

# **SOUTH HARRISBURG SINKHOLE EVALUATION WORK ORDER # 2**

## **HARRISBURG, PA**



**Prepared for:  
City of Harrisburg**

**Prepared By:**



**November 2014**

**Project Number: 59166**

**Copyright 2014**

**SOUTH HARRISBURG SINKHOLE EVALUATION  
WORK ORDER # 2**

**HARRISBURG, PENNSYLVANIA**

**TABLE OF CONTENTS**

INTRODUCTION .....	1
GEOLOGIC SETTING .....	1
MASW SURVEY RESULTS.....	2
SITE RECONNAISSANCE OBSERVATIONS.....	3
DISCUSSION .....	4
REFERENCES .....	6

**ATTACHMENTS**

**Tables**

Table 1 – Summary of Field Surface Feature Observations

**Figures**

Figure 1 – Site Plan

Figure 2 – Site Geology

MASW Derived Shear Wave Velocity ( $V_s$ ) Profiles

Figure 3A – Hanover Street  $V_s$  Profile

Figure 3B – Hanover Street  $V_s$  Profile

Figure 4 – Magnolia Street  $V_s$  Profile

Figure 5 – Cloverly Terrace  $V_s$  Profile

Figure 6A – Scott Street  $V_s$  Profile

Figure 6B – Scott Street  $V_s$  Profile

Figure 7 – S. 14<sup>th</sup> Street  $V_s$  Profile

Figure 8 – Agnew Street  $V_s$  Profile

Figure 9A – S. 13<sup>th</sup> Street  $V_s$  Profile – Hanover to Cloverly

Figure 9B – S. 13<sup>th</sup> Street  $V_s$  Profile – Hanover to Cloverly

Figure 10 – S. 13<sup>th</sup> Street  $V_s$  Profile – Cloverly to S. 12<sup>th</sup> St.

Figure 11A – Pigeon Street  $V_s$  Profile

Figure 11B – Pigeon Street  $V_s$  Profile

Figure 12A – S. 12<sup>th</sup> Street  $V_s$  Profile

Figure 12B – S. 12<sup>th</sup> Street  $V_s$  Profile

Figure 12C – S. 12<sup>th</sup> Street  $V_s$  Profile

Figure 13 – Map of Geophysical Findings

Figure 14A – City of Harrisburg GIS Data WO#2 Study Area

Figure 14B – City of Harrisburg GIS Utility Data Overlay

**Appendices**

Appendix A - Description of the MASW Method

Appendix B – Site Photographs

## **SOUTH HARRISBURG SINKHOLE EVALUATION WORK ORDER # 2**

### **HARRISBURG, PENNSYLVANIA**

#### **INTRODUCTION**

This report presents the results of an office investigation of published geologic reports and historical records, coupled with a multi-channel analysis of surface waves (MASW) survey, and field observations for a study area bounded by Hanover Street, Scott Street, Cloverly Terrace, S. 13<sup>th</sup> Street and S. 12<sup>th</sup> Street. The location of the study area is shown on the Site Plan, Figure 1 and the Site Geology Plan, Figure 2.

#### **GEOLOGIC SETTING**

The study area is underlain by carbonate rocks of the Ordovician age St. Paul Group. The St. Paul Group is predominantly a thick-bedded, very fine-grained, high-calcium, light gray, limestone. Other lithologies occurring in this group are medium-gray granular limestones; limestones with black chert nodules; dolomite interbeds; and skeletal-detrital limestone. Thickness of the group is estimated to be about 1,000 feet in Dauphin County.

The St. Paul Group has undergone intensive folding and faulting which has created extensive fracturing of the rock. Most joints have a blocky pattern, are open, and are steeply dipping to vertical. The extensive jointing exposes a greater surface area of the carbonate rocks to groundwater movement, which can increase the potential for development of solution channels and sinkholes within the rocks. Pinnacle development at the bedrock/overburden interface is common in the St. Paul Group. An east-west trending inferred thrust fault is mapped crossing the area just north of Magnolia Street. The exact location and angle of the fault is not known and has been “inferred” by the author of the geologic reference based on surface features on the west shore of the Susquehanna River. Fault zones are areas of intensely fractured rocks and often have rapid groundwater movement, further increasing the possible development of sinkholes.

The bedrock is overlain by unconsolidated terrace deposits composed of gravely silts derived from glacial outwash (MacLachlan, 1967). Thickness of these deposits is variable. A deposit of fill is mapped near the south end of Scott Street. The fill deposits may be composed of quarry spoil, sanitary and structural landfill, or slag. The exact boundaries and thickness of the fill is not known and may extend into the study area.

Aerial photography (Penn Pilot website) from 1937, 1956, and 1958 show the area east of South 13<sup>th</sup> Street to be undeveloped and in agricultural use. Aerial photography from 1970 shows the same area to be fully developed to present day conditions. No karst related features or fracture traces (naturally occurring fractures in the bedrock can sometimes be detected by a geologist’s evaluation of aerial photography) were observed on the photographs due to urban development surrounding the project area. Property tax data shows that the northwestern part of the study area, between 12<sup>th</sup> and 13<sup>th</sup> Streets, was developed between the early 1900’s and late 1940’s. The

remainder of the area was developed between 1958 and 1970. The 1958 photograph shows possible earthwork in the vicinity of the mapped artificial fill discussed above.

## **MASW SURVEY RESULTS**

The multi-channel analysis of surface waves (MASW) survey was performed October 7-9 and 27-30, 2014 and included the following streets:

Hanover Street (S. 12<sup>th</sup> Street to Scott Street)  
Magnolia Street (S. 12<sup>th</sup> Street to Scott Street)  
Cloverly Terrace (S. 13<sup>th</sup> Street to Scott Street)  
Scott Street (Magnolia Street to Cloverly Terrace)  
S. 14<sup>th</sup> Street (Hanover St. to Magnolia Street)  
Agnew Street (Magnolia Street to Cloverly Terrace)  
S. 13<sup>th</sup> Street (Hanover to Cloverly Terrace, and Cloverly Terrace to S. 12<sup>th</sup> Street)  
Pigeon Street (Hanover Street to S. 12<sup>th</sup> Street)  
S. 12<sup>th</sup> Street (Hanover Street to S. 13<sup>th</sup> Street)

MASW is a geophysical method that produces a continuous profile of the subsurface based upon differences in shear wave velocity ( $V_s$ ).  $V_s$  is a measure of material stiffness much like N-values from standard penetration test (SPT) borings. Higher  $V_s$  indicate stiffer materials; lower  $V_s$  indicate less stiff materials. This makes the method applicable to profiling top of rock (TOR) since rock is stiffer than soil. MASW can also identify karst features because sinkhole activity tends to make materials less stiff. Voids are characterized by low  $V_s$  anomalies (localized decrease in  $V_s$ ) because the materials within the voids (air, soil, or water) are less stiff than the surrounding rocks. Fractures are generally expressed as thin, near-vertical zones of lower  $V_s$  that are traceable across multiple survey lines.

MASW is not impacted by buried piping (unlike electrical resistivity methods) and can investigate to far greater depths than the maximum of approximately 3 feet characteristic of ground penetrating radar (GPR) for soils in and around Harrisburg. A further discussion of the MASW method, and how the data were acquired and processed, is provided in Appendix B.

A single line was run along each street, as shown in Figure 1. The MASW survey was conducted in the same manner as in Work Order #1, using the same equipment and data acquisition and processing parameters. The  $V_s$  profiles are shown in Figures 3A through 12C. The profiles were constructed with a horizontal scale of 1 inch = 50 feet and a vertical scale of 1 inch = 25 feet. The data were contoured between 500 and 4,500 feet per second (fps), using a color contour scheme whereby cooler colors indicate lower  $V_s$  (less stiff materials) and warmer colors indicate higher  $V_s$  (stiffer materials).

In general, top of rock (TOR) is equivalent to approximately 1,200 fps, based upon the verification boring conducted in Work Order #1. In the Work Order #2 study area, TOR varies from approximately 15 feet to 40 feet below ground surface (BGS). The TOR surface also varies from relatively flat (e.g., S. 13<sup>th</sup> Street, Hanover St. to Cloverly Terrace, Figures 9A and 9B) to highly irregular (e.g., Agnew Street, Figure 8). In the local limestone geology, an irregular rock surface is generally due to pinnacles.

Twenty (20) fracture-like anomalies were observed. They are designated #1 through #20 in the profiles and are plotted in Figure 13. Some fracture-like anomalies such as #1 in Figure 4 and #10 in Figure 8 appear to extend to the top of the rock surface and are associated with a localized depression in the TOR. Soil piping (raveling) can be expected where fractures extend to the rock surface because fractures are planes of weakness that can allow soils to migrate into openings (voids) at depth.

Based on the judgement of the geophysist, some of the fracture-like anomalies, in collaboration with those identified in Work Order #1, “line-up” to form seven potential fractures. They are shown in Figure 13 as PFZ#1 through PFZ#7. PFZ#1 through PFZ#5 trend approximately northeast-southwest; PFZ#6 and PFZ#7 trend close to north-south. PFZ#1 through PFZ#5 were identified in Work Order #1; PFZ#1 and PFZ#2 have been extended further to the south based upon the results of Work Order #2. PFZ#6 is based on Work Order #2 findings. PFZ#7 is based on both Work Order #1 and Work Order #2 findings.

Forty (40) zones of potential voids were also identified. They are characterized as localized low  $V_s$  anomalies in the rock. They are highlighted in the profiles and plotted in Figure 13.

## **SITE RECONNAISSANCE OBSERVATIONS**

During the course of their field work the Quantum crew documented surface features that may indicate sinkhole activity or sinkhole repairs. Following the MASW survey, a site reconnaissance was performed on 1) problem areas identified by City records and, 2) areas of concern based on the results of the MASW survey (i.e. locations of potential voids and fracture-like anomalies). The site reconnaissance was performed by a Geotechnical engineer and a Geotechnical designer.

Observed surface features are summarized in Table 1 and the locations are shown on the Map of Geophysical Findings, Figure 13. Photographs are included in Appendix A.

In general, there is some correlation between surface features and zones of potential voids. Good examples of this include the following:

1. The intersection of Cloverly Terrace and S. 13<sup>th</sup> Street
2. Magnolia Street from S. 12<sup>th</sup> Street to Pigeon Street
3. S. 12<sup>th</sup> Street from Magnolia Street to S. 13<sup>th</sup> Street
4. S. 14<sup>th</sup> Street from Magnolia Street to Cloverly Terrace (Work Order #1).

Surface features are also associated with the seven potential fractures.

Note that surface features described as closed depressions may be attributable to factors other than sinkhole activity, such as tree removal and settlement of improper fill material or poorly compacted fill material.

## DISCUSSION

The results of the studies described in this report indicate that the study area overlies limestone bedrock which is characterized by fracture-like features and voids. These features allow the overburden soil to migrate downwards and sinkholes and closed depressions to develop. Migration of soil into voids in the limestone bedrock, also known as piping, is primarily due to movement of water in the subsurface. The water can originate from leaky utility lines, infiltration of surface drainage, or fluctuations in the groundwater level. The data collected in this study does not rule out any of these potential causes, nor does it implicate one cause as primary.

The location of water, sanitary and stormwater pipes are shown on Figures 14A and 14B. Figure 14B is an overlay of the utility data on a line diagram of the geophysical findings. Many of the subsurface features identified by the MASW survey (potential voids or fracture-like anomalies) and all of the surface features are in the vicinity of one or more underground utility facilities. However, subsurface features were also identified along roadways with no utilities, such as Scott Street between Hanover Street and Magnolia Street, and most of Pigeon Street between Magnolia Street and S. 12<sup>th</sup> Street. Additionally, the site reconnaissance was performed along streets and sidewalks where the majority of utilities are located.

The area is prone to fluctuations in groundwater level due to periods of heavy precipitation. McGlade and Geyer (1976) indicate that in the limestone geology found in the greater Harrisburg metropolitan area, “Ground-water levels fluctuate seasonally and respond rapidly to heavy rains and surface runoff.” It is also stated in the same reference that, “Water table shows rapid response to heavy rains because of recharge to well-developed subsurface drainage.”

The natural arching action of overburden soils and pavement sections can delay the surface expression of developing voids such as sinkholes and closed depressions. Therefore, deterioration of subsurface conditions caused by leaky utility lines, infiltration of surface water or fluctuations in the groundwater level can be a factor in sinkhole development at a later date making it difficult to attribute a single cause to a sinkhole.

Control of stormwater and prevention of water accumulation into the subsurface can aid in preventing future sinkholes. The following may help in mitigating future sinkholes:

- Patch pavement areas and seal the joint between the new and old pavement where excavation has been performed and aggregate is exposed. Pavement areas with aggregate exposed were identified along Magnolia Street at the location of Surface Features 3, 4, and 5.
- If the parking lot where Surface Feature 22 is located is City property, consider paving or performing the permeability reduction detail included in the Work Order # 3 Report (Gannett Fleming, October 2014).
- Prioritize the study area for inspection of water, stormwater and sanitary sewers to identify and replace deteriorated lines. Perform reconstruction or repairs incorporating the most watertight and flexible joints possible.

- In future pavement projects, any full depth joints in pavement, including where pavement meets curb lines should be sealed to make the joint as watertight as practically possible.

