

Thames-Sydenham and Region

Proposed

Approach to consideration of Transport
Pathways in the Vulnerability Assessment
of Groundwater Based Vulnerable Areas

May 29, 2009
Version 0.3

1 Table of Contents

1	Table of Contents	2
2	Introduction.....	3
2.1	Groundwater Vulnerability Assessment (Part IV of the Rules).....	4
3	Discussion.....	5
3.1	Buffer around Transport Pathway.....	6
3.2	Areas of increased density of Transport Pathways	6
3.3	Possible investigations to determine interaction with surface	6
3.3.1	Groundwater Modeling.....	6
3.3.2	Geochemical Analysis	7
4	Recommendations.....	8
4.1	Horizontal Transport Pathways.....	8
4.2	Vertical Pathways	9
4.2.1	Oil and Gas Wells	10
4.2.2	Water Wells	10
4.2.3	Excavations	13
4.3	Other Transport Pathways.....	14
5	Additional comments	15
6	References.....	15

2 Introduction

The vulnerability of an aquifer may be increased by any land use activity or feature that disturbs the surface above the aquifer, or which artificially enhances flow to the aquifer. This implies the existence of preferential flow paths that permit shallow recharge water and contaminants to move through a confining layer. Constructed transport pathways can circumvent the natural protection offered by soils and overlying materials. Transport pathways can be small diameter vertical pathways such as a well or large features such as a quarry. Some pathways are horizontal in nature (pipes such as water or sewer lines); while others are vertical (e.g. wells). In Part IV Groundwater Vulnerability Assessment of the Technical Rules: Assessment Report; Clean Water Act, 2006 (dated December 12, 2008), there are rules that pertain to the framework for assessing transport pathways. Within a zone of vulnerability, transport pathways such as abandoned wells or quarries can eliminate partially or entirely the protective layers above the aquifers and form a direct conduit between the ground surface and the aquifer. Such features significantly increase locally the vulnerability of the zone, and this should be reflected in the vulnerability assessment of the area. The original intent was to assess possible anthropogenic effects. Natural transport pathways such as fracturing and karst should be accounted for under the vulnerability assessment and therefore do not need further consideration as transport pathways.

Due to scientific uncertainty, it is difficult to provide exact numbers to estimate risks. Risk assessment and comparative risk models are not solely science-based; they involve professional judgment and a degree of uncertainty. As with the Vulnerability Assessment of vulnerable areas related to drinking water sources the consideration of transport pathways has a significant level of uncertainty associated with it. Inventories of transport pathways may not be complete. The nature of the construction of the transport pathway may also involve some level of uncertainty. It is important however that the relative vulnerability of an area be assessed and given due consideration to how that vulnerability is affected by known transport pathways.

Excerpts from Part IV of the rules are included below as they pertain to transport pathways. The current document is intended to foster discussion on methodologies for considering the effect of transport pathways on the vulnerability of an area. The methodology will be finalized upon consideration of comments from consultants and municipality staff working on technical studies in the Region, as well as conservation authority staff. The finalized methodology will be provided to those undertaking this work in the region to serve as guidance on possible modifications to vulnerability assessment in the Region based on transport pathways.

Where conservative assumptions have already been applied in mapping the vulnerability, additional adjustments for transport pathways may not be necessary. Where transport pathways result in an increased risk to drinking water systems an adjustment to the vulnerability in the area of the transport pathways is an effective methodology for reflecting the increased risk.

2.1 Groundwater Vulnerability Assessment (Part IV of the Rules)

The following section includes excerpts from the Technical Rules: Assessment Report Clean Water Act, 2006 (December 12, 2008). Part IV describes the methods of assessing the vulnerability of an area.

