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1.0 Executive Summary

RETTEW Associates, Inc. (RETTEW) has prepared this Aquifer and Geologic Hazards Investigation for the LeTort Spring Run located in South Middleton Township, Cumberland County, Pennsylvania (Appendix A - Figure 1). The LeTort Spring Run study area (later referred to as "stream", "site", or "study area") (Appendix A - Figure 2) is located along LeTort Spring Run and extends south of Interstate 81 to the headwaters of the watershed.

The goal of this study is to attempt to answer the following questions:

- Are sinkholes present within the LeTort Spring Run headwaters at the time of this study, and where are the sinkholes located?
- Are groundwater springs present along the banks of the LeTort Spring Run, and can they be identified as discrete seeps?
- What is the current base flow condition of the LeTort Spring Run in the study area? Can reaches of the stream be delineated as areas that represent surface water "loss" or "gain?"
- Are there regional geologic features (i.e. fractures, faults etc.) that exist which may impact stream base flow? Do these geologic features correlate with observed stream base flow conditions and how so?
- What is the current regional water table configuration? Is it influenced by the LeTort Spring Run and the adjacent quarry dewatering activities? Is it influenced by regional geologic features?
- What is the complex relationship between stream base flow, regional geologic features, and the underlying water table configuration? Is there a correlation between regional geology, stream base flow conditions and the presence and/or absence of sinkhole formation?
- Are there areas that represent potential "hot spots" that the Authority could monitor that would represent areas of the LeTort Spring Run that have a higher potential for sinkhole formation?

The key results of the Hydrogeologic Assessment and other activities performed in support of this report are as follows:

- The subsurface conditions underlying the LeTort Spring Run, in descending order, include: 1) silt and clay and 2) Cambrian-aged limestone of the Zullinger Formation.
- Pumping of the basin at Union Quarry is significantly controlling regional groundwater flow. The potentiometric surface observed in both the shallow and deep piezometers has been depressed in the vicinity of the Union Quarry Basin causing a substantial gradient

and a north / northeastern groundwater flow direction. Flow direction was consistent throughout the monitoring period between January 2004 and June 2004.

- Union Quarry is an important regional groundwater sink in the LeTort Spring Run study area. Under normal conditions, the pumping station operates almost continuously to draw down the groundwater table to maintain the basin water level of 400 feet above mean sea level (ftmsl). Increased rainfall or snowmelt is compensated by increasing pumping occurrence and rates.

- A conservative estimate of total groundwater flux into LeTort Spring Run Watershed from the area underlying the LeTort Spring Run is on average 4.1 million gallons per day (based upon a simplified hydrologic budget). This quantity is greater than the total maximum volume of water pumped from Union Quarry, which is estimated to be an approximate maximum of 2.9 million gallons per day (based on measured outflows at the quarry discharge and personal conversations with quarry personnel). This quantity is also greater that than maximum allowable discharge set forth in the NPDES permit for Union Quarry of 3 million gallons per day. The NPDES permit expires February 14, 2007.

The LeTort Regional Authority respectfully requests the Pennsylvania Department of Protection's (PADEP) review and comment of this Hydrogeologic Assessment and the above listed activities to satisfy the goal of the Growing Greener Grant to describe the relation between the karst geology and surface/groundwater in an area previously impacted by sinkholes.

2.0 Introduction

LeTort Spring Run has long been recognized as the premier limestone trout stream of Pennsylvania. The LeTort Spring Run's reputation is in fact world renowned, made famous by the likes of fly fishermen and authors Vincent Marinaro and Charles Fox. The stream's uniqueness is also recognized among environmental agencies within the Commonwealth of Pennsylvania, being given "scenic rivers" status in March of 1988 and placed on the Pennsylvania Rivers Conservation Registry in September of 2001. The headwaters have the designation of "exceptional value" within the state's Chapter 93 – Water Quality Standards listing. In addition, the Pennsylvania Department of Environmental Protection utilizes the LeTort Spring Run as a "model" for determining the health and vigor of other limestone streams.

In November of 2000, the LeTort Regional Authority (LRA) completed a conservation plan of the entire LeTort Spring Run Watershed. The study was funded by the Pennsylvania Department of Conservation and Natural Resources (DCNR) and was intended to serve as a means of documenting past and present watershed conditions and offer various management options to strengthen and broaden the stream's preservation. The most critical management option defined by the conservation plan concerned the need to further investigate, "groundwater additions and subtractions along the stream in order to analyze the impacts that the quarrying operation may have on the stream and to possibly identify sinkholes and springs."

The headwaters of LeTort Spring Run are located within a geologically sensitive area underlain by fractured carbonate bedrock. For years, Authority and Trout Unlimited members have worked diligently to patch sinkholes that have appeared within the headwaters. Although sinkholes are caused by other related geologic hazards and are very common in carbonate terrains with or without quarries, the concern is that the neighboring quarry and related quarry dewatering operations may impact base flow conditions of the stream. Sinkhole formation may potentially increase in reaches of the LeTort Spring Run that are "losing" surface water to the underlying carbonate aquifer.

This investigation was completed to document current conditions of the LeTort Spring Run, and to further define the interaction between surface water of the LeTort Spring Run and the underlying carbonate aquifer. Groundwater flow within carbonate rock is controlled typically by discrete fracture zones, which have been enhanced by natural dissolution processes. In a case where a geologic fracture zone intersects a stream, stream base flow has the potential of decreasing (being lost to the subsurface) due to the direct hydraulic connection of the stream to the underlying carbonate aquifer system. In particular, this study defines the effects of the neighboring quarry dewatering operation on the underlying water table and stream base flow of the LeTort Spring Run.

