Review of

Level 1 and Level 2
Hydrogeological Evaluation for
Above Water Table Aggregate Extraction
Hallman Pit
(Harden Environmental Services Ltd, Sep. 3, 2019, Ref 1728)

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Executive Summary

Harden contends that there will be no water quality or water quantity impact to any private well or municipal well arising from the proposed aggregate extraction. This review reveals some serious deficiencies that raise question about this contention.

A basic concern is the adequacy of the site characterization, both spatially and temporally. Spatially, there are not enough wells, and the wells that exist are not deep enough to characterize the highly heterogeneous hydrogeologic system that is replete with discontinuous aquifers/aquitards. There are no cross-sections for the site itself. Temporally, the monitoring does not extend over a long enough time period to capture expected climatic extremes that would affect water levels in the pit area.

The groundwater flow system is poorly understood. Some local drainage areas that extend partly over the site are found to be affected within the pit area, but off-site effects are ignored. Water balances are not done in a transparent manner, with water use for gravel washing and dust suppression remaining unclear.

Cumulative or synergistic effects due to other aggregate pits in the same general area have not been investigated. These could include pits that are presently active, expected to be active during the lifetime of the Hallman pit, or that have been mined out. Such cumulative effects could impact aquifers.

Harden contends that with the pit in operation, there will be more water available due to the absence of evapotranspiration—a contention that rests on certain simplifying assumptions that should be re-examined. The effect of future climate change extremes on water quantity has been essentially ignored. A potentially critical situation could arise if, due to a climate extreme, the water table elevation were to rise higher than the pit floor, thus flooding the pit. Or, extreme drought could result in nearby private wells running dry.

Although the proposed pit abuts the wellhead protection area of the nearby regional wells, a thorough analysis of potential impacts on the wells is lacking. Instead, Harden simply insists that the groundwater beneath the site cannot contribute to the regional wells—an assertion that conflicts with physical reality. Such impacts can become more critical upon consideration of potential changes in recharge due to climate change or possible increases in pumping, all of which can expand the wellhead protection areas.

Potential impacts on water quality have not been sufficiently investigated. The loss of the overburden soil layer protecting the underlying aquifer could potentially affect the quality of the water reaching the wells. The impact of any fuel spills remains unknown. An abnormal rise in the water table at or above the pit floor could also lead to water-quality impacts. Turbidity due to gravel-washing is another concern.

The risk of spills is treated rather lightly by Harden in relying entirely on the presumption that all spills will be minor and spill-control materials will always be readily available on-site. The reality is that accidents can and do happen, and the risk to wetlands, private wells, and the municipal wells should not be ignored.

In general, Harden neglects the large uncertainties that are expected in a complex system such as the Waterloo Moraine. This deficiency affects the predictive credibility of the Harden study.

It should be noted that this review is based on the report by Harden Environmental Ltd, dated Sept. 3, 2019 (reference number 1728). Any subsequent updates of this report are not considered in this review.

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Introduction

Jackson Harvest Farms Ltd. proposes to set up an aggregate pit (the Hallman Pit) on their property on 1894 Witmer Rd. in the Township of Wilmot, Regional Municipality of Waterloo. Harden Environmental Services Ltd. has prepared a hydrogeological evaluation for above-water-table aggregate extraction (the Harden report) at the Hallman pit. This review focuses on the Harden report with particular emphasis on the groundwater, thereby identifying some concerns.

Adequacy of site characterization and monitoring

The Harden report refers to wells that have been drilled in the overburden (Section 1.3 Methodology and Appendix B). Issues of concern here include insufficient depth of wells which tends to miss deeper layers, and the location of the wells with respect to the proposed footprint of the pit.

In Appendix B, Harden provides the logs from five boreholes (MW1 through MW5). These five monitoring wells are single-level, in the shallow aquifer only, showing sand, gravel, and cobbles (excluding topsoil), but no aquitard materials. Because no bedrock was reached, there is no information on the existence of any deep aquitard layers below the bottom of the proposed pit.

In order to assess the impact of the proposed pit, deeper boreholes and monitoring wells at more locations will be needed. Also, the monitoring program will need to be expanded to a scale sufficient for capturing long-term trends in water quantity and quality. This is essential both for establishing a baseline and for identifying changes due to the proposed pit. For example, pit operations are commonly associated with water becoming more turbid in neighbouring residential wells, and only by having a sufficient baseline will a trend of this type be quantifiable once extraction begins.

