On-Site Wastewater Treatment Systems in Subdivisions

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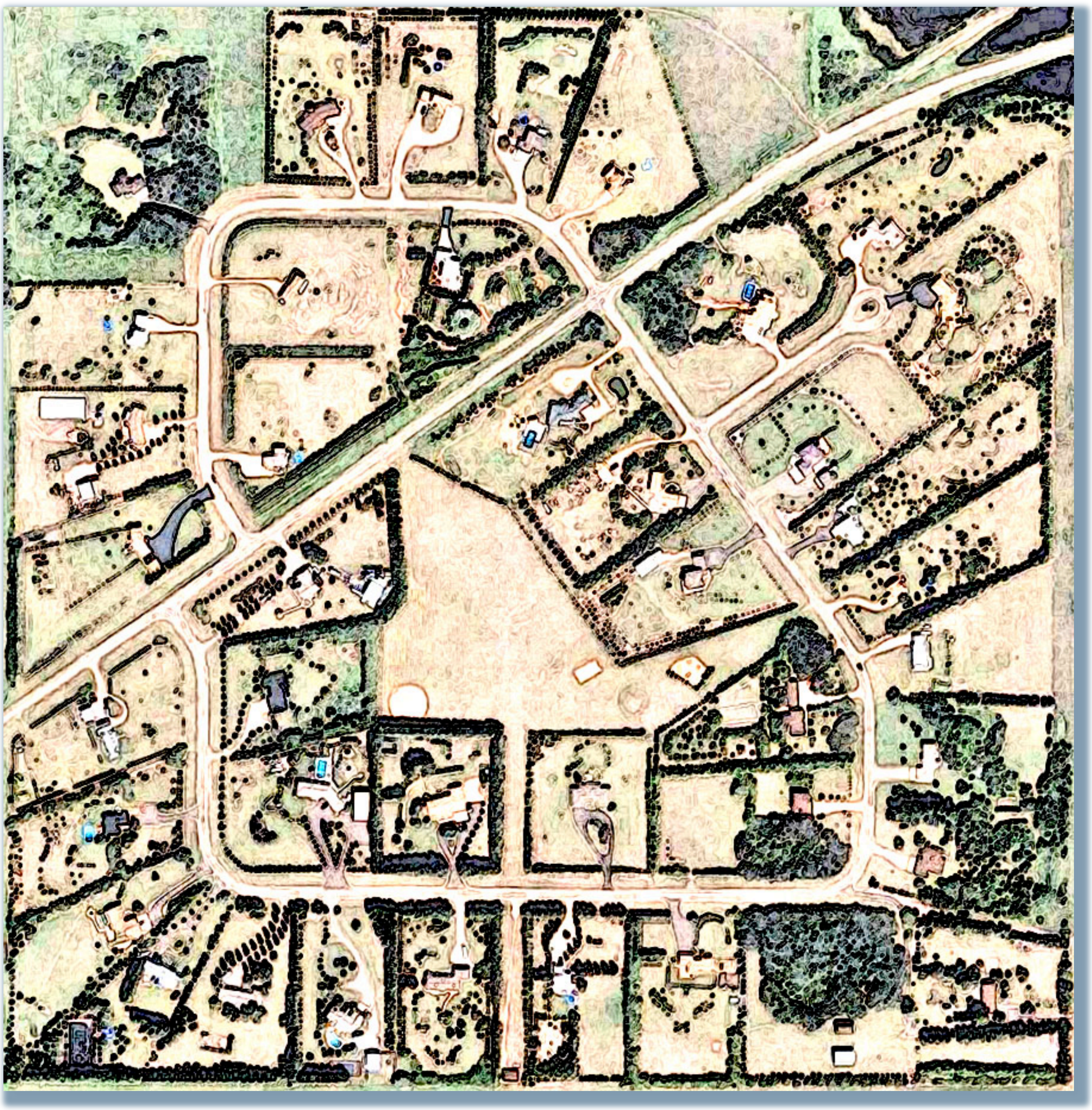

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1 Introduction

1.1 Overall Context

Sewage treatment, and its associated public sanitation benefits, is one of the most important functions contributing to societal sustainability. It affects not only the protection of public and environmental health, but also affects how much economic development is possible, as well as the overall quality of life within a community (Figure 1).

Wastewater treatment is needed everywhere there are people. In concentrated population centers such as urban areas, centralized wastewater treatment systems are economically practical. In rural areas, where population density is lower, other forms of wastewater treatment are needed. On-site wastewater treatment systems (OWTS) have been shown to be an effective and economically practical solution to rural wastewater management (USEPA 2002).

OWTS are smaller wastewater treatment systems, comprised of a number of components, that can provide effective sewage treatment directly at the site. They eliminate the need for capital- and maintenance-intensive sewage collection pipeline networks, and associated infrastructure. Common configurations of OWTS include the conventional septic tank and associated soil absorption field, but a wide range of technology options exist for OWTS, with the most advanced systems being able to produce a disinfected effluent that is fit to be used as drinking water (USEPA 2002).

As our awareness and experience with environmental management grows, it has become more apparent that when OWTS are not implemented and managed in an appropriate manner, degradation to the environment and health risks can occur.

We have been engaged to provide expert review and evaluation of Saskatchewan's *Interim Guidance Document for Developments and Subdivisions where Private Sewage Systems are Proposed*. This report provides that review, and discusses what are the potential concerns posed by on-site wastewater treatment, which of these concerns the current state of the art addresses, and what concerns remain.

1.2 Our Overall Approach

Our overall approach to this project is to frame the guidance development process within the overarching public health drivers of such guidance efforts. This is a systems-based approach to the task of developing policy that can serve this aspect of community growth throughout the province. In Figure 1 we show a general overview of the context of OWTS in the broader public health view. The highest system level is societal sustainability, which depends, in part, on community and individual wellness (2^{nd} system level). The exact definition of wellness will vary for individuals, communities and cultures. Regardless of the exact definition, however, a broad set of determinants is responsible for maintaining that state of wellbeing. Health Canada has developed a list of 12 determinants of health (www.phac-aspc.gc.ca/ph-sp/determinants/index-eng.php), which encompass various aspects of public health protection, environmental integrity and socio-economic drivers (attributes of the 2^{nd} system level).

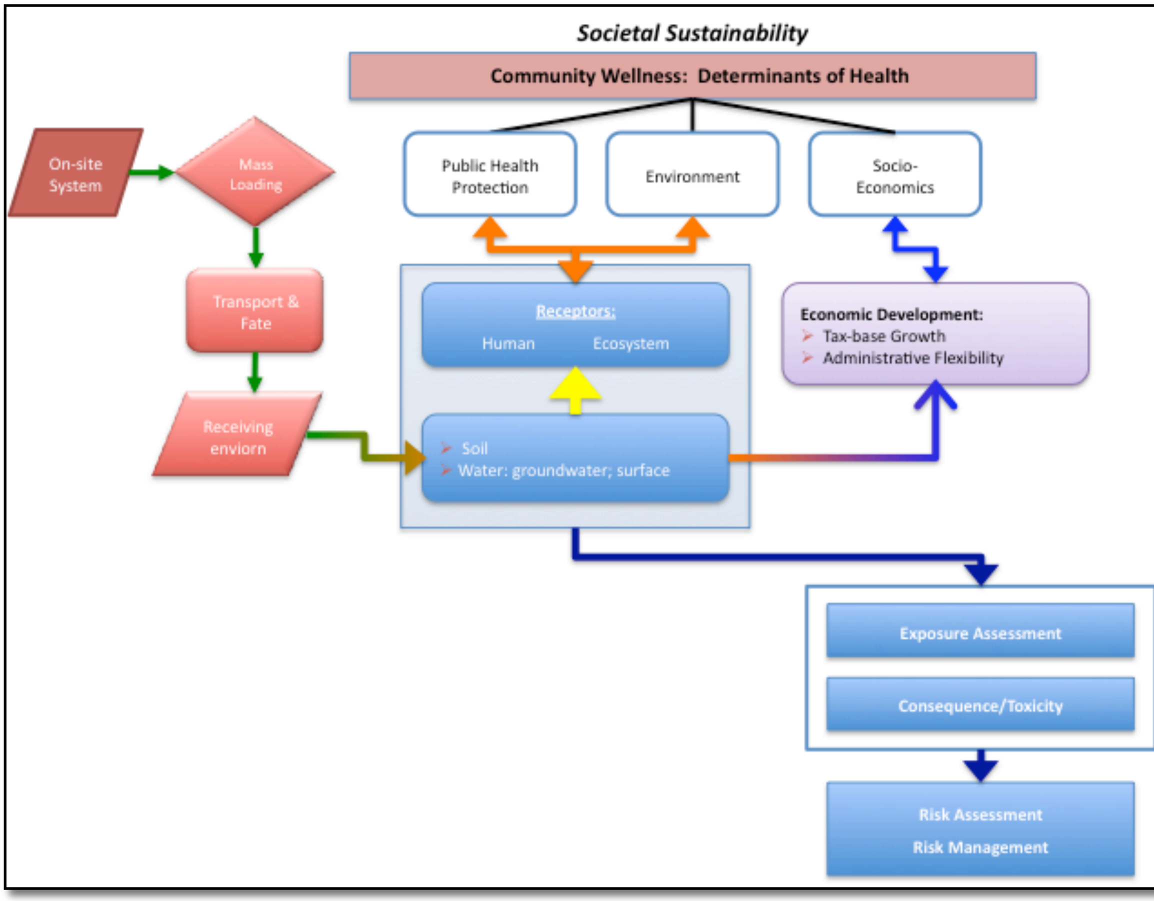

Figure 1. Public health context for OWTS.

People and communities rely on a balance of those determinants; ecosystems rely on parallel determinants of health. For the purposes of this project, people, their communities and ecosystems are viewed as a single system level (3rd level). Soil and water provide fundamental life-support to both people and ecosystems (4th system level). Finally, the particular nutrients or contaminants in soil and water can affect their capability to provide the appropriate balance of conditions required by people and ecosystems. OWTS effluents moving into soil and water can upset or otherwise influence this balance of conditions, for example by increasing the nitrate concentration in groundwater. If our questions about the risks of OWTS in subdivisions of various residential densities are about individual people and communities, we need to ensure that we develop an approach to these questions that acknowledges the different system levels and their ability to inform questions at the people and community level. Much of this can be accomplished by asking the question "Why does this matter?" at various points in the process. By asking this question and relating back to the context of OWTS in public health, we are more likely to achieve a review, assessment guideline and risk approach that meets policy objectives and facilitates further practical policy development at various governmental levels. This approach is consistent with the environmental health goals detailed in Public Health / Population Health Services in Saskatchewan (Saskatchewan Health 2001).

The policy objectives that must be considered when reviewing onsite treatment in subdivisions are:

1. Protective of public health and the environment;
2. Consistency with other jurisdictions;
3. Consistency with the precautionary principle as described in *A Canadian Perspective on the Precautionary Approach/Principle Proposed Guiding Principles* (Government of Canada, 2001);
4. Provide collaborating information to assist Health Regions in the review of sewage permit applications; and,
5. Specify outcomes rather than specific technical solutions.

The project has been divided into three major tasks, with significant overlap among them.

1. Task 1 is a review and assessment of the current primary literature and documents from other jurisdictions with respect to current approaches to OWTS and associated drinking water concerns in subdivision developments.
2. Task 2 incorporates a technical and professional experience-based review and critique of the Saskatchewan *Interim Guideline* document from Saskatchewan Ministry of Health, with specific goals of assuring scientifically defensible technical direction and sufficiently comprehensive guidance.
3. Task 3, along with components of Tasks 1 and 2, is an assessment of the residual risks to human health and ecological integrity that may arise from implementation of the *Interim Guidance*. Risk-based performance outcomes, rather than prescriptive specifications.

By structuring the study objectives in a way to provide a series of direct questions to answer, we can state the study objectives as follows:

- Do OWTS work?
    - If not, how severely and how often do they fail?
- Do these system failures affect drinking water quality?
    - Does this have an adverse affect on human health?
- What needs to be done to achieve the widespread occurrence of properly functioning OWTS?
- Is the Saskatchewan *Interim Guideline* technically adequate to achieve this?
- What are the technical limits of OWTS? Would a properly functioning OWTS be sufficiently protective of human and environmental health? What risks still remain? Are these risks acceptable?

1.3 References

Saskatchewan Health (2001). Public Health/Population Health Services in Saskatchewan. Regina, Saskatchewan Health.

USEPA (2002). Onsite Wastewater Treatment Systems Manual. Document # EPA/625/R-00/008. Published by the Office of Water, Office of Research and Development, US Environmental Protection Agency.

2 Literature Review and Options Development – Wastewater

One component of the scope described above is to review the technical literature on on-site wastewater treatment systems ("OWTS").

2.1 Assumptions

The following assumptions were used in this literature review, as a contextual framework:

- On-site wastewater treatment systems can take a variety of physical and technical configurations. These include not only conventional septic tanks followed by a soil absorption field, but also systems that include more advanced components such as aerobic bioreactors; sand filters; constructed wetlands; "package plants" such as small-scale Activated Sludge treatment systems; and a variety of other technologies. This literature review does not exclude any of these possible technologies or configurations.
- It was assumed that the OWTS under discussion are those systems that have been properly designed, installed and maintained in compliance with current regulations.[1]

2.2 Overview

OWTS have been used for an extended period of time in countries around the world, to provide treatment of wastewater for rural homes and other locations that are not serviced by some form of a centralized sewage treatment system. Public health administrators are typically mandated with protecting public, and often environmental, health. Therefore, a set of related questions becomes fundamental:

1. *Do on-site wastewater treatment systems work?* Yes.
   (**Crites and Tchobanoglous 1998**; Metcalf and Eddy 1991; USEPA 1997; USEPA 2002)
2. *Do on-site wastewater treatment systems* *<u>always</u>* *work?* No. *Why not?*
   (Beal *et al*. 2008; Charles *et al*. 2005; Collick *et al*. 2006; Hart *et al*. 2008; Oliphant *et al*. 2002; Pang *et al*. 2004; Reed *et al*. 2002; US EPA 2002)

A properly designed, installed and maintained OWTS can provide as much or better treatment of domestic wastewater as will a large city's centralized sewage treatment plant that is configured to provide primary and secondary treatment (Metcalf and Eddy 1991). However, as referenced above, the technical literature is replete with examples of where

[1] While we acknowledge that many OWTS may pose a risk to human and environmental health due to non-compliance with current regulations, that situation is a firstly a compliance issue. This literature review has a different focus, as it is intended to support an assessment of whether the *Interim Guideline* itself provides sufficient protection of human and environmental health, if complied with.

OWTS are not providing adequate treatment. Understanding the conditions under which OWTS do not work is one of the critical pieces of information necessary to be able to make effective and informed policy management decisions.

One of the most broadly effective ways of discerning what will and will not work is to start from first principles (i.e., the basic scientific and engineering principles that are well-established with a given discipline).

2.3 Approach

It is with this in mind that this literature review has been structured as follows:

1. Summarize what the major constituents of domestic wastewater are;
2. Summarize what are the main mechanisms for removing these constituents, thereby treating this wastewater;
3. Identify which of these removal mechanisms are currently practical to incorporate into an OWTS;
4. Discuss the role played by effluent polishing in an assimilative zone within the receiving environment;
5. Identify what constituents of domestic wastewater are unlikely to be removed by current OWTS, and therefore what are the main Contaminants of Potential Concern ("CoPC") that can be expected to be discharged from OWTS;
6. How does the expected mass-loading and risks of the CoPC from OWTS compare to the mass-loadings and risks posed by other land uses (e.g., agriculture).
7. Identify whether the observed performance gaps of OWTS correspond to removal mechanisms that are likely to be impractical to implement or likely to have a high implementation risk.