Part IV.1 - Vulnerability Assessment and Delineation, Groundwater

37. The vulnerability of groundwater within a source protection area shall be assessed using one or more of the following groundwater vulnerability assessment methods,

- (1) intrinsic susceptibility index;*
- (2) aquifer vulnerability index;*
- (3) surface to aquifer advection time;*
- (4) surface to well advection time, or*
- (5) a method that in the opinion of the Director is equivalent or better than the methods permitted by subrules (1) through (4).*

38. A source protection area shall be delineated into areas of high, medium or low groundwater vulnerability, high corresponding to greater vulnerability, as follows;

- (1) where a method described in subrule 37(1) or (2) was used to assess vulnerability;*
 - (a) areas of high vulnerability are those areas with scores that are less than 30,*
 - (b) areas of medium vulnerability are those areas with scores that are greater than or equal to 30 but less than or equal to 80, and*
 - (c) areas of low vulnerability are those areas with scores that are greater than 80;*
- (2) where a method described in subrule 37(3) or (4) was used to assess vulnerability;*
 - (a) areas of high vulnerability are those areas with results that are less than 5 years;*
 - (b) areas of medium vulnerability are those areas with results that are greater than or equal to 5 years but less than or equal to 25 years, and*
 - (c) areas of low vulnerability are those areas with results that are greater than 25 years, or*
- (3) where a method described in 37(5) was used to assess vulnerability, using a methodology that in the opinion of the Director is comparable to the assignment of vulnerability categories in subrules (1) and (2).*

Within the Thames-Sydenham and Region the vulnerability of Wellhead Protection Areas have been Assessed through the use of ISI. In a few of the systems Surface to Well or Aquifer Advection Time has been used. The following section describes how the vulnerability of an area may be modified due to the existence of transport pathways. In particular Rules 39 to 41 define the framework for rating transport pathways

Vulnerability increase, transport pathways:

Rule 39: Where the vulnerability of an area identified as low in accordance with rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of medium or high vulnerability, high corresponding to greater vulnerability.

Rule 40: Where the vulnerability of an area identified as medium in accordance with rule 38 is increased because of the presence of a transport pathway that is anthropogenic in origin, the area shall be identified as an area of high vulnerability.

Rule 41: When determining whether the vulnerability of an area is increased for the purpose of rules 39 and 40 and the degree of the increase, the following factors shall be considered:

- (1) Hydrogeological conditions;*
- (2) The type and design of any transport pathways;*
- (3) The cumulative impact of any transport pathways; and*
- (4) The extent of any assumptions used in the assessment of the vulnerability of the groundwater.*

3 Discussion

Rules 39 and 40 allow the adjustment of vulnerability because of the presence of transport pathways and 41 defines the factors to be considered for increasing the vulnerability rating. The rules do not, however, define criteria that should be applied in order to increase the vulnerability. In addition, there are no definitions for transport pathways. For example, Rules 39-41 do not provide information on the extent of the area around a transport pathway whose vulnerability may be modified. This allows for local interpretation of appropriate measures within a source protection region. This document is intended to consider factors affecting vulnerability of a vulnerability area due to anthropogenic transport pathways using a consistent and systematic approach while recognizing the need for local flexibility.

Transport pathways (referred to in past guidance as constructed pathways) can be large or small diameter borings, such as water wells, oil and gas wells, exploration or test wells. Transport pathways can also be horizontal or vertical excavations such as pits, quarries, mines, road cuts, ponds, ditches, storm water management features and other excavations. Also pipelines and sewers are horizontal features that could possibly increase the vulnerability of an aquifer or provide a pathway for contaminants to move horizontally to an area of higher vulnerability.

The physical characteristics of the transport pathway need to be considered to determine if the pathway extends to the water table or breaches protective layers above the aquifer of interest. For example where the transport pathway is not deep enough to penetrate the natural protective layers above the aquifer, an adjustment may not be needed or the adjustment may be small enough to not result in a change in the vulnerability score applied to the area.

The general factors that should be considered in the evaluation for the need for an adjustment should include:

1. Hydrogeology: transport pathways may have a more significant impact in some areas (e.g. low vulnerability areas could be more impacted than highly vulnerable aquifers). In these areas of lower vulnerability transport pathways may have a

2. Nature and design of constructed pathways. For example, does the constructed pathway extend close to or beneath the water table, or does the pathway extend through a protective confining layer?
3. Likelihood of the occurrence of improperly abandoned or decommissioned wells.
4. The construction, maintenance and density of wells within the vulnerable area.
5. The occurrence and nature of other constructed pathways.

