Terran Corporation

Environmental Services

Mr. James Yskamp, Esq.
Fair Shake Environmental Legal Services
159 South Main Street, Suite 1030
Akron, Ohio 44308

February 1, 2018

RE: Technical Report Review: *"Evaluation of Groundwater Impacts, Dewatering of Proposed Enon Quarry, Clark County, Ohio"*

Dear Mr. Yskamp,

I, Brent E. Huntsman, CPG, President and Principal Hydrogeologist of Terran Corporation (Terran) was retained by Fair Shake Environmental Legal Services to review and comment upon the hydrogeologic characterization and predicted dewatering effects to the water resources of Mad River Township, Clark County, OH as described in a groundwater model report prepared for a mining permit modification. This report review was to include an evaluation of the aquifer response and hydraulic performance predicted by the model simulations of the groundwater system; the magnitude and extent of a cone of depression resulting from dewatering various limestone quarry pits. The purpose of my review is to provide a letter report summarizing my expert opinions regarding the adequacy of the groundwater model to appropriately simulate dewatering effects upon the local groundwater regime. All opinions in this report are based upon my review of existing information (developed through the litigation process in this case or in the public record) together with my 43-years of experience in applied hydrogeology, specifically aquifer characterization and water resources development. My current curriculum vita is included with this letter report as Attachment 2. These opinions are expressed to a reasonable degree of scientific and professional certainty. I reserve the right to supplement this report and opinions as additional material becomes available through the litigation process or continued review of public literature. Documents used in formulating and expressing these technical opinions will be referenced at the end of this letter report.

As you are aware, I previously prepared an initial review of the 2016 groundwater modeling report prepared by Eagon & Associates, Inc. (EAI) referenced above. This was completed at the request of the Mad River Township Trustees and the Village of Enon. The initial review, prepared as a letter report, was submitted to Mr. Lanny E. Erdos, Division Chief of Mineral Resources Management (DMRM) at the Ohio Department of Natural Resources (ODNR) on May 15, 2017. The primary purpose of the initial review was to determine if the model credibly represented the existing groundwater resources in proximity of the proposed mining operations and was capable of correctly simulating the effects of long-term quarry dewatering on existing groundwater users.

On June 19, 2017, Ms. Kelly Barrett, Geologist with DMRM, provided responses to my May 15 review comments for the Division. In her reply, Ms. Barrett acknowledged some of the problems and issues I identified in the EAI model report, but dismissed these concerns as not being required or not within the scope of ORC 1514.13 and OAC 1501:14-5-01. She further stated my concerns did not consider the entirety of the groundwater model report that the Division had during its review.

According to Ms. Barrett, the DMRM and the ODNR, Division of Water Resources (DWR) reviewed the EAI report per requirements in the Ohio Revised Code 1514:13 and Ohio Administrative Code 1501:14-5-01 and approved the EAI report after the applicant provided clarification and additional data for further review. Using the clarifications and technical responses provided by Ms. Barrett in the June DMRM reply together with additional information recently provided by ODNR through the discovery process, I have revised, amended and expanded my initial review of the EAI model report. This updated review will retain much of the initial review report material and will be presented in the same letter report format. At the end of the review comments for each major section of the EAI model and model report, I will summarize the potential impact of identified deficiencies or misrepresentations in correctly assessing the long-term effects of mine dewatering.

Model Purpose and Requirements

ORC 1514.13 (A) states that the chief of DMRM shall use the compilation of data for groundwater modeling submitted under section 1514:02 of the Revised Code to establish a projected cone of depression for any surface mining operation that may result in dewatering. The chief shall consult with the chief of the division of water resources when projecting a cone of depression. An applicant for a surface mining permit for such an operation may submit groundwater modeling that shows a projected cone of depression for that operation to the chief, provided that the modeling complies with rules adopted by the chief regarding groundwater modeling. However, the chief shall establish the projected cone of depression for the purposes of this section. Subsection (A) 1 of this code expresses groundwater modeling used for projecting the cone of depression shall be generally accepted in the scientific community. Subsection (A) 2 indicates groundwater modeling will be used in the replacement of water supplies. ORC 1514.01 (K) defines a cone of depression as meaning a depression or low point in the water table or potentiometric surface of a body of groundwater that develops around a location from which water is being withdrawn.

As clarified by Ms. Barrett in her June 19, 2017 letter, a groundwater model is currently an ODNR requirement of any Industrial Minerals permit holder requesting modifications to their existing mining plans incorporating dewatering in the mining process. The permit holder may prepare the requisite model or request ODNR to prepare a model. The primary purpose of the groundwater modeling simulations is to establish a cone of depression created by the mining operations. Regardless of who prepares the model, the ultimate goal is to establish a preliminary regulatory ten-foot cone of depression contour map based upon guidelines established by the DMRM chief who will then use this preliminary demarcation to establish the final cone of depression (OAC 1501:14-5-01 (E)). It is noted that the chief of DMRM may designate a different regulatory contour line based upon water resources availability, seasonal variations, other water users in the hydrologic study area as well as other groundwater data available (OAC 15:14-5-03).

OAC 1501:14-05-01 (C) describes the groundwater model submitted by the applicant used to define the projected cone of depression will be a three-dimensional groundwater flow model utilizing finite difference modeling software such as MODFLOW. The model must accurately reflect the groundwater flow conditions associated with the hydrologic study area and be consistent with ASTM international standards. OAC 1501:14-5-01 (A) and (B) sets forth the types of hydrogeologic data necessary to use in the construction, calibration and model simulations of the dewatering cone of depression.

Failure to Follow ASTM Guidance: Impact to Model Predictions

Based on the references cited in the EAI report and the cursory discussion of any apparent conceptual model of the subsurface in Mad River Township, it does not appear applicable ASTM standards were considered for this modeling project. ASTM defines a conceptual model as an interpretation or working description of the characteristics and dynamics of the physical system. The purpose of the conceptual model is to consolidate site and regional hydrogeologic and hydrogeologic data into a set of assumptions and concepts that can be evaluated quantitatively. Compiling, reviewing and evaluating available hydrogeologic information into a realistic conceptual model provide the technical foundation and much of the preliminary data needed to consider numerical modeling. This is lacking in the EAI modeling efforts. If the guidance provided in the *Standard Guide for Conceptualization and Characterization of Ground-Water Systems* (ASTM D5979-96 (2008)) was considered prior to EAI initial modeling attempt, a different model construct and simulation of a more extensive preliminary cone of depression would have undoubtedly occurred.

