Hydrogeological Investigation of the Timken Faircrest Steel Plant Construction Dewatering Project Stark County, Canton and Perry Townships, Ohio

Prepared by:

Curtis J. Coe, CPG, PG, and James Raab

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NOTE REGARDING APPENDICES

Nine appendices, "A" through "I", totaling 175 pages have been intentionally left out of this printed version of the report to save paper and printing costs.
These appendices are available online for download as a separate PDF file from:
http://ohiodnr.com/soilandwater

Also available online is a 253 page, 98 megabyte, complete version of the report with appendices.

Please visit the ODNR Soil and Water Resources mapping and technical services program web site (http://ohiodnr.com/soilandwater) for these download options.

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ABSTRACT

Timken Corporation (Timken) began upgrading and remodeling of the Timken Faircrest Steel Plant (TFSP) located southwest of Canton, during the summer of 2012. Part of the remodeling involved the installation of a vertical steel pipe caster that would be installed 89 feet below the land surface. Timken had done a geotechnical investigation of the subsurface for the vertical caster foundation engineering design. However, Timken did not include a hydrogeological impact assessment to determine how the construction dewatering would affect the ground water levels in local domestic water supply wells in the surrounding area.

During the excavation of the foundation, the contractor encountered ground water. Timken installed six (6) dewatering wells around the excavation. Shortly after the dewatering operation started in August 2012, local residents complained to the Stark County Health Department (SCHD) that they were having problems with their wells. In response to the request by the SCHD for assistance, the Ohio Department of Natural Resources – Division of Soil and Water Resources (ODNR-DSWR), met with Timken to assess the site hydrogeological characteristics near the dewatering operations. The ODNR-DSWR designed and implemented a long-term monitoring program to determine the extent of the cone of depression created by Timken dewatering operations.

The ground water impact assessment was accomplished during August and September of 2012. It was concluded that the cone of depression had migrated beyond Timken's property boundary. The main area affected was to the south and east of the TFSP. The September 2012 monitoring data was used to define the approximate geographic extent of the impacted area. Timken used the inferred impact area to sort through the complaint list compiled by the SCHD. In total, Timken responded to 77 complaints from local homeowners. Timken's response was as follows:

- Eighteen (18) complaints were outside the inferred impact area.
- Nineteen (19) complaints included residents that wanted to get their name on the complaint list as a precautionary measure, in case problems developed later.
- Six (6) complaints were related to the water pumping and storage system and not caused by the Timken construction dewatering operations.
- Thirty-four (34) wells were replaced because there was legitimate problem that could be traced back to the Timken construction dewatering operations. In this case, Timken contracted with a local well driller to install new wells and pumps to replace the older shallower wells. The old wells were sealed in accordance with SCHD requirements.
- One (1) homeowner was connected to the public water system that was available on the street.

Long-term monitoring data confirmed that ground water levels in the area were impacted by the Timken dewatering operation, but as of September 2013 the ground water levels in the area had returned to normal. At this time, it has been concluded that Timken has taken the precautionary steps necessary to protect the public health and safety. There does not appear to be any long-term impacts to the ground water supplies available from either the glacial or bedrock aquifer systems in the area.

1.0 INTRODUCTION

Timken Corporation (Timken) began upgrading and remodeling of the Timken Faircrest Steel Plant (TFSP) located southwest of Canton Ohio in Stark County, Perry and Canton Townships, during the summer of 2012. According to Timken, part of the remodeling and upgrade for the steel plant involved the installation of a vertical steel pipe caster that would be installed 89 feet below the land surface. At the time, Timken had completed a geotechnical investigation of the subsurface for the vertical caster foundation engineering design. However, the geotechnical investigation did not include a hydrogeological investigation of the surrounding area. During excavation necessary to install the vertical caster foundation, the contractor encountered ground water. The contractor indicated to Timken that it would be necessary to install dewatering wells around the excavation to keep it dry during the vertical caster foundation installation. Shortly after the dewatering operation started in August of 2012, local residents began to complain to the Stark County Health Department (SCHD) that they were having problems with their wells.

In response to the request by the SCHD for assistance, the Ohio Department of Natural Resources – Division of Soil and Water Resources (ODNR-DSWR), met with Timken to assess the site hydrogeological characteristics of the subsurface near the dewatering operations. Upon looking into the matter it was noted that Timken did not conduct a hydrogeological investigation of the area. As a result, no baseline ground water level data was available, so the ODNR-DSWR worked with Timken and the SCHD to establish a ground water monitoring network to determine the extent of the cone of depression. Also, the ODNR-DSWR conducted a hydrogeological investigation to determine the short-term and long-term impacts to the glacial and bedrock aquifer systems.

1.1 SITE LOCATION AND SETTING

Figure 1 is a general site location map that shows the location of the TFSP study area in Stark County, Perry and Canton Townships. Figure 2 shows the extent of the study area; and the approximate limits of the Timken Property, as well as the dewatering site relative to important geographic features in the area.

Topographically, the area is characterized by a gently rolling appearance. Surface elevation across the area ranges from 1140 feet to 1050 feet above mean sea level (amsl), giving the area a topographic relief of approximately 90 feet.

Physiographically, the study area is located in the Glaciated Allegheny Plateaus Province (Brockman, 1998). Surface water drainage follows a typical dendritic drainage pattern. In the study area surface water runoff is directed to Sherrick Run and Nimishillen Creek, which discharges to the Tuscarawas River. All surface runoff eventually drains to the Ohio River.

Land use in the area is dominated by industrial and commercial activity with some urban development. Home development has occurred around the entire TFSP.

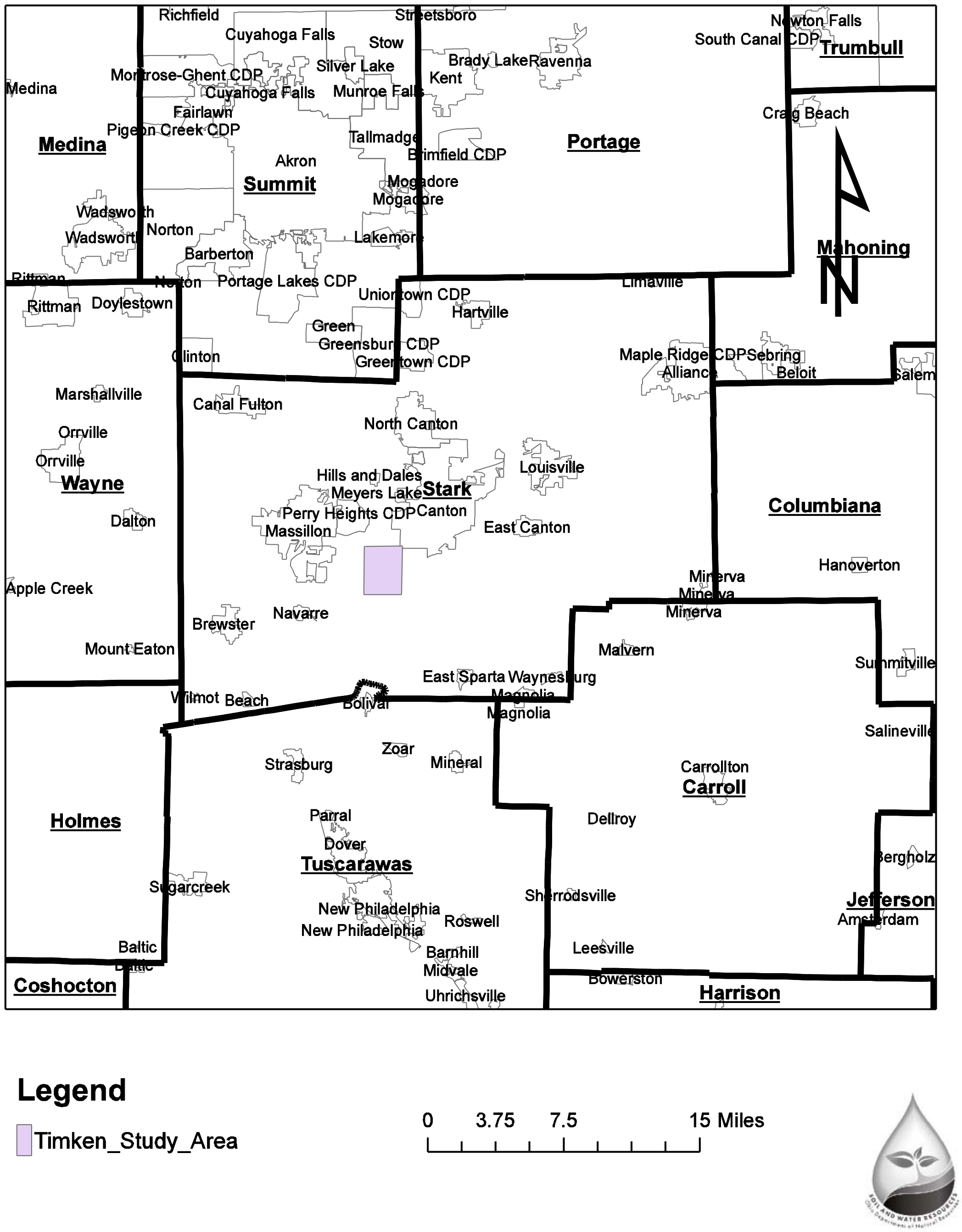

Figure 1. General Site Location Map of the Timken Construction Dewatering Project Study Area

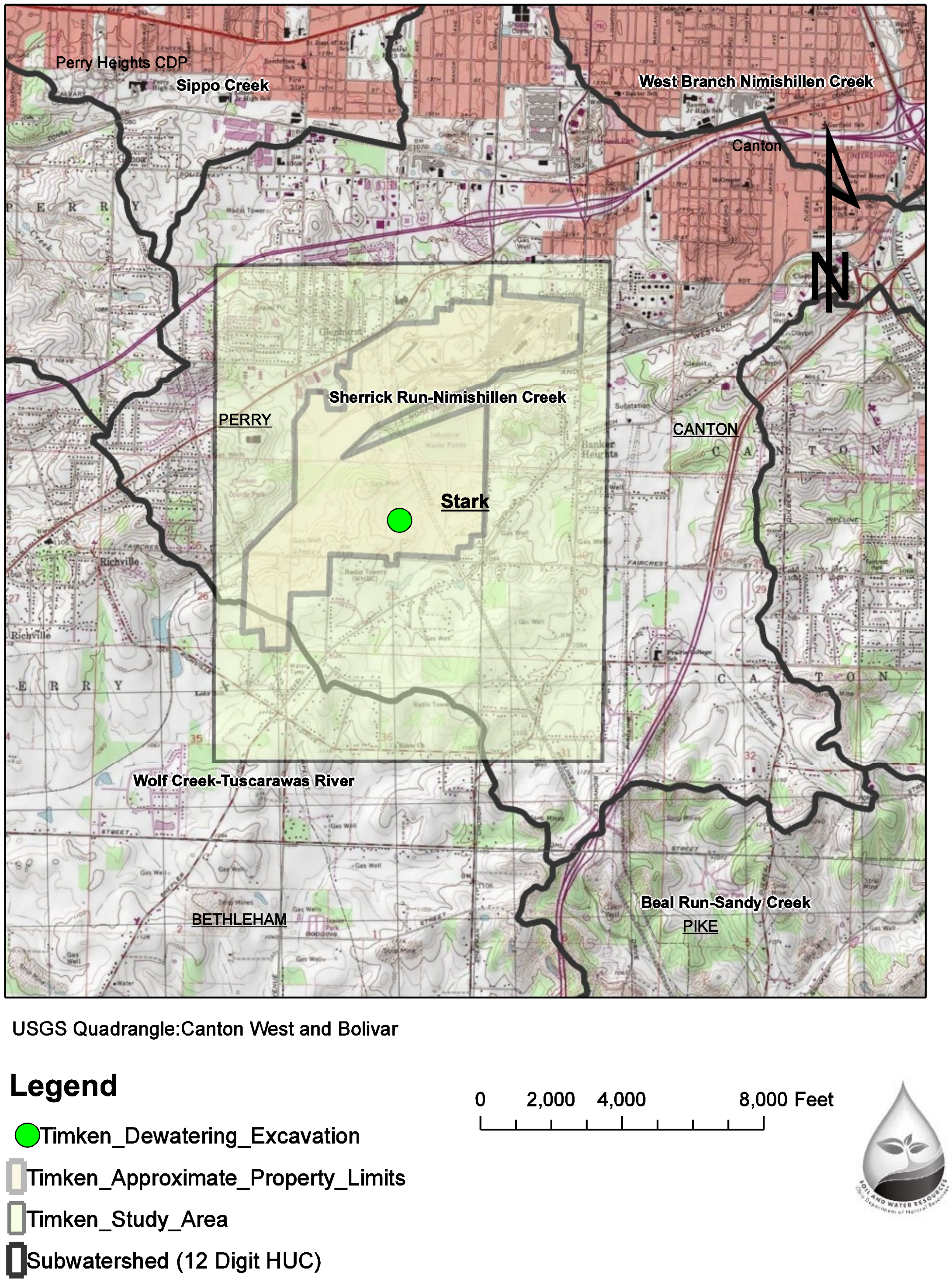

Figure 2. Topographic Map of Stark County, Timken Construction Dewatering Study Area Showing Surface Water Drainage Divides

1.2 PURPOSE AND SCOPE OF WORK

The ODNR-DSWR has the authority to collect data to help resolve conflicts between ground water users by conducting technical investigations and preparing related reports to help all ground water users understand the impacts to the resource.

In areas where ground water withdrawals are exceeding natural recharge, the Division can designate ground water stress areas with special reporting requirements for all ground water users. The Division can hold public meetings or hearings upon request from local governments and boards to help disseminate ground water information in conflict areas.

The purpose of this project was to investigate what impact the Timken construction dewatering had on the ground water levels in nearby domestic water supply wells. The ODNR-DSWR assessed the validity of allegations made by local homeowners that the Timken dewatering wells were exceeding reasonable ground water withdrawal rates from the glacial and bedrock aquifers, resulting in the dewatering of the domestic water supply wells.

The scope of work for the project was as follows:

- Review the previous work regarding the hydrogeology of the glacial and bedrock aquifers in northeastern Ohio, Stark County, Perry and Canton Townships.
- Review the well construction and well completion details for the Timken construction dewatering wells.
- Review the well construction and well completion details for domestic water wells in Stark County, Perry and Canton Townships near the TFSP construction dewatering excavation.
- Implement a field investigation to monitor water levels in the subsurface relative to the TFSP dewatering wells and selected domestic water wells in the study area.
- Analyze the data to determine the impact the Timken dewatering wells had on the ground water levels in the nearby domestic wells.
- Write a report summarizing the data collected along with conclusions and recommendations to assist with the resolution of any ground water conflicts caused by the pumping of the Timken construction dewatering wells.

2.0 PREVIOUS WORK

2.1 HYDROGEOLOGY OF THE STUDY AREA

The bedrock in the area of the TFSP is characterized by the Pennsylvanian-age Pottsville and Allegheny formations. The bedrock is overlain by a variable thickness of unconsolidated glacial sediment. Both the bedrock and the glacial sediments are sources of water to drilled wells in the area (Delong, RM and White, GW, 1963 and Sedam, A 1973, and Walker, Alfred, 1979).

Figure 3 shows an interpretive stratigraphic section for Stark County. The most important bedrock aquifers in the study area are the sandstone units that make up the Pottsville formation. In descending order the sandstone aquifers that make up the Pottsville formation are:

Homewood Sandstone Member

Connoquenessing Sandstone Member

Sharon Sandstone and Conglomerate Member

Each of the sandstone aquifers is separated by a variable thickness of shale, siltstone and coal seams. Many domestic wells in the study area produce water from these transitional units.

Near the TFSP, the primary bedrock aquifer is the Homewood Sandstone (Pa-up) member of the Pottsville Formation. Figure 4 shows the extent of the Homewood Sandstone Member of the Pottsville Formation in the study area. Based on historic drilling data, the Homewood Sandstone is not continuous in the study area. It is absent in the deeper parts of the glacial valley fill. In these areas the bedrock consists of the Mississippian Cuyahoga Formation (Mcg). Ground water yields from the bedrock generally range from 5-25 gallons per minute (gpm).

Under the TFSP the bedrock is overlain by a variable thickness of unconsolidated glacial sediments that consist of silt and clay beds interbedded with sand and gravel outwash channels (White, GW, 1982). Figure 5 shows the aquifer names and the thickness of the glacial sediments over the bedrock. In the Timken dewatering area two (2) aquifers have been named:

- Lisbon Thin Upland Aquifer can vary from less the 25 feet up to 100 feet in thickness
- Sandy Creek Buried Valley Aquifer is generally over 100 feet thick.

Ground water yields from the silt and clay tills are in the range of a few gallons per minute. Ground water yields from the sand and gravel units can be as much as 500 gpm depending on drilling locations (Walker, Alfred 1979, and Williams, Steven 1991).

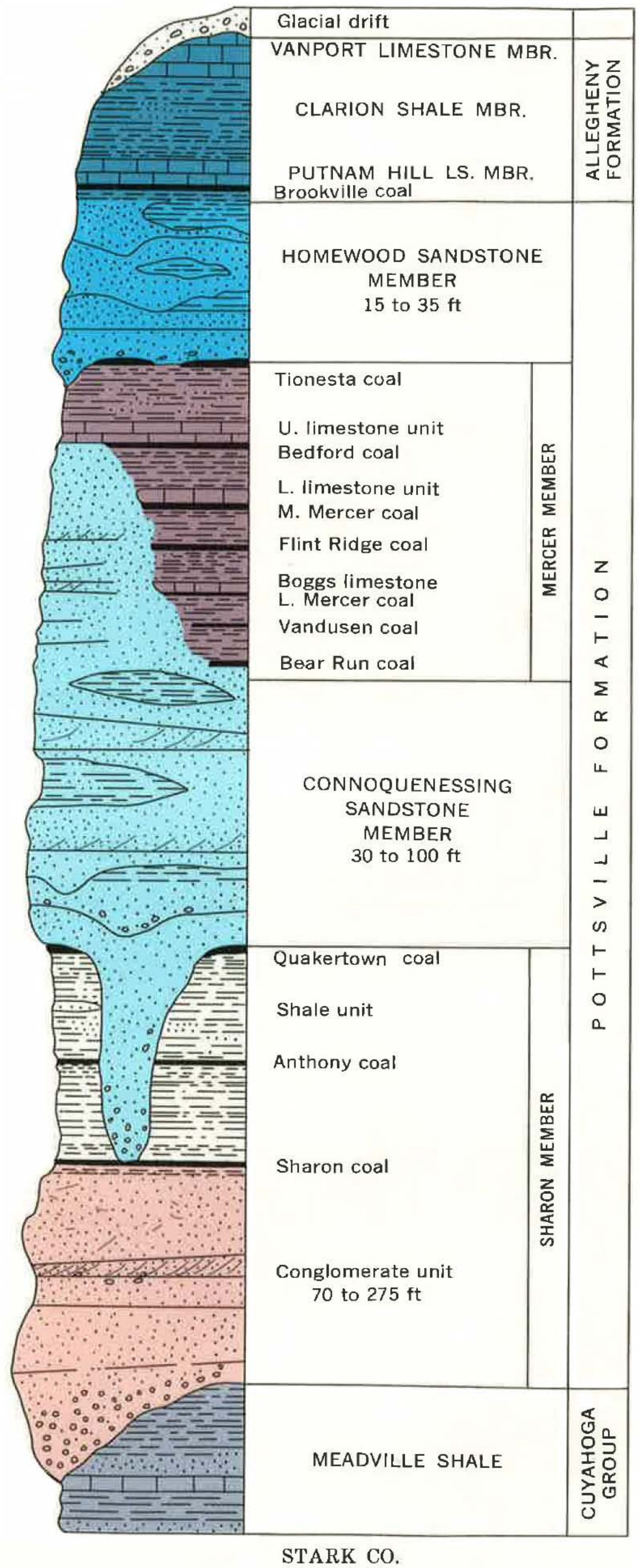

Figure 3. General Interpretive Stratigraphic Section for Stark County (after Sedam, 1973)