Figures 4.1 (A-A') and 4.2 (B-B') show the borehole-log cross-sections along Bleams and Witmer Roads, which run to the north and south of the subject property. Although the variation in borehole-log quality between drillers is well-known (e.g. some drillers simply record everything as “till”), a handful of the logs do show significant variation in quaternary-geologic findings. These depict alternating layers of “sand and gravel” and “silt/clay/till”, thereby pointing towards a picture of geologic complexity.

The implications for such hydrogeologic variability are not trivial. For example, Table 2 in Freeze and Cherry (1979) shows that the silt/clay/till material could have a hydraulic conductivity ranging from 1×10^{-12} to 1×10^{-5} m/s, while “sand and gravel” can range from 1×10^{-5} to 1 m/s. This geologic complexity (which itself varies with spatial scale) is not unexpected in morainic landscapes, and it serves to highlight the uncertainties that can arise when major changes are imposed on the system.

Monitoring of all aquifers by multilevel monitoring is needed, including the deep ones. Aquitards are not perfectly impervious, and they can be discontinuous and may have windows or pinch-outs. Also, monitoring needs to be done farther afield, in order to gather baseline datasets at distance.

Section 1.3.3 indicates that testing was done on MW1, MW2, and MW5, but it is not clear why such testing was not done for MW3 and MW4.

Figure 1.4 (Monitoring Locations), shows a lack of monitoring wells around the periphery of the proposed pit. Of the five monitoring wells present, four (MW1-MW4) are at the edge of the property, while MW5 sits in the southeast corner. Monitoring wells should extend below the water table (which should always be below the level of the aggregate pit's operational floor), and should be placed in such a way that they will remain undisturbed during the actual sand-and-gravel extraction work. Thus the wells would provide a pre-extraction baseline and allow during-excavation as well as post-closure monitoring.

A comprehensive (both spatially and temporally) network of monitoring wells will be needed in order to record the before, during, and after-excavation water levels. To monitor the multilayered geology implied by the noted borehole logs (i.e. the deeper wells of nearby landowners), multilevel monitoring wells are needed. This will provide needed site-scale insight into the layering of sand, clay, gravel, till, etc., at a range of spatial scales.

Harden indicates that dataloggers were installed in all onsite monitors, and that water levels were recorded at hourly intervals from May 2017 to July 2019. In addition, water levels were recorded manually at irregular intervals. Both the data logs and the manual measurements are shown in the hydrographs, Figures 1.5 through 1.11. The manual measurements are also summarized in Table 2 of the Harden report.

In order to determine the highest expected water level as a basis for establishing the pit floor at the required 1.5 m above this high level, Harden presents plots of both the seasonal lows (Fig. 3.3A) and highs (Fig. 3.3B). The latter figure then states, without explanation, a high of 123.9 m for July 2019 and a low of 123.1 m for January 2019, for a seasonal difference of 0.8 m. There is no explanation of how the plots were obtained (by interpolation from the sparse data?), nor how the final high/low values were determined (where?).

There may be some doubt about the representativeness of these datasets because (1) the range of seasonal variation seems low in comparison other areas of the Waterloo Moraine, and (2) the single-season observation period chosen to show seasonal variations is too short to identify year-to-year variations in weather patterns in this area.

Water levels not only vary seasonally, but also from year to year, and the trend is toward larger variations as climate extremes become more frequent due to global climate change (see also discussion below under Climate Change). Extremes will be reflected in year-to-year variations in the elevation of the water table. The risk of a pit designed for above-the-watertable extraction being flooded is that contamination can be very quickly carried into the aquifer and contaminate the groundwater. This would take years to clean up.

In order to get a reasonable chance to capture at least some of the long-term variations in the water table, a minimum of five years of continuous monitoring is recommended. Also, the resulting records should be matched to similar records at other monitoring wells in the general area, including regional wells. This would help to identify peaks outside the monitoring period.

Regarding Section 8.0 (Monitoring Program), Harden considers it adequate to merely continue monitoring MW1 (6 metres deep) and SG1 (1 metre deep). This modest goal is unlikely to reflect the changes that will be imposed on the local hydrogeology by a pit that will be far deeper than 6 metres.