To achieve the goal of this investigation and to define the dynamic processes at work in the LeTort Spring Run, a combination of geologic analysis techniques were employed:

- Geologic literature review;
- Aerial photography and site reconnaissance to determine current conditions of the LeTort Spring Run and the location of existing sinkholes and springs;
- Fracture trace analysis to determine the possible presence of regional geologic features such as fracture zones and their location with respect to the LeTort Spring Run and the adjacent quarry;
- Geophysical survey to analytically measure the presence and location of underlying regional geologic features such as fracture zones that may encroach the LeTort Spring Run and impact base flow conditions;
- Stream base flow monitoring to gauge and measure groundwater additions and subtractions along the stream;
- Surface water temperature survey to determine if reaches of the stream are "gaining or losing" in correlation with the stream base flow monitoring. Groundwater has less variation in temperatures; reaches of the stream that are gaining would reflect that temperature;
- Nested monitor wells to gauge underlying water table conditions to determine local trends within the study area and the relationship between stream base flow, regional geologic features, and pumping centers.

A better understanding of this complex relationship between regional geologic features, stream base flow, sinkholes, and water table configuration would provide the PADEP and the Authority with a conceptual model of the dynamic processes at work in the LeTort Spring Run. Results of this study may be used to identify possible solutions and/or appropriate corrective action to be taken for future stream restoration and protection endeavors.

3.0 Background

Streams that gain groundwater in some sections, and lose groundwater in others, are common to carbonate bedrock terrains, also known as "karst" terrains. Carbonate rock types, such as limestone (calcium carbonate) and dolomite (magnesium/calcium carbonate) are easily dissolved by slightly acidic water and result in the typical variety of karst features of the region; including sinkholes, closed depressions (ground subsidence), small caverns, pinnacled bedrock, and highly variable depths to bedrock. Waters that flow through regions where decaying vegetation is abundant may exhibit increased acidity. If the carbonate bedrock is also extensively fractured and is high in calcium carbonate content, dissolution of the bedrock increases, with a subsequent increase in sinkhole development. Consequently, a stream that flows over competent bedrock may disappear downstream into a sinkhole that has formed over a solution-enlarged fracture.

Sinkholes may also form over deep soil profiles in areas away from the stream channel such as flood plains. This can result from the percolation of ponded surface water down through the soil and into fractured bedrock. This percolation of water, over time, erodes the sub-soils and eventually creates a small void or soil "pipe." This continued process, over time, can lead to the development of interconnected voids that eventually coalesce and create the sub-surface cavity that results in a surface collapse or sinkhole. Ponds, stormwater retention basins, and drainage swales are other typical surface features that may lead to sinkhole development in karst terrains. Ponding of water during construction or remediation activities may also have the same effect.

These naturally occurring processes may be exacerbated by water supply wells or de-watering operations if pumping rates exceed the rate at which the aquifer system is recharged. In such a scenario, the aquifer cannot sustain a yield equal to the pumping rate, which causes a decrease in hydrostatic pressure. As the hydrostatic pressure of the aquifer typically adds structural integrity to open fractures, a decrease in pressure may cause a collapse of overlying soils or rock that are no longer supported by groundwater.

Previous attempts to delineate and remediate sinkholes along and in the LeTort Spring Run have been marginally successful. Repeated soil piping adjacent to existing repairs has occurred despite exhaustive efforts. These repairs consisted of over-excavating the sinkhole(s) to bedrock and backfilling the sinkhole with concrete. If the bedrock in the vicinity of the stream is extremely fractured, additional isolated sinkhole repairs will not preclude the occurrence of future sinkholes at different locations within the stream and other means of sinkhole mitigation should be pursued.

4.0 Site Description

The headwaters of the LeTort Spring Run are located approximately two miles south of the center of the Borough of Carlisle in South Middleton Township, Cumberland County. Two main headwater locations, fed primarily by multiple springs, are the source of LeTort Spring Run. These two headwater locations form two branches (hereinafter referred to as the East and West Branch) that merge in the vicinity of Union Quarries, Inc. and Bonny Brook Road. At the merger of the two branches, the LeTort Spring Run flows northward towards Carlisle and the Conodoquinet Creek for a distance of approximately six miles.

Historically, the LeTort Spring Run has been surrounded by primarily agricultural and quarrying operations. Watercress bogs have been farmed in the headwaters of both the East Branch and West Branch.

Aerial photographs from 1946 reveal that the study area was slightly different than present day. First, the quarrying operation was much smaller than it is today; however, quarrying was taking place adjacent to the stream on the east side. Second, the stream channel was observed to be in a different location as it traversed the quarry property. It was seen to flow directly to the rear of the current quarry office building. These differences are constant in historical aerial photographs taken from 1947, 1958, 1964, and 1971. Observations of the aerial photographs indicate that the re-channeling of the LeTort Spring Run took place between 1971 and 1988. Presently, the quarrying operation has been expanding to the east of its 1946 working area. The 1971 historical aerial photo reveals the first deep quarrying where the current pool/basin exists.

The study area (as shown on Figure 3) was defined by the LRA as the area of the LeTort Spring Run from the headwaters in the areas located around the watercress farm beds to an area approximately 1,000 feet downstream from the Union Quarries, Inc. property and approximately 2,500 feet south of Interstate 81.

