STATE OF NEW YORK
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

IN THE MATTER OF THE APPLICATIONS OF CWM CHEMICAL SERVICES, LLC, Pursuant to to Articles 17, 19, 24, and 27 of the Environmental Conservation Law (ECL); Parts 201-5 (State Facility Permits), 373 (Hazardous Waste Management Facilities), 663 (Freshwater Wetlands Permit Requirements), 750 (State Pollutant Discharge Elimination System [SPDES] Permits) of Title 6 of the Official Compilation of Codes, Rules and Regulations of the State of New York (6 NYCRR); Section 401 of the federal Clean Water Act (CWA); and 6 NYCRR 608.9 (Water Quality Certifications), for required permits and approvals for the RMU-2 Project in the Towns of Porter and Lewiston, New York

DEC Application Nos. 9-2934-00022/00225
9-2934-00022/00231
9-2934-00022/00232
9-2934-00022/00233
9-2934-00022/00049

NEW YORK STATE FACILITY SITING BOARD

In the Matter of an Application for a Certificate of Environmental Safety and Public Necessity pursuant to 6 NYCRR Part 361 (Siting of Industrial Hazardous Waste Facilities) by CWM Chemical Services, LLC, Applicant (RE: Residuals Management Unit - Two [RMU-2]).

DIRECT TESTIMONY OF

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ANDREW MICHALSKI

Q. Please state your name and address.

A. My name is Andrew Michalski. I reside at 1301 Jankowski Court, South Plainfield, New Jersey.

Q. What's your employment status?

A. I am a semi-retired. Prior to my retirement at the end 2018, I was employed by my former environmental consulting firm, Michalski & Associates, Inc., located in South Plainfield, New Jersey.

Q. Please summarize your related educational background and professional experience.

A. I have a Masters of Science degree in Hydrogeology and Engineering Geology (1969) and a Ph.D. (1973) in Geological Engineering from Akademia Górniczo-Hutnicza im. Stanisława Staszica, or Academy of Mining and Metallurgy named after Stanisław Staszic (now AGH University of Science and Technology), in Krakow, Poland. I have over 50 years of consulting, academic and research experience, including 38 years of consulting in hydrogeology in the United States. I am a Certified Ground Water Professional (CGWP). Certification is maintained by completing annual continuing education, attesting to compliance with the Association's Canons of Professional Practice, and maintaining applicable state licenses to practice. Before retiring, I had Professional Geologist (PG) registrations in several states. I was also a Licensed Site Remediation Professional (LSRP) in New Jersey. A copy of my CV is provided in Attachment 1.

In my consulting capacity, I have conducted or supervised hydrogeologic investigations and designs of groundwater monitoring systems at numerous contaminated sites located within both unconsolidated and bedrock formations. I have developed an innovative set of testing methods and a conceptual flow model for contaminated sedimentary bedrock sites that has been incorporated into the New Jersey guidance manual for conducting remedial investigations at bedrock sites. My landfill-related experience includes reviews of Part B permit applications for the USEPA; conducting a remedial investigation of chemical waste landfill in Puerto Rico karst; and providing hydrogeologic support for environmental groups contesting proposed waste disposal facilities in several counties in the New York State.

Q. When did your involvement with the CWM matter start and what was the scope of your services?

A. In October 2011, I was retained by the Law Office of Gary A. Abraham representing the Municipalities (Niagara County, the Town and Village of Lewiston, and the Village of Youngstown) to provide expert hydrogeologic services related to the proposed expansion of CWM's landfilling operations at its Model City site in Niagara County, NY. Since that time, I have reviewed a number of available reports and other documents on the CMM site and the two adjacent sites (Modern Landfill and NFSS). I prepared an expert report dated November 2014 titled *Report on Groundwater Flow and Contamination at Chemical Waste Management, LLC, Model City, New York, and Proposed RMU-2 Permitting and Siting Issues*, with 15 exhibits. A copy of this report with its exhibits was submitted to the record of this proceeding with the Municipalities' Petition on November 24, 2014. I also prepared certain memoranda on hydrogeologic issues in response to subsequent submissions by CWM's environmental consultants, also found in the record of the Issues Conference.

Q. Are you relying on your previous reports you've just identified?

A. Yes.

Q. What other evidentiary basis do you have for your testimony?

A. I am also relying on several attachments to my testimony which are generally graphical depictions of the site hydrogeological features I will be discussing, and background documentation listed in a reference page also attached here. I will be discussing each of those listed documents.

Q. What are the key points of your testimony regarding hydrogeologic issues of the RMU-2 Permit Application?

A. My key point is that CWM has misrepresented the hydrogeology and groundwater flow at and in the vicinity of the RMU-2 site by disregarding the role of alluvial sand and bedrock as the main aquifer units that control groundwater flow and create preferential contaminant migration pathways should discharges from the proposed landfill occur. The Applicant's conceptualization of groundwater flow at the site is inconsistent both with hydrogeologic principles and the regulatory requirements of 6 NYCRR 372-2.6(f)(1). Consequently, the CWM-proposed groundwater monitoring would not work.

My other major points include: 1) The northern portion of the proposed RMU-2 does not comply with the Part 373 minimum hydraulic conductivity standard of $1x10^{-5}$ cm/s. 6 NYCRR § 373-2.14(b)(1). 2) Locating RMU-2 immediately downgradient of existing RMU-1 combined with the presence of prior contamination in the area impedes monitorability of potential releases from RMU-2. See 6 NYCRR § 373-2.6(h)(1)(iii). 3) DNAPLs have likely contaminated bedrock in the former Process Area where the Glaciolacustrine Clay is very thin so the bedrock should become the regulatory uppermost aquifer in adjacent portions of RMU-2, but CWM has proposed no bedrock monitoring there. See generally 6 NYCRR §§ 373-2.6(h)(1), (2).