## REFERENCES

- Gannett Fleming (August 2014), *Emergency Sinkhole Investigation, Work Order #1, 1400 Block of South 14<sup>th</sup> Street, Harrisburg, PA.*
- Gannett Fleming (October 2014), *Emergency Sinkhole Investigation, Work Order #3, Sinkhole Mitigation at 1400 Block of South 14<sup>th</sup> Street, Harrisburg, PA.*
- Kochanov, W.E. (1989), *Sinkholes and Karst-Related Features of Dauphin County, Pennsylvania*, Pa, Geol. Survey, Open-File Report: 8901.
- MacLachlan, D. B. (1967), *Structure and Stratigraphy of the Limestones and Dolomites of Dauphin County, Pennsylvania*, Pa. Geol. Survey, 4th ser., General Geology Report 44, 168 p.
- McGlade, W.C. and Geyer, A.R. (1976), *Environmental Geology of the Greater Harrisburg Metropolitan Area, Pennsylvania*, Pa. Geol. Survey, 4th ser., Environmental Geology Report 4, 42p.
- Penn Pilot website, Aerial Photographs: AHE-15-30 (9/20/1937), AHE-4R-44 (11/6/1956), AHD-2V-51 (5/27/58), <http://www.pennpilot.psu.edu/>
- Root, S. I. (1977), *Geology and mineral resources of the Greater Harrisburg West Area, Cumberland and York Counties, Pennsylvania*, Pa. Geol. Survey, 4th ser., Atlas 148ab, 106 p.



***Tables***

**Table 1**  
**Harrisburg Sinkhole Study - WO #2**  
**Summary of Field Surface Feature Observations**

Feature No.	Type	Observation Source	Location <sup>(2)</sup>	Description and Observations
1	Closed Depression	Gannett Fleming	Hanover Street Between Approx. Stations 100 - 150	2 Small depressions in lawn between sidewalk and street. May have been from tree removal. Observed 11/18/2014.
2	Closed Depression	Gannett Fleming	Hanover Street Approx. Station 450.	Undeveloped block bordered by Hanover, S. 14th, Magnolia, and S. 13th Streets. Terrain generally hummocky. Several ground surface openings suspected to be animal burrows observed. One possible closed depression in open area SE of Hanover Street. Observed 11/18/2014
3	Closed Depression	Gannett Fleming	Magnolia Street Approx. Station 50	Depression along SE curb line with evidence of previous pavement repairs. Observed 11/18/2014.
4	Closed Depressions	Quantum Crew, Gannett Fleming	Intersection of Magnolia and Pigeon Streets; Magnolia Street Approx. Station 170 to 180.	<ul style="list-style-type: none"> <li>- Depression with aggregate exposed. Appears to have been prior excavation activity in street nearby. Sanitary sewer and water main pass through this location. Observed 10/8/2014.</li> <li>- Significant depressions in roadway. Nearby repair along SE curb line, observed 11/18/2014.</li> <li>- Four water main breaks were repaired by CRW Water Division between 3/15/2014 and 3/18/2014. Breaks were triggered by heavy equipment used for demolishing a church that had been condemned by the City.</li> </ul>

(1) Photo documentation and enhanced description of 1400 Block of S. 14th Street Surface Features is presented in Work Order # 1 Report (Gannett Fleming, August 2014)

(2) All stationing is in feet along MASW Survey Lines

**Table 1**  
**Harrisburg Sinkhole Study - WO #2**  
**Summary of Field Surface Feature Observations**

Feature No.	Type	Observation Source	Location <sup>(2)</sup>	Description and Observations
5	Street Cuts and Backfill	Gannett Fleming	Intersection of Magnolia and S. 14th Street; Magnolia Street Approx. Station 600.	Street cuts and exposed aggregate backfill where new water line work along 1400 block of S. 14th Street connected to existing. Observed 11/18/2014.
6	Closed Depression	Gannett Fleming	Cloverly Terrace Approx. Station 100	Closed depression on east side of road. Utility pole tie down shows evidence of being extended. SW inlet nearby. Observed 11/18/2014
7	Closed Depression	Gannett Fleming	Cloverly Terrace Approx. Station 375	Closed depressions on east side of road. May be due to poor compaction of fill. Observed 11/18/2014.
8	Closed Depression	Gannett Fleming	Scott Street Approx. Station 780	Small depression in pavement. Observed 11/18/2014.
9 <sup>(1)</sup>	Sinkhole	City of Harrisburg	S. 14th St. 1417 to 1425	Sinkhole developed in street and yards 3/20/2014. Repaired by City/CRW.
	Closed Depressions	Gannett Fleming	S. 14th St. 1417 to 1425	Several closed depressions observed within backfill surface of sinkhole repair. Observed 7/15/2014.
10 <sup>(1)</sup>	Sinkhole and Closed Depressions	Gannett Fleming	S. 14th St., 1426	Sinkhole observed at base of slope and closed depressions at top of slope in front of house. Observed 7/15/2014.
11 <sup>(1)</sup>	Closed Depression	Gannett Fleming	S. 14th St., 1433	In front of house. Observed 7/15/2014
	Closed Depression	City of Harrisburg	S. 14th St., 1435	Depression in lawn in front of residence. Also observed by Gannett Fleming, 7/15/2014.
	Sinkhole	Quantum Crew	S. 14th St., 1436 - 1439	Sinkhole revealed during MASW survey. Observed 7/14/2014.
	Sinkhole	City of Harrisburg	S. 14th St., 1440 to 1436	Large Sinkhole Repaired by City, 2007.

(1) Photo documentation and enhanced description of 1400 Block of S. 14th Street Surface Features is presented in Work Order # 1 Report (Gannett Fleming, August 2014)

(2) All stationing is in feet along MASW Survey Lines

**Table 1**  
**Harrisburg Sinkhole Study - WO #2**  
**Summary of Field Surface Feature Observations**

Feature No.	Type	Observation Source	Location <sup>(2)</sup>	Description and Observations
12	Closed Depression	Gannett Fleming	S. 13th St. (Hanover to Cloverly), Approx. Station 50	Small depression in lawn between sidewalk and street. May be from tree removal. Observed 7/14/2014.
13	Pavement Patch	Gannett Fleming	S. 13th St. (Hanover to Cloverly), Approx. Station 600	Pavement patch located at approximate location of potential fracture identified by MASW. Observed 11/18/2014.
14	Pavement Patch	Gannett Fleming	S. 13th St. (Hanover to Cloverly), Approx. Station 1000	Pavement patch located at approximate location of potential void identified by MASW. Observed 11/18 2014.
15	Closed Depression	Gannett Fleming	S. 13th St. (Cloverly to S. 12th), Approx. Station 50	Closed depression in lawn between sidewalk and street. Observed 11/18 2014.
	Structure Damage	Gannett Fleming	S. 13th St. (Cloverly to S. 12th), Approx. Station 50	Crack in retaining wall located across sidewalk from closed depression. Observed 11/18 2014.
	Pavement Patch	Gannett Fleming	S. 13th St. (Cloverly to S. 12th), Approx. Station 50	Pavement patch. Observed 11/18 2014.
	Closed Depression	Gannett Fleming	S. 13th St. (Cloverly to S. 12th), Approx. Station 50	Closed depressions in grassy area on N side of 13th Street across from pavement patch, lawn depression and cracked retaining wall. Observed 11/18 2014.
16	Closed Depression	Quantum Crew	S. 13th St. (Cloverly to S. 12th), Approx. Station 150	Depression located just inside the curb in front of house. Possible slope failure across the road from the depression. Observed 10/28/2014.
17	Closed Depression	Quantum Crew	S. 13th St.(Cloverly to S. 12th), Approx. Station 585	Depression located about 15' behind eastern curb across from homes. Observed 10/28/2014.

(1) Photo documentation and enhanced description of 1400 Block of S. 14th Street Surface Features is presented in Work Order # 1 Report (Gannett Fleming, August 2014)

(2) All stationing is in feet along MASW Survey Lines

**Table 1**  
**Harrisburg Sinkhole Study - WO #2**  
**Summary of Field Surface Feature Observations**

Feature No.	Type	Observation Source	Location <sup>(2)</sup>	Description and Observations
18	Pavement Patch	Gannett Fleming	S. 12th St., Approx. Station 75	Pavement patch located at approximate location of potential void identified by MASW. Observed 11/25/2014.
19	Sinkhole	City of Harrisburg	S. 12th St., Approx. Station 150	Sinkhole temporary patched by City, driveway patching also observed
20	Closed Depression, Structure Repairs	Quantum Crew	S. 12th St., Between Approx. Stations 500-550	In front of house. Observed 10/30/2014. Masonry foundation wall of 3 homes impacted. One recently repaired, one buttressed by soil fill, and one undermined by closed depression.
21	Closed Depression	Quantum Crew	S. 12th St., Approx. Station 675	Depression under porch footing. Observed 10/30/2014.
22	Closed Depression	Quantum Crew	S. 12th St., Approx. Station 750	Large depression in the parking area next to house. Appears to have been filled with gravel. Observed 10/30/2014.
23	Sinkhole	Quantum Crew	S. 12th St., Approx. Station 1000	Apparent sinkhole in yard. Some minor depressions in immediate area surrounding the sinkhole. Observed 10/30/2014. Asphalt patch observed in roadway 11/18/2014 by Gannett Fleming.
24	Sinkhole	Quantum Crew	S. 12th St., Approx. Station 1125	Depression under concrete pad. Within area where sidewalk was replaced per resident. Observed 10/30/2014. Asphalt patches observed in roadway 11/18/2014 by Gannett Fleming.
25	Sinkhole	City of Harrisburg	S. 12th St., Between Approx. Stations 1200 - 1225	Sinkhole repaired by City. Pavement patches and new sidewalk observed 11/18/2014 by Gannett Fleming.

(1) Photo documentation and enhanced description of 1400 Block of S. 14th Street Surface Features is presented in Work Order # 1 Report (Gannett Fleming, August 2014)

(2) All stationing is in feet along MASW Survey Lines

**Table 1**  
**Harrisburg Sinkhole Study - WO #2**  
**Summary of Field Surface Feature Observations**

Feature No.	Type	Observation Source	Location <sup>(2)</sup>	Description and Observations
26	Sinkhole	Gannett Fleming	S. 12th St., Approx. Station 1450	Evidence of concrete fill next to large tree in area between S. 12th Street and Pigeon Street. Local resident indicated that it was a sinkhole repair. Observed 11/18 2014.
27	Sinkhole	Quantum Crew	S. 12th St., Approx. Station 1650	Sinkhole in front yard. Exposed rock also seen. Observed 10/302014.

(1) Photo documentation and enhanced description of 1400 Block of S. 14th Street Surface Features is presented in Work Order # 1 Report (Gannett Fleming, August 2014)

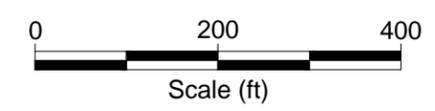
(2) All stationing is in feet along MASW Survey Lines



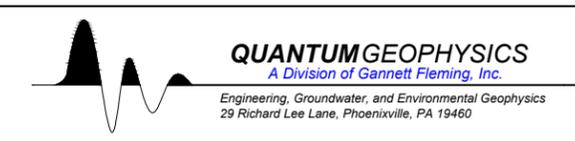
***Figures***



**LEGEND**  
 \_\_\_\_\_ MASW Line.



Basemap: CRW\_Export.gdb provided by the City of Harrisburg.



**Site Plan**  
**South Harrisburg Sinkhole Evaluation W.O.#2**  
**Harrisburg, Pennsylvania**

For: City of Harrisburg			Figure <b>1</b>
Date: 11-20-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 1.dwg	



**LEGEND**

Surficial deposits composed of colluvial deposits and alluvial deposits including terrace gravels and sands.	
Martinsburg Formation (undifferentiated)	Om
HERSHEY FORMATION (LV) 3	Oh
MYERSTOWN FORMATION (LV)	Omy
SAINT PAUL GROUP (CV)	Osp
PINESBURG STATION FORMATION (CV)	Ops
ROCKDALE RUN FORMATION (CV)	Orr

ARTIFICIAL FILL

FAULT (HIGH ANGLE, THRUST)

