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Attn Cathy Little Beaver Valley rate Payers Association

Re. An Analysis of the Hydrogeology and Karst Investigations Beaver Valley Village Development
Undertaken for the Beaver Valley Rate Payers' Association

Chris Smart©, PhD Karst Hydrologist

I have been asked by the Beaver Valley Rate Payers Association to review the available documents concerning the proposed development of a low density residential property known as Beaver Valley Village located near the Beaver Valley Ski Club, Markdale Ontario. The particular request was to provide an independent expert opinion concerning the likely impact and feasibility of the proposed development.

My particular expertise is in karst hydrogeology a field in which I have published for over 30 years drawing on experience across Canada and internationally. I have a particular interest in the karst in south western Ontario and the effect of glaciation on karst aquifers. I also have expertise in environmental monitoring strategies and protocols in surface and karst ground waters. I have conducted numerous field trips and investigations in the Beaver Valley. I have general knowledge of the lands in question, but I have not conducted field work in support of this review. Accordingly, I have focused my analysis on the hydrogeology including the required geomorphology and hydrological studies. I do not claim professional expertise in septic system design or planning regulations.

I was provided with the documents identified below by headline date and author. Not all appendices were provided. I have read through the documents, undertaken a critical review as detailed below. This is followed by conclusions and some provisional recommendations. My apologies for the lack of figures, academic referencing and conciseness of the report; I have provided as thorough a review as possible and have considerably extended the time initially allocated.

Our agreed upon charge for this analysis and report was \$1200.

Please let me know that you receive this report. Let me know if you have any further questions of clarification or justification.

Yours sincerely

C.C.Smart, PhD
Professor,
University of Western Ontario

Documents Reviewed

07 06 20 Ian Wilson Hydrogeological Evaluation.PDF
07 11 00 DC Slade Planning Report.pdf
08 10 14 DC10-14-08 cover.pdf
08 10 14 DC101408 response to concerns.pdf
08 11 03 Marcus Buck 11_03_08.pdf
08 12 05 DC120508 email response to marcus buck comments.pdf
08 12 16 MMAH.pdf
09 02 25 Settlement study BVVSA Report.PDF
09 03 09 MOE armstrong letter copy.pdf
09 06 02 DC Slade Response060209 copy.pdf
07 14 00 RJBurnside cover.pdf
09 10 16 Updated DC KARST EVALUATION REPORT_final_Oct1609 copy.pdf
09 10 19 BVV ian wilson Supplement HG .pdf
09 12 10 Grey Bruce CA121009.pdf
09 12 11 RJB 2nd hydrogeol investigation.pdf
09 12 22 Karst.Review.MJB..pdf
10 01 29 DC Slade karst response.pdf
10 02 19 Burnside Comments Feb 2010.pdf
10 06 16 Karst.Review.MJB.pdf
10 12 13 GB Planning report

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An Analysis of the Hydrogeology and Karst Investigations Beaver Valley Village Development

Chris Smart©, PhD Karst Hydrologist

A substantial body of reports has been provided and they furnish an adequate background on which to identify the underlying characteristics of the site, including the surface karst and the hydrogeology. Unfortunately, these two independent lines of enquiry have not been appropriately integrated to explain how the site hydrogeology might be affected by karst development. As a result, the site characterisation has been rather inefficient as it has been based on a conceptual model based on porous media juxtaposed with an assessment of surface karst features. Most of the statements concerning site karst hydrogeology are based on geomorphic assessment and lack substantive support from theory or field data and in my view are largely inconsistent of the likely hydrogeological setting.

Rather than providing an exhaustive review of each report, I am highlighting my concerns, my inferences and my suggestions below. My apologies for the lack of figures, academic referencing and conciseness of the following; it has been undertaken with very limited support. I have not visited the site in the context of this report, although I know the site and have worked extensively in the Beaver Valley karst

1. Conceptual model

None of the reports develops an adequate conceptual model for the site. The entire hydrogeological assessment draws on an implicit porous medium model that is demonstrably inappropriate. All quantitative and most qualitative interpretations based on such an interpretation are likely to be substantially and systematically in error. In particular, such concepts as Storativity and Transmissivity assume that water is both stored and travels through intergranular voids whereas it is clear that the bulk of water travels through fractures, some of which may have been solutionally enlarged, thereby significantly increasing groundwater velocities and expanding and complicating “source area”; the range from which well water is retrieved. The aquifer is also considered to be confined, though this is clearly not the case for the primary Amabel aquifer.

