protects these wells from the landfill. It is a true statement that deeper, confined aquifers are generally safer from contamination than shallow, unconfined aquifers. This is because they are usually farther removed from potential contaminants and they tend to have longer residence (and travel) times in the aquifer, allowing more time for natural filtration and biodegradation. However, all aquifers are recharged from somewhere, and any ground higher than the final water level in the well is a potential recharge area. In fact, on page 14 of the *PTA Attachment XI Hydrogeologic and Geotechnical Report* that “Recharge areas on the Facility coincide with most topographically elevated areas where permeable granular materials are exposed at the surface.” Much of the southern portion of the disposal area is topographically higher than many of the nearby domestic wells, and thus may act as a local recharge zone. With only shallow borings in the disposal area, there is no way to know if vertical fractures exist in that recharge area that might carry groundwater and contaminants to the domestic wells.

Moreover, many of the deeper bedrock wells described in the LIS yield as much as 50 gpm, which is consistent with the modern two-layer model and inconsistent with DAA’s statement that, “Flow of groundwater in bedrock primarily occurs in the upper weathered portions, and not the underlying, less weathered and more competent portions.”

V. Rerouting of Spring Fed Streams: Could the underdrain system alter groundwater flow directions and volumes? Could the underdrain system cause private wells to dry up?

Let me start by saying that I have no appreciable experience in surface water hydrology, but intuitively I agree that grading the headwaters of the stream is not “re-routing” the stream. As far as impacts to the local groundwater users, those users with shallow bored wells or wells completed in the upper bedrock are much more likely to experience negative impacts than those with deeper bedrock wells. In general, an underdrain system that collects water is likely to alter the flow direction and gradient of the shallow groundwater aquifer. Thus, there is the potential for impacts to wells completed in the shallow aquifer.

VI. Flawed Flippen Pond Dam Break Analysis

Again, I have no experience modeling surface water, but I have considerable experience as a groundwater modeler, and I expect that most of the general principles and procedures are similar. Generally, I construct the numerical model to reasonably match existing conditions, and that involves calibrating the model to historical groundwater data. Once the model is calibrated, I usually evaluate a variety of “what if” scenarios in what is called a sensitivity analysis. This gives me an indication of how accurate my model is if I am off on my model input. I consider both the calibration and sensitivity analysis to be important components of a credible groundwater model. It is reasonable to apply this principle to surface water models and I would expect a credible model of dam failure to simulate a variety of conditions, including flood conditions.

VII. Pine Grove School Not Recognized as a Public Water System

I cannot identify a question here for me to answer. You have provided a rationale for its classification as a public water system, but I cannot speak to the regulatory aspects of this decision by DEQ, whether or not DAA recognizes it as such.

VIII. Public Water Systems Associated with C F Marion Trucking and the Former County Line Auto Parts Salvage Yard

I cannot speak to this issue.

IX. Base Grade at the Bottom of the Landfill is Required to be Set a Minimum of 5 feet Above the Potentiometric Groundwater Surface (Water Table)

I have looked at the data that you use to support this conclusion, and I agree that the base grade should be raised. It appears that the existing grade is below the water table at least part of the time, based on temporal fluctuations in the water table.

X. Draper Aden has determined that a component of the ground water from beneath the landfill…

There are multiple occurrences in the hydrogeologic report and LIS where DAA uses language about surface water streams as a barrier to groundwater flow. While this principle has been accepted as common knowledge among geologists for generations, it applies primarily to shallow groundwater flow. Surface water streams in no way act as barriers to deeper, larger flow systems. It has been accepted by hydrogeologists for decades that flow systems occur at varying scales and that larger-scale flow systems can by-pass local streams. Figure 19 is a schematic diagram that has been modified from Fetter (1988), Tóth (1995), and Tóth (2008). There is no information that would preclude the possibility that the site is part of local, intermediate, and regional flow systems as depicted here.