INFERRED FORMATION/FAULT CONTACT

CONCEALED FORMATION CONTACT

1000      -0-      1000      2000

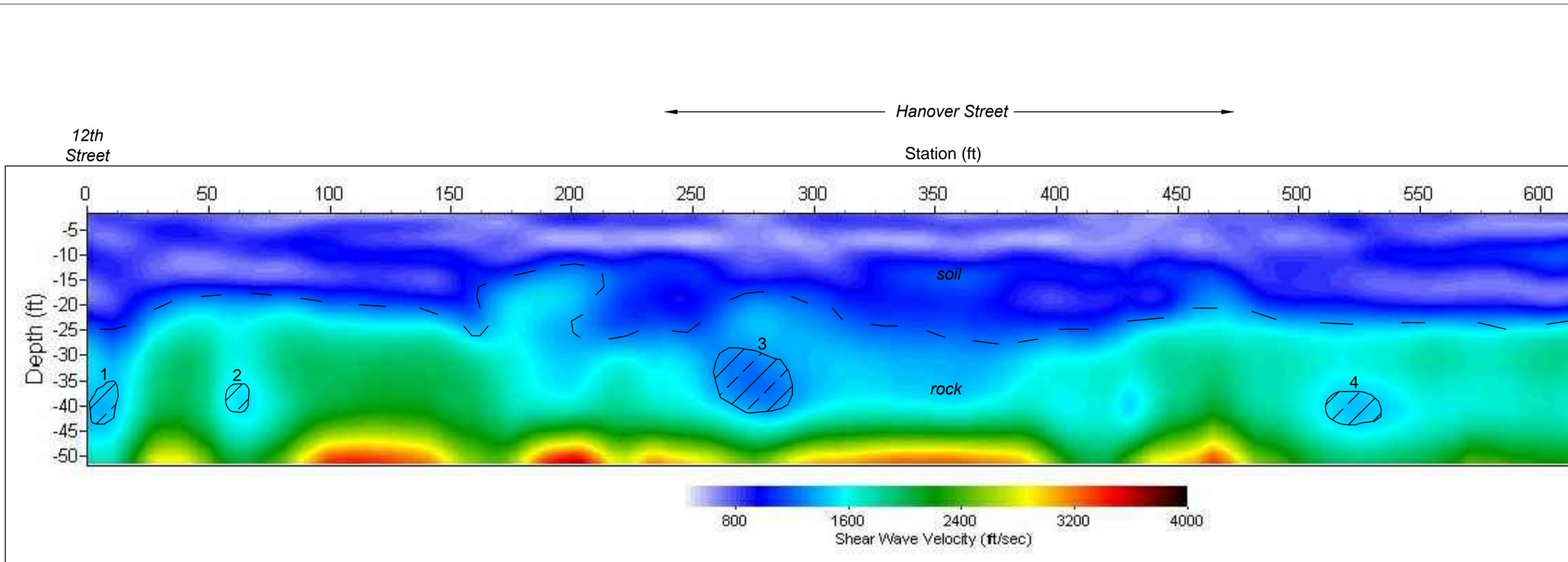
SCALE IN FEET

REF: MCGLADE AND GEYER, 1976

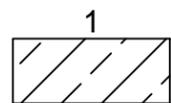
**CITY OF HARRISBURG**

**SOUTH HARRISBURG SINKHOLE EVALUATION W.O. #2**  
**SITE GEOLOGY PLAN**

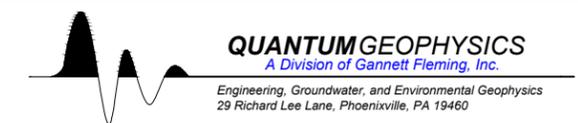
<b>Gannett Fleming</b> HARRISBURG, PENNSYLVANIA	DATE: 11-26-14	SCALE: AS SHOWN
	<b>FIGURE 2</b>	



LEGEND

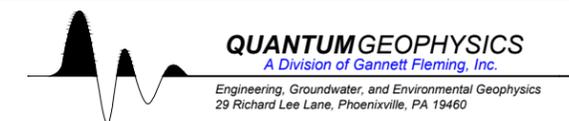
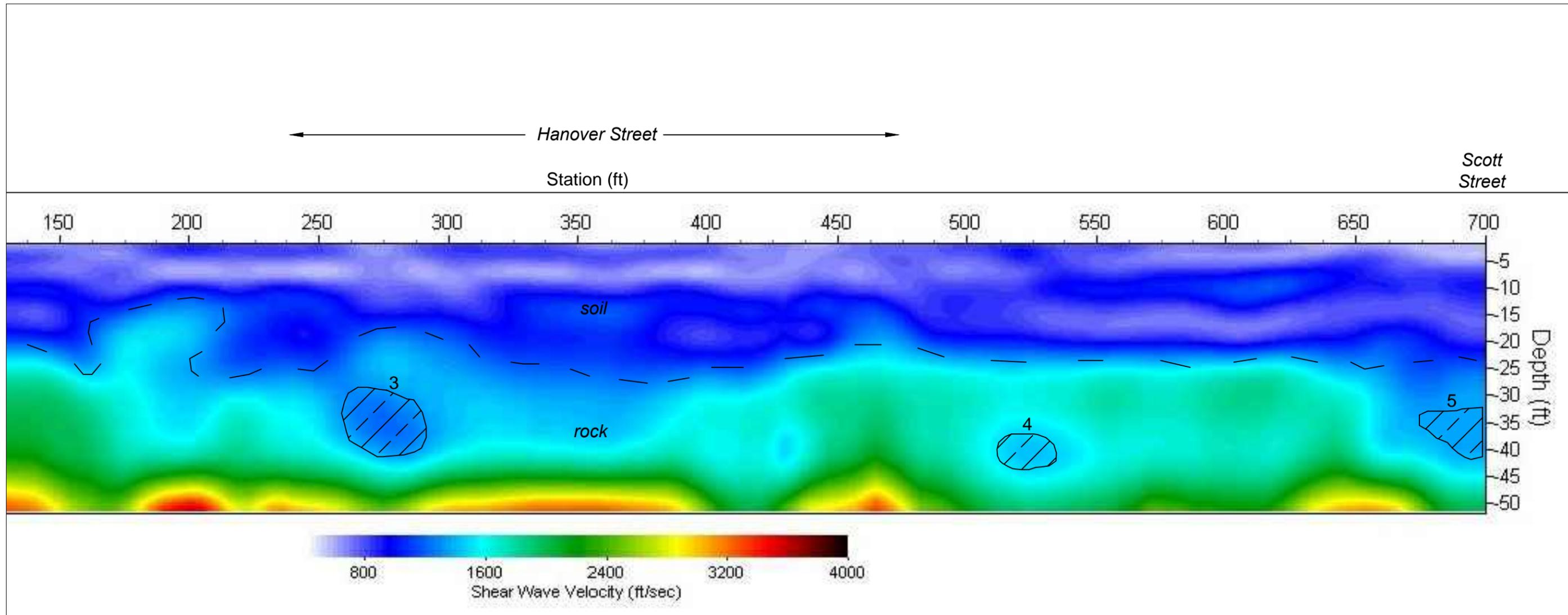
-  Interpreted Top of Rock.
-  Fracture-Like Anomaly.
-  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



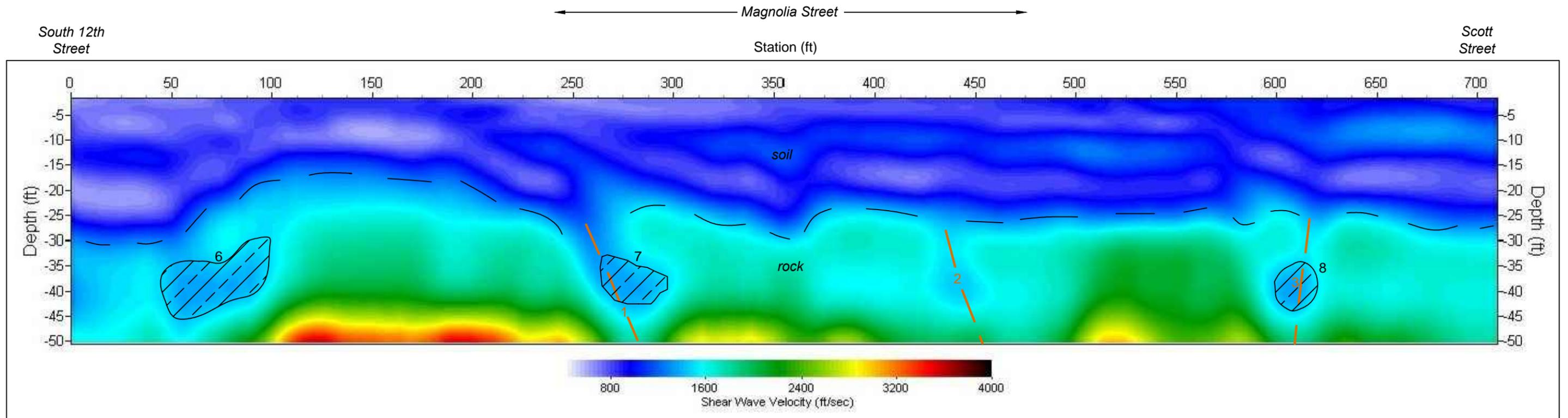
Hanover Street  $V_s$  Profile  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania

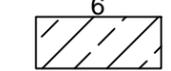
For: City of Harrisburg			Figure <b>3A</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 3A.dwg	



Hanover Street  $V_s$  Profile  
 South Harrisburg Sinkhole Evaluation  
 Harrisburg, Pennsylvania

For: City of Harrisburg			Figure <b>3B</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 3B.dwg	



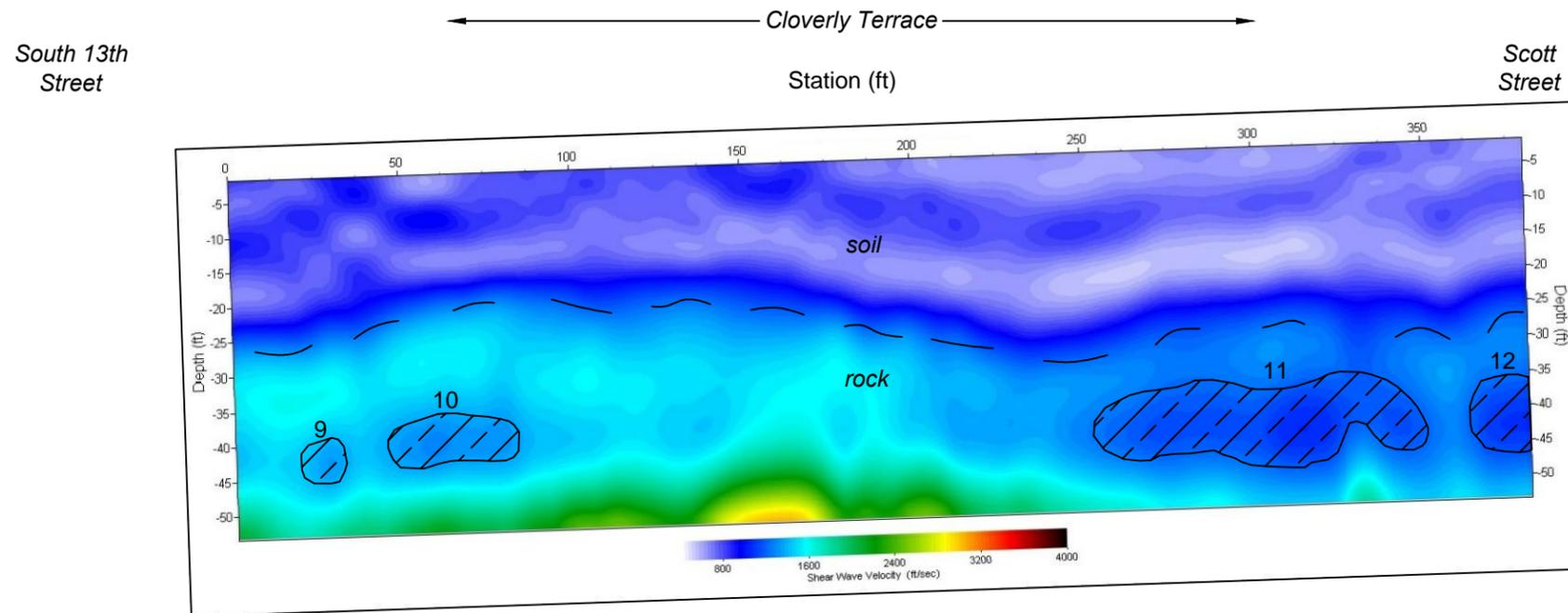
- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



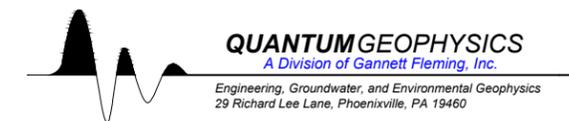
Magnolia Street  $V_s$  Profile  
 South Harrisburg Sinkhole Evaluation  
 Harrisburg, Pennsylvania

For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 4.dwg
		<b>4</b>



- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.

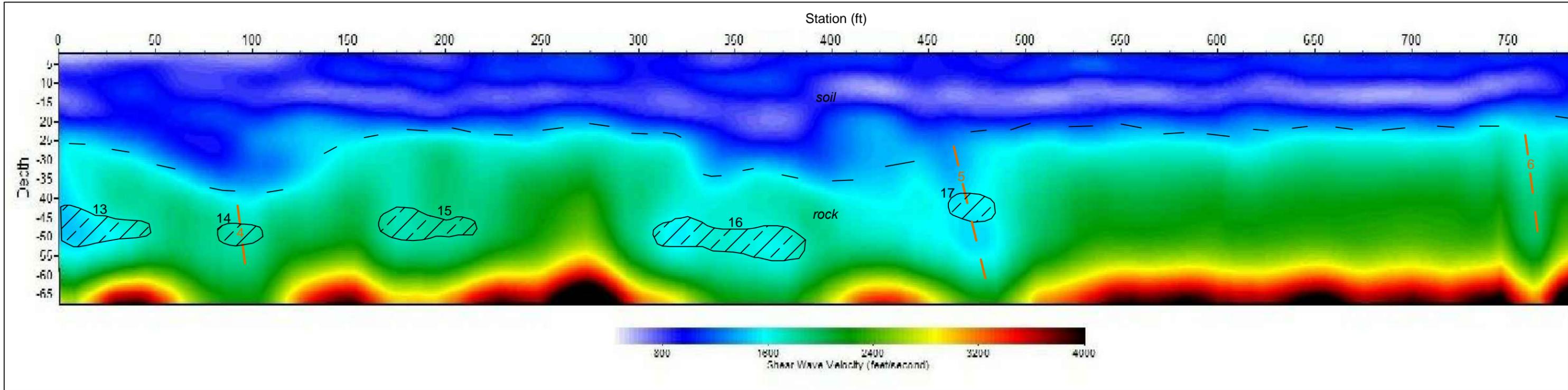


**Cloverly Terrace  $V_s$  Profile**  
**South Harrisburg Sinkhole Evaluation**  
**Harrisburg, Pennsylvania**

For: City of Harrisburg			Figure <b>5</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 5.dwg	