The primary October 2016 report submission by EAI was a hydrology information data package used in constructing and applying a regional groundwater flow model. The model was coded using modified MODFLOW 2000 software. The EAI model is a regional groundwater flow model since its design incorporates approximately 90 square miles of area within the model boundaries. The two proposed quarry sites within Enon Sand & Gravel 450-acre Mad River Township property will affect about 200 acres. This is less than one third of a square mile. Using a regional model to accurately simulate the effects of quarry operations on adjacent groundwater supplies in the area can be misleading if appropriate site-specific hydrogeologic data is not used.

Guidance provided in the *Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem* (ASTM D5447-94 (2010)) details the benefits of both quantitatively and qualitatively evaluating groundwater flow model simulations with site-specific information. It is obvious EAI had not considered these guidelines before constructing the submitted MODFLOW model. Had EAI incorporated elements of this guidance document, such as code selection, boundary conditions or model calibration and sensitivity analysis, a much better understanding of why the model results provided are not complete and produced unrealistic simulations of the quarry dewatering impacts.

Controlled lowering of the water table near open pit mines depend mainly on the hydraulic characteristics of the aquifer close to the mine, regional aquifer properties and the amount and distribution of natural recharge and discharge (Dudgeon, 1998). Specifically, use of model parameter values to represent aquifer hydraulic performance (e.g. transmissivity, recharge, storativity, etc.) that are too high or too low will lead to erroneous determinations of the cone of depression shape and size, poor prediction of aquifer water level drawdown, and underestimating the volume of water to be pumped by the proposed dewatering activities.

Absent from this modeling exercise was a supportable estimation of effects of the quarry operation on groundwater supply to existing wells. Also absent was assessment of quarry dewatering operations on local surface water – groundwater flow interconnections. Specifically, recharge seized from streams, springs and wetlands (fens) (i.e. the Verbillion homestead) in this fracture and karstic flow regime will affect the amount of groundwater captured by the quarry sumps and the size of the cone of depression. These concerns need to be addressed in any model used for estimating the effects of dewatering.

A further complication initiated through improper and/or incomplete characterization of aquifer properties or local boundary conditions is nonuniqueness of model output or solutions. This rather complex problem and how to minimize adverse effects and improper results acquired during modeling simulations is discussed in some detail in the *Standard Guide for Calibrating a Ground-Water Flow Model Application* (ASTM D5981-96 (2008)). Simply stated, a good match of hydraulic heads and/or hydraulic conductivities does not prove the model validity since nonuniqueness can provide a good comparison with an inadequate or erroneous model (Castro & Goblet, 2003; Konikow & Bredehoeft, 1992). It is not apparent from the EAI report that the ASTM D5981-96 model guidance procedures were considered as part of the reported calibration of the EAI model. This will be discussed further in this review when the model results are considered. The underlying impact to the model predictions caused by neglecting model nonuniqueness will be in establishing the cone of depression.

Hydrogeologic Setting

ORC 1514.13 (A) states that the chief of DMRM shall use the compilation of data for groundwater modeling submitted under section 1514:02 of the Revised Code to establish a projected cone of depression for any surface mining operation that may result in dewatering. OAC 1501:14-5-01 expands the amount and type of data required to develop a hydrogeologic description in sufficient detail to determine the hydrologic cone of depression for the proposed dewatering operations. The EAI report addressed these requirements under the report heading "HYDROGEOLOGIC SETTING".

Site Geology

Excepting one test boring log, all quarry site-specific geologic and hydrogeologic information was redacted in the copy of the EAI report Terran reviewed. This limits what conclusions can be made as to the thickness, extent and continuity of the identified geologic units at the proposed mining sites.

The one available test boring, Jurgensen Aggregates Boring No. 14-C-1, was completed near the intersection of Garrison Road and Fairfield Pike. The subsurface geology at this location was described as 14.5 feet of silty clay overburden atop of 30.5 feet of (Lockport) dolomite belonging to the Cedarville/Springfield/ Euphemia Formations. In the EAI model, this rock unit was assigned to model layer 1. Below model layer 1, 6.2 feet of shale of the Massie Formation (model layer 2) was encountered. Model layer 3 consisted of 24.3 feet of shale and dolomitic limestone assigned to the Laurel/Osgood/Dayton Formations together with 46.5 foot thick unit of Brassfield Formation limestone. The Brassfield Limestone aquifer rests upon Ordovician shale identified as the Elkhorn Formation. Shale is designated to be in layer 4 of the EAI model. It should be noted the bedrock surface elevation of the Elkhorn shale will be approximately the bottom of the quarry dewatering operations, ranging between 846 to 853 feet msl in Phase 1 quarry operations and between 834 to 846 feet msl in Phase II mining. Proposed bottom elevation of the dewatering sump for Phase 1 will be about 836 ft msl and 826 ft msl for Phase II. This implies the entire aquifer of Silurian carbonate rock within and adjacent to the quarries is intended to be dewatered during the duration of mining at the permitted site.

When describing the occurrence and use of groundwater in the vicinity of the proposed quarry sites, the EAI report correctly identified the primary aquifer as Silurian age carbonate bedrock. Perhaps to downplay the importance of the carbonate bedrock aquifer in Mad River Township, the EAI report openly follows this declaration with an accurate but misleading statement "*Residential and municipal water supply wells are completed in unconsolidated sand and gravel deposits in the buried bedrock valleys.*" When considering the residential land potentially affected by the proposed quarry operations, the vast majority of the groundwater pumped by land owners in the EAI report study area is obtained from water wells completed in the bedrock. This was acknowledged in the EAI report with the admission that nearly 2,000 water well-logs within the report study area are on file at ODNR. In addition to residential wells, it should be noted that both public and commercial water wells are also completed in the carbonate bedrock aquifer near the proposed quarry sites. Greenon High School, Young's Jersey Dairy and Taylor's Tavern are examples (OEPA, 2017). The carbonate aquifer also provides water for agriculture use at such locations as the Verbillion homestead and Mud Run Farms, LLC.