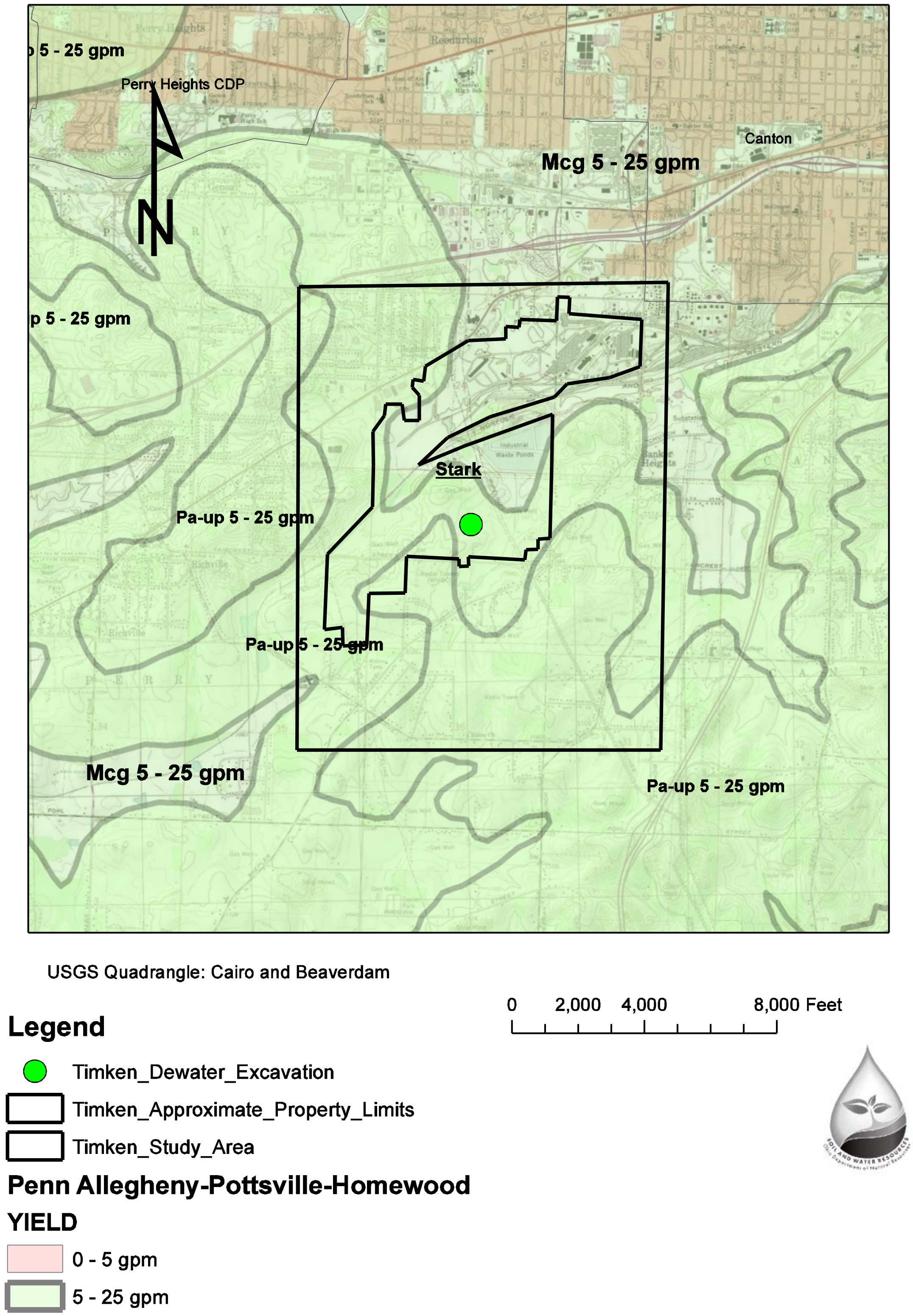

Figure 4. Bedrock Map Showing the Extent of the Homewood Sandstone Member of the Pottsville Formation in the Study Area

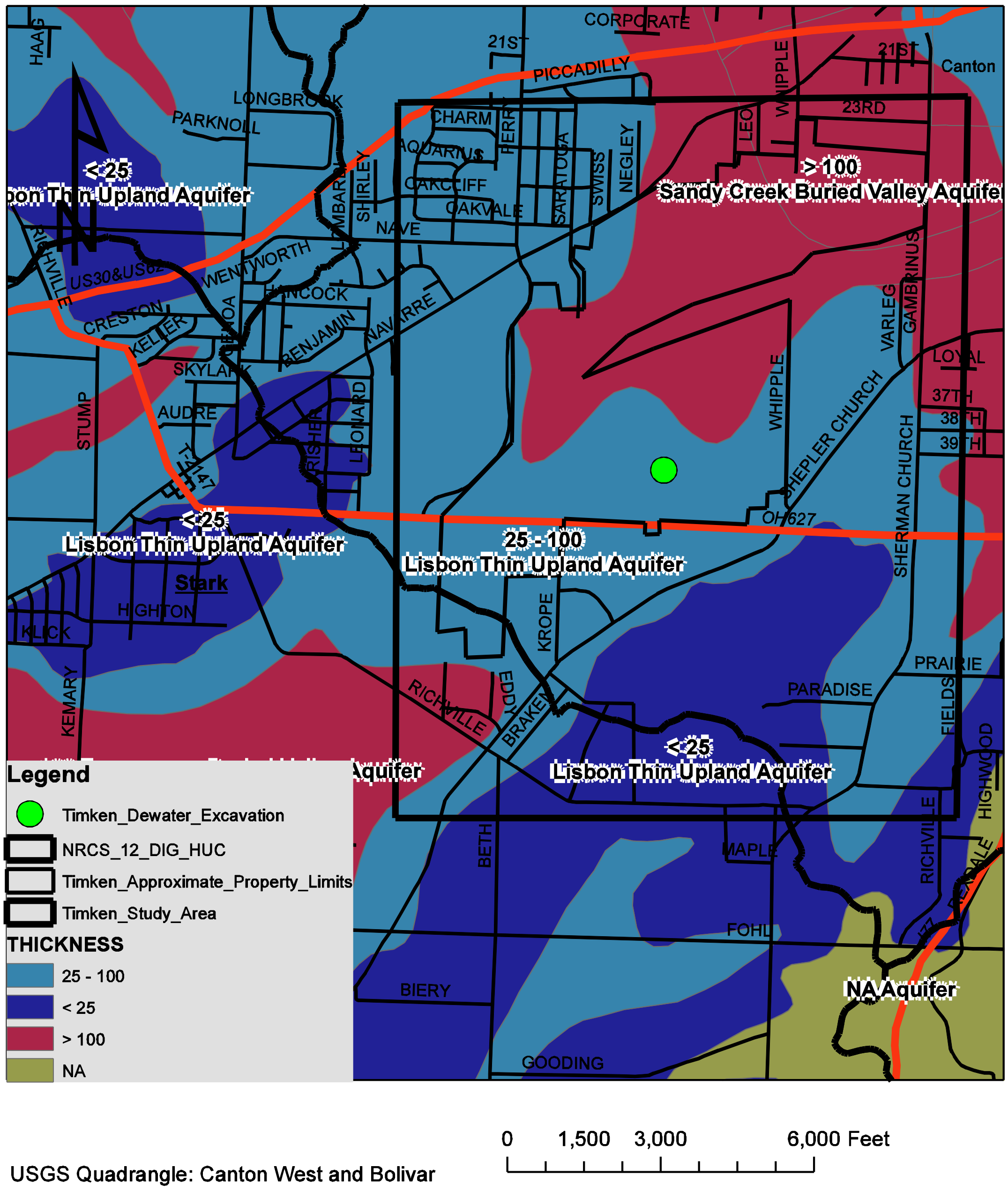

Figure 5. Glacial Aquifer Thickness in the Study Area

2.2 REGIONAL GROUND WATER OCCURRENCE AND MOVEMENT

Figure 6, developed from the ODNR-DSWR well log database, shows the regional ground water gradient in the bedrock. This figure shows the presence of a natural ground water divide in the southern part of the study area. As a result, the natural ground water gradient in the Timken study area is from the southwest toward the northeast. The elevation of the ground water under the TFSP is approximately 1050 feet above mean sea level (Crist and Raab, 2006).

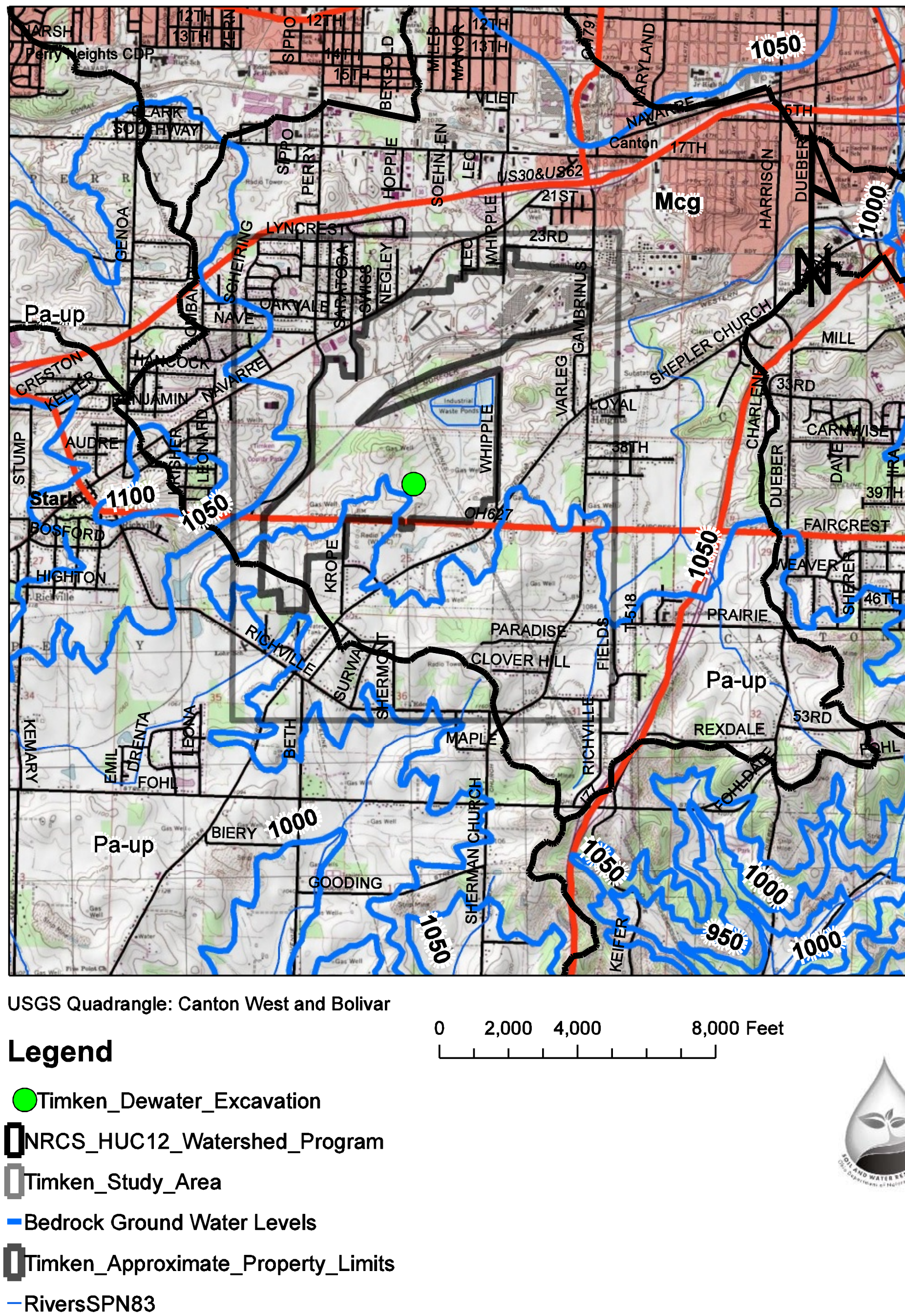

Figure 6. Regional Bedrock Ground Water Flow Gradient in the Study Area

3.0 METHODS OF THE INVESTIGATION

Prior to implementing this project, the ODNR-DSWR reviewed the Ohio Revised Code concerning ground water supply development in Ohio. Standard hydrogeological as well as engineering practices were used to carry out all fieldwork and data analysis (Bair and Lahm, 2006; Driscoll, 1986; Fetter, 2001; Kruseman and deRidder, 1990; Merritt, 1983 Powers; et.al., 2007).

A partial glossary of terms used in the report has been attached for those who are not familiar with the subject matter. The reader can refer to the Encyclopedic Dictionary of Hydrogeology by Poehls and Smith (2009) for further reference.

3.1 TIMKEN VERTICAL CASTER CONSTRUCTION DEWATERING EXCAVATION DETAILS

The first step in the project was to meet with Timken and review the vertical caster excavation construction details. Timken explained the technical aspects of the vertical caster design and how the molten steel from the foundry would be cast into various pipe sections using the vertical caster design

Based on the information provided, the molten steel would be poured into the vertical caster as shown in Figure 7. As shown on the figure, the vertical caster would be constructed partially underground to accommodate the design criteria. The molten steel would be poured into the vertical caster at the top of the caster. Water would be used to cool the steel pipe. The steel pipe would be removed from the caster by a conveyor belt and stored in a holding area. The waste water would be collected at the bottom of the caster excavation. This waste water would be pumped into the vertical caster scale pit. Eventually the waste water would be pumped to a central location for treatment and discharge under the company's OEPA NPDES permit.

At the time that the construction began during July 2012, Timken had not considered the need for continuous dewatering of the vertical caster excavation. However, shortly after the excavation work began, the contractor informed Timken that ground water was accumulating in the excavation. Timken would need to install dewatering wells so that the construction could continue as planned. Timken installed dewatering wells around both the Vertical Caster Excavation and the Scale Pit Excavation.

3.1.1 Vertical Caster Excavation Dewatering Wells

Figure 8 shows the location of the vertical caster and scale pit excavations. The total depth of the vertical caster excavation would be approximately 89 feet below the original land surface of 1081.5 feet amsl. Two (2) cross sections were drawn by the Timken engineers through the excavation to depict the excavation construction details. Cross section A-A' is drawn through the excavation in the north-south direction (Figure 9). Cross section B-B' was drawn in the east-west direction (Figure 10).

Figure 11 shows the well completion details for the six caster excavation dewatering wells with the stratigraphic interpretation. These wells were drilled after the excavation work was initiated. As a result, the elevation for each well on the cross section represents the depth of the excavation at the time the individual well was drilled. The wells were drilled to a depth of between 86 feet to 93 feet. Based on the information:

- depth to ground water was estimated by the ODNR_DSWR to be 1050 feet amsl,
- finished floor elevation was estimated by Timken to be 992 feet amsl,
- And pumping water level was estimated by Timken to be 972 amsl or 20 feet below the finished floor elevation.

Information about the six caster excavation dewatering wells is listed in Table 1. Shown in the table are the ODNR well log number, well sealing report number, well ID, surface elevation, total depth, casing length, static water level, and aquifer type. The Timken dewatering well logs, well sealing reports and ground water monitoring details can be found in Appendix A.

Table 1. Timken Dewatering Wells Construction Details

Well Log Number	Well Sealing Number	Well ID	Surface Elevation	Total Depth Feet	Casing Length Feet	Static WL Feet (log)	Aquifer Type
2039329	302534	TDW1	1057	96	54	5	Sandstone
2039330	302533	TDW2	1057.5	96	44	5	Sandstone
2039331	301986	TDW3	1046.4	86	32	1	Sandstone
2039333	302532	TDW4	1051.8	93	18	8	Limestone
2039335	301987	TDW5	1056.2	93	2	10	Sandstone
2039336	302531	TDW6	1057.6	96	53	3	Sandstone

*Original land surface was 1081 feet above mean sea level

3.1.2 Timken Scale Pit Dewatering Wells

Water is used to cool the molten steel once it is poured into the vertical caster. The waste water is collected at the base of the caster and is pumped to the caster scale pit where the water is stored until it can be pumped to a treatment facility.

Figure 8 shows the location of the eight (8) scale pit dewatering wells around the excavation. These wells were drilled during January 2013. Table 2 summarized the data for these eight wells. These wells were installed to dewater the excavation in the event that it would be necessary to dewater the pit during the construction work. However, the wells were dry at the time of drilling. The ground water levels were below the bottom elevation of the scale pit because of the dewatering that was occurring around the vertical caster excavation. As the construction progressed through time, the vertical caster excavation dewatering wells were plugged. The scale pit dewatering wells were used for ground water level monitoring only. The primary well for measuring ground water levels was TDW-3A. The Timken caster scale pit dewatering well logs, well sealing reports and ground water monitoring details can be found in Appendix B.

Table 2. Timken Scale Pit Dewatering Wells, Stark County, Perry and Canton Townships

Well Log Number	Well Sealing Number	Well ID	Surface Elevation	Total Depth Feet	Casing Length Feet	Static WL Feet (log)	Aquifer Type
2042009	302596	TDW-1A	1074.2	55	40		SHALE
2042016	302592	TDW-2A	1072.8	55	40		SHALE
2042010	302591	TDW-3A	1071.5	57	40	45	SHALE
2042011		TDW-4A	1072.7	55	40	45	SHALE
2042012	302430	TDW-5A	1064.5	55	40		SHALE
2042013	303299	TDW-6A	1066.8	55	40		SHALE
2042014	302400	TDW-7A	1068.7	55	40		SHALE
2042015	302590	TDW-8A	1068.5	45	40		SHALE

3.2 STARK COUNTY HEALTH DEPARTMENT (SCHD) RESPONSE TO HOMEOWNER COMPLAINTS

Shortly after the Timken construction dewatering operation began on August 6, 2012, the SCHD began to receive complaints from local homeowners that ground water levels in there wells were declining. In some cases, homeowners with shallow wells complained that their wells were going dry. As a result, the SCHD began to investigate the validity of the homeowner complaints. The SCHD began to keep records of the complaints and pass them on to Timken and the ODNR-DSWR. The list of complaints can be found in Appendix C.

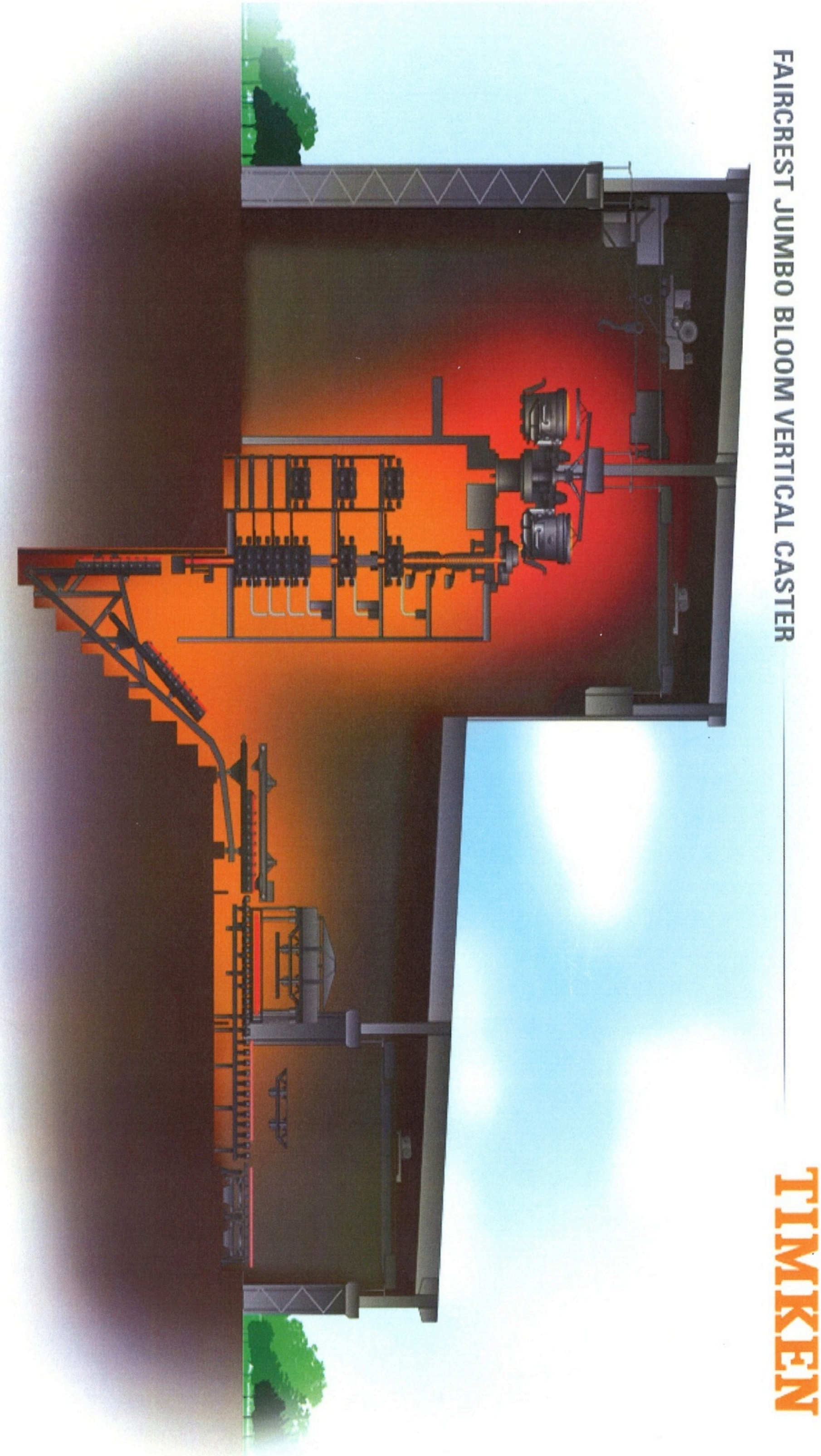

Figure 7. Timken Faircrest Jumbo Vertical Caster Schematic Diagram Design (After Timken, modified by ODNR-DSWR, map not to scale)

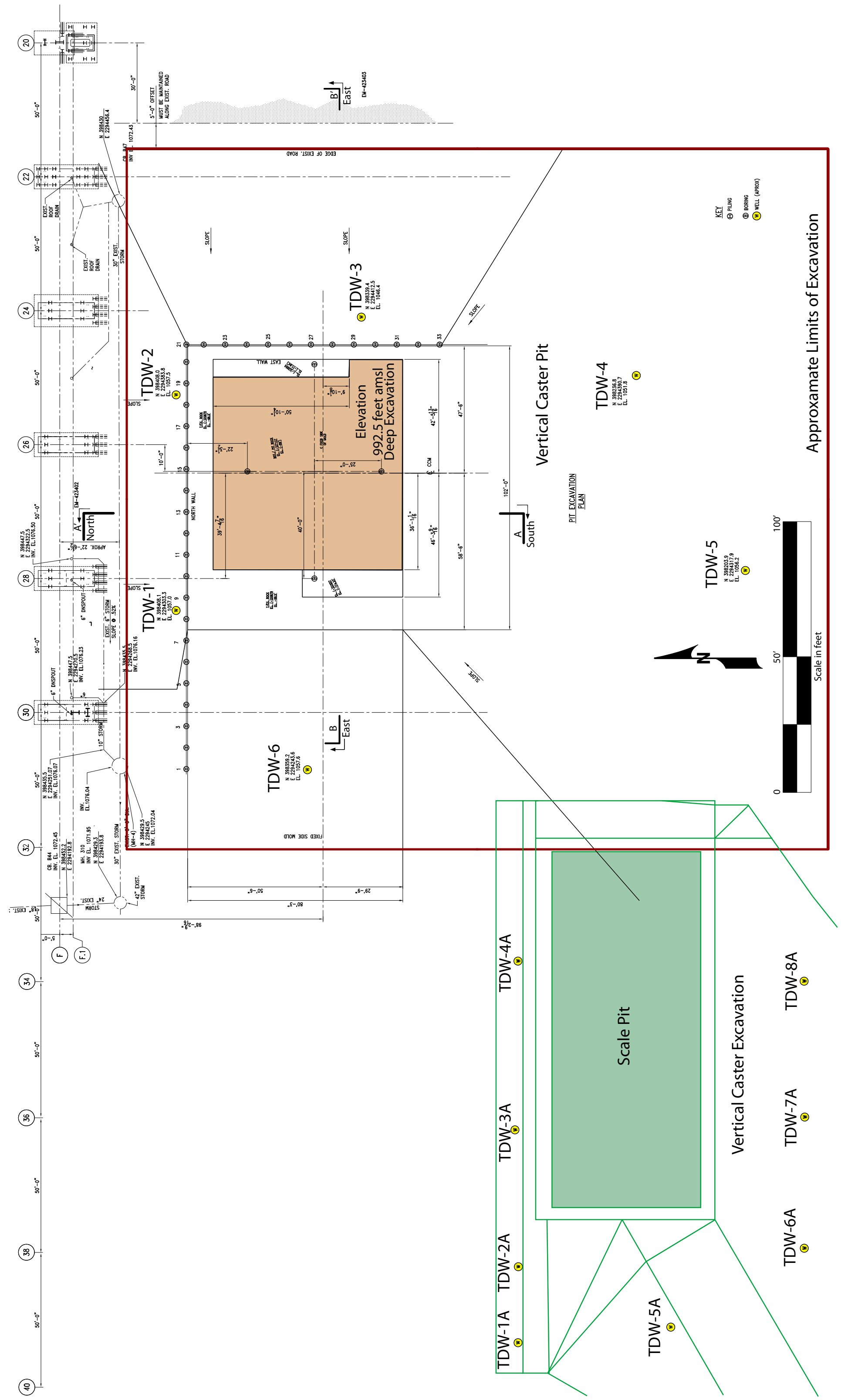

Figure 8. Approximate Extent of the Timken Faircrest Steel Plant (TFSP) Vertical Caster Excavation Construction Dewatering wells (TDW-1 through TDW-6) and Scale Pit Wells (TDW-1A through TDW-8A) After Timken, modified by ODNR-DSWR, map not to scale.