Hanover Street

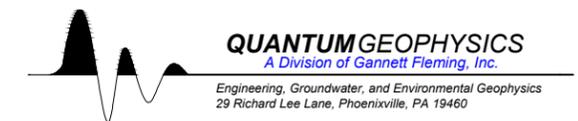
Scott Street



LEGEND

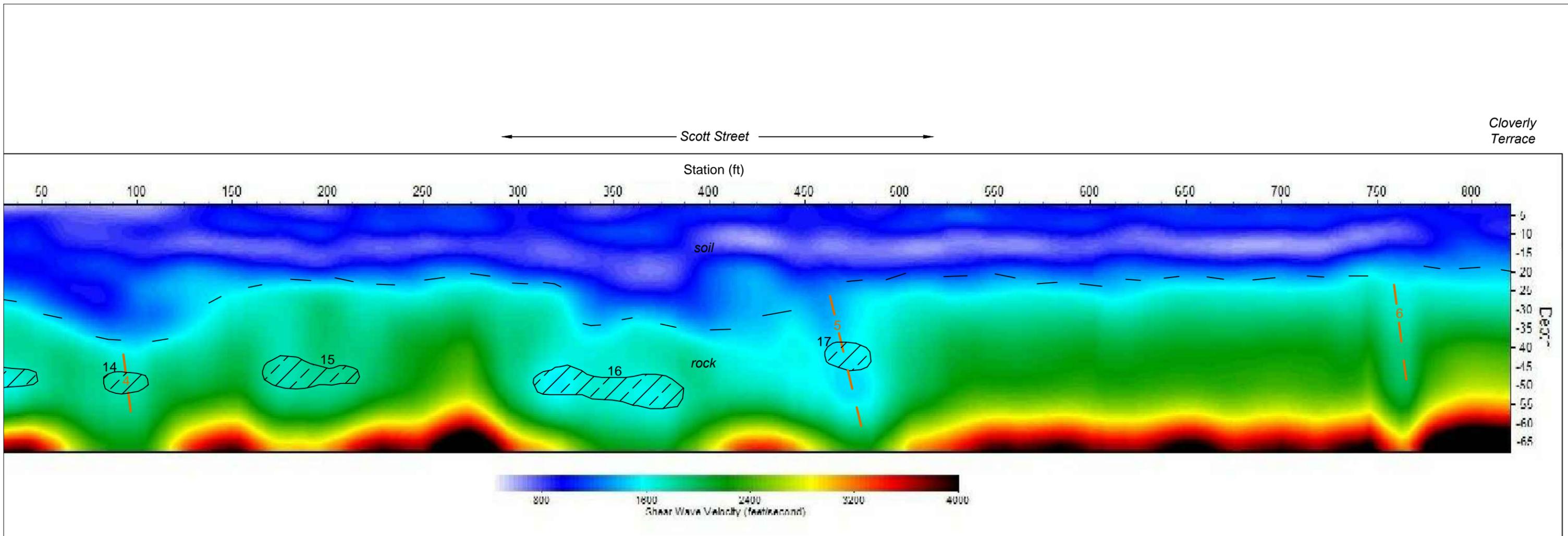
- Interpreted Top of Rock.
- Fracture-Like Anomaly.
- Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



Scott Street Vs Profile  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania

For: City of Harrisburg			Figure <b>6A</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 6A.dwg	



- Interpreted Top of Rock.
- - - Fracture-Like Anomaly.
- ▨ Zone of Potential Voids.

Vertical exaggeration ~ 2H:1V.

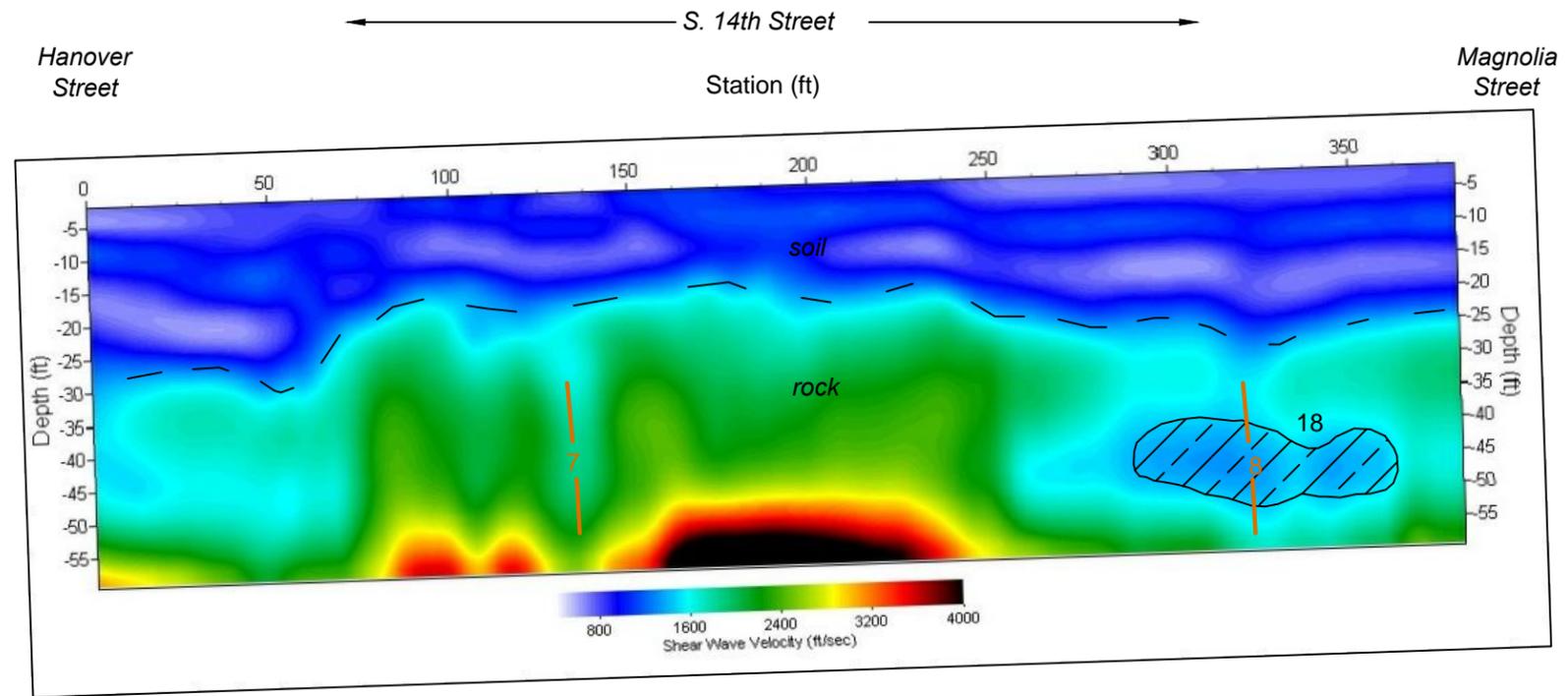


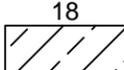
**QUANTUMGEOPHYSICS**  
 A Division of Gannett Fleming, Inc.  
 Engineering, Groundwater, and Environmental Geophysics  
 29 Richard Lee Lane, Phoenixville, PA 19460

Scott Street  $V_s$  Profile  
 South Harrisburg Sinkhole Evaluation  
 Harrisburg, Pennsylvania

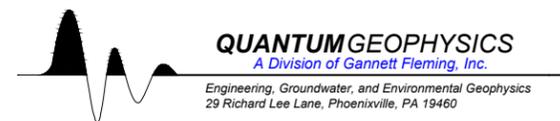
For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 6B.dwg

6B



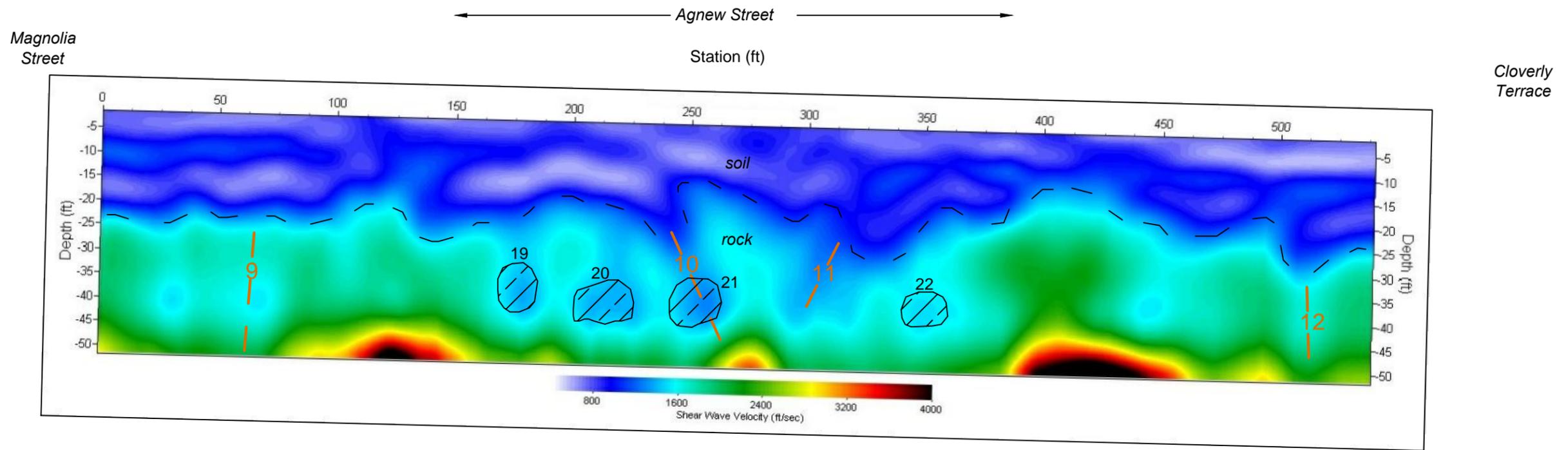
- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

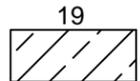
Vertical Exaggeration ~ 2H:1V.



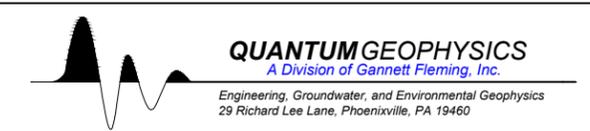
S. 14th Street  $V_s$  Profile  
 South Harrisburg Sinkhole Evaluation  
 Harrisburg, Pennsylvania

For: City of Harrisburg			Figure <b>7</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 7.dwg	



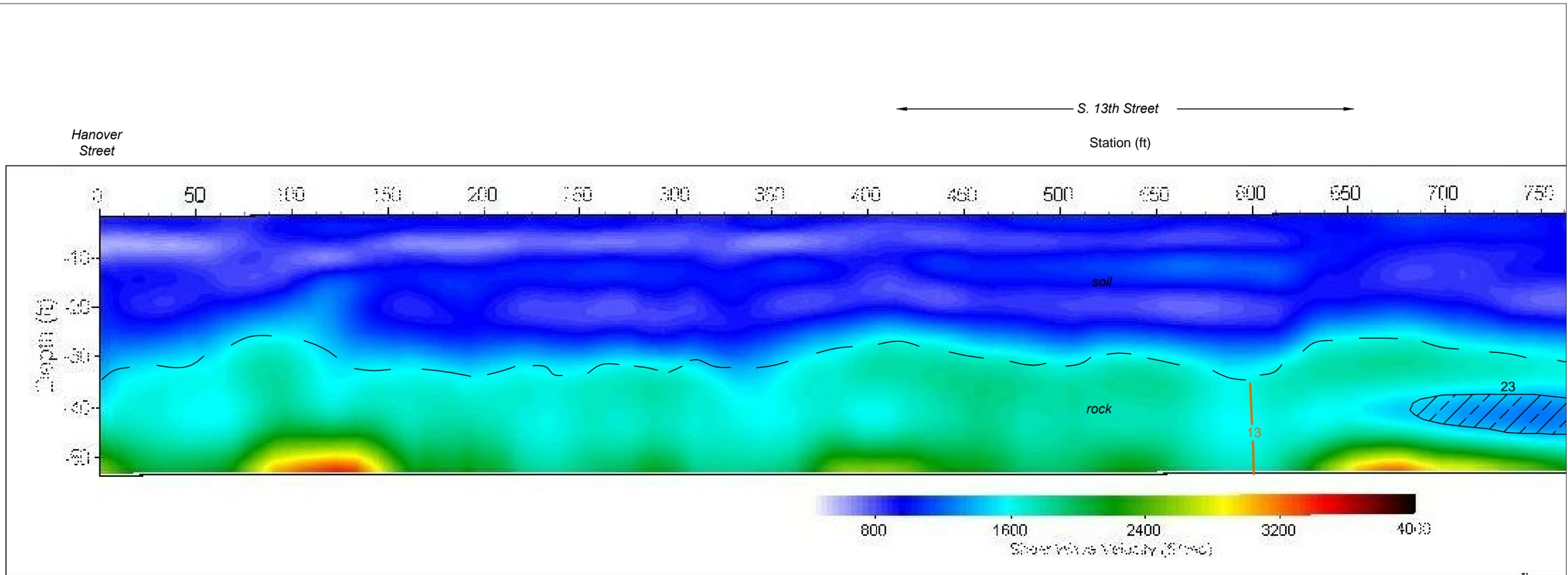
- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



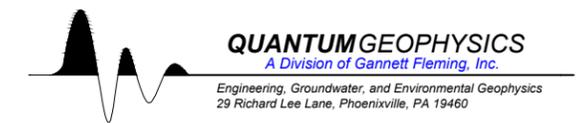
**Agnew Street  $V_s$  Profile**  
**South Harrisburg Sinkhole Evaluation**  
**Harrisburg, Pennsylvania**

For: City of Harrisburg			<b>Figure</b> <b>8</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 8.dwg	



