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FINAL REPORT

The Effect of Aggregate Extraction on Groundwater Quality

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REPORT

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EXECUTIVE SUMMARY

The aggregate industry is of critical importance to Ontario's economy. Although the extraction of aggregates, including sand, gravel, and in some cases bedrock, has historically been considered a low risk land use from the perspective of groundwater contamination, there is growing concern about the possible impact of aggregate extraction on the long term vulnerability of underlying aquifers to contamination, which is based on the perception that the removal of the aggregate and its associated contaminant filtration capacity poses a significant threat to groundwater quality.

Since aggregate operations themselves are unlikely to constitute a significant threat to groundwater quality, a better understanding on the potential impacts of aggregate extraction must consider the uses to which former aggregate sites are returned after closure, the potential contaminants associated with those land uses, and the actual attenuation mechanisms for those contaminants most likely to be of concern. In Ontario, the overwhelming majority of aggregate sites will be returned to either a naturalized condition, an unlikely source of groundwater contamination, or agricultural production. Numerous studies of rural groundwater quality, including a major survey of water quality in rural south-western Ontario, consistently demonstrate that agricultural production is the source of widespread adverse impacts to rural groundwater quality by nitrate and pathogens as a result of the land application of animal wastes and chemical fertilizers, with pesticides considered a potential concern. Nitrate is relatively stable in groundwater and is unlikely to degrade to a significant extent above the water table, regardless of the extent of aggregate removal. Pesticides rapidly degrade and do not pose a significant threat to groundwater quality. Although there is limited scientific data describing the attenuation of pathogens above the water table, it appears likely that aggregate extraction decreases the attenuation capacity of the remaining overburden material to some extent; however, aggregate extraction has no impact on pathogen attenuation below the water table where significant attenuation occurs through filtration and pathogen inactivation.

These findings suggest that former aggregate sites will only be associated with a very limited range of groundwater quality impacts that are typical of rural settings where the predominant land use is agricultural. At former aggregate sites returned to intensive agricultural or other land uses associated with significant potential for groundwater impacts (e.g., industrial), site-specific studies may be necessary to ensure that adverse groundwater quality impacts are avoided. Agricultural management practices that minimize the use of animal wastes and chemical fertilizers will be an effective means of ensuring that post-extraction use of former aggregate sites do not result in adverse impacts to groundwater quality.

1.0 INTRODUCTION

Approximately 25% of Ontario’s population is dependent on groundwater as a drinking water supply with the percentage approaching 100% in rural areas. An abundant supply of safe, clean groundwater is critical to the quality of life of all residents in Ontario and an invaluable resource. Similarly, the availability of an adequate supply of aggregate is also of great importance, with an annual per capita production rate of approximately 13 tonnes of aggregate material required to meet demand in the Province of Ontario (The Ontario Aggregate Resources Corporation, 2008).

The extraction of sand, gravel, and in some cases bedrock, above the water table is a relatively low risk land use from the perspective of groundwater contamination, given the limited use of potential groundwater contaminants by the aggregate industry. There are no documented instances of adverse impacts to groundwater quality as a result of normal operational activities associated with aggregate extraction (Blackport and Golder, 2006) and the potential for activities associated with above water table aggregate extraction to adversely impact groundwater quality is principally related to the land uses following final rehabilitation.

However, there is a growing awareness and concern about the impact of aggregate extraction on the long term vulnerability of an underlying aquifer to contamination. The concern that aggregate extraction could increase aquifer vulnerability was identified in a report released by the Province of Ontario in November 2004 titled “Watershed Based Source Protection: Implementation Committee Report to the Minister of the Environment” in which a series of recommendations were made related to specific potential issues and/or threats to drinking water sources. The Committee highlighted potential source water concerns related to the removal of aggregates reducing the ability of the remaining material to provide filtering above a groundwater source and, for situations where the water table is exposed, allowing for easier introduction of contaminants at ground surface.

To better assess the issue of increased vulnerability from the potential loss of filtering due to aggregate extraction, the Ontario Stone, Sand and Gravel Association (OSSGA) retained Golder Associates Ltd. (Golder) to carry out a study of the potential impact of aggregate extraction on groundwater quality. Given the wide diversity of aggregate sites; the range of possible post-extraction land uses, their associated contaminants and the range of contaminant release mechanisms; the complexity of the environmental pathways by which adverse impacts to human health and the environment can occur; and the complexity of the subsurface processes that decrease (or “attenuate”) the concentration of a groundwater contaminant, it is difficult to provide any widely-applicable and quantitative analysis of the role of any one factor on groundwater quality. Recent criticism of the aggregate industry has focused on the perceived loss of attenuation capacity resulting from the removal of the overlying aggregate, an intuitively understandable argument.

However, this undeserved focus on unsaturated zone attenuation distracts from an improved understanding of the potential groundwater quality impacts at former aggregate sites and the context in which they might occur. This improved understanding, which is necessary if the aggregate industry is to effectively address the concerns of the public and government agencies with respect to potential adverse groundwater quality impacts, recognizes that aggregate extraction is an almost exclusively rural land use and the existing municipal and/or provincial planning processes will result in the redevelopment of these sites following the cessation of aggregate operations to relatively limited range of alternative land uses.