This last component is critical to answering the "*Why not?*" posed in Section 2.2 above. It allows us to separate the discussion into a form of failure analysis, where we can then determine why the OWTS was unable to provide adequate treatment consistently and reliably. Was it due to:

1. Inadequate or improper design?
2. Improper construction / installation?
3. Inadequate maintenance / improper operation?

Understanding the failure mode is essential to solving the issue. Modes (a) and (b) are easier to regulate than (c), and thus pose more manageable risks. For example, if it turns out that the failures are largely associated with improper operation and maintenance (c), then design modifications might be necessary to make the system more robust. Should that not be practical then other forms of risk management might be necessary (e.g., requirements that minimum operation and maintenance standards be observed, complete with a manageable compliance system).

It is important to keep in mind that this review does not exclude any particular OWTS technology, and in fact strongly recommends that the full spectrum of OWTS technologies, from basic through to advanced, be considered. As discussed further in Section 2.4.3, sites with challenging soils (e.g., very high or very low permeabilities) or other constraints likely need to use treatment technologies on the more advanced side of the technology spectrum. When system failures at sites with poor soils occur, the failure mode is often inadequate or improper design, which resulted in the installation of a technology choice that is unsuitable for the particular conditions at that site.

Note that for the purposes of this literature, individual OWTS technologies and products will not be examined. Rather, at this stage the above discussion will take place at a broader level, in order to lay a framework for evaluating the various approaches that are being used by other Canadian, US and international jurisdictions to reduce and minimize the cumulative impacts of OWTS on human and environmental health.

2.4 Discussion

2.4.1 Composition of domestic wastewater

Wastewater, or sewage, contains a variety of constituents, which are determined by the various sources of materials that contribute to it. Domestic wastewater, comprised of drain water from residential sinks and showers plus toilet flushing, is fairly well characterized for its major physical, chemical and biological constituents.

Table 1 presents the typical range of concentrations for wastewater produced by North American consumption patterns.

Table 1. Typical composition of domestic wastewater.

Constituent	Unit	Low	Typical	High
Total Suspended Solids (TSS)	mg/L	100	220	350
Biochemical Oxygen Demand (BOD_5)	mg/L	110	220	400
Total Coliforms	MPN [1]	10^6	10^8	10^9
Nitrogen (total, as N)	mg/L	20	40	85
Ammonia (NH_4^+–N)	mg/L	12	25	50
Nitrate (NO_3^- –N)	mg/L	0	0	0
Phosphorus (total, as P)	mg/L	4	8	15
Chlorides	mg/L	30	50	100
Metals	mg/L	Low	Low	Unknown
Synthetic Organic Compounds	µg/L	Low	Unknown	Unknown

Source: Metcalf and Eddy (1991);

[1] MPN = Most Probable Number per 100 mL

More recently, less obvious inorganic constituents (e.g., metals) and synthetic organic compounds such as pharmaceuticals, hormones, endocrine disrupting compounds, and an increasing variety of organic compounds from household cleaners and other personal use products are also becoming the focus of study and monitoring, as they become more of a concern from an environmental and human health management perspective (Conn *et al.* 2006).

Once wastewater composition is understood, it forms the basis for deciding how much treatment (i.e., removal) is needed for the various constituents.

2.4.2 Removal mechanisms and relevance to OWTS

The vast volumes of wastewater produced in large cities are treated in centralized treatment plants. There, scale and efficiency are obviously important. Designers of these systems have developed several important concepts to aid in the design, construction, operation and monitoring of these large systems.

Several of the concepts also have relevance to the OWTS sector. Among them are the concepts of “unit process” and “treatment train” (Metcalf and Eddy 1991).

A “unit process” (or “unit operation”) is a specific unit within the overall treatment system (e.g., settling basin; activated sludge reactor; or a membrane filter) that is known to behave in a specific way and achieve specific forms of treatment according to specific removal mechanisms. For example, a settling basin provides quiescent (calm) hydraulic conditions, thereby allowing settable material to sink out of the flow pathway and be removed from the wastewater. Each type of unit process is known to accomplish a specific task, and only that task. (e.g., The settling basin is only expected to remove settable solids, and it is known that all dissolved materials will pass through without any treatment at this stage of the treatment process).

Thus, a specific sequence of unit processes can be built to provide specific sequence of removal mechanisms. This sequence of unit processes is referred to as a “treatment train”. Mixing and substituting various unit processes along this sequence can form different treatment train designs, which will have different overall performance capabilities. The complete treatment train, along with any ancillary monitoring and control equipment, is the “treatment system”.

From this, it can be seen that a “treatment system” is not a single “black box” of unknown mechanisms, but rather is comprised of specific components that are meant to achieve specific outcomes. The overall performance of the treatment system is determined in large part by what unit processes are present. Incomplete treatment trains are only capabale of providing incomplete treatment. For example, if none of the unit processes in the treatment train are capable of removing nitrate, then the treatment system cannot be expected to remove nitrate.

The same concepts equally apply to the design and management of OWTS. The conventional septic tank plus tile field is actually a treatment train comprised of two unit processes (i.e., septic tank; tile field). A different OWTS, with different performance characteristics, can be built just be substituting unit processes (e.g., put in an aerated reactor, rather than an anaerobic septic tank) or by adding unit processes (e.g., adding a filtration unit).

For local policy administrators to be able to effectively assess the various development approval applications for on-site treatment and make informed decisions based on the technical reports provided to them, it is beneficial for them to have a firm grasp of these treatment fundamentals.

It is in this light that descriptions of the main removal mechanisms are summarized below in Table 2. Also listed are examples of unit processes applicable to OWTS.

Table 2. Summary of main removal mechanisms used in wastewater treatment.

Removal Mechanism	Conditions Needed	Constituents Removed	Unit Process Examples
Solids removal via **settling**	Calm flow conditions; a sludge accumulation chamber out of the flow pathway	Settable solids (grit; larger pieces of organic material, plus any pathogens and nutrients adsorbed / adhering to this particulate matter)	Septic tank (non-agitated / non-aerated); Imhoff cone Constructed wetland
Solids removal via basic **filtration** [a]	Slow flow through a porous media (effective nominal average pore size <150 μm)	Filterable solids (fine grit; smaller pieces of organic material; larger geochemical precipitates; larger pathogens such as helminthes [worms] and large protozoa)	Sand filter; Mature biomat (e.g., on boundaries of gravel soakage trenches and infiltration galleries); Commercial filtration units
Digestion of organic material	Correct microbial populations; Steady supply of organic material (i.e., microbial food source); Correct oxygen regime [b]	Organic materials (fats; proteins; carbohydrates; some predation of pathogenic organisms)	Septic tank or aerated equivalent; Suspended growth reactor [c]; Fixed film reactor [d]; Constructed wetland
Pathogen **die-off** & predation	Aerobic conditions	Sewage pathogens (which are anaerobic, and cannot survive for lengthy periods in aerobic conditions) [e]	Any aerated unit process; Mature biomat; Constructed wetland
Micro- and Ultra-filtration	Slow flow through a membrane or very fine porous media [f]	Bacteria; viruses; *Giardia* and *Cryptosporidium* cysts; colloidal materials	Membrane bioreactors (MBR); Occurs passively in fine-grained soils.
Phosphorus precipitation	Various specific redox conditions plus chemical additions	Phosphorus (as a variety of precipitates, specific to the process used)	Only specialized dedicated unit processes -- rare in OWTS; Also occurs passively in some soils
Nitrification	Aerobic conditions	Ammonia [NH_4^+] (is oxidized to nitrate)	Any aerobic unit process, including sand filters and soakage trenches
Denitrification	Anoxic conditions [g]; Sufficient carbon (food) source	Nitrate [NO_3^-] (is reduced to elemental nitrogen [N_2])	Only specialized dedicated unit processes -- very rare in OWTS. Also occurs passively in organic soils.

NOTES:

- a Only effective if majority of the larger solids have already been removed via settling.
- b Oxygen regime: aerobic microbialy-mediated degradation requires a constant supply of oxygen, usually supplied by an aerator; more passive systems (e.g., conventional septic tanks) rely on anaerobic digestion.
- c Suspended growth reactors include: activated sludge reactor; sequencing batch reactor (SBR); extended aeration units.
- d Fixed film reactors include: rotating biological contactor (RBC); submerged aerated filter; moving bed bioreactor.
- e Exceptions are cysts and other resistant dormant life stages, which are capable of surviving in aerobic conditions.
- f Microfiltration has pore sizes on order of 0.05 to 5.0 µm; ultrafiltration has pore sizes of on order of 0.005 to 1.0 µm.
- g Anoxic conditions are those where elemental oxygen (O_2) is absent, but molecular oxygen is present. Molecular oxygen is oxygen that is molecularly bound within a compound, such as nitrate (NO_3).

Sources: Beal *et al.* 2005; Crites and Tchobanoglous 1998; Etnier *et al.* 2005; Kadlec and Knight 1996; Metcalf and Eddy 1991; Munch 2005; Oakley 2006; Sawyer et al. 1994; Urynowicz *et al.* 2007; Van Cuyk *et al.* 2001

As can be seen from Table 2, various unit processes suitable for OWTS are capable of addressing most of the constituents of domestic wastewater. However, the correct unit processes need to be combined in the correct sequence for the OWTS to work properly.

Thus, part of the answer to the "*Why don't OWTS always work?*" question posed earlier in Section 2.2 is related to making sure that the treatment system design incorporates the correct components. Incomplete treatment trains are only capable of providing incomplete treatment.

2.4.3 Role of the assimilative zone within the receiving environment

Another part of the answer to the "*Why not?*" question lies in the concept of an assimilative zone within the receiving environment.

It is a well-recognized fact that the natural environment has, within limits, an ability to remove or treat introduced contamination through a variety of natural processes (Common 1995). This assimilative capacity is used frequently in the permitting and management of a wide variety of civic and industrial infrastructure and facilities, including road and highway systems (e.g., urban stormwater runoff), industrial wastewater treatment systems (pulp and paper, mining, etc.), and centralized sewage treatment systems (Dow *et al.* 2009; Walker *et al.* 2002).

Part of this discussion hinges on how the limits of the "treatment system" are defined, and hence where the treatment system ends and the receiving environment begins. For the purposes of this discussion, a "treatment system" is considered to be comprised of engineered components, while the "receiving environment" is the adjacent environment (US EPA 2002).

Using this convention, a conventional septic tank plus soil absorption field (including the gravel-filled trenches) would be the "treatment system", because all of these components have been engineered and specific materials selected for use in their construction (e.g., tank specifications; excavation specifications for the trenches; gravel and pipe specifications in the trenches). In contrast, the unsaturated soil (vadose zone) beneath the trenches is not engineered, nor is it put in place during construction. Rather, the treatment system is placed adjacent to (on top of) the natural soils that happen to exist at the site. We have no control over is characteristics (and therefore can only control the decisions regarding what and how much wastewater to load it with). Thus, the soil beneath the trenches is considered to be part of the "receiving environment".

However, most OWTS (especially the conventional septic tank + field configuration) are reliant on the unsaturated soil (vadose) zone beneath the trenches to achieve the final reduction of concentrations for certain parameters. EDAW (2008, pg 2-1) stated "The depth and type of unsaturated soil below the (soil absorption area) system are the most important factors in the…process".

Thus, this initial zone of unsaturated soil should be considered an important assimilative zone within which to reach compliance concentrations (typically via sufficient retention time within specific natural attenuation processes). It performs a critical attenuation function and it is incorrect to view the soil absorption field as merely a component to disperse the effluent (Beal 2005; Van Cuyk et al. 2004).

Matching the system design to the site conditions is critical. Therefore *"appropriately design for the soils"* should be one of the major themes in any OWTS regulation / guidance document that intends to adequately protect human and environmental health.

This is especially important when you consider that once an aquifer is contaminated, it is extremely difficult to "clean up" (decontaminate). Therefore, the Agencies mandated with protection of groundwater need to take the necessary steps to prevent contamination that results in unacceptable risks to humans or the environment. One of the effective ways of achieving this is to encourage and support the use of more advanced treatment technologies. The advancements that have been made over the last few decades in this field should be allowed to gain wider acceptance and adoption.[2]

A second part of the answer to the "*Why don't OWTS always work?*" question lies in the fact that certain equipment configurations are not appropriate for use in certain conditions. This "right tool for the job" concept is well understood and accepted for many other situations (e.g., construction, transportation and vehicle use, outdoor recreation, agriculture, etc). It applies just as much to OWTS. For example, use of an OWTS over very permeable soils (coarse sands and gravels) should not necessarily be rejected outright. Rather, the correct OWTS equipment needs to be specified (i.e., <u>not</u> a conventional septic tank and tile field), given that these soils would have a very low assimilative capacity and the effluent plume would have a very short hydraulic retention time before entering the groundwater - the concept of on-site treatment is still possible and appropriate for a site like this, as long as the <u>correct</u> unit processes are in place to provide a high degree of treatment within the treatment system proper and little/no attenuation from the assimilative zone is expected.

This also relates back to the issue of setting prescriptive construction codes for how much soil needs to be present underneath an OWTS. What depth of soil is sufficiently protective? Two feet; three feet; five feet? Unfortunately, that answer not only depends of the soil present within the assimilative zone at any given site, but also on what OWTS treatment train is to be built above it (MAF 1998). Equipment that delivers higher performance results can reply on shallower and/or less assimilative soil vadose zones.[3] There are several possible responses to this issue, including:

- Prescribe a minimum depth of unsaturated soil that is protective under reasonably worst case conditions, such as lower-performing technology (e.g., septic tank plus tile field) discharging into highly permeable soils, and apply this standard to all situations. While administratively simple, this approach sets in place a strong disincentive to implement newer and better performing technology, since no benefits (e.g., reduced assimilative zone requirements) are realized by those property owners who choose to use more advanced technologies. Over the long-term, this type of disincentive can result in a jurisdiction becoming technologically stagnant and suffering from an over-abundance of entrenched, obsolete systems.
- Gather a body of knowledge that identifies (a) the assimilative capacity of different soils for specific parameters (pathogens, phosphorus, etc), and (b) the effluent quality expected from the various OWTS treatment configurations. By cross-referencing (a) and (b), it would be possible to predict how much of an assimilative

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[2] See end of this section for further discussion about advanced treatment systems.

[3] EDAW stated "In areas with poor soils, the widespread (and eventually exclusive) use of (advanced) treatment components would lead to water quality improvements for all types of contaminants because poor soil conditions are not helpful with treating effluent. The water quality benefits resulting from this alternative would also help reduce a number of public health risks associated with pathogens, nitrogen, endocrine disruptors, heavy metals, and other contaminants found in OWTS effluent." (EDAW 2008, pg 6-35)

zone (i.e., soil depth) is needed for any given combination of site conditions (e.g., soil types) and technology choices. This approach, while more involved, provides an incentive for the property owner to pursue better performing technologies in order to achieve development of more challenging sites and/or development plans.

- Use monitoring programs and a centralized information management system to assess the actual performance of existing treatment systems and their assimilative zones, and use this information to establish the empirical knowledge base needed to make informed decisions on the suitability of proposed installations.