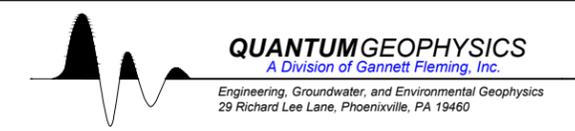
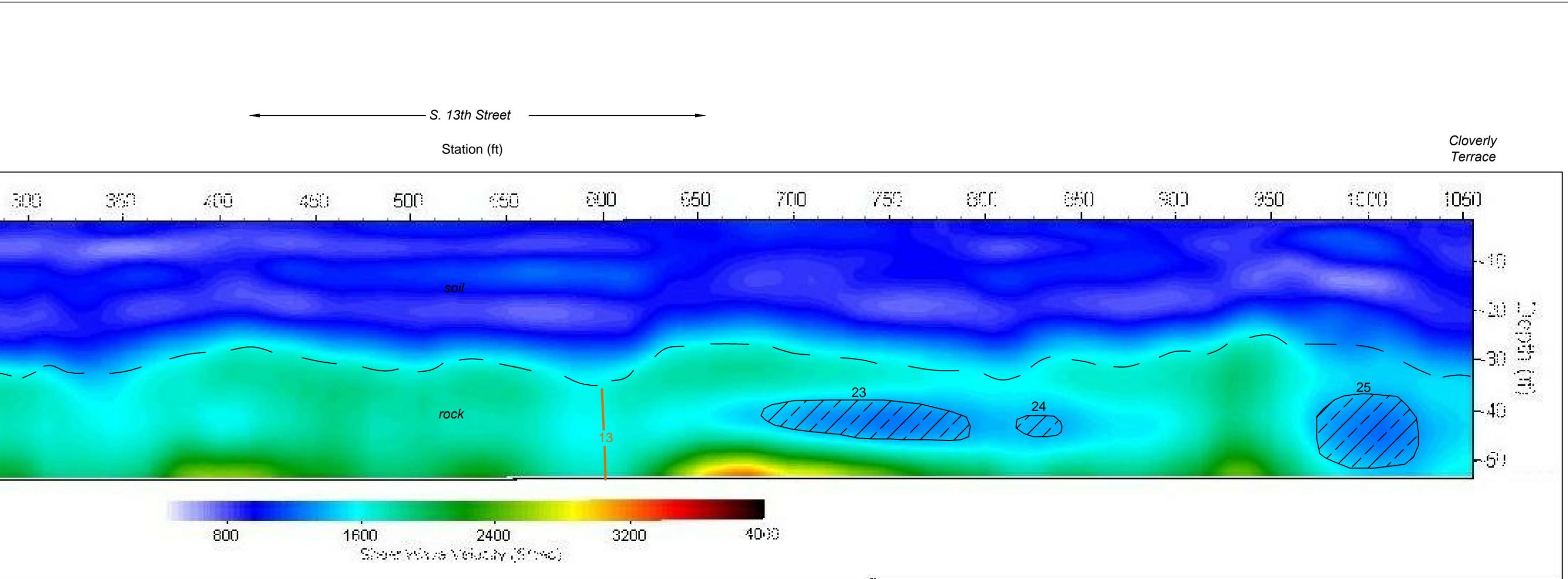
- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



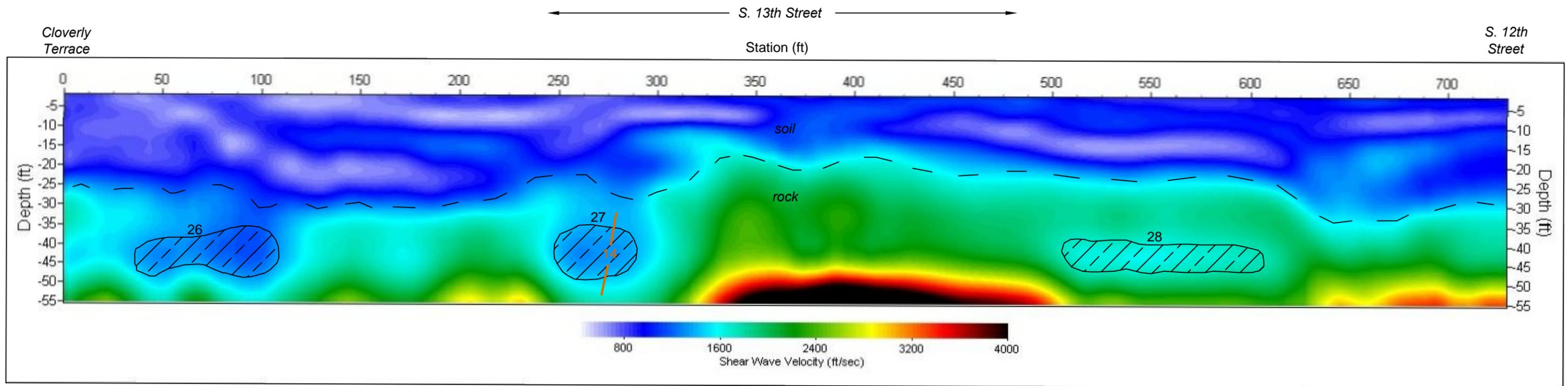
S. 13th Street  $V_s$  Profile - Hanover to Cloverly  
 South Harrisburg Sinkhole Evaluation  
 Harrisburg, Pennsylvania

For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 9A.dwg
		<b>9A</b>



**S. 13th Street  $V_s$  Profile - Hanover to Cloverly  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania**

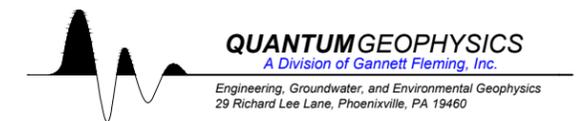
For: City of Harrisburg			Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 9B.dwg	<b>9B</b>



**LEGEND**

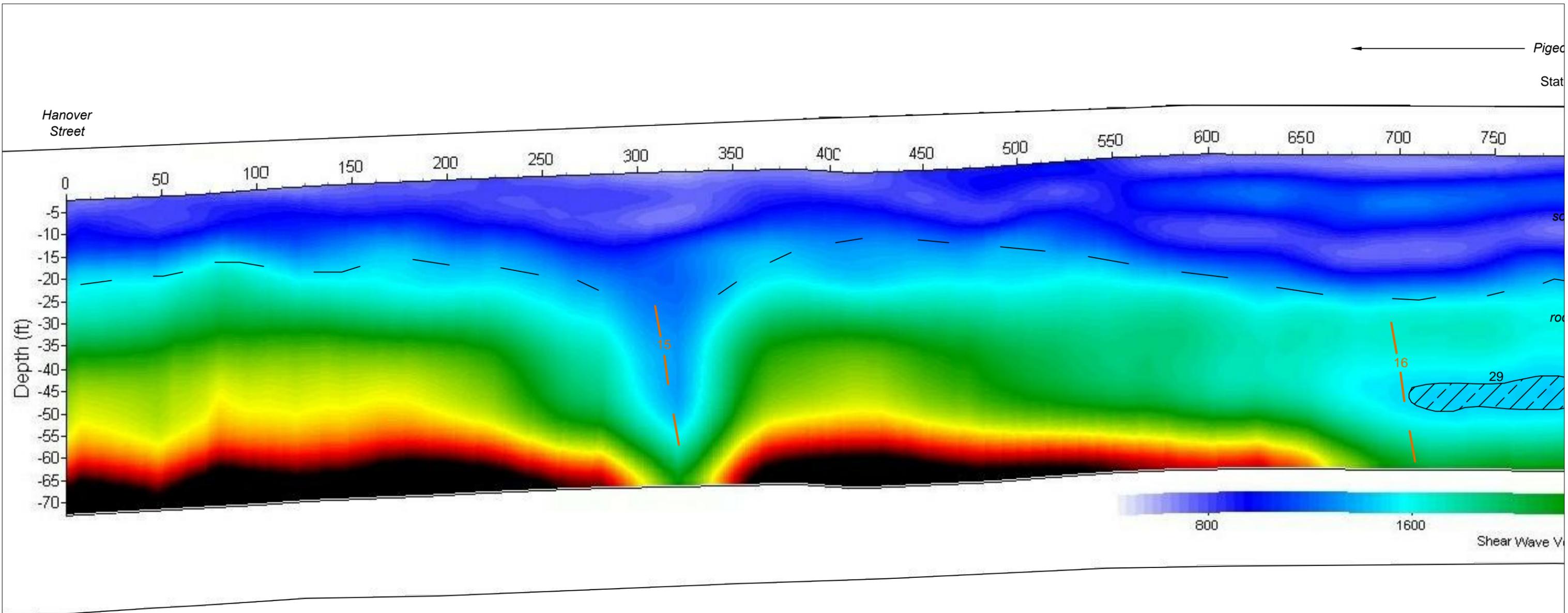
- Interpreted Top of Rock.
- Fracture-Like Anomaly.
- Zone of Potential Voids.

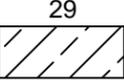
Vertical Exaggeration ~ 2H:1V.



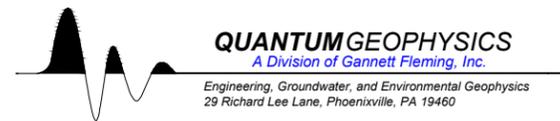
**S. 13th Street  $V_s$  Profile - Cloverly to S. 12th St.  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania**

For: City of Harrisburg			<b>Figure 10</b>
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 10.dwg	



- LEGEND**
-  Interpreted Top of Rock.
  -  Fracture-Like Anomaly.
  -  Zone of Potential Voids.

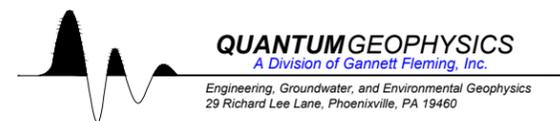
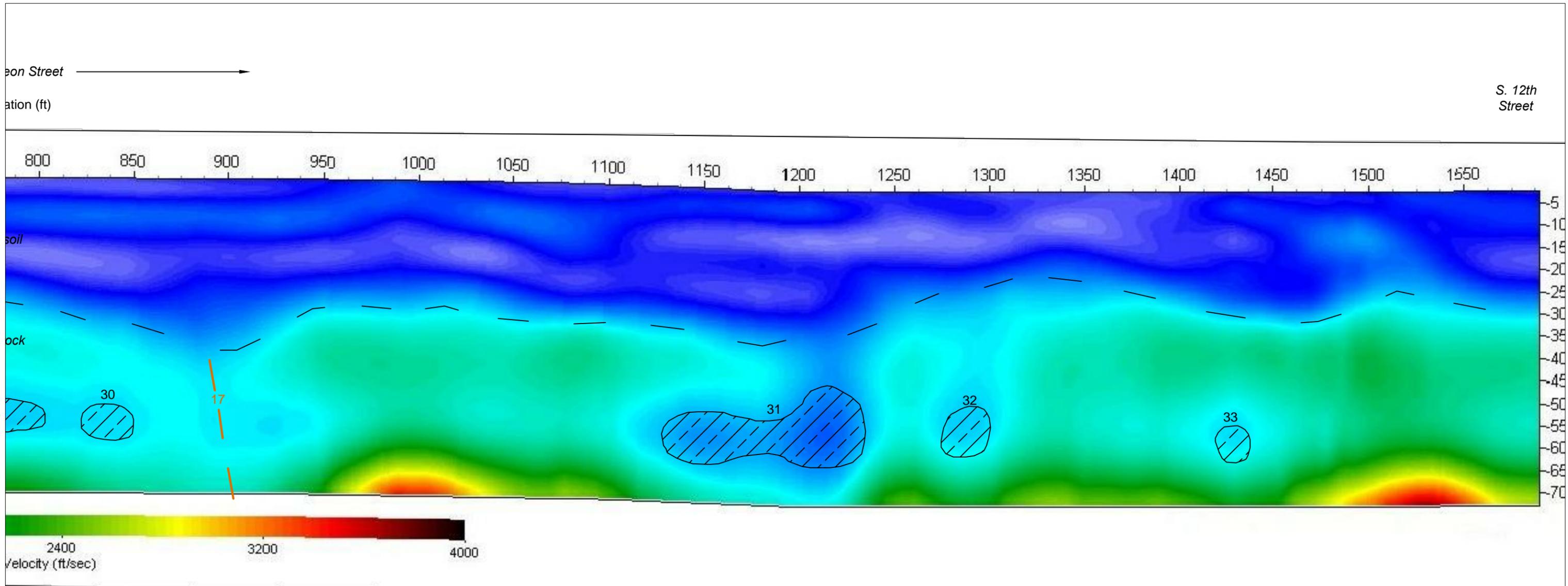
Vertical Exaggeration ~ 2H:1V.