Q. With regard to your key point, can you briefly describe the hydrostratigraphy of the CWM site?

A. There are two conflicting conceptualizations of the site hydrostratigraphy. The first one is presented by Wehran (1977), the hydrogeological consultant for CWM's predecessor, Chem-Trol Pollution Services, Inc. As shown in Attachment 2, Wehran's geologic column includes (starting from the oldest): the Queenston Formation bedrock; the Basal Till; the Alluvial Sand and Gravel filling-in bedrock depressions; the Glaciolacustrine deposits with a Silty Till sandwiched in them; the Upper Till; and the recent Alluvium. The same hydrostratigraphic conceptualization was used by HGL, a contractor to the U.S. Army Corps of Engineers for the adjacent NFSS site. The Wehran and Army Corps conceptualizations are summarized graphically in Attachment 2, plates 1 and 2.

The other conceptualization ~~of~~ was advanced by Golder, the hydrogeologic consultant for CWM. Golder's schematic cross-section (Attachment 2, plate 3) eliminates the Alluvial Sand and Gravel as a separate unit and implies layered and lateral continuity of all units except the Middle Silt. This conceptualization is incorrect and misleading.

Q. What is the basis for your opinion that CWM's depiction of site hydrogeology is "incorrect and misleading"?

A. To answer this question, I'd like to make a brief tour through geologic history of the site and emphasize how this history impacted the current flow of groundwater.

The top surface of the Ordovician Queenston Formation bedrock, which underlies the Model City site, exhibits a series of small ridges and intervening valleys that follow the ENE-WSW strike of bedrock beds. These ridges and valleys reflect different erosional resistance of the bedrock beds. The ridges are apparent on a 1913 topographic map of the study area. See 2014 Michalski Report, Exhibit 2, Figs. 3a and 3b (after Kindle and Taylor (1913) who described the ridges as "[c]omposed mainly of stony till generally overlying ridges of shale"). LiDAR imagery, (id., Fig. 4), also shows several ENE-WSW trending lines in the vicinity of the CWM site. These lineaments run parallel to the bedrock strike and run for long distances.

The presence of a bedrock valley running across the southern portion of the CWM site from ENE to WSW was first uncovered by Wehran (1977; Sheet 2), and is apparent on the top of bedrock map in an early report by Golder (1993), provided as Exhibit 1 to the November 2014 Michalski Report. The southern half of the RMU-2 footprint is located directly over this subterranean valley. The valley is even more evident on the latest (2016) top of Basal

Till map that I include as Attachment 3. An offsite extension of this valley beyond the southwest portion of the CWM site into the adjacent Niagara Falls Storage Site (NFSS) was documented by USACE (2007; Figure 2.20).

The buried valley beneath RMU-2 is bounded by ridges to the north and south that rise to an elevation of 285 ft msl. The bottom of the bedrock valley with a veneer of Basal Till is at an approximate elevation of 270 ft msl (Attachment 3). Another buried valley, which is even more deeply incised, has been mapped past the northern ridge and beyond the northern CWM site boundary. It is likely that the buried valley found beneath the CWM site joins that main valley someplace west-northwest of the site.

The bedrock surface is coated with a patchwork of the Red Basal Till. This highly indurated and fractured till is different from the Late Wisconsin Upper Till found at the site near ground surface. The Red Basal Till is more than 100,000 years old (Kindle and Tylor, 2014).

During a long hiatus between the deposition of the Red Basal Till and the Late Wisconsin period (which started some 20,000 years ago), the topographic relief in the area was much greater than today. Streams eroded some the Red Basal Till within the valley bottom, as evidenced by the absence of Basal Till in some borings, including borings for monitoring wells R-119D through R-122D (Golder 2014). The streams deposited alluvial and glaciofluvial sand and gravel within the valley. These are the most permeable material within the overburden section, as I will explain.

Afterwards, a “proglacial” lake, forming between the glacier and the Escarpment, covered this area. Over time, this lake allowed glaciolacustrine deposits, consisting of silt and clay, to cover the alluvium-filled valley. The lacustrine period was interrupted by a temporary glacial advancement that left the Middle Silt unit over the northern portion of the site. Subsequent advancement of the Late Wisconsin glacier disturbed and re-worked the soft lacustrine sediments, and left till deposits atop the sediments and over the bedrock ridges, as described by Kindle and Taylor (1913).

The hydrogeologic consequences of the geologic history of the site are as follows: 1) The alluvial and glaciofluvial Sand and Gravel unit that fills the lower portion of the buried valley is the most permeable unit of the overburden section and the only true aquifer unit, and 2) The northern ridge impedes groundwater flow to the north and re-directs the flow westward along the course of the buried valley.

That is how the sand and gravel unit deposited within the buried valley channels provides a preferential flow and contaminant migration pathway at the CWM site.

Q: How do we know that the materials deposited on top of the buried valley bottom are much more permeable than subterranean materials to the immediate north?