3.1 Buffer around Transport Pathway

Some alternatives for considering transport pathways focus on the assumption that it is not the individual occurrence of a feature, but the increased density of the features in an area which affects the vulnerability. If, on the other hand, one is to consider that an individual feature affects vulnerability then the extent of the area affected by that pathway will need to be considered. Some have suggested that each feature be identified and a buffer be applied to the feature. The vulnerability of the area of the buffer could be increased. To evaluate the distance criteria accurately, a case-by-case analysis would be required, taking into account topography and soil type for each mapped transport pathway feature. A buffer may be an approach for assessing increased vulnerability around a transport pathway feature for certain types of pathways where the individual occurrence is of concern.

3.2 Areas of increased density of Transport Pathways

In areas of increased transport pathway density, such as a hamlet with residences on small lots serviced by private wells or septic systems, a zone could be delineated. The vulnerability of this zone could then be increased to reflect the increased risk resulting from the high number of transport pathways in the area. The size and density of housing would need to be considered.

3.3 Possible investigations to determine interaction with surface

Although a definitive connection between the surface and the aquifer will be difficult to determine there are methods which could provide insight into whether such a connection exists. These methods will not identify whether transport pathways are responsible for the connection or which transport pathways is the likely cause of the connection. These methods may however provide justification for adjustments to vulnerability scores within the area.

3.3.1 Groundwater Modeling

The increased vulnerability of an area could be assessed through the construction calibration and simulation of a local-scale groundwater flow and transport models.

Utilizing particle track models where appropriate or available could assess the effect transport pathways have on the travel time to the well. Transport models have been developed for many municipal wells in the Thames Sydenham and Region and could be applied in select cases where warranted. Solute movement (of potential contaminant) could be simulated in a transport model to determine if transport pathways are a significant influence on the vulnerability of an aquifer.

3.3.2 Geochemical Analysis

In most aquifers, the horizontal permeability is greater than the vertical permeability. This inhibits vertical movement of water and water in a particular zone develops chemical characteristics that are substantially different from water in other zones above or below. A basic description of groundwater age and selected age tracer concentrations may assist with demonstrating the connection between aquifer units. It is possible in localized areas to compare and contrast this with the results from the particle tracking models discussed above. A significant contrast in the results could support an increase in vulnerability due to transport pathways.

Water-quality samples collected from wells screened through unconfined and confined water-bearing units could be compared with samples collected from a public supply well, screened in the confined portion of the aquifer. If analytical results show that samples collected from the public supply well have chemistry and age-tracer concentrations consistent with young water derived from unconfined recharge areas, mixing between these sources is likely to have occurred. If results indicate a mixing, this could imply the existence of preferential flow paths that permit shallow recharge water and contaminants to move through the confining layer. It does not rule out that the paths are not anthropogenic in nature, but none-the-less identify that the vulnerability may well be greater than the sparse data may represent.

Developing good non-anthropogenic indicators of groundwater age (older water is generally more pristine) is problematic and requires statistically significant set of reliable data collected during a period of time. But age dating using isotope information may also be a possibility.

This would require additional analysis and study and is therefore not possible to undertake for the current planning period. This methodology could be applied prior to future plan updates to demonstrate whether the areas where vulnerability adjustment have been undertaken are justified or determine if other areas warrant an adjustment to the vulnerability score.

In some areas, a particular anthropogenic source, if present, may indicate interaction with surface water. For example, if e-coli or elevated nitrate have been detected, it is likely that surface water is affecting an area of perceived natural wellhead protection (i.e. thick overburden material).

4 Recommendations

4.1 Horizontal Transport Pathways

Horizontal transport pathways would be those which allow for the transport of contaminants from an area of lower vulnerability laterally into an area of higher vulnerability. In the case of groundwater sources these pathways tend to short circuit the natural protection which may be available in the area in which the activity is undertaken.