For the survey of private wells (Section 1.3.5 and Appendix E), Harden staff went door-to-door for all well owners within 500 metres of the edge of subject property. This survey appears to have been done satisfactorily. A remaining question is whether a half-kilometre zone is adequate (irrespective of what provincial regulations require). Consider, for example, a spill of some fluid from heavy machinery in the proposed sand-and-gravel pit (i.e. material of high hydraulic conductivity). The fluid will seep down almost instantly to the water table. Simple calculations can show that, depending on the hydraulic gradient, contamination could reach nearby wells and/or wetlands in short order. Plus, with several wells of unknown depth (Appendix E), and given the dates and descriptions, it is reasonable to expect that some of these are shallow wells, which are very vulnerable to contamination.

Section 3.2 of the Harden report notes that, from a single deep well (6503292) to the west of the property, the geologic strata, including the entire Quaternary geology down to bedrock, is 87 metres thick. This provides an indication of scale, and the log shows silt/clay/till layers at depth. But looking at the logs from other wells in the area (Figures 4.1 and 4.2), and given that neither of the two cross-sections shown by Harden actually run through the proposed pit area, all that can safely be concluded is that the aquitard layering beneath the proposed pit is highly discontinuous. This means that any spill of contaminant in the pit can potentially spread into an aquifer that will likely connect to someone's drinking-water supply—a serious concern that deserves serious attention.

Also, the cross-sections (A-A' and B-B') are not sufficient to provide a full picture of the geologic complexity. For example, A-A' could be extended westwards at least to capture the Regional wellfield (Shingletown supply, Wilmot Centre). There is a need for some cross-sections that actually run through the subject property, and the proposed pit in particular. This emphasizes again the need for a greater number of boreholes and monitoring wells, and at greater depth.

There is no information about "trigger points", nor about "contingency measures" for what measures will be taken if the wells of nearby landowners were to experience impacts to either water quality or quantity. Will the proponent be expected to pay if problems arise and corrective work is required (i.e. deeper wells, new wells, connection to municipal services)?

In summary, the currently proposed monitoring plan needs to be greatly expanded in number (more monitoring wells), depth (wells need to go deeper), and extent (i.e. wells are needed offsite too, since the pit will generate offsite impacts even though it is of the above-the-water-table type).

Potential impacts on the groundwater flow system

In Section 2.4 (Topography, Drainage, and Soils), Harden briefly describes the site topography, and how more than a third of the site drains to a wetland on the eastern margin. This already implies that this wetland will be affected by the proposed pit, in terms of groundwater-surface-water interactions.

The topographic contours in Figure 1.3 imply that the proposed pit will exert significant impacts on the creek complex (Hunsberger) that has its beginnings on the property west of the subject property and that flows southwestwards on the next property to the west. Harden mentions the Hunsberger Complex in Section 2.1, without discussing potential impact.

Groundwater flow direction is inferred from the groundwater contours derived from the rather sparse set of groundwater monitoring data (Figures 3.3A and 3.3B), which are limited to the site itself. The results show that for both the seasonal lows and highs, the flow is from the northwest to the southeast.

However, as the subject property is part of the larger landscape with farmlands, private households, etc., it is essential that the groundwater flow system be defined within the context of the larger picture. The subject property is not isolated from the surrounding properties by a wall.

Harden states that "Overland drainage will only occur during frozen ground conditions and winter-time thaws." However, despite the high hydraulic conductivity of sands and gravels, during heavy rainfall some overland flow is to be expected, especially if the soil has already become saturated due to previous rainfall.

Figures 2.5, 2.6, and 3.2 show the complexity of the soils at the site. Although Figure 2.6 is intended for agriculture and thus shows the topsoil variations, it illustrates the kind of subsoil complexity that can be expected in this landscape.

Local drainage areas

Figure 4.7 shows the site subdivided into micro-drainage areas, which must be part of larger drainage areas extending outside of the site. However, these outer areas are not depicted anywhere (not even in Figure 1.3, which shows subwatersheds.) Meanwhile, Figure 6.1 shows how the micro-drainage areas change as a result of extraction. But given that the on-site drainage areas must be part of the larger drainage areas that extend outside the site, and given that the on-site portions change, it follows that the off-site parts of the drainage areas will also be affected. The off-site impact has been ignored by Harden.

Water balance

Concerns arise also with Harden's water-balance calculations, which appear in various locations in the report. It is not easy to trace the numbers and to see how the calculations fit together. Better transparency is needed.