The closest to a site conceptualisation is Cowell’s Figure 3 (09 10 16 Updated DC KARST EVALUATION REPORT_final_Oct1609 copy.pdf) which describes the nearby Wodehouse Creek Karst. (Contrary to the author’s claim that this cross section is based on direct observation, I am sure that the subsurface information is conjectural, though reasonable.) The section shows the inferred conduit, but does not clarify the aquifer. This appears to be the basis of the claim that “...small conduits tend to concentrate flow through the aquifer, their effect is highly localized and ‘normal’ fractured aquifer flow tends to occur within very short distances of the karst.”(page 5) . I could find no evidence other than the figure in support of this claim.

Buck (09 12 22 Karst.Review.MJB.pdf and 10 06 16 Karst.Review.MJB.pdf) suggests that more extensive interaction might be expected, but Cowell (in 10 01 29 DC Slade karst response.pdf) does not accept this opinion. Regrettably, there is little direct investigation of these claims beyond a presentation of a groundwater mass balance based on likely inaccurate assumptions, a consideration of the extent of escarpment and conduit associated effects on the aquifer. My *opinion* in this matter is that I would expect quite active exchange between a karst conduit and the surrounding karst aquifer. I find some evidence to support this from analysis of the data.

My provisional conceptual model for the site based on previous work in the valley and throughout south-western Ontario is that the conduit descends first on vertical fractures until it reaches the base of the Amabel (on whatever perching horizon is involved) whereupon it follows enlarged horizontal bedding plane out to the springs. The “aquifer” is likely composed of similar though less enlarged openings creating a matrix of sparse vertical pathways connecting extensive horizontal planes with varying

solutional enlargement. Large sections of bedrock that lack vertical fractures or where the bedding plane has not been enlarged will have limited connection to the fracture/karst drainage system. In addition, there are likely more soluble components within the bedrock that are predisposed to more extensive solutional opening. The aquifer surface is likely a series of bedrock ridges or steps that has been buried by heterogeneous glacial deposits varying from impermeable lake clays in low areas, local sands and gravels where active streams have acted and a peculiar coarse till characteristic of the margins of the south end of Beaver Valley. The resulting surface landscape leads me to expect significant variation in the spatial pattern of recharge.

My intention is to review the information available to test and apply the above conceptual model and then to use this model as a basis for assessing vulnerabilities in the aquifer and for suggesting possible actions.

2. Recharge conditions

The site characterisation places considerable emphasis on the barrier presented by the extensive clay silt deposits. This provides isolation of the aquifer from surface contaminants including road runoff and septic tank seepage. However, it is also claimed (09 02 25 Settlement study BVVSA Report.PDF) that 190mm/a of recharge is generally expected which implies a highly permeable and relatively thin cover. Yet the primary hydrogeological evaluation (07 06 20 Ian Wilson Hydrogeological Evaluation.PDF page 10) states that “The underlying clayey silt was not encountered at Test Pits 3 and 7 while the overlying sandy silt was not encountered at Test Pit 5.” Clearly, the cover is not uniform. Furthermore, in no case did the test pits encounter the dominant “stoney clay” reported by virtually all drilling reports. So there is little knowledge of actual disposition of surface materials.

The karst report (09 10 16 Updated DC KARST EVALUATION REPORT_final_Oct1609 copy.pdf) highlights sinks (Karst area B, a few metres above the ponor level (Area A), a boulder-filled sink on the ridge top (area C) and a “soakaway” (area C). These suggest that there is point recharge (focused inflow of surface water) in some locations where vertical fractures and underlying karst exist and have managed to draw in substantial surface material. Such openings pose a particular risk as surface water can be conveyed rapidly into the aquifer without filtration. Such features are unlikely to develop without a significant subsurface void capable of holding and transmitting the surface materials. This is much more likely to occur when cover is thin, so it is surprising if the cover is 10-20m in thickness as is implied from drillers logs (e.g. 09 12 11 RJB 2nd hydrogeol investigation.pdf). (Note that till cover is ~20m near the escarpment, but ~4-10m on the property, some distance back.)

The main superficial material described by drillers (probably a stony diamicton: a generic name for a stones in a finer matrix) has not been characterised because it lies beneath the lake clays and (probably) wind-blown loess sampled in shallow pits. If it is similar to the peculiar gravelly “tills” around Flesherton and Eugenia, then it has quite high permeability and local highly coarse units. If it is more typical of the clay-rich Precambrian-dominated marginal moraines (e.g. above Kimberley), then it may have quite low permeability.