These latter two approaches represent more up-front work and design considerations. However, they do result in increased protection of human and environmental health.

Furthermore, as mentioned above, one of the more effective ways of achieving this is to encourage and support the use of more advanced treatment technologies. The advancements that have been made over the last few decades in this field should be allowed to gain wider acceptance and adoption.

Advanced treatment systems are sometimes subjected to much more intense monitoring requirements then conventional systems, despite the fact that their design intent almost always is to provide better treatment than conventional systems. (The rationale for this is that there is less experience with the newer advanced systems, and therefore more uncertainty concerning their performance. However, little consideration seems to be given to the benefits that monitoring and/or inspections would provide with regards to identifying those conventional systems that are poorly operated and maintained, and therefore pose a risk to humans and the environment.) We recommend performance monitoring of all types of systems (conventional and advanced), especially where the consequences of performance failures would be significant.

Saskatchewan already employs the concept of "responsible management entities" (i.e., different levels of management entities for increasing size or complexity of OWTS). Other jurisdictions employ a similar mechanisms under a "qualified service provider" concept. Assigning the monitoring, interpretation and response requirements to these entities can keep the resourcing requirements to within sustainable levels.

It should also be noted that the Saskatchewan Health Regions require that "package plants" (i.e., electromechanical systems such as household-scale activated sludge plants, sequencing batch reactors, rotating biological contactors, or membrane bioreactors that are sold as a pre-configured system) be third-party certified that they conform to NSF 40 standards.

2.4.4 Contaminants of Potential Concern from OWTS

Given the removal mechanisms presented in Section 2.4.2 and the importance of assimilative zones discussed in Section 2.4.3, Contaminants of Potential Concern ("CoPC") can now be identified.

In very general terms, a CoPC is any contaminant that discharges from the treatment system. Subsequent evaluation of each CoPC through a risk assessment can determine which of them pose an actual risk to receptors and are thus actual Contaminants of Concern ("CoC").

As can be seen in Table 2, which contaminants discharge from an OWTS is somewhat dependant on the unit processes employed in the treatment system. That notwithstanding, these are the wastewater constituents most likely to be CoPC:

1. *Pathogens:* While most OWTS configurations will remove most of the pathogens, common configurations will still result in pathogens being released to the soil assimilative zone beneath the OWTS. Thus, the treatment system itself (especially a conventional system) is typically not able to achieve full removal of pathogens and it relies on the proper assimilative zone being present (GWMAP 2000; Pang *et al.* 2004; Van Cuyk *et al.* 2004).
   - While many sites will have the necessary soil conditions in the vadose zone to remove the rest of the pathogens (see Appendix III), other sites will not. There are numerous documented cases where the subsurface conditions were such that pathogens entered the groundwater aquifer and posed a risk to human health (Booth *et al.* 2003; Oliphant *et al.* 2002). The greater the hydraulic retention time within the vadose zone below the soil absorption field, the more protected the underlying groundwater is likely to be. Of all the CoPC, pathogens pose the most severe acute effects to human health.
2. *Phosphorus:* Very few OWTS unit processes effectively remove phosphorus directly, and so whatever isn't removed via solids removal will typically exit the treatment system. Therefore, phosphorus is a CoPC from OWTS.
   - However, many soils are able to retain phosphorus very effectively, and so usually within less than 50 lateral feet the assimilative zone will effectively reduce phosphorus concentrations to below levels of environmental concern (Etnier et al. 2005; GWMAP 2000). Exceptions are where assimilative zone conditions are not appropriate for binding of phosphorus to the soil column (e.g., coarse sands, swelling clays) or where there is a fairly direct connection to a surface water receiving environment (i.e., insufficient retention time within the soil column).
3. *Ammonia:* Several OWTS unit processes provide sufficient exposure to aerobic conditions to allow nitrification (i.e., the conversion of ammonia to nitrate). However, the retention times within some of these aerobic unit processes (e.g., gravel distribution trench) is likely too short to achieve full nitrification prior to entering the soil vadose zone. Therefore, ammonia is a CoPC from OWTS.
   - The aerobic conditions with the soil vadose zone are typically sufficient to allow nitrification to be completed. Therefore, typically ammonia has been fully converted to nitrate before leaving this assimilative zone (Oakley 2006).
4. *Nitrate:* Removal of nitrate via denitrification is very rare in OWTS. A few unit processes are available which provide some level of reliable denitrification, but they are not commonly employed (Oakley 2006). The majority of "typical" OWTS designs have either ignored denitrification or have assumed that the nitrate will be removed in the underlying assimilative vadose zone. Therefore, nitrate is a CoPC from OWTS.
   - Very little denitrification occurs in vadose zone, due to the absence of the necessary conditions (e.g., anoxic; availability of carbon source) (Oakley 2006). Some consumption (uptake) of nitrate will occur within the root zone of plants, but discharges from OWTS typically occur deeper in the soil profile than the root zone. Also, mass loadings per discharge area of nitrate from a typical OWTS typically meet or exceed the maximum uptake rate of the grasses and forbs present (Oakley 2006).

- *Total Suspended Solids (TSS):* Strictly speaking, TSS includes all solid (i.e., undissolved) materials in the wastewater retained by a 1.2 μm filter (Metcalf & Eddy 1991). As such, it is an aggregation of a wide range of materials (e.g., inorganic grit; organic solids; microbial biomass). This is in contrast to phosphorus, ammonia and other clearly identifiable chemical species. All of those OWTS unit processes that achieve effective settling and/or filtration will remove TSS (see Table 2). Effluent TSS concentrations in OWTS effluent are typically on the order of <15 mg/L for basic treatment technologies, and even lower for more advanced systems (USEPA 2002). Therefore, TSS is typically not a CoPC from a properly functioning OWTS.

5. *Biochemical Oxygen Demand (BOD)*: BOD is the measure of how much oxygen a wastewater or effluent will use over a given period of time. Mechanistically, it is caused by the degradation of organic compounds, including organic solids. All OWTS unit processes that involve either the removal (i.e., settling, filtration) or digestion (aerobic or anaerobic) of organic solids will cause a reduction in effluent BOD. Effluent BOD concentrations in OWTS effluent are typically on the order of <1 mg/L for basic treatment technologies. (USEPA 2002). Therefore, BOD is typically not a CoPC from a properly functioning OWTS.

6. *Metals*: Metals such as cadmium, copper, lead, mercury and zinc can cause human and environmental health problems if present in drinking and surface waters in high enough concentrations. However, as discussed in the California OWTS *Environmental Impact Report*, the research conducted to date indicates that metals are typically discharged at low enough concentrations to not be a CoPC from a properly functioning OWTS.

> "Studies have found the presence of some metals in septic tank effluent (Otis et al. 1978, DeWalle et al. 1985). Metals can be present in the domestic waste stream because many commonly used household products contain metals. Aging interior plumbing systems may contribute lead, cadmium, and copper (Canter and Knox 1986). Other sources include vegetable matter and human excreta." (EDAW 2008, pg 2-24)
>
> Several metals "have been found in domestic septic tank effluent…at low concentrations. Copper and zinc were the only trace metals found in any significant amounts, and those concentrations were less than in tap water (Whelan and Titmanis 1982). Reviews and studies to date, although not extensive, suggest there is very little concern over heavy metals in domestic septic tank effluent (Siegrist, Tyler, and Jenssen 2001). The fate of metals in soil is varied and depends on complex physical, chemical, and biochemical interactions.[4] Although studies appear to indicate possible removal of metals in both septic tanks and soils, some risk remains and groundwater contamination in specific cases is possible (EPA 2002)." (EDAW 2008, pg F-3)
>
> "Removal of sources of metals from the wastewater stream by altering user habits and implementing alternative disposal practices is recommended.[5] In

[4] "Dissolved metals typically form cations, positively charged ions (e.g., Fe2+, Zn+2)….The primary processes controlling the fixation or mobility potential of metals in subsurface infiltration systems are adsorption onto negatively charged soil particles and interaction with organic molecules. The solubility of metals is pH dependent, and tends to be lowest between pH 6 and 8." (EDAW 2008, pg F-3)

[5] Several advanced treatment systems, including constructed wetlands, are able to remove elevated concentrations of metals quite effectively (Kadlec and Knight 1996; Leverenz et al, 2002).

addition, the literature suggests that improving treatment processes by increasing septic tank detention times, ensuring greater unsaturated soil depths, and improving dose and rest cycles may decrease risks associated with metal loadings from on-site systems (Chang and Page 1985, Evanko and Dzombak 1997, Lim et al. 2001)." (EDAW 2008, pg 2-24)

7. *Synthetic Organic Compounds*: These include a broad range of chemicals that are found in wide variety of household and personal care products, including detergents and cleaners; solvents; pesticides; antibiotics; pharmaceuticals; and endocrine-disrupting compounds. As discussed in Appendix II, there currently is insufficient scientific information available to determine whether synthetic organic compounds (including surfactants[6]) exist at high enough concentrations within OWTS effluent to pose a concern, or indeed even what concentrations would represent a concern. Therefore, as new information becomes available over the forthcoming years, this information should be evaluated to determine which synthetic organic compounds might end up being considered a CoPC with respect to a properly functioning OWTS.
8. *Chlorides*: Dissolved chlorides, and dissolved ions of similar salts, are not removed by the majority of OWTS unit processes, and therefore exit via the effluent stream.
   - However, the chloride concentrations encountered in OWTS effluent are typically not high enough to pose a concern[7]. Therefore, chlorides are typically not a CoPC from a properly functioning OWTS.

Strictly speaking the first four of these contaminants (i.e., pathogens, phosphorus; ammonia; and nitrate) could be considered CoPC, along within possibly metals and synthetic organic compounds under certain site-specific conditions. However, it can be seen from the details presented above that the two which are most likely to pose a threat downstream of the assimilative zone are *pathogens* (under certain conditions) and *nitrate* (under most conditions)[8].

Without the necessary conditions for denitrification, nitrate is fairly persistent ("conservative") in groundwater aquifers (GWMAP 2000; McCallum *et al.* 2008; Oakley 2006). Thus, of the contaminants discussed above, it is the most suitable to use an effluent indicator or tracer. However, other conservative constituents of the effluent, such as chloride, make better tracers (more reliable; easier field detection) (Vandenberg *et al.* 2005).

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[6] Several studies (Conn et al. 2006; Huntsman et al. 2006; McAvoy et al. 2002; Nielsen et al. 2002) conducted specifically on detergent-sourced surfactants have indicated that OWTS treatment efficiencies for these compounds range from <1% to >99.9%, depending on the compound and the treatment system. When treatment does occur, the absorption trenches are the unit process that can account for the majority of the treatment. Significant treatment can also occur in the vadose zone. There is also some evidence that surfactants will continue to degrade once in the groundwater. A lot more research needs to be conducted before the factors affecting treatment are fully understood.

[7] Activities that increase salt loading to the wastewater stream (e.g., water softener regeneration discharge; or large quantities of higher-strength reverse osmosis brine) should be avoided or minimized, as excessive salt concentrations can harm the biological processes that need to occur within the OWTS and/or adversely modify the downstream soils.

[8] It should be noted that many large centralized wastewater treatment plants also release nitrate into the receiving environment. Only those treatment plants that incorporate "advanced treatment" processes will be able to remove nitrate (Metcalf and Eddy 1991).

2.4.5 Performance limitations of OWTS

2.4.5.1 Overall

When installed and maintained according to current, broadly accepted practices, OWTS are capable of removing TSS and BOD to acceptable levels. When installed over an adequate soil vadose zone, they are also capable of removing phosphorus and pathogens to acceptable levels.

However, as has been pointed out in the above sections, their design and installation needs to be tailored to the site-specific conditions. All OWTS (except the most advanced technology options) depend on the underlying soil for final attenuation or polishing. Therefore, the pivotal consideration is to "*Design for the Soil*". The importance of this cannot be overstated.

In order to accomplish this, a careful site-specific (i.e., fieldwork-based) assessment needs to be done for every system that is installed (CSWRCB 2008; Yates 1985). Without this, the site-specific soil conditions cannot be appropriately accommodated in the design, resulting in uncertainty about how the resulting OWTS will perform at that location.

In addition to proper site-appropriate design, maintenance & monitoring are also key issues. Traditionally, OWTS (especially conventional septic systems) have been assumed by many homeowners to be "maintenance free", and hence "monitoring free". However, it needs to be recognized by the broader user audience that, irrespective of their small size, *OWTS are wastewater treatment plants*. Large centralized wastewater treatment plants are required to monitor treatment performance, and then make the necessary operating adjustments. Doing the same for OWTS (at a scale and frequency appropriate for the technology) would help reduce the occurrence of unacceptable treatment performance. There is truth to the maxim that "what you don't measure, you can't manage".

Similar to their larger centralized cousins, OWTS do not have simple, single parameter that can be used as an indicator of overall treatment performance -- the various wastewater constituents all behave too differently. However, in most cases a limited number of parameters of concern can be identified, preferably based on the site conditions and the design knowledge of the technology installed. This much-reduced parameter list can then be monitored more cost-effectively. For example, if nitrate is shown to be the only likely effluent parameter of concern at a site, based on the OWTS technology used and these site's soil conditions, then a simple monitoring program that focuses mostly on nitrate could be a sufficiently effective management tool.

2.4.5.2 Nitrate

Nitrate is the most likely parameter of concern for all OWTS (expect those more advanced systems that specifically target nitrate). Effluent concentrations in the range of <10 mg/L to 40 mg/L[9] can be expected from conventional OWTS.

It is difficult to improve this treatment performance for most the of OWTS configurations currently available. (A few unit processes are capable of effectively removing nitrate, but they are rarely implemented, for cost and/or unfamiliarity reasons.) Therefore, discharges of nitrate in OWTS effluent at this range of concentrations can be expected to continue until more advancements are made in OWTS technologies.

[9] Section 5 discusses what risk these concentrations may pose.

To put these OWTS nitrate discharges in context, the following list compares a sampling of nitrate groundwater concentrations (measured as NO_3-N) from other sources:

Agricultural manure-spreading	**5 to 87 mg/L**	McCallum et al. 2008; Harter et al. 2002
Agricultural animal feed operations	**<1 to 66 mg/L**	Harter et al. 2002
Agricultural manure lagoons	**<1 to >150 mg/L**	Harter et al. 2002
Agricultural crop fertilizers	**<10 to 51 mg/L**	Derby et al. 2009
Urban lawn fertilizers	**0.3 to 5 mg/L**	Guillard and Kopp 2004
Golf course fertilizers (soil- or sand-based)	**<5 to 200 mg/L**	Wong et al. 1998; Snyder and Cisar 2000
Community sewage lagoons	***unknown***	no literature found
Septage (sewage sludge) applied to crops	**up to 40 mg/L**	Harter et al. 2002

*Note that these are nitrate concentrations that end up in the groundwater, *after* having experienced nitrate removal via percolation through root zones and organic soils.

From an areal basis, and therefore a *mass-loading* perspective, most of the above-listed sources, with the possible exceptions of lawn and golf course fertilizers, are likely to be greater nitrate contributors than OWTS when viewed on a regional scale.