As required by ODNR for preparation of the numerical model, EAI assembled and tabulated a variety of publically available lithologic and hydrogeologic literature data for the Mad River Township area. It should be recognized that much of the data cited in the EAI report was of a general nature developed to represent a regional trend in the parameter under consideration. Overall accuracy of this type of general or regional data should be determined and incorporated into any model development efforts. For example, the drift thickness map (Plate 3 of the EAI report) contour interval varies and is projected on the map with a change in color. The accuracy of the drift thickness interpreted at anyone specific area on that map will be quite variable. This lack of accuracy for drift thickness in Mad River Township was identified by researchers carrying out the Clark County Karst Investigation (OEPA, 2007). Stated in the report was field inspections and review of local well logs indicated some areas mapped by ODNR as having 25-100 feet of glacial till are inaccurate. Field inspections further identified a location mapped as having drift greater than 25 feet depth to bedrock as actually being exposed bedrock. The same sort of error should be expected and taken into consideration for other general or regional data sources (potentiometric surface maps, groundwater resources maps, bedrock contour maps, etc.) used for the EAI model development.

Little discussed in the EAI report was the lithology of the carbonate aquifer and how it affects the occurrence and supply of groundwater. Brief mention was made that wells completed in the carbonate bedrock *"are sometimes completed in the upper part of the bedrock above the shale and sometimes penetrate the entire thickness of the carbonate bedrock."* Comments were made that well yields from the carbonate aquifer generally correlate with aquifer thickness, well yields from bedrock are higher in the eastern portion of the model study area and that underlying Ordovician bedrock is a poor producer of groundwater. Absent from the EAI report was any recognition or quantification the epikarst aquifer beneath the shallow unconsolidated overburden and how it recharges the underlying fractured and fissured formations. For use in numerical modeling, this cursory hydraulic conceptualization of the carbonate aquifer throughout the potentially affected areas of Clark and Greene Counties is insufficient and negligent.

Failure to Correctly Characterize Site Geology: Impact to Model Predictions

The proposed quarry study site is located in a unique region of the Lockport – Sub Lockport formations known as the Dissected Niagara Escarpment. Unlike other Lockport quarry sites in the state, hydrogeologic characteristics of the upper Silurian carbonate aquifer within the Escarpment need to be better understood and quantified for use in any groundwater flow model. The carbonate aquifers in Mad River Township are known to have higher permeability at the top and potentially the bottom of the Silurian bedrock formations. At the bedrock top in the Cedarville/ Springfield/Euphemia Formations, due to karstification processes, increased groundwater flow and storage occurs. Aden and Martin (2012) have identified over 112 karst features including 32 springs just north of the proposed quarry site in the Springfield area. Peterson (2017) has continued a field reconnaissance from the southern-most extent of ODNR's Springfield karst review to south of the proposed quarry sites. To-date, more than 35 additional karst features, including sinkholes, disappearing rivulets and springs, have been located (see Attachment 1). The Ohio EPA (2007) while completing a hydraulic study of karst features in northern Mad River Township, identifying two caves, seven major sinkholes, two disappearing streams, thirteen spring and numerous smaller sinkholes. Flow in the epikarst sustains the recognized high-quality wetlands and fens (minerotrophic groundwater fed wetlands) throughout the area in addition to ongoing recharge/discharge of the carbonate aquifer(s).

Dissolution-enhanced joints and fractures within these formations are extremely important pathways for recharge or discharge for the aquifer, and as potential pathways for groundwater contamination (Bates and Evans, 1996). Karst areas in Mad River Township and other regions of Ohio are known to be sensitive due to bedrock dissolution along fractures that increases ground water flow rates. Enlarged fractures increase the potential for rapid infiltration of surface water while reducing natural filtration processes. The recharge pathways are both vertical and horizontal on the south side of the Mad River, with vertical recharge more dominate in the shallower carbonate formations and horizontal deeper recharge to the lower carbonate aquifer (OEPA, 2008). In Clark County, water wells that tap the fractured and weathered portions of these formations can yield up to 30-50 gallons per minute (Bendula and Moore, 1999). Review of Table 1 in the EAI report lists some limestone wells capable of pumping up to 350 gallons per minute.

For conceptualization of the hydrogeologic setting in the vicinity of the quarry, the EAI report contends the upper and lower portions of the carbonate aquifer are separated by what is locally known as the Massie Shale. According to the EAI report, because drillers and drilling techniques for most residential wells in the area could not identify this unit, the lateral extent and thickness of the Massie Shale in the report study area could not be determined. Based on one cross-section in the EAI report, the Massie Shale thickness appears to thin from 30 feet outside the Enon Sand & Gravel property to about five feet within the area to be mined. The shale unit is completely absent in the Mud Run buried valley where it has been eroded. This lack of detail as to the shale's occurrence throughout the Mad River Township limits its suggested use as a competent aquitard unit in any groundwater flow model.

This was further realized in the EAI report when a representative potentiometric surface map was attempted for the model study area; *"No clear distinction could be made between water levels from wells completed only in the upper bedrock versus those completed through the entire thickness of the carbonate strata."* This same difficulty was encountered by Bowser-Morner (2009) when attempting to construct a MODFLOW model of the former Demmy quarry adjacent to the proposed Phase I Enon Sand and Gravel quarry. Since most water well casings only extend through the unconsolidated overburden to the top of rock, formation(s) heterogeneity with respect to transmissivity and storage would be the major influence on local water levels.

To summarize, the EAI report geologic characterization does not correctly interpret the important role natural fracturing and karst forming processes of rock units (various limestones, dolomites, shales, etc.) has in creating the permeable pathways and amount of water storage of the aquifers affected by the mine dewatering. Data that supports this mischaracterization was used to construct the MODFLOW model. This model was then used to calculate a cone of depression that does not accurately represent the effects of the proposed dewatering activities. Its accuracy is indefinable. However, there are better approaches to geologic characterization for use in groundwater flow system model conceptualizations this type of carbonate aquifer that EAI should have considered.
Not referenced in the literature cited for the development of EAI model were detailed investigations characterizing and modeling the same Silurian Lockport and Sub Lockport formations considered in this permit application. Research by Ritzi & Andolsek (1992), Smith & Ritzi (1993) and Podgorney & Ritzi (1997) has provided demonstrable understanding of the fractured carbonate aquifer groundwater flow system of the Dayton

dolomite and the Brassfield limestone formations. Among the findings from these investigations were hydraulic conductivity varied by approximately three orders of magnitude in the vertical direction and by as much as two orders of magnitude in the horizontal direction. The hydraulic conductivity decreased with depth from the bedrock surface as the degree of fracturing decreased. The carbonate aquifer transitioned from porous media type (continuum) flow near the bedrock surface to discrete fracture (noncontinuum) flow at depth. And, major principal direction of transmissivity parallels developed joints and fractures. These findings are expected and observed in heterogeneous carbonate aquifers (Smart et al., 1992; Lolcama et al., 2002).