Table 8 under Section 4.5 shows the pre-development water balance for entire site. Although the micro-drainage areas (Figure 4.7) are reasonable, their use is oversimplified. For example, instead of using the actual rainfall at or near the site, Harden used the Environment Canada dataset from the airport at Breslau, which is roughly 25 kilometres to the east. While placing a rain gauge on the site and waiting 10 years for a dataset might seem impracticable, it would have been helpful to interpolate from other rain gauges that have 10-year histories or more. One example is that at the University of Waterloo.

Also, regarding the Excel spreadsheet of water balances that Harden provides, detailed explanatory notes and reasoning for the underlying assumptions (e.g. choice of area boundaries, how these are accounted for, etc.) would be helpful.

Gravel washing and other water usage

Table 12 (page 17) shows the effect of aggregate extraction by comparing the "before" against the "during" scenarios. This table shows that the loss of evapotranspiration due to the absence of vegetation will confer a net surplus of 4,739 cubic metres of water during the time of mine operation, which works out to 13 cubic metres per day, a modest amount when the size of the proposed extraction operation is taken into account.

The on-site aggregate-washing plant is expected to consume 66,750 cubic metres per year, or 183 cubic metres per day (assuming all feasible on-site water-conservation measures will be used). This means that the aggregate-washing plant's consumption is 14 times greater than the surplus. This raises the question of whether a deficit in water could occur in the event of an extended drought. (Note: All numbers quoted in this paragraph are taken directly from Table 12.)

In other words, the "net surplus" can be thought of as a delicately balanced knife edge that can be easily toppled by a relatively modest change in everyday parameters such as rainfall. Or, for that matter, what would happen if the aggregate-washing plant's consumption were to increase by 15 m^3/day, thus from 183 to 198 m^3/day? Then the "net surplus" would change to a 2 m^3/day deficit, which works out to 730 m^3/year.

The aggregate-washing consumption (Table 12) of 66,750 m^3/year will need to be pulled from wells, thereby impacting the local aquifer. Because the "slim margin" (4,739 m^3/year) of surplus water hinges so heavily on general-area precipitation, it would have been appropriate for Harden to include multiple scenarios in order to account for future climatic extremes.

As a further note, no mention is made of water usage for dust-suppression purposes (as pumped from water-tender trucks at regular intervals throughout the day). This usage can be significant, and during dry periods the consumption of water for dust-suppression purposes could increase dramatically.

Potential impact on future agricultural productivity

In Section 7.1.3 (Post-Development Agricultural Use), the Harden report discusses post-closure conditions, recommending that best management practices be followed. Here, again, some questions remain unanswered.

Harden asserts that the proposed pit is only "temporary", which is true only in the narrow sense of the word. After the pit has exhausted its resource, the usual approach would be to replace the topsoil and then revegetate the area. Some permanent impacts can be expected, one being a change in the flow system due to the removal of the material overlying the aquifer, as discussed below under Groundwater Quality. Another will be the potential degradation of the productivity of the original farmland due to the loss of the fine draining subsoil layers. Therefore, Harden's assertion calls for re-examination.

In contrast to sustainable agriculture, where the goal is food production in perpetuity, aggregate extraction either results in a degradation of farmland quality or a permanent loss of farmland altogether. To show how these impacts can be mitigated, the onus will be on the proponent to provide concrete examples of aggregate pits (in areas of similar geology to this one) where, after pit closure, the land has been successfully restored to its former state of long-term agricultural productivity and functionality.

Cumulative effects, interaction with other pits

In Section 2 of the Harden report, Figure 2.1 shows existing aggregate sites, including land owned by aggregate firms with sizeable future resource-extraction plans. Obviously, the operational timelines for each pit will vary. The hydrogeologic effects of these aggregate pits can very easily end up being additive. In fact, if the drawdown from the proposed aggregate-washing-plant consumption is such that private wells in the vicinity are drawn dry, then the effect could be described as synergistic (in the sense that the effect of all the pits together would have a greater impact than the sum total of the individual drawdowns).

In order to understand any such interactions, the future development plans of the aggregate properties between Witmer and Huron roads, as well as those of others of similar proximity, should be taken into account. To consider each pit in isolation, even though this is what has been done for past aggregate pits, is not acceptable considering the large number of planned operations in the general area.