2.4.5.3 Pathogens

Pathogens can be a parameter of concern for those OWTS where there has been an incorrect pairing of OWTS technology and soil conditions (i.e., the technology chosen was not a suitable design for the soil conditions at the site.) "The soil is the final and most important treatment component for pathogen removal in a conventional OWTS." (EDAW 2008, pg 2-3)

For existing systems, correcting this problem involves upgrading the existing treatment system so that it will achieve an effluent quality suitable for the site's soils. Preventing this problem at new installations is achieved by *designing for the soils* that are present at the site. By consistently following the recommendation to "*Appropriately Design for the Soil*" (i.e., with regards to vadose zone retention times), OWTS can consistently provide effective protection against pathogens (see Appendix III).[10]

Other sources of pathogens include runoff and leachates from manure spreading, feedlots, barns and other areas where concentrations of animal manure are found. By breaking the pathway between this hazard and the receptor (i.e., humans), the risk can be avoided. Thus, it is necessary to make sure that installation of shallow drinking water wells are

[10] The primary consideration in managing OWTS is the protection of human health. Other objectives are secondary to that. "It is crucial that sanitation systems have high levels of **hygienic standards** to prevent the spread of disease. Other treatment goals include the recovery of **nutrient** and water resources for **reuse** in agricultural production and to reduce the overall user-demand for water resources" (Volkman 2003).

discouraged, or if present, then at least constructed properly (cased, sealed, capped, etc). In practice, this is often difficult to achieve, due to a variety of reasons.

2.4.5.4 Other Parameters

TSS and BOD: Sufficient experience with OWTS has been accumulated over the decades that OWTS treatment performance for these parameters is now consistently reliable. All of the well-established OWTS technologies and all of the more advanced treatment technologies achieve adequate (or better) treatment of TSS and BOD.

Phosporus: When the OWTS is appropriately designed for the soil conditions at a given site, the combination of the OWTS plus the attenuation in the vadose zone soils will achieve adequate phosphorus removal.

Synthetic organic compounds: Not enough is known yet about the behaviours and effects of many of these compounds, and as such it is too early to make any informative statements.

2.4.6 Setback Considerations

Minimum setback distances from the effluent discharge point of an OWTS are typically specified for drinking water wells and other points of concern (e.g., surface water bodies). However, it is important to understand what protection these setback distances are actually able to provide.

As discussed above, OWTS discharge into a soil absorption field creates two very distinct types of flow patterns.

- Drainage into the vadose zone will create a vertical discharge (Figure 2), where the effluent moves downward through the unsaturated soil under the influence of gravity. Thus, the movement through the vadose zone will be primarily restricted to the area underneath the soil absorption field.
- Once this drainage reaches the aquifer, its movement will be directed horizontally, due to the lateral force applied by the aquifer's hydraulic gradient. Thus, a plume will begin to form (Robertson et al. 1991; USEPA 2002) (Figure 2). Unlike rivers, where the turbulent flow produces mixing, flow within a groundwater aquifer is typically laminar (i.e., parallel flow lines), and this lack of turbulence results in very little opportunity for mixing between the plume and the surrounding bulk water. Thus, the plume remains narrow and extends lengthwise, as governed by the aquifer's hydraulic gradient. The result is a long, narrow plume that extends parallel to this hydraulic gradient (USEPA 2002). [Note: some dilution models used in the past to estimate nitrate attenuation assumed higher mixing or dispersion rates, but are now considered unrealistic (USEPA 2002).]

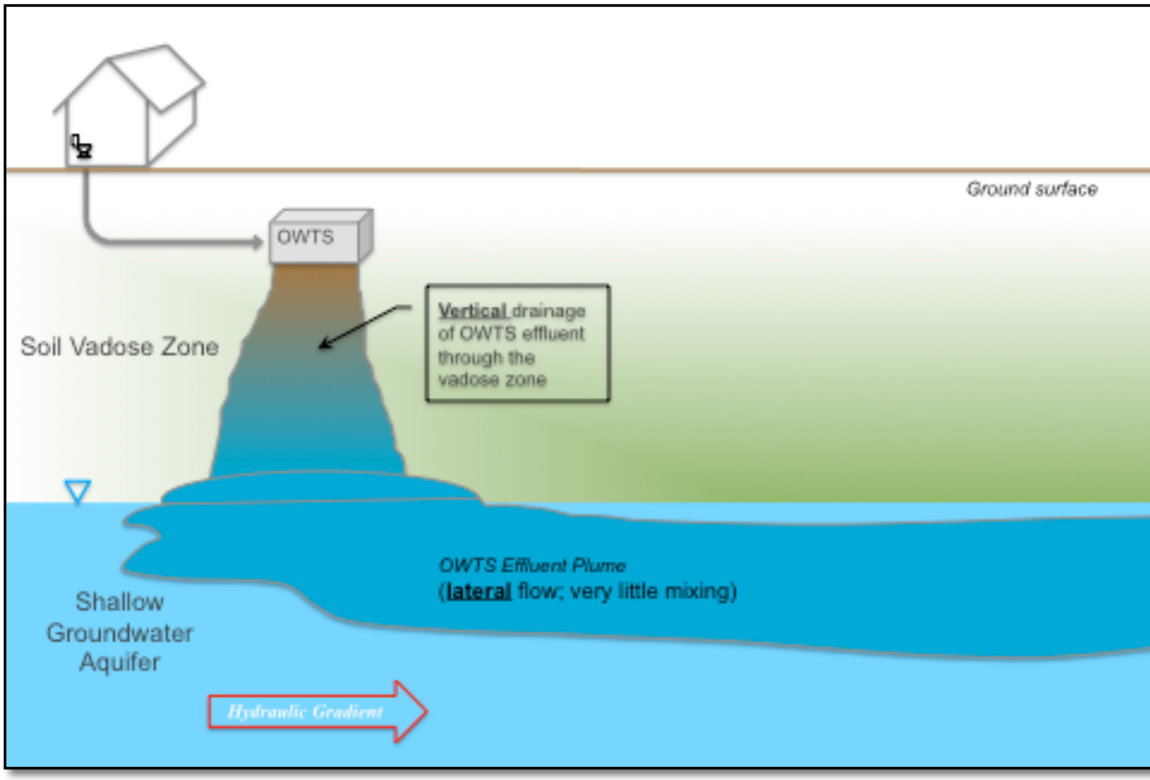

Figure 2. OWTS discharge patterns in vadose zone vs aquifer.

For nitrogen and pathogens, our two primary Contaminants of Potential Concern, it has been demonstrated that very little attenuation of these contaminants occurs once they reach the groundwater[11].

Given the lack of in-situ degradation, combined with the limited opportunities for mixing (i.e., dilution)[12], it is no surprise that these effluent plumes can extend for significant distances (i.e., 100s to 1,000s of meters) without significant changes in contaminant or pathogen concentration (Gerba and McNabb 1981; USEPA 2002).

[11] For pathogens, retention time within the vadose zone is the critical factor that determines final attenuation. It has been shown that flow through a few meters of the correct type of *unsaturated* soil can remove 99.99% of bacteria and protozoa and 99% of viruses (Van Cuyk et al., 2001). However, pathogens that make it into the groundwater will only be removed very slowly and may be carried long distances during this time (Gerba and McNabb 1981; Schaub and Sorber 1977) For nitrate, the situation is even more stark, as almost no nitrate is removed within OWTS. Furthermore, little to no nitrate is degraded in the vadose zone. The exception is at those locations where the vadose soil conditions are suitable for denitrification (i.e., sufficient retention time; sufficient carbon source {a C:N ratio of 3:1}; and anoxic conditions), such as in the corn belt of the US. (Spalding and Exner 1993). Thus, typically the majority of the nitrate reaches the aquifer. Once in the groundwater, nitrate is fairly persistent (e.g., only 2% to 9% mass-reduction of nitrate after 34 months; Desimone & Howes 1996).

[12] Dilution by infiltrating rainfall can provide some dilution under conditions of abundant precipitation (Spalding and Exner 1993), but that is not likely for many areas of Saskatchewan. [North Carolina, where this study observed rainfall-sourced dilution, averages between 50 and 500 mm/yr in total infiltration (Haven 2003), while Saskatchewan averages between 0 and 200 mm/yr).] Therefore, really all that we are left with as a dilution mechanism is the very slow lateral dispersion that occurs as a plume moves forward under mostly laminar flow conditions.

Therefore, setback distances should *not* be viewed as "minimum lateral distance needed to achieve treatment". Treatment, downstream of the treatment system proper, occurs in the vadose zone, where drainage is vertical (i.e., beneath the soil absorption field). Once movement becomes horizontal (i.e., within the groundwater aquifer), then little to no attenuation is occurring (at least on the distance scales relevant to most rural lots, i.e., 10s of meters) (USEPA 2002).

So do setback distances provide any protection? What kind?

Setback distances provide two forms of risk management:

1. *Separation from immediate vicinity:* By distancing the well from the soil absorption field, the setback prevents effluent from being pulled into the well directly from possible groundwater mounding (or even from the vadose zone itself, depending on how the well screen is located).
2. *Reducing probability of plume intersection further afield:* Once beyond this immediate zone, the protection provided by a setback distance is limited to reducing the probability that a well will intersect the effluent plume. A diagram (Figure 3) provides further explanation. It is important to keep in mind that this protection mechanism changes the *probability* of intersecting a plume, not the *concentrations* found within that plume. A comparison can be made to a lottery, where the probability is "your chances of winning". The concentration is the "size of the prize" and is, strictly speaking, unrelated to your chances of winning. Thus, whether you are 10 m or 100 m from the OWTS discharge will affect your chances of intersecting a plume, but if your well does intersect it, the concentrations in the plume will be relatively similar, regardless of the setback distance.[13]

[13] Note: the setback distance and plume intersection discussion above applies to a single plume. When multiple plumes are present, the probabilities become additive.

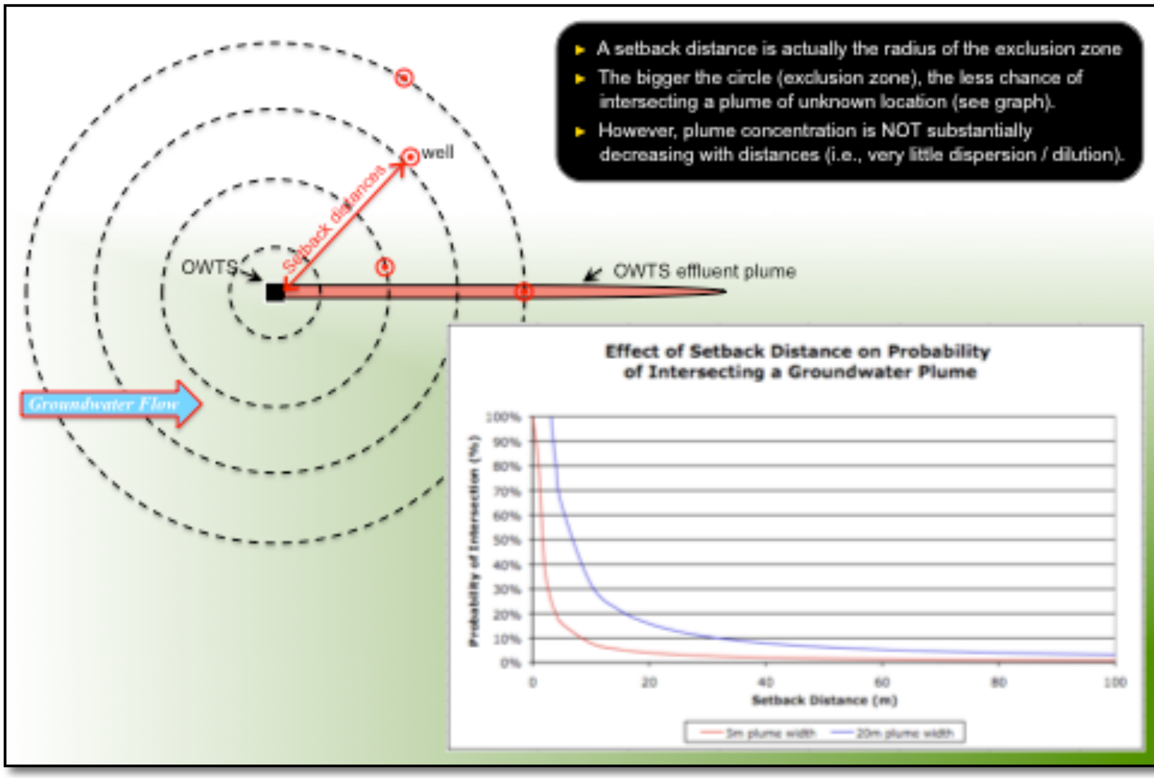

Figure 3. Effect of setback distance on plume intersection.

Thus, setback distances should to be viewed and used in a manner consistent with what they are able to deliver.

So if setback distances don't provide attenuation of nitrate concentrations, what other risk management options are available?

For nitrate-laden groundwater discharging to surface waters, the organic soils and vegetation in riparian zones can reduce nitrate concentrations dramatically within very short distances (e.g., from 65 mg/L down to 3 mg/L, due to passing through 3 meters of vegetated riparian zone) (Geary 2005). Therefore, protection of surface water from groundwater-sourced nitrate should include significant protection of those riparian zones, including ensuring they have plenty of biological activity and deep-rooted vegetation!

With regards to drinking water wells (municipal or private), significant dilution may occur as a result of the well's zone of capture.

2.4.7 Well Capture Zones

The setback discussion, above, talks about a well *intersecting* a plume. However, there is a difference between a plume being *intersected* and a plume being *captured*. This can be seen when comparing the plan (or "birds eye") view with the cross-section (or "profile") view. Compare Figure 4 with Figure 5. In the plan view (Figure 4), well A intersects the effluent plume. However, since the plume only occupies a certain depth range within the aquifer (Figure 5), we also need to consider the vertical configuration of this well before we can say whether it actually captures effluent from the plume.

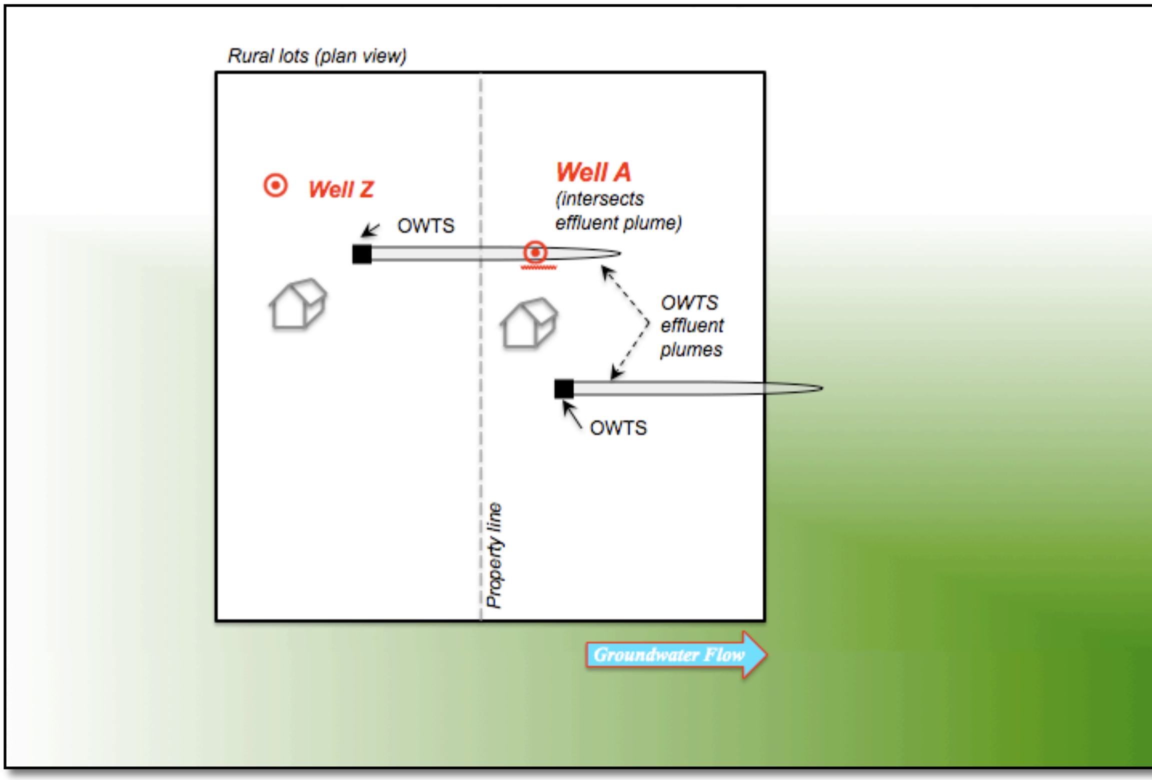

Figure 4. Plume density and geometry (plan view).