2.0 AGGREGATE INDUSTRY IN ONTARIO

Aggregate materials, which include gravel, sand, clay, earth, shale, stone, limestone, dolostone, sandstone, marble, granite, rock and other prescribed materials (*Ontario Aggregate Resources Act*, 2006) are of vital importance to the Ontario economy. Sand and gravel pits represent the bulk of aggregate production in Ontario, with the production of crushed stone at quarries representing the largest part of the balance of production. Other aggregate materials (e.g., clay, ornamental stone) represent a small, albeit high value, component of total aggregate production. More than half of Ontario's aggregate production is used by provincial and municipal governments for the construction and maintenance of public infrastructure (The Ontario Aggregate Resources Corporation, 2009).

In 2008, Ontario produced approximately 167 million tonnes of aggregate from nearly 6,550 aggregate sites, including both pits and quarries located on both public and private lands. In the past decade, provincial production of aggregates has remained relatively constant, ranging from 144 million tonnes to 179 million tonnes. Aggregate sites are located based on the potential for developing an economically viable resource, which is primarily dictated by the availability of suitable geologic material, proximity to market and regulatory constraints. Typically, intensive development in urban areas favour the development of new aggregate sites in rural areas; however, distance to market is an important consideration, since trucking costs represent a major component of the end user price.

2.1 Regulatory Environment

The aggregate industry in Ontario is primarily regulated by the Ministry of Natural Resources (MNR) through the *Aggregate Resources Act* (ARA). The main purposes of the ARA are:

- to provide for the management of the aggregate resources of Ontario;
- to control and regulate aggregate operations on Crown and private lands;
- to require the rehabilitation of land from which aggregate has been excavated; and
- to minimize the adverse impact on the environment in respect of aggregate operations.

Specific standards for the development, operation and closure of aggregate sites are imposed on the aggregate industry through the ARA, which requires that an aggregate operator must obtain a licence to operate a pit or quarry. Following final rehabilitation and removal of the aggregate licence by the Province, the planning

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provisions of the local and regional municipal governments control future land use. Although these provisions can vary widely between municipalities, the Planning Act specifically addresses aggregate extraction through the Provincial Policy Statement (PPS), which provides municipal governments with policy direction on matters of provincial interest related to development and land use planning:

> *In prime agricultural areas…..extraction of mineral aggregates is permitted as an interim use provided that rehabilitation of the site will be carried out whereby substantially the same areas and same average soil quality for agriculture are restored.*

Although specific authority for land use planning approvals resides with municipalities, Official Plan policies and decisions made pursuant to the *Planning Act* are required to be consistent with the PPS, through which the Province has established policies to encourage the redevelopment of former aggregate sites in a manner that is consistent with surrounding land uses, with an emphasis on returning lands to their original use as defined in municipal zoning by-laws. Following final rehabilitation, changes of land use for a former aggregate site generally requires a zoning by-law (and possibly an Official Plan) amendment by the regional and/or local municipal governments.

Approvals and requirements for former aggregate sites are potentially required under other legislative instruments, depending on the indentified issues with respect to the requested land use change, particularly with respect to potential adverse impacts to water quality. These legislative instruments include the *Ontario Water Resources Act*, the *Environmental Protection Act*, the *Environmental Assessment Act*, the *Conservation Authorities Act*, the *Greenbelt Act*, the *Oak Ridges Moraine Conservation Act*, *Niagara Escarpment Planning and Development Act*, and the *Clean Water Act*. Municipal source water protection measures implemented under the auspices of the *Clean Water Act* are of particular relevance, since they provide a regulatory mechanism for identifying valuable groundwater resources, characterizing their vulnerability to adverse impacts and identifying land uses that pose potential threats to the quality of groundwater resources.

2.2 Hydrogeologic Setting of Aggregate Sites

License and permit categories correspond to four generic types of aggregate extraction sites, which are differentiated based on the type of aggregate operation (pit or quarry) and the depth of extraction relative to the water table (see Figure 1). Of these sites, approximately 14% of aggregate licenses allow extraction below the static water table. Upon the cessation of aggregate operations, these sites will become wetlands and/or open bodies of water that cannot be restored to agricultural or other land uses. Accordingly, the direct release of contaminants to groundwater at these sites is effectively precluded, except as a result of the importation of contaminated soil for in-filling during site rehabilitation, illegal waste disposal, or drainage of surface water originating from an adjacent location carrying contaminants into the new surface water body (Blackport and Golder, 2006).