Synergistic hydrogeological effects between pits within the same watershed could occur if a neighbouring pit were active or were to become active at the same time, or if it had been terminated. The core issue is one of cumulative impacts, and it becomes incrementally more serious with each pit added in a given area. Here are some examples of the types of cumulative effects that call for investigation:

- Since no study has been done into all the existing pits extracting together, we have no way of knowing whether an additional pit will draw down the local aquifer system to a point whereby insufficient water is available for nearby domestic wells (in particular the shallower ones). Concerns would be heightened during a prolonged drought (and with climate change, more extreme events such as droughts are to be expected).
- Given that aggregate-pit operations in many locations have been found to correlate with a trend of increased groundwater turbidity (for example, due to subtle interactions between water-level changes and local geochemistry consequent to the vadose zone being lowered into different strata), could adding one more pit be enough to trigger turbidity appearances in shallow wells?
- Could the addition of another pit cause a wetland to dry out during extreme droughts? The potential for interaction between drought and extraction activities should be investigated.
- What about the combination of the existing gravel pits and the proposed new pit, in conjunction with more pumping from Regional wells consequent to drought, or consequent to increased demand due to more urban development? Clean and sufficient drinking water is top priority, even more so than aggregate.
- What about any potential combination of the above, in conjunction with a rise in agricultural water usage due to installation of large-scale crop irrigation systems, consequent to increased drought events? What if this possible future irrigation draws from various depths (e.g. shallow, deep, or both)? Could domestic wells dry up? Could other problems arise?

Groundwater quantity and climate change

In Section 7.1.1 (Water Quantity), Harden concludes that the mining of aggregate will result in more groundwater availability because of the loss of evapotranspiration from vegetation. No detailed discussion is given regarding evaporation from pit walls and floor during operation. The balance between consumptive losses and the water surplus is discussed above under Gravel washing and other water usage.

In Table 9 under Section 4.6, which calculates the pre-development water balance for the wetland at the eastern edge of the site only, the calculation is oversimplified, since it assumes no groundwater involvement to the wetland. This is at odds with Section 4.0 Hydrogeology, which notes that there is an intimate involvement between the wetland and the water table.

In Section 4.3 (also Fig 4.5), Harden notes that the site is situated in an area of Significant Groundwater Recharge. Harden contends that the amount of groundwater recharge will not change as a result of the aggregate extraction. However, this would assume that the existing combination of evapotranspiration from farmland vegetation and recharge (i.e. infiltration and runoff from cropland) is the same as the water balance during pit operation (i.e. open pit excavation, with aggregate washing and settling ponds and direct infiltration via the pit bottom). This is an inherently tenuous and questionable assumption.

Climate change

In Section 7.4 (Climate Change), it is surprising that only three lines were written on the complex topic of climate change. Harden merely states that "surplus water at this site either infiltrates via the land surface or via the on-site wetland. This is also the case post-extraction. Therefore, any long-term change in climate will have a similar impact on groundwater resources with or without the proposed development."

The real situation may be more complex, given that the local hydrogeology is altered when a gravel pit is in operation. Even if the pit is "only" above the water table, the protective overburden is gone, leading to potential water quality issues, as discussed below. Vegetation and evapotranspiration are altered as well.

Perhaps most notable is the reality that climate change will impact mine operations and thenceforth their impact on the surrounding environment. Climate change is already causing unexpected extremes such as a 100-year storm occurring 3 years in row, for example. How would several abnormally wet years in a row affect the water table? Given that the pit floor is to be located a minimum of 1.5 m above the highest water level, what would happen if that water level were to experience a major rise as a result of climate change? How would the operation of the pit be affected, and more importantly, how would such a situation impact the quality of the water?

Conversely, if a major extended drought were to occur, the "surplus water" (4739 m^3/year, from Table 12, page 17) would become a major deficit (as noted above under Gravel washing).

Connection to RMOW wells

A specific concern about the proposed Hallman pit is its proximity to the Regional wells K50/K51/K52. In Section 4.2 (Aquifer Connection to RMOW Wells), Harden quotes from the 2018 Stantec report on the Wilmot Centre Wellfield pertaining to these wells. Upon finding groundwater at the site to flow in the southerly direction, Harden concludes that "groundwater beneath the Site cannot contribute to the municipal wells via the shallow aquifer AFB1". This conclusion needs more substantiation by field data. (It should be noted that this flow-direction information was unknown to Stantec at the time they wrote their report.)