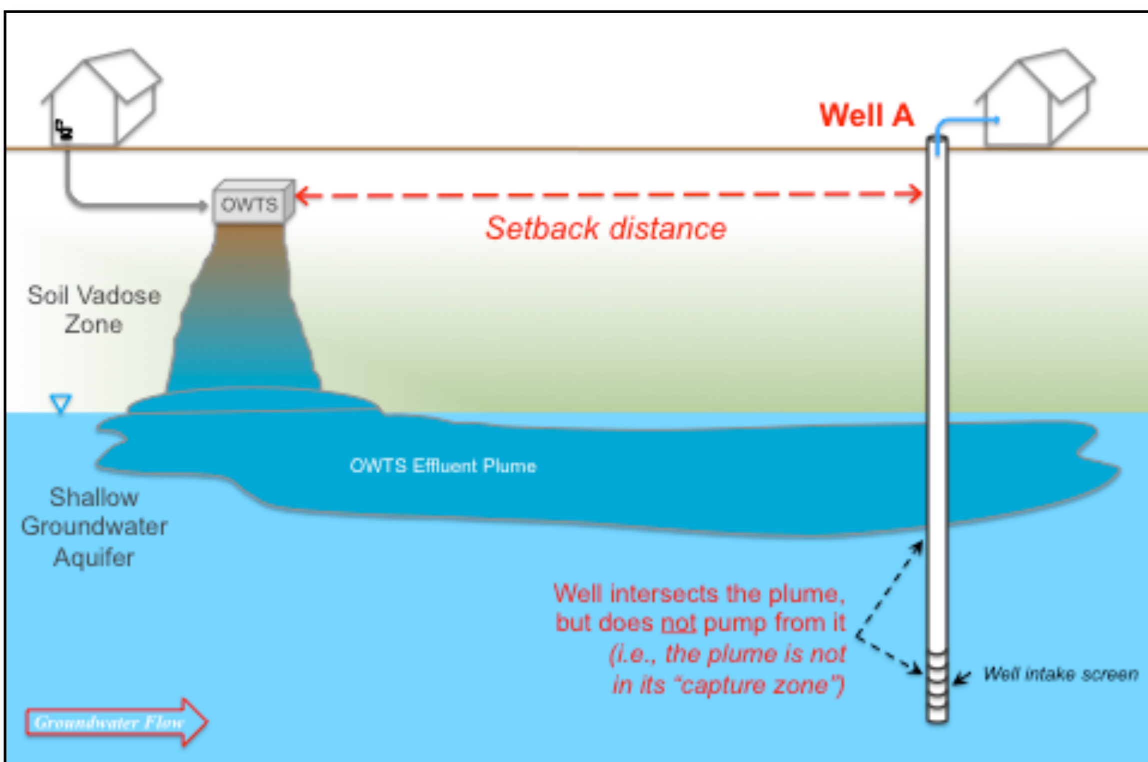

Figure 5. Plume density and geometry (cross section view).

The concepts and analytical tools for determining "well capture zones" (Figure 6) are fairly well established. (Note: site-specific information is required for this, as the relevant hydrogeological parameters can vary up to 6 to 12 orders of magnitude!) These tools are frequently used when determining protection plans for municipal groundwater supply wells.

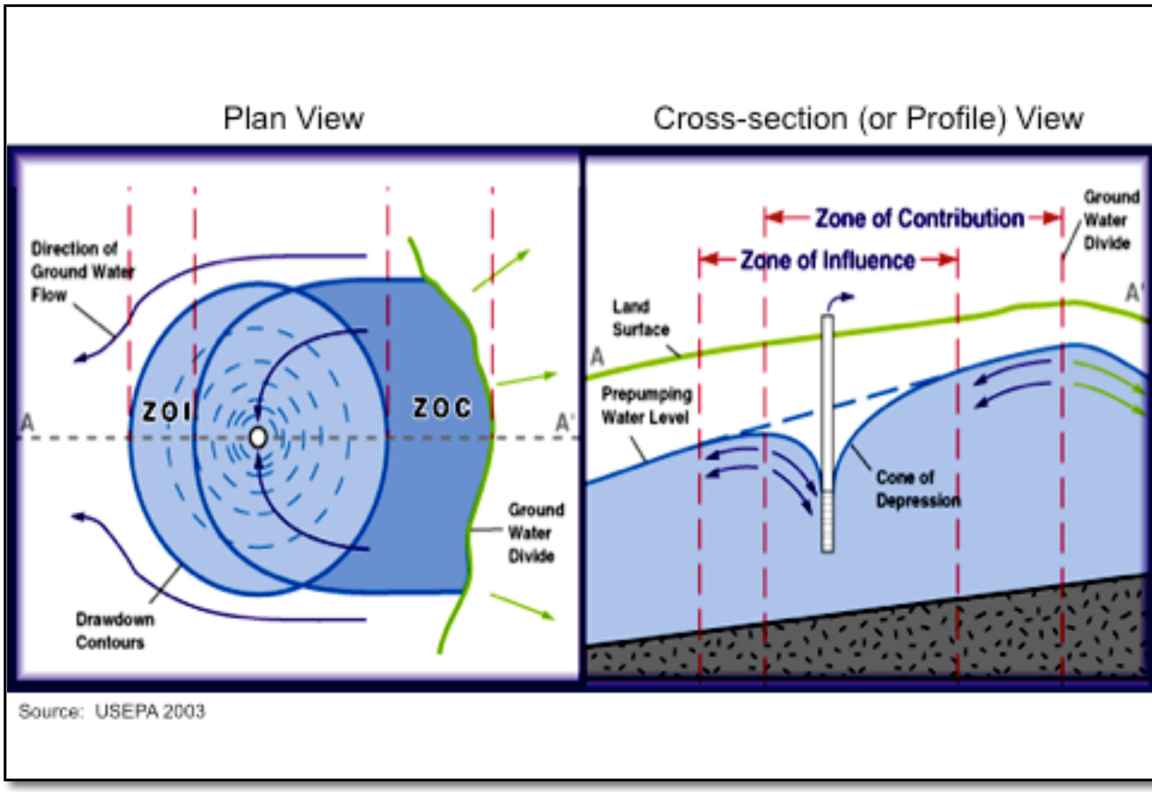

Figure 6. Well "capture zone" (plan and cross section views).

Depending on the well configuration (e.g., well screen depth and size, pumping rates, etc) and the characteristics of the aquifer that it is installed in (e.g., total depth, soil permeability, etc), the lateral extent of a well capture zone may extend for 100's of meters (and more than 1 km for large municipal or industrial wells) (Ryan, *personal communication*). However, as discussed above, this only addresses the lateral extent of the capture zone. It is then necessary to consider the vertical profile of this capture zone, relative to the effluent plume's depth and vertical extent (Figure 7).

Thus, depending on the situation specifics, a well that intersects an effluent plume when viewed in plan view may not actually capture any of the effluent when the vertical profile of the capture zone is evaluated (e.g., Well A in (Figure 7). Even when the effluent plume is within the capture zone, the proportion of effluent captured relative to the surrounding bulk water may result in significant dilution of the effluent occurring at the wellhead (e.g., Well B in (Figure 7). The situation that should be avoided is where a well with a small capture zone is placed exactly within the effluent plume (e.g., Well C in Figure 7). (Note: only site-specific field-based assessments will be able to provide the necessary information to differentiate between these situations.)

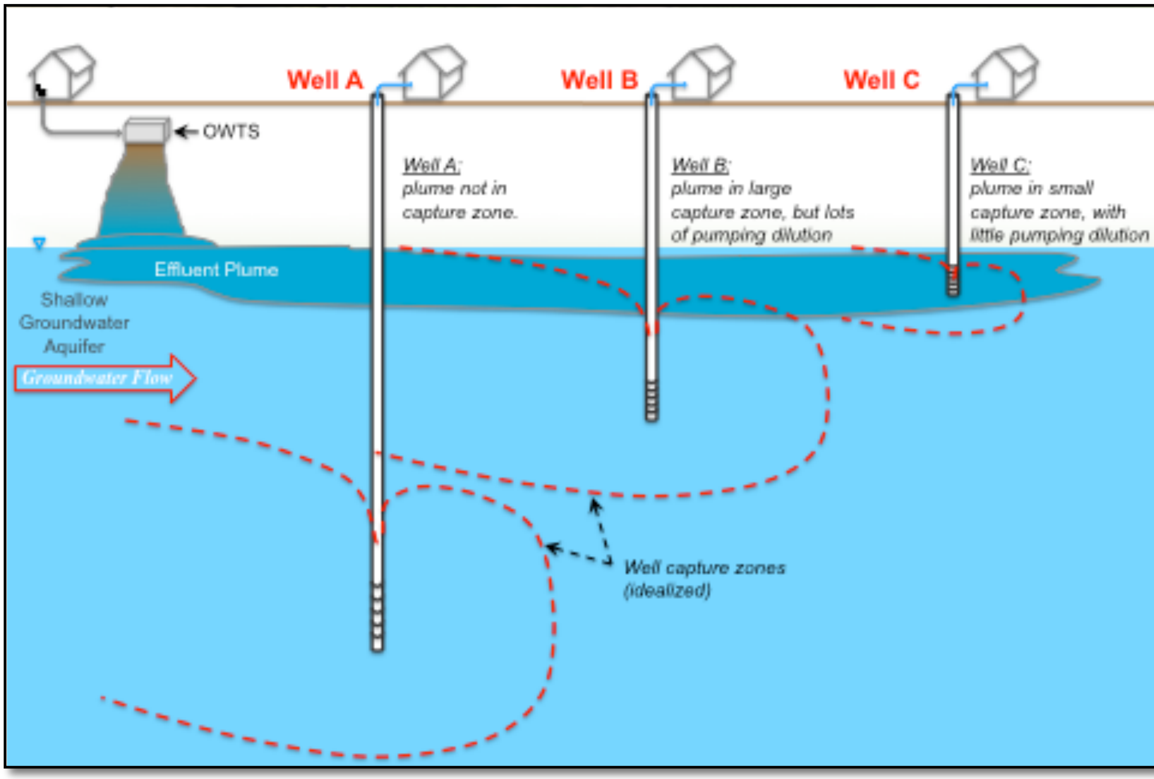

Figure 7. Interactions of well capture zones with effluent plume.

2.4.8 Lot Size, Density, and Subdivision Layout

Given the discussion above on the importance of plume intersection, an obvious question is how lot (or parcel) size and density affect the chances of intersecting an effluent plume. However, before entering the details of that conversation, it is important to clear up a common misunderstanding that exists about how OWTS effluent plumes affect concentrations of CoPC (e.g., nitrate) within the aquifer.

Figure 8 shows what is a common, but *incorrect*, assumption of how OWTS plumes affect aquifer water quality. Figure 9 shows how it actually occurs.

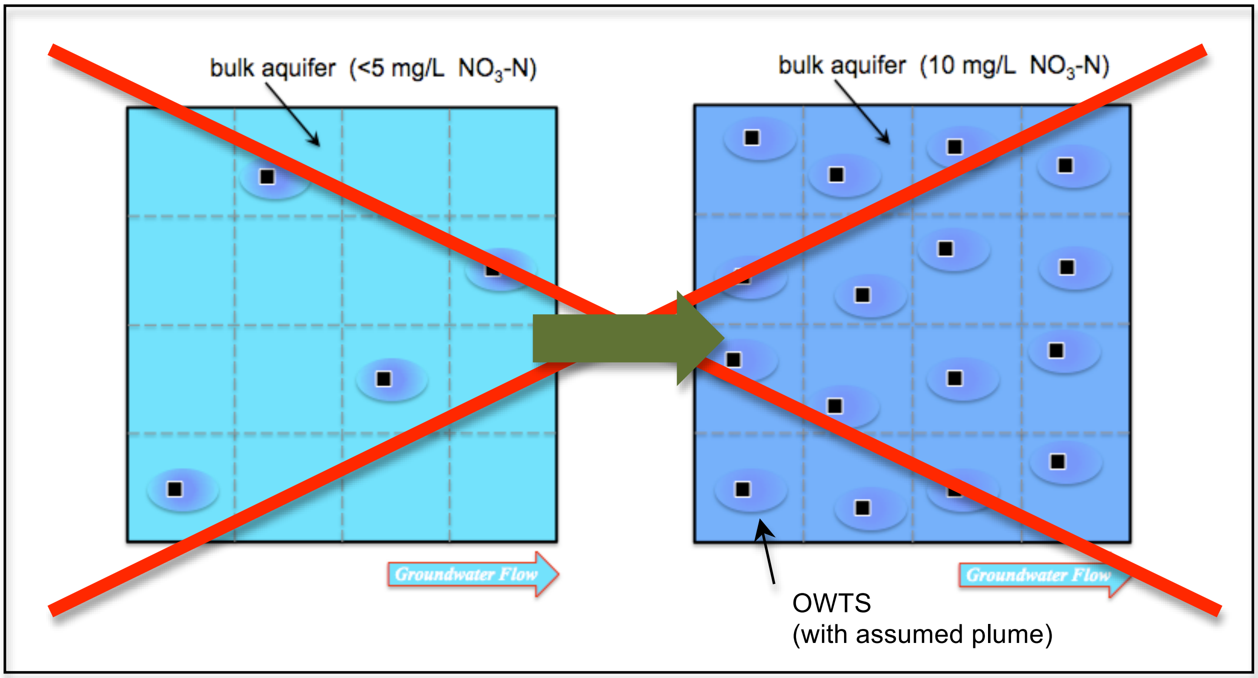

Figure 8. OWTS effluent plumes do NOT readily disperse into the bulk aquifer, thereby increasing bulk aquifer concentration of CoPCs (e.g., nitrate) with increasing density of development lots.

