Mr. Lanny E. Erdos, Chief
Division of Mineral Resources Management
2045 Morse Road, Building H-2
Columbus, Ohio 43229-6693

May 15, 2017

RE: Initial review of report: *"Evaluation of Groundwater Impacts, Dewatering of Proposed Enon Quarry, Clark County, Ohio"*

Dear Chief Erdos;

At the request of Mad River Township Trustees and the Village of Enon, Terran Corporation hydrogeologists have completed their initial review of the 2016 groundwater modeling report referenced above prepared by Eagon & Associates, Inc. (EAI). This report and accompanying Hydrology Information Data package was developed as part of the Industrial Minerals Permit No. IM-340 submission requirements (OAC 1501:14-5-01(A) and (B) for development of Enon Sand & Gravel II Quarry in Mad River Township.

Although not strictly adhering to the reporting requirements set forth in OAC 1501:14-5-01, EAI submission included a presentation of some available information relative to local subsurface conditions but mainly focused on regional hydrogeology and geology settings. A computer model was constructed attempting to estimate the effects of quarry dewatering on groundwater levels in the vicinity of the proposed quarry pits. Absent from this model exercise was a supportable estimation of effects of the quarry operation on ground-water quality and supply to existing wells. Also absent was assessment of quarry dewatering operations on surface water flow regimes, specifically streams, springs and wetlands (fens) or the effects of operational blasting on the regional groundwater system.

The primary submission of this data package was a regional groundwater flow model constructed by EAI 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. The model consists of four layers: 1) unconfined upper carbonate bedrock aquifer, 2) shale layer aquitard, 3) confined lower carbonate bedrock aquifer, and 4) poorly producing Ordovician shale confining unit. Using a regional model to accurately simulate the effects of quarry operations on adjacent groundwater supplies in the area can be misleading if site-specific hydrogeologic data is not used. 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 radius of influence, poor prediction of aquifer water level drawdown, and underestimating the volume of water to be pumped by the proposed dewatering activities.

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.

The following discussion will briefly outline readily recognizable deficiencies or misrepresentations in each of the major sections of the EAI model and model report.

Hydrogeologic Setting

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 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.

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. 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.

Some general hydrogeologic characteristics of the Silurian carbonate aquifer within the study site that need to be understood and quantified for use in any groundwater flow model is the aquifer water transmissive capacity, both primary and secondary pathways, the aquifer's current production potential and sustain yield. The carbonate aquifer in Mad River Township has higher permeability at the top and bottom of the 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). Although it would require field verification, identified spring flows may be sustaining the recognized high-quality wetlands (fens) throughout the area in addition to ongoing shallow carbonate aquifer subsurface recharge/discharge.

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).

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."*

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.

Water-Well Logs and Data Analysis

To determine the hydrologic cone of depression for the proposed quarry operations, OAC 1501:14-5-01 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 the modelling scenarios presented.

Critical aquifer parameters needed (and required in OAC 1501:14-5-01 (B)) to calculate a realistic radius of influence (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.

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 will increase the natural hydraulic conductivity of the bedrock. 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.

Using the specific capacity values summarized for wells in the EAI model study area, more representative site-specific transmissivity and hydraulic conductivity values could be calculated for use in any groundwater flow model. For example, 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.

The analysis of the well log data provided in the EAI model report did not include an assessment of spatial hydraulic conductivity variability throughout the carbonate aquifer beneath Mad River Township. If this assessment was to be completed, water-wells constructed in significant joint/fracture zones or in the Sugar Rock at bottom of the carbonate aquifer would be found very productive. 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.

If the EAI model was to utilize ranges of hydraulic conductivity that are calculated from well logs and distributed appropriately throughout the model report area, 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. 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).

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. 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. This inaccurate depiction of areal groundwater recharge will significantly affect dewatering capture zone calculations required in the permit application.

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. 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 with the bedrock aquifers are significant (Sheets and Yost, 1994). Seyoum (2012) investigated the hydraulic relationships amid buried valley sediments and adjacent bedrock formations and found nearly 40% exchange of water between aquifers. 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 may cause 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.

Groundwater Monitoring

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. 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 sufficiently to dry up springs on their property.

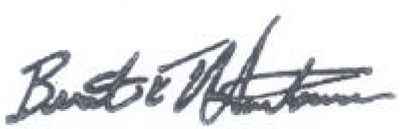
Missing from consideration in remedial measures of this permit application are remedies for property owners subjected to adverse water quality effects of the mining operations. Increased turbidity from blasting, bacterial or nitrate contamination resulting from accelerated induced recharge from lowered groundwater levels are two probable scenarios that need to be addressed.

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.