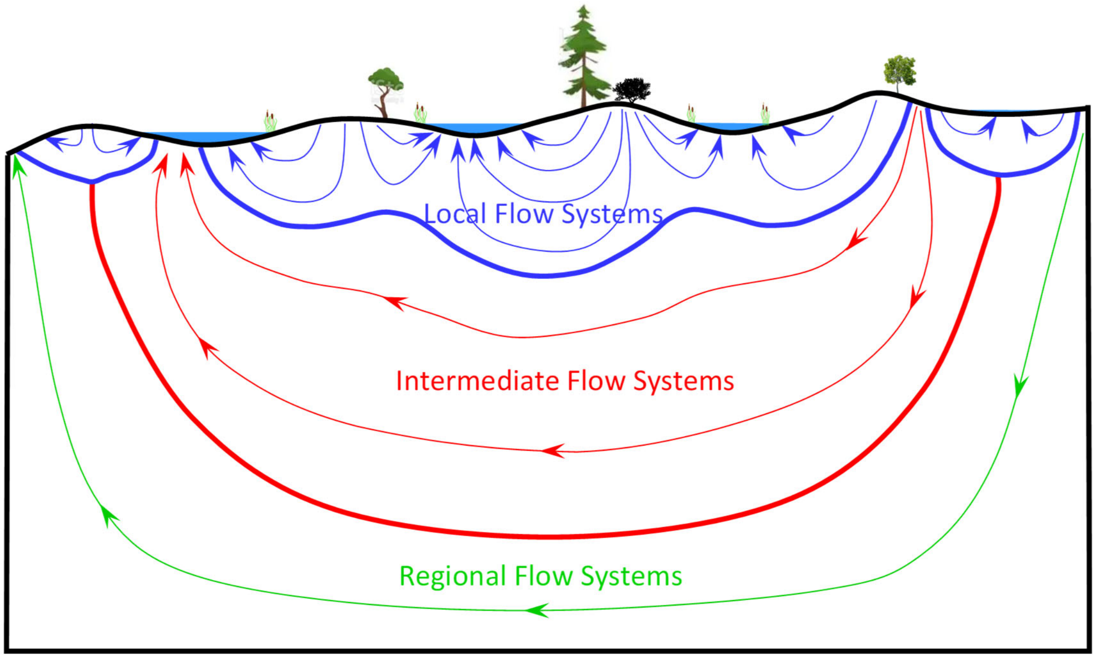

Figure 19. Schematic diagram illustrating the relationship between local (blue), intermediate (red), and regional (green) flow systems. Modified from Fetter (1988), Tóth (1995), and Tóth (2008).

Conclusions and Recommendations

1) Though the DEQ landfill regulations allow a landfill to be constructed with the liner resting on bedrock, future seismic activity is likely to result in shearing forces on the liner from the differential shaking between the waste and the bedrock. A liner resting on a softer material such as compacted clay will experience less shearing force from smaller differential shaking.

2) The *PTA Attachment VII Landfill Impact Statement* and the *PTA Attachment XI Hydrogeological and Geotechnical Report* ignore certain important aspects of the hydrogeology of the site. Specifically, the reports ignore the possibility that faults, fracture zones, and/or diabase dikes exist beneath the site and are exerting influence on the local hydrogeology. Moreover, the reports ignore the fact that groundwater flow in the Blue Ridge and Piedmont is usually anisotropic because of the influence of mineral banding, foliations, and fracture zones. These features can dominate the groundwater flow in the Piedmont and Blue Ridge yet have thus far not been recognized in the science.

3) DAA has oriented its narrative of the hydrogeology to that of an outdated hydrogeologic model that is consistent with their statement that "Flow of groundwater in bedrock primarily occurs in the upper weathered portions, and not the underlying, less weathered and more competent portions." However, this is not consistent with the description of some of the domestic wells in the area which draw their water from deep, confined fractures. Moreover, many of these domestic wells produce as much as 50 gpm, indicating that the aquifer from which they are

drawing may be much more productive than the shallow aquifer, consistent with a two-aquifer system as put forward by Seaton and Burbey.

4) The geologic investigations to date have only considered the shallow groundwater, and no borings or corings have been conducted to the depths equivalent to the bedrock wells surrounding the site. Therefore, the geology has not been characterized relative to the domestic water supplies in the area. To do so, it will be necessary to drill wells up to depths comparable to the domestic wells and to design pump tests that will evaluate a) the potential for hydraulic communication between the shallow and deep aquifers (including evaluating of natural vertical gradients), and b) the potential for communication between the site and nearby domestic wells. Therefore, I recommend that the pump tests be conducted near the boundary of the property close to the clusters of domestic wells described in the LIS. This will allow domestic wells within 500 feet of the site to be monitored during the pump tests.

5) I recommend that the residents within 1000 feet of the disposal area hire a third party expert to collect base line data on the specific capacity and water quality of their well. The specific capacity is measured by pumping the well and measuring its drawdown to determine the sustainable yield of the well. For the parameters measuring water quality I suggest all of the natural cations and anions as well as pH, alkalinity, and turbidity. It is reasonable to request that Green Ridge bear these costs.

6) I recommend that residents within 1000 feet of the proposed blasting retain a third-party expert to conduct a pre-blast inspection of their homes to document existing conditions.

7) It is my opinion that resistivity imaging data should be collected to evaluate the presence of potential faults, fractures, and/or breach zones within the proposed disposal area.

It has been a pleasure serving you on this project. I am available to answer any questions that may arise as you review this document. If there is any other way that I can assist you on this project please let me know.

Best regards,

Warren Dean
President
GeoScience Professionals, LLC

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