A. Hydraulic conductivity is the key metric used to compare the permeability of geologic materials. As I show in Figure 5 and Exhibit 5 of the November 2014 Michalski Report, hydraulic conductivity values of the Alluvial Sand and Gravel measured in wells located within the buried valley (10^{-3} to 10^{-2} cm/sec.) are at least two orders of magnitude greater than the values found on the northern side of the valley and at the top of the northern ridge. This indicates that deposits found on the northern bedrock ridge behave as an aquitard, blocking the groundwater flow to the north.

Q: Why do you conclude that the sand and gravel within the valley bottom provide a preferential path for the flow of contaminants?

A. Wehran (1977, 43) emphasized that the sand and gravel fill of the buried valley forms a distinct and separate water-bearing unit that would be considered the most vulnerable to any landfill-derived contamination should it occur. The hydrogeological characterizations in USACE (2007) are consistent with this conclusion. Wehran estimated groundwater velocity in the buried alluvial valley beneath the central portion of the CWM site in the range of 88 to 624 feet per year. Wehran (1977) made a number of recommendations, including installation of an addition well into the Alluvial Sand and Gravel unit at the valley outlet along the western property line.

Q. How does CWM's theory of the hydrogeological setting differ from Wehran's and yours?

A. When CWM became the new site owner and hired another hydrogeologic consultant, a new aquifer unit known as Glaciolacustrine Silt/Sand (GSS) was conceived in an apparent attempt to eliminate the vulnerability associated the Alluvial Sand and Gravel unit. The latter unit has become a part of the GSS (Golder 1985). Whereas the stratified sand and gravel was acknowledged as the most permeable sub-unit of the four sub-units of the GSS (Golder, 1985, page 34), such acknowledgement is meaningless if this sub-unit is claimed to be randomly distributed and not mappable.

Q. How would you characterize CWM's Glaciolacustrine Silt/Sand (GSS) Unit?

A. The so-called GSS Unit is neither a hydrostratigraphic unit as defined conventionally in hydrogeology, nor is it an aquifer unit as defined by 6 NYCRR § 370.2(b)(12).

Q. What is a hydrostratigraphic unit?

A. Hydrogeologists group soil and bedrock into hydrostratigraphic units based on similar permeability and origin of geologic materials. Such hydrostratigraphic units are then designated as one of three hydrogeologic entities: aquifers, aquitards or aquicludes (impervious units). The alluvial and glaciofluvial deposits in the lower section of the buried valley are very different from the overlying glaciolacustrine silt deposits, in terms of their origin and age, grain size distributions, hydraulic properties, and areal distribution. On the adjacent NFSS site, the U.S. Army Corps of Engineers considers the sand and gravel unit to be an aquifer unit separate from the overlying glaciolacustrine deposits. Combining these distinct units into one hydrostratigraphic unit named the GSS, as Golder has done, obscures the hydrogeological setting.

It is contrary to hydrogeologic principles to lump units of different origin and permeability into a single hydrostratigraphic unit (GSS), especially while already knowing that hydraulic conductivity values measured in wells assigned to the GSS range from $3x10^{-1}$ cm/s (B-38) to $1.8x10^{-8}$ cm/s (WDA1D). Such an enormous permeability difference, by a factor of 10,000,000, practically covers the entire range of hydraulic conductivity values for all types of unconsolidated sediments, from gravel to clay (Attachment 4 after Fetter, 2001 Table 3.7). At the CWM site, this enormous permeability range is found within a single hydrostratigraphic unit designated as the GSS, which is in violation of hydrogeologic principles. This single GSS unit simultaneously incorporates aquifer, aquitard, and even aquiclude entities within its lateral extent.

Q. Does CWM's GSS unit satisfy the regulatory definition of an aquifer?

A. No. As per 6 NYCRR § 370.2(b)(12), an aquifer is a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of ground water to wells or springs. Only the sand and gravel unit in the buried valley and the bedrock satisfy this definition. See Figure 5 of the 2014 Michalski report. All other units, including portions of the GSS unit overlying the bedrock ridge, are not aquifers but aquitards, low-permeability units.

Any assertions that the sand and gravel deposits within the buried valley are not continuous misrepresent the actual site data. First, logs of available soil borings and wells show the continuous presence of a sand and gravel unit along the bottom of the buried valley. This alluvial and glaciofluvial sand and gravel unit is not present in well borings installed over the bedrock ridge north of the buried valley. In general, the thickest portions of the unit are present where depressions occur in the underlying bedrock, but that is not evidence of discontinuity.

Second, results of slug tests conducted in wells completed within alluvial deposits of the buried valley show much higher hydraulic conductivity compared to wells installed in the ridge area. *See* Michalski Report, 9, Fig. 5. This pattern is most evident in the area of RMU-1 and the proposed RMU-2 landfill, (north of Facultative Ponds 3 and 8). (Although as I will explain, CWM has installed an insufficient number deep monitoring wells directly into the buried valley.)

Q. What do CWM's hydraulic conductivity measurements for the bedrock aquifer tell us?

A. The hydraulic conductivity values measured for the alluvial sand and gravel deposits were as high as 10^{-2} cm/s (Table 5 in Golder, *2014 Hydrogeologic Update*), typical of well-sorted sand with gravel (cf. Attachment 4). Mixtures of sand, gravel and silt within the buried valley show hydraulic conductivity values in the 10^{-3} cm/s to 10^{-4} cm/s range. These values are approximately one hundred times greater than hydraulic conductivity values for wells installed in the GSS unit in the ridge area to the north of the valley. Such a large contrast in hydraulic conductivity values produces a preferential flow pathway along the most permeable buried valley deposits and parallel to the ridge.