**Pigeon Street  $V_s$  Profile**  
**South Harrisburg Sinkhole Evaluation**  
**Harrisburg, Pennsylvania**

For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 11A.dwg

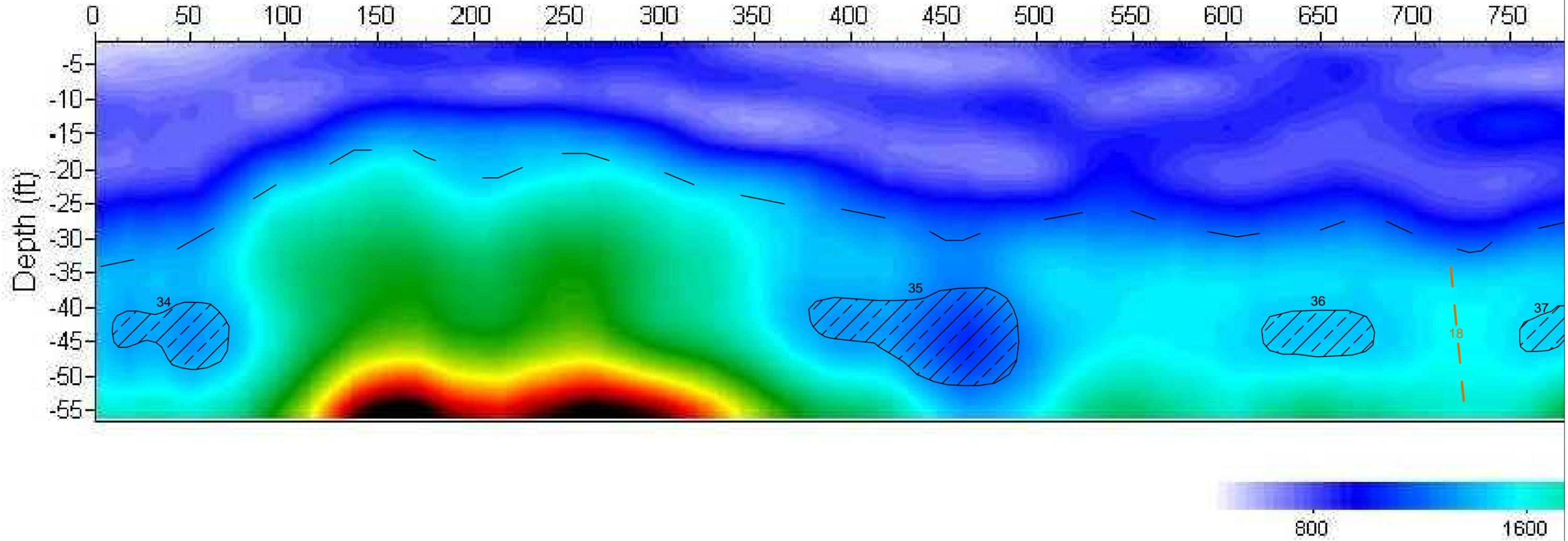
11A



**Pigeon Street  $V_s$  Profile**  
**South Harrisburg Sinkhole Evaluation**  
**Harrisburg, Pennsylvania**

For: City of Harrisburg			Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 11B.dwg	<b>11B</b>

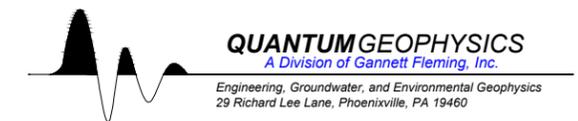
Hanover Street



LEGEND

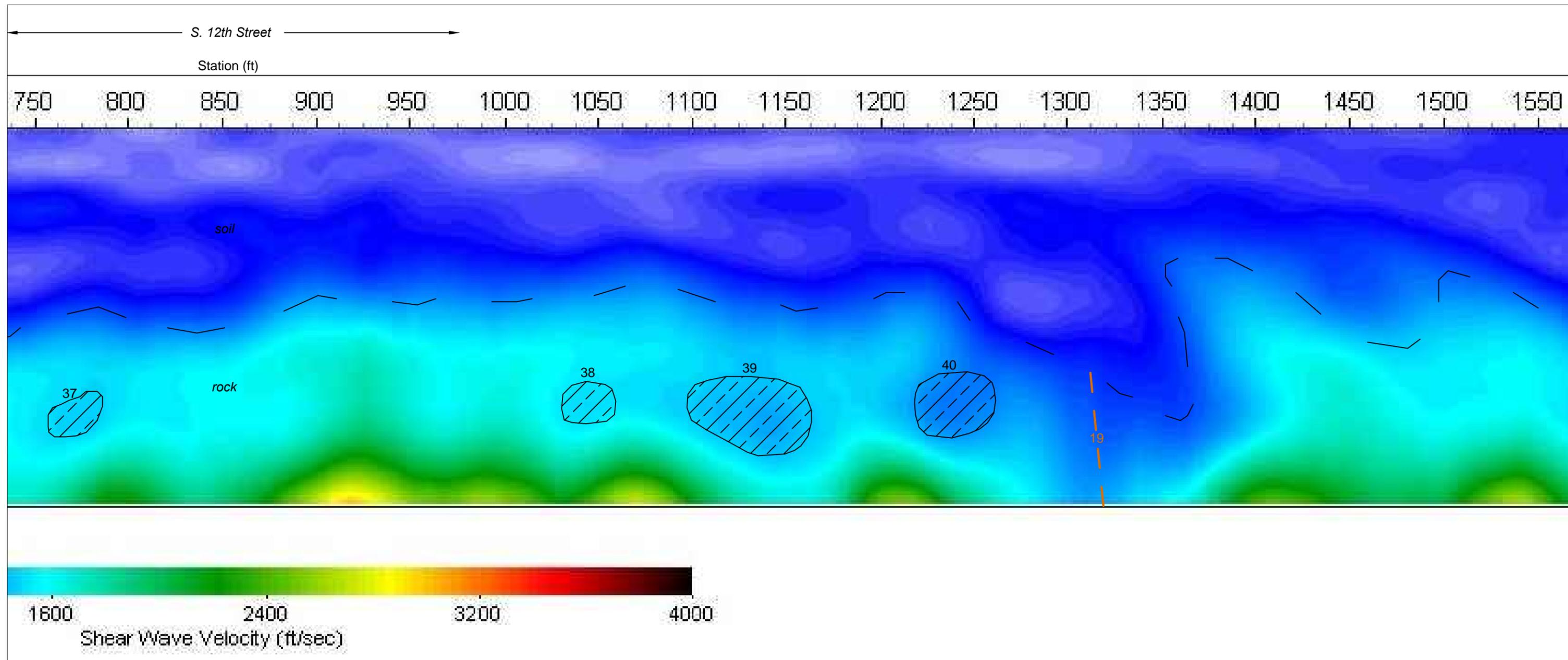
-  Interpreted Top of Rock.
-  Fracture-Like Anomaly.
-  Zone of Potential Voids.

Vertical Exaggeration ~ 2H:1V.



S. 12th Street  $V_s$  Profile  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania

For: City of Harrisburg			Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 12A.dwg	<b>12A</b>



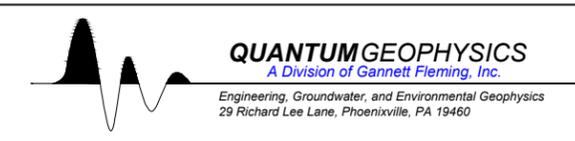
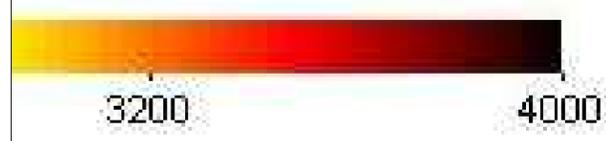
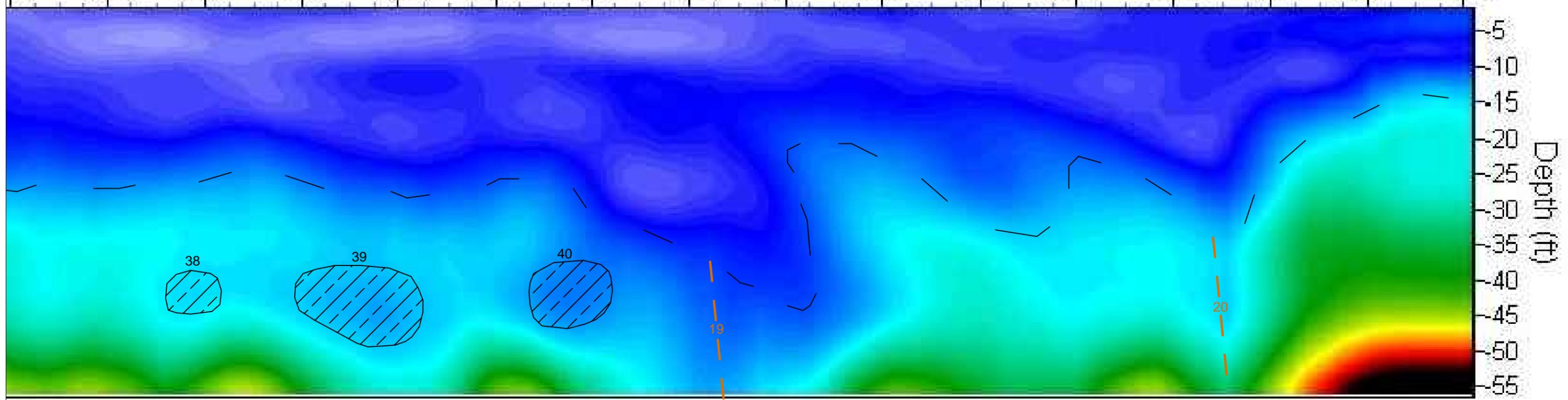
S. 12th Street  $V_s$  Profile  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania

For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 12B.dwg

**12B**

S. 13th Street

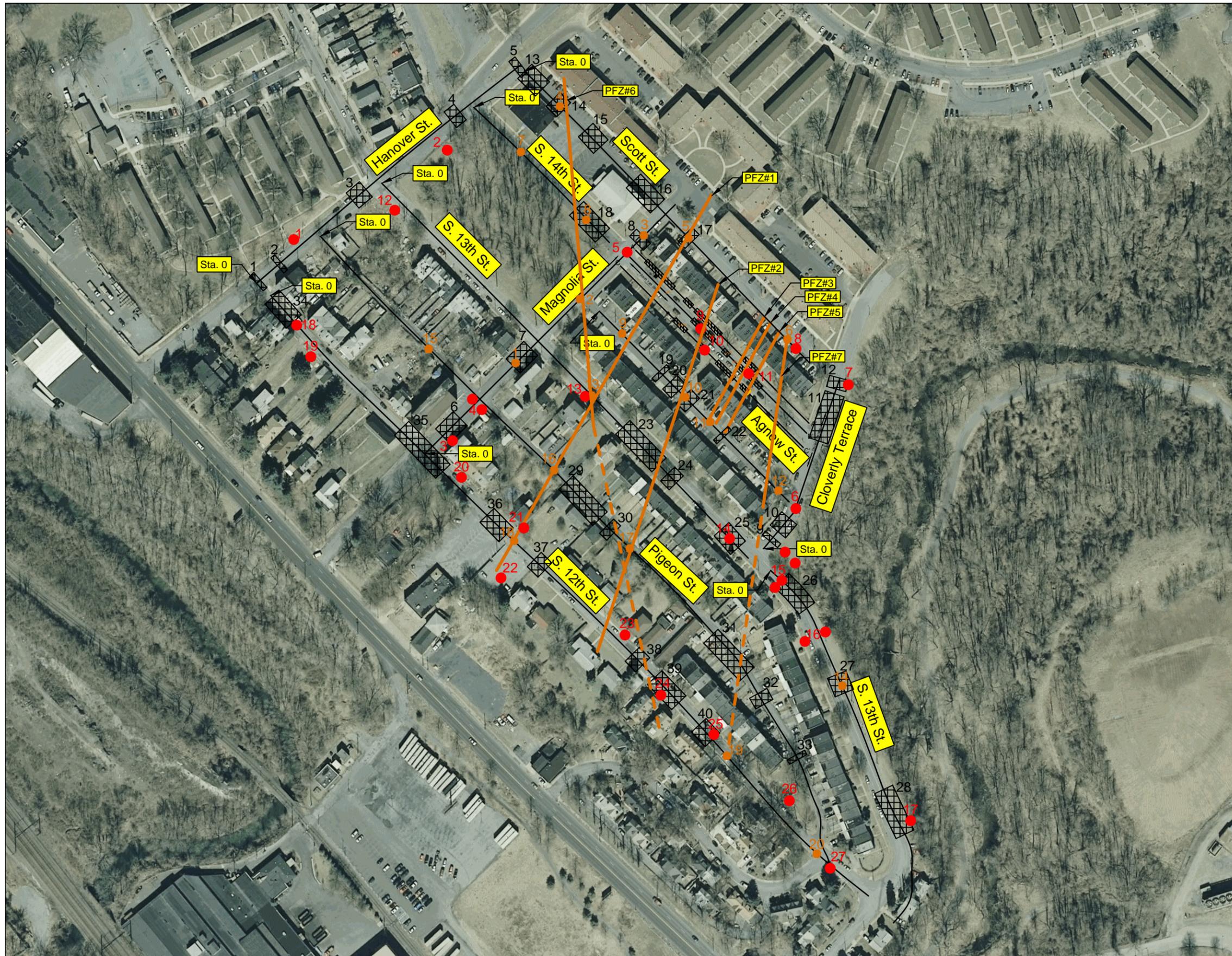
50 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700



S. 12th Street  $V_s$  Profile  
South Harrisburg Sinkhole Evaluation  
Harrisburg, Pennsylvania

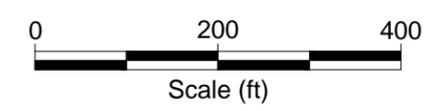
For: City of Harrisburg		Figure
Date: 11-18-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 12C.dwg

**12C**

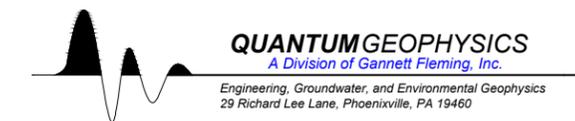


**LEGEND**

-  MASW Line.
-  17 Surface Feature (see Table 1).
-  x#4 Fracture-Like Anomaly, Based Upon W.O.#1 (S. 14th Street - Magnolia St. to Cloverly Tr.).
-  12 Fracture-Like Anomaly, Based Upon W.O.#2.
-  PFZ#1 Potential Fracture, Dashed Where Inferred.
-  38 Zone of Potential Voids.
-  B-1 Verification Boring (approx. location), W.O.#1.
-  1427 House Number (W.O.#1).