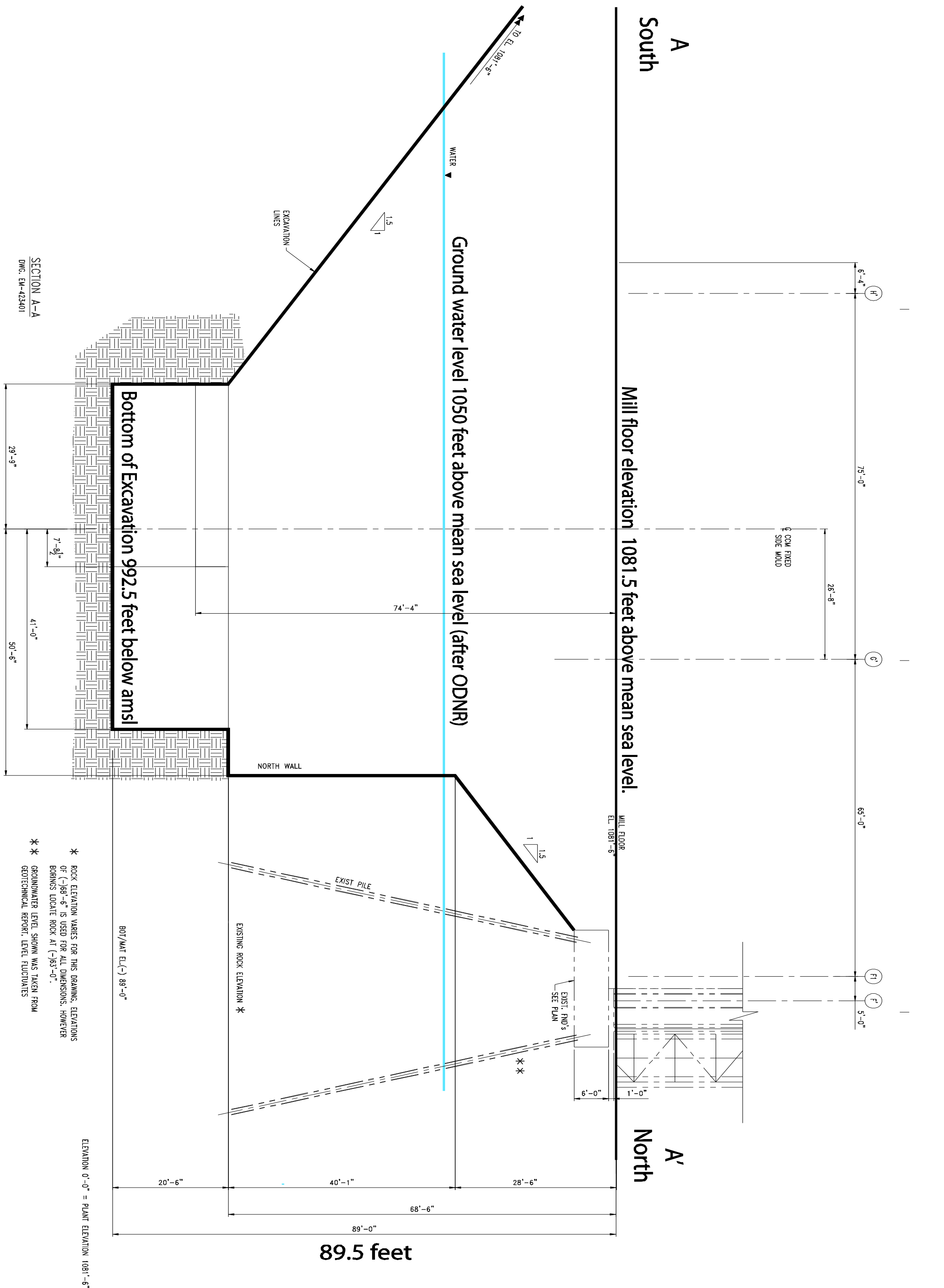

Figure 9. Cross Section A-A' Drawn Through the Timken Construction Dewatering Excavation (After Timken, modified by ODNR-DSWR, figure not to scale)

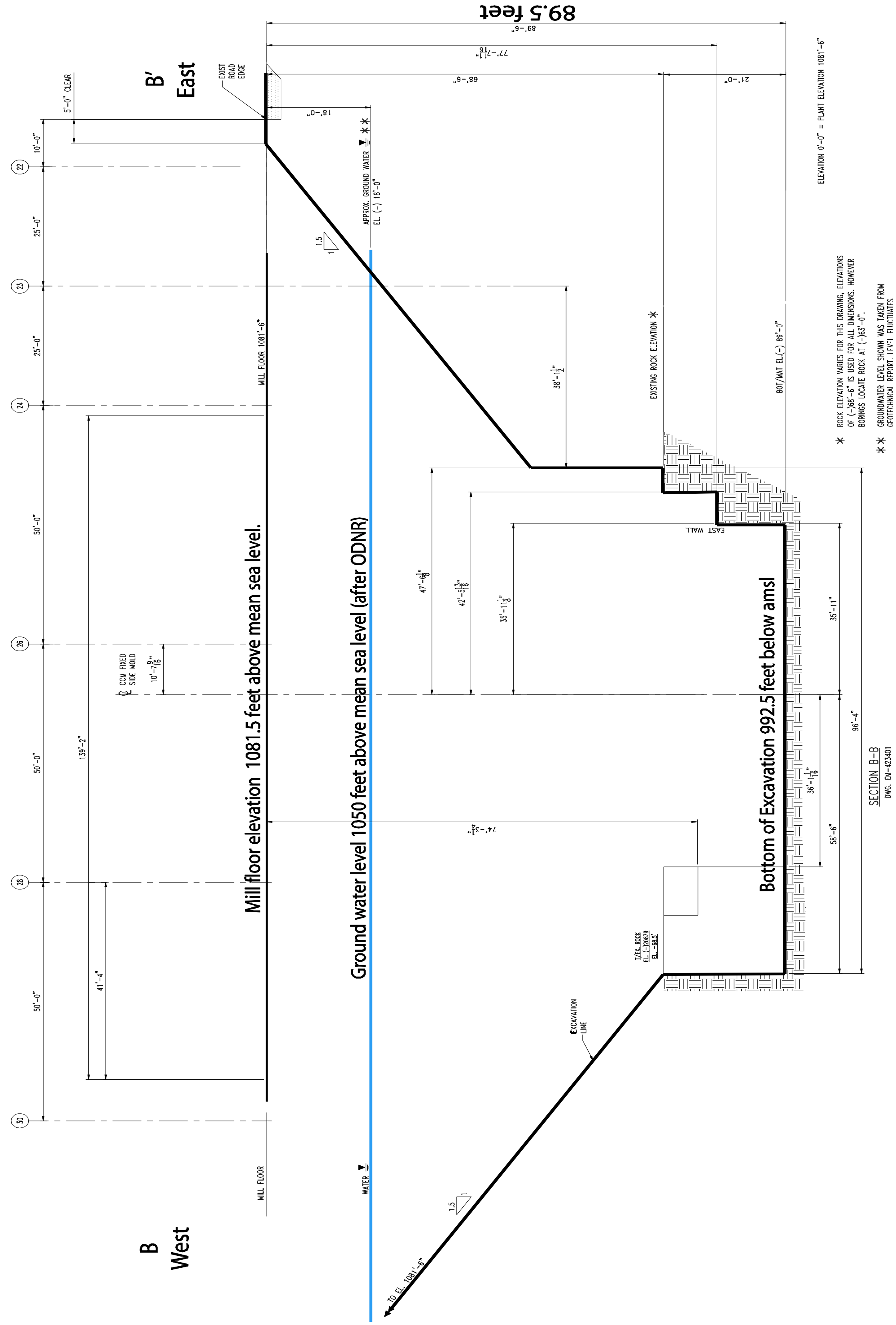

Figure 10. Cross Section B-B'' Drawn West To East Through the Timken Construction Dewatering. Excavation (After Timken, modified by ODNR-DSWR, figure not to scale)

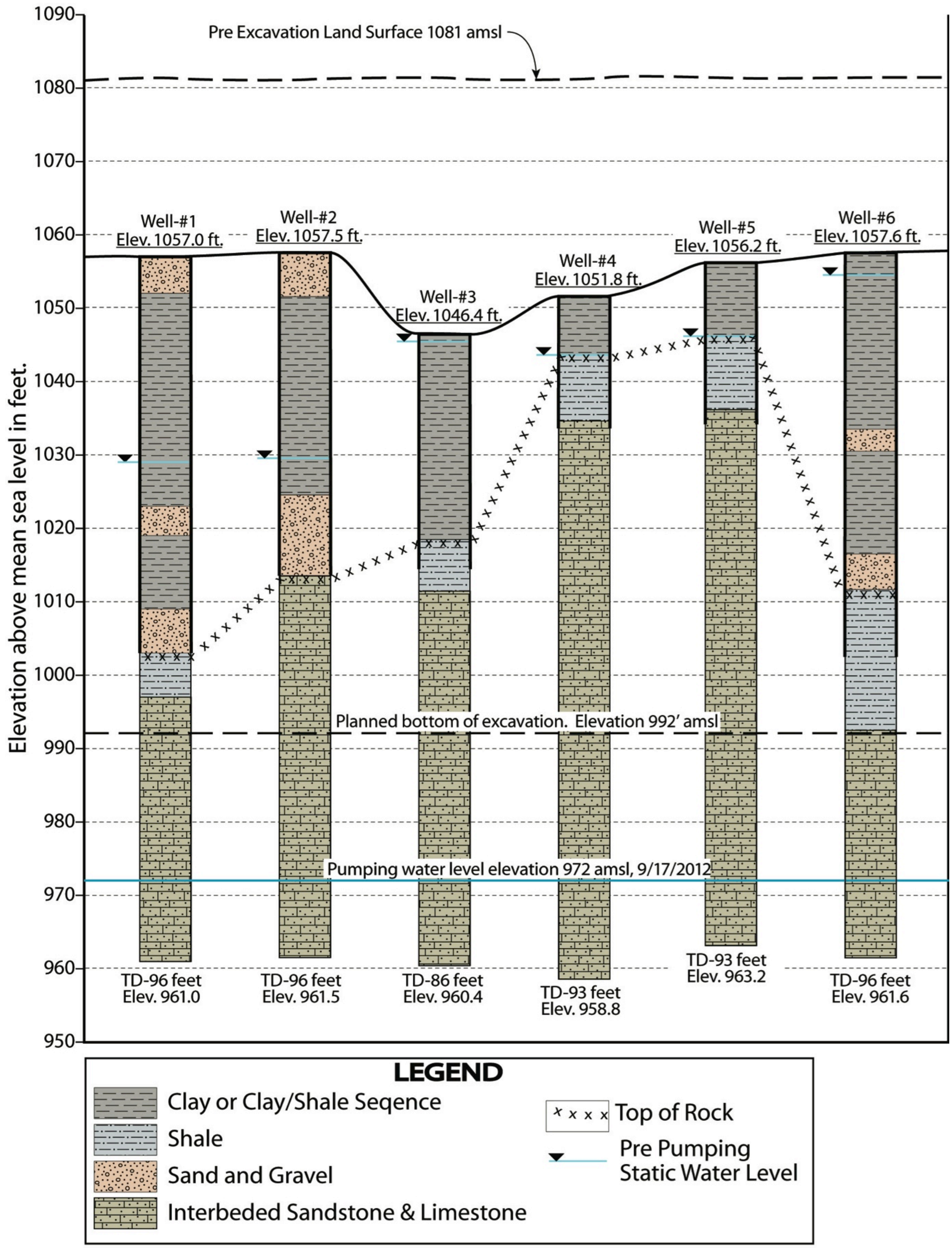

Figure 11. Well Completion Diagrams for Timken Faircrest Construction Dewatering Wells TDW-1 through TDW-6 Showing Stratigraphic Interpretation of Data (after Timken, modified by ODNR-DSWR)

3.3 ODNR WELL LOG DATABASE WEBSITE SEARCH

The next step in the investigation was to define the limits of the study area. This was done based on the geographic location of the TFSP construction dewatering excavation as well as the location of the initial homeowner complaints. The ODNR-DSWR then identified nearby domestic wells that could be used to monitor ground water levels near the dewatering operation.

As part of the investigation, the ODNR-DSWR conducted a search of the water well record database for Stark County, Perry and Canton Townships to identify the number of domestic water wells within the study area (ODNR-DSWR website, 2011). The records show that approximately 3,820 wells have been drilled in Perry Township since the late 1940's. Approximately 3,890 wells have been drilled in Canton Township since the late 1940's. Items identified in the database are the ODNR-DSWR well log number, original owner of the well, well depth, test rate, static water level and aquifer type.

Figure 12 shows the locations of approximately 77 wells with known coordinates located in the vicinity of the study area. Based on county records, the majority of the homeowners are dependent on ground water as a source of supply. Public water supply is very limited in the area. Therefore the number of wells in the area is far greater than the number of wells shown on the map.

All water wells in the database were evaluated to select the most appropriate data points for use in the study. A print-out of the ODNR-DSWR well log database for the wells in the study area is presented in Appendix D.

3.4 DOMESTIC WATER WELLS USED TO MONITOR THE EFFECTS OF PUMPING THE TIMKEN DEWATERING WELLS

Once the study area was defined, the next step was to select observation wells from the available records. The ODNR-DSWR and the SCHD were responsible for setting up the original monitoring well network for the project. To define the cone of depression caused by the Timken construction dewatering, it was necessary to find observation wells 360 degrees around the site so that ground water levels around the TFSP could be measured. The selection process was based on:

- The availability of an ODNR-DSWR well log for the well to be monitored.
- The location of the well relative to the pumping center.
- The homeowner's willingness to allow the well to be used for observation throughout the project duration.
- The accessibility of the well for measurement (i.e. was the well inside or outside the house).

In a few cases, well log records were not available for the location, but the well was located in an area where ground water levels were necessary to define the cone of depression caused by the Timken dewatering operations. In this case the well was included in the data set. Each homeowner was approached to gain permission to monitor the water level in their well. Several ground water level measuring events were necessary to settle on the final observation well network. Timken had several monitoring wells located at the former waste lagoon ponds that they wanted included in the data set. These wells were completed in both the unconsolidated glacial and bedrock aquifer units.

Well locations for the final monitoring network are shown on Figure 13. Data regarding these water wells is shown in Table 3. Water well records used for this investigation are presented in Appendix E. Timken lagoon monitoring well logs are in Appendix F.

3.5 LONG-TERM GROUND WATER LEVEL MONITORING AND IMPACT ASSESSMENT

The ODNR-DSWR and the SCHD measured the water levels during August and September 2012. Responsibility for measuring the ground water levels in the available wells over time were split up between Timken, SCHD and ODNR-DSWR as follows:

- Timken construction dewatering contractor was responsible for measuring the ground water levels in the dewatering wells and reporting the amount of water discharged on a monthly basis during the construction dewatering operations.
- Timken was responsible for measuring the ground water levels in the pond lagoon monitoring wells.
- SCHD and ODNR-DSWR were responsible for measuring the water level measurements in the surrounding domestic water supply wells.

Upon establishing a ground water monitoring network, regular weekly to biweekly conference calls were set up with Timken, ODNR-DSWR, SCHD, as well as Timken's consultant. The conference calls would continue until ground water levels had completely recovered in the subsurface. At this point, Timken suggested that the ground water dewatering would continue until June of 2013. At that time the pumps would be turned off and the ground water levels recovered. The ODNR-DSWR suggested that the ground water monitoring should continue until the ground water levels under the Timken study area returned to the approximate original elevation of 1050 feet amsl. During each phone call the following items would be discussed:

- New complaints from the public would be discussed.
- Action to be implemented by Timken to resolve the homeowner complaint.
- Trends in the ground water levels near the construction dewatering study area based on the SCHD ground water level monitoring data.

All of the monthly ground water level measurements were obtained by the SCHD and were sent to the ODNR-DSWR so that the data could be tabulated and added to the attribute table. A ground water level map was generated for each month's ground water level measurements using the Surfer 10 program. The data was imported into ArcGIS 10. Field data showing the water level measurements are presented in Appendix G.

3.6 TIMKEN RESPONSE TO HOMEOWNER COMPLAINTS

In response to the homeowner complaints, Timken initially hired a well driller to evaluate the validity of each complaint. However, the ODNR recommended that Timken hire a consultant that could assist both Timken and the driller with an evaluation of each complaint. Timken hired Sanborn Head to assist with the evaluation of the individual complaints. The impact assessment was done as follows:

- The consultant reviewed the location of the well to determine if the affected well was located inside or outside the cone of depression caused by the Timken dewatering operation.

- If the well was outside the affected area, the homeowner was notified and no action would be taken. However, for a few homeowners that were located just outside the affected area, Timken provided a water tank which was periodically filled until the water levels returned to normal.

- If the well was inside the affected area, Timken would supply the homeowner with water and the consultant would evaluate the well completion details. This involved measuring the depth of the well, ground water level, pump condition and other details if appropriate. The information was used to determine the best course of action to resolve individual homeowner complaints.

- If the well was affected by the dewatering operations Timken would lower the pump to a deeper level. If the pump could not be lowered Timken would drill the homeowner a new well. New wells completed in the study area are attached in Appendix H.

- Upon putting the new well into service, the driller would seal the old water supply well and submit the well sealing report to the SCHD and ODNR-DSWR. The well sealing reports are presented in Appendix I.