The lower section of the carbonate aquifer in Mad River Township consists of the Laurel/Osgood/Dayton formations overtop a thicker section of the Brassfield formation. The Brassfield formation has been recognized as a significant aquifer for well over a century (Orton, 1874). According to Frost (1977), the Brassfield can be dense and possess relatively low intergranular porosity. However, near the base of the rock unit can be a two to six foot zone of coarse, very porous sucrosic dolomite, commonly called "Sugar Rock". In outcrop, this zone provides copious springs. In the more dense portions of the Brassfield, joints appear to contribute the bulk of the vertical permeability. Recharge reaching the Sugar Rock is probably dominated by the orientation and degree of weathering of joints and fracture. Joint patterns have been identified in the Brassfield throughout Clark and Greene Counties trending mainly north-north east and north-northwest, perpendicular to Mud Run and the two proposed quarry sites. Since the descriptive lithology obtained from the on-site boring logs were redacted from Terran's review copy of the EAI report, the occurrence of this porous and permeable unit is unconfirmed at the potential quarry sites.

Water-Well Logs and Data Analysis

As referenced above, the hydrologic cone of depression for the proposed quarry operations requires a detailed hydrogeologic description for the proposed permit and hydrologic study area. The EAI report provided a narrative of the regional hydrogeologic conditions that served as an introduction to the model development. This was augmented with plates, figures, tables and appendices that compiled and summarized information gathered from public sources, mainly the Ohio Department of Natural Resources, Division of Water Resources. Unfortunately, little analysis or interpretation of this compiled data was used in creating the modelling scenarios presented.

Critical aquifer parameters needed (and required in OAC 1501:14-5-01 (B)) to calculate a realistic cone of depression for the quarry dewatering activities include transmissivity, hydraulic conductivity, aquifer thickness, storativity and specific yield. Literature values for hydraulic conductivity in the outwash aquifers and streambed permeability for streams and rivers were used in the model construct. The hydraulic conductivity values for the various model layers of bedrock aquifers and aquitards was estimated during the model calibration process without regard to published literature data or calculable values from specific capacity measurements in local wells. Probably the most misrepresented aquifer coefficient used in the EAI model was a hydraulic conductivity of 1.0 ft/day for the carbonate aquifer.

Referring to Table 1 of the EAI model report, the specific capacity values summarized for wells in the model study area could have been used to determine a more representative site-specific transmissivity and hydraulic conductivity values for the model. For an initial test of this analysis approach, data from ODNR Well #s 771225 and 803866 listed in Table 1 of the EAI report were used to estimate a transmissivity and hydraulic conductivity for all of the carbonate aquifer sections down to the shale; the bottom of the proposed quarry. Using calculation methods described by Bradbury and Rothschild (1985) transmissivities for these wells were estimated to be 2,553 and 1,516 ft^2/day, respectively. Using the open borehole interval as the aquifer thickness, hydraulic conductivities were calculated to be 15 to 20 ft/day. To compare, Bowser-Morner (2009) used hydraulic conductivity values from 3 to 65 ft/day.

If this type of data analyses assessment was to be expanded for water wells constructed in significant joint/fracture zones or in the Sugar Rock at bottom of the carbonate aquifer, these wells should have much higher specific capacity values. Two examples would be the former Mad River-Green Local School on Husted Rd, located approximately 2,500 feet east of the proposed Phase I quarry (Well # 271726). The second would be a well located on the Enon Sand and Gravel property on the border of the proposed Phase 1 quarry (Well # 902119). Using the same single-well calculation procedures discussed, the transmissivity for Well # 271726 was estimated at 29,623 ft^2/day and resulting hydraulic conductivity of 215 ft/day. At the time of installation, the well test results for Well # 902119 reported sustain pumping for one hour at 40 gpm with no drawdown. This is improbable, so a drawdown of 0.5 feet was assumed which provided a calculated transmissivity of 23,178 ft^2/day and a hydraulic conductivity of 203 ft/day.

When describing and quantifying groundwater flow in the carbonate aquifers of northwest Ohio, ODNR used a technique for comparing water well specific capacities calculated as a function of penetration (open hole) depth (ODNR, 1970). Based on the work of Zeizel et al. (1962), specific capacities per foot of penetration are arranged in order of magnitude and plotted according to frequency of occurrence. By using this approach, the trend in aquifer transmissive and production characteristics can be estimated from water wells throughout a study area.

Using a subset of 69 water wells near the proposed quarry operations in Mad River Township, a graph was developed using the calculated specific capacities normalized by the length of open hole exposure. This is compared to the same graph developed by ODNR (1970) for wells completed largely in the Lockport Formation (Figure 1).