5.0 Topographic Survey

RETTEW conducted topographic surveys of base-flow monitoring stations at various locations along the LeTort Spring Run within the study area. At each location where flow discharge was measured, RETTEW first installed steel pins on both sides of the stream channel. The pins were set at equal elevations with the aid of a rod and level. Guard stakes with orange ribbon indicating the location of the pins were installed so the pins could be easily relocated for subsequent measuring events. The pins served as anchors for stretching a measuring tape horizontally across the stream channel. A total station and data collection system was then utilized to profile the stream channel. The profile and water elevation was then used to calculate the total area of the stream cross-section, which was used to calculate flow rates.

Professional surveyors from RETTEW also surveyed the elevation (above mean seal level) of the eleven (11) piezometers that were installed for the groundwater portion of this study. A United States Geological Survey disk was utilized as the control benchmark for the transfer of elevation data to the piezometers. This disk was located on the southeast wingwall of the bridge at the intersection of the LeTort Spring Run and the abandoned railroad bridge north of the quarry.

6.0 Geology

6.1 Regional Geologic Framework

The study area is located within the Cumberland Valley of the Valley and Ridge Physiographic Province (Becher and Root, 1981). The Valley and Ridge Physiographic Province has been deformed multiple times during its geologic history; resulting in a complex series of folded and faulted layers of the bedrock. The rocks of the Cumberland Valley lie on the northwest limb of a regional anticline. The anticline has its axis in South Mountain in Franklin County. Located on the limb are asymmetric folds and steeply dipping faults.

The regional complexity is evident in the local structural geology of the area. The study area is sandwiched between the Bonny Brook Fault to the north and the Sinking Springs Fault to the south. The orientations of the two faults are approximately northeast-southwest. The Bonny Brook Fault forms the northern boundary of the study area. A normal fault extends from the confluence of the East and West Branches of LeTort Spring Run northward towards the Bonny Brook Fault. The faults have placed younger rocks in contact with older rocks.

Because of the folding and faulting of the area, most of the beds have been overturned to some extent. The strike of the beds roughly parallels the orientations of the faults. Near the northeastern corner of the study area and adjacent to the Bonny Brook Fault, the beds have been overturned and strike parallel to the orientation of the fault (northeast) and dip 20 degrees to the southeast (Becher and Root, 1981). Along the East Branch near the quarry, the beds have been overturned, striking northeast, and dipping 45 degrees to the southeast. Along the western extent of the study area, the beds have also been overturned, dipping 35 degrees southeast and striking northeast. South of the watercress bogs along the East Branch of LeTort Spring Run, the beds strike north and gently dip 10 degrees to the east.

Further tectonic stresses are evidenced by a diabase dike which transects Cumberland County in a north-south direction (Becher and Root, 1981). The dike is situated approximately 2.5 miles east of the study site. It consists of crystalline igneous rock which, when molten in the geologic past, forced its way into the parent bedrock and then hardened.

Figure 4 in Appendix A shows the geology of the study area. The oldest bedrock underlying the study area consists of the Cambrian-aged Zullinger Formation (Socolow, 1980). The Zullinger Formation immediately underlies the study area and consists of thick-bedded limestones and dolomites. The limestones are detrital, stromatolitic, and/or banded (Geyer and Wilshusen, 1981). Outcrops of the Zullinger Formation were observed along portions of LeTort Spring Run. The outcrops consisted of moderately fractured thick-bedded limestone interlayered with thin beds of shaly limestone. The piezometer logs also revealed encountering a shaly limestone.

The next oldest bedrock has been classified as the Cambrian-aged Shadygrove Formation. Because the contact between the Shadygrove Formation and the Zullinger Formation is difficult to distinguish, a brief description of the Shadygrove Formation is included. The Shadygrove Formation may be present in the northwestern corner of the study area. The Shadygrove Formation consists of limestone interbedded with dolomites (Geyer and Wilshusen, 1981). Nodules of brown chert are common.

6.2 Hydrogeologic Framework

LeTort Spring Run drains into the Conodoguinet Creek. Conodoguinet Creek flows east-west, parallel to the structural trend of the Cumberland Valley. In the Conodoguinet Creek drainage basin, approximately 80% of stream flow is base flow, in that 80% of the surface water in the streams comes from groundwater discharging into the stream channel (Becher and Root, 1981).

The rate of groundwater flow within the underlying aquifers depends on the abundance of openings within the bedrock and how much clay has filled the openings. As the groundwater percolates downward through the carbonate bedrock, it dissolves the calcium carbonate and magnesium carbonate, leaving behind impurities of clay. The clays may fill the voids, reducing the ability of the groundwater to migrate through the bedrock.

The diabase dike located east of LeTort Spring Run acts as a subsurface dam. The diabase, an igneous rock, is more resistant to chemical and physical weathering than the surrounding carbonate rocks. Diabase also contains fewer openings and no bedding planes along which groundwater can easily migrate. Therefore, when the groundwater encounters the diabase, the diabase inhibits the groundwater flow and the groundwater builds up behind the diabase. The groundwater elevations are higher on the western side of the diabase than on the eastern side.