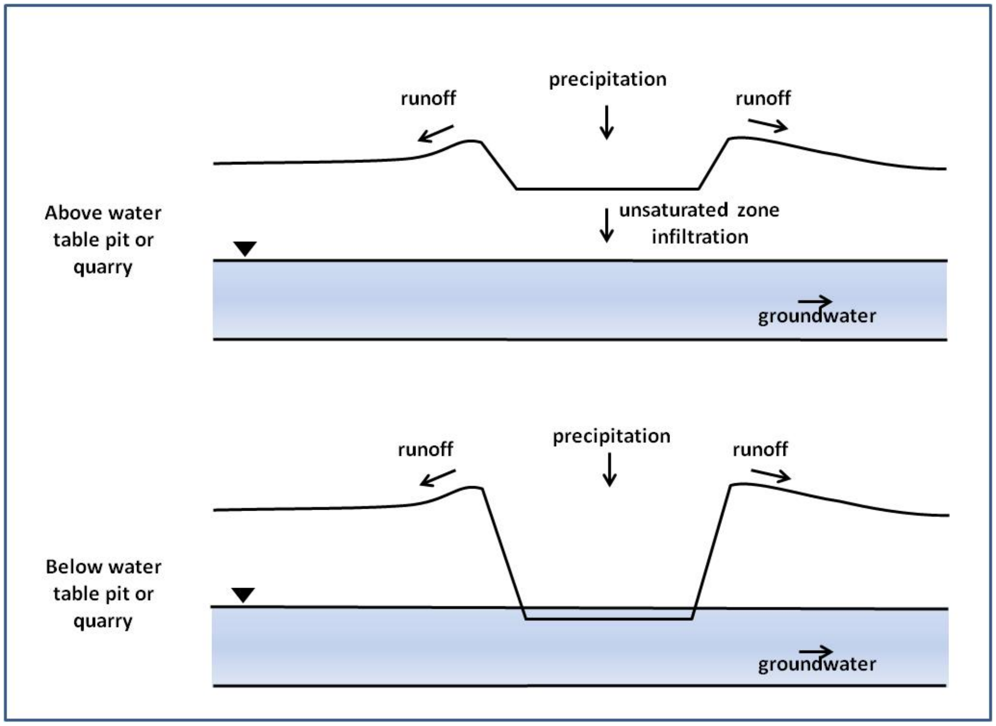

Figure 1: Types of Aggregate Operations

Sites where excavation is completed above the water table have common hydrogeologic characteristics. The minimum thickness of aggregate materials that can be left above the water table without obtaining a more stringent “below water table” aggregate licence is 1.5 metres. At pit sites, this remaining material between the excavation floor and the water table will, in most cases, be comprised of permeable aggregates through which water can readily infiltrate. In contrast, at quarry sites the remaining geology will consist of bedrock that, depending on the degree of fracturing, can vary widely in terms of permeability.

For most of these sites (currently approximately 86% of the total number of sites in Ontario) where excavation will be completed above the water table, post-extraction land uses at the site potentially could result in the introduction of contaminants into the water table. At these sites, the extent to which overburden removal increases the potential for the introduction of contaminants to the water table depends greatly on the quantity and type of soils present and the nature of the post-extraction land use activities, including the potential for run-off from adjacent lands.

From a purely hydrogeologic perspective, overburden removal increases the vulnerability of aquifers to contamination since it decreases the travel time between the point of release and the water table, allowing less time for attenuation processes (if any) to occur, and decreases the likelihood that a small quantity of a contaminant may be held in the soil above the water table rather than migrating down to the underlying aquifer. However, this perspective provides only a partial understanding of the potential for adverse groundwater quality impacts in that it:

focuses solely on contaminant attenuation processes that are assumed to occur above the water table while neglecting attenuation processes that occur below the water table; it neglects the broader context of the impacts of surrounding land uses on groundwater quality; and does not consider the implications on these surrounding land uses on the types of land uses to which aggregate sites are likely to be returned to following final rehabilitation. Understanding the interrelationship of these elements is essential to developing a better understanding the potential groundwater quality impacts resulting from aggregate extraction in Ontario.

2.3 Threats to Groundwater Quality During Aggregate Site Operation

During the life of an aggregate extraction operation, the potential impacts to groundwater quality are related to the use of heavy machinery for both aggregate excavation and processing and, the principal potential threat to groundwater quality is the release of petroleum hydrocarbons from equipment or on-site storage facilities (Blackport and Golder, 2006). Such a release, were it to occur, would be subject to a comprehensive regulatory framework (i.e., the *Ontario Environmental Protection Act*) that requires operators to implement management measures to address threats to groundwater quality of this nature, including the specification of stringent standards for site cleanup.

The extent to which aggregate operations have resulted in actual adverse impacts to groundwater quality appears limited. The potential impacts of typical aggregate operations on groundwater quality were evaluated in a multi-jurisdictional literature review commissioned by the Ontario Ministry of Natural Resources, which was unable to identify any instances of groundwater contamination resulting from aggregate extraction operations (Blackport and Golder, 2006).

Under the *Clean Water Act* (2006), Source Water Protection Committees are required to identify activities that may constitute threats to drinking water quality for all vulnerable areas within the Source Water Protection Committee's jurisdiction. Drinking water threats are identified in the Ministry of the Environment's *Tables of Drinking Water Threats (November 2009)*. These Tables set out circumstances that make an activity a significant, moderate or low drinking water threat, based on available data and/or professional judgment, within areas that are vulnerable to quality impacts (i.e., within a wellhead protection area).