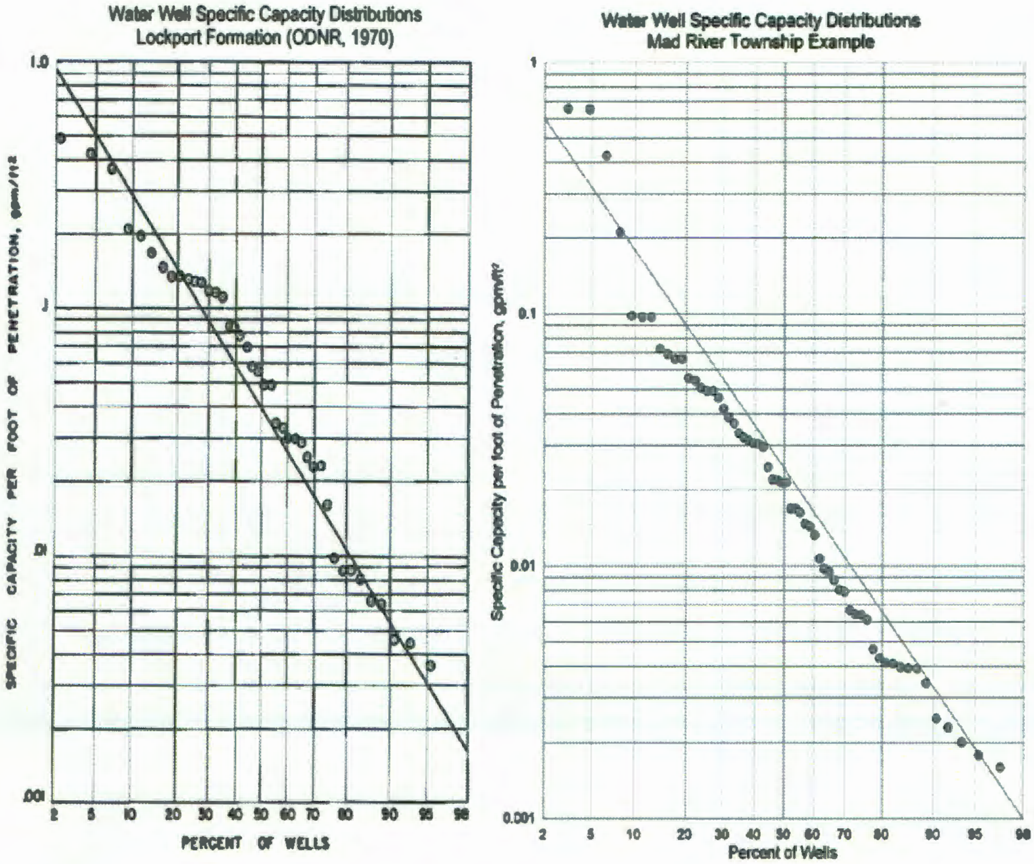

Figure 1. Specific capacity frequency graphs for wells near the proposed quarry pits in Mad River Township compared to ODNR (1970) wells in northwest Ohio.

In discussing the results of the graphical analyses presented above for the northwest Ohio wells, ODNR (1970) concluded:

> *All of the wells penetrated the Lockport and in all cases the greatest amount of water was encountered in the Lockport.*
>
> *The extensive range in the specific capacity per foot of penetration of the wells is attributed to differential weathering of the rock walls during periods of active erosion in the valley and to differences in the amount and size of secondary solution openings with in the rock aquifers.*
>
> *Maximum safe yields to the test wells ranged from 175 to 1000 gpm with a median of 500.*

The specific capacity per foot of penetration ranged from a minimum of .0036 to a maximum of .1680 gpm/ft/ft. The median was .0380.

Although this area contains large variations in the parameters, it has one of the best potentials of any of the areas in the study. Yields of from 250 to 800 gpm can be anticipated based on extended periods of continuous pumping.

What should also be noted from this comparison is both graphs presented in Figure 1 show the highest specific capacity values for about 20% of the wells in the data set. According to Smart et al. (1992), those higher capacity wells would represent groundwater flow from fissures and well connected fissures in the carbonate aquifer. Furthermore, the average specific capacity per foot of penetration for the wells in the ODNR (1970) investigation was approximately 0.038. For Mad River Township wells nearby the proposed quarry pits, the approximate average for specific capacity was 0.025, indicating the groundwater production potential will be virtually the same. This follows well the groundwater flow conceptualization discussed by Podgorney & Ritzi (1997) for the Sub Lockport formation.

In carbonate aquifers, Rovey (1994) contends small-scale measurements of hydraulic conductivity, such as those obtained from single-well tests, do not average to regional values. Instead, mean hydraulic conductivity values increase with measurement scale up to a critical distance. This scale effect explains why the aquifer parameters used to model sub-regional or regional groundwater systems need to be obtained from multi-well aquifer tests as opposed to those determined using laboratory or single-well test methods.

Transmissivity values derived from aquifer tests for the Silurian age carbonates in the Mad River Valley range from 70 to 28,000 ft^2/day (Sheets and Yost, 1994; Joseph and Eberts, 1994). Sheets and Yost (1994) further references Casey (1992) using this range of transmissivities to derive calculated horizontal hydraulic conductivities of 10^{-2} to 5×10^2 ft/day for the carbonate aquifers. Furthermore, the blasting and extraction of the carbonate aquifer during quarrying operations increases fractures and the natural hydraulic conductivity of the bedrock (Langer, 2002; Gunn & Bailey, 1993). The Ohio EPA required CEMEX to increase the assumed hydraulic conductivity of unmined Brassfield Formation from 0.5 ft/day to 100 ft/day for areas in which the formation was mined in evaluating the acceptability of a groundwater flow model (OEPA, 2006). A similar increase in hydraulic conductivity of the overlying carbonate aquifer above the Massie Formation should be anticipated due to the mining operations at the proposed quarry sites.

Failure to Correctly Utilize Water Well Data: Impact to Model Predictions

If the EAI model was to utilize ranges of hydraulic conductivity that are calculated from well logs and/or pumping tests completed in the Silurian bedrock, it would be readily apparent the previously assumed hydraulic conductivity value of 1.0 ft/day substantially underestimated both the volume of water to be pumped from each quarry site and the areal effects of quarry operations on groundwater levels in Mad River Township. Also, by using a single hydraulic conductivity value for all of the carbonate aquifer (an equivalent porous media approach) the resultant modelled cone of depression appears to be coarsely circular around each quarry pit, not actually representing preferential flow pathways of joints and fractures in the aquifer. This is an unrealistic conceptualization of the Silurian fractured and karstic media, specifically the Brassfield formation, where anisotropic transmissivity predominates (Raab, 1990; Ritzi and Andolsek, 1992).

Until the permit applicant builds a groundwater model which uses data that suitably represents the fractured and epikarst portions of the aquifers at and around the proposed quarry pits, no truthful size, shape or extent of a cone of depression can be predicted. What can be concluded from just the comparison of ODNR (1970) investigation results to the example Mad River Township local well analysis, the aquifer(s) have virtually the same potential for high volume water producing wells. This suggests dewatering the quarry pits (essentially very large diameter open hole wells) will require pumping thousands of gallons per minute to maintain the desired permitted quarry water levels, not the few hundred calculated by the current model. This will also affect the cone of depression calculations and the areal extended groundwater capture.