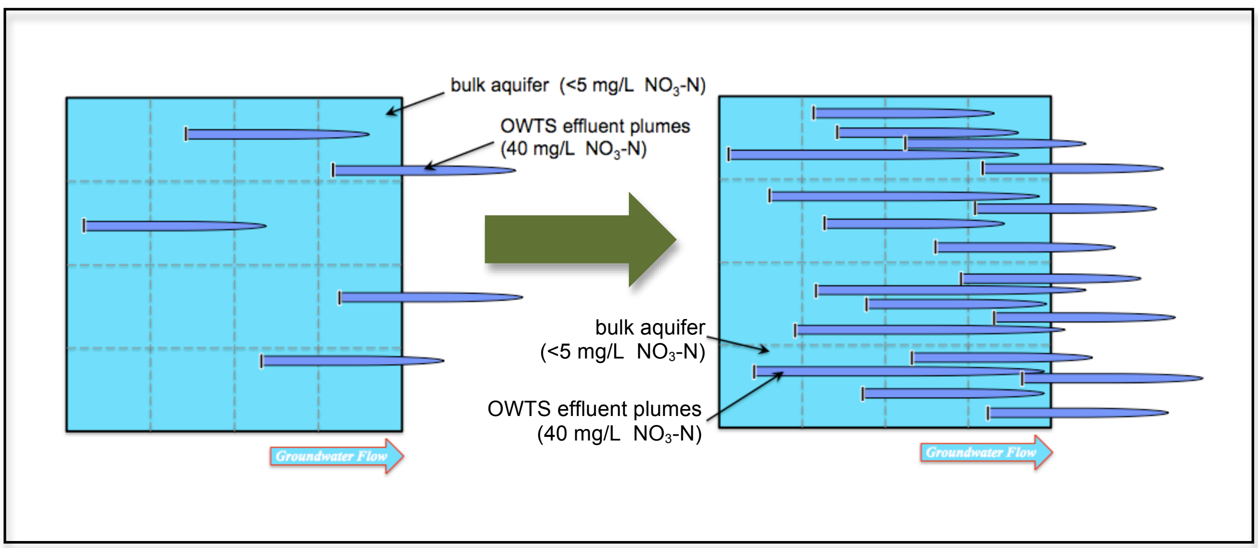

Figure 9. Rather, OWTS effluent plumes remain as discrete plumes. With increasing density of development lots there is an increase in the *probability* of intersecting a plume with elevated CoPC (e.g., nitrate) concentrations. Note that outside of the plumes, the bulk aquifer concentrations remain relatively unchanged.

Thus, we see that lot density does not directly affect CoPC (e.g., nitrate) concentrations in the bulk aquifer. However, higher lot densities do affect the probability of individual wells intersecting a plume and capturing elevated concentrations from the effluent plume. Lot size and layout configurations also play a role (Figure 10 and Figure 11).

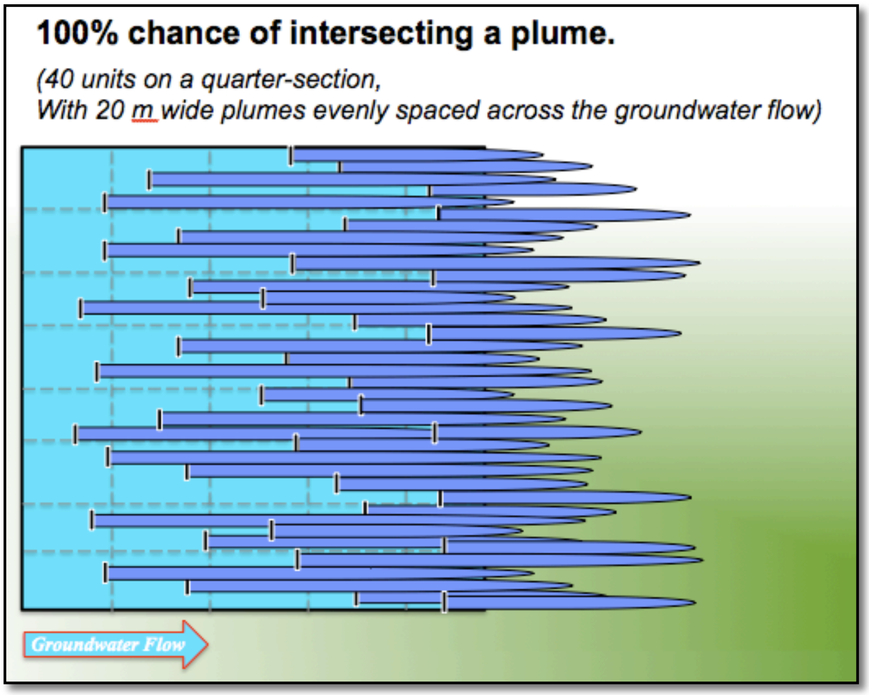

Figure 10. Potential coverage of OWTS effluent plumes when evenly spaced.

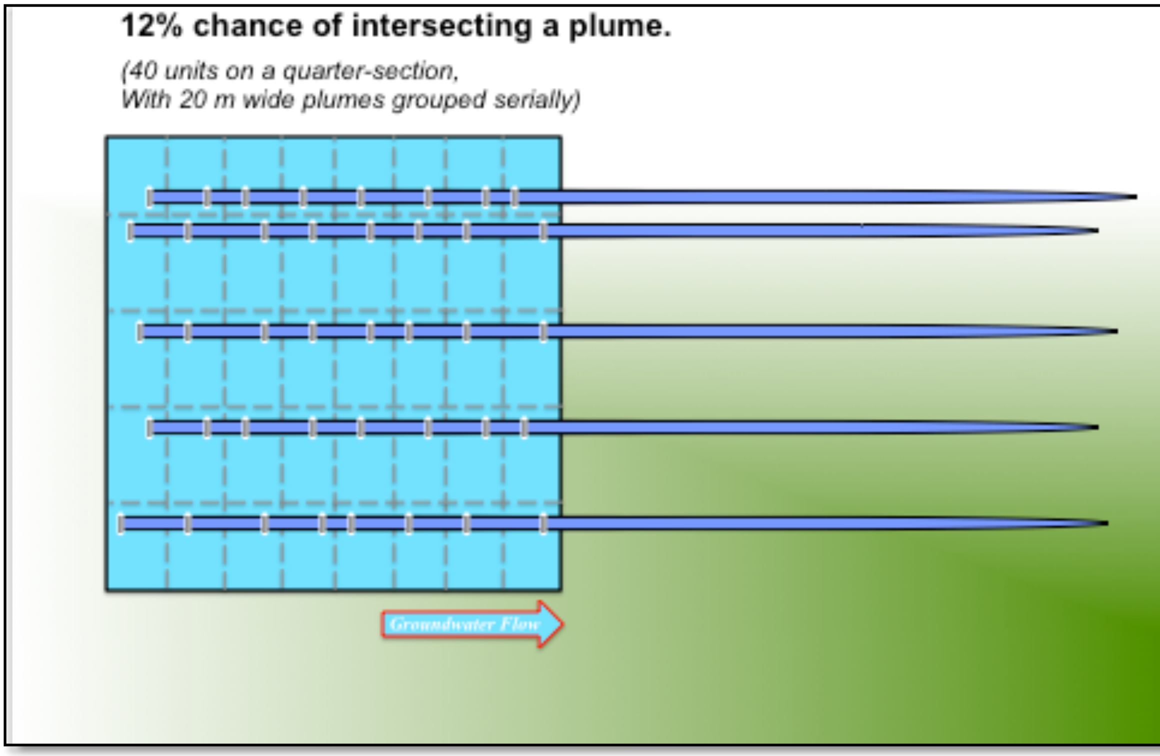

Figure 11. Potential coverage of OWTS effluent plumes when serially spaced ("stacked").

Note that the configuration shown in Figure 11, with the OWTS orientated in a "stacked" configuration is not meant to represent a recommendation. It is just a conceptual exercise to illustrate the other end of the range of possibilities, relative to the configuration shown in Figure 10. While a stacked configuration would reduce the probability of intersecting a plume laterally, it would increase the probability of one or more effluent plumes being within the capture zone of an intersecting well, due to the vertically stacked effluent plumes that would result (the 2-dimensional diagrams in the figures do not indicate the potential depth of the plumes). Such plumes are more likely to persist for greater distances. Furthermore, under certain soil conditions it might also increase the amount of groundwater mounding that occurs. The site-specific benefits and tradeoffs of various configurations between these two extremes would need to be evaluated on a case-by-case basis.

2.4.9 Approaches used in other jurisdictions - Comparison of Guidance Documents

Table 3 is a summary of over 1,800 pages of regulatory guidance documents and associated technical documents from six Canadian and US jurisdictions that have shown leadership and initiative in addressing the management of OWTS.

Below are general comments concerning the technical advantages and disadvantages of the approaches used by each of these jurisdictions, based on their respective Guidance Documents, Regulations and/or associated supporting technical documents.

2.4.9.1 Alberta

Alberta takes a very comprehensive and detailed approach to OWTS approvals. Their guidance document has been presented in the form of a "Model Process", thereby setting a template for individual local jurisdictions with the province to work from. The subdivision approval process is well-defined, but perhaps somewhat involved. Various "Tool Kits" are provided to guide administrators and service professionals through the requirements of various steps.

A good amount of technical detail is provided, especially with regards to soils and site assessment considerations. A sample site assessment report is provided, which is an excellent way of establishing a baseline that administrators can use for comparison when trying to determine if the submissions from various service professionals should be considered as sufficiently detailed and of adequate quality.

A fieldwork-based assessment is required for every new system installed. Provides detailed guidance on minimum site suitability criteria.

Ongoing operation, maintenance and monitoring considerations are light and could benefit from further development.

2.4.9.2 British Columbia

British Columbia's guide is well structured, has a well-defined process, and provides sufficient technical detail for an experienced professional to benefit from.

The requirements for fieldwork-based site assessments are thoroughly and succinctly explained. A fieldwork-based assessment is required for every new system installed. Provides detailed guidance on minimum site suitability criteria. It recognizes the importance of hydraulic loading (which affects vadose zone retention time).

It recognizes and allows advanced systems, and provides treatment performance targets for these systems. (However, no treatment performance targets are set for conventional septic systems!)

Ongoing operation, maintenance and monitoring considerations are light and could benefit from further development.

2.4.9.3 Ontario

Ontario's *Technical Guideline* is brief, and light on the technical details.

The only parameter of concern that Ontario's 1996 guidance document addresses is nitrate. There are some strict, potentially unrealistic, restrictions surrounding the nitrate considerations.

- A site boundary target criterion of 10 mg/L NO_3-N has been set.
- Yet, little provision is provided for consideration of advanced treatment systems.
- Furthermore, their Regulation 358 assumes every household system to discharge at least 1000 L/day of effluent with a minimum of 40 mg/L NO_3-N. However, the only allowable mechanism for reducing nitrate concentrations is dilution via precipitation. (Dilution via mixing with the groundwater is not an allowable consideration.) Diluting from the assumed 40 mg/L to the 10 mg/L target using only precipitation may require unrealistically high amounts of infiltration.

Pathogen considerations are not mentioned. Vadose zone attenuation is not considered, and therefore no minimum vadose depth/retention time is required. In our opinion, this inadequately addresses the potential risks posed by pathogens.

Commendably, they do consider density, lot size and whether the effluent discharge will be isolated from a supply aquifer. Ongoing operation, maintenance and monitoring considerations are light and could benefit from further development.

Ontario does recognize that as new information becomes available, revisions of their guideline is warranted.

2.4.9.4 Nova Scotia

Nova Scotia's approach to OWTS does not split the assessment and approvals into separate processes for subdivisions versus individual lots within the development. Their approach is a very comprehensive and detailed approach to OWTS approvals. Their guidance document is well structured, has a well-defined process, and provides plenty of technical detail (starting from the basics, which in our opinion is crucial, to ensure consistent understanding and application by as much of the full user community as possible). In comparison to other jurisdictional and provincial guidelines, these documents are very accessible for a broad audience {Nova Scotia Environment, 2008 #170;Nova Scotia Environment and Labour, 2004 #169}. They describe in plain language and exceptional text and graphic layout, what OWTS and water wells are, how they work, technical details of construction and function, common failures, and the reasons for proper maintenance. The guidelines include true examples of application forms (and who is responsible for each step in the application review process), well reports, and OWTS schematics and plans. Tables in each document show minimum clearance distance requirements for each system under different conditions.

A good amount of technical detail is provided, especially with regards to soils and site assessment considerations. A fieldwork-based assessment is required for every new system installed. Provides detailed guidance on minimum site suitability criteria. It recognizes the importance of soil hydraulic conductivity and vadose zone depth (which affects vadose zone retention time).

Ongoing operation, maintenance and monitoring considerations are light and could benefit from further development.

Recommendation: for SH and SWA to evaluate the Nova Scotia documents for incorporation into the Saskatchewan OWTS policy development strategy. These publications offer strategic risk management elements for reducing sewage- and well water-related risks through education.

Nova Scotia Guide for OnSite Sewage Construction

Nova Scotia Guide for Well Construction

2.4.9.5 Montana

Montana's *Nondegradation* guideline has a strong hydrogeology and groundwater-modeling basis.

However, the only parameters of concern that Montana's guidance document addresses are phosphorus and nitrate. Pathogen considerations are not mentioned. In our opinion, this inadequately addresses the potential risks posed by pathogens.

Vadose zone attenuation for phosphorus is considered in detail, and a performance-based approach is taken to determined the required vadose zone depth. A minimum vadose depth is also specified.

The various discussions on groundwater mixing zones need clarification to prevent giving the impression that mixing and dispersion of OWTS plumes is common and occurs over short distances. Clarification is also needed on the difference between a setback distance and a plume mixing zone.

Commendably, they do consider whether the effluent discharge will be isolated from a supply aquifer, and include a provision for ongoing monitoring. Inclusion of operation and maintenance topics would be beneficial.

Advanced treatment systems are encouraged, especially those that remove nitrate.

2.4.9.6 California

Of all the jurisdictions reviewed, California's is the most comprehensive, by far. The California State Water Resources Control Board published Assembly Bill 885 Onsite Wastewater Treatment Systems (OWTS) Proposed Regulations {California Environmental Protection Agency, 2009 #175} and the accompanying Program Draft Environmental Impact Report (DEIR) {EDAW, 2008 #174} for public comments (until February 29, 2009) at www.waterboards.ca.gov/water_issues/programs/septic_tanks/index.shtml. California is nearing the end of a policy development, program evaluation, and public commentary process very similar to that which Saskatchewan is engaged in.

In addition to having to deal with a very complex, multi-layered regulatory regime, they also deal with the technical considerations in a very comprehensive manner.

OWTS and related groundwater concerns are currently regulated via a broad, complex, and jurisdictionally inconsistent network of federal, state, and local environmental and public health regulations and agencies. The primary intent of AB 885 is to require the State Water Board, in consultation with a broad set of governmental and community stakeholders, to develop and adopt statewide OWTS regulations to address substantial environmental and public health issues (including drinking water) and incidents that arise from the current inconsistent regulatory policies.

The seven minimum regulatory requirements for permitting, monitoring and operation of OWTS specified by AB 885 are {EDAW, 2008 #174`, Section 2}:

a) Minimum operating requirements that may include site, construction, and performance requirements
b) Requirements for OWTS adjacent to waters listed as impaired under Section 303(d) of the Clean Water Act
c) Requirements authorizing local agency implementations
d) Corrective action requirements
e) Minimum monitoring requirements
f) Exemption criteria
g) Requirements for determining when an existing OWTS is subject to major repair

As part of developing their guide, they engaged the services of some of the most knowledgeable independent consultants in the field of onsite wastewater treatment. A comprehensive technology review was conducted, where it was recognized that OWTS technology is advancing rapidly and that more advanced treatment systems now exist which can reliably deliver superior on-site wastewater treatment, to the benefit of the receiving environment and downstream users. (It was also acknowledged that some technology packages being offered for sale are not reliable and/or well-designed.)

Treatment performance targets set for advanced systems. (However, no treatment performance targets are set for conventional septic systems!)