The risk associated with point recharge arises from land use in the area of land that might drain to them. Thus the ponor has a large catchment and any contaminants released in that area will enter the aquifer (unless the stream is overflowing at the surface). Karst areas B and C appear to have limited catchment areas and probably pose less risk. Karst area D may have a significant catchment area including a road intersection. Off site point recharge may also pose a risk (primarily to the west).

The conclusion I reach is that the thickness of the cover may not be uniform because of hummocky and westward rising bedrock topography. The composition of the surficial materials is spatially variable and inadequately mapped. There may be significant point recharge at a few locations on and off site. The impact of contaminated point recharge depends on where the contaminated water goes in the aquifer.

3. The “conduit”

The linear alignment of the conduit between the ponor (sink point: Karst area A) and spring seems a reasonable approximation for its pathway, given the presence of a large joint at the spring site. (Regrettably, no bedrock description is provided from the sink point itself; perhaps it is buried in sediment?) There are no observations as to whether the limit to the capacity of the sink point is a surface blockage (typically coarse woody debris supporting an intermittent dam of twigs and leaves) or a limit to the capacity of the underlying conduit. This is a critical distinction.

There is no information on the configuration of the conduit as it is not large enough to enter and has not been observed under high flow conditions to determine if Buck’s proposed “distributary” or overflows (or underflow exist). My guess would be that the conduit is likely a braided network on a bedding plane that extends laterally some distance either side of the main axis that is oriented along a vertical fracture (i.e. 09 10 16 Updated DC KARST EVALUATION REPORT_final_Oct1609 copy.pdf Photo 6).

Such details have important implications for determining the likely influence of the conduit on the surrounding aquifer as they determine the hydraulic head developed during higher flow conditions. High pressure within the conduit is likely to drive contaminated surface water out of the conduit into the aquifer, especially if there are actively pumping wells nearby.

4. The aquifer

4.1. *Introduction to southern Ontario karst*

There is increasing evidence that the concept of a karst conduit and a host aquifer as separate entities is inappropriate because karst solution creates a pervasive network of connected channels down to very fine scales. It is not yet possible to characterise such a system so karst investigations tend to follow tradition and map a few conduits and then place these in a distinct “diffuse flow” aquifer.

This difficulty seems particularly difficult to resolve in south-western Ontario where the “karst” has been under present interglacial conditions for 10-12 thousand years, a relatively short time period. Given the low solubility of the largely dolomitic limestone, it is surprising that karst is so widespread, especially in the subsurface underneath thick glacial deposits.

The origin of subsurface karst in Ontario presents problems. However, there is evidence that more soluble minerals in the bedrock such as gypsum may be responsible for rapid development. It also appears that the subsurface may have been subject to very rapid development during deglaciation, especially near the ice margin and in rugged terrain like the escarpment in Beaver Valley.

The primary lesson from this is that subsurface karst conditions are much more extensive than surface karst might indicate. It is important to realise that even a few millimetres of enlargement will have a profound effect on groundwater flow. The difficulty is that we have no basis for predicting where the karst enlargement has taken place. What is expected is that there will be karst dissolution opening up particularly vulnerable parts of the rock where pre-existing weaknesses or soluble minerals exist. Apart from particular blocks of rock prone to dissolution, there will be preferred flow horizons separated by less permeable layers of unaltered rock. There is likely a network of flow paths through these (generally horizontal) zones. These flow paths will become more organised and larger as they approach groundwater discharge points.

Karst is expected to occupy a few horizontal bedding planes where preferred flow will occur separated by low permeability beds and sections. The intensity and organisation of the karst enlargement will increase near to low pressure zones like a karst conduit or the escarpment face.

4. 2. *Porous medium approximation*

The complexity of karst and lack of established protocol mean that in many cases, the more tractable porous medium approach is adopted in tackling groundwater problems. This method assumes groundwater flow through a consistent granular material and so allows relatively straightforward development of theory and investigative approaches.

The standard porous medium approach adopted in the hydrogeological assessment for BVV thus assumes that a uniform silty fine sand makes up the aquifer. The proponents are not to be faulted for this, as it is standard practice. However, the resulting data and analysis appears to have been taken at face value, rather than providing an opportunity to test the underlying assumptions, and to identify the presence of karst.