The sustained yield is the volume of water that can be obtained continuously from a well without the well becoming devoid of water. The sustained yield is an indication of the productivity of an aquifer. A median sustained yield of 82 gallons per minute (gpm) can be obtained from the Zullinger Formation. Water-bearing zones have been encountered as deep as 450 feet below ground surface. The Shady Grove Formation has a reported median sustained yield of 26 gpm. Most water-bearing zones are present within the first 200 feet (Becher and Root, 1981).

Bedding generally enhances flow parallel to bedding strike and inhibits flow perpendicular to strike. Becher and Root (1981, p. 34) have stated that "wells in areas of folding or in areas where the strike of the beds was nearly perpendicular to the regional strike" were more productive than other wells. In other words, groundwater flow is greater in these areas. The springs forming the headwaters of the Eastern Branch of the LeTort Spring Run are located along the strike of the bedding (north), which is nearly perpendicular to regional strikes (northeast).

7.0 Fracture Trace Analysis

Groundwater will typically move preferentially through fractures and along bedding planes. The preferential flow paths can be inferred through linear features, i.e., lineaments, on high-altitude aerial photographs as "lines" of different colored vegetation, straight sections of stream channels, alignment of topographic lows, etc. The lineaments may be a surficial representation of fractures within the earth's subsurface. These lineaments are interpreted as the remnants of "cracks" or bedding planes within the underlying bedrock and likely represent areas where groundwater is able to travel more quickly through the aquifer.

7.1 Methodology

A fracture trace analysis was performed for the study area to determine the potential for preferential flow paths in the vicinity of Union Quarries, Inc., and LeTort Spring Run. The analysis was conducted by viewing historic high-altitude aerial photographs stereoscopically. Photographs available from the Pennsylvania Bureau of Topographic and Geologic Survey from the years 1947, 1958, 1964, and 1971 were utilized (see Appendix C). The high-altitude aerial photographs allow viewing of the site in 3-dimension, thereby emphasizing higher and lower topographic elevations and emphasizing the identification of lineaments.

As many of the geologic features are visible only by air, and are not always discernable on high altitude photographs, RETTEW augmented historic information with two low-altitude photographic surveys. The first survey was conducted utilizing low-level color aerial photography performed by Axis Geospatial Inc. in April 2003. The second survey was conducted by RETTEW personnel from helicopter in April 2003. The purpose of these two surveys was to identify geologic features not visible from historical aerial photography and geologic literature. Also, it was necessary to view the active quarry operation and the study area from an oblique overhead view to photograph and note the geologic framework of the study area. Approximately 100 high resolution digital photos of the study area were taken by helicopter in April 2003.

Using the information gleaned from the historic aerial photographs as a basis, RETTEW conducted the detailed, low altitude - high resolution geologic surveys of the study area. The combination of the low altitude photographs and the historical high altitude photographs were used to locate fracture traces, closed depressions, sinkholes, and springs in the field.

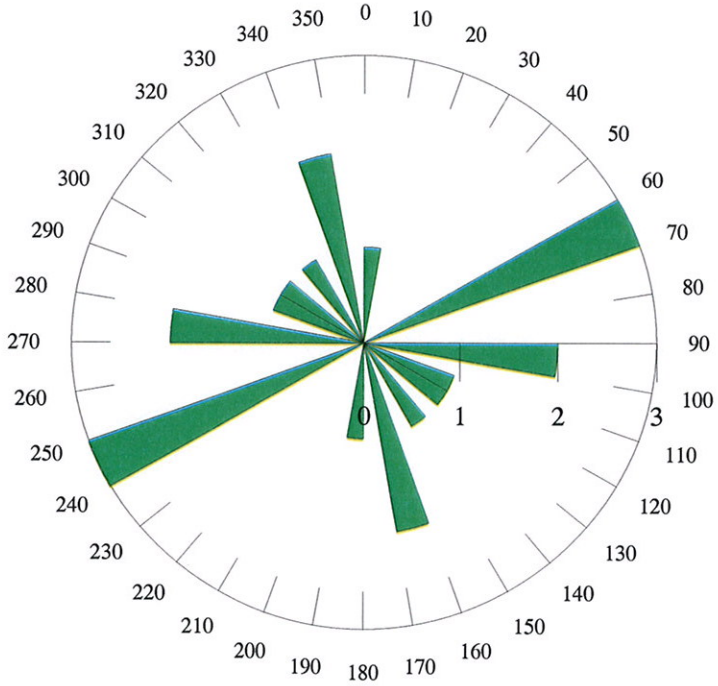
The Axis Geospatial Inc. low altitude aerial photography consisted of eight (8) images with a higher resolution than the historical photographs, These color images (see attached CDs in Appendix L) were used for further analysis of geologic features within the study area, which included fracture zones and fractures, sinkholes, springs, etc.; the low-altitude images were also utilized to create a base map of the study area.

7.2 Results

The locations of lineaments, likely representing potential large-scale bedrock fracture zones, are interpreted on Figure 7 in the Appendix A. A rose diagram of the fractures is shown below on

Figure 7.A. The rose diagram groups like-oriented fractures together and allows sets of fractures to be identified. The orientations of the lineaments identified on the historic aerial photographs were measured. The number of like-orientations is then reflected by the length of the 'petals'.

Figure 7.A.
Fracture Trace Analysis
Letort Spring Run



Based upon the rose diagram, three prominent sets of potential fracture traces were noted. Their orientation ranged from:

- N60E to N70E;
- N10W to N20W; and
- N80W to N90W.