On the basis of the Harden data, groundwater flow in the general area is in the southerly to south-easterly direction. In the immediate area of the regional wells, however, flow must be toward the wells. Flow cannot be away from the wells and toward the wells at the same time. This apparent contradiction is explained through the principle of the contributing area, which extends in all directions from a well, including the downgradient direction. Within the contributing area, flow will always be toward the well.

To address the questions arising, the relevant Stantec figures should be shown, and whatever new datasets are available should be integrated into these figures. Currently, with only two new data points at hand, there is considerable doubt that definite conclusions about flow directions can be drawn.

Harden concludes that "The proposed extractive operation will not be physically disturbing any local aquifer, and water quality improvements will be made through the reduction of nutrient applications." Unfortunately, the paucity of data points and the very limited fieldwork that was done is simply not enough to give confidence to such a conclusion. Geological and hydrogeological uncertainties remain unaddressed.

It would have been helpful if Harden had considered past maximum pumping rates at the nearby Regional wells. Such maxima probably would have occurred during summer drought periods, when demands on groundwater are greatest.

An important issue that also needs to be addressed is the possibility of future increases in water withdrawals at the Regional wells. The Region, which depends on groundwater for 75% of its drinking water, is rapidly growing, and so is the water demand. A similar situation exists locally for the community of Shingletown. The existence of an aggregate pit abutting the well fields could constrain or pose a risk to the future availability of water at the wells.

At present, the WHPA-Ds for the Shingletown wells already lie under the northern portion of the subject land. If pumping rates at the regional wells increase, then the WHPAs will expand. If recharge decreases due to climate change, then the WHPAs will also increase. Furthermore, if large-scale agricultural irrigation becomes necessary, thereby requiring more pumping, further increases in the WHPAs will result.

As aggregate demand is driven by population growth, so is water demand. These competing demands will increase the likelihood of future conflict between the proposed pit and the Regional wellfields. This potential conflict must be taken into account in any future aggregate pit planning. In terms of essential services, reliable, clean, and long-term-sustainable drinking water supplies rank at the top of any listing of resources.

Groundwater quality and the risk of spills

Figure 4.3 of the Harden report shows the municipal wellhead protection areas (WHPAs), and Figure 4.6 shows the vulnerability scoring. The Shingletown community wells (operated by the Regional Municipality of Waterloo), situated near the northwest corner of the property, lie within the WHPA-D (which implies a 25-year contaminant travel time to the municipal wellfield). The northern portion of the subject land lies within the zone of medium vulnerability. The proximity of the pit to the wells could pose a risk to the quality of the water.

Harden states that the pit floor will be a minimum of 1.5 metres above the water table, as required by regulations. However, because the range of water-level variations may be underestimated, this margin may be too close, with the result that the water table may be too close to the pit floor. This possibility could also pose a risk to water quality.

In Section 7.1.2 (Water Quality), Harden states that gravel mining will "temporarily replace" the existing farming which depends on the use of fertilizers, and that the groundwater quality will improve simply because of the discontinuance of nitrate-type fertilizer application. Firstly, such a statement ignores the reality that modern agriculture can make use of precision targeting of fertilizer to the crop at hand, so that very little waste occurs and thus nitrate impacts to aquifers are minimized, all while crop productivity is maintained. While not all farmers employ this "precision-ag" approach, the topic merits consideration. Omitting this topic entirely would effectively serve to make the pit "look better" than it really is.

Secondly, Harden seems to be forgetting about the protective effect of the overburden soil layers and aquitards above the drinking-water aquifer. In Section 4.3 (Source Water Protection), Harden contends that the removal of overburden "is of little or no consequence to nitrate movement", a topic returned to in Section 6.3.1 (Reduction in Thickness of Unsaturated Zone). While nitrate moves conservatively (i.e. no sorption, no decay) through sand and gravel, Harden is neglecting the effect of the topsoil layers, in which biological activity affects and tends to attenuate nitrate behaviour. Although the conversion of cropland to aggregate mining will reduce nitrate input over the mined area, remaining nitrates will still move through the subsoil. A mention of the effect of topsoil loss is needed, in order to give a more complete picture.

Although the sand-and-gravel extraction process itself does not use chemicals, Harden seems to be forgetting about ultra-fine suspended sediment from aggregate washing. Settling ponds and recirculation of water are expected to eliminate most of this, but in practice it is inevitable that some suspended-sediment-laden runoff will leave the site at some point (most likely via streams or wetlands).