The most obvious indication of non-uniform conditions at Beaver Valley Village is the high level of variability in the tested wells. Buck points out the two order of magnitude variation in Transmissivity for the three on-site test wells! The one in three “marginal” (low performance) wells is a fraction consistent with the other wells reported in the area (09 10 19 BVV Ian Wilson Supplement HG .pdf). This variability is powerful confirmation of highly variable conditions typical of a karst aquifer. Some wells happen to connect to solutionally enlarged sections of the aquifer, others do not. It has been wisely suggested that wells should be approved prior to planning permission being granted, although no threshold for “acceptability” was provided. The fact that TW5 was rated “acceptable” despite its marginal performance is not reassuring that any threshold will be adopted.

A careful inspection of the pumping test results shows quite variable response that is inexplicable in a uniform porous medium aquifer. Such evolution is indicative of the well drawing on variable source reservoirs during the pumping test. It is surprising that the Jacob Cooper approximation is used uncritically to obtain aquifer parameters and that these parameters are then averaged. The method requires a uniform, extensive porous medium with a confined aquifer. It is clear that the Amabel aquifer meets none of these conditions and so the parameters and their application can not be blindly accepted. Certainly such parameters should not be averaged to assess the collective risk.

When a well is pumped in a moderately karstified layered carbonate, it draws water through the few solutionally enlarged fractures rather than from the intergranular matrix. Water is drawn from a correspondingly wide radius, though not in a uniform manner. In karst aquifers, it is important to observe the effect of pumping on a number of surrounding observation wells to get some idea of the pattern and extent of drawdown. Regrettably, this practice was not followed. Furthermore, two wells were tested simultaneously in two separate occasions, preventing drawdown observations in a nearby well and obfuscating the effect of a single well pumping.

Some limited drawdown information is provided. But in one case, the observation well is cascading and in no case was it clear that stable conditions prevailed prior to testing. There was no observation of the character of the water extracted from pumping which might have indicated if water from distinct sources (such as the conduit) were being drawn into the aquifer.

Elsewhere in Ontario, it has been observed that pumping tests in a carbonate aquifer can vary in their source waters within minutes over periods of days with effects in minutes over hundreds of metres. Such effects may not appear in all wells, but indicate that the effect of aggressive pumping (for example from multiple wells in a single site) can result in unpredictable interaction between wells and in wells located some distance away.

The interaction analysis (09 10 19 BVV Ian Wilson Supplement HG .pdf) while following standard practice, does not provide any assurance as the assumptions are not met and it has not been subject to adequate testing.

4.3. Well capture zones

A critical question in source water protection is defining well capture zones: the area of land surface from under which a well obtains its water. In a uniform porous medium with a flat water table, the resulting area is defined by a simple circle around the well. The hydrogeological study (09 10 19 BVV ian wilson Supplement HG .pdf) provides a mass balance assessment of source water that seems to assume that the primary source is within the proponent lands. This is not necessarily the case as indicated above in reviewing recharge conditions.

A key indicator of failed source water protection is contamination of the aquifer. But this requires a contaminant to be released which is not ethically responsible. However, the limited water quality data provide a worrying anomaly in the high reported levels of sodium and chloride in all wells on site. High levels are not expected in shallow aquifers. Where available (the raw water quality analyses were not all provided to me), the ratio confirms the likely source is salt, the most likely origin is road deicing. This suggests a strong connection between the site and the nearest maintained road up gradient: 7th line being the closest likely source, particularly the intersection with Grey Road 30. (An alternative source of salt is septic seepage which is expected to be less pervasive a problem.)

However, surficial materials are claimed to provide a substantial barrier to infiltration because of their pervasive thickness, low permeability and absorbance capacity. The presence of sodium and chloride in apparent eutectic balance suggests that such protection is ineffective. Road salt is gaining access to the aquifer and is present in all the wells despite surface concentrations being so brief in spring.

Two possible explanations can be proposed. First, spring runoff in lower Wodehouse Creek is conveying salt enriched water into the conduit which may be under high pressure at the time. This conveys water into the aquifer. However, it might be expected to be focused quite close to the conduit as the gradient would be reversed once the spring freshet is over. The other explanation is that salty water is ponding in karst area D (the “soakaway” that does not link to the aquifer) and that this is providing point recharge that has a widespread effect. This wide extent of the salt in test wells may indicate that this is *the* dominant source of recharge. Or else the phenomenon is widespread along local roadways. There may also be point recharge off site.

Collectively, there is considerable evidence for point recharge of the aquifer. Such preferential flow routes are particularly of concern as they allow ready entry of bacteria and hazardous materials. UV sterilisation can protect from the former, but not the latter.

5. Aquifer conduit interaction

The information provided on the conduit and its relation to the aquifer is so limited that it is scarcely interpretable. Most of the comments provided are subjective speculation, although it does appear that hydraulic heads (water levels) may be lower adjacent to the conduit.