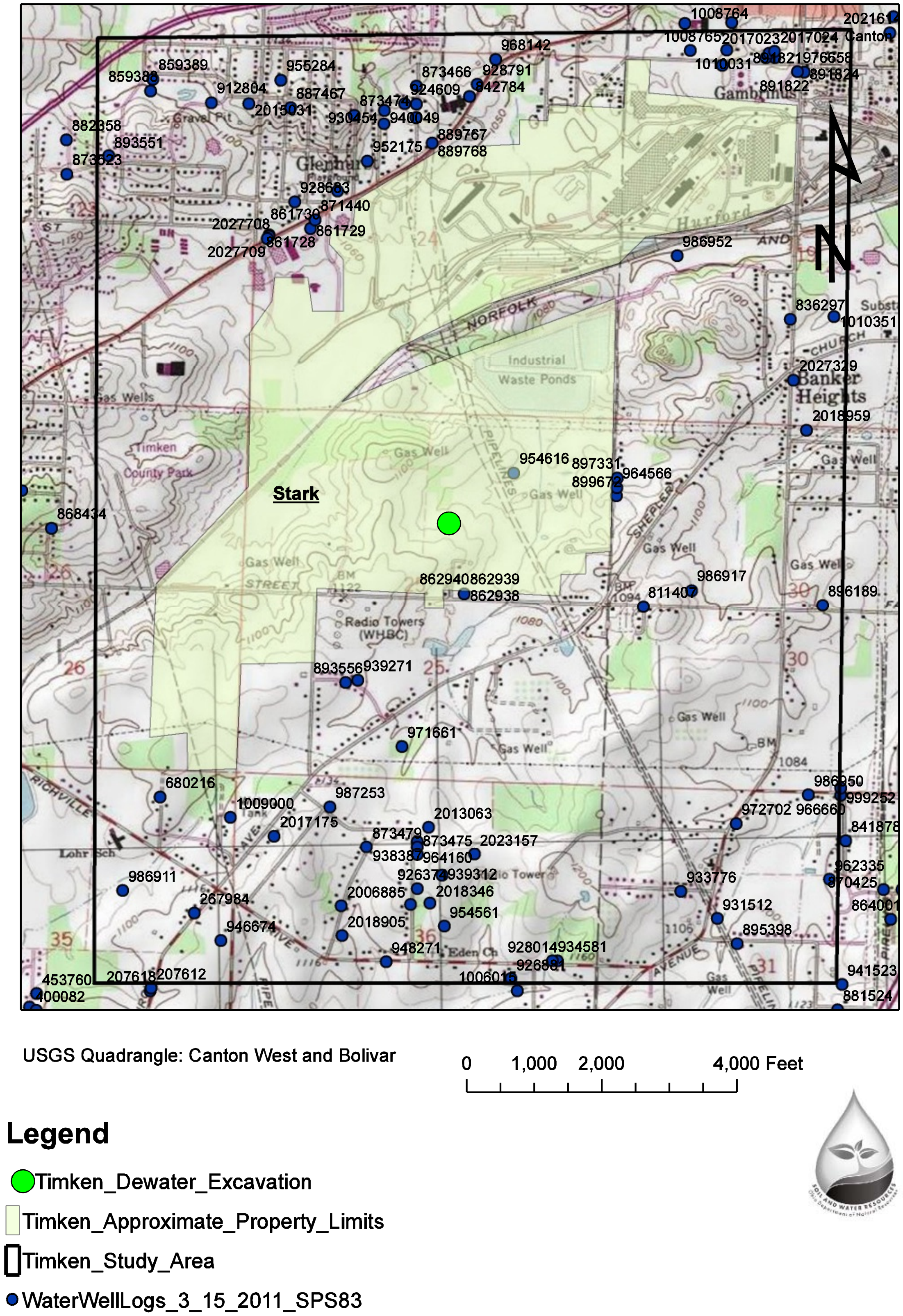

Figure 12. Water Supply Well Locations in the Stark County Study Area

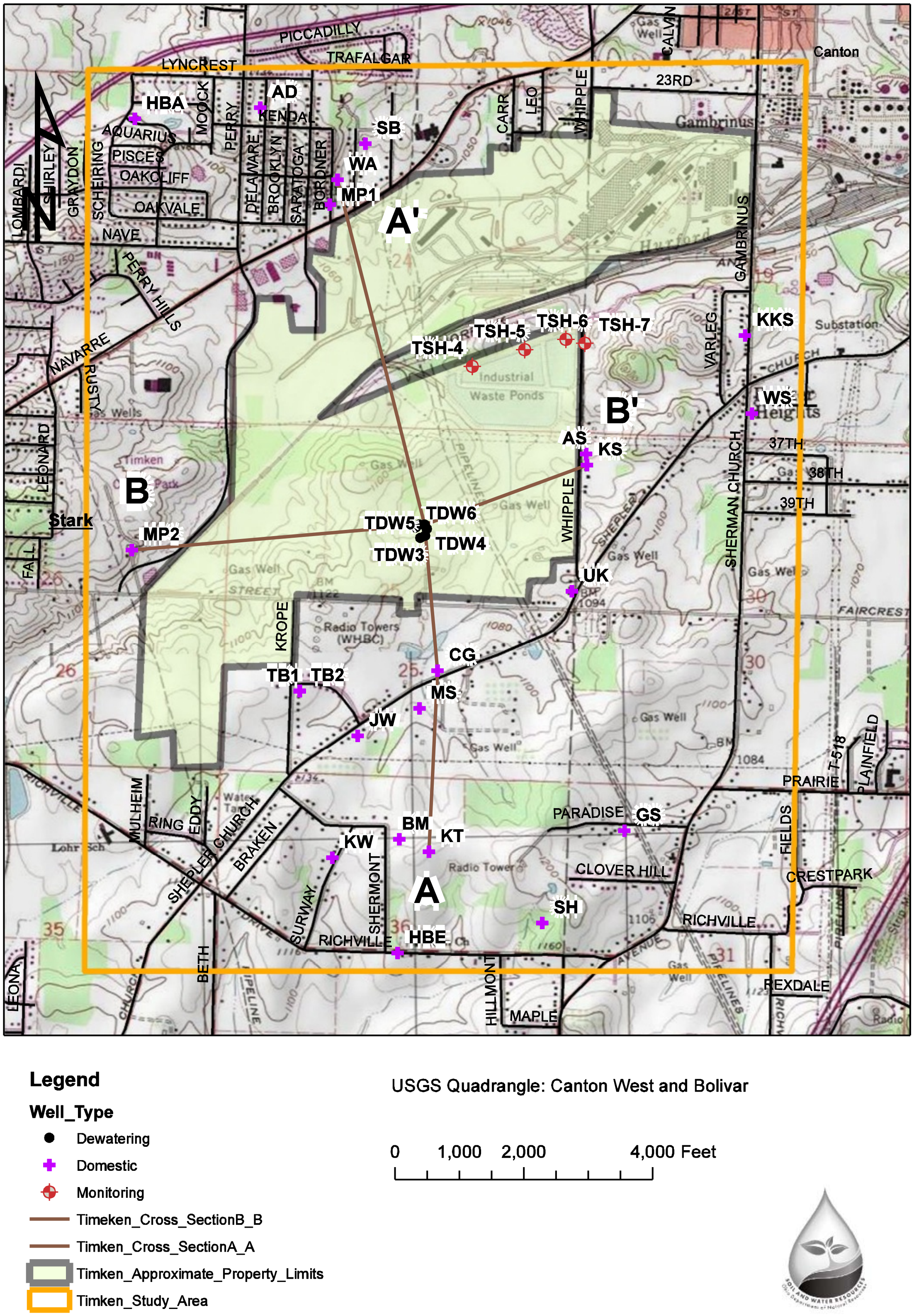

Figure 13. Location of Domestic Water Supply Wells Used to Monitor Ground Water Levels in the Bedrock Aquifer

Table 3. Water Wells Monitored During the Study.

Well Log Number	Well ID	Latitude	Longitude	Surface Elevation	Total Depth Feet	Casing Length Feet	Static WL Feet (log)	Aquifer Type
Wells Completed in the Unconsolidated Glacial Aquifers								
	TSH-5	40.762798	-81.431525	1087.27	49		30.61	Clay
964566	AS	40.758317	-81.428151	1068	60	57	15	Gavel
	TSH-7	40.76303	-81.42814	1068.2	22		3.81	Sand
559730	KKS	40.76328	-81.41916	1087	94	94	50	Sand and Gravel
	TSH-6	40.76321	-81.42921	1081.38	51		21.7	Sand and Gravel
Wells Completed in the Consolidated Bedrock Aquifers								
605207	MP2	40.75445	-81.45367	1101	115	70	65	Limestone
601049	WP	40.74822	-81.43279	1114	48	31	22	Limestone
605215	NW	40.754746	-81.426199	1117	93		45	Limestone
800458	LC	40.75518	-81.41904	1094	77	56	30	Limestone
262417	TB1	40.74835	-81.44436	1131	150	102	52	Sandstone
438679	CG	40.74915	-81.436614	1083	81	77	2	Sandstone
930454	SB	40.77166	-81.44032	1081	120	80	40	Sandstone
955284	AD	40.77324	-81.44617	1130	210	106	80	Sandstone
2027329	WS	40.75996	-81.41884	1086	216	176	55	Sandstone
2038384	KW	40.74123	-81.44263	1132	75	32	24	Sandstone
2039329	TDW1	40.7553815	-81.4375244	1057	96	54	5	Sandstone
2039330	TDW2	40.7553785	-81.4372338	1057.5	96	44	5	Sandstone
2039331	TDW3	40.7551893	-81.4371333	1046.4	86	32	1	Sandstone
2039333	TDW4	40.7549084	-81.4372165	1051.8	93	18	8	Sandstone
2039335	TDW5	40.7548205	-81.4374807	1056.2	93		10	Sandstone
2039336	TDW6	40.7552493	-81.437742	1057.6	96	53	3	Sandstone
231501	TB2	40.74836	-81.44436	1131	46	33	16	Shale
643125	EP	40.758317	-81.428151	1077	53	50	20	Shale
744587	GS	40.74224	-81.42625	1125	115	64	59	Shale
859388	HBA	40.77283	-81.45322	1105	90	64	50	Shale
873475	KT	40.74144	-81.43721	1183	145	73	69	Shale
899672	KS	40.75784	-81.42811	1073	155	132	40	Shale
964160	BM	40.74198	-81.43887	1156	133	49	43	Shale
1006015	SH	40.73835	-81.4309	1140	110	58	50	Shale
2015013	WA	40.77013	-81.44189	1086	58		38	Shale
	TSH-4	40.76211	-81.43446	1092.95	66		40.58	Shale
638362	CH	40.74951	-81.43356	1101	70		30	Shale
729470	HBE	40.73714	-81.43904	1115	58	39	20	Shale
793890	RG	40.747339	-81.432223	1122	92	62	31	Shale
811407	OC	40.75135	-81.4271	1123	105	46	30	Shale
2039116	RH	40.74874	-81.4359	1090	68	61	15	Shale
Wells With Unknow Aquifer Type								
	MP1	40.76907	-81.44235	1082				
	UK	40.75247	-81.42904	1097				
	CC	40.747882	-81.436496	1087				
	MS	40.747558	-81.437661	1087				
	JW	40.74642	-81.44113	1110				

4.0 FIELD INVESTIGATION RESULTS

To evaluate the impact that the Timken dewatering operation was having on subsurface conditions, the ODNR-DSWR reviewed the operational history for the construction dewatering. In addition, the ODNR-DSWR drew cross sections and ground water gradient maps to define the extent of the cone of depression in the subsurface. The ODNR-DSWR worked with the SCHD, Timken, and Sanborn Head to collect the field data to insure that the public complaints were addressed. The important trends in the data are presented for review.

4.1 TIMKEN CONSTRUCTION DEWATERING OPERATIONS HISTORY

Table 4 documents the complaint historical timeline. Based on the historic record, Timken began pumping from the six dewatering wells on August 6, 2012. Within seven days of starting the dewatering operations, the SCHD started to receive complaints from residents in the area. The residents complained that the water levels in their water supply wells had begun to decline. During late August, the ODNR-DSWR began the process of setting up a ground water monitoring network to determine the extent of impact due to Timken's dewatering.

Timken responded to individual complaints by supplying bottled drinking water, replacing pumps and drilling new water supply wells.

Table 4. Timken Dewatering Complaint Response Timeline

▪ August 6, 2012 – Start of dewatering.
▪ August 13, 2012 – First report of residential water shortage.
▪ August 14, 2012 – Bottled drinking water supplied to residents.
▪ August 16, 2012 – Water tanks and pumps installed and connected to existing plumbing.
▪ August 17, 2012 – Start of well monitoring program.
▪ August 29, 2012 – First replacement well was drilled for residents.
▪ November 2012 – Bottom of Excavation reached.
▪ December 17, 2012 – Begin sequence of concrete pours and backfilling.
▪ February 8, 2013 – Discontinued use of extraction wells, relied solely on sump pumps.
▪ June 6, 2013 – Discontinued dewatering with sump pumps.
▪ July 26, 2013 – Concrete foundation completed to ground surface.

Table 5 documents the history of the Timken dewatering operations. The data was collected by Timken and summarized by Sanborn Head. Shown in the table are the:

- pumping rate in gallons per minute (gpm),
- dewatering elevation in feet above mean sea level (amsl),
- average pumping rate since the prior date,
- pumping volume since the prior date,

From the table, the construction dewatering started on August 6, 2012. Initially, Timken started pumping water from all six dewatering wells. The initial combined total flow rate from all six wells was 400 gpm. The goal was to keep the excavation dry while the vertical caster foundation was being constructed. As a result, the goal was to maintain the ground water level 20 feet below the bottom elevation of the excavation at 992 feet amsl. The initial pumping water level in the dewatering wells was set at 972 feet amsl.

During November 2012, the construction contractor reached the bottom of the excavation at a depth of 89 feet (approximately 992 feet amsl). The contractor began the process of constructing the foundation on which the vertical caster would rest. Events were as follows:

- The pumping rate from the six wells began to decline to approximately 78.2 gpm.
- Timken raised the pump intake from 972 feet amsl to 981.5 feet amsl.
- By January 18, 2013 the pumping rate from the wells was approximately 31 gpm.
- Starting on February 11 the pumping from the wells was discontinued.
- Timken began to pump from the sump installed at the bottom of the vertical caster foundation.
- The water pumped was a combination of storm water and ground water.
- At this time the ground water levels were rising in the subsurface around the newly installed vertical caster foundation.
- On June 6, 2013 the ground water levels in the subsurface had recovered to approximately 1049 feet amsl.

The total volume of water pumped from the exaction was approximately 57,811,392 gallons of water.

Table 5. Timken Dewatering Well Pumping Data and Statistics .

Date	Pumping Rate (gpm)	Dewatering Elevation (ft)	Average Pumping Rate Since Prior Date (gpm)	Volume Pumped Since Prior Date (gal)	Comment
8/6/2012	400.0	972.0			Start Dewatering
8/27/2012	400.0	972.0	400.0	12,096,000	
8/28/2012	280.0	972.0	340.0	489,600	
9/25/2012	280.0	981.5	280.0	11,289,600	Pump intakes raised
10/11/2012	252.0	981.5	266.0	6,128,640	
11/19/2012	78.2	981.5	165.1	9,272,016	
12/21/2012	71.2	981.5	74.7	3,442,176	Inferred steady state
1/18/2013	31.2	981.5	51.2	2,064,384	
2/11/2013	55.0	1016.0	43.1	1,489,536	Pump intakes raised, pumping from sumps only
2/19/2013	89.0	1016.0	72.0	829,440	Flow from sumps is combined storm water and groundwater
3/15/2013	89.0	1016.0	89.0	3,075,840	
4/16/2013	75.0	1033.0	82.0	3,778,560	
5/20/2013	55.0	1033.0	65.0	3,182,400	
6/6/2013	0.0	1049.0	27.5	673,200	Sump elevation raised above water table
Total volume of water pumped				**57,811,392**	

After Timken and Sanborn Head, modified by ODNR-DSWR

4.2 HYDROGEOLOGY OF THE STUDY AREA

Figures 14 and 15 represent regional hydrogeological cross sections drawn through the study area. The locations of the cross sections are shown on Figure 13. Shown on the cross sections are the:

- top of bedrock,
- thickness of the glacial till over the bedrock,
- original depth to water in each well measured when the well was drilled,
- water column in each well,
- water level measured on September 17, 2012,
- dewatered zone resulting from pumping the six dewatering wells (TDW-1 through TDW-6).

From the cross sections, it can be noted that individual water wells across the area are completed in a variety of aquifer types ranging from bedrock to unconsolidated glacial materials. The one well in common with both cross sections is TDW-6. The thickness of the glacial materials can vary from a few feet to over several hundred feet. The depth to water can also vary depending on surface elevation. Wells completed in the bedrock have a casing set into bedrock and an open rock hole completion. Wells completed in the glacial materials are generally set in sand and gravel outwash. These wells are completed with a well screen to hold back the unconsolidated sediment and to allow water to flow freely into the well.

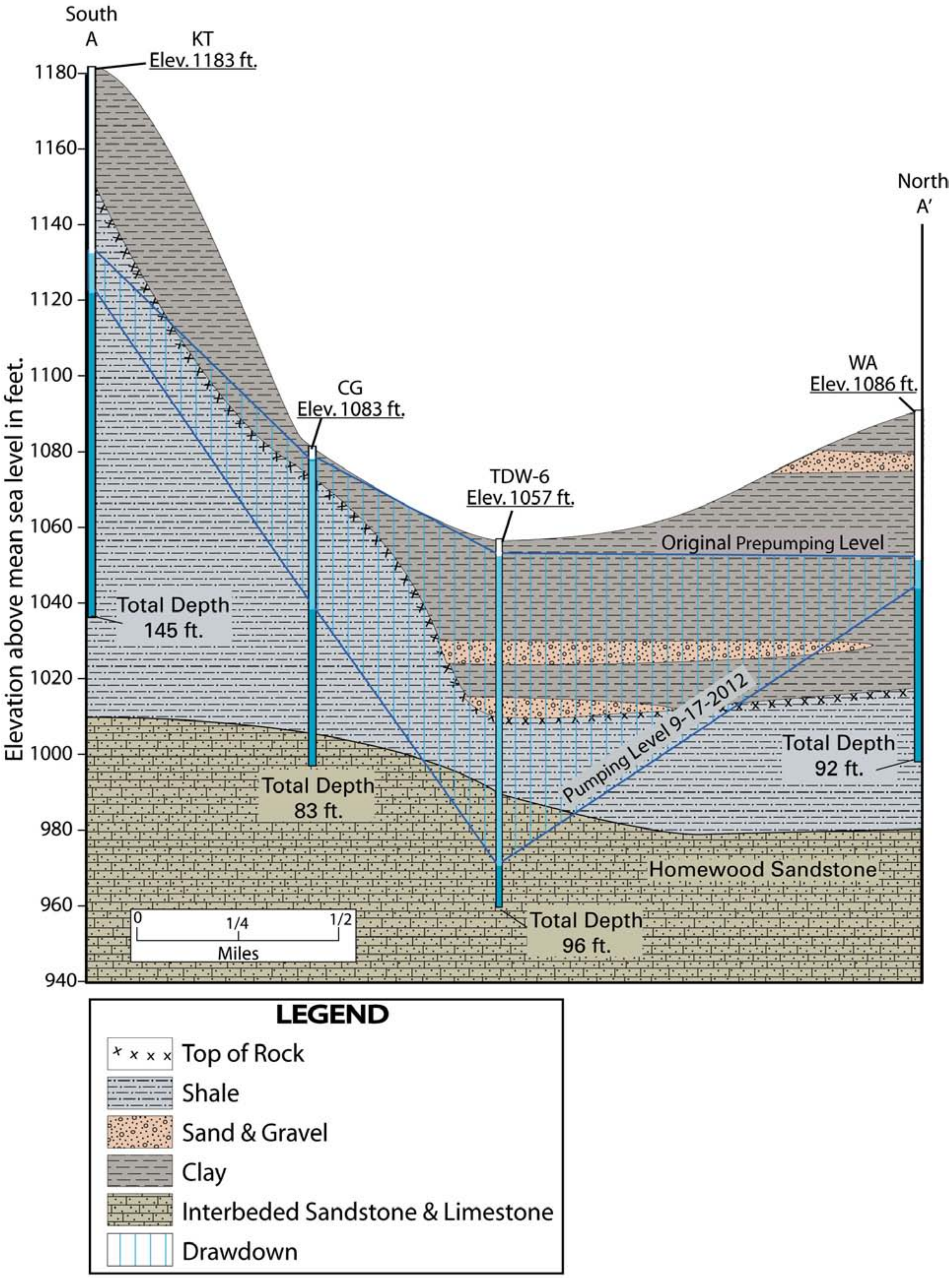

Figure14. Hydrogeological Cross Section A-A' Extended South to North across the study area

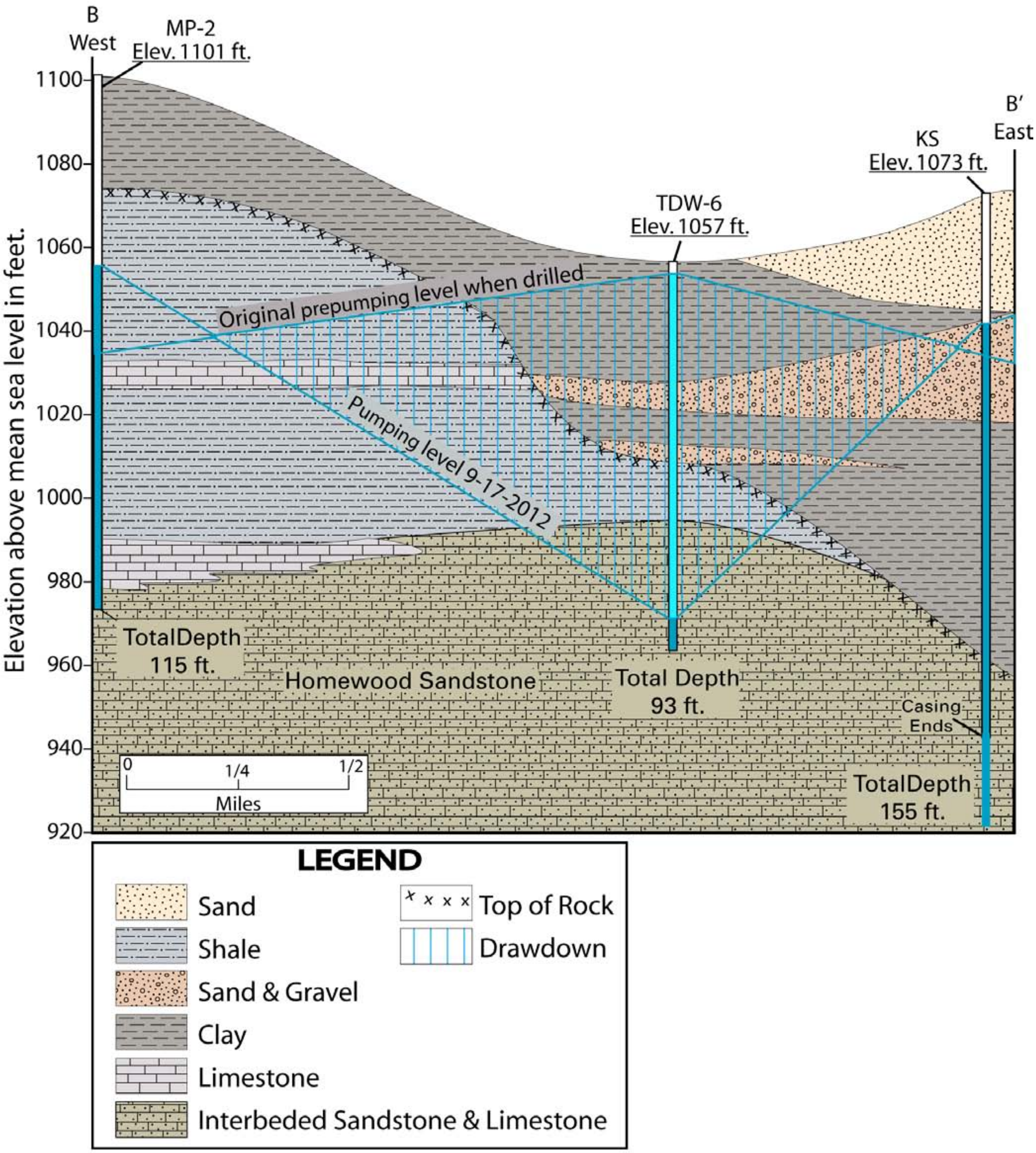

Figure15. Hydrogeological Cross Section B-B’ Extended West to East across the study area

4.3 WATER SUPPLY WELL HYDRAULIC CHARACTERISTICS FOR DEWATERING AND DOMESTIC WELLS BASED ON ODNR WELL LOG DATA

In addition to the ground water level measurements, the ODNR-DSWR made an attempt to evaluate the well hydraulics of both the domestic water supply wells and the dewatering wells based on the data supplied by the well driller at the time that each individual well was drilled. This was done by analyzing the data from the driller's log on record with the ODNR-DSWR. The drillers' pumping/bail-down test data was used to calculate the specific capacity of the wells. Specific capacity of the well in terms of gallon per minute per foot of drawdown (gpm/ft.) was estimated. These data were used to determine how much water was flowing into the well for every foot of drawdown based on the pumping rate.