Operation, maintenance and monitoring are also dealt with in a proactive manner, and reasonable requirements for these are set, including an inspection frequency.

A number of difference approaches for structuring their regulations and approvals process were evaluated, including the matrix approach (density vs. site attenuation potential and increasing use of advanced treatment). They concluded that the matrix approach was a valid one, but it was not pursued due to an incompatibility with other existing regulations residing at more local levels of government.

Given the solidity and thorough level of detail of its other aspects, this guide was surprisingly light on considerations involving a risk-based approach and cumulative effects. This is likely reflective of team composition (i.e., an absence of risk assessors).

Table 3. Comparison of OWTS guidance documents from various jurisdictions.

Guideline Element	Saskatchewan (Recommended)[1]	Saskatchewan (Current Interim)	Alberta	British Columbia (Coastal Health)	Ontario	Nova Scotia	Montana	California [2]
Development Scale	(Same as current)	Subdivision (max 18 m^3/day/system)	Subdivision (max 25 m^3/day/system). Systems >5.68 m^3/day require more assmt.	Individual lots (max 1.36 m^3/day/system); *or* Communities (max 22.7 m^3/day/system)	More than 5 lots, with total discharge of <4.5 m^3/day.	Individual lots (max 1.5 m^3/day/system); or Commercial, etc as per provided Design Tables	Subdivision (i.e., 2 or more lots) (discharge volume limits not stated)	Systems with total discharge of >13.2 m^3/day need specific Water Board approvals.
Development Criteria: *- Housing Density / Lot Size*	(Same as current)	Defines: *Low* (<5 units per 160 acres)[3], *Medium*, and *High* (>39 units per 160 acres)	Defines: *Low* (<5 units per 160 acres) through *High* (>30 units per 160 acres)[4]	A lot size <2.5 acres or >10 units in a subdivision (area not specified) triggers a hydrogeological assmt	Average lot size <2.5 acres triggers a hydrogeological assessment	Criteria not specified – subject to approval by Dept. of Environment and Labour	Density limits not set	Density limits not set – matrix approach was rejected due to potential conflicts[5]
- Setback Distances	See setback discussion in text	Min. 9 m from wells and water bodies. Within 1 km of other subdivisions triggers higher sensitivity rating.	Minimum 60 m from wells, and 150 m from surface water bodies	Minimum 30 m from wells and surface water bodies	Minimum 30 m from wells (as referenced in Ontario Regulation 350/06 – Building Code)	Minimum 15 m from cased wells; 30 m from surface water bodies	60 m to 154 m from wells and surface water bodies (setback distance depends on lot size)	Minimum 30 m from wells, and 183 m from surface water bodies (or upgrade to advanced treatment system)
- Depth to Water table	Used retention-time based approach to determine required vadose zone depth. Minimum 1.0 meter (from <u>bottom</u> of absorption trench).	Water table within 3 meters of ground surface triggers higher sensitivity rating	Water table within 2.5 meters of ground surface triggers reduced suitability rating. Depths less than 0.9 m considered unsuitable.	Soil depths of 0.5 m to 1.2 m are acceptable, given a large enough absorption field and low enough lot density	Not typically considered - any attenuation in the vadose zone to be typically considered as extra safety factor (unless proponent can demonstrate that this attenuation is occurring)	Minimum 1 m between <u>bottom</u> of absorption field trench and groundwater table or restrictive layer (e.g., low or high permeability soil, fractured bedrock, etc).	Minimum 4 m between <u>bottom</u> of absorption field trench and seasonal high groundwater table – governed by phosphorus removal	Minimum 1 m between <u>bottom</u> of absorption field trench and groundwater table. Allows a reduction in soil depth requirements for advanced systems.
- Size of Soil Absorption Field	Design for the soil re: adequate retention time in vadose zone	Specified, based on soil percolation rate or soil texture and system type	Specified, based on soil percolation rates, soil texture and treatment system type	Specified, per soil type and treatment system type (conventional vs. advanced)	Not mentioned	Specified, based on vadose zone depths and soil percolation rates and system type	Based on preventing phosphorous breakthrough from vadose zone	Size based on soil texture or hydraulic conductivity rate (ie, retention times)
Site Assessment elements	*Add to current:* - Front-end weight the Field Assmt requirements (see text) - Assess seasonal high groundwater elevation - Measure on-site hydraulic conductivity - Front-end assessment of effluent isolation from supply aquifer; - Predictive elements for OWTS effluent plumes	*Phased process.* No field assmt required for subdivision application when <5 units per 160 acres. Defines *Cumulative*, *Basic*, & *Advanced*; Assessments. - lot density - dugout & well inventory w/in 1km - topography (slope; drainage) - soil profiles (texture, structure, depth, parent	*Single-stage process.*[6] Field Assmt required for all applications. - site plan & lot density - topography (slope; drainage)& vegetation - soil profiles (texture, structure, type, depth) - moisture conditions & seasonal high water - perc test (optional) - evaluation of impacts to nearby wells - evaluation of impacts to surface waters	*Single-stage process.* Field Assmt required for all applications. - site plan - type of water supply (well, etc) proposed - ground slope - absorption field area - soil observation holes (0.6m dia) - depth of soil (to groundwater / restrictive layer) - soil description (texture, type, etc)	*Phased process.* Field Assmt required for all lots <2.5 acres. - lot size (density) - background nitrate concentrations - groundwater impact predictions, at site boundary - demonstrate that effluent plume will remain isolated from supply aquifers and/or surface water; *or* - assess the risk that the	*Single-stage process.* Field Assmt required for all applications. - site plan (incl. surface water bodies) - min. lot size (depends on soil depth avail.) - proposed water supply (source type, location, etc) - proposed usage of OWTS (volume, etc) - ground slope - soil test pits - soil description (type,	*Single-stage process.* Field Assmt required for all applications. - lot layout plan - well locations (on-site and neighbouring), and zones-of-influence - drainfield mixing zones (i.e., plumes) - ground slope - soil test pits - soil texture description - groundwater gradient - hydraulic conductivity - depth of soil (to	*Single-stage.* Field Assmt required for all applications. "A qualified professional shall perform all necessary soil and site evaluations" …but details not specified, other than: - determine seasonal high groundwater elevation - need aerobic conditions in

Guideline Element	Saskatchewan (Recommended)[1]	Saskatchewan (Current Interim)	Alberta	British Columbia (Coastal Health)	Ontario	Nova Scotia	Montana	California [2]
Site Assessment elements (cont.)		material) - moisture conditions - background nitrate concentrations - groundwater impact predictions, at site boundary	- treatment system type - cumulative effects assessment (under certain conditions) - Site suitability assessment	- perc test <u>*or*</u> on-site field-saturated hydraulic conductivity test - hydrogeological assmt, including cumulative effects (under certain conditions)	effluent will cause >10 mg/L NO_3-N in the groundwater; *and* - predicted impact of OWTS effluent on surface water (where applicable)	texture, structure, etc) - depth of soil (to groundwater / restrictive layer) - seasonal high groundwater elevation - on-site field-saturated hydraulic conductivity	groundwater / restrictive layer) - seasonal high groundwater elevation - background nitrate concentration - groundwater sensitivity calculations for nitrate - vadose zone breakthrough calculations for phosphorus	unsaturated zone
Site Suitability Criteria	Risk-based suitability and development evaluation process. Sufficient vadose zone retention for pathogen attenuation is primary criterion.	Provides detailed guidance of what factors contribute to a suitable site, but leaves final interpretation up to user.	Provides detailed prescription of minimum criteria needed for a suitable site. e.g.: *Percolation rates in absorption field needs to be between 60 cm/day and 720 cm/day.*	Provides detailed prescription of minimum criteria needed for a suitable site. e.g.: *Field-saturated hydraulic conductivity in absorption field needs to be between 4.5 cm/day and 300 cm/day.*	- Background nitrate concentrations in groundwater of <10 mg/L - And background nitrate will decline after subdivision development - Not in a hydrogeologically sensitive area (e.g., fractured bedrock; thin or highly permeable soils)	Provides detailed prescription of minimum criteria needed for a suitable site. e.g.: *Minimum lot widths and areas.*	Provides prescription of criteria needed for a suitable site, focused on reducing degradation of groundwater and surface water by nutrients (phosphorous and nitrate).	A qualified professional is to determine site suitability, based on the site evaluation. Min. vadose zone depth only criteria specifically stated.
Treatment Technologies Considered	Smooth the process for getting advanced systems approved (espc. re: nitrate)	Geared towards conventional septic systems[7], but allows for advanced treatment systems	Geared towards conventional septic systems[7], but allows for advanced treatment systems	Geared towards conventional septic systems[7], but allows for advanced treatment systems	Geared towards conventional septic systems	Geared towards conventional septic systems[7], but allows for advanced treatment systems	Encourages use of advanced treatment systems, espc. for nitrate removal	Regulations provide for both conventional and innovative system designs
Cumulative Effects	Redefine to include regional point and non-point nitrate sources	Considered	Considered	Considered	Not considered	Mentioned	Considered	Considered
Water Quality Target	No OWTS-related pathogens released into ground water; 10 mg/L nitrate-nitrogen as predicted well water quality at down-gradient boundary	"Water quality cannot be degraded by an amount that may result in an unacceptable impact on human health or the environment."	"Development…will not result in, or cause degradation of, groundwater resources beyond acceptable limits." Nitrate is used as the groundwater impact indicator.	Not specified for conventional septic systems. <u>Advanced systems:</u> *"Type 2":* TSS[(8)] and BOD_5 <45 mg/L; or *"Type 3":* TSS and BOD_5 <10 mg/L, and fecal coliforms <400 CFU per 100 mL.	"That the combined effluent discharges …will have a minimal effect on the groundwater" "10 mg/L of nitrate-nitrogen is used as an indicator of groundwater impact potential."	"Avoid contamination of groundwater" "Effluent…entering the groundwater or reaching the ground surface, will not adversely affect public health or the environment"	Protection of "high quality groundwater" (<2,500 umhos/cm specific conductance) <u>*Discharge limits*</u> *to groundwater:* <7.5 mg/L after mixing *to surface waters:* - Nitrate: <0.01 mg/L - Phosphorous: <0.001 mg/L	Not specified for conventional septic systems. <u>Advanced systems:</u> TSS and BOD_5 <30 mg/L, and total coliforms <10 MPN (if sand) or <1,000 MPN (for slower hydraulic conductivities)

Guideline Element	Saskatchewan (Recommended)[1]	Saskatchewan (Current Interim)	Alberta	British Columbia (Coastal Health)	Ontario	Nova Scotia	Montana	California [2]
Monitoring	More monitoring - see discussion in text	Provision for this under the *Cumulative Assessment* process	Provision for this under the *Contaminant Attenuation* step	Not discussed	Provision for this under *Contaminant Attenuation* step	Not discussed	Long-term monitoring of aquifer quality and nitrate may be required	Ongoing monitoring and inspections required
Ongoing Operation and Maintenance	(Same as current)	Presents spectrum of four management models (from "Homeowner Awareness" to "Responsible Management Entity Ownership")	Differing levels of O&M reliance considered (i.e., in Level 1 vs. Level 4 assessments), but no details specified.	Individual systems operated by homeowner. Community systems operated by Regional District; Municipality; or Strata Corporation	Not mentioned	Homeowner's responsibility to have their individual system maintained (i.e., can contract out if they so choose).	Not mentioned	Must conform with the system's O&M manual.[9] All advanced systems must be maintained by a qualified service provider.
Guidance Type	Risk- & performance-based; incl. education	Matrix & Prescriptive	Prescriptive	Prescriptive	Prescriptive (outdated)	Performance & education-based	Performance-based	Performance-based

NOTES:

1. Includes recommended additions and modifications to Saskatchewan's *Interim Guideline*.
2. As presented in the proposed Regulation. California currently has a patchwork of county-specific and Regional Water Board-specific guidelines, and the proposed Regulation is intended to replace these with a consolidated state-wide Regulation.
3. 160 acres = one quarter-section.
4. The Alberta *Model Process* is structured to consider a wide variety of development scenarios, other than just those based on quarter-section increments (e.g., sub-dividing a 10 acre lot). Hence, their treatment of the density issue also includes a consideration on individual lot size. This differs somewhat from the approach used in some other jurisdictions.
5. A "matrix approach" (i.e., development density considerations crossed with vadose depth and hydraulic conductivity considerations) was considered by California, but was rejected due to potential conflicts with existing land use policies, plans and regulations in various jurisdictions throughout the state. Aside from these administrative impediments, the matrix approach was considered to be somewhat more protective of groundwater and public health (EDAW 2008).
6. The site assessment process in Alberta's *Model Process* is a single-stage assessment (i.e., not phased). One of four different levels of assessment comprehensiveness is assigned, based on specific characteristics of the proposed development (size, density, etc). A provision is available in the process to ask for a more detailed assessment if the initial work doesn't provide sufficient information.
7. "Conventional septic system" = septic tank (anaerobic), following by a (buried) soil absorption field (or "tile field"). Other common typical systems include a septic tank followed by an absorption mound. "Advanced" systems are those designed to give higher treatment efficiencies, including both electro-mechanical "package plants" (e.g., activated sludge; sequencing batch reactors; rotating biological contactors; membrane bioreactors), as well as other more passive designs (e.g., sand filters; constructed wetlands; biolfilters). Other techniques that can contribute greatly to improved treatment include low-flow fixtures (e.g., low-flow faucets and shower heads; source-separation toilets) and no-flow fixtures (e.g., composting toilets).
8. "TSS" = Total Suspended Solids; "BOD" = Biochemical Oxygen Demand.
9. A system-specific Operation and Maintenance (O&M) manual must be supplied by the qualified designer / installer of each system. It is to include a detailed description of the technology installed, as-built plans for the system, and the expected nature and frequency of the OWTS maintenance. (CSWRCB 2008)
10. This table summarizes over 1800 pages of regulatory guidance documents and associated technical documents from seven Canadian and US jurisdictions that have shown leadership and initiative in addressing the management of OWTS.
11. SOURCES:
    - Saskatchewan: *Interim Guidance Document for Developments and Subdivisions where Private Sewage Systems are Proposed* (2008); and *Saskatchewan Onsite Wastewater Disposal Guide* (2007).
    - Alberta: *Model Process Reference Document to Guide Municipal Consideration of Subdivision and Development using Private Sewage Treatment Systems* (2004); and *Alberta Private Sewage Systems Standard of Practice* (2007)
    - British Columbia: *Subdivision Guide – Vancouver Coastal Health* (2007) <http://www.vch.ca/environmental/docs/environments/subdivision_guide.pdf>
    - Ontario: *Procedure D-5-4: Technical Guideline for Individual On-Site Sewage Systems: Water Quality Impact Risk Assessment* (1996) <http://www.ene.gov.on.ca/envision/gp/d5-4.htm>
    - Nova Scotia: *On-Site Sewage Disposal Systems: Technical Guidelines* (2007) <http://www.gov.ns.ca/nse/water/docs/OSTG_OnsiteTechnicalGuidelines.pdf>
    - Montana: *How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Systems (SWTS) under the Subdivision Review Process* (2009) <http://deq.state.mt.us/wqinfo/Nondeg/FormsList.asp>
    - California:
      Regulation AB 885 - Proposed OWTS Regulations and Conditional Waiver (2008);
      Statement of Reasons Addressing: Rulemaking by the State Water Resources Control Board to Regulate Onsite Wastewater Treatment Systems for the Protection of Surface Water and

Groundwater (2008);
Program Draft Environmental Impact Report: AB 885 Onsite Wastewater Treatment Systems (2008);
and associated documents, all at <http://www.waterboards.ca.gov/water_issues/programs/septic_tanks>

2.4.10 Risk Management elements

While OWTS are an appropriate long-term approach to wastewater management, they are not fail-safe nor risk-free. Approvals and related decision-making concerning OWTS needs to be done within this framework of awareness.