Horizontal pathways could include such things as:

- Storm and Sanitary Sewers
- Agricultural drainage
- Pipelines
- Septic beds
- Conduits for hydro or communications lines

Maps showing the locations, depths and diameters of sewers and water mains could be considered. Details about the nature of the preferential pathway would also need to be considered. For sewers, the approximate depth of the sewers and whether the sewer transects confining layers should be considered. In many cases, the alignment of the sewers may not cause an increase in vulnerability.

For septic systems, there may be a need to increase the vulnerability if it is thought that the vertical depth of excavated material (to install the tank/tile bed) would sufficiently reduce the thickness of the protective material over the aquifer. This increase is more related to the vertical pathway created than the horizontal nature of the tile bed. This may have a significant effect on vulnerability if this reduction in thickness is sufficient to reduce the ISI score such that vulnerability would decrease from low to moderate or moderate to high. For many situations, such as in areas where the vulnerability is already high, this would likely not occur. In areas where the vulnerability is lower and the depth to the water table is high this may be more of a concern.

True horizontal pathways only constitute an increase to vulnerability if they have the potential to direct contaminants towards an area of higher vulnerability from an area of lower vulnerability. The following method could be applied to assess the vulnerability increases resulting from these features:

- A buffer could be mapped around the feature to represent areas which could contribute contaminants to the pathway. This buffer would need to consider the topography and hydrology of the area.
- The intersection of the buffered zone with the vulnerability zones could be analyzed and the highest vulnerability score that is intersected by the feature could be applied to the buffered zone.

Recommendation

It is proposed that this methodology only be applied where the system operator is concerned about activities being undertaken in areas which could pose a higher risk to the system than reflected by the vulnerability scoring assigned to the area in which the activity is occurring. As such it is not proposed that extensive inventories be developed for all such situations, but rather specific instances where this concern is identified be examined to determine if horizontal transport pathways effectively increase the vulnerability of a specific area.

4.2 Vertical Pathways

Vertical Transport Pathways are pathways which may provide a vertical pathway from the surface or another aquifer to the aquifer which is providing the source of water being protected. The vulnerability of an aquifer may be increased by a land use activity (such as improperly constructed or maintained wells as illustrated in Figure 1) or a feature that disturbs the surface above the aquifer or which artificially enhances flow to that aquifer.