As part of the work, the driller estimated the pumping capacity for the well by conducting a short term pumping/bail-down test on the well. These tests are generally done by pumping, bailing, or blowing air into the well to extract water at a known rate in gallons per minute (gpm). Prior to conducting the test, the driller measured the static water level in the well. Near the end of the test, the driller measured the pumping water level in the well. The driller then determined the total drawdown in the well during pumping. These tests are generally done to estimate a sustainable yield of the well and to determine the depth at which to set the pump.

4.3.1 Timken Dewatering Well Hydraulics

Table 6 shows the well hydraulics for each of the six Timken dewatering wells identified as TDW-1 through TDW-6. The pre-pumping water level was calculated based on the original land surface of 1081 feet amsl. These data indicate the pre-pumping water levels varied from 26 to 52 feet below the land surface. Based on the data that was provided by Timken, wells TDW-3 through TDW-6 were drilled prior to TDW-1 and 2. As a result, the water levels in TDW-1 and 2 were affected by the pumping from TDW-3 through 6.

The pumping rates in the wells varied from 5 gpm in TDW-6 up to 150 gpm in TDW-4 and 5. Drawdown in the wells varied from 83 feet to 57 feet below the land surface. The specific capacity of the wells varied from 0.06 gpm/foot of drawdown in TDW-6 to a high of 2.42 gpm/foot of drawdown in TDW-4.

These data confirm that the hydraulic characteristics of the bedrock near the excavation are highly variable and based on fracture flow patterns. Individual wells that did not encounter a fracture in the bedrock have low specific capacities. Wells that encountered fracture flow in the subsurface had higher specific capacities.

Table 6. Well hydraulics for the Timken Dewatering Wells

Well Log Number	Well ID	Pre-Pumping Static WL Feet Surface Elevation 1081 *	Pumping Water Level Feet	Pumping Rate GPM	Drawdown Feet	Specific Capacity GPM/Foot	Aquifer Type
2039329	TDW1	52	109	10	57	0.18	Sandstone
2039330	TDW2	52	109	10	57	0.18	Sandstone
2039331	TDW3	36	109	75	73	1.03	Sandstone
2039333	TDW4	47	109	150	62	2.42	Sandstone
2039335	TDW5	35	109	150	74	2.03	Sandstone
2039336	TDW6	26	109	5	83	0.06	Sandstone

*Original static water levels calculated from depth to water data on well logs

4.3.2 Domestic Water Well Hydraulics near the Timken Dewatering Operations

Table 7 shows the results of the pumping/bail-down tests done by the well driller for the domestic water wells at the time that the well was drilled. Two types of aquifers are represented: the unconsolidated glacial sand and gravel beds and the bedrock.

Specific capacity of the well in terms of gallon per minute per foot of drawdown (gpm/ft.) was estimated. These data were used to determine how much water was flowing into the well for every foot of drawdown based on the pumping rate.

Trends in the data for the domestic water wells completed in the sand and gravel aquifers are as follows:

- Pumping rates varied from 10 to 30 gpm.
- Pre-pumping water levels varied from 15 to 50 feet below the land surface depending on elevation.
- Drawdown in the well during pumping was generally zero, indicating that these wells could have been pumped at a higher rate.
- Specific capacity of the wells varied from 10 to 30 gpm/foot of drawdown.

Trends in the data for the domestic water wells completed in the bedrock are as follows:

- Pumping rates varied from 6 to 27 gpm.
- Pre-pumping water levels varied from 2 to 80 feet below the land surface depending on elevation.
- Drawdown in the wells during pumping varied from zero to 100 feet.
- Specific capacities of the wells varied from 0.1 to 25 gpm/foot of drawdown.

Table 7. Domestic Well Hydraulics Based on Driller Bail-down Test Data

Well Log Number	Well ID	Total Depth Feet	Casing Length Feet	Static WL Feet (log)	Pumping Water Levels Feet	Pumping Rate GPM	Drawdown Feet	Specific Capacity* GPM/FT	Aquifer Type
Unconsolidated Glacial Sand and Gravel Aquifers									
964566	AS	60	57	15	15	30	0	30	Gavel
559730	KKS	94	94	50	50	10	0	10	Sand and Gravel
Consolidated Bedrock Aquifers									
605207	MP2	115	70	65	83	25	18	1.4	Limestone
605215	NW	93	60	45	73	12	28	0.4	Limestone
601049	WP	48	31	22	22	12	0	12.0	Limestone
800458	LC	77	56	30	47	16	17	0.9	Limestone
955284	AD	210	106	80	180	10	100	0.1	Sandstone
262417	TB1	150	102	52	130	6	78	0.1	Sandstone
438679	CG	81	77	2	14	20	12	1.7	Sandstone
2027329	WS	216	176	55	55	25	0	25.0	Sandstone
2038384	KW	75	32	24	35	27	11	2.5	Sandstone
930454	SB	120	80	40	40	20	0	20.0	Sandstone
729470	HBE	58	39	20	32	16	12	1.3	Shale
2015013	WA	58	72	40	42	20	2	10.0	Shale
859388	HBA	90	64	50	50	20	0	20.0	Shale
811407	OC	105	46	30	70	18	40	0.5	Shale
744587	GS	115	64	59	100	20	41	0.5	Shale
1006015	SH	110	58	50	55	25	5	5.0	Shale
638362	CH	70	53.1	30	35	14	5	2.8	Shale
2039116	RH	68	61	15	40	25	25	1.0	Shale
793890	RG	92	62	31	39	20	8	2.5	Shale
964160	BM	133	49	43	53	18	10	1.8	Shale
873475	KT	145	73	69	84	18	15	1.2	Shale
899672	KS	155	132	40	80	25	40	0.6	Shale
643125	EP	53	50	20	20	10	0	10.0	Shale

*Calculated value from well log data - parameter not provided by driller

4.4 INITIAL GROUND WATER LEVEL IMPACT ASSESSMENT

Figure 13 shows locations of the water supply wells used to monitor ground water levels during the investigation. The field work to set up the monitoring locations for the wells was done during August, 2012. Field measurements were obtained during September 2012 through September

2013. It should be noted that at the time that the project was set up the Timken dewatering operation was already in effect. As a result, background water levels prior to pumping were never measured and not available for reference. As a result, the original water levels in the domestic wells, documented on the well logs at the time they were drilled were used for reference. The original ground water elevation across the study area was taken from the ODNR-DSWR Potentiometric Surface Mapping for the area (Figure 6). The original water level elevation at the Timken dewatering site was estimated to be 1050 feet amsl.

4.4.1 Ground Water Elevation Levels for September 17, 2012

Figure 16 shows the ground water elevation in the monitoring well network as measured on September 17, 2012. The pumping water level in the Timken dewatering wells was 972 feet amsl. At this time Timken was pumping at a rate of approximately 280 gpm. Approximately 24 million gallons of water had been pumped from the subsurface (Table 4).

Based on the mapping, two (2) ground water highs were present in the study area:

- The first ground water high was noted in the southern part of the study area south of Allenwood Road. This ground water high is associated with monitoring wells TB-1, TB-2, KW, BM, and KT. This ground water high is associated with a natural surface and ground water divide defined by the boundary between the Sherrick Run and Wolf Creek basins (Figure 2).
- The second ground water “high” shown on the map is associated with the Timken ground water monitoring wells TSH-4 through TSH-7. These wells are nested wells completed at different elevations in both the glacial materials and the bedrock. The ground water level is higher in the shallower wells completed in the glacial materials. The ground water levels are deeper in the bedrock wells. As a result, these wells reflect the downward movement of the ground water from a high head in the glacial materials to a lower head in the bedrock. In addition these wells demonstrate the interconnection of the two aquifer systems confirming the movement of water from the glacial materials into the bedrock.

Based on the mapping, the majority of the cone of depression resulting from the Timken dewatering operation is confined to the Timken property to the west and north of the pumping center. However, the cone of depression south and east of the Timken dewatering center does extend off-site under Whipple and Shepler Church Roads.

4.4.2 Distance Drawdown Assessment Based on September 17, 2012 Ground Water Level Measurements

To evaluate the impact that the Timken construction dewatering was having on nearby water supply wells, the ODNR-DSWR calculated the drawdown in individual wells by using the original static water levels at the time that the wells were drilled and subtracting the measured water levels in the wells.

Table 8 shows the observation well data used for the distance-drawdown plot. Shown in the table are the distance each observation well was from the Timken dewatering wells, the original static water level, the final water level, and the total drawdown in each well.

Based on the observation well data, the following trends in the data are presented for review:

- Aquifer types for individual wells can vary from bedrock wells completed in sandstone, limestone and shale units to wells completed in the unconsolidated glacial ground moraine or outwash material.
- Individual well depths can vary from 46 feet up to 216 feet below the land surface.
- Casing lengths vary from 32 feet up to 176 feet.
- Original static water levels in the wells at the time the wells were drilled varied from 1 to 2 feet below the land surface up to 65 feet below the land surface depending on surface elevation.

Figure 17 represents a distance drawdown plot developed from the data presented in Table 8. Trends in these data shows:

- Drawdown in the Timken dewatering wells is variable and most likely depends on well completion and fracture pattern in the bedrock.
- Drawdown in the domestic water wells is also variable and also depends on well completion and fracture pattern in the bedrock.
- Based on the linear regression analysis it would appear the zero drawdown for wells in the area would extend approximately 5500 feet from the Timken construction dewatering center.

The most highly affected wells are located along Whipple, Faircrest and Shepler Church Roads located southeast of the construction dewatering operations. In this area, the drawdown can vary from approximately 5.39 feet up to 19.24 feet in individual wells.

Figure 18 shows the actual drawdown in the individual wells relative to the Timken dewatering wells. The area of impact is defined by the zero drawdown contour line. Trends in the data are as follows:

- The majority of the cone of depression is confined to property owned by Timken in the west, north and eastern parts of the Timken property.
- The cone of depression spreads off site to the east under Whipple Road. The drawdown in an individual well could vary from 5 up to 25 feet.
- The cone of depression spreads off site to the south under Faircrest Road and Shepler Church Road. Under Faircrest Road, the drawdown in an individual well could vary from 35 up to 55 feet. Under Shepler Church Road, the drawdown in an individual well could vary from zero up to 35 feet depending on the distance from the dewatering center.

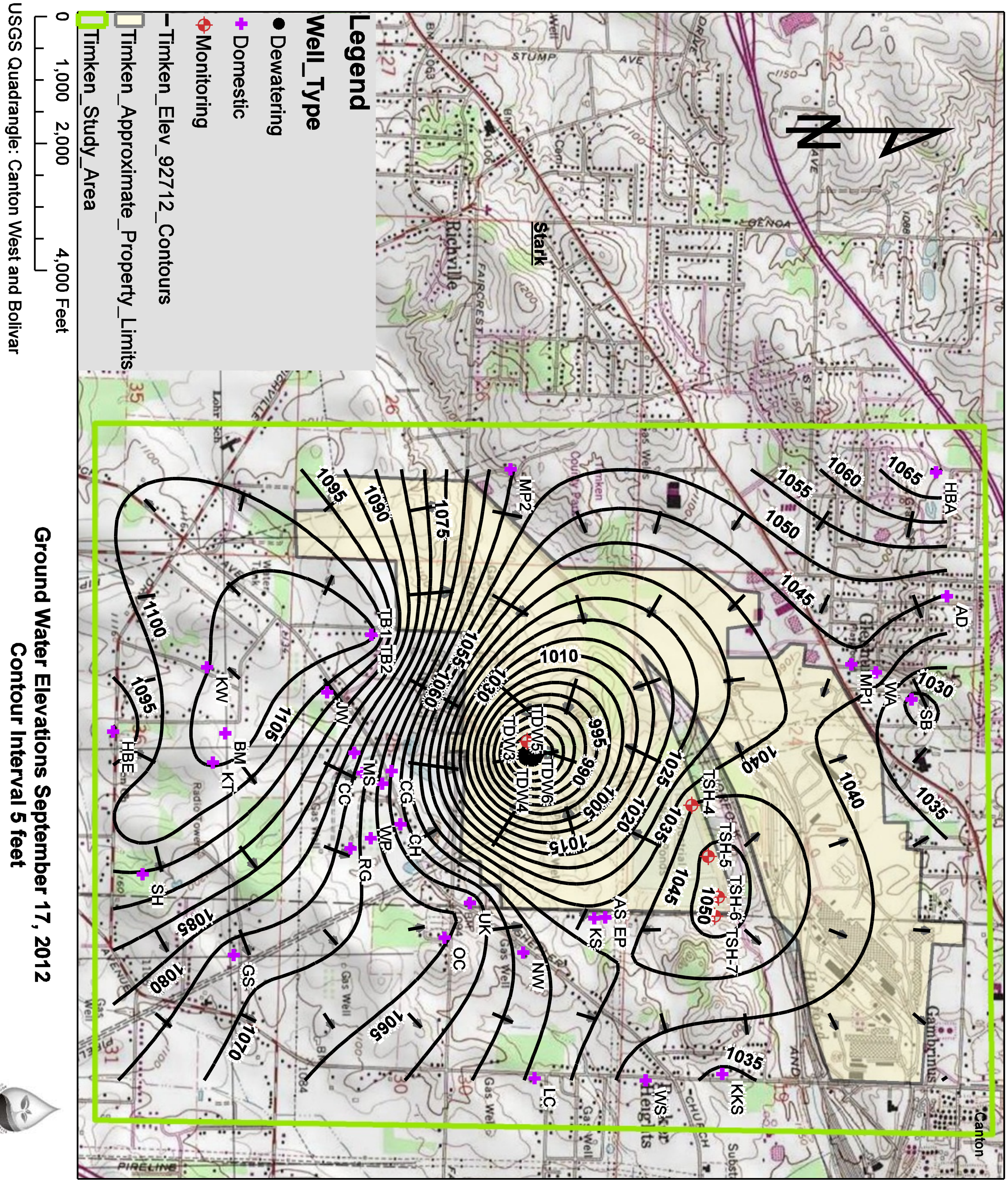

Figure 16. Ground Water Levels for September 17, 2012

Table 8. Timken Dewatering Distance Drawdown Observation Well Data.

Well Log Number	Well ID	Total Depth Feet	Casing Length Feet	Static WL Feet (log)	Surface Elevation	Depth 9/17/12	Distance from Timken DWW Feet	DD Original-91712	Aquifer Type
Unconsolidated Glacial Aquifers									
	TSH-5	49		30.61	1087.27	36	3247.4	-5.39	Clay
964566	AS	60	57	15	1068	26.06	2852.3	-11.06	Gavel
	TSH-7	22		3.81	1068.2	15.5	3844.9	-11.69	Sand
	TSH-6	51		21.7	1081.38	30.33	3742.2	-8.63	Sand and Gravel
559730	KKS	94	94	50	1087	52.78	5899.9	-2.78	Sand and Gravel
Consolidated Bedrock Aquifers									
2039333	TDW4	93	18	8	1051.8	79.8	0	-71.8	Sandstone
2039329	TDW1	96	54	5	1057	85	0	-80	Sandstone
2039330	TDW2	96	44	5	1057.5	85.5	0	-80.5	Sandstone
2039331	TDW3	86	32	1	1046.4	74.4	0	-73.4	Sandstone
2039335	TDW5	93		10	1056.2	84.2	0	-74.2	Sandstone
2039336	TDW6	96	53	3	1057.6	85.6	0	-82.6	Sandstone
438679	CG	81	77	2	1083		2184.4		Sandstone
262417	TB1	150	102	52	1131	85.51	3103.6		Sandstone
2038384	KW	75	32	24	1132	27.25	5255.4	-3.25	Sandstone
2027329	WS	216	176	55	1086	49.35	5512	5.65	Sandstone
930454	SB	120	80	40	1081	52.86	6089.1	-12.86	Sandstone
955284	AD	210	106	80	1130	85.34	7040.5	-5.34	Sandstone
	TSH-4	66		40.58	1092.95	47.67	2628.6	-7.09	Shale
231501	TB2	46	33	16	1131	23.85	3103.6	-7.85	Shale
964160	BM	133	49	43	1156	46.35	4796.1	-3.35	Shale
873475	KT	145	73	69	1183	77.54	4976	-8.54	Shale
744587	GS	115	64	59	1125	53.22	5613	5.78	Shale
2015013	WA	58		38	1086	42.2	5615.9	-4.2	Shale
1006015	SH	110	58	50	1140	35.55	6362.8	14.45	Shale
859388	HBA	90	64	50	1105	34.58	7802.2	15.42	Shale
729470	HBE	58	39	20	1115	25.85	6558.3	-5.85	Shale
605207	MP2	115	70	65	1101	45.76	4423.5	19.24	Limestone

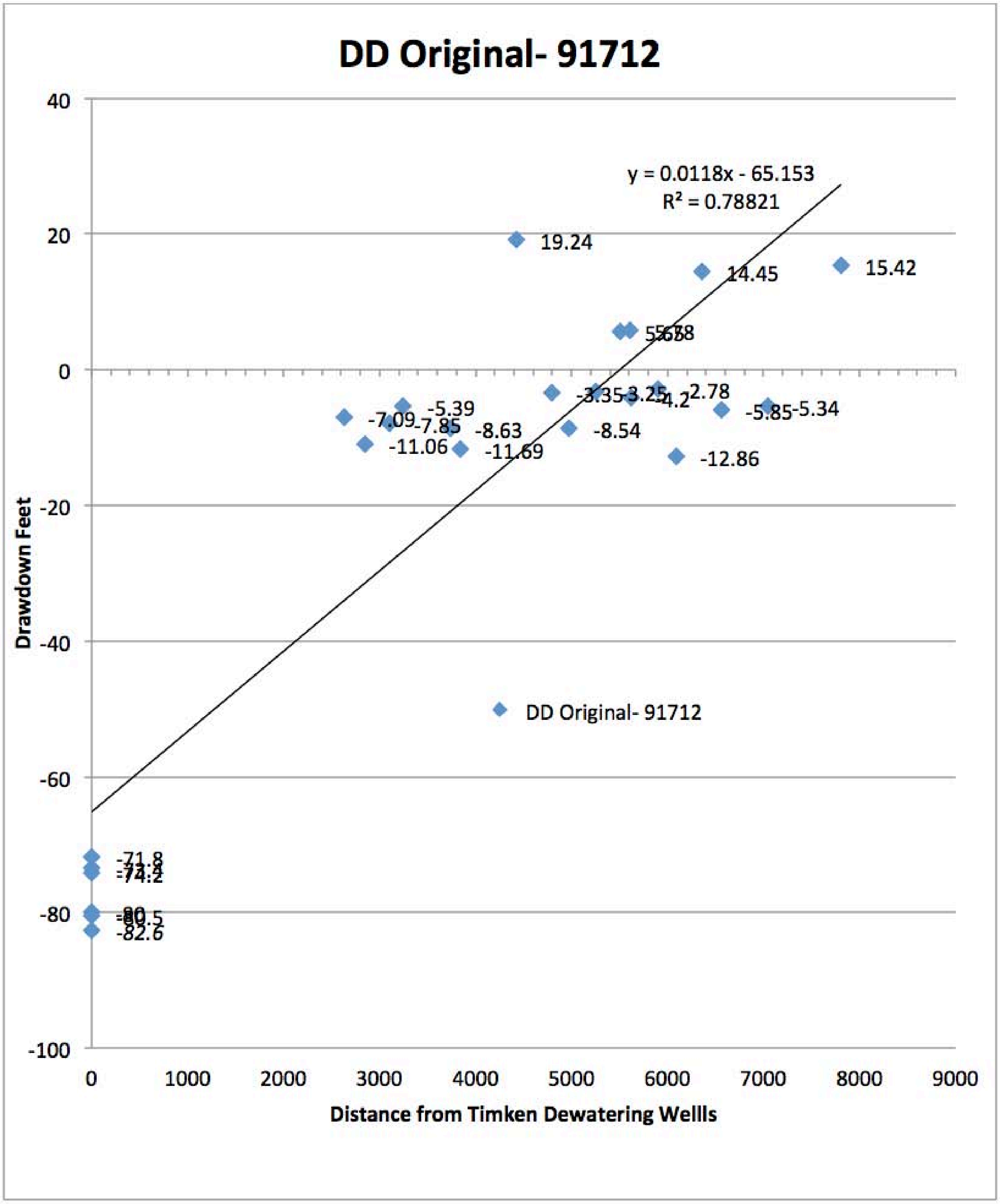

Figure 17. Distance Drawdown Plot for Domestic Water Wells Within Cone of Influence of the Timken Construction Dewatering Study Area