The only substantive evidence provided is the limited water quality analysis of the surface waters. (The raw analyses were not provided) These data suggest elevated chloride in the spring relative to the ponor. The most likely source for this is the slightly saline aquifer. The other reported parameters seem to confirm this mixing, though a thorough analysis is not undertaken here.

In general, the conduit should be a recipient of aquifer water for most of the time. Only under flood conditions (contrary to Buck) would the conduit be expected to drive water into the aquifer. The slight enrichment observed suggests the conduit is capturing aquifer water.

However, as Buck points out, there remains a substantial mass balance discrepancy between the substantial estimated aquifer discharge and the limited observed discharge. This suggests the flows (and therefore available water) are over-estimated. Another subtle hint, however is provided by the water quality data from one sample collected downstream of the spring. This shows reduced chloride, DOC and electrical conductivity, with increased sulphate. It may be that there is a buried outlet (possibly from a

lower aquifer) that is conveying a distinctive water through the debris cover at the foot of the escarpment.

Groundwater flows in a porous medium are slow, on the order of metres per year. As a result, there is little risk of acute (sudden) contamination and well capture zones are local and symmetrical. But in fracture and karst aquifers, groundwater travels much faster than predicted along preferential flow routes. Contamination can be within hours from releases located hundreds of metres from a well. The flow within the aquifer is also prone to not only seasonal, but event driven changes. If the aquifer is isolated from the surface by a superficial barrier, then it can be protected from surface events like rainstorms. However, the groundwater will still respond to local events within the aquifer caused by pumping or surcharge of conduits fed by surface streams.

Conventional groundwater monitoring techniques can not capture event-driven responses in karst aquifers and so fail to characterise the system. As Buck emphasises, the system can not be characterised by single one-off or infrequent measurements. *Observations have to be undertaken at high frequency throughout the year, so that the presence and character of transient event responses can be understood.*

6. Interpretation

The proponents have undertaken a substantial investigation in support of their proposed development, and have endeavoured to provide documentation of the karst on the site. The primary karst study was focused on surface features and did not attempt to consider the nature of the underlying aquifer, and was dismissive of there being any likely effect. The supplementary karst report (08 11 03 Marcus Buck 11_03_08.pdf) made some headway in addressing this issue, and encouraged generation of some additional basic data. Unfortunately, the follow up to this effort (09 10 16 Updated DC KARST EVALUATION REPORT_final_Oct1609 copy.pdf, 09 10 19 BVV Ian Wilson Supplement HG .pdf) was incomplete and did not pick up on important indicators in the additional karst and hydrogeological studies.

My analysis is incomplete because of limited resources and so is brief and based exclusively on a review of existing documents and incidental knowledge of the site and situation. However, there are strong indications that the aquifer in question is karstic. Accordingly, it exhibits concentrated point recharge, rapid, event driven groundwater flow, variable well-connectivity and exhibit water exchange with a conduit conveying a surface stream.

Such aquifers are not uncommon and are widely exploited throughout the world. However, there are significant consequences implied from such resource exploitation.

6.1. The aquifer

Groundwater in the aquifer is expected to be concentrated in a few fractures that have been selectively enlarged by groundwater erosion. The pattern of these openings reflects the rock structure and is likely dominated by spatially extensive, sub-horizontal bedding planes. The location of vertical connections is less predictable and likely they will be less common with distance from the escarpment. The intensity of solutional enlargement is also likely to decrease, but not disappear with distance from the escarpment. Groundwater will travel predominantly through solutionally enhanced parts of the bedding planes and substantial differences in hydraulic head may occur between separate bedding planes. Groundwater flow may be quite rapid compared to expected flow rates (typically two orders of magnitude) and vary in magnitude and direction in response to short term forcing (rapid recharge or well pumping). Groundwater movement through solutionally enlarged fractures does not filter contaminants from the water so that pathogens and other contaminants can migrate rapidly and substantially unaltered through the ground over long distances (100s of metres).

6.2. Recharge

The surface above the aquifer consists of poorly characterised surficial materials (till, outwash, lake clays and loess) overlying an undefined bedrock topography. Karstic openings through this cover indicate that rapid infiltration routes can develop either due to shallow bedrock, large karst openings or coarse surficial materials. Water can pass very rapidly (in minutes) through such openings into bedrock. The risk associated with such point recharge is that whatever is present in surface waters can penetrate rapidly into the ground water. Point recharge may be moderated by a natural tendency to become blocked with its own sediments and surface materials, particularly if the site drains a substantial surface catchment.