The fracture orientations generally coincide with the strike of the beds and tectonic features (such as Bonny Brook Fault) and perpendicular to the strike of the beds. Fracture traces originating from or transecting the quarry were not noted on the aerial photographs due to manmade disturbances that have altered the landscape.

8.0 Geophysical Surveys

Electrical resistivity (ER) surveying is a commonly used near-surface geophysical tool. The ER technique is based on the premise that materials have a wide range of resistance to electricity, and in cases where targets of interest have sufficiently different electrical resistivity properties than the surrounding materials, a change in the measured electrical current will be detected. The purpose of the geophysical survey is to analytically measure the presence and location of underlying regional geologic features such as fracture zones that may encroach the LeTort Spring Run and impact base flow conditions.

8.1 Methodology

The electrical resistivity method consists of the input of electrical current into the subsurface by using calibrated electrodes ("current" electrodes) and measurement of the change in potential voltage by potential electrodes. The change in voltage measured by a set of receiving "potential" electrodes allows for the resistivity of the subsurface materials to be calculated. The resistivity of a material is simply the inverse of the conductivity. Some geologic materials that may have a relatively higher resistivity include, for example: air-filled voids, sands and gravels, and bedrock. Geologic materials that may have a relatively low resistivity include, for example: water filled voids, clays and silts.

The results of the electric resistivity method provide a profile or cross-section of the surveyed area which can then be utilized to define differing geologic materials. The Proposal for the Growing Greener Grant dated November 12, 2002, stated that electrical resistivity (using Sting/Swift technology) and conductivity surveys would be conducted. Electrical resistivity measurements were collected using the OhmMapper® Earth Resistivity Meter manufactured by Geometrics, Inc. Following is a description of the methodology and reasoning for using OhmMapper® over Sting/Swift and electrical conductivity surveys that were proposed.

OhmMapper® is a high productivity, electrical resistivity mapping system. Because the instrument's transmitter and receiver are capacitively coupled to the ground, there was no need for metal probes, which would have been utilized with proposed Sting/Swift resistivity technology. During the field survey, the OhmMapper® was pulled along the surface. The OhmMapper® employed the commonly-used dipole-dipole configuration. The system consisted of a transmitter, receiver, matching antennae, fiber optic isolator, and data logging console. The dipole lengths and Tx-Rx separation ("a" spacing) were varied in order to provide apparent resistivity readings from multiple depths. Subsurface profiles made with both the OhmMapper and with Sting/Swift measurement are very similar. The OhmMapper® generally shows more detail however, since measurements were taken every few centimeters, whereas the conventional resistivity methods generally limited to a few meters between probes. The detail gained by using OhmMapper offset the need to utilize proposed EM-61 conductivity measurements at the site.

The locations of the electrical resistivity survey lines were selected to characterize the subsurface conditions between LeTort Spring Run and Union Quarries, Inc. Both line length and site accessibility were the overriding factors in the determination of line location. Two 350-meter long lines were setup over the survey area (as shown in Appendix E). The two surveys were conducted at the following locations:

- Trail Survey: Aligned north-northwest to south along the east side of the LeTort Spring Run along the LRA trail. The survey extended from the railroad bridge to the north, to the east/west branch merger south of the railroad bridge.

- Watercress Survey: Aligned east to west along the northern edge of the watercress farm beds and located to the south of the quarry operation.

Geophysical surveys could not be conducted in areas previously defined by the LeTort Regional Authority as areas of concern. A sinkhole had been repaired in a meadow area north of the quarry in 1995. The goal of conducting geophysical work in this area was to identify and locate any additional subsurface anomalies related to the formation of the 1995 sinkhole. However, the operation of electrical resistivity equipment was not possible in this meadow area due to the flooded nature of the stream at the time of the investigation.

The trail survey was conducted approximately 50 to 90 feet east of the repaired sinkhole area and was aligned north to south parallel with the LeTort Spring Run. The location of this survey provided a subsurface profile which would identify connecting fracture zones or voids located between the quarry operation, the stream and the repaired sinkhole.

The electrical resistivity data were transferred from the OhmMapper® Earth Resistivity Meter to a computer by a data transfer serial cable using the RES2DINV software program. RES2DINV inversion produces a 2-D subsurface model from the acquired apparent resistivity data.

The RES2DINV software program was used to invert the resistivity data and create a 2-D subsurface model from the acquired apparent resistivity data. In general, relatively low resistivity areas (high conductivity) are represented as shades of blue, intermediate resistivity areas are represented by yellow and green, and relatively high resistivity areas (low conductivity) are represented as shades of orange and red. It should be noted that color scales on the apparent resistivity pseudo sections were not normalized relative to sections to which they were compared.

8.2 Results

The electrical resistivity profiles depicted a typical subsurface profile that one would find in carbonate geology. The pinnacled bedrock surface ranged from approximately 3 feet below the surface to approximately 14 feet. The average depth to rock appeared to be 7 feet below the surface at the locations of the survey lines.

Potential fracture zones were visible in three areas. One fracture zone was depicted on the trail survey run, located approximately 30 feet south of the area of the unused quarry access bridge over the LeTort Spring Run. Two additional fracture zones, one approximately 30 feet east of Peizometer P-4 and one approximately 60 feet west of Peizometer P-6, were located between the Quarry and the watercress beds and LeTort Spring Run. These fracture zones appear to range in width from 30 to 50 feet.

Regional geologic fractures between the quarry and the stream, north of the unused quarry access bridge, were not noted. The line adjacent to the repaired sinkhole did not exhibit a conductive pathway between the repaired sinkhole and the quarry, as evidence by the lack of fractures and the presence of competent bedrock.