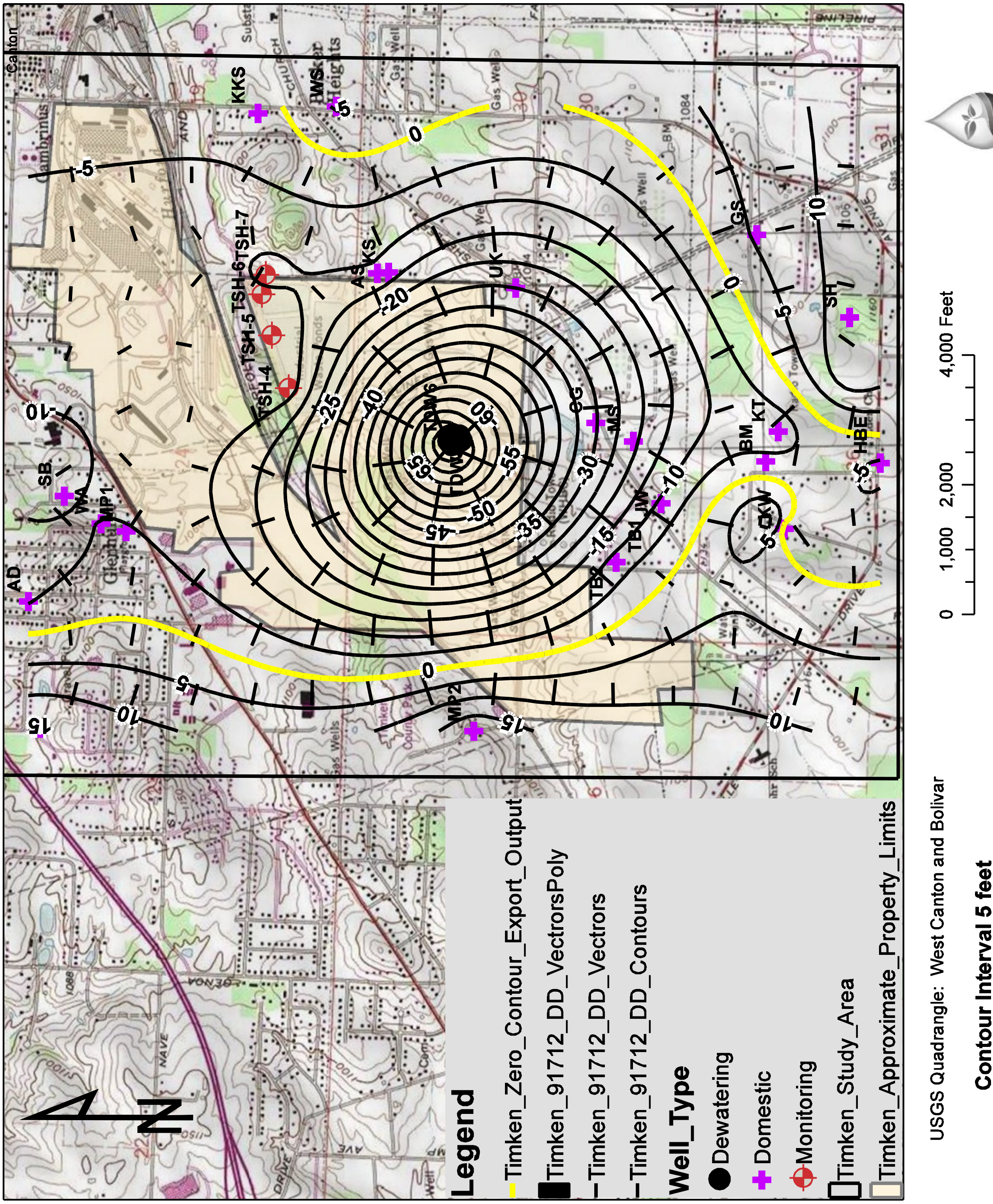

Figure 18. Actual Ground Water Level Drawdown Measured for September 17, 2012

4.5 LONG-TERM GROUND WATER MONITORING PROGRAM

After the initial ground water assessment was complete, the ODNR-DSWR and the SCHD set up a program to measure the continued impact of the construction dewatering on the local domestic water supply wells. The SCHD agreed to assist with monthly ground water level data collection. In addition, the SCHD would continue to interact with the local residents and document any continued complaints. The ODNR-DSWR would continue to map the ground water data. Weekly conference call would be held with Timken, SCHD, and ODNR-DSWR to review the progress of the construction, ground water levels and complaints. It was agreed that the ground water level monitoring would continue until the ground water levels had recovered to normal or near normal. It was estimated that the ground water monitoring would continue through at least September of 2013.

4.5.1 Ground Water Elevation Levels for December 18, 2012

Figure 19 represents a map showing ground water elevations as measured on December 18, 2012. Based on the historic data, Timken set the target depth for the vertical caster excavation at 89.5 feet below the land surface. This target depth was reach during November 2012. The pumping rate from all six dewatering wells had declined to approximately 71.2 gpm. At this time, Timken had decided to raise the pump intakes to approximately 981.5 feet amsl. Timken had pumped approximately 44 million gallons of water from the dewatering wells (Table 4).

The shape of the cone of depression shown on the figure is similar to the cone of depression measured on September 17, 2012. Two (2) ground water highs are present in the study area:

- The first ground water high is located north of the dewatering operation near the intersection of Navarre and Saratoga Roads. The ground water elevation in the area is approximately 1075 feet amsl.
- The second ground water high is located in the southern part of the study area south of Allenwood Road near monitoring wells KW, BM and KT. The ground water elevation in the area is approximately 1105 feet amsl.

At this time, the cone of depression appeared to have stabilized**.**

4.5.2 Ground Water Elevation Levels for March 15, 2013

Figure 20 represents a map showing the ground water elevations as measured on March 15, 2013. Based on the data, the pumping rate from the dewatering wells had continued to decline to approximately 31.2 gpm on January 18, 2013. The pumps had been raised to approximately 1016 feet amsl. Timken had pumped approximately 46 million gallons of water from the subsurface. On February 8, Timken had discontinued use of the extraction wells and was relying solely on the two (2) sump pumps to remove storm water and ground water from the excavation.

Based on the ground water level mapping the ground water levels around the excavation and in the monitoring wells were beginning to rise. The pumping water level had risen from 975 feet to 1025 feet amsl since the December 18, 2012 measurements.

4.5.3 Ground Water Elevation Levels for July 18, 2013

Figure 21 shows the ground water elevation as measured on July 18, 2013. On June 6, Timken had discontinued dewatering with the sump pumps and ground water levels were allowed to continue to rise. In addition, dewatering wells TDW-1 through TDW-6 had been plugged. Well TDW-3A near the scale pit was used for monitoring ground water level recovery near the vertical caster excavation.

Based on the ground water elevation across the area, ground water levels had returned to normal or near normal. The ground water high near the south was still present. The ground water gradient was flowing toward the northeast. The artificial ground water high caused by the pumping near TSH-4 through 7 appeared to no longer be present. Ground water elevations ranged from 1115 near well KW (along Surmay Road) to a low of 1030 near 23rd Street to the north. Near the Timken pumping center, the ground water elevation was mapped at approximately 1060 feet amsl. This level is approximately 35 feet higher than what was measured on March 15, 2013.

4.5.4 Ground Water Elevation Levels for September 19, 2013

Figure 22 shows the ground water elevation as measured on September 19, 2013. These data show a similar trend to the July 18, 2013 data. The ground water gradient is from the southwest toward the northeast. There is some flattening of the ground water elevations. The ground water elevations range from 1105 feet amsl in the south to 1035 feet amsl near 23rd Street. At the Timken dewatering center the ground water elevation was mapped at approximately 1055 feet amsl. These ground water elevations correlate with the historic regional ground water flow as mapped in Figure 6.

4.5.5 Hydrographs for the Domestic Wells Located Inside and Outside the Impacted Area

Figures 23 and 24 are hydrographs drawn using the ground water level data obtained from the 2012 through 2013 measurements. These graphs show the fluctuation in ground water levels with time showing the degree of impact caused by the dewatering and the subsequent recovery of the ground water levels. The pumping water level in the Timken dewatering well TDW-6 is shown on the graph. The depth to water for the last couple months of dewatering was taken from the sump pit elevation. In addition, all of the ground water level data is compared to rainfall data over the same period of time.

Figure 23 represents hydrographs for individual water wells outside the zero drawdown contour line. These data suggest that the ground water levels in individual wells did not fluctuate more than a few feet. The fluctuation in water levels is due to normal seasonal variations and individual well usel. From May to November, the water table typically declines ½ to 1 foot each month. From December to May, the ground water levels typically rise ½ to 1 foot per month.

The water level fluctuations measured in these wells is within the seasonal variation expected for this aquifer.

Figure 24 represents hydrographs for individual water wells inside the zero drawdown contour line. These wells show some impact to the ground water levels depending on well location. It is possible that some of the ground water level fluctuation could be the result of seasonal ground water level changes as well as normal pumping. However, when the total ground water level fluctuation is compared to the pumping in TDW-6, the water level declines appear to coincide with the construction dewatering. Of special note are the water level declines recorded in the wells at 3990 and 4004 Shepler Church Road. The water level in these two wells declined 10-12 feet over the first four months of dewatering. This decline is due to more than the normal seasonal decline and can be attributed to the Timken dewatering. Upon turning the dewatering pumps off and allowing the ground water levels to return to normal, the water levels in the domestic water wells inside the zero drawdown contours returned to their natural static water levels. As of September 19, 2013, all but one well had higher water levels than on August 31, 2012.