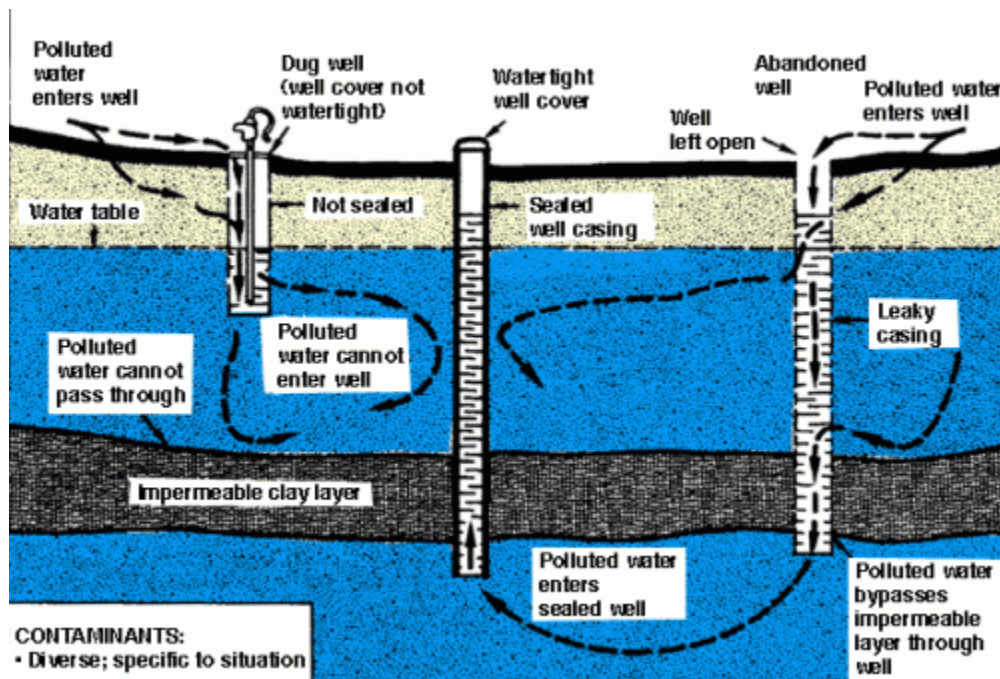


Figure 1 Possible transport pathways, from <http://groundwater.oregonstate.edu/protect/wellreferences>

These transport pathways might include such features as:

- Water wells
 - Abandoned or improperly decommissioned
 - Poorly constructed or maintained
- Gas and Oil wells,
 - especially older wells with no or non-effective casings
- Exploration holes or wells

These are each discussed separately in the sections below.

Wells in areas known to be screened in both the unconfined and confined portions of an aquifer may provide a preferential pathway, or “short circuit”, for water moving from the unconfined to the confined units of the aquifer. As discussed above, ground-water flow and transport models could be used to simulate the processes controlling movement of contaminants to public supply wells in the layered unconsolidated deposits where there is an indication of increased risk to contamination as a result of this type of transport pathway. This is, however, not something that is possible within the current planning cycle.

4.2.1 Oil and Gas Wells

Historic oil and gas wells represent potential conduits for contaminants to travel from ground surface to deeper aquifer units, from shallower units to deeper units or from deeper units to shallower aquifers. Oil and gas wells can generally be located using well record information from the Ontario Oil, Gas and Salt Resources Library (<http://www.ogsrlibrary.com/>). Unfortunately, this inventory may not include older wells which are likely a more significant concern than the newer operating wells. It is considered likely that older oil and gas wells are inadequately sealed.

Recommendations

Where documented oil and gas wells exist within a WHPA, the system operating authority or owner should consider whether these features have a significant effect on the vulnerability of the area. Consideration should be given to the level of vulnerability assigned to the area and whether the feature removes a portion of that natural protection. If it is deemed locally desirable to adjust the vulnerability score, a buffer by a set radius could be utilized around these features if sparsely distributed. Where concentrated in a specific area, an area around the concentration of the features could be delineated. The size and shape of the buffer should depend on the local characteristics and whether the concern is a transport pathway originating from the surface or an interconnection of confined units. Surficial characteristics such as topography and drainage should be considered in determining the area. The vulnerability score of the area affected by the features could be increased one or two levels.

4.2.2 Water Wells

Water wells that are improperly abandoned or poorly constructed can act as conduits for contaminants to move from ground surface to a confined aquifer. Wells within the MOE water well database (WWIS) could be incorporated into a transport pathways database. This however does not account for the fact that many wells are properly constructed and as a result are unlikely to significantly affect the vulnerability of a specific area. It is also important to note that the WWIS is incomplete and also contains improperly located information even with the significant efforts undertaken recently to correct known deficiencies.

Abandoned wells which have not been properly decommissioned are of specific concern. In many areas, efforts have been undertaken to identify where there is a likelihood of a significant number of these abandoned wells. These efforts have focused on aerial photo reconnaissance looking for evidence of farmsteads and other structures predating municipal water services. In some studies, areas which are now serviced by municipal water, which did not include the decommissioning of the private wells, have been identified as having a higher likelihood of abandoned wells. In some areas surveys of landowners have been undertaken in an effort to identify abandoned wells. In most cases it is felt that these methods have not been very effective in identifying the magnitude of the impact these abandoned wells may have on the vulnerability of the municipal drinking water sources.