Q. Is there additional evidence for the continuity of the buried valley aquifer?

A. Yes. A reliable and recognized method of evaluating hydraulic continuity between wells is based on drawdown responses observed during groundwater pumping tests. Although no pumping tests have been conducted at the CWM site, dewatering pumping conducted at the adjacent Modern Landfill and at two clay mining pits located west of the CWM site provide important evidence. The wells that were pumped were completed in the sand and gravel unit in the bedrock. As discussed in the 2014 Michalski Report, analyses provided by Carey~~,~~ (2005) show that dewatering pumping at the Modern Landfill caused a potentiometric head decline of as much as five (5) feet in wells located more than 2,000 feet away. Larger observed drawdowns, on the order of 10-15 feet, were attributed to dewatering pumping at the Pletcher Road borrow pit ponds located approximately 1,500 feet to the WSW of the CWM site. The drawdown was more pronounced in the western direction, towards the pit.

As documented in the Golder, 1994 report, dewatering operations at Modern Landfill produced drawdown of approximately 5 to 7 ft in GSS wells located in the southeastern portion of the site during the 1991 peak of the dewatering pumping (wells BW02D, W1001D, B34A, W1101D, W1102D; see Table 2 of Golder, 1994). No significant drawdown impact was noted in the Upper Till wells. It is worth noting that even during the maximum of dewatering impacts on onsite GSS wells, the westerly groundwater flow direction within the Alluvial Sand unit still persisted, as indicated by potentiometric levels in GSS wells located along the course of this unit (Figure 11 in Golder, 1994).

Furthermore, available historic hydrographs for CWM onsite wells indicate large fluctuations of potentiometric levels in GSS wells during the 1979-1981 period; see Exhibit 14 the November 2014 Michalski Report, and Appendix F in Golder, 1985. A 33-foot decline was recorded in well B-38 located along the axis of the buried valley north of the onsite Fire Pond (NE of East Salt), a 25-foot decline in B-34 located farther to the east, and a 22-foot decline in well B-44 located east of RMU-1. But only a small decline was observed in GSS wells screened within low-permeability deposits overlying the northern ridge (*e.g.*, well W-3); see Page 6 of Exhibit 14 of the November 2014 Michalski Report. The reason for such large water level fluctuations is not clear, but some dewatering operations could cause the observed decline. This is based on elimination of possible natural causes: No droughts occurred during that period, as showed by Buffalo precipitation records, and normal water levels were recorded in a USGS Ransomville observation well located 2.5 miles from the CWM site and completed within the sand and gravel unit. USGS Current Conditions for USGS 431308078544501 Local number, Ni-70, near Ransomville NY

The large lateral extent of drawdown along the buried valley, stretching for a distance of thousands of feet from the borrow pits to beyond the eastern boundary of the CWM site, attests to the hydraulic continuity and significant transmissivity of the semi-confined sand and gravel unit within the buried valley and the underlying bedrock. On the other hand, the lack of any significant drawdown responses in CWM's wells located at the northern ridge to the dewatering operations at Modern Landfill and the borrow pits, indicates that this ridge acts as a flow barrier.

Q. Is the GSS unit truly the regulatory uppermost aquifer, as CWM claims?

A. Only the most permeable portion the GSS unit, which is the Alluvial Sand and Gravel within the buried valley bottom, should be designated as the regulatory uppermost aquifer, as it provides preferential groundwater flow and a contaminant migration pathway. Outside the buried valley, specifically atop and on the sides of the bedrock ridge, bedrock takes over as the regulatory uppermost aquifer. I will address how surface contaminants released in this area can migrate to bedrock later in this testimony.

Q. Can you characterize groundwater flow directions within the GSS unit and particularly within its buried valley portion?

A. Yes. A large number of potentiometric maps of the GSS unit have been generated for the CWM site since the first map prepared by Wehran in 1977. As additional wells were installed over time, I am going to discuss the latest potentiometric map for March 2016. This map is included in Attachment 5, together with its zoom-in version with my interpretive markings added onto the map.

Before going to my interpretations, several points need to be clarified. First, a common practice of drawing groundwater flow direction perpendicularly to potentiometric contours is only valid for homogeneous and isotropic (having properties that remain the same when tested in different directions) aquifers. The GSS satisfies neither of these restrictions.~~.~~ As I stated earlier, the GSS fashioned by CWM is a highly heterogeneous unit that includes both the aquifer unit (the Alluvial Sand and Gravel) and an aquitard unit on the top and sides of the bedrock ridge. CWM does not account for such critical lateral permeability changes within their GSS unit (Figure 5 in 2014 Michalski Report). As a result, CWM's claimed northwesterly groundwater flow direction across the site is only apparent and incorrect.

Second, the monitoring well coverage within the GSS unit, CWM's regulatory uppermost aquifer and the detection zone, is not uniform: The majority of wells are located on the eastern and northern sides of the regulated units, based on an apparent north-westerly flow direction. A very sparse well coverage exists west-southwest of RMU-2. This is a crucial issue, as only the Alluvial Sand and Gravel portion of the GSS unit constitutes the actual uppermost aquifer and a preferential flow and contaminant migration pathway.

Third, not all of CWM's sparse west-southwest wells were installed into the lowermost portion of the GSS (i.e. just above the Basal Till) that is most permeable. As a result, measured potentiometric levels include a mixture of horizontal and vertical hydraulic heads but are attributed only to the former.