Therefore, areas of fractured bedrock were noted in isolated areas south of the unused quarry access bridge and along the former water cress beds. Significant fractures were not observed north of the unused quarry access bridge.

9.0 Base Flow Monitoring

9.1 Methodology

The purpose for measuring the flow discharge was to aid in the determination of gaining and losing stream reaches due to suspected geologic features such as springs and sinkholes. Flow discharge data was also compared and considered with data collected from the monitoring wells and piezometer installations (See Section 10.0).

Flow discharge (Q) is the volume of water passing a cross-section per unit of time and is generally expressed as cubic feet per second (cfs). Discharge is simply velocity (V) times cross-sectional area (A), or Q = VA.

RETTEW measured flow discharge at 12 strategic locations on June 20, 2003, and again on April 20, 2004. Three locations were positioned downstream of the quarry's discharge. The remaining nine locations were positioned upstream of the quarry discharge. Figure 8 in Appendix A depicts the locations of the base flow monitoring stations. GPS coordinates for each of the base flow stations are located in Table 9.A.

Table 9.A

Station Number	Description	Latitude	Longitude
W-1	Downstream of watercress ponds	N40° 10' 24.7"	W77° 11' 20.2"
W-2	Near P-1	N40° 10' 28.4"	W77° 11' 08.6"
W-3	Bonnybrook Road bridge	N40° 10' 33.1"	W77° 11' 10.4"
W-4	Foot bridge	N40° 10' 35.4"	W77° 11' 14.1"
E-1	Downstream of watercress farm culvert	N40° 10' 36.6"	W77° 10' 47.3"
E-2	Railroad Bridge	N40° 10' 36.3"	W77° 11' 05.5"
E-3	Foot bridge	N40° 10' 35.9"	W77° 11' 07.7"
1	Near P-2	N40° 10' 38.0"	W77° 11' 09.9"
2	Upstream of quarry outfall	N40° 10' 42.3"	W77° 11' 13.4"
3	Downstream of quarry outfall	N40° 10' 42.5"	W77° 11' 13.6"
4	Railroad Bridge	N40° 10' 47.4"	W77° 11' 13.5"
5	Upstream of I-81 bridge	N40° 11' 07.4"	W77° 11' 14.9"

At each location where flow discharge was measured, RETTEW first installed steel pins on both sides of the stream channel. The pins were set at equal elevations with the aid of a rod and level. Guard stakes with orange ribbon indicating the locations of the pins were installed so the pins could be easily relocated for subsequent measuring events. The pins served as anchors for stretching a measuring tape horizontally across the stream channel.

Because water in a natural stream channel flows at different depths and velocities, it is necessary to divide a channel's cross-section into subsections. For this reason, RETTEW took horizontal measurements every foot across the stream channel beginning and ending at the water's edge. Water depth and velocity were recorded at each horizontal foot. RETTEW used a "Flowatch" by JDC Electronic S.A. to measure velocity in meters per second (later converted to feet per second). Discharge (Q) was calculated for each subsection by multiply the area (A) with the velocity. All subsection values were then added together for an overall discharge volume for that particular cross-section of the stream channel.

Velocity readings were taken standing downstream of the velocity meter at arm's length. Depending on the water depth, the meter was held at a different position in the water column. If the depth was less than 2.5-feet, the velocity reading was taken at 0.6 times the actual depth. If the depth was greater than 2.5-feet, two velocity readings were taken and averaged; one reading was taken at 0.2 times the depth and the other at 0.8 times the depth. The most significant influence on measuring error was likely due to the presence of aquatic vegetation (mainly waterweed Genus *Elodea*) and its waving action back and forth across the current. Similar to a flag flapping in the wind, the lush growths of *Elodea* would wave back and forth across the flow path being measured by the flow meter. It was routinely observed the flow meter would speed up and then slow down as the waving aquatic plants influenced the current. To compensate for this influence, the meter was held in place until a steady reading was obtained.

9.2 Results

The measurements from June 20, 2003, and April 20, 2004 are summarized below on Table 9.B. Figures 9.A and 9.B show the difference between stream flows from June 2003 and April 2004.

Table 9.B

Station #	Location	Flow (cfs) June 20, 2003	Flow (cfs) April 20, 2004
E1	Eastern Branch	11.93	9.12
E2	Eastern Branch	8.12	8.69
E3	Eastern Branch	9.76	8.13
W1	Western Branch	23.87	22.04
W2	Western Branch	18.49	24.04
W3	Western Branch	36.24	29.65
W4	Western Branch	21.40	22.11
1	Downstream of Confluence	29.64	33.00
2	Downstream of Confluence	30.69	30.89
3	Downstream of Confluence	35.02	35.61
4	Downstream of Confluence	54.78	51.77
5	Downstream of Confluence	41.18	37.84