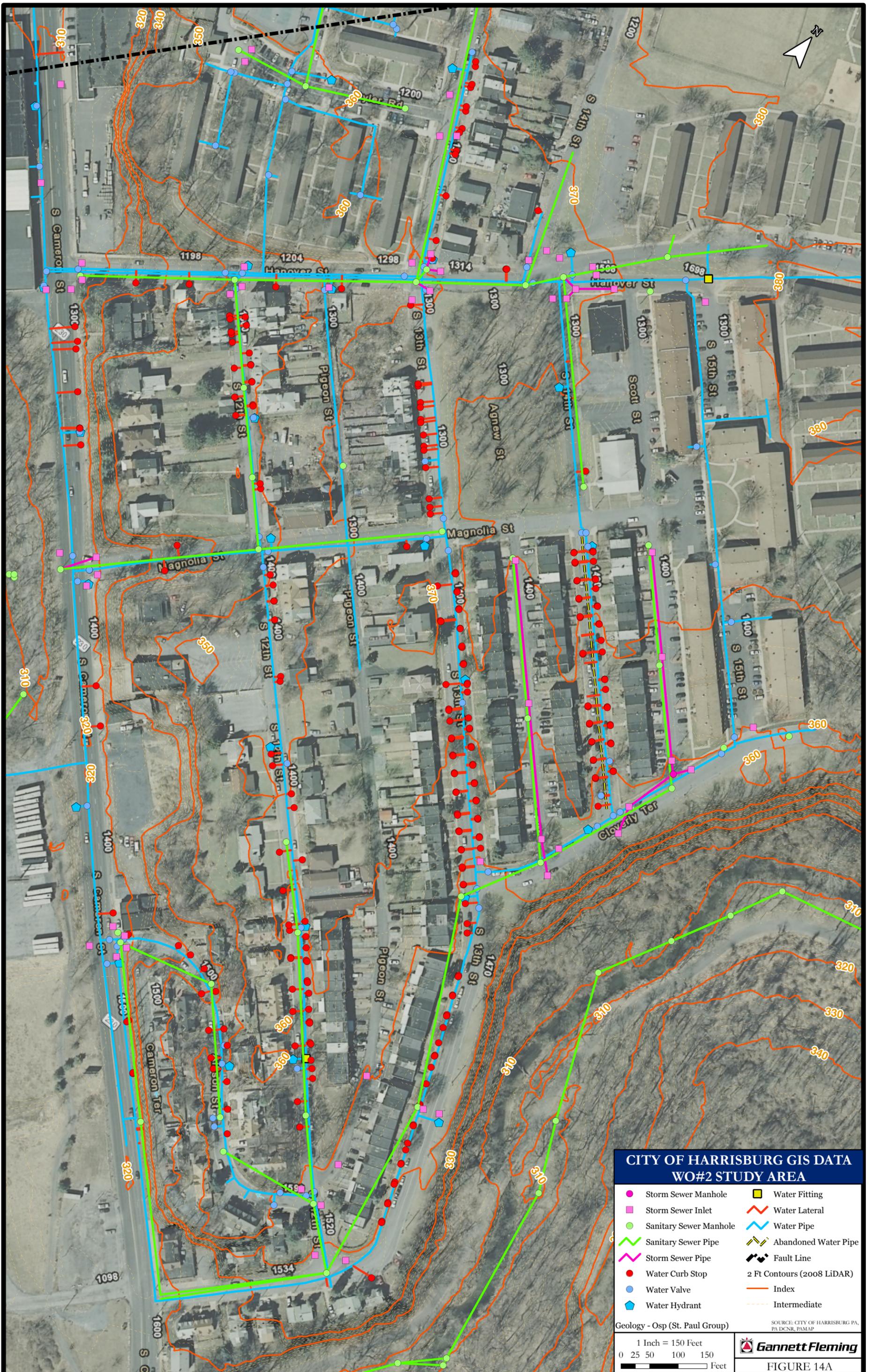


Basemap: CRW\_Export.gdb provided by the City of Harrisburg.



**Map of Geophysical Findings  
South Harrisburg Sinkhole Evaluation W.O.#2  
Harrisburg, Pennsylvania**

For: City of Harrisburg			Figure
Date: 11-20-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 13.dwg	<b>13</b>



**CITY OF HARRISBURG GIS DATA  
WO#2 STUDY AREA**

- |                          |                              |
|--------------------------|------------------------------|
| ● Storm Sewer Manhole    | ■ Water Fitting              |
| ■ Storm Sewer Inlet      | — Water Lateral              |
| ● Sanitary Sewer Manhole | — Water Pipe                 |
| — Sanitary Sewer Pipe    | — Abandoned Water Pipe       |
| — Storm Sewer Pipe       | — Fault Line                 |
| ● Water Curb Stop        | — 2 Ft Contours (2008 LiDAR) |
| ● Water Valve            | — Index                      |
| ● Water Hydrant          | — Intermediate               |

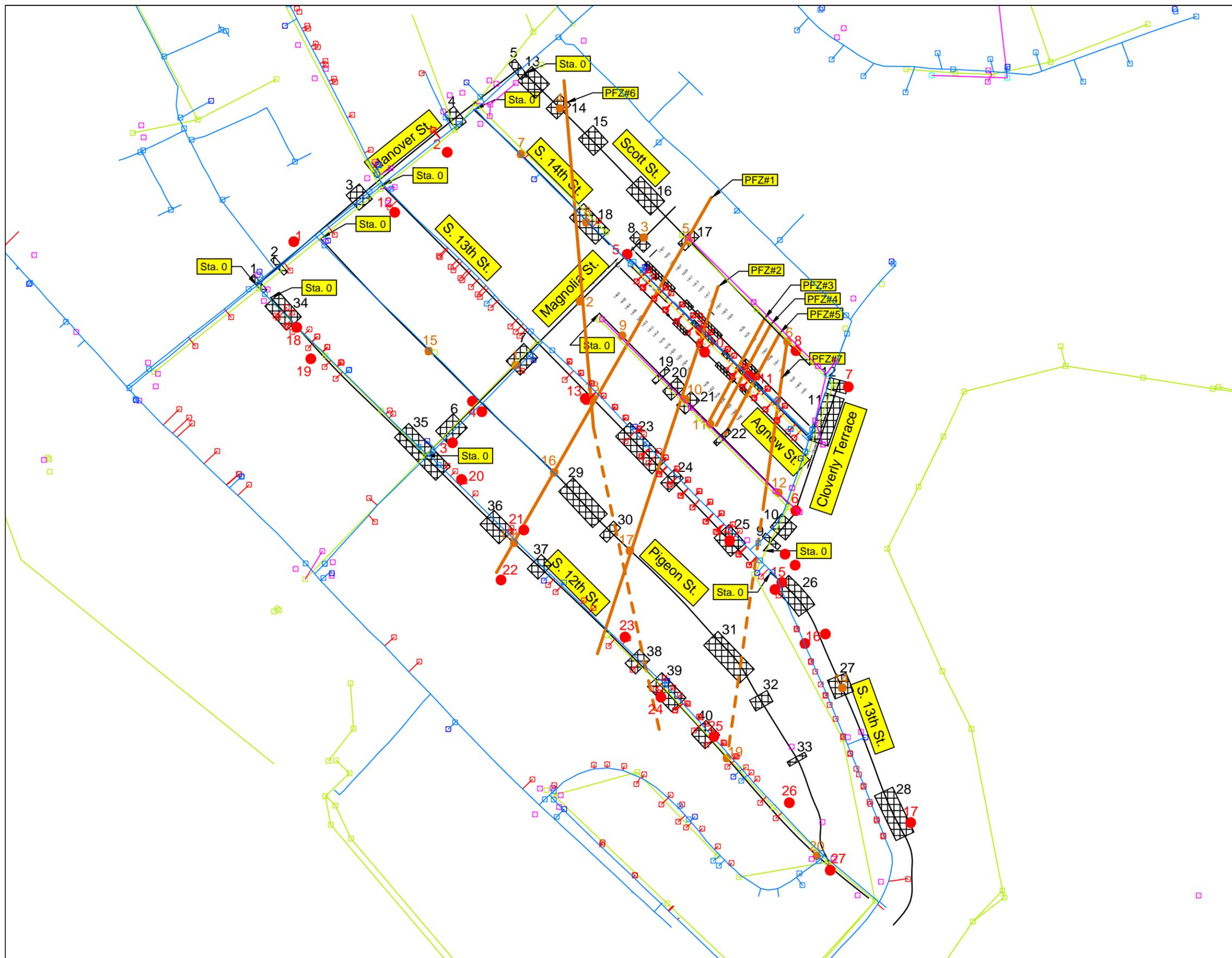
Geology - Osp (St. Paul Group)

SOURCE: CITY OF HARRISBURG PA, PADGMR, PAMAP

1 Inch = 150 Feet  
0 25 50 100 150 Feet



FIGURE 14A

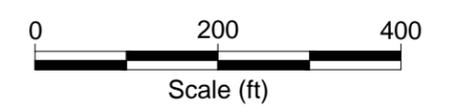


**UTILITIES LEGEND**

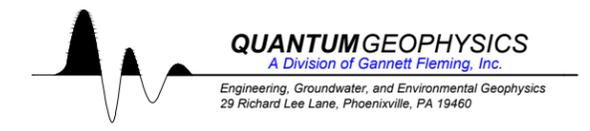
- Storm Sewer Manhole
- Storm Sewer Inlet
- Sanitary Sewer Manhole
- Sanitary Sewer Pipe
- Storm Sewer Pipe
- Water Curb Stop
- Water Valve
- Water Hydrant
- Water Fitting
- Water Lateral
- Water Pipe
- Abandoned Water Pipe

**LEGEND**

- MASW Line.
- 17 Surface Feature (see Table 1).
- x#4 Fracture-Like Anomaly, Based Upon W.O.#1 (S. 14th Street - Magnolia St. to Cloverly Tr.).
- 12 Fracture-Like Anomaly, Based Upon W.O.#2.
- PFZ#1 Potential Fracture, Dashed Where Inferred.
- 38 Zone of Potential Voids.
- B-1 Verification Boring (approx. location), W.O.#1.
- 1427 House Number (W.O.#1).



Basemap: CRW\_Export.gdb provided by the City of Harrisburg.



**City of Harrisburg GIS Utility Data Overlay  
South Harrisburg Sinkhole Evaluation W.O.#2  
Harrisburg, Pennsylvania**

For: City of Harrisburg			Figure
Date: 11-20-14	Project No.: 059166.WO2QTM	File: O:\City of Harrisburg\Fig 13.dwg	<b>14B</b>

---

***Appendix A***  
***Description of the MASW Method***

## The MASW Method

MASW is a seismic method that determines the vertical distribution of shear wave velocities based upon the dispersion of surface waves (Rayleigh Wave). It was first described for engineering applications in the late 1990's by the Kansas Geological Survey (KGS). Seismic surveys generate two types of seismic waves – body waves (Compressional Wave and Shear Wave) and surface waves (Rayleigh Wave and Love Wave). Body waves penetrate into the earth; surface waves travel along the earth's surface. The different types of waves differ in how they displace particles with respect to the direction of wave propagation. P-waves displace particles in the direction of wave propagation; S-waves displace particles perpendicular to the direction of wave propagation. Rayleigh Waves displace particles in an elliptical motion in planes normal to the surface and in the direction of wave propagation. Surface waves are not limited to seismic waves. Ocean waves are also surface waves.

The penetration depth of the Rayleigh Wave depends on the wavelength which, in turn, depends on frequency. When the velocity of materials changes with depth, each frequency component of the surface wave is affected by the different velocities and, therefore, propagates with different phase velocities. This phenomenon is known as dispersion. By recording the fundamental-mode Rayleigh Waves propagating from the source to the receiver, the dispersive properties directly beneath the seismic spread can be measured and represented by a curve (dispersion curve). This curve is used to estimate the vertical variation of  $V_s$  through a process known as inversion.

The schematics shown below illustrate how MASW data are collected and processed:

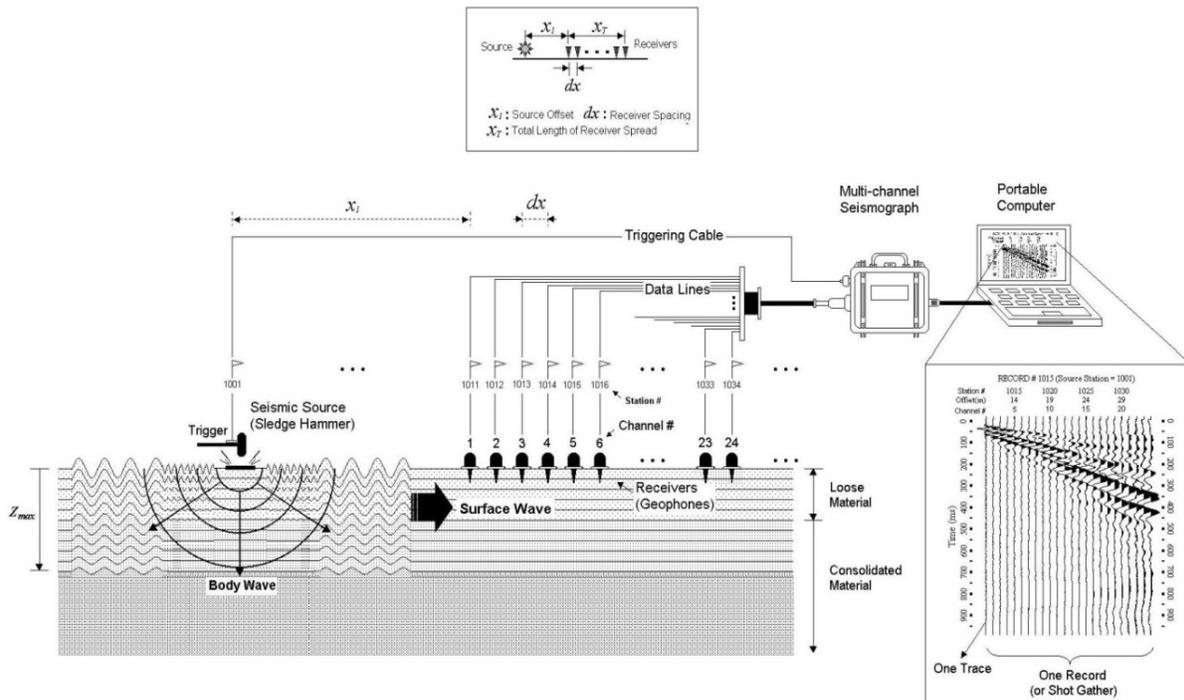


Exhibit 1 - MASW Data Acquisition.