Fourth, a potentiometric map were supposed to represent a snap-shot condition, but at the CWM site water level readings were collected from individual wells over a period of 2-3 days, disregarding water-level changes in some wells during that period.

Despite these issues, a consistent groundwater flow pattern emerges for the GSS if lateral permeability changes within this artificial unit are accounted for. On the zoom-in map in Attachment 5, I have added two west-to-east trending lines. The orange line represents a groundwater divide, as it connects the highest potentiometric levels over the bedrock ridge where the GSS unit is thin and exhibits low permeability. The green line connects points/wells with the lowest potentiometric levels. The green line follows the bottom of the buried valley. The blue arrows show groundwater flow directions within the GSS unit. The draining effect of the Alluvial Sand and Gravel unit within the buried valley is clearly evident.

All potentiometric maps available for the GSS unit exhibit this common theme: A wide spacing of potentiometric contours along the course of the Alluvial Sand and Gravel unit of the buried valley, but a very narrow spacing north of the bedrock ridge. The wide spacing (low hydraulic gradient) reflects high transmissivity of the Alluvial Sand and Gravel unit, while the narrow spacing (steep hydraulic gradient) is indicative of a low-permeability flow barrier.

CWM has acknowledged the presence of a westerly flow "component" within the GSS unit. However, as my Attachment shows, the entire flow beneath a large portion of RMU-2 south of the groundwater divide line is directed westward along the higher-permeability deposits of the buried valley. This is much more than a minor component of the hydrogeological setting.

Q. Is the groundwater monitoring plan for the GSS unit proposed by CWM effective and adequate?

A. No. An effective monitoring plan must be based on a realistic site conceptual model that is backed by adequate hydrogeologic characterization. The CWM-proposed monitoring well network for the GSS unit is based on an assumed north to northwesterly groundwater flow direction. It will be ineffective for the southern half to two-thirds of the RMU-2 footprint, where the preferential groundwater flow and contaminant migration pathway is directed into deep Alluvial Sand and Gravel. There are very few truly downgradient monitoring wells in along the western footprint. The CWM plan submitted to DEC proposes no monitoring wells for a 750 ft long landfill segment south of R216D, or for a 500 ft segment between R201DR and the groundwater divide (Attachment 6). These distances are far less than the 140 ft spacing proposed along the northern segment of RMU-2.

Beyond that, the configuration of the bedrock valley, and the Alluvial Sand and Gravel deposited within it, is very poorly defined downgradient (westward) of RMU-2. As I noted previously, there are very few wells there, and CWM has not used any surface geophysical method to elucidate the topography of the top of bedrock (basal till) along the preferential contaminant migration pathway within the site boundaries and beyond and to clarify how this buried valley relates to the deeper buried valley north of the ridge.

Q. Has CWM proposed to install any additional monitoring wells to bedrock?

A. No. Through a recent discovery request, a September 15, 2017 letter from Waste Management to USEPA Region II was discovered. An enclosure to this letter contains a CWM proposal to modify an existing monitoring network by the addition of eight deep monitoring wells along the western footprint of RMU-2. However, CWM's proposal does not include any shallow (Upper Till) wells in cluster with the deep wells. This is odd considering the presence of shallow wells in all existing upgradient well clusters and the presence of contamination in the Upper Till along the western/downgradient RMU-2 footprint. No bedrock wells are included in this CWM proposal to the USEPA.

Q. Can you summarize your main concerns about CWM's ability to effectively monitor potential releases from RMU-2 to groundwater?

A. Yes. The ability to monitor RMU-2 releases is complicated by 1) the need for bedrock monitoring, unaddressed in CWM's application, 2) the presence of existing groundwater contamination, including DNAPLs containing PCBs and other bioaccumulative chemicals of concern, toxic at very minute concentrations, and 3) obstacles to effective groundwater monitoring that result from locating RMU-2 next to existing RMU-1.

Q. Why should monitoring of bedrock groundwater be required?

A. The importance of bedrock groundwater monitoring stems from bedrock attributes that are commonly unappreciated or misunderstood. First, migration velocity in bedrock is much faster than in porous media with the same hydraulic conductivity values by virtue of much lower bedrock effective porosity. Darcy's equation, the fundament of quantitative hydrogeology, states that groundwater velocity is inversely proportional to effective porosity of geologic materials. While a typical effective porosity value for a sand and gravel unit is approximately 20%, that value is approximately 1% for fractured bedrock. By plugging these numbers into the Darcy equation one concludes that migration velocity in bedrock would be approximately 20 times faster than in a sand and gravel unit of the same hydraulic conductivity.

Second, it is well-established for other sedimentary bedrock sites that bedding plane separations (often referred to as bedding fractures) provide preferential pathways for fast migration over large distances owing to their lateral continuity. The low water levels measured in some bedrock wells at CWM and the adjacent two sites imply a direct hydraulic connection with the Niagara River where the Queenston Formation bedrock is reportedly exposed on the river bank.

I could not identify any analytical data on organic compounds in CWM bedrock wells. At the time of the 1977 Wehran investigation, monitoring wells were only tested for inorganic contaminants, which was then a standard practice. This is another reason why monitoring of bedrock groundwater should be required.

Q. Why do you conclude that, in order to effectively monitor the groundwater aquifer beneath RMU-2, some bedrock wells must be installed?