Table 1 provides a comparison of the typical operating practices at aggregate sites to the potential water quality threats occurring during aggregate extraction operations and the circumstances under which these threats might be considered significant. Under this assessment framework and in the absence of any significant on-site fuel storage, it is unlikely that typical aggregate operations within a vulnerable area would be considered a significant threat to groundwater quality.

2.4 Threats to Groundwater Quality Following Aggregate Site Closure

Over the long-term it is the use of aggregate sites following final rehabilitation that is relevant to the concern that aggregate extraction may result in adverse impacts to groundwater quality. A summary of the land uses within a 1,000 metre buffer zone surrounding every existing aggregate site in Ontario is presented in Table 2. Within this buffer zone, the surrounding land uses are almost exclusively natural and agricultural, with less than 2% of the area occupied by settlement and other developed lands. Following final rehabilitation, the redevelopment of the site will be undertaken within the context of existing municipal and provincial land use planning policy, which identifies the preference for their return to land uses that are compatible with the surrounding land uses (Provincial Policy Statement, 2005), suggesting that redevelopment to natural and/or agricultural (i.e., rural) land uses are the most likely end uses for former aggregate sites. Natural land uses are not associated with any threats to groundwater quality, leaving agricultural uses as the only potential land use relevant to groundwater quality impacts.

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The relevant requirements for drinking water protection for the new land use will be set out under the associated Source Water Protection Plan developed in accordance with the requirements of the *Clean Water Act*. Depending on the location, these requirements may require certain practices or management programs, or, in some instances may even preclude some forms of rehabilitation and new land uses entirely. The Source Water Protection Plan will have already identified and accounted for all highly vulnerable areas in the watershed, and established any necessary land use controls. Under the *Clean Water Act* process, the vulnerability of former aggregate sites will be assessed and, along with other properties of similar vulnerability and proposed land use, the Source Water Protection Plan will identify appropriate risk management methods. Former aggregate sites will not be the only highly vulnerable locations since there are many naturally-occurring highly vulnerable areas already used for agricultural production.

Table 3 provides a description of the circumstances under which agricultural practices located in close proximity to groundwater supply wells (i.e., within the wellhead protection area) would be considered a significant groundwater quality threat under the *Clean Water Act*. In general, the identification of a particular agricultural operation as a groundwater quality threat depends greatly upon the type of operation, whether it uses animal wastes, biosolids or chemical fertilizers for crop nutrients, the surrounding agricultural land uses, the use of some specific pesticides, and on-site storage practices. Identification of a significant threat would depend upon the site-specific agricultural operation although it is clear that there are more potentially significant threats associated with livestock operations than with crop production.

It is important to note that a site's former interim use for aggregate extraction is not a relevant circumstance under the threat identification framework described in the *Clean Water Act*.

2.5 Rehabilitation of Aggregate Sites

Progressive rehabilitation is mandatory under the ARA with the site plans for licensed and permitted sites providing the primary mechanism defining rehabilitation requirements. The Aggregate Resources of Ontario Provincial Standards set out minimum rehabilitation standards. Where supported by site-specific studies, these standards are sometimes varied to achieve specific objectives, such as compatibility with surrounding land uses and enhancing biodiversity.

Most above water table pits are returned to agricultural land use or naturalized as open space. Pits and quarries that extend below the water table are usually rehabilitated as open space or recreational lands with ponds or small lakes created in the former excavations. Other post-extraction land uses, such as housing or commercial development, are possible but would require approval by the appropriate regional and/or local municipal governments. Open space or agricultural rehabilitation is therefore the default, as well as the most common, post-extraction land use.

According to the Provincial Policy Statement:

On these prime agricultural lands, complete agricultural rehabilitation is not required if:

- there is a substantial quantity of mineral aggregates below the water table warranting extraction; or
- the depth of planned extraction in a quarry makes restoration of pre-extraction agriculture capability unfeasible;
- other alternatives have been considered by the applicant and found unsuitable; and
- agricultural rehabilitation in remaining areas will be maximized.

Typical rehabilitation practice for the restoration to agricultural use involves grading the pit slopes, removing some or all of the perimeter berm around a pit, replacing topsoil stockpiled during the original pit development, reseeding, and fertilizing. Site rehabilitation is the responsibility of the licence or permit holder.

3.0 RURAL GROUNDWATER QUALITY: KEY CONTAMINANTS AND THEIR ATTENUATION MECHANISMS

In general, aggregate operations located in rural settings will eventually be returned to land uses compatible with those in the surrounding area. This includes wetlands, habitats for species at risk, conservation areas and parks, which are not associated with chemical use, but also agricultural land uses which may involve the use and storage of nutrients, chemicals and/or fuels. The routine land application of chemical fertilizers, animal wastes and pesticides is a wide-spread and ongoing practice that represents a significant potential for groundwater contamination in agricultural areas (OMAFRA, 2006). While the use and storage of other materials, such as fuel oil and vehicle fuels, are also associated with agricultural land uses, various investigations of rural groundwater quality in Ontario and other jurisdictions have consistently identified nitrate and pathogens as the only significant rural groundwater contaminants (for a summary of these studies see Goss et al., 1998).