Of the four karst sites identified, areas A and D constitute the highest risk because they drain substantial surface catchments. They may open and close unpredictably. Areas B and C appear to be less risky as they do not have large topographic catchments and so are less likely to import contaminants unless direct dumping takes place. This eventuality is not uncommon as karst openings provide universally attractive waste disposal sites.

Karst area D is dismissed in the reports, but it appears to have a substantial catchment including a major road intersection and it lies up the hydrogeological gradient (meaning that it will feed groundwater under the study site). It poses substantial risk, though its slow infiltration rate and limited volume suggest that bacteria may currently be filtered from infiltrating water. This protection can not be assured should the barrier suddenly collapse. In any case dissolved or liquid contaminants are not necessarily removed by sediment filtration.

Karst area A (the “ponor” or stream sink for Lower Wodehouse Creek) conveys surface water at varying rates and quality directly into the aquifer. Fortunately, the sink lies largely down gradient of the site and appears to head directly to the escarpment front. The capacity of the ponor will vary with the extent of plugging of the sinks. Periodically, ponding will lead to surface overflow along the dry channel.

6.3. The “conduit”

There is a discrete link between the sinking stream and the spring that has been termed the “conduit”. This is unfortunate as it suggests that this is the only solutionally enhanced opening in the aquifer which is extremely unlikely. There is little information about the nature of this conduit and on travel times and water pressures within. It probably constitutes an enlarged bedding plane opening oriented along a vertical fracture and overlying an “impermeable” bed. More critical is its hydraulic characterisation as this will determine interaction with the aquifer. It can be assumed that flow under normal conditions is as a free surface stream that will be at a lower hydraulic head than the surrounding aquifer. Under these conditions, the low pressure will act as a “target” for flow in the aquifer. As indicated in the reports, hydraulic heads will decrease in the aquifer around the conduit, but this would have limited effect as the conduit parallels the general hydraulic gradient. However, the likely north-south fracture system paralleling the escarpment front may cause the conduit to capture aquifer water across a broad front. The flow convergence on the conduit is likely to have promoted solutional channel development, thus enhancing the connectivity with the aquifer.

Hydraulic conditions during high flow are of greater concern as high conduit pressures will drive conduit water out into the aquifer. Sinking streams commonly exceed the capacity of their ponor and so pond and overflow. If the conduit is restricted at the sink point, then internal pressures may not rise significantly. If the sink is not the dominant restriction, then high pressures may occur along the conduit with a systematic decline towards the spring. High conduit pressure will drive water back into the aquifer, including all the contaminants that may be present. Such reverse flow is strongly enhanced by the presence of solutional channels and may penetrate some distance into the aquifer.

None of these descriptions can be quantified in this case, though they can be representationally modelled.

6.4. Waste disposal

Settlement inevitably results in polluted water in the form of sanitary waste and road runoff. Storm water management can moderate the magnitude and intensity of road runoff. In an isolated low density cul-de-sac, there is little threat from chronic or acute contamination providing the residents are aware that they are ultimately likely to be drinking their own runoff. The risk here arises from creating detention ponds over a karst aquifer prone to point recharge. Incipient openings in the subsurface can result in spontaneous drainage of the pond, feeding the water and accumulated contaminated sediments directly into the aquifer.

Septic systems are beyond the scope of this report, but the risk arises again from imperfections of installation and operation rather than design. There is a low but finite risk of a septic system encountering or reactivating a point recharge site.

6.5. Wells

The variability of well performance is a strong indicator of a karst aquifer. Ironically, the “best” wells generating the most water are drawing on karst openings and so much more likely to draw in contaminated water if it is present in the aquifer. Less productive wells are less risky.

Pumping a well develops locally low hydraulic head drawing in water from the surrounding aquifer. This effect is concentrated on any solutional openings that respond rapidly over large distances (100s of metres). This draws water from wherever the solutional openings extend, including down gradient. Surface streams and ponds perched on surficial materials are unlikely to be affected by this. Nor is the conduit under low flow likely to respond to pumping of a distant well, providing it rests on the underlying aquiclude. If the conduit is pressurised, pumping can draw water further in to the aquifer.

As noted above, limited cross connection through vertical fractures will result in water in different bedding planes having different hydraulic heads. Wells provide an important cross link in between bedding planes and so act as collectors in the higher hydraulic head bedding planes even when not pumping.

The result is that in karst aquifers, wells induce mixing between bedding planes and across wide areas both passively and when pumping. If the aquifer is contaminated at any point served by solutional openings, then the contaminant can become widely distributed and subsequently prone to enter other wells.