A. Bedrock should have been designated as the regulatory uppermost aquifer in the ridge area where the northwestern portion of RMU-2, the Process, Lagoon, and West Drum Areas are located. Bedrock monitoring is needed there because of 1) the confirmed presence of DNAPLs within the basal till on the top of bedrock in the ridge area; 2) the shallow depth to bedrock (approximately 35 ft, or even 25 ft as reported for boring B3 by Wehran, 1977, p. 65); 3) the thin or absent overburden made of tills with Glaciolacustrine Clay; and 4) the small thickness and very low permeability of the GSS unit, the assumed uppermost aquifer, in the ridge area.

Hydraulic conductivity values for GSS wells located over the ridge (R202SR, 202DR and R218D) range from 10^{-7} to 10^{-6} cm/s, documenting that non-aquifer low-permeability facies of GSS is present there. Consequently, vertical flow into the bedrock provides the fastest migration pathway within the northwestern portion of RMU-2 located over the ridge area. The same applies to DNAPLs released over the ridge in the adjacent Process Area, particularly where Glaciolacustrine Clay (GC) has eroded. The erosion of clay (the GC unit) creates permeability windows into bedrock. See Exhibit 8 of the 2014 Michalski Report.

As I've noted, no bedrock monitoring wells have been proposed for RMU-2, despite the fact that several bedrock wells were installed at the site by Wehran (1977) and Golder (1993). On the adjacent Modern Landfill and the NFSS sites, the GSS unit and shallow bedrock are hydraulically connected members of the Lower Aquifer. The shallow bedrock is monitored at both adjacent sites, and is even pumped at Modern Landfill as part of a groundwater suppression system. Similarly, a direct connection between the Alluvial Sand and Gravel and the bedrock is expected at the CWM site where well logs show that the basal till is thin or completely eroded within portions of the buried valley bottom. Reported geometric hydraulic conductivity values for shallow bedrock are 1.2×10^{-5} cm/s for the CWM site and 2.2×10^{-5} cm/s for the NFSS site (Golder, 1993; USACE, 2007).

Q. You mentioned DNAPLs in the ridge area. Would you expand on this and address its relevance for the existing groundwater contamination?

A. Yes. DNAPL is an acronym for "dense non-aqueous phase liquid", generally oily-like contaminants that are denser than water and poorly soluble. I addressed the DNAPLs present in the ridge area on pages 19-21 of my 2014 report, so now I wish to supplement that report by concentrating on areas adjacent to the northwestern perimeter of RMU-2 (Attachment 7).

A groundwater sample collected from boring PRO-9 showed PCB at 35,000 ppb (Table 5.24-5, page 2 in Golder 1993 RCRA report). This boring is located a short distance from well cluster R201S/D. The boring reached a depth of 28 ft that corresponds to the top of the GSS unit, based on data from adjacent borings and an increased blowcount at the bottom of PRO-9. The latter indicated that different, more indurated material typical of GSS, was encountered.

The high PCB concentration found in this groundwater sample exceeds the aqueous solubility of PCB by orders of magnitude, which indicates that PCB was co-solved in a DNAPL solvent mixture. The dominant DNAPL constituents in this groundwater sample were chlorinated solvents TCA-DCA (1,1,1-Trichloroethane-1,1-Dichloroethane) detected at a concentration of 364,950 ppb. See Attachment 8.

Interestingly, TCA-DCA was not detected in any of 13 soil samples collected from boring PRO-9. This indicates that TCA-DCA and the PCB present in this solvent mixture migrated laterally to the PRO-9 location from some other source, possibly from the PRO-4 area where even a higher TCA-DCA concentration of 520,000 ppb was detected in groundwater. PRO-4 is located approximately 200 ft north of PRO-9 (Attachment 7) and close to the top of the bedrock ridge and the potentiometric divide in the GSS unit I drew in Attachment 5. This puts the PRO-9 location onto the southern slope of the bedrock ridge, which favors southward migration of the TCA-DCA DNAPL and possibly eastward migration toward a buried valley tributary beneath the RMU-2, which I interpret on Figure 5 of my 2014 report.

As I mentioned in my 2014 report, DNAPL-level contamination was also found in soil and groundwater samples within the Basal Till in PRO-21, (*id.*, 20), which indicates that the underlying bedrock was also likely impacted.

CWM has not delineated the lateral and vertical extent of such deeper groundwater contamination in the Process Area (PRO-9, 10 and 21). The more recent investigative borings installed east of the Process Area and next to the RMU-2 footprint were generally too shallow for deep plume detection and delineation. Nevertheless, very high concentrations of VOCs (volatile organic compounds), as high as 7,260,000 ppb in 61R, were detected in groundwater in that area (see Attachment 7). (Note that values reported in that Attachment area in parts per million, or ppm).

Another area of existing contamination at the proposed RMU-2 footprint is found at the eastern side of Facultative Pond 3, where VOC concentrations of 20,400 ppb were detected in TW24S and 2,080 ppb in W1002S (Figure 5 in Golder, 2009). Across Facultative Pond 3, on its downgradient side, VOC concentrations of 27 ppb were detected in well W-39 (*id*). Should the Pond become part of the proposed RMU-2 footprint, it would be difficult to separate pre-existing impacts from RMU-2 discharges. It needs to be pointed out that CWM proposes no monitoring wells downgradient of the TW24S/ W1002S area.

Thus far, no corrective action has been proposed to address the likely deeper contamination in those areas, and any corrective action would not be effective without prior delineation.