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In a survey of groundwater quality in domestic supply wells at Ontario farms, 40% of the nearly 1,300 wells sampled exceeded the drinking water criteria for at least one of these contaminants (Goss et al., 1998). Concentrations of coliform bacteria and nitrate exceeded these regulatory criteria in 34% and 14% of wells, respectively. These contaminants were not closely associated with point sources of contaminants such as feedlots, exercise yards, milk-house waste disposal systems, manure stores and septic systems, with the exception of coliform bacteria, which decreased in concentration with increasing separation from feedlots or exercise yards (Goss et al., 1998). Of key importance, frequency of manure application is a critical agricultural practice contributing to the risk of well contamination (Conboy and Goss, 2000).

Although pesticides were frequently detected in groundwater samples collected from wells included in this survey, exceedences of regulatory limits were infrequent (6 of 1,175, or 0.5% of wells) and limited to the pesticides alachlor, metalochlor and atrazine, while contaminants commonly associated with releases of petroleum fuels (e.g., benzene, toluene, ethylbenzene and xylene isomers) were not detected in any wells (Goss et al., 1998). The demonstrated absence of significant impacts by pesticides and petroleum fuels likely results from the attenuation of these contaminants by natural degradation processes in groundwater.

These findings, which are consistent with prior surveys of water quality in Ontario, suggest that impacts to groundwater quality are primarily associated with nitrate and pathogens released from the widespread application of fertilizer and manure, and further, that natural processes appear to be effective in attenuating pesticide and petroleum contamination. It is important to better understand the potential sources of nitrate and pathogens and their environmental fate in the subsurface in order to develop an improved understanding of how specific agricultural practices influence groundwater quality. Like all groundwater contaminants, these contaminants can attenuate through processes such as dispersion, adsorption or filtration. However, these processes do not remove contaminant mass; instead, they essentially result in dilution, a highly site-specific phenomena which may or may not be sufficient to reduce contaminant concentrations below the applicable regulatory criteria. Processes that result in the degradation or transformation of the specific contaminant of interest are described in the following sections.

3.1 Nitrate

Sources of nitrate in rural groundwater can include septic systems, surface application of fertilizers, manure and municipal biosolids and plowdown legume crops (OMAFRA, 2006). Aggregate production is unlikely to contribute significant nitrate. These sources typically involve the release of a chemical fertilizer product based on ammonium nitrate or animal wastes containing organic nitrogen compounds that can be biodegraded to ammonium and then nitrate under aerobic conditions. Above the water table, where aerobic conditions are favoured since oxygen can be readily supplied from the atmosphere, aerobic biodegradation to nitrate is rapid. However once formed, nitrate is generally recalcitrant to further biodegradation although some denitrification occurs in saturated topsoil (Rheinbaben, 2007). Under anaerobic conditions (i.e., with oxygen absent), nitrate can further biodegrade resulting in its conversion to inert nitrogen gas, although this process is often limited by the absence of sufficient dissolved organic carbon (Keeney, 1986; Richards and Webster, 1999). Even under conditions of high organic carbon loading immediately above the water table, as may be expected with the land application of animal wastes as fertilizer, limited nitrate biodegradation is commonly observed in groundwater (Wilhelm et al., 1998). Accordingly, significant nitrate degradation is not expected to occur above the water table and the depth of overburden above the water table is not likely to have a significant impact on the potential for adverse impacts to groundwater quality by this contaminant.

3.2 Pesticides

Pesticides in rural groundwater are associated with releases from bulk storage or through application to crops (OMAFRA, 2006). Aggregate production is unlikely to involve releases of pesticides to groundwater. A wide range of agricultural pesticides are used in Ontario but those mostly frequently detected in rural groundwater include alachlor, atrazine, cyanazine, metribuzin and metolachlor (Goss et al., 1998). As previously discussed, these pesticides are infrequently detected at concentrations exceeding their respected regulatory criteria, suggesting that their presence in groundwater is limited by careful application practices and/or their susceptibility to various degradation processes. In soil, pesticides can be taken up by crops, retained within the root zone, adsorbed to soil or transformed into other compounds via both abiotic and biotic degradation process (Hancock et al., 2008). Typical degradation half-lives under aerobic conditions for pesticides commonly used in Ontario range from 15 to 146 days (PAN Pesticide Database, 2009), suggesting that rapid pesticides degradation in soil and groundwater is a likely explanation for the absence of these contamination in rural groundwater.