Finally, there is a major inconsistency between Harden's general statements about the value of the protective effect of aquitards on one hand (for example, "In this way the water source is naturally protected" in Section 7.1.2 on page 22), against the reality that the monitoring wells for the site show no aquitards being present. After all, an aquitard layer that is situated above the wellhead of a drinking-water well will not protect against contamination introduced directly into the aquifer by a nearby sand-gravel pit situated in the exact same aquifer.

Spills and Spill Contingency Plan

In Section 7.1.2 (Water Quality), Harden argues that water quality impacts are unlikely because "any accidental spills would likely be minor in nature and the operator will maintain spill control materials on site". This claim remains unsubstantiated, especially given that the size of the proposed pit implies that considerable machinery could be present. Plus, as the history of the site shows, fuel spills can easily occur and pose a risk to the water.

In Section 1.3.1, Harden notes that MW5 was drilled in July 2017 as part of a Phase 2 environmental investigation. Although no details are given as to exactly what event triggered this type of invasive investigation, the fact is that Phase 2 investigations are done as a result of evidence of contamination. Hence this piece of information already points to known contamination at the site. And, given the location of MW5 on the site and the aerial photo (Fig 1.2), and given the past history of the site as a farmstead, it is most likely that the contamination was due to a past fuel-tank spill (gasoline and diesel fuel for farm machinery, as are routinely filled from onsite aboveground tanks).

Irrespective of the numbers of machines and amounts of fuel involved in aggregate-pit work versus in agriculture, the reality is that the pit machinery will be sitting directly on an aquifer, without even the minimal protection of a thin overburden layer. All of this poses a potential risk to the groundwater.

The Spills Contingency Plan (Appendix F) seems to have been taken from a template. Since there is no detailed aggregate-mining plan for the site, specific questions are left unanswered. Examples of such questions include the following:

- Will fuel storage occur on the pit floor or in the surrounding out-of-pit area?
- What are the maximum quantities of these liquids that can be expected?

Details such as these can have significant risk-related implications with respect to the water table and the site (spatially) in general (e.g. distance to nearby wells and wetlands).

Given that this site is inherently highly sensitive due to the proximity of wetlands and numerous private wells, it seems that adhering to the provincial regulation of requiring notification (for MOECP and RMOW) only for spills over 80 litres (for oils such as engine oil and hydraulic oil) and 40 litres (for fuels, etc) does not inspire confidence.

Firstly, the entire plan hinges on the person's estimate of the amount spilled. How exactly is a heavy-equipment operator to know how much was spilled in the first place? Anything spilled onto the pit floor will seep in rapidly, and with the water table nominally only 1.5 metres below the pit floor, and with no carbon-and-microorganism-rich topsoil layer to help attenuate a minor leak, it should be clear that the contamination risks and costs are serious.

Given that a single litre of hydrocarbon fluid can contaminate roughly a thousand cubic metres of water according to drinking-water standards, it is advisable for simple calculations be done on the cost of spills and the cost of remediation to drinking-water standards.

Secondly, what if the spill is not immediately noticed? Thirdly, because of the financial incentive to be profitable, the time lost in reporting and cleaning up a spill will be worth orders of magnitude more than the value of the lost fluid. Given also that this is private property, the obvious result is an incentive to simply not report spills.

More detail on spill-prevention measures (such as secondary containment trays) around stationary machinery would be appropriate. For mobile equipment, all maintenance and refuelling should be done on impervious surfaces equipped with spill-capture systems. All equipment should also be diligently maintained so as to minimize the risk of leaks developing during operation. Simple details such as these are just as important as keeping spill kits on-site, but Harden attaches too much importance to the latter. (For example, spill kits are useless if not deployed in time. This also points to the absence of discussion on topics normally covered in a spills plan, such as declaring who is responsible for what, when, and where.)

It would also be appropriate to have more details on how subsequent cleanup would be done, beyond the simplistic descriptions of excavating and pumping (Appendix F, Subsections 4.6 through 4.6). For example, in the event of a spill that would impact nearby domestic wells, merely notifying the homeowners will not protect them against contamination of their wells.

Automatic spill detection with remote monitoring and reporting technology also deserves mention and arguably should be required for all sites of this nature. Also, given the highly sensitive and critical nature of the groundwater resource, it would be appropriate to require physical security sufficient to guard against spills due to vandalism. The number and close proximity of private wells, and also nearby wetlands, definitely merits extra precautionary measures.