The presence of existing contamination at and adjacent to the proposed RMU-2 landfill, together with complex contaminant migration pathways, makes it extremely difficult to distinguish between contamination that might be released from RMU-2 and contamination originating from numerous other sources. The vertical distribution of soil contamination revealed by the PRO-series borings (installed in 1990) points to tortuous contaminant migration pathways that follow the least resistance within heterogeneous glacial deposits. Such pathways differ from straight downward or lateral migration paths within a layered flow system, as postulated by CWM. It also shows that the Glaciolacustrine Clay unit is significantly more permeable, and less effective~~,~~ as a principal migration barrier than claimed by CWM.

Q. What data can you provide that contradict the claimed role of the Glaciolacustrine Clay as an effective migration barrier?

A. The results of 18 soil samples collected from boring PRO-5, which I provide in Attachment 9 along with the field log of this boring, contradict CWM's claim. Six of the samples, numbered 6 through 11, were collected from the Glaciolacustrine Clay at depths between 18 and 30 ft, according to the boring log. The uppermost two of these six samples were essentially clean. The remaining four were contaminated, with the highest contamination recorded near the contact of the Glaciolacustrine Clay and the underlying GSS unit. This vertical contaminant distribution pattern points to a lateral contaminant migration within the Glaciolacustrine Clay, presumably along more sandy laminations (or other features discussed next), rather than vertical migration as assumed by CWM. The contamination somehow bypassed the Glaciolacustrine Clay in the vicinity of PRO-5 that was located within the ridge area.

Following its deposition in a proglacial lake, the Glaciolacustrine Clay was contorted, scoured and eroded by a re-advancing glacier, which produced large thickness variations and admixture of till materials. This re-working impaired the ability of the Glaciolacustrine Clay to provide an effective barrier against contaminant migration.

The Clay thickness map (Figure 9 in Golder 2014) documents large thickness variations over short distances of this contorted unit. The map also documents small thickness of this unit beneath the northern portions of RMU-2 and south of R216D. Specifically, beneath the western portion of Cell 18, the Clay thickness is only between 1.9 ft (RMU2-W39) and 4 ft (SB02-2). The permeability window identified at that location in the 2014 Michalski report constitutes vulnerable spots for downward groundwater flow and contaminant migration. In the area between the Process Area and RMU-2, the Glaciolacustrine Clay is only 1.7 ft thick at RMU2-W23, 2.3 ft thick at W19-W4-N3, and 4 ft thick at SB-0203. These three borings define a large area of RMU-2 beneath the proposed Cell 15.

Moreover, isopach contours shown on Golder (2013) Figure 9 were improperly drawn for an area between SB-02-3, W19-W4-N3 and R118D. No data supports drawing the 15-ft isopach twice through this area of RMU-2 with sparse data points.

The effectiveness of the Glaciolacustrine Clay unit as a barrier to contaminant migration into the lower aquifer should also be questioned based on the lessons learned from the Smithville, Ontario case. The Smithville site, located merely 35 miles west of the Niagara River, has had similar glacial history and stratigraphy as the CWM site. The thickness of glaciolacustrine clay at the Smithville site ranges from 18 ft to 30 ft, greater than reported for the CWM site. See DEIS, 57. The clay overlies dolomitic bedrock of the Lockport Formation. It was estimated that several thousand gallons of PCB DNAPL migrated from a waste lagoon into the bedrock through unrecognized vertical fractures in the thick glaciolacustrine clay unit that was originally presumed to provide a tight barrier against downward contaminant migration. McIelwain (1989).

Q. Do you agree with the groundwater flow and migration rates calculated by CWM?

A. No. I addressed this issue in my 2014 report on pages 12 through 15. The CWM-calculated migration rates are unrealistically low and misleading. They are contradicted by examples of migration rates I provided in my 2014 report, which are based on actual site data.

There are two major reasons for the large discrepancy between the calculated and actual flow and migration rates. One is the use, in the CWM calculations, of artificially low hydraulic conductivity values. I give an example of such misuse at the end of my answer to the following question. The example deals with the representative hydraulic conductivity value for the Upper Till at RMU-2. Also questionable are individual hydraulic conductivity values calculated from slug testing graphs included in 2016 Supplemental Report. On those graphs, early time data are missing, which resulted in a bias that lowers the calculated hydraulic conductivity values. Attachment 10 provides an example of this bias.

The other much more important reason is that the migration rate calculations are based on a simplistic conceptual site model that ignores lateral and vertical heterogeneities, inherent in glacial deposits within the 43-acre RMU-2 area. RMU-2 has a diagonal length of approximately 2,000 ft. The CWM model does not recognize different hydrogeologic conditions and flow patterns present across this area large area that includes the buried valley and the ridge area. For example, as previously discussed, CWM fails to acknowledge that bedrock provides the fastest migration pathway within the ridge and its slope area.

Q. Does the RMU-2 area meet the minimum landfill siting permeability standard?

A. No. Part 373 establishes minimum standards for permeability, or hydraulic conductivity at a proposed hazardous waste facility site. Part 373-2.14(b)(1) requires that the soil beneath the facility have a hydraulic conductivity of 10^{-5} centimeters per second or less, as determined by in-situ hydraulic conductivity test methods. The majority of the shallow/upper till wells installed at the RMU-2 footprint show that RMU-2 does not meet this minimum permeability standard.