Model Construct and Quarry Expansion Simulations

In the EAI model, the values for aquifer coefficients of the unconsolidated sand and gravel materials that fill the buried valleys of the Mad River, Mud Run and other tributaries were selected from published literature. So were stream infiltration values for modeling the stream-aquifer interface. These selected coefficient values appear low but reasonable as initial tenets to begin the modeling process, knowing adjustments must be made during the calibration process. Unfortunately, since the EAI model assumed a low hydraulic conductivity value for most of the carbonate aquifer, calculation of or adjustment to other hydraulic parameters in the model are suspect and unreliable.

For example, areal groundwater recharge to the aquifer is one parameter calculated in the EAI model that appears implausible. From water budget calculations for the carbonate aquifers in the Mad River Valley, Sheets and Yost (1994) determined groundwater recharge through overlying ground moraine to range 4 to 6 in/yr. Essentially this same range of recharge was referenced in the EAI report; 4 to 7 in/yr. Recharge of this amount is evident in the upper portion of the carbonate aquifer through the formation of many perennial springs discharge areas. Furthermore, in Silurian aquifers, recharge has been measured to increase with increased groundwater pumping (Rowland & Kunkle, 1970) However, in the model simulations, the recharge was reduced to as little as 0.5 in/yr. over large portions of the carbonate aquifer in an attempt to calibrate the water levels around the proposed quarry sites. Attempting to vary recharge to unsubstantiated low values so that the model will better fit the improperly assigned aquifer flow and storage coefficients is "black box" science and should be avoided.

Failure to Correctly Understand Recharge: Impact to Model Predictions

This inaccurate depiction of areal groundwater recharge will significantly affect dewatering cone of depression calculations, not allowing realistic determination of the cone size and extent caused by long-term pumping. Once the growth of a cone of depression stabilizes by removing the water from aquifer storage, assuming a constant drawdown in the quarry pits is maintained, the cone of depression size and shape is controlled by the amount of recharge water available.

Another aspect of recharge that was not discussed in the EAI model report relates to direct precipitation into the operating quarries. Average precipitation for the Mad River Valley is about 40 in/yr or approximately 3.3 feet/yr. If 3.3 feet of precipitation is applied to the anticipated 73 acre working area of the Phase I quarry, this would be about 240 acre/ft (78,200,000 gal/yr) of water that the dewatering system discharge would be pumping directly to Mud Run. I have assumed negligible evaporation would occur in the quarry. The EAI model steady-state modeling simulation of the Phase I quarry dewatering estimated about 260,000 gpd (94,900,000 gal/yr) would need to be pumped to maintain desired water levels. If it is assumed the withdrawal of the 78.2 million gallons of direct precipitation into the quarry is annualized, about 330 gpm would need to be pumped from the quarry, not the hypothesized 180 gpm extraction rate from the model, to maintain water levels. This is a 55% increase in daily discharge to Mud Run. A greater increase in daily discharge from dewatering operations in Phase II would be predicted, due to the larger quarry footprint.

Where buried valley aquifers have incised the Silurian carbonate formations, lateral inflow exchanges (recharge) with the bedrock aquifers are significant (Sheets and Yost, 1994). As an example of the magnitude of water flux between aquifers, although not in the Silurian carbonates, Seyoum (2012) investigated the hydraulic relationships amid buried valley sediments and adjacent bedrock formations and found nearly 40% exchange. Between the two proposed quarry sites, as depicted in the EAI report cross-section, a sand and gravel buried valley aquifer exists beneath Mud Run. Blasting will cause enlarged fracturing of quarry walls, increasing permeability and increasing drainage towards the quarry face (Langer, 2002). Inflow exchange between aquifers, either before or after quarry blasting increases permeable pathways, was not addressed in the EAI model. The effect of lateral inflow between aquifers or quarry pits on the calculated cone of depression or the proposed dewatering operations is unknown at this time. However, greater volumes of water flowing into/from the quarry pit highwalls adjacent to the Mud Run buried valley aquifer should be anticipated.

Model Calibration

As previously stated in this review, a good match of hydraulic heads and/or hydraulic conductivities does not prove the model validity since nonuniqueness can provide a good comparison with an inadequate or erroneous model. The reported R-squared statistic value of 0.99976 for matching measured vs. model heads suggests the EAI model will be a superior predictor of water levels and the required preliminary delineation of the cone of depression. The calibration processes used to achieve this high degree of apparent accuracy involved wildly imprecise water level measurements and should be considered suspect.

The EAI model is reported as calibrated to water wells listed in Table 2, where wells with water level elevations completed above the shale were assigned to Model Layer #1. Water level elevations from wells with a surface elevation below 908 ft. were assigned to Model Layer #3 for calibration. Water levels in wells that cross the Massie Shale aquitard, when present, represent an intermediate water level that may not represent the true water level in either part of the aquifer. EAI opted to assign that calibration point to both Layers #1 and #3; effectively creating two calibration points for every one of these shale interbed crossing wells.

Reviewing Table 2, there are 458 individual wells listed for calibration of which 398 are couplets (i.e. Layer #1 and Layer #3), comprising 87% of the 856 total reported calibration points. This means 43% of the calibration is redundant; all based on the assumption that 398 water level elevations may not represent Layer #1 or Layer #3. This inflates the model calibration data base to a statistically much greater population than is actually present in the model domain.

The counter argument is that because a bedrock well crosses the aquitard, it will therefore have an intermediate water level representative of both model layers. Inherent in this presumption is the well's water level will be less than the water level elevation found in the upper aquifer and conversely higher than the water level elevation found in the lower aquifer (assuming a competent aquitard separates the two aquifers). This single well error difference is likely inconsequential given the margin of error present in the data base due to temporal and spatial variations of well water level measurements.

Podgorney and Ritz (1997) determined flow in the Sub Lockport is transitional from a porous media type (continuum) flow to a discrete fracture flow (noncontinuum) with depth regardless of the presence of a shale interbeds present within the geologic sequence. With depth, the aquifer becomes a less fractured, essentially no-flow carbonate aquitard. This vertical transition would indicate that the uppermost continuum hosts predominant hydraulic flux of the bedrock aquifer. Each well's open borehole that penetrates to depth below the noncontinuum level is essentially storage. This would suggest that the majority of the bedrock wells calibration points should represent Layer #1 only (where present) and not both layers simultaneously.