The summary statement *"The results from the model analysis are theoretical and represent only the general magnitude of impacts that might be expected."* is provided in the ***Conclusions*** section of the EAI model report. This is regrettably true of the EAI model and report submission. By not adequately characterizing the actual hydrogeologic conditions and groundwater occurrence in the carbonate aquifer underlying Mad River Township, the presented groundwater flow model should be considered simply an academic exercise as to how one might assess the potential dewatering effects of a quarry. The model results *represent only the general magnitude of impacts*, not the real-world impacts of the proposed mining operations in Mad River Township. The means and methods to 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 realistic delineation of the cone of depression, water level changes and dewatering volumes for this permit application.

After you or your staff has had the opportunity to review my comments concerning the EAI report and model, please do not hesitate to call me with any questions or if additional support material is need.

Respectfully submitted,



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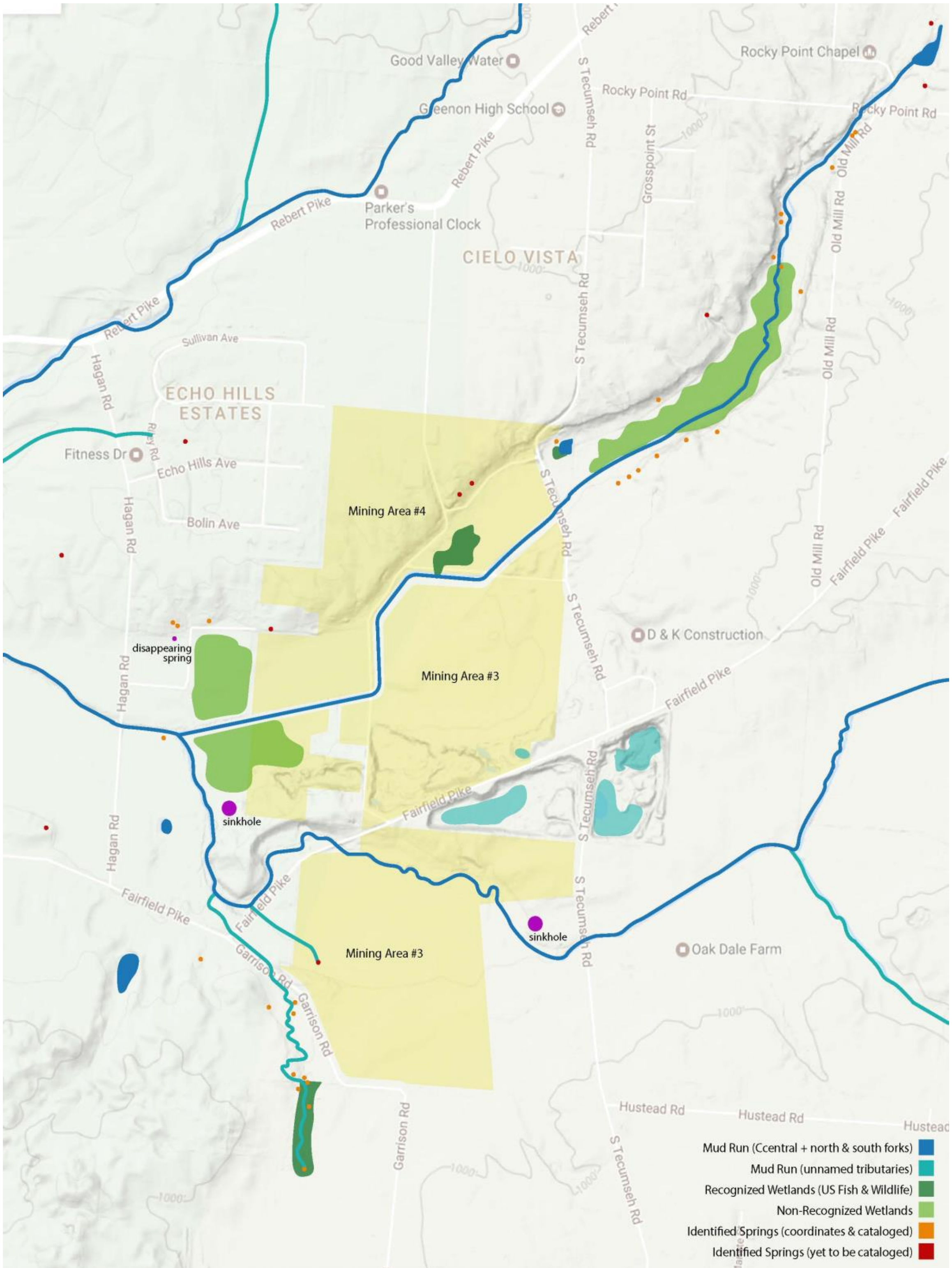

Attachment 1. Field reconnaissance map of surface expressions of karst features in the vicinity of proposed quarry locations, Mad River Township, Clark County, OH (Peterson, 2017).