3.3 Pathogens

Groundwater contamination by pathogen microorganisms is associated with fecal waste released from septic systems, applied to land (including both animal wastes and municipal biosolids), and manure storage (OMAFRA, 2006). Pathogen contamination of drinking water wells at Ontario farms is well-correlated with the frequency of land application of manure to cropland and the proximity of supply wells to livestock feedlots and exercise yards (Goss et al., 1998; Conboy and Goss, 2000). The pathogen concentrations in different waste types and their transport and survival in the subsurface are not well-understood (Gerba and Smith, 2005) although there is an emerging body of scientific literature providing at least some insight into these processes. Given the complexity of characterizing the wide range of pathogenic organisms in animal wastes, including bacteria, viruses, and protozoa, and the challenging methods required to accurately identify and enumerate these microorganisms in a groundwater sample, studies of pathogenic contamination typically focus on the presence of simple indicator microorganisms that are widely associated with fecal wastes (e.g., fecal coliform bacteria). A substantial body of research exists regarding the removal of pathogens and other bio-colloidal particles that is relevant to groundwater below the water table. Filtration is a commonly-used process used for the treatment of municipal water supplies. Filtration routinely achieves four-log unit reductions (i.e., a concentration reduction by a factor of 10,000) of pathogen concentrations in porous media beds of only a few meters depth (LeChevallier and Au, 2004). The substantial interest in the removal of pathogens such as *Cryptosporidia* and *Giardia* has resulted in extensive research on their filtration (see Huck et al., 2001 for a review) and, not surprisingly, microbial transport in groundwater appears to be greatly limited by filtration (Harvey et al., 1989; Ryan et al. 1996; Pang et al., 1996). Much of the filtration literature is based in physico-chemical colloidal filtration theory, which describes the attachment of pathogen-sized particles to porous media, and is widely used to describe the removal of pathogens by porous media (e.g., Tobiason et al. 1988). Important filtration mechanisms include both physico-chemical filtration, resulting from surface charge interactions between the pathogen and the porous medium, and mechanical straining, where the spaces between soil grains can exclude a microorganism based on its size (Tufenkji et al., 2004). In groundwater, numerous laboratory and field studies have demonstrated that pathogens and other microorganisms are strongly attenuated by these filtration processes, with order-of-magnitude concentration reductions occurring over travel distances as short as 0.1 to 10 metres (e.g., Harvey et al., 1995; Harter et al., 2000; Tufenkji et al., 2004; Emelko et al., 2006). Filtration also occurs above the water table although in general, unsaturated filtration processes are not as well-understood. In one of the few studies of bacterial filtration in unsaturated sand, filtration increased in drier soils, an effect likely attributable to filtration occurring at air-water interfaces (Won et al., 2007; Garguilo et al., 2007). Theoretical predictions indicate that filtration is almost irreversible although the dynamics of fluctuating water tables and the subsequent dissolution of trapped air can result in pathogen remobilization (Sirivithayapakorn and Keller, 2003).

In addition to their removal from groundwater by filtration, pathogens also spontaneously deactivate over time at rates that vary in response to changes in water chemistry, temperature and/or predation by protozoan species commonly found in groundwater (Gordon and Toze, 2003; John and Rose, 2005). Reported linear inactivation rates for bacteria and viruses range from 0.02 to 0.1 $\log_{10}$ day^{-1} (order-of-magnitude concentration reductions per day, Keswick et al., 1982; John and Rose, 2005; Azadpour-Keeley and Ward, 2005) with higher inactivation rates for viruses expected to occur under aerobic conditions (Gordon and Toze, 2003). In general, there are extensive data on the inactivation of viruses and bacteria with relatively limited data on the inactivation of pathogens. One study reported an average inactivation rate for the pathogen *Cryptosporidia* of 0.044 $\log_{10}$ day^{-1} (Ives et al., 2007), which is comparable to the inactivation rates reported for viruses and bacteria. In comparison to groundwater travel times, these inactivation rates are relatively rapid. For example, an inactivation rate of 0.02 $\log_{10}$ day^{-1} corresponds to a 1,000-fold reduction in concentration (i.e., 99.9% removal) in 150 days while an inactivation rate of 0.044 $\log_{10}$ day^{-1} corresponds to 99.9% removal in 68 days. In comparison, source water protection measures for municipal drinking water supply wells typically focus on excluding sources of contaminants within a two-year travel

…the relatively rapid rate of spontaneous pathogen inactivation indicates that this is an important attenuation mechanism…

time, a time frame which will ensure adequate pathogen removal. Accordingly, the relatively rapid rate of spontaneous pathogen inactivation indicates that this is an important attenuation mechanism preventing adverse impacts to groundwater quality.

The substantive body of literature on the attenuation of microorganisms and pathogens in groundwater strongly indicates that their migration is greatly attenuated by filtration and rapid pathogen inactivation. Under these conditions, adverse groundwater quality impacts are likely to be limited to the area within short travel times of the point of contaminant release.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on this report the following conclusions may be made:

1) In the absence of any significant on-site fuel storage, it is unlikely that typical aggregate operations within a vulnerable area would be considered a significant threat to groundwater quality under the *Clean Water Act.*

2) Pits and quarries that become surface water bodies or wetlands following rehabilitation will not be associated with significant post-extraction development. Accordingly, the potential for these sites to adversely impact groundwater quality is limited and primarily associated with illegal waste disposal, the potential placement of contaminated fill during rehabilitation, and the impacts of contaminated storm water runoff from surrounding land uses.