Hydraulic conductivity values for the upper tills greater than 10^{-4} cm/s have been measured in shallow/upper till wells R214S, R2015S, W1003S and W1004S located at the RMU-2 footprint, and directly above the buried valley. See Exhibit 10 and Figure 5 in my 2014 report. Also, these wells are located near the vertical permeability window labeled with letter D on Exhibit 8 of my 2014 report. Another well with elevated hydraulic conductivity values, R203S, is located near another vertical permeability window labeled “A” on that exhibit. These excessively high permeability values combined with their vulnerable locations point to a much faster contaminant migration pathway into the lower aquifer than CWM acknowledges, particularly in areas with permeability windows where clay unit (GC) is eroded or very thin.

Results of field hydraulic conductivity measurements conducted within the proposed RMU-2 footprint, provided in Table 3 of Golder (2010), show that out of a total of 13 shallow or

"S" (Upper Tills) wells tested, ten wells show hydraulic conductivity values greater than $1x10^{-5}$ cm/s. 2014 Michalski Report, Exhibit 10. Only three wells tested meet the minimum hydraulic conductivity standard. These three wells are located at the northern perimeter of the proposed RMU-2 footprint. The 13 shallow wells tested within the RMU-2 footprint have a geometric mean hydraulic conductivity value of $6.9x10^{-5}$ cm/s. Clearly, the RMU-2 location does not meet the permeability standard.

I should add that this geometric mean value is 28 times greater than the geometric mean of $2.47x10^{-6}$ cm/s that CWM claims is representative for the upper tills. CWM's geometric mean value is used in flow and migration rate calculations (Tables 7 and 12 of Golder, 2014). However, the CWM value is based on a large data set that includes wells located outside the RMU-2 perimeter.

Q. Is there any other hydrogeologic issue you would like to discuss?

A. Yes, specifically the issue of hydrostatic uplift, which I believe should be re-visited now in light of additional information verifying the assumptions relied upon in the hydrostatic uplift calculations performed by Dr. Anirban De, geotechnical consultant for the Municipalities. A series of PowerPoint slides with Dr. De's calculations are included in Attachment 11. Factor of safety (FS) calculations to protect against floor blow up due to hydrostatic uplift for Cell #15 sump, provided on Slide 28 of this Attachment, exemplify the concern about the floor instability caused by the uplift: The calculated FS value of 0.8 for that spot was much lower than 1.0, representing an equilibrium condition.

Dr. De's calculations in Attachment 11 were based on data from the 2013 Hydrogeologic Update (Golder 2014) and earlier reports. Because a true value for the elevation of the top of GSS unit at the Cell #15 sump was then unknown, Dr. De used a value generated by Terramodel software, which introduced some uncertainty into the calculated FS value. This uncertainty can be eliminated now, as the true value of the top of GSS unit has been ascertained by data from boring SB16-04 installed at that very spot in February of 2016 (Golder, 2016). A log of this boring, provided in Attachment 12, shows the top of the GSS unit is at an elevation of 288.2 ft msl. This is virtually the same elevation as 288 ft msl Dr. De used on Slide 28 of Attachment 11, which verifies the correctness of Dr. De calculations.

The above FS calculations were performed for the highest potentiometric level condition in the GSS (315.2 ft msl used on Slide 28 of Attachment 11). However, it is now apparent that floor blow up due to hydraulic uplift would occur at sumps in Cells #15 and #16 not only under the highest potentiometric level but under any potentiometric level condition measured there. Figure 8 through 13 in Golder 2016 show that GSS potentiometric contours during six consecutive months (January through June) have much higher values in the vicinity of these two cells than the lowest potentiometric head at an equilibrium condition (FS=1) Dr. De calculated on Slide 30 in Attachment 11.

Q. Can the potential floor blow up be controlled or mitigated?

A. CWM has not demonstrated it can be. CWM argues that the floor instability from hydraulic uplift could be controlled by lowering the potentiometric levels in the GSS unit through pumping. However, there are serious constraints with this approach. The two cells most impacted by the uplift are located over the bedrock ridge where the GSS unit exhibits low permeability.

As I mention earlier, the hydraulic conductivity values for GSS wells located over the ridge and at the western footprint of Cell #15 (R202SR, 202DR and R218D) range from 10^{-7} to 10^{-6} cm/s, which make it a non-pumpable unit. Consequently, pumping would need to be from the bedrock. But doing that presents a serious risk of inducing DNAPL migration and dissolved plumes from the adjacent Process Area, and would heighten concerns about monitorability.

Q. Are your opinions held with a reasonable degree of scientific certainty?

A. Yes, they are.

Q. Does this conclude your direct testimony on these subjects at this time?

A. Yes, it does.

ANDREW MICHALSKI

LIST OF ATTACHMENTS

1. Andrew Michalski CV
2. Three conceptualizations of Site Hydrostratigraphy
3. Top of Basal Till- Figure 4 of Golder, 2016
4. Ranges of Hydraulic Conductivity Values – Table 3.7 of Fetter, 2001
5. Interpretation of Potentiometric Map - Figure 10 of Golder, 2016
6. RMU-2 Monitoring Wells
7. Groundwater and Soil Sampling Results for RMU-2 Western Boundary Area – Figure 5A of Golder, 2009
8. Sample Results and Log of PRO-9 – Golder, 1993
9. Sample Results and Log of PRO-5 – Golder, 1993
10. Hydraulic Conductivity Re-calculation for R2017D – Based on Graph in Appendix E of Golder, 2016
11. Hydrostatic Uplift – PowerPoint Presentation by Dr. Anirban De
12. Log of Boring SB16-04 – Appendix A of Golder 2016

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