The water wells within a vulnerable area are difficult features to assign an increase in vulnerability rating. While it was considered reasonable to state that older oil and gas wells, especially those not currently in use, are likely to be poorly constructed or maintained, the same is not true for functioning water wells. The risk that water wells pose depends on the quality of well construction and maintenance or decommissioning (for decommissioned wells). The following attributes are available in the water well information system (WWIS) and could provide insight into the likelihood that a well constitutes a transport pathway:

Field	Comment
D_Location_misc.Comp_Date	Provided that the quality of well construction stayed constant over time, older wells are more likely to show signs of aging including the possibility of the degradation of the casing, or possibly compromised grout
Borehole_Construction.ConSubtype_Code	Risk of open hole > steel > PVC It is to be mentioned that steel corrodes; but, on the other hand, PVC is more likely to age and break above the water level, or simply have a slight diameter change that could break the annular cement.
D_Location.Loc_Active	Decommissioned wells are flagged in the database. Properly decommissioned wells are not of significant concern. It is, however, likely that most abandoned wells are not reported as such and that these actually represent a higher risk than the reported wells which are indicated in the database.
Well coordinates	Well coordinates can be used to map wells and to calculate the well density. In an area with a high water well density, it is more likely that one of the wells casings is leaking than for a single well. However, it is very difficult to associate a well density with a risk increase and to define a discrete threshold. An area of a high density of wells within in a municipally serviced area may indicate an area where there are likely to be abandoned wells, especially if that area does not contain a relatively high number of decommissioned wells as indicated in the field discussed above.

The available attributes of the WWIS database are limited and cannot be used with good confidence to develop a reliable estimate of whether a well is properly constructed,

maintained or decommissioned. Further, the WWIS may not have reliable records within the area being considered for an adjustment to the calculated vulnerability.

The Water Well Information System (WWIS) does not account for the current state of an area. Changes may have occurred since the older wells were constructed. Excavations and re-grading are examples of areas which may have been modified and not accurately represented in the WWIS. These transport pathways are covered separately later in this document.

A possible way of dealing with the increased vulnerability due to water wells is to develop a buffer around known wells. There is no recommendation as to the size of the buffer which would have its vulnerability adjusted. Wellhead protection areas include a buffer of 100 m around the well as WHPA-A, but this is more related to the protection of that well than it is a representation of any increased vulnerability. It is also difficult to differentiate between properly constructed and maintained wells which, do not require an adjustment, and wells which may actually increase the vulnerability. This methodology would not account for the well locations which are not known, nor does it address the abandoned wells.

An area where the density of wells is higher than typical can be assigned a higher vulnerability score. This would recognize that within an area of higher density of wells, there is a higher likelihood of poorly constructed, maintained or abandoned wells. Determining the density at which an adjustment should be made is very subjective. One could consider lot size and whether it could safely contain both a well and a septic system with adequate separation between them. The opportunity to optimally site a well is reduced with respect to septic systems on small lots. This does not however, consider other types of threats or activities. More work is required to determine if general guidelines for flagging areas to be considered using this method could be developed. If such a threshold were to be developed it would only be used for the purposes of flagging those areas for closer examination. An increase in vulnerability score would only be undertaken through discussion with the operating authority focused on whether there is a concern with the increased risk to the drinking water systems as a result of the higher density of wells in the area.

Recommendation

It is recommended that areas of higher than typical density be considered on a case by case basis in close consultation with the municipal water system operating authority. Further analysis of typical well densities may be undertaken to determine if appropriate density ranges can be developed which might assist in the flagging of areas to be considered for density adjustments. When considering adjustments, consideration should be given to the hydrogeology of the area and should include such factors as the unit that a municipal well is located, the location, depth and nature of the private wells and the depth to the water table. This can only be considered in areas which are low or moderate vulnerability as no adjustment can be made in areas which are already high vulnerability.

4.2.3 Excavations

Excavations, such as pits and quarries, are constructed by removing surficial geological material that provides a natural barrier or zone of filtration to the movement of contaminants towards deeper aquifers. These features have the potential to act as conduit for the movement of contaminants to deeper aquifers within the groundwater flow system. Although pits and quarries are examples of readily identifiable excavations, any known deep excavation in a Wellhead Protection Area should be considered in this way.

Pits and quarries could be identified using Ontario base maps and aerial photography. Properties that have pits, quarries and excavations should be identified and considered for adjustments to the vulnerability. Other significant excavations could be identified through review of aerial photography and discussion with the system operating authority.