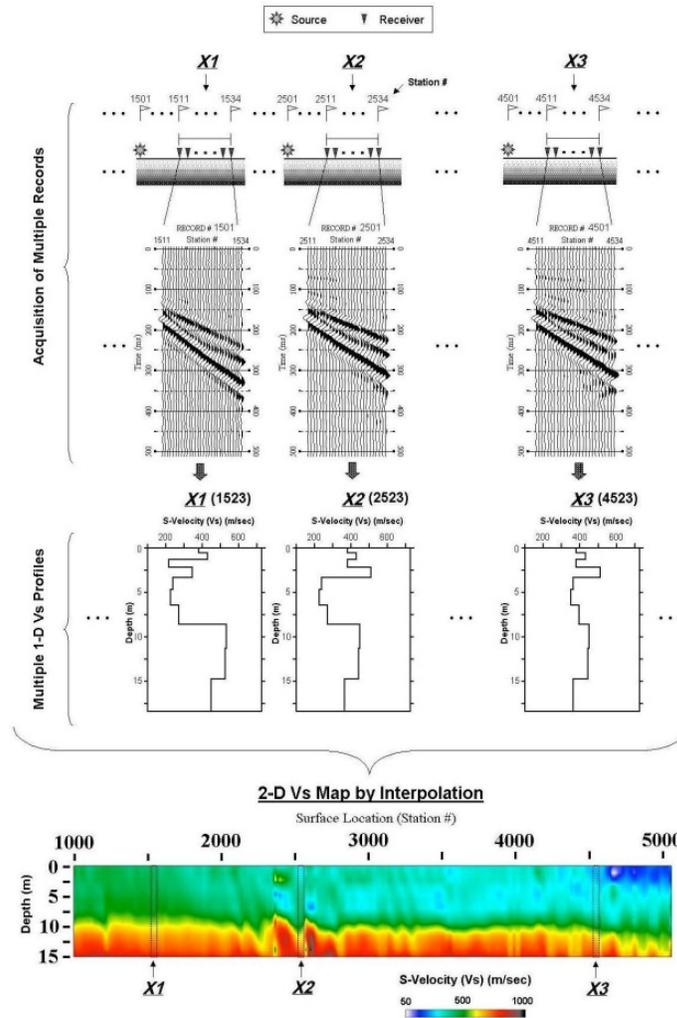


Exhibit 2 - MASW Data Processing

The MASW survey on S. 14<sup>th</sup> Street was carried-out using a Geometrics Stratavisor 24-channel seismograph and 4.5 Hz vertical geophones mounted on a landstreamer (Kevlar strip with adjustable metal plates). Seismic waves were generated by striking a metal plate coupled to the ground with a 12 lbs sledge hammer (lines A-A' and C-C' on the sidewalks) and a Peg Kg-40 accelerated weight drop (line B-B' on S. 14<sup>th</sup> Street). Data were acquired with geophones spaced 3 ft apart and a shot offset (distance between the source and the first in-line geophone) of 12 ft. The data were recorded as 0.7 second shot records at a sampling rate of 62.5  $\mu$ sec. A shot record was acquired every 5 ft of traverse. Each shot record was created by stacking three shots (multiple impacts of the hammer & plate or Peg Kg-40) to increase the signal-to-noise ratio. An ATV was used to pull the landstreamer along the sidewalk, and a van was used to pull the landstreamer along the street with the Peg Kg-40 mounted in a 2 inch receiver hitch.

The data were processed using the Kansas Geologic Survey (KGS) software program *Surfseis*. *Surfseis* converts the raw data (SEG-2) into KGS processing format, combines all shot records into a single file, assigns field geometry (geophone spacing and shot offset), recompiles the data

into a roll-along data set, identifies the range of surface wave velocities for each shot record, conducts dispersion curve analysis for all shot records, applies an inversion process to the dispersion curves to determine 1-D  $V_s$ , and constructs 2-D  $V_s$  profiles by interpolating the 1-D  $V_s$  profiles using a Bilinear algorithm.

Each 1-D  $V_s$  is plotted in the middle of the active receiver array because it is representative of conditions beneath the array.

The relative elevation along each line was measured using a 2X hand-level and a stadia rod, and entered into a field book for later use in adjusting the  $V_s$  profiles for changes in elevation.

---

***Appendix B***  
***Site Photographs***

**Surface Feature 1**  
**Between Approximate Stations 100 and 150 Hanover Street**



Two Small Depressions in Lawn between Sidewalk and Street  
May be from Tree Removal

**Surface Feature 2**  
**Approximate Station 450 Hanover Street**



Possible Closed Depression in Open Area SE of Hanover Street

**Surface Feature 3**  
**Approximate Station 50 Magnolia Street**



Depression and Pavement Repairs along SE Curb Line of Magnolia Street

**Surface Feature 4**  
**Approximate Station 170 to 180 Magnolia Street**



Repair along SE Curb Line, Looking Ahead Station



Pavement Cut Area with Depression Beyond, looking NW

**Surface Feature 4**  
**Approximate Station 170 to 180 Magnolia Street**



Depression Looking Ahead Station

**Surface Feature 5**  
**Approximate Station 600 Magnolia Street**



Street Cuts and Exposed Aggregate Backfill Where New Water Line Work Along  
1400 Block of S. 14<sup>th</sup> Street Connected to Existing Line

**Surface Feature 6**  
**Approximate Station 100 Cloverly Terrace**



Closed Depression on East Side of Cloverly Terrace  
Utility Pole Tiedown Shows Evidence of Extension  
SW Inlet Nearby

**Surface Feature 7**  
**Approximate Station 375 Cloverly Terrace**



Closed Depressions on East Side of Cloverly Terrace  
May be Due to Poor Fill Compaction

**Surface Feature 8**  
**Approximate Station 780 Scott Street**



Small Depression in Pavement

**Surface Feature 12**  
**Approximate Station 50 S. 13<sup>th</sup> Street (Hanover to Cloverly)**



Small Depression in Lawn between Sidewalk and Street  
May be from Tree Removal

**Surface Feature 13**  
**Approximate Station 600 S. 13<sup>th</sup> Street (Hanover to Cloverly)**



Pavement Patch Located at Approximate Location of Potential Fracture Identified by MASW

**Surface Feature 14**  
**Approximate Station 1000 S. 13<sup>th</sup> Street (Hanover to Cloverly)**



Pavement Patch Located at Approximate Location of Potential Void Identified by MASW

**Surface Feature 15**  
**Approximate Station 50 S. 13<sup>th</sup> Street (Cloverly to S. 12<sup>th</sup>)**



Crack in Retaining Wall S of 13<sup>th</sup> Street

**Surface Feature 15**  
**Approximate Station 50 S. 13<sup>th</sup> Street (Cloverly to S. 12<sup>th</sup>)**



Closed Depression in Lawn between Sidewalk and Street Adjacent to Retaining Wall



Pavement Patch Across from Lawn Depression and Cracked Retaining Wall

**Surface Feature 15**  
**Approximate Station 50 S. 13<sup>th</sup> Street (Cloverly to S. 12<sup>th</sup>)**



Closed Depressions in Grassy Area on N Side of 13<sup>th</sup> Street Across From Pavement Patch, Lawn Depression and Cracked Retaining Wall

**Surface Feature 16**  
**Approximate Station 150 S. 13<sup>th</sup> Street (Cloverly to S. 12<sup>th</sup>)**



Depression Located Just Inside the Curb

**Surface Feature 16**  
**Approximate Station 150 S. 13<sup>th</sup> Street (Cloverly to S. 12<sup>th</sup>)**



Possible Slope Failure across Street from Depression

**Surface Feature 17**  
**Approximate Station 585 S. 13<sup>th</sup> Street (Cloverly to 12<sup>th</sup>)**



Depression Located 15 feet Behind Eastern Curb across Street from Homes

**Surface Feature 18**  
**Approximate Station 75 S. 12<sup>th</sup> Street**



Pavement Patch Located at Approximate Location of Potential Void Identified by MASW

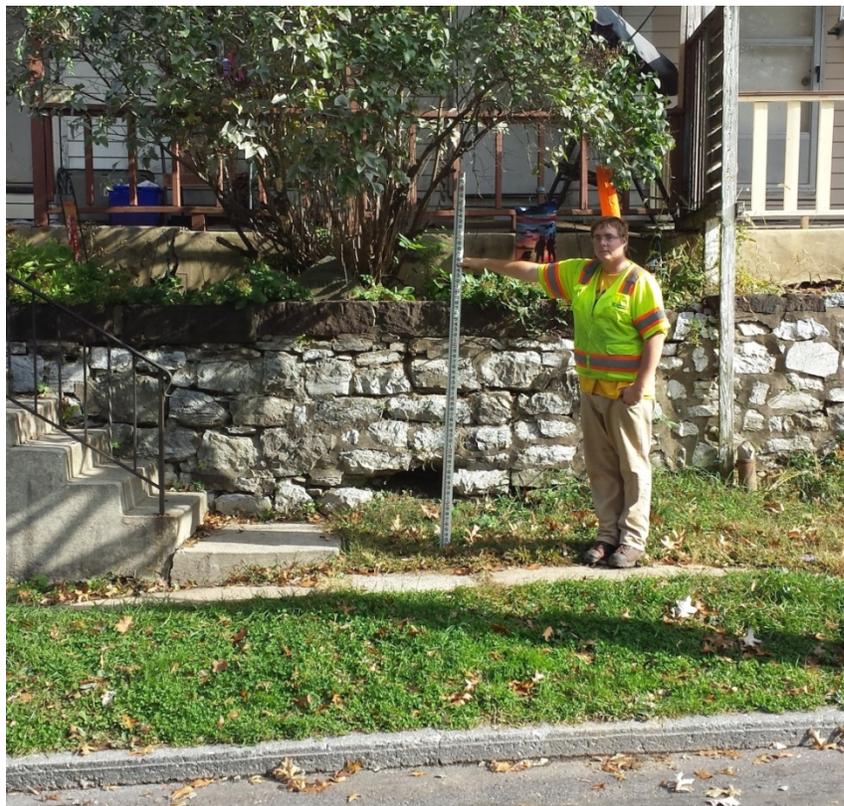
**Surface Feature 19**  
**Approximate Station 150 S. 12<sup>th</sup> Street**



Sinkhole Repaired by City (City Photo)



Driveway Patching Nearby (City Photo)  
**Surface Feature 20**  
Between Approximate Stations 500 to 550 S. 12<sup>th</sup> Street



Masonry Retaining Wall in Front of 3 Row Homes on E Side of Street  
From Left to Right: Repair, Buttress by Soil Fill, and Undermined by Closed Depression

**Surface Feature 21**  
**Approximate Station 675 S. 12<sup>th</sup> Street**



Depression Under Porch Footing

**Surface Feature 22**  
**Approximate Station 750, S. 12<sup>th</sup> Street**



Large Depression in Parking Area Next to House  
Appears to Have Been Filled with Gravel

**Surface Feature 23**  
**Approximate Station 1000, S. 12<sup>th</sup> Street**



**Apparent Sinkhole in Yard**  
**Some Minor Depressions in Immediate Area Surrounding Sinkhole**

**Surface Feature 23**  
**Approximate Station 1000, S. 12<sup>th</sup> Street**



Asphalt Patch in 12<sup>th</sup> Street Across from Yard Sinkhole

**Surface Feature 24**  
**Approximate Station 1125 S. 12<sup>th</sup> Street**



Depression under Concrete Pad  
Within Area Where Concrete was Replaced by Resident

**Surface Feature 24**  
**Approximate Station 1125 S. 12<sup>th</sup> Street**



Asphalt Patches in S. 12<sup>th</sup> Street across from Observed Depression

**Surface Feature 25**  
**Between Approximate Stations 1200 to 1225 S. 12<sup>th</sup> Street**



Sinkhole Repaired by City (City Photos)

**Surface Feature 25**  
**Between Approximate Stations 1200 to 1225 S. 12<sup>th</sup> Street**



Pavement Patches and New Sidewalk Observed 11/18/2014

**Surface Feature 26**  
**Approximate Station 1450 S. 12<sup>th</sup> Street**



Evidence of Concrete Fill in Area Between S. 12<sup>th</sup> Street and Pigeon Street  
Local Resident Indicated that it was a Sinkhole Repair

**Surface Feature 27**  
**Approximate Station 1650 S. 12<sup>th</sup> Street**



**Sinkhole in Front Yard**  
**Exposed Rock also Observed – Possible Outcrops**