The second issue regarding the model calibration is the issue of fidelity, a property used in establishing model calibration targets and residual limits as discussed in ASTM D5981-96 (2008). The degree of fidelity proposed for a model's application inherently determines the quality of calibration targets and acceptable residuals. A low-fidelity model will require fewer calibration targets and permit larger residuals; medium to high-fidelity models require more accuracy and precision in its targets for calibration and less residual in the model errors. As discussed above, the EAI model has nearly 400 calibration targets (aside from the inflation issue argued above) in its domain which is very reasonable for a regional model. However, the calibration targets are of the poorest quality available when it comes to aquifer characterization (i.e. single well water levels from estimated TOC elevations collected randomly over a span of 50+ years used to represent a single piezometric surface at a single point in time). The property of fidelity becomes an issue of concern when the calibrated regional model is then used in the capacity of a site-specific model to predict the potential drawdown around the Phase I and II quarry operations. The fidelity of the regional model, in spite of the large number of calibration targets used, has a significant margin of error (as a result of seasonal, temporal, spatial and elevation variations in the input data) which is on the order of tens of feet vertically across the model domain. This margin of error in turn impacts the predictive fidelity of the simulated drawdown around the two quarry operations. For example, the reported 10-foot drawdown contour may be in error by 10 feet or more. The model report does not provide a 1-foot drawdown contour in Plates 12 and 13; however this contour line may be more definitive of the 10-foot contour level around the quarries because of the fidelity of the model inputs.

EAI compiled a significant amount of existing water well data as required in the OAC 1501 regulations for the mine permitting process, although it appears little local aquifer hydraulic data from this data compilation was used in the model construction. Similarly, EAI chose not to include ranges of values for aquifer coefficients representing local hydraulic conditions or found in the published literature for Ohio carbonate aquifers to perform sensitivity analysis of the model predications. Sensitivity analyses are needed to quantify the uncertainty in the calibrated model caused by the vagueness in the estimated parameter values (Anderson & Woessner, 1992; Hill & Tiedeman, 2007) as well as characterize the model output reliability.

Failure to Correctly Calibrate Model: Impact to Model Predictions

ASTM D5981-96 (2008) describes model calibration as the process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the groundwater flow system. EAI model calibration efforts, while appearing to be effective, did not prove the model validity since nonuniqueness provided a good comparison with an inadequate and/or erroneous model. Incorporation of poor quality data (hydraulic properties) into a poorly conceptualized (hydrogeologic framework & boundary conditions) model followed by less than rigorous calibration testing has produced a meaningless estimation of the cone of depression for the proposed quarry site.

Groundwater Monitoring

Presumably in response to submission requirements (OAC 1514:13) for this permit application, the EAI report outlines broadly how Enon Sand & Gravel plans to evaluate possible effects of Phase I quarry operations on groundwater levels and quality in all wells encompassed by the modeled 10-foot drawdown contour. This information would be used to determine if the quarry operations creates a diminution, contamination, or interruption of the owner's water supply. Work would consist of a survey (not defined) to update and expand the pre-mining database of water levels and water quality (not defined) together with establishing a network of key wells (not defined) to annually monitor groundwater levels. It was further stated this monitoring approach would be expanded for Phase II operations if needed.

With the lack of any specificity, this proposed groundwater monitoring approach completely sidesteps any demonstrable actions that are needed to accurately assess the effects of on-going quarry operations let alone determine if a nearby property has experienced the diminution, contamination, or interruption of the owner's water supply. Proposed groundwater monitoring programs should consider, at a minimum;

- Verification that the cone of depression 10-foot drawdown contour is correct,
- Completion of a well/spring inventory and evaluation at each property in the monitoring area,
- Measure specific capacity and well efficiency of all wells in the monitored area,
- Determine baseflow of all springs in the monitored area,
- Obtain baseline water quality at all wells/springs in the monitored area for such parameters as turbidity, electrical conductivity, nitrogen compounds, bacteria, etc.; parameters that detect water quality degradation introduced by enhanced infiltration due to decreased water levels,
- Installation, development and sampling of a separate monitoring well network specifically designed for fractured-rock and karst aquifers (ASTM D5717-95),
- Quarterly measurements of water levels in all wells and springs for three years to establish seasonal background variations,
- Annual measurements of water quality at all wells and springs,
- Annual reports summarizing and interpreting all groundwater monitoring results in relation to the ongoing quarry operations.

Blasting and groundwater extractions, in all cases, serve to reactivate and enhance karst, leading to sinkhole development (Lolcama et al., 2002). Quarry blasting may result in the destruction or disruption of groundwater flow paths, changes in the pattern of groundwater movement and changes in the quantity of water flowing through the karst system (Ekmekci, 1993). There are documented occurrences of increases in turbidity of groundwater to wells and springs at limestone quarries that utilize blasting (Green et al., 2005). Any groundwater monitoring program designed for determining potential adverse effects of the proposed quarry operations in the carbonate aquifers beneath Mad River Township must pay special attention to the disturbs of blasting. How this will be assessed is completely missing in the current groundwater monitoring outline provided in the EAI report.

Groundwater Remediation

Should quarry operations create any adverse effects to existing groundwater wells, the stated remedial action options offered by Enon Sand & Gravel would include lowering of pumps, deepening of existing wells, or installation of replacement wells. These remedial actions might be plausible for some wells distant from the quarry whose water levels have not been lowered near the top of the Elkhorn shale. These remedial measures would not be successful for wells close to the quarry where essentially the entire thickness of the carbonate aquifer has been drained. There are no aquifers in the Elkhorn shale to deepen or replace the affected homeowner well. The proposed remedial measures would not be successful for well owners if the lower portion of the carbonate aquifer has minimal saturated porosity or lacks permeability. Also, these remedial measures would not address the taking of groundwater from owners whose groundwater levels have been lowered by induced infiltration resulting in damage to springs or wetlands (fens) on their property. The survival of fens, such as the nearby Vanderglass Fen, is especially sensitive to a constant, stable and adequate groundwater supply.