7. Recommendations

People have been living (and dying) on karst aquifers for millennia. However, they have generally developed resilience and good practices that afford some protection. The final recommendations (10 12 13 GB Planning report) indicate an attempt to implement good practices based on substantial background evaluation and planning. I am not in a position to make substantial planning recommendations. However, some comments can be made about improvements to characterisation and protection.

7.1. Aquifer characterisation: wells

Boreholes provide the primary window on the aquifer. Unfortunately, wells are scarce and penetrate only a small portion of what is probably a complex three-dimensional aquifer. One of three on-site wells showed “cavernous rock”, though this is dismissed based on two subsequent wells not indicating such conditions. Well drillers’ reports are not a reliable source of information, though they may hint at problems. Karst wells should be routinely calliper and video logged to allow full review of the well bore for openings and to allow characterisation of those openings. More specialised logging of the water quality and flows in the well under passive and active pumping provides information on the karst connectivity of the well and its behaviour within the aquifer. This is especially important if there is a known risk such as a surface water conveying conduit within or point recharge of the aquifer.

Karst well water quality can be quite variable through the year, in response to rainfall and pumping patterns. Characterising this variability requires analysis of many water samples. Using routine water quality sampling and analysis is prohibitively expensive. However, inexpensive surrogate measurements such as electrical conductivity can provide adequate high frequency coverage at reasonable cost. The difficulty in characterising karst well water is that it typically is drawn from a small number of openings each with a particular composition. The resulting pumped product is a mixture of these portions that can be challenging to interpret. Similarly within the well, the record from an in situ sensor is particular to that zone in the well and does not characterise the well. A combination of in situ and outflow measurements with profiling has proven effective in understanding how a well works, but becomes expensive.

Preferential connectivity is characteristic of karst aquifers. “Cross-talk” studies are based on slug and bail testing of individual wells and observing the response in surrounding wells. The results do not fully characterise the aquifer, but provide a statistical representation of the interconnectivity of wells. Undertaking pumping tests simultaneously at multiple wells prevents any cross-talk analysis, as well as limiting the definition of any drawdown effect.

It is recommended that the on site wells should be calliper and video logged. The most productive well (TW1) should be studied to determine the karst connectivity and obtain some idea of its possible source area.

7.2. Aquifer characterisation: conduit

The conduit contains unaltered surface water and if it is under pressure poses a possible threat to the aquifer. The internal characteristics of a conduit can be assessed using dye and flood pulse tracer techniques that compare the input and output signals to assess the internal hydraulics and geometry under various flow conditions. Even a basic field inspection under high flow might indicate the presence of pressurisation indicated by a proliferation and high kinetic energy springs appearing in the face.

An alternative approach is to undertake sustained monitored pumping of a well(s) near the conduit to seek the appearance of surface water in the well. In the circumstances, it should be possible to confirm this suspicion by an immediate follow-up dye trace.

The presence of “aquifer” water in the conduit outflow is less critical, except it would demonstrate (reversible) connectivity with the conduit. Such a study could be undertaken through more accurate and detailed measurements of inflow and outflow quantity and quality.

7.3. Aquifer characterisation: recharge

There are at least four points of connection between the surface and the aquifer on site that threaten the aquifer with rapid recharge. These sites suggest that the overburden is thin due to removal (Karst area A) or a bedrock high (Area C?), or the surficial deposits are permeable (Area D). It is imperative that no septic systems or retention pond is developed on any potential direct recharge point. Excavation may reveal shallow bedrock or permeable materials. However, human nature makes it unlikely that any alteration of plans will occur at this stage. A broad area geophysical survey might reveal significant changes in materials or shallow bedrock.

Karst area D has been proposed as a possible source of elevated salt in groundwater. It would be relatively easy to conduct a soakaway study using natural or artificial flooding and tracking the drainage route. Excavation might reveal subsurface conditions. In any case, it is clear that the primary risk is from ponding of contaminated water. Constructing a drainage ditch from this area would reduce the risk by redirecting runoff to Lower Wodehouse Creek and the ponor. The conduit is receiving a substantial quantity of road runoff anyway, so this could not be considered a serious additional burden.

Given the speed and distance of karst groundwater flow, especially in response to pumping, it should be

recognised that point recharge off-site poses at least as great a risk to the aquifer under the development. Particular attention should be paid to up-gradient (SSE) areas.