Figure 9.A

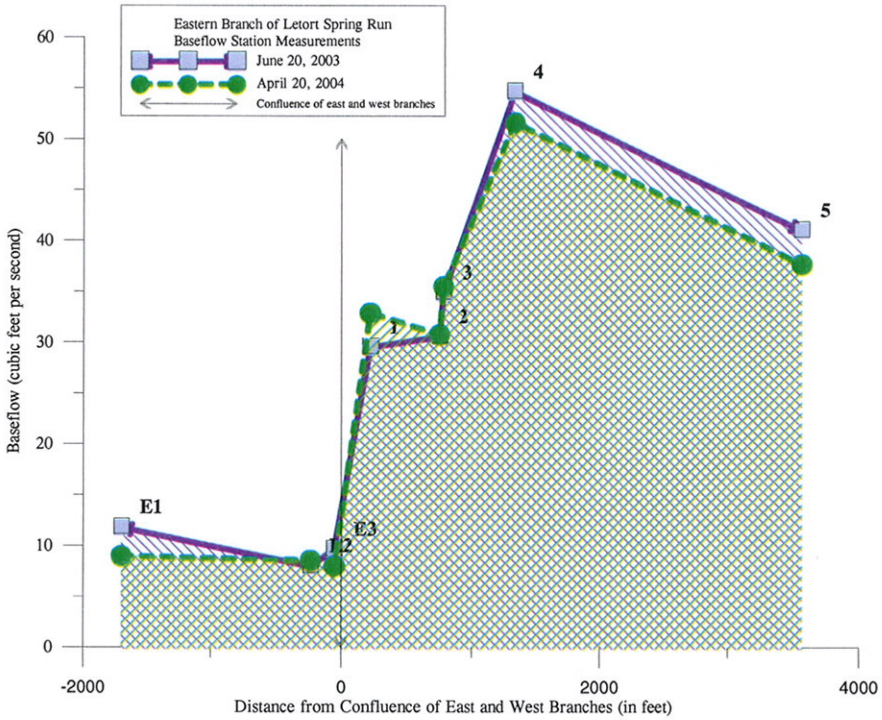
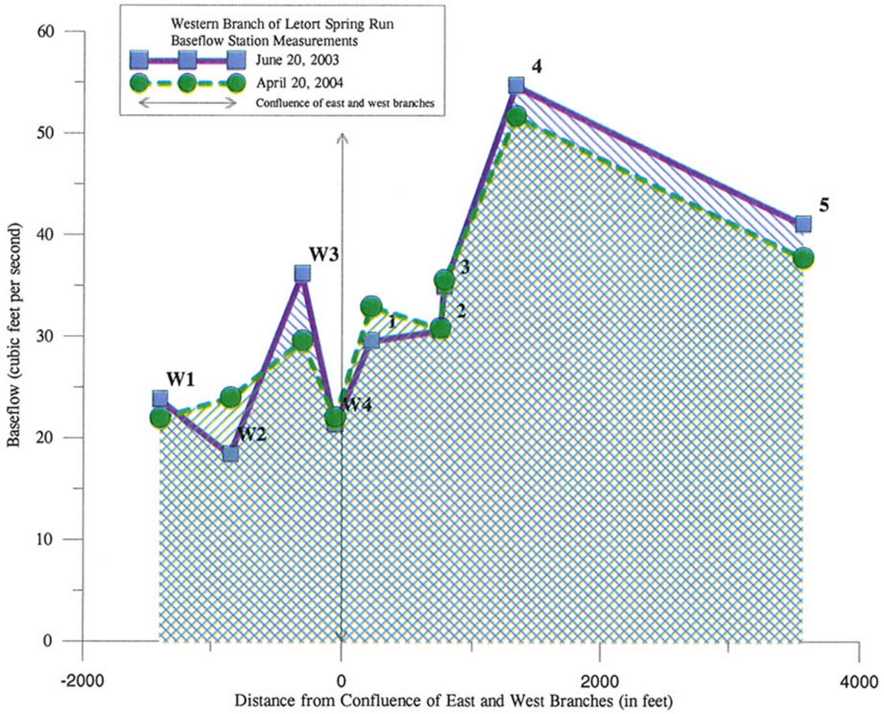


Figure 9.B



The flow monitoring measurements revealed the following:

1. General increase in base flow from headwaters to downstream measurements.
2. Decrease in base flows (4% and 31%) in watercress bed area.
3. Steady increase in base flows along west branch.
4. Decrease in base flows (9% and 30%) in stream branch merger area.
5. Steady flows along stream through quarry property.
6. Quarry pumping adding 12-13% to base flow.
7. Increase in base flow (45% and 56%) from repaired sinkhole area to railroad bridge.
8. Decrease in base flow (25% and 25%) from railroad bridge to most downstream measurement.

Along the Eastern Branch, base flow is slightly declining. Few springs were noted along the stream reach where measurements were obtained. Base flow measurements from the Western Branch show a general increase through its reach, except a slight decrease in flow near the spring. After the two branches form the main channel of LeTort Spring Run, base flow increases. The flow measurements from the monitoring station immediately north of the confluence were approximately 8.13 cfs (East Branch) and 22.11 cfs (West Branch), for a combined flow of 30.24 cfs. The flow measurement immediately downstream of the confluence was 33.00 cfs. Base flow decreases slightly to the outfall from the quarry, and then doubles to the railroad bridge. The base flow measurement at the northern extent of the study area shows a decrease.

The banks in undisturbed areas of LeTort Spring Run slope gently from the stream channel, and are covered by extended periods of standing (or slowly moving) water. Reeds and other wetland vegetation cover this area. The portion of the west bank situated between Station 3 and Station 4 exhibited this wetland terrain. After visually investigating and traversing the west bank, no sinkholes, closed depressions, or significantly flowing seeps were observed.