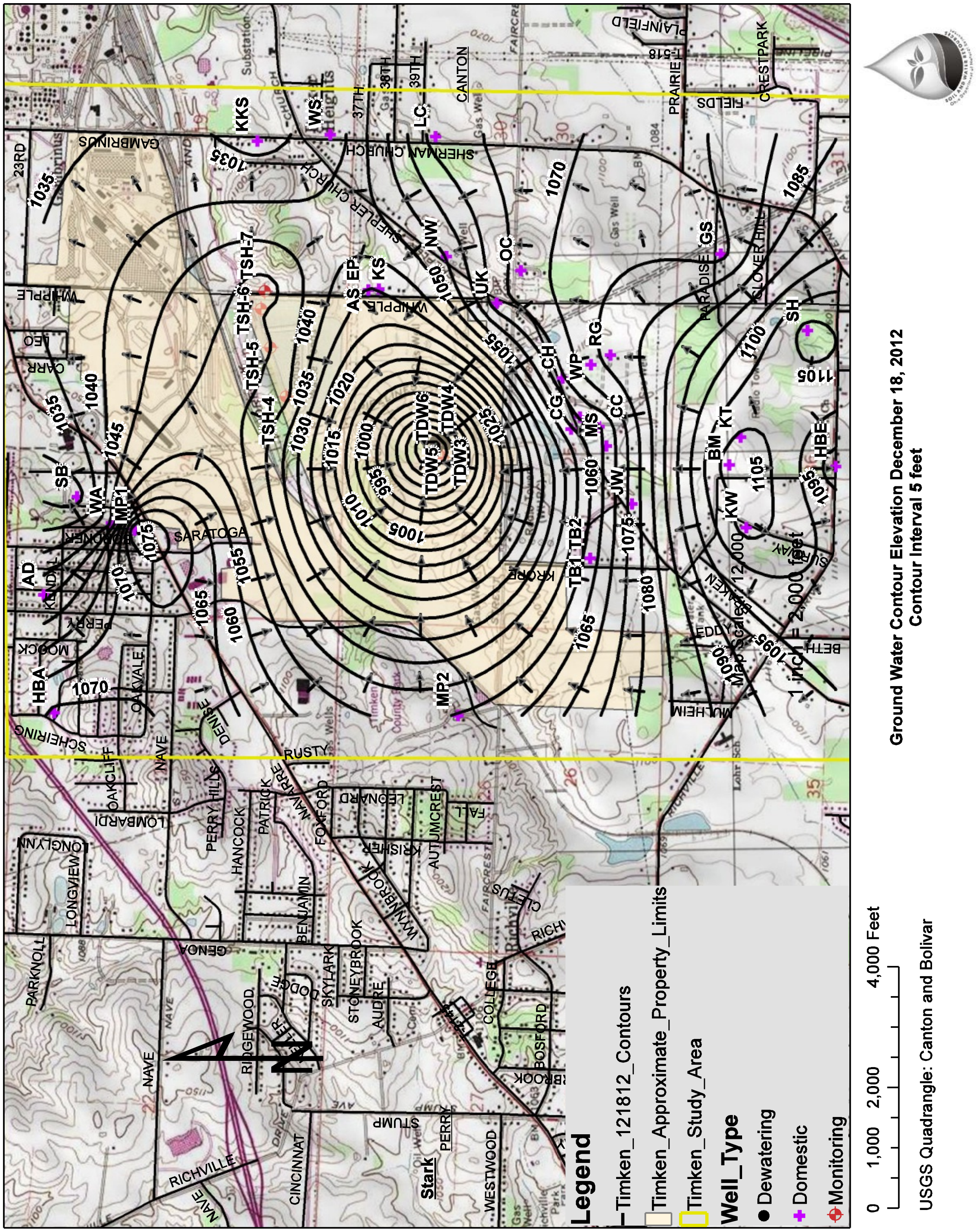

Figure 19. Ground Water Elevations Measured on December 18, 2012

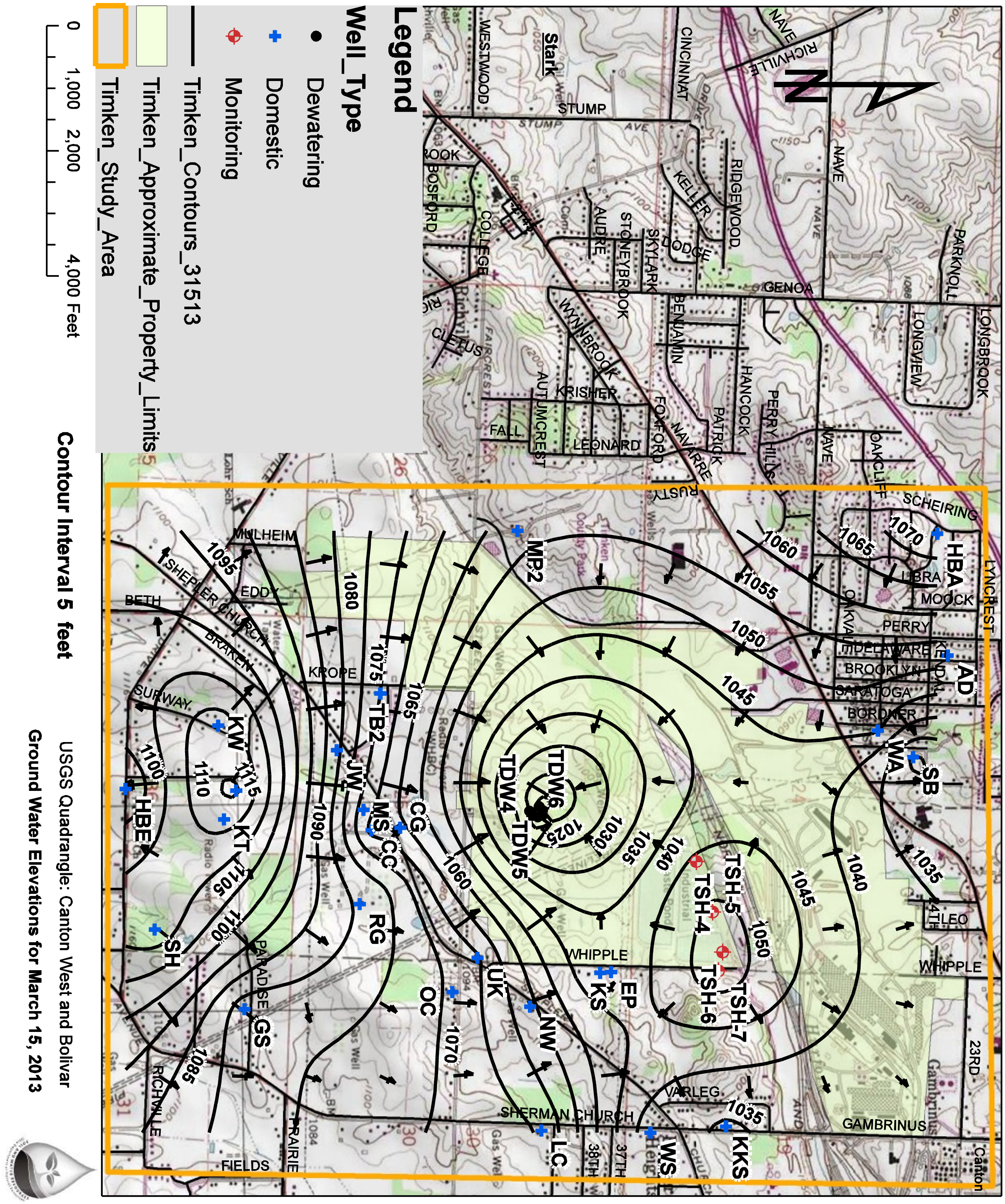

Figure 20. Ground Water Elevations Measured on March 15, 2013

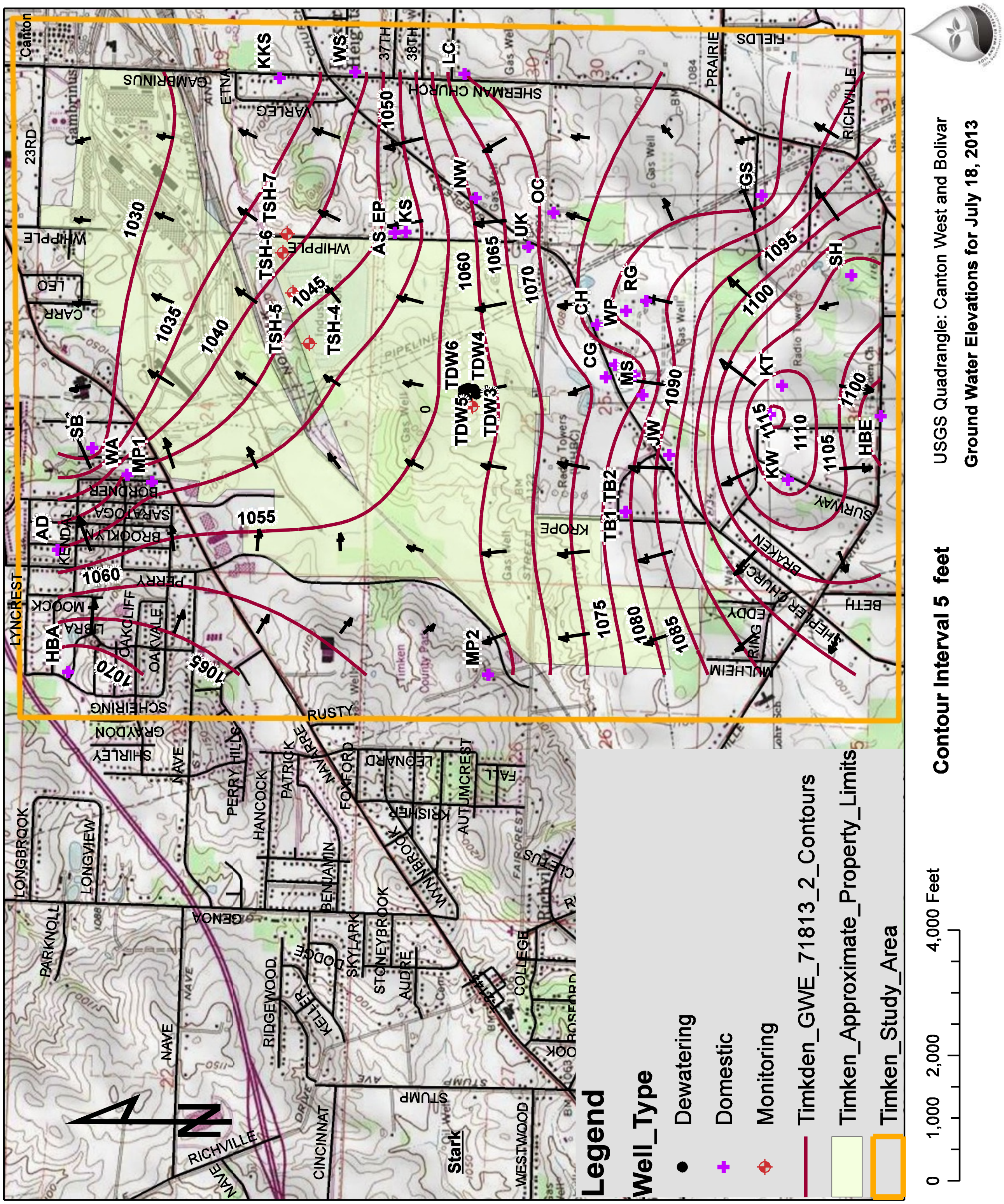

Figure 21 Ground Water Elevations Measured on July 18, 2013

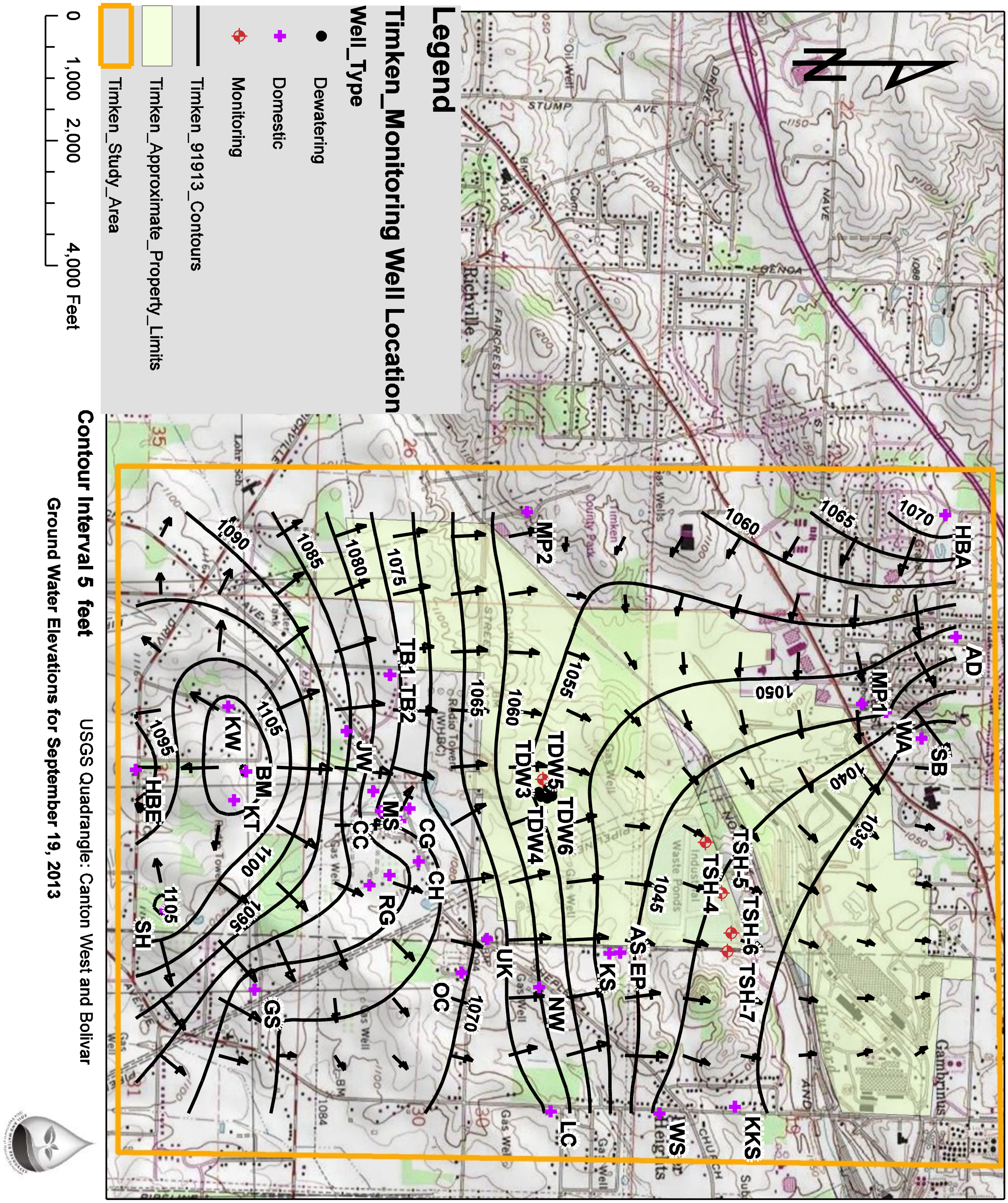

Figure 22. Ground Water Elevations Measured on September 19, 2013

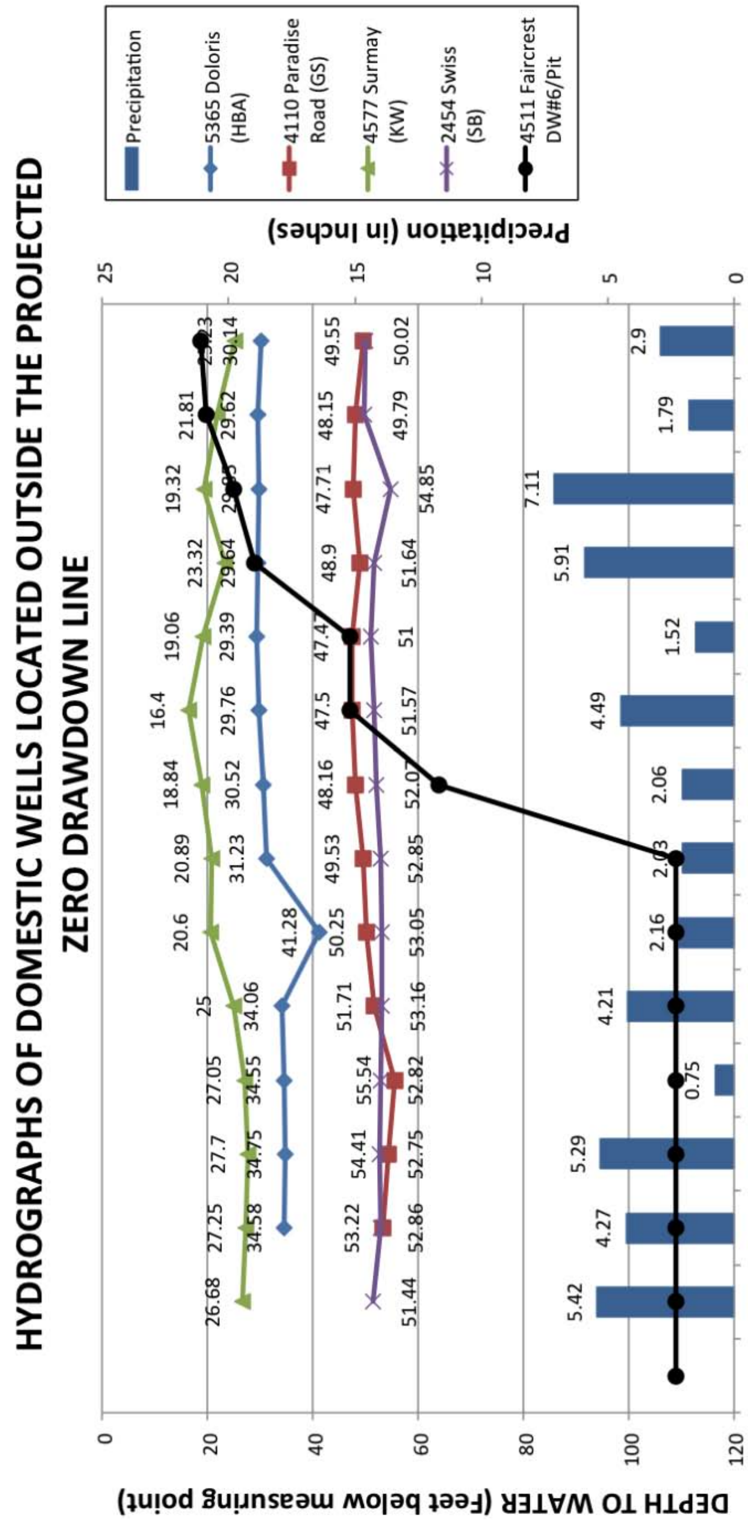

Figure 23. Hydrograph of Water Levels in Domestic Water Wells Outside the Zero Drawdown Contour Line

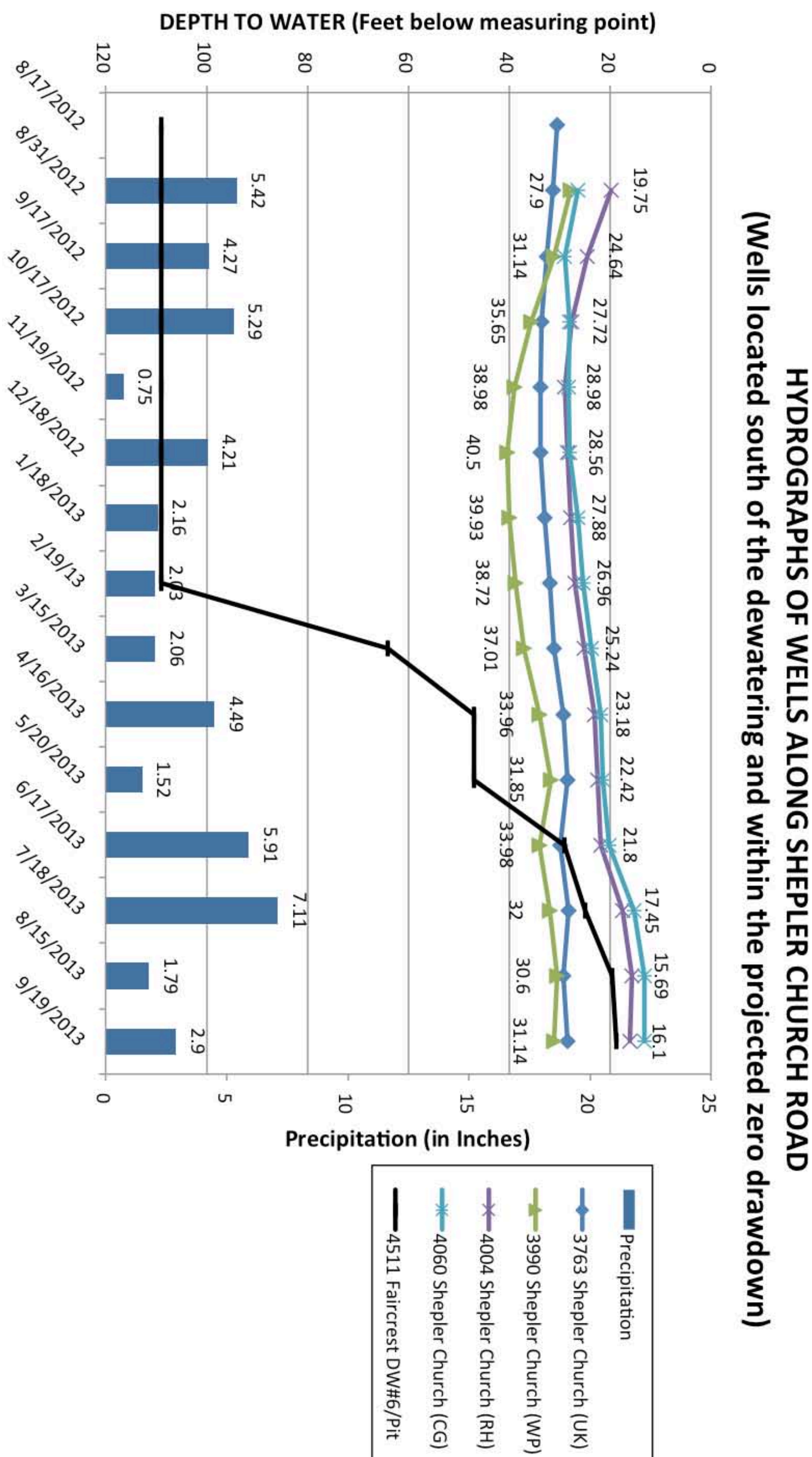

Figure 24. Hydrograph of Water Levels in Domestic Water Well Inside the Zero Drawdown Contour Line.

5.0 FINAL IMPACT ASSESSMENT AND COMPLAINT RESOLUTION

Once the initial ground water impact assessment and the long-term ground water monitoring program was established, the ODNR-DSWR suggested that Timken hire an outside consultant that could sort through the data and assist with the assessment of individual complaints. As a result, Timken retained Sanborn Head (SH) to work with the homeowner, driller and the SCHD to validate the condition of each well and the need to drill a new well as a result of a decline in ground water levels.

5.1 GEOGRAPHIC EXTENT OF THE INFERRED IMPACT AREA

The geographic extent of the impact area was established by using the distance drawdown plot shown on Figure 17. In addition, the drawdown data for September 17, 2012 data set as shown on Figure 18 was also used to define the geographic extent of the impact area. The -10 foot contour was the first contour on the map to show full closure. The closure of the -10 foot contour was based on the two ground water highs defined by the September 17, 2012 data set.

The lack of closure for the -5 and zero drawdown contours in the study area is most likely the result of a lack of data points. In addition, the lack of closure could also be due in part to the periodic pumping of the domestic water wells, thus causing some lowering of the ground water levels in the northern and southern parts of the study area. However, the most conservative option for determining the geographic extent of the cone of depression was to infer closure of the -5 foot and zero drawdown contours in the northern and southern parts of the area. The extent of the inferred geographic impact from the Timken construction dewatering is shown on Figure 25.

5.2 TIMKEN RESPONSE TO COMPLAINTS

Initially SCHD screened complaints before forwarding them to Timken. If a complaint came from a property owner located several miles outside the inferred zone of influence, SCHD told the property owner that the Timken dewatering operations were not the cause of the problems associated with the well. If the complaint was inside the inferred zone of influence, the SCHD forwarded the complaint to Timken for response. Timken's response to complaints was to:

- Provide bottled drinking water and temporary water tanks as soon as logistically practical.
- Retain the services of a well driller and pump installer to assist in the evaluation of complaints.
- Evaluate the condition of each individual water supply well.

To evaluate an individual complaint, the driller would assess the flow rate from the well. If the well ran dry in a relatively short period, Timken provided replacement water. In some instances, it was concluded that there were other problems not associated with the Timken dewatering operations (e.g., bad pressure tank, pipes clogged with iron precipitation, poor water quality, etc.).

If the residence was out of water and located within the inferred zone of influence, Timken paid to replace the well. If the residence was out of water but located just outside the zone of influence, Timken continued to provide temporary water tanks until the monitoring program concluded.

In total, Timken responded to 77 complaints. Table 9 summarizes the status of the complaints. The complainants are split into the following categories:

- **Out of Range (18)** – this category included properties that were outside the inferred zone of influence.
- **No Problem Identified (19)** – this category included residents that wanted to get their name on the complaint list as a precautionary measure, in case problems developed later.
- **Problem Unrelated (6)** – in this category, some systems had problems related to their water system and not due to the Timken construction dewatering operations.
- **Well Replaced (34)** – this category included property owners that had a legitimate problem. In this case, Timken contracted with a local well driller to install new wells and pumps to replace the older wells. The old wells were sealed in accordance with SCDH requirements.
- **Public Water Connection (1)** – Timken paid for connecting one resident within the zone of influence to public water that was available on the street.

Table 9. Complaint Database Summary Report for the Timken Study Area.

Address	Parcel ID	Date Reported	Review Status
Homeowners Out of Range (18)			
4125 Groveland	4303644	20-Aug-12	Out of Range
4555 Surmay	4315505	20-Aug-12	Out of Range
4591 Richville	4302124	20-Aug-12	Out of Range
2347 Delaware	4319161	11-Sep-12	Out of Range
3113 Varley	1300979	11-Sep-12	Out of Range
4754 Allenwood	4300140	11-Sep-12	Out of Range
4730 Allenwood	4315501	18-Sep-12	Out of Range
5340 Charm	4313883	18-Sep-12	Out of Range
4411 Shepler Church	4315819	1-Oct-12	Out of Range
4124 Paradise	1302229	15-Oct-12	Out of Range
4001 Clover Hill	1305421	29-Oct-12	Out of Range
4685 Allenwood	4315339	29-Oct-12	Out of Range
5601 Faircrest	4305047	29-Oct-12	Out of Range
4119 Paradise	1310061	5-Nov-12	Out of Range
4663 Surmay	4315495	4-Jan-13	Out of Range
3203 Gambrinus	1300177	5-Feb-13	Out of Range
4440 Shepler Church	4301222	25-Feb-13	Out of Range
4555 Surmay	4315505	14-May-13	Out of Range
Homeowners No problems Identified (19)			
4070 Kropf	4300469	17-Aug-12	No Problems Identified
3913 Shepler Church	4316420	20-Aug-12	No Problems Identified

4191 Shepler Church	4300802	20-Aug-12	No Problems Identified
4500 Shermont	4318382	20-Aug-12	No Problems Identified
4545 Surmay	4315165	20-Aug-12	No Problems Identified
3990 Shepler Church	4312432	22-Aug-12	No Problems Identified
4020 Faircrest	4316428	23-Aug-12	No Problems Identified
4161 Shepler Church	4308481	27-Aug-12	No Problems Identified
3331 Gambrinus	1309708	30-Aug-12	No Problems Identified
3718 Whipple	1308958	4-Sep-12	No Problems Identified
4020 Shepler Church	4301740	18-Sep-12	No Problems Identified
4422 Shepler Church	4301221	18-Sep-12	No Problems Identified
4144 Shepler Church	4317129	24-Sep-12	No Problems Identified
3963 Shepler Church	4316331	15-Oct-12	No Problems Identified
3831 Shepler Church	4316632	17-Oct-12	No Problems Identified
4681 Hurless	4306817	11-Dec-12	No Problems Identified
4667 Allenwood	4317587	13-Feb-13	No Problems Identified
4111 Shelpler Church	4300980	22-Feb-13	No Problems Identified
4075 Faircrest	4300775	14-May-13	No Problems Identified
Homeowners Problem Unrelated (6)			
3728 Whipple	1309046	20-Aug-12	Problem Unrelated
4060 Shepler Church	4318489	17-Aug-12	Problem Unrelated
3751 Shepler Church	4301730	25-Oct-12	Problem Unrelated
3849 Shepler Church	4302030	25-Jan-13	Problem Unrelated
4641 Allenwood	4315275	25-Feb-13	Problem Unrelated
4232 Shelpler Church	4301147	19-Mar-13	Problem Unrelated
Homeowners Well Replaced (34)			
3920 Shepler Church	4315830	17-Aug-12	Well Replaced
3932 Shepler Church	4315539	17-Aug-12	Well Replaced
4002 Faircrest	1302190	17-Aug-12	Well Replaced
4031 Shepler Church	4315423	17-Aug-12	Well Replaced
4066 Shepler Church	4318488	17-Aug-12	Well Replaced
4080 Shepler Church (rental)	4315533	17-Aug-12	Well Replaced
4180 Shepler Church	4315253	17-Aug-12	Well Replaced
3966 Shepler Church	4300680	20-Aug-12	Well Replaced
4151 Shepler Church	10002913	20-Aug-12	Well Replaced
4160 Shepler Church	4315595	20-Aug-12	Well Replaced
4202 Sherman Church	1301838	20-Aug-12	Well Replaced
4181 Shepler Church	4301467	21-Aug-12	Well Replaced
4110 Shepler Church	4315617	27-Aug-12	Well Replaced
4200 Shepler Church	4300024	27-Aug-12	Well Replaced
4126 Shepler Church	4300852	30-Aug-12	Well Replaced
4210 Shepler Church	4301951	4-Sep-12	Well Replaced
4026 Shepler Church	4300707	5-Sep-12	Well Replaced
4141 Shepler Church Rd.	4300268	7-Sep-12	Well Replaced
3969 Shepler Church	4316268	11-Sep-12	Well Replaced
4130 Kropf	4301592	11-Sep-12	Well Replaced
4215 Shepler Church	4300231	13-Sep-12	Well Replaced
4101 Shepler Church	4301619	18-Sep-12	Well Replaced
4004 Shepler Church Rd.	4319160	26-Sep-12	Well Replaced

3502 Shepler Church	1308980	27-Sep-12	Well Replaced
3476 Shepler Church	1308880	1-Oct-12	Well Replaced
4014 Shepler Church	4315273	4-Oct-12	Well Replaced
4022 Shepler Church	4315597	9-Oct-12	Well Replaced
4077 Shepler Church	4315375	9-Oct-12	Well Replaced
4000 Shepler Church	4312149	16-Oct-12	Well Replaced
3949 Shepler Church	4316278	17-Oct-12	Well Replaced
3810 Whipple Ave	1301827	24-Oct-12	Well Replaced
4024 Shepler Church	4315249	25-Oct-12	Well Replaced
3984 Faircrest	1302006	6-Nov-12	Well Replaced
3820 Whipple	1301992	9-Nov-12	Well Replaced
Homeowner Connected to City Water (1)			
4230 Kropf	4302006	24-Sep-12	City Water

After Timken, SCHD and Sanborn Head

5.3 TIMKEN NEW WELLS DRILLED IN THE STUDY AREA

Upon deciding to drill a new water supply well, Timken contacted a well driller. The well driller would apply to the Stark County Health Department for a permit to drill the new water supply well.

Figure 26 shows the locations of the new wells drilled by Timken. Table 10 shows the data for each individual well drilled by Timken to replace a specific water supply well affected by the dewatering operations. Based on the data provided by Timken, 34 new replacement wells have been drilled in the study. Trends in these data are as follows:

- Aquifer type for these wells vary from sandstone, shale and limestone
- Depth for the new wells range from 146 feet up to 400 feet below the land surface
- Static water levels varied from 21 up to 176 feet below the land surface

Appendix H contains the water well records for the new wells drilled by Timken.

Table 10. New Wells Drilled in the Timken Study Area.