7.4. Aquifer characterisation: flow routes

Tracing using fluorescent dyes is a standard method used in karst hydrogeology, primarily to identify where a sinking stream reappears. In southern Ontario karst aquifers, sinking streams are uncommon or their destination is obvious. Aquifers are typically buried under surficial deposits, so well-to-well tracing is more appropriate, but much more difficult to undertake. However, it is not apparent that well-to-well tracing will reveal anything that much simpler cross-talk analysis will provide. If karst area D is considered to pose a real threat, then it could be advisable to undertake a trace, but it would not necessarily be resolved clearly without substantial prior work. Tracing from a well to the spring would be possible and would give some characterisation of the aquifer-conduit connection.

7.5. Prior approval

“13. That prior to final approval, the developer conducts Geotechnical investigation on the site that clearly confirms the assumptions of the Hydrogeological Analysis.”

The primary assumption of the hydrogeological analysis is that this is a porous medium that has a thick and extensive (yet miraculously permeable) cover. Neither of these assumptions is supported by the data contained in the reports to date, so it is not clear how the proponent can fulfill this requirement.

“A well be constructed and subjected to contractor’s testing, for the purpose of identifying water quality and quantity, prior to issuance of a building permit on a lot by lot basis.”

It has been sensibly suggested that planning permission be withheld until a proven well has been developed on the respective property. It is not clear what is meant by “confirms” in the first statement, nor is it clear that any threshold exists in the second. Clearly, even the poorest well (TW5) has been rated as adequate. Ironically, it is probably the least risky well of the three on property as it is not well connected to the karst system and thus to the conduit or any point recharge location.

I would advocate development of a karst well assessment based on borehole calliper and video logs and tests and sustained pumping test on higher yield wells. The idea is to identify risks and inform purchasers.

Additional requirements on storm water management and maintenance of the pond are not likely to be of great significance, nor is routine maintenance likely to be undertaken.

7.6. Monitoring

It has been proposed that additional monitoring of the conduit and other wells would be desirable prior to and following development (09 12 22 Karst.Review.MJB..pdf). The final planning report (10 12 13 GB Planning report.pdf) requires that...

“...test well 4 to be equipped with a data logger and be monitored for a period of two years.”

Such a monitoring requirement has limited merit as there is no specification on what is to be measured according to what protocol, nor is there any expedient to collect, analyse and act on the resulting data. (or even whether the logger is to be activated).

I would suggest logging and profiling of existing wells so that we know what is actually happening in them. The highest risk well is TW1 and this well should be the target for monitoring at a carefully selected depth at an interval of not more than one hour for pressure, temperature and electrical conductivity. In addition, hourly stage measurements should be made at the sink and spring outlet to obtain an indication of environmental forcing. Without this (or a dedicated weather station), the in-well data will not be readily interpreted. A local barometric pressure monitor is also required to correct the

pressure transducer data.

The data stream from these loggers should be subject to qualified analysis for the influence of external forcing (runoff) and pumping in a karst aquifer. Ideally, TW1 would not be pumped itself as this would greatly perturb the data series. I suggest monitoring should continue until two years after development is completed so that the effect of additional wells could be evaluated.

I would also suggest that future property owners be provided with the characterisation report on their well and that they should be encouraged to install loggers in their wells, especially those closer to the conduit.

It goes without saying that UV sterilisation should be required, though this does not protect consumers from pathogens in dirty water, or from non-biotic hazards. Those with a clearly karstic well might be wise to provide themselves with a continuous monitoring system to warn them of surface water appearing in their supply.

8. Conclusions

The thorough research undertaken on the BVV property has provide a limited basis for assessing the risks of development on karst, but has left us far from adequately characterising the site, its aquifer and hydrology. The primary expedient for a hazardous sites (foundation failure) is unlikely to be a problem; the aquifer presents the most significant challenge. The conceptual model for the aquifer is not presented and the likely karst conditions and processes have remained largely unanticipated and even qualitatively evaluated. The likely impact and interaction of planned and future development on the property and neighbouring sites can not be accurately evaluated.

While I would advocate substantial informed additional work, it is clearly impractical at this point and there is considerable value in the existing studies and well infrastructure. I have detailed recommendations above, but I would require logging and cross-talk analysis of existing wells. An inexpensive cross talk analysis for off-site on-site cross talk can be undertaken using incidental pumping in neighbouring wells while carefully monitoring the site wells. I would also study the risk of point recharge more thoroughly, especially karst area D. Finally, I would provide much more prescriptive direction as to determination of the “suitability” of wells and future monitoring protocol. I would also require that the characterisation documents be provided to prospective purchasers without bias.