The watercress farming activities may be one cause of stream base change in the upper reaches of the east branch of the LeTort Spring Run. In June 2003, when base flow was established, the watercress farming operation was active. The watercress beds were taking water from the stream at various points and spreading the flow of water in a sheet-type flow over the watercress. At the end of each bed, pipes took the water and eventually reintroduced it to the LeTort Spring Run; however, as the water flowed through the beds, it can be assumed a certain amount of vertical infiltration, in addition to evaporation and transpiration from the plants, was taking place. This can account for the 31% decrease in base flow. In April 2004, when the second base flow measurement took place, only 4% of base flow was lost. The difference can be attributed to the fact that watercress farming was inactive. All piping utilized to feed water to the beds was temporarily shut off. As no water was flowing through the beds, evaporation, transpiration, and infiltration were not taking place in the water cress beds, and a much lesser percent decrease in base flow was measured.

In addition to measuring the stream flow discharge within the actual stream channel as explained above, there were several occasions when it was necessary to measure flow discharges originating from pipes.

One such example was at the quarry's discharge. RETTEW located a measuring station above and below the quarry's discharge point (Station #3 below the discharge; Station #4 above the discharge). On June 20, 2003, 4.33-cfs or 12% of the total 35.02-cfs flowing passed station #3 came from the quarry discharge. On April 20, 2004, 4.72-cfs or 13% of the total 35.61-cfs flowing passed Station #3 came from the quarry discharge. Actual pumping quarry rates were not provided; Union Quarries did, however, state that the water level in the quarry was maintained at an approximate elevation of 400 feet above mean sea level.

Assuming the quarry pumping rate observed on June 20, 2003, and April 20, 2004, can be considered normal given stream flow conditions during those same times, then it could be stated that on average the quarry discharge accounts for over 10% of the flow in the stream immediately below the quarry discharge. According to Union Quarry's personnel, the quarry basin is pumped almost continuously, except during extended periods of little or no precipitation.

10.0 Physical Characteristics Monitoring

10.1 Methodology

In September of 2003, RETTEW traversed the study area, in particular, the stream itself with the following objectives:

1. Identify and locate areas of the stream that can be physically seen to be losing or gaining flow, in addition to mapping any springs.
2. Collect surface water temperature data as a means to identify evidence of springs (groundwater discharging into the stream) and sinkholes (possible groundwater recharge from the stream).
3. Classify the stream-bottom characteristics

The stream temperature data survey was not originally proposed in the Growing Greener Grant. However, in order to better identify areas where sinkholes may have developed, the temperature survey was conducted to compliment the visual identification of sinkholes. This completion of these objectives allowed RETTEW to identify qualitatively the extent of groundwater recharge to the stream.

RETTEW utilized a dissolved oxygen/temperature probe attached to a probing stick to measure the water temperature of the stream. The premise behind the temperature survey was that groundwater has a lower temperature than surface water. Areas where groundwater is upwelling into the stream would be marked by decreases in water temperature. RETTEW waded and probed the stream along the entire study area.

During the temperature survey, the bottom of the stream channel was also observed for silt/gravel content. A silty bottom was interpreted as indicating potential downward or absent surface water migration. As the surface water traveled downward, it potentially leaves behind particles of silt and clay. A gravelly bottom indicated areas of man-made influence (such as placing gravel for trout hatching) or recharge to the stream. As groundwater upwelled into the stream, it potentially forces the movement of small particles (silt and clay) off the stream bottom and downstream. The channel bottom was noted to be very silty from the most downstream measurement, the rail-trail railroad bridge, through the quarry stretch and on through the watercress farm of the Eastern Branch. Gravel was observed on the channel bottom between the two quarry access bridges; however, the gravel content appeared to be from a foreign source (granites, sandstones, etc.) and was placed to enhance fish spawning.

10.2 Results

The stream channel was visually inspected for indications of sinkholes and springs. No sinkholes or closed depressions were identified within the stream channel throughout the study area during the field investigations. Temporary subsidence features were noted on two occasions in the active water cress beds in June 2003. In December 2003, these features were no longer observed. The water cress beds had been tilled between these two time frames. No sinkholes were subsequently observed in the water cress beds. Springs encountered during the visual inspection are shown on the Base Map located in Appendix A.

The results of the temperature measurements are compiled in Table 10.A and Figures 10.B and 10.C. The stations on Table 10.A correspond to the Temperature Measurement Location Map shown in Figure 10.A.

Table 10.A

Station #	Description	Deg Celsius
1	East Branch	11.9
2	East Branch	12.0
3	Small foot bridge	12.0
4	Creek south of watercress lagoon	12.0
5	Creek south of watercress lagoon	12.0
6	25' upstream of previous measurement	12.1
7	East Branch	12.1
8	Culvert pipes from watercress lagoons	12.2
10	Change of lithology to shaly limestone	12.2
11	End of watercress field at small bridge	12.2
12	East Branch	12.2
13	Springhouse on Spring Garden Street	11.9
14	Quarry outfall	18.1
15	Railroad Bridge	13.3
16	Floodplain area	13.1
17	Former sinkhole area	13.4
18	Channel through quarry property	12.3
19	Channel through quarry property	12.2
20	Channel through quarry property	12.1
21	Stream Divides to East and West	12.1
22	Spring	11.6
23	West Branch	12.0
24	Gravel Spot – Groundwater Recharge	11.6
25	Gravel Spot – Groundwater Recharge	11.3
26	Groundwater Recharge	11.1
27	Spring	11.1
28	Spring	11.1