Uncertainty

In Section 9.0, the reader is presented with a simple one-sentence blanket assurance that no mitigation measures are required. Such a blanket assurance can only be made if uncertainty (geologic, hydrogeologic, climatologic, etc.) are ignored. An accounting for future climate change scenarios is not provided.

In reality, numerous uncertainties exist. These include (but are not limited to):

- uncertainties about the geology and hydrogeology,
- uncertainties about potential synergistic effects with other pits in the same areas—currently active, in the process of becoming active, or already mined out,
- uncertainties about future climatic conditions,
- uncertainty about future water demands/withdrawals.

As a consequence of these multiple uncertainties, blanket statements of “No Impact” carry little credibility. One way to understand the effect of uncertainties is to perform sensitivity analyses with respect to the controlling parameters. No such sensitivity analyses have been undertaken.

Geological/hydrogeological complexity and predictive reliability

The proposed pit is located in the area of the Waterloo Moraine, which is notable for its geological and hydrogeological complexity on both the micro-scale and macro-scale. On the micro-scale, as can be observed in existing sand pits, is the varving, which explains much of the heterogeneity and anisotropy of the geologic material. On the macro-scale, the moraine consists of aquifers interleaved with aquitards, with the latter being disrupted by windows and other discontinuities and pinch-outs. This explains some of the variation in the borehole logs. It also explains variations in water quality, contamination susceptibility, and complexity of well capture zones—and the uncertainty inherent in assessing impacts of sand-gravel pits.

Several of the private well borehole logs show significant local geological complexity. These are apparent in Figures 4.1 and 4.2, but the geological complexity is not discussed.

Given the inherent geological and hydrogeological uncertainties of the Waterloo Moraine setting, and also given the yawning data gaps (both spatially and temporally) pertaining to the site, Harden's medium-term and long-term predictions for the site cannot be considered reliable.

The role of modelling

A suitable 3D model would not be limited to the subject property itself, but would extend over a larger area between natural flow boundaries. As such, it would immediately resolve the implausible situation where a part of a drainage area within the site is affected by the pit, while another part of the same drainage area outside the site is said to be unaffected.

A 3D model can also extend to encompass nearby pits, whether active, planned or rehabilitated, in order to investigate potential additive or synergistic effects. In a model, the status of individual pits can be easily changed in order to ascertain the effect of each pit separately.

Uncertainties with respect to geology/hydrogeology, as well as uncertainties with respect to future climatic conditions, can be investigated by means of multi-scenario analysis. For example, with a model, it is a simple matter to run a model repeatedly with different annual rainfall amounts (hence changes in recharge due to climate change), or different interpretations of the local geology from the nearby well boreholes. (It must be kept in mind that modelling should not be used as a substitute for satisfactory site characterization, which can only be done through adequate fieldwork.)

Meanwhile, concerns of WHPA infringement are further heightened by the reality that the expected residential growth that drives aggregate demand will also drive up the demand for drinking water.
With a model, the effects of future changes in the pumping rates of the regional wells can be easily simulated. Changes in the WHPAs, for example due to a combination of increased water demand and a persistent decrease in precipitation due to climate change, can also be investigated. With the proposed site already infringing on the WHPAs of the regional wells, this could be a critical issue.

In short, a properly constructed and executed numerical model could help to understand the effects of uncertainties and in this way improve the predictive credibility of the study—which is presently lacking.

Conclusion

The Harden report has a number of deficiencies with respect to water issues that can potentially arise at the Hallman pit, and as such the report does not form a reliable basis for approval of this pit.

Addressing these issues would require measures such as a better site characterization, monitoring over sufficiently long time periods to cover extremes, developing a more thorough understanding of the groundwater-flow system including off-site impacts, considering (or at least attempting to consider) cumulative effects due to other pits in the same area, performing a realistic analysis of the effects of climate change (including the possibility of pit flooding due to extreme climate events), making a realistic assessment of potential impacts on private and municipal wells under various conditions, and making an assessment of the risk of contamination from fuel spills.

Three-dimensional numerical modelling could help to address some of these deficiencies.

References

Freeze, R.A. and Cherry, J.A. (1979). Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey.

Harden Environmental Services Limited, Level 1 and Level 2 Hydrogeological Evaluation for Above Water Table Aggregate Extraction, Hallman Pit, Township of Wilmot, Regional Municipality of Waterloo. Prepared for Jackson Harvest Farms Ltd. September 3, 2019, Ref. No. 1728