In assessing the vulnerability of an area, the type and thickness of materials over the aquifer is considered. This has been calculated utilizing a methodology known as Intrinsic Susceptibility Index (ISI). In this methodology the thickness of a layer is multiplied by a coefficient which is inversely proportional to the relative ease with which water (and potential contaminants) flow through the material. Sands and gravels have a lower score and clays and silts have a higher score. Figure 2 illustrates the calculation of the ISI and the changes in ISI as a result of excavation.

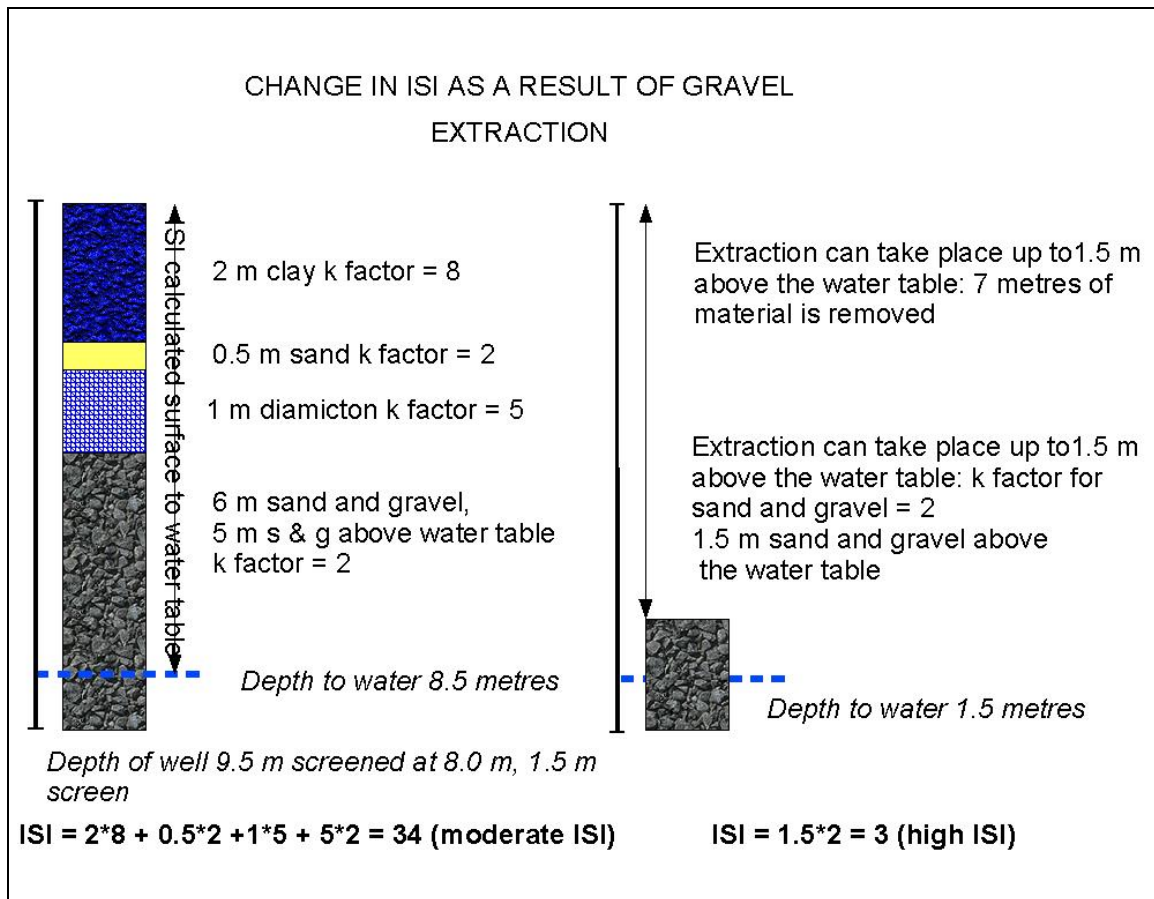


Figure 2 Change in ISI as a result of gravel extraction

Excavations can also modify the drainage patterns of an area. Reducing the elevation of an area may cause the surrounding areas to drain across or into the area of the excavation. If the vulnerability of the area has been increased it may be desirable to increase the vulnerability of nearby areas which drain over the area. Buffers could be applied to the area which has been modified to include the areas which drain directly through or across the area.