Missing from consideration in remedial measures of this permit application are remedies for property owners subjected to adverse water quality effects or contamination from the mining operations. Increased turbidity from blasting and/or bacterial or nitrate contamination resulting from accelerated induced recharge from lowered groundwater levels are two probable scenarios that need to be addressed. Excess turbidity is an indicator of contamination by suspended solids mobilized by blast vibrations or increased groundwater velocities caused by quarry pumping. Increased bacterial counts or larger concentrations of nitrogen compounds in wells may result from augmented recharge of known contaminated groundwater being pulled to the bottom on the aquifer by pit dewatering.

Responses in the EAI report on groundwater monitoring and groundwater remediation are incomplete in scope and, for the most part, inadequate to accomplish the stated purpose of the task or activity. Second to the poorly conceptualized and unrepresentative groundwater flow model, these cursory responses are major deficiencies in this permit application.

Statement of Opinions

Based on my review of the EAI model report, pertinent published literature and the examination of available water well logs in the vicinity of the proposed quarry pits in Mad River Township, it is my professional opinion the carbonate aquifer underlying Mad River Township has not been adequately characterize to allow for an accurate or even realistic calculation of the preliminary 10-foot contour of the cone of depression required by ODNR of the permit applicant.

Specific observations and opinions made during my review include:

- A regional groundwater flow model was developed where a site-specific groundwater flow model is needed for a more truthful determination of the cone of depression.
- An incomplete and inconsistent conceptualization of the Silurian aquifer flow regime at the proposed quarry pits was used for model development, resulting in inaccurate projections of the dewatering cone of depression.
- Significant hydrogeologic information and data in the public record germane to this modeling effort was not utilized, resulting in poor and inaccurate predictions of the dewatering cone of depression.
- There is risk of increased areal expansion of aquifer contamination from inducing recharge of known contaminated groundwater near the top of the aquifer to lower aquifer depths by the proposed dewatering practices.
- Since the upper portion of the bedrock aquifer is epikarstic, drawdown in the natural groundwater table by the proposed dewatering operations will adversely affect existing springs and wetlands (fens).

The model results represent only the general magnitude of possible impacts, not the real-world impacts of the proposed mining operations in Mad River Township. The means and methods to identify and mitigate any adverse impacts of the quarries to the local populace are also inadequately developed and presented in this submission. A new modeling approach or a total rework of the current model construct is needed to provide a genuine delineation of the cone of depression, accurate simulations of well water level changes with time and better estimate dewatering volumes for this permit application.

Respectfully submitted,

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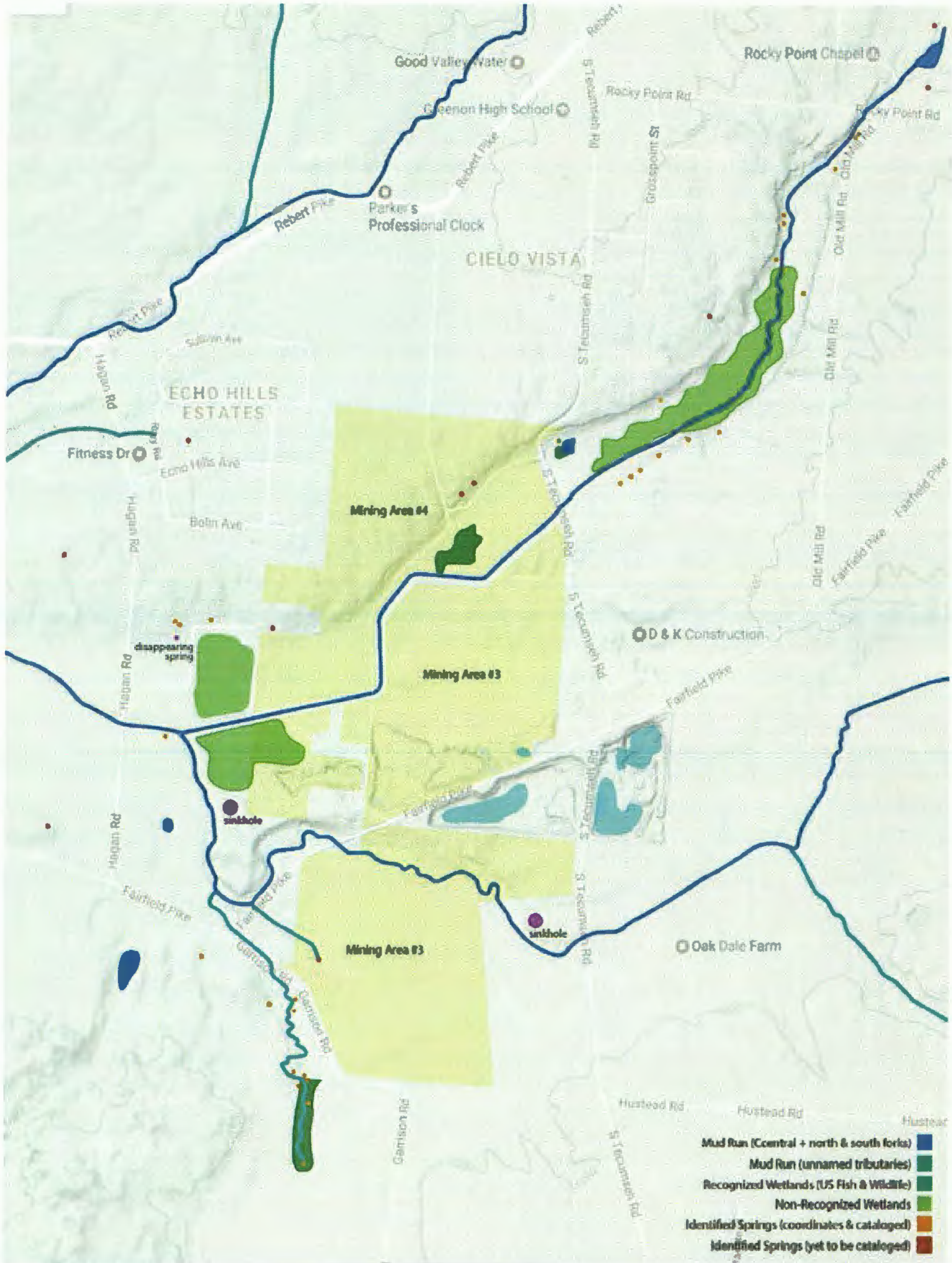

Attachment 1. Field reconnaissance map of surface expressions of karst features in the vicinity of proposed quarry locations, Mad River Township, Clark County, OH (Peterson, 2017).