3) Aggregate sites are predominantly located in rural settings. Following rehabilitation, these sites will usually be redeveloped for natural or agricultural land uses. Redevelopment projects involving land uses other than natural or agricultural are likely to require zoning approvals by the local municipal government.

4) In general, adverse groundwater quality impacts by nitrate and pathogens resulting from widespread agricultural production are common in rural Ontario. These contaminants are the most likely contaminants to be associated with rehabilitated aggregate sites.

5) Nitrate attenuation is not impacted by the depth of overburden material and is often relatively stable in groundwater. Bacteria and viruses spontaneously inactivate in groundwater and are unlikely to result in adverse impacts to groundwater quality except within and immediately down-gradient of releases of wastes containing these pathogens. The limited data describing protozoan inactivation indicates similar results.

6) Land uses for former aggregate sites will reflect the surrounding land uses and are likely to include land uses with potential adverse impacts to groundwater quality that are either similar to those impacts associated with the surrounding land uses (i.e., agriculture) or are unlikely to result in any groundwater impacts whatsoever (naturalized land uses).

Recommended best practices for final rehabilitation and redevelopment of former aggregate sites include:

1) Final rehabilitation practices for all types of aggregate sites should include storm water management measures around the perimeter of the excavated area that ensure that focused storm water recharge does not occur and, as a result, does not potentially contribute contaminants from adjacent land uses.

2) The potential for the inadvertent or illicit introduction of contaminants should be controlled. Access to former aggregate sites should be carefully designed to minimize the potential for illegal waste disposal. The importation of fill materials should be closely monitored to ensure that it meets applicable soil quality criteria.

3) At aggregate sites that are returned to agricultural production following final rehabilitation, applicable best management practices to reduce nitrate and pathogen impacts should be determined on the basis of the agricultural operations, rather than their former interim use for aggregate extraction.

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TABLES

Table 1: Drinking Water Threats and Circumstances Related to Aggregate Operations

Drinking Water Threat[2]	Typical Practices At Aggregate Sites	Circumstance 1[1]	Circumstance 2[1]
Storage and Handling of Fuel	Storage of small quantities of fuel (<2,500 L) in above-ground storage tanks, or refueling using mobile tankers to avoid storage	Below Grade Handling	>2,500 L
		Below Grade Storage	>250 L
		Partially Below Grade Storage	>250 L
		Above Grade Storage	>2,500 L
Sewage System or Works - Septic Systems[3]	Use of temporary sanitation facilities with aboveground waste storage (<10,000 L capacity)	System is an earth pit privy, privy vault, greywater system, cesspool, or a leaching bed system and its associated treatment unit	System falls under Ontario Water Resources Act (meaning >10,000 L capacity or serves multiple properties)
Sewage System or Works - Sewage Holding Tank[3]	Use of temporary sanitation facilities with self-contained waste storage that are not a sewage works within the meaning of the Ontario Water Resources Act	The system requires or uses a holding tank for the retention of hauled sewage at the site where it is produced before its collection by a hauled sewage system	The system is subject to the Ontario Building Code Act (1992) or is a sewage works within the meaning of the Ontario Water Resources Act

Notes

1 Where two circumstances are listed, both must be met to result in the threat being considered "significant"

2 For a threat to be significant, it must be occurring in a high vulnerability area (i.e., within 100 m of a supply well, or within the two year time of travel to a supply well)