Licensed quarries within the WHPA should be identified so they may be considered during policy development. Although the natural vulnerability may not have been modified yet, future extraction may result in a future modification of the vulnerability. Although policies are unlikely to affect the excavation, the future land use of the area may need to consider the modified vulnerability score.

Recommendation

In excavations, the removal of enough of the protective soil material from above an aquifer effectively removes the natural protection of the aquifer and increases the vulnerability of the aquifer. In considering the vulnerability of an area where an excavation has removed material the vulnerability of the area should be recalculated based on the actual materials left in place. This should not be considered an adjustment to the vulnerability as discussed in the other transport pathways, but rather a correction to account for the actual conditions of the site.

Active and rehabilitated sites should be considered in this manner. The full area of the excavation should be considered. This may be best represented by the licensed area. Areas directly draining across the area with increased vulnerability can be considered for adjustment as part of the transport pathway.

4.3 Other Transport Pathways

In some cases features that might not be intuitively obvious may need to be further investigated. Smaller diameter features such as test holes, fence posts, and field drainage tiles may also need to be included. Larger scale features may include excavations and construction activities, storm water infiltration ponds, etc. could also provide a transport pathway.

Groundwater Impacts Caused by Construction Works

A range of temporary and permanent impacts on the groundwater environment may result from civil engineering works. Perhaps because a full assessment of the impacts requires an understanding both of the construction and groundwater issues, it appears that no comprehensive summary of these potential impacts exists in the literature. A number of publications have dealt with discrete aspects of the subject. Powers (1985) described what he termed 'unwanted side effects' of temporary dewatering. The recent Construction Industry Research and Information Association (CIRIA) guide to best practice for

temporary dewatering (Preene et al., 2000) discusses environmental issues, mainly in relation to pollution risks during construction. Brassington (1986) discussed the potential impacts on springs and private water supplies resulting from temporary dewatering and from permanent disruption of groundwater flow by engineering works.

Activities which present a risk to drinking water sources are known as threats. The Clean Water Act and its regulations prescribe activities which can be considered threats. Construction as described above may well pose a risk, either temporary, during construction, or in the future. These activities, where they permanently affect the vulnerability of an aquifer, should be considered as transport pathways and appropriate adjustments made to the vulnerability of the area. As the nature of the construction activity is likely to be unique, each occurrence of concern to the operator should be considered based on sound professional judgment to identify an appropriate adjustment.

Where the activity is considered a threat in itself, the SPC may wish to consider this activity as a threat pursuant to rule # 119.

Some forms of construction inadvertently form permeable pathways along which groundwater may flow preferentially. Some of these pathways may be temporary (such as investigation and dewatering wells) and can be sealed on completion. Other pathways are formed by parts of the structure or works and may exist in perpetuity. Examples of permanent pathways include the granular bedding of pipelines (which may allow horizontal flow) or some types of piling or ground improvement processes (which can form vertical pathways). Open excavations such as road or rail cuttings may themselves form potential vertical pathways. Where applicable these pathways can be considered through the most appropriate methodology discussed above.

5 Additional comments

Where the density of an identified transport pathways is relatively high (e.g. a cluster of private wells in an area), the likelihood of a connection is also relatively high and this should be considered in assigning the vulnerability modification. Independent of the above considerations, the resultant vulnerability score cannot be increased above 10 points for WHPA's or 6 points for HVAs and SGRAs. Where conservative assumptions have already been applied in mapping the vulnerability, additional adjustments for transport pathways may not be necessary.

6 References

Ontario Ministry of the Environment, 2006: Water Well Sustainability in Ontario, final Report January 2006. Expert Panel Report
Ontario Ministry of the Environment, 2006: Wells Inspection Report