WELL LOG NUMBER (NEW WELL)	WELL LOG NUMBER (OLD WELL)	SEALING REPORT NUMBER (OLD WELL)	HOUSE NO.	STREET NAME	OWNER'S FIRST NAME	OWNER'S LAST NAME	SEALING REPORT DEPTH OLD WELL	TOTAL DEPTH NEW WELL	STATIC WATER LEVEL NEW WELL	AQUIFER TYPE NEW WELL
2040779	*N/A	200122	3984	FAIRCREST		PFIFFNER	50	180	80	SANDSTONE
2039246	N/A	200041	4002	FAIRCREST	JASON	AQUINO	21	150	37	SHALE
2039836	192847	200106	4130	KROPF	ROBERT	MILLER	18	400	160	SANDSTONE
2041121	N/A	200134	4130	KROPF	ROBERT	MILLER	N/A	400	176	SANDSTONE
2040203	N/A	200116	3476	SHEPLER CHURCH		PINKERTON	N/A	240	76	SANDSTONE
2040271	N/A	200117	3502	SHEPLER CHURCH	JOHN	NOLEN	67	300	125	SHALE
2039879	N/A	300332	3920	SHEPLER CHURCH	DAVE	YOUNG	62	150	28	SHALE
2039245	336740	200048	3932	SHEPLER CHURCH		SANKO	30	150	31	SHALE
2041119	N/A	N/A	3949	SHEPLER CHURCH		GOLLIHER		150	40	SHALE
2039597	N/A	200050	3966	SHEPLER CHURCH		MODRANSKI	74	150	23	SHALE
2040205	N/A	201908	3969	SHEPLER CHURCH	RED	CHAMBERS	72	150	35	SANDSTONE
2040652	N/A	200121	4000	SHEPLER CHURCH		PITMAN	14	150	34	SHALE
2039994	2039116	200147	4004	SHEPLER CHURCH	HOBERT	HARMON	N/A	150	34	SANDSTONE
2040347	N/A	200115	4014	SHEPLER CHURCH		HAUGHT	76	220	73	SHALE
2040234	N/A	200120	4022	SHEPLER CHURCH	RICHARD	ESSIK	63	150	37	SANDSTONE
2040697	N/A	200118	4024	SHEPLER CHURCH	JOSEPH	GANG	48	220	84	SHALE
2039516	N/A	200102	4026	SHEPLER CHURCH	ED	JORDAN	N/A	150	31	LIMESTONE
2039334	438679	200043	4031	SHEPLER CHURCH		GILLILAN	75	150	21	SANDSTONE
2039363	N/A	200045	4066	SHEPLER CHURCH	MIKE	SHAPUITE	N/A	150	30	SHALE
2040751	N/A	200148	4077	SHEPLER CHURCH	RHONDA	HAMILTON	68	150	60	SHALE
2039247	N/A	200042	4080	SHEPLER CHURCH	KIRK	CHRISTMAN	47	150	31	SHALE
2041177	2041177	301858	4101	SHEPLER CHURCH		SHAW	320	320	110	SHALE
2041957	2041957	301859	4101	SHEPLER CHURCH		SHAW	320	320	130	SANDSTONE
2041959	2041959	301857	4101	SHEPLER CHURCH		SHAW	150	150	30	SHALE
2042017	N/A	N/A	4101	SHEPLER CHURCH		SHAW		340	140	SANDSTONE
2039436	N/A	200044	4110	SHEPLER CHURCH	JOHANNES	SCHLABACH	31	150	32	SHALE
2041692	493527	200135/ 200144	4126	SHEPLER CHURCH	RICHARD	MARSH	N/A/48	320	150	SANDSTONE
2039596	N/A	200104	4141	SHEPLER CHURCH		BOWMAN	N/A	280	95	SANDSTONE
2041512	N/A	200136	4151	SHEPLER CHURCH		BAKER	180	280	100	SANDSTONE
2039364	N/A	200049	4160	SHEPLER CHURCH	SCOTT	ZOLLARS	65	180	50	SHALE
2039883	N/A	300334	4180	SHEPLER CHURCH	JIM	WOODLOCK	79	146	58	SHALE
2039595	N/A	200101	4181	SHEPLER CHURCH		MCCLEARY	66	280	105	SANDSTONE
2039434	N/A	200046	4200	SHEPLER CHURCH	BRENDA	WILKS		180	50	SHALE
2039572	N/A	200103	4210	SHEPLER CHURCH	JACK	URBAN	68	220	50	SHALE
2039835	252928	200108	4215	SHEPLER CHURCH	KEN	BROWN		280	95	SHALE
2041653	N/A	200138	4202	SHERMAN CHURCH		LAHER	63	150	50	SHALE
2040698	643125	200149	3810	WHIPPLE	DIANA	SCOTT	57	150	30	SANDSTONE
2040781	N/A	N/A	3820	WHIPPLE		HECK		150	35	SANDSTONE
*N/A Not Available for reference						Max	320	400	176	
						Min	14	146	21	
						Average	84	209	67	

5.4 TIMKEN WELL SEALING REPORTS FOR THE OLD WELLS

Once the new well was installed, the driller applied for a permit from the Stark County Health Department for permission to seal the old well. Table 10 shows the details for those wells that were sealed during this project. As shown on the table, if a well log was available for the well to be plugged it was noted on the table for reference.

Based on the data, the wells that were sealed ranged from 14 feet up to 180 feet deep. At 4101 Shepler Church Road, the driller had trouble finding water. Multiple wells were drilled on their property to find an acceptable water supply. All but the latest well were sealed. Appendix I contains copies of all the well sealing reports.

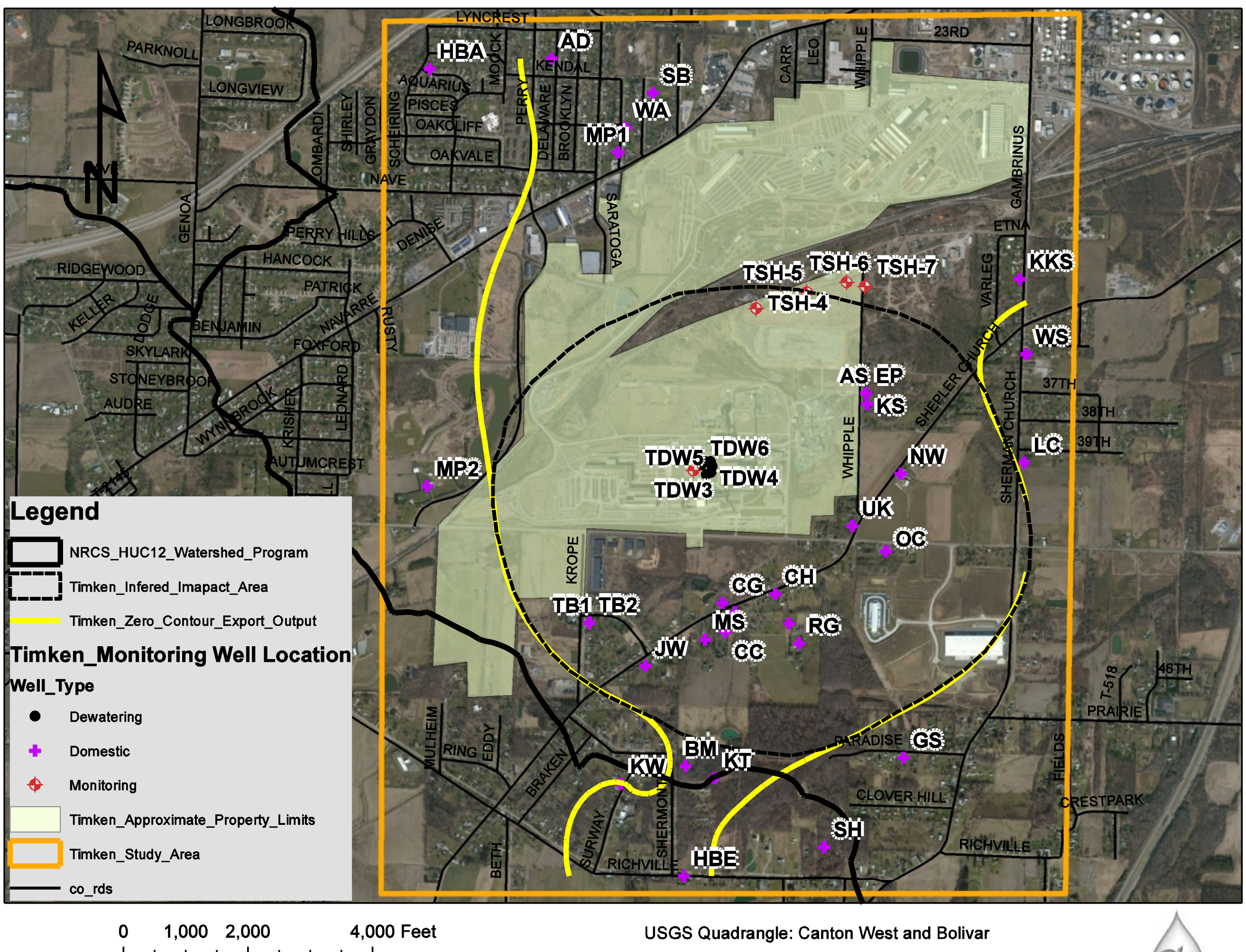

Figure 25. Inferred Cone of Influence as Defined by Sanborn Head Based on the September 17, 2012 Ground Water Monitoring Data after Timken and Sanborn Head, modified by ODNR-DSWR

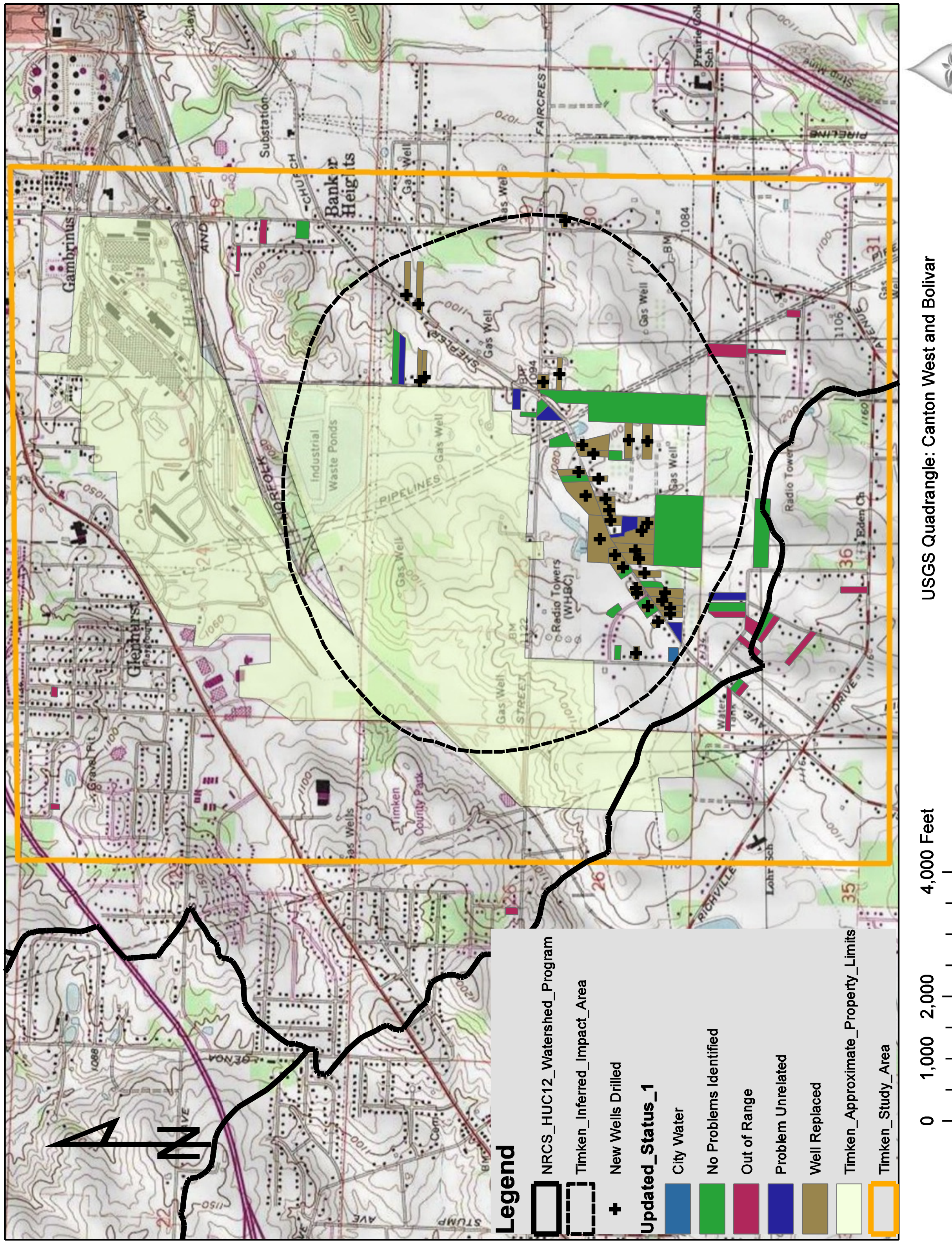

Figure 26. New Wells drilled in the Timken study area After Timken and Sanborn Head, modified by ODNR-DSWR

6.0 CONCLUSIONS

6.1 SITE HYDROGEOLOGY CONCLUSIONS

The bedrock in the area of the TFSP is characterized by the Pennsylvanian-age Pottsville and Allegheny Formations. The bedrock is overlain by a variable thickness of unconsolidated glacial sediment. Both the bedrock and the glacial sediments are sources of water to drilled wells in the area.

The bedrock aquifers in the area are separated by a variable thickness of shale, siltstone and coal seams. Many domestic wells in the study area produce water from these transitional units. Based on historic drilling data, the Homewood Sandstone is the main bedrock aquifer in the study area. However, it is not continuous in the study area. It is absent in the northeastern and southwestern parts of the Timken study area. Ground water yields from the Homewood Sandstone generally produce from 5-25 gpm.

The bedrock is overlain by a variable thickness of unconsolidated glacial sediments that consist of silt and clay beds interbedded by sand and gravel outwash channels. In the Timken construction area, the unconsolidated glacial sediments are approximately 0 to 30 feet in thickness. The unconsolidated sediments thicken toward the north eastern parts of the study area where this thickness can reach of 227 feet. Ground water yields from the sand and gravel units can be as much as 500 gpm.

6.2 CONCLUSION REGARDING THE GEOGRAPHIC EXTENT OF THE IMPACTED AREA

At the time that Timken initiated the construction dewatering, the company had failed to conduct a hydrogeological investigation of the area. As a result, the ODNR-DSWR needed to use the public records to establish baseline conditions present in the subsurface in the study area using existing well log records.

To determine the long term impacts and the geographic extent of the cone of depression created by the construction dewatering, the ODNR-DSWR set a long-term ground water monitoring program to evaluate the ground water levels around the TFSP. The impact assessment for the area was done by comparing the initial static water level in the well at the time it was drilled, to the water levels as measured on September 17, 2012. These data were then used to determine the drawdown in individual wells in the study area. The ODNR-DSWR used the data to define a zero drawdown contour for the study area. The zero drawdown contours were used to define the inferred zone of impact from the pumping associated with the Timken construction dewatering center. It has been concluded that the cone of depression was confined to the Timken property to the north and west of the pumping center. However the cone of depression migrated off site under property owned by private landowners to the south and east of the Timken dewatering center.

6.3 COMPLAINT RESOLUTION CONCLUSIONS

Once the inferred geographic extent of the cone of depression associated with the Timken dewatering operation was established, Timken set up a decision criterion for resolving individual complaints. In total Timken responded to 77 complaints. The decision tree set up by Timken was as follows:

- Eighteen (18) complaints were outside the inferred impact area.
- Nineteen (19) complaints included residents that wanted to get their name on the complaint list as a precautionary measure, in case problems developed later.
- Six (6) complaints were related to the water pumping and storage system and not caused by the Timken construction dewatering operations.
- Thirty-four (34) wells were replaced because there was legitimate problem that could be traced back to the Timken construction dewatering operations. In this case, Timken contracted with a local well driller to install new wells and pumps to replace the older shallower wells. The old wells were sealed in accordance with SCDH requirements.
- One (1) homeowner was connected to the public water system that was available on the street.

At this time, it has been concluded that Timken has taken the precautionary steps necessary to protect the public health and safety.

6.4 CONCLUSIONS REGARDING GROUND WATER LEVEL RECOVERY

Timken began the construction dewatering during August 2012. At that time, Timken had not done any studies to evaluate the impacts that the construction dewatering would have had on the surrounding water wells. The ODNR-DSWR initiated a field investigation to evaluate the impacts that the dewatering would have on the surrounding domestic water wells.

Based on the historic ground water level mapping for the area, it was determined that the natural ground water gradient in the area was from the southwest toward the northeast. The natural ground water level in the area of the Timken dewatering was approximately 1050 feet amsl.

Long-term monitoring data confirms that ground water levels in the area were impacted by the Timken dewatering operation, but as of September 2013 the ground water levels in the area had returned to normal. There does not appear to be any long-term impacts to the glacial or bedrock aquifer systems.

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8.0 PARTIAL GLOSSARY OF TERMS USED IN THE REPORT

Anisotropic: A material that changes in its physical properties with direction as well as having non-uniform spatial distribution of properties throughout the substance. An anisotropic medium displays directional differences in hydraulic conductivity with direction. A property of a material in which spatial characteristic can change with both the distance and the direction between two locations.

Aquifer: a consolidated or unconsolidated geologic formation or series of formations that have the ability to receive, store or transmit water.

Aquifer (artesian): An aquifer that is bounded above and below by impermeable rock or sediment layers. The water in the aquifer is also under enough pressure that, when the aquifer is tapped by a well, the water rises up the well bore to a level that is above the top of the aquifer. The water may or may not flow onto the land surface.

Bedrock: Solid rock present beneath any soil, sediment or other surface cover. In some locations it may be exposed at Earth's surface.

Contour Line: A line on a map that traces locations where the value of a variable is constant. For example, contour lines of elevation trace points of equal elevation across the map. All points on the "ten foot" contour line are ten feet above sea level.

Discharge: The volume of water in a flowing stream that passes a given location in a unit of time. It is frequently expressed in cubic feet per minute or gallons per minute (gpm). Calculated by the formula Q = A x V where Q is the discharge, A is the cross sectional area of the channel and V is the average velocity of the stream.

Datum: A reference location or elevation which is used as a starting point for subsequent measurements. Sea level is a datum for elevation measurements. Datums can also be arbitrary such as the starting point for stream stage measurements or based upon a physical feature such as the base of a rock unit.

Drawdown: A lowering of the water table around a producing well. The drawdown at any given location will be the vertical change between the original water table and the level of the water table reduced by pumping.

Heterogeneous: A material consisting of dissimilar or diverse ingredients or constituents.

Homogeneous: A material consisting of uniform structure or composition throughout.

Hydraulic Conductivity (K): The ability of a porous material to transmit a fluid. It is usually expressed as gallons/day/foot sqared or feet per day.

Hydrogeology: The study of the interrelationship of geologic material and processes with water that control the distribution and character of water bodies.

Hydrograph: A graph that shows the change of a water-related variable over time. Example: A stream discharge hydrograph shows the change in discharge of a stream over time.

Impermeable Layer: A layer of rock, sediment or soil that does not allow water to pass through. This could be caused by a lack of pore space or pore spaces that are so small that water molecules have difficulty passing through.

Infiltration: The movement of surface water into porous soil.

Isotropic: A material that is uniform in its physical properties with direction as well as having uniform spatial distribution throughout the substance. An isotropic medium displays uniform hydraulic conductivity in all direction. It is a property of a material in which the spatial characteristic of the material do not change between two locations.

Joint: A fracture in rock along which there has been no displacement.

Limestone: A sedimentary rock consisting of at least 50% calcium carbonate (CaCO3) by weight

Porosity: The volume of pore space in a rock, sediment, or soil usually expressed as a percentage of pore space that containing water. This pore space can include openings between grains, fracture openings and caverns.

Recharge: Water added to an aquifer or other water body. An aquifer is recharged by precipitation in an area where the aquifer has a porous connection to the surface.

Recharge Area: The geographic area where water infiltrates into the ground and enters an aquifer.

Sediment: A loose, unconsolidated deposit of weathering debris, chemical precipitates or biological debris that accumulates on Earth's surface

Seepage: The slow movement of water through the pore spaces of a solid material. This term is also applied to a loss of water by infiltration through the bottom of a stream, canal, irrigation ditch, reservoir or other body of water.

Shale: a clastic sedimentary rock that is made up of clay-size (less then 1/256 millimeter in diameter) weathering debris. It typically breaks into thin flat pieces

Specific Capacity: The quantity of water produced in a well per unit foot of drawdown. Specific capacity is commonly expressed as gallons per minute per foot of drawdown (gpm/foot) over a specific time interval.

Storativity (S): A dimensionless quantity also called the storage coefficient. It is the volume of water that an aquifer released from storage or takes into storage per unit surface area of the aquifer per unit change in head

Stratification: A layered structure of sedimentary rocks in which the individual layers can be traced a considerable distance. The layers can be caused by many differences which include materials of different composition, color, grain size or orientation.

Stratigraphic Sequence: The sequence of sedimentary rock layers found in a specific geographic area, arranged in the order of their deposition.

Topographic Map: A map that shows the change in elevation over a geographic area through the use of contour lines. The contour lines trace points of equal elevation across the map. See also: contour line and contour map.

Transmissivity (T): The rate of movement of water at a prevailing viscosity through an aquifer of unit width under a unit hydraulic gradient. It is usually defined a gallons/day/foot or feet squared per day.

Water Table: A level beneath the Earth's surface, below which all pore spaces are filled with water and above which the pore spaces are filled with air. It is the top of the zone of saturation in a subsurface rock, soil or sediment unit.

Unconsolidated: A term used when referring to sediment that has not been lithified into a rock.

Withdrawal: A removal of water from a surface or ground water source for use.

Yield (Q): The quantity of water that can be produced from an aquifer. It is generally express as gpm.

Zone of Saturation: The zone beneath the water table where all pore spaces are completely filled with water. Water that exists within this zone is known as "ground water".

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