3 For a pathogen-related score, Circumstance 2 is not applicable

Table 2: Adjacent Landuses (Hectares) by Type of Aggregate Operation

Licence/Permit Type	Number of Sites	Water	Marshes	Open Wetlands	Treed Wetlands	Tundra Heath	Deciduous Forest	Coniferous Forest	Mixed Forest	Sparse Forest	Early Successional Forest	Successional Forest	Mine Tailings, Quarries, Bedrock Outcrop, Mud Flats	Settlement and Developed Land	Agriculture	Unclassified Areas (within the province)	Unclassified Areas (outside the province)	Total Area
Class A Pit Above Water	960	9,329	282	417	4,370	0	47,956	16,100	61,342	36,265	6,932	1,864	10,244	14,480	277,166	37	119	486,905
Class B Pit Above Water	699	11,042	71	532	3,097	0	42,607	8,542	89,167	32,220	1,994	87	760	5,888	103,018	404	178	299,607
Pit Above Water (permit)	1,321	23,494	0	207	3,572	0	65,467	64,504	137,169	61,436	69,095	26,117	4,030	6,485	5,199	100	36	466,914
Class A Pit Below Water	313	2,908	6	133	2,037	0	9,165	2,575	11,498	6,833	406	347	2,703	2,373	135,682	541	0	177,205
Class B Pit Below Water	102	1,694	0	0	366	0	4,602	735	10,050	7,634	161	0	673	280	21,279	95	0	47,570
Pit Below Water (permit)	5	415	0	139	216	0	185	50	587	74	161	47	28	0	0	0	0	1,903
Class A Quarry Above Water	100	1,617	102	497	347	0	7,795	1,754	8,686	8,541	510	523	2,282	3,286	19,921	0	0	55,862
Class B Quarry Above Water	55	1,318	93	108	685	0	4,567	2,313	4,437	3,566	0	58	16	365	7,994	98	0	25,618
Quarry Above Water (permit)	68	1,999	0	0	2	0	3,641	2,350	12,651	8,234	2,084	118	1,405	522	532	0	28	33,567
Class A Quarry Below Water	92	2,778	85	60	1,575	0	9,292	1,592	3,522	1,581	267	0	3,283	1,172	43,146	0	0	68,353
Class B Quarry Below Water	8	282	0	0	0	0	655	54	986	794	0	0	0	0	764	0	0	3,535
Quarry Below Water (permit)	3	224	0	0	47	0	208	963	434	84	0	0	0	0	74	0	0	2,034
Aggregate Permit Extraction from Land Under Water	1	0	0	0	0	0	0	0	5	222	100	0	0	0	0	0	0	327
Forest Industry	18	52	0	0	298	0	744	2,278	1,595	598	339	177	0	0	0	0	0	6,081
Unknown	2,805	42,796	837	2,526	22,711	0	138,419	80,091	166,296	77,989	61,194	21,941	21,615	14,903	541,352	149	129	1,192,948
Total	**6,550**	**99,948**	**1,477**	**4,619**	**39,325**	**0**	**335,304**	**183,899**	**508,425**	**246,071**	**143,245**	**51,278**	**47,041**	**49,755**	**1,156,127**	**1,424**	**490**	**2,868,428**

Notes

[1] All landuse areas are given in hectares and represent a summary of the area of each land use type within an assumed 1,000 metre buffer zone surrounding all aggregate sites in each licence/permit catagory. The "unknown" catagory represents aggregrate sites for which the licence/permit catagory has yet to be updated in the ALPS data set.

[2] Data source: Ontario Ministry of Natural Resources, Aggregate Licensing and Permitting System, 2008.

Table 3: Drinking Water Threats and Circumstances Related to Agricultural Production

Drinking Water Threat[2]	Circumstance 1[1]	Circumstance 2[1]
Application of Agricultural Source Material to Land; Application of Commercial Fertilizer to Land; Application of Non-Agricultural Source Material (Biosolids) to Land	Occurs in an area with < 40% managed lands	Area has sufficient livestock density to generate >1.0 nutrient units per acre
	Occurs in an area with between 40 and 80% managed lands	Area has sufficient livestock density to generate >1.0 nutrient units per acre
	Occurs in an area with > 80% managed lands	Area has sufficient livestock density to generate >1.0 nutrient units per acre
	Occurs in an area with > 80% managed lands	Area has sufficient livestock density to generate < 0.5 nutrient units per acre
	Occurs in an area with > 80% managed lands	Area has sufficient livestock density to generate between 0.5 and 1.0 nutrient units per acre
	Contaminant of concern is a pathogen	n/a
Application of Pesticide to Land	Area of application is less than 1.0 hectares	Ingredients include MCPA or Mecoprop
	Area of application is at least 1.0 hectare and less than 10 hectares	Ingredients include Atrazine, Dicamba, 2,4-D, Dichloropropene-1,3, MCPA, MCPB, Mecoprop, Metalaxyl, or Pendimethalin
	Area of application is greater than 10 hectares	Ingredients include Atrazine, Dicamba, 2,4-D, Dichloropropene-1,3, Glyphosate, MCPA, MCPB, Mecoprop, Metalaxyl, Metolachlor or s-Metolachlor, or Pendimethalin
Application of Hauled Sewage to Land	Area of application is at least 1.0 hectare	n/a
	Contaminant of concern is a pathogen	n/a
The Use of Land as Livestock Grazing or Pasturing Land, an Outdoor Confinement Area or a Farm-Animal Yard	The number of animals on the land at any time is sufficient to generate nutrients at an annual rate that is at least 0.5 nutrient units per acre	n/a
	Contaminant of concern is a pathogen	n/a
Storage of Agricultural Source Material	Storage of Agricultural Source Material above grade	The weight of volume of material stored annually on the farm unit is sufficient to apply material at a rate of greater than 0.5 nutrient units per acre
	Storage of Agricultural Source Material below grade	The weight of volume of material stored annually on the farm unit is sufficient to apply material at a rate of greater than 0.5 nutrient units per acre
	Contaminant of concern is a pathogen	n/a
Storage of Commercial Fertilizer	Quantity stored is > 2,500 kg	n/a
Storage of Non-Agricultural Source material (biosolids)	Material is stored above grade	Quantity of material stored is at least 0.5 tonnes
	Material is stored below grade	Quantity of material stored is at least 0.5 tonnes
	Contaminant of concern is a pathogen	n/a
Management of Agricultural Source Material	Use of the land or water for aquaculture	Contaminant of concern is a pathogen

Notes

1 Where two circumstances are listed, both must be met to result in the threat being considered "significant"

2 For a threat to be significant, it must be occurring in a high vulnerability area

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