The matrix approach laid out in Table 2.1 of the Saskatchewan *Interim Guideline* is an appropriate and effective method for categorizing and managing some of the key risks associated with OWTS planning at a subdivision level.

At a more detailed level, additional technical details should be considered that represent key factors influencing risk. Table 3 (see Section 2.4.9 Approaches used in other jurisdictions - Comparison of Guidance Documents above) provides a comparison of specific elements of the regulatory guidelines from a number of Canadian and US jurisdictions. The items discussed in Table 3 are all essentially Risk Management elements because they all intended to make sure that treatment systems are either a) designed and installed properly; b) maintained within necessary performance criteria; or c) failures identified and appropriate corrective actions taken.

To reduce OWTS performance risks, we recommend the following be established as requirements within Saskatchewan's OWTS approval process:

- There is a huge amount of incomplete and incorrect misinformation circulating about septic systems and other OWTS. Therefore, the first step in effectively managing OWTS is to provide educational material to the service providers throughout the complete service chain (i.e., from pump truck operators, through to installers, designers and site assessors). Where appropriate, require mandatory training and certification of specific types of service providers (e.g., designers; installers).
- The same goes for the administrative and regulatory staff tasked with OWTS management (e.g., local health officials; inspectors). Without an understanding of at least the fundamentals, incorrect decisions will be made, leading to either unnecessary expenses and/or risks.
- Provide educational material to homeowners regarding their OWTS. (Nova Scotia has some excellent pamphlets – simple, short (2 pages each), very clear and informative. Also, California requires that all OWTS suppliers provide a comprehensive Operation and Maintenance manual with every system they sell.)
- Conduct fieldwork-based site assessments for *every* system installation, regardless of the lot size / density[14].
- Demonstrate an understanding of probable effluent plume density and geometry for all proposed subdivisions, and discuss how that relates to existing and planned water supply well locations and their zones of capture (lateral and vertical).

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[14] We realize that in Saskatchewan, currently, the subdivision approval process is separate from (and precedes) the OWTS permitting process for individual lots. Regardless of the administrative mechanisms and sequences that are in place, it is still necessary to have site-specific fieldwork-based assessments. Otherwise, as stated by California's State Water Resources Control Board (CSWRCB 2008), "With little or no knowledge of the local (conditions) beneath the site, it is a questionable practice to install an OWTS and assume that it poses no human health threat to people with wells immediately downgradient".

- Establish clear ownership responsibilities (as already provided for under your four existing models of "Responsible Entities") and attach operation, maintenance, inspection and monitoring requirements that are appropriate for the various site configurations and OWTS technology options being used.
- Encourage source reduction of wastewater generation, through the appropriate use of low-flow and no-flow fixtures and technologies.
- Encourage the use of those advanced treatment systems that can reliably deliver improved effluent quality, especially with regards to pathogens and nitrate. Inclusion of requirements for monitoring, qualified service providers and responsible management entities can bring resourcing requirements to within sustainable levels.
- Practice failure recognition and prevention through maintenance and inspections (e.g., require inspections at time of property sale; also see California's requirements for 5-yr inspections). In the case of system failure, clear and strict requirements should be in place for taking appropriate corrective actions (via a qualified service provider) (e.g., California's requirements for corrective action within 90 days when a defined failure has occurred).
- Conduct OWST effluent quality monitoring for systems and/or locations of potential concern. To facilitate this, it should be required that all system installations or upgrades be accompanied by the installation of simple, cost-effective monitoring ports that allow sampling of effluent within the vadose zone (i.e., downstream of the soil absorption trenches (Costa et al. 2002; Huntsman et al. 2006)), should it become necessary in the future (i.e., proactively plan for effective reaction to future situations).

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3 Literature Review and Options Development – Drinking Water

3.1 Approach

This literature review of drinking water considerations for Subdivision Developments Where OWTS are Proposed will begin to address questions specific to drinking water, in the context of the overarching questions posed earlier. The information gathered here is a preliminary step in setting up the risk assessment and risk management approaches in this project.

- Do OWTS failures affect drinking water quality and subsequently human health?
- What evidence do we have for specific CoC in well water (potable ground water supplies)?
- Does OWTS density influence groundwater quantity or quality?
- Are subdivision development policies in place to mitigate risks?

3.2 Importance of drinking water policy for subdivisions

Primary literature sources contain many accounts and investigations of water quality affected by wastewater, including specifically OWTS. We have sufficient experience and evidence to know that failed systems can and do contaminate groundwater. The central question to be considered here is for *properly functioning* OWTS, are there significant risks to drinking water? OWTS policies for subdivisions must fundamentally be concerned with proper planning and design of OWTS to mitigate failure in the first place. This is the best protection mechanism for local private drinking water sources.

3.2.1 Microbiological concerns

Drinking water supplies in populated areas, whether they are shallow or deep groundwater wells, spring-fed lagoons, or other surface water sources, are susceptible to contamination from raw sewage or wastewater treatment effluents through various pathways. As population densities increase, the challenges in keeping pure drinking water sources pathogen-free, or in treating drinking water to deactivate or eliminate pathogenic entities, become greater or more intensive. Hrudey and Hrudey (Hrudey and Hrudey 2004) investigated numerous waterborne disease outbreaks in affluent nations from 1974 through 2002. Three of the outbreaks they evaluated were linked to OWTS failures, with dye tracers reaching groundwater wells in as few as 9 hours. The estimated cases totaled >2100, with at least 6 hospitalizations. In most instances, while gastrointestinal disease cases occur due to exposures from private wells, they are largely unrecognized as outbreaks and go unreported. These three particular outbreaks evaluated by Hrudey and Hrudey occurred at a school, a resort and a popular tour bus stop, resulting in large numbers of people being exposed.

Illness outbreaks continue to occur with OWTS contributing through system failures or large-scale weather-related events (usually flooding). In 2004 a series of extreme precipitation events on South Bass Island, Ohio, led to large-scale groundwater contamination, near-shore Lake Erie contamination, rising water table, and significant surface water – groundwater interchange. The resulting contamination of drinking water resulted in an outbreak that affected approximately 1,450 people (Fong, Mansfield et al. 2007).

A 1996 – 1998 study of a Wisconsin population of children looked at pathogen occurrence in well water in an area primarily using OWTS (Borchardt, Chyou et al. 2003). Borchardt et al. reported a statistically significant association between the number of holding tank septic systems[15] in the surrounding square mile and cases of viral or bacterial diarrhea.

Subsequent studies of enteric viruses in drinking water by Borchardt and colleagues (Borchardt, Bertz et al. 2003; Borchardt, Bradbury et al. 2007) resulted in detections of infectious viruses (hepatitis A, rotavirus, Norwalk-like viruses, and various enteric viruses) at different private wells on different sampling occasions. The detections of these viruses in well water could be due to numerous pathways, and the authors reviewed numerous studies showing the persistence (several months) and migration capabilities of the viruses - up to hundreds of metres in till and more than 1 km in fractured limestone. Zessner et al. (Zessner, Blaschke et al. 2007) used Monte Carlo flow distance modeling to estimate the distances necessary to sufficiently reduce enteric viruses to achieve drinking water quality. Dependent variables were the depth of the vadose zone (1m or 20m), soil type and water table slope. With a 1m unsaturated zone (generally what is prescribed as the minimum vadose zone depth below OWTS dispersion fields in many jurisdictions in Canada), the minimum distance required for virus reduction was > 100m in loamy sand.

A risk management question that arises from the studies of OWTS density and virus persistence and migration, is whether current set-back requirements and lot size/subdivision density regulations are adequate for groundwater protection. Are the current regulations (usually 15 to 30 m separation between OWTS and wells) sufficiently conservative to protect against pathogen exposures that could lead to outbreaks? Our discussion of setback distances (Section 2.4.6) addresses this question.

3.3 Jurisdictional policies and guidelines

3.3.1 Canada

A number of provincial and regional or municipal jurisdictions in Canada have published subdivision-specific guidelines for the supply of drinking water to proposed or planned subdivisions. We have summarized the common aspects of these guidelines in Table 4. Most provincial or municipal governments publish guidelines for OWTS and drinking water supply and quality that are not specific for rural subdivisions (i.e. do not explicitly discuss subdivisions or refer to density of lots within residential developments). We have included brief reviews of the Manitoba, Ontario and Nova Scotia guidelines in this report.

3.3.1.1 British Columbia

[15] The authors provide no clarification of 'holding tank septic systems' in their publication.

Guidelines for British Columbia regions include the Vancouver region (Vancouver Coastal Health 2007), the Fraser Valley Regional District (Fraser Valley Regional District), and BC Interior (BC Interior Health 2006). These regions refer to provincial regulations for drinking water quality (BC Ministry of Environment 2009) and general subdivision requirements (BC Ministry of Transport 2009), however, they retain significant autonomy in specific designations, such as the definitions of water systems and in primary approvals for the different systems. Regional health authority public health engineers are responsible for most approvals. Evaluation and approvals across the province may vary due to regional regulations – the important consideration is whether the final performance requirements of subdivision OWTS are consistent.

3.3.1.2 Alberta

AENV provides guidelines for supplying drinking water via groundwater wells to subdivisions in cases where municipal supplies are not available or practical. Municipalities and counties must achieve the minimum standards set in provincial water and sewage guidelines (Alberta Environmental Protection 2006) and the development of new subdivisions (Alberta Environmental Protection 1998). In the case of the Municipal District of Rocky View, however, more explicit regulations are published (Municipal District of Rocky View No 44 1999; Municipal District of Rocky View No 44 2001; Municipal District of Rocky View No 44 2004). Rocky View is situated around the west, north and east sides of the City of Calgary. Aside from many rural farming community towns, rural subdivisions and hamlets of varying population densities have developed in this region, with subdivision density adjacent to Calgary increasing substantially in recent years.

3.3.1.3 Manitoba

Manitoba has no subdivision-specific guidance on for drinking water. There is a provincial water policy under which general policies for drinking water protection are outlined. The Manitoba Water Stewardship Office of Drinking Water administers the province's drinking water mandate. The Office was established following recommendations in the 2000 Drinking Water Advisory Committee Report (Manitoba Health 2000), at which time numerous agencies shared this administration.

Approximately 15% of Manitobans rely on private water supplies for their source of drinking water. The vast majority of private water systems are comprised of wells and cisterns. To encourage sampling of private water systems (a significant element of risk management), the Province of Manitoba subsidizes 70% of the analysis costs of one bacteriological sample per year. The current cost to homeowners for the testing is $8.00. If the analysis indicates that the water sample is contaminated, the province covers 100% of the analytical cost for an additional sample (re-sample) to confirm the initial sample results.

3.3.1.4 New Brunswick

New Brunswick requires a water supply assessment (Government of New Brunswick 1998) to be submitted as part of a subdivision planning and application package if an existing municipal water supply will not be use. Two water supply reports are possible, contingent upon the number of lots proposed immediately or for future development in the subdivision, and whether the area has documented water quantity or quality concerns. An abbreviated water supply report is required for subdivisions of 10 or more lots; a comprehensive report for subdivisions of 25 or more lots.

The following items must be addressed in the abbreviated report (Government of New Brunswick 1998):

- Site visit
- Discussions of the proposal with local well contractors
- Review of NB Department of Environment publications on groundwater potential
- Assess local geology and soils information
- Develop property maps for lands considered to be within the influence area or supplied with water from the same groundwater resource
- Determine if there are, or have been, uses in the assumed groundwater influence area that may contaminate groundwater resources
- Determine if there are uses in the assumed groundwater influence area that draw large quantities of water;
- Examine nearby water wells and DOE water well records for water quality or quantity concerns, and for well design or construction abnormalities (well depth, casing length, low static water level, etc.)
- Examine available groundwater studies and/or literature on the area; and
- Consultant's own familiarity with the area.

If the consultant concludes that there are concerns with some aspect of the water supply or quality, a comprehensive assessment will be required.

The comprehensive report must ensure adequate quantities of acceptable quality water for future residents, specify well construction techniques to mitigate water quality degradation, and show low probability of water in the subdivision being affected by, or affecting, water sources on adjacent lands, including water use conflicts between users.

A comprehensive water supply report is substantially more effort, because it includes test wells, water supply and quality testing. The parallel comparison is Phase I vs. Phase II environmental site investigations, with Phase I being largely a paper exercise and Phase II requiring more detailed field investigation, sampling, testing, and more comprehensive, interpretive reporting. Cost differences between Phase I and Phase II assessments can easily be 10- to 20-fold, and we would expect a similar difference between the abbreviated water supply report and the comprehensive report.

3.3.1.5 Ontario

Ontario provides guidelines for individual autonomous water supply and sewage disposal systems. These guidelines are relevant for subdivisions, however, the structure and content of the documents is such that they do not lend themselves to the same comparisons as we provided for BC, Alberta and New Brunswick. Frankly, the Ontario guidelines are cumbersome, onerous regulatory documents from which to extract applicable guidance for OWTS and private wells at a subdivision scale.

Individual autonomous water supply and sewage disposal systems are defined as owned, operated and managed by the owner of the property upon which the system is located and which do not serve more than five residential units/lots. Requirements for application for review of individual on-site sewage and water services include terrain analysis, hydrogeological report or an assimilation capacity study, completed in accordance with the requirements of the Environmental Protection Act and Ontario Water Resources Act

(Ontario Ministry of Environment 2008). The developers must demonstrate through these reports that the proposed development (≥ 5 residential lots) will not have an adverse effect upon the environment or public health (Ontario Ministry of Environment 1996). Municipalities, through regional Boards of Health, are generally under contract with the Province under Part VIII, Environmental Protection Act, RSO 1990 (Ontario Ministry of Environment 2008), with respect to septic tanks and certain other sewage systems, including communal sewage systems which discharge to the subsurface.

Ontario Ministry of Environment and Energy provides guidance for a water quality risk assessment for groundwater potentially affected by OWTS (Ontario Ministry of Environment 1996). The intention of the risk assessment is that it includes the combined impact of all of the individual systems in a development. The MOEE provides an outline of a three-step assessment process: 1) Lot size considerations; 2) System isolation considerations; 3) Contaminant attenuation considerations. These three considerations are common to most OWTS and private well guidelines and form the basic structure of the common risk mitigation model for OWTS and drinking water protection.

Table 4. Jurisdiction-specific requirements for drinking water in subdivisions.

Jurisdiction	BC[1]	BC Interior[2]	AB[3]	MB[4]	ON[5]	NB[6]	NS[7]
Subdivision-specific drinking water requirements	Yes	Yes	Yes	No	Yes Subdivision development not supported by MOE where background groundwater NO_3-N > 10mg/L	Yes	No
Water source	Groundwater; surface water; new water system (2 or more residences); extension of existing system	Groundwater or surface intake.	Extension of municipal source or groundwater if sufficient supply	Ground or surface	Prioritize subdiv development where municipal water and sewer can accom-modate or be expanded in near future. Groundwater and OWTS last choice when other options unavailable	Groundwater	Groundwater
Water quantity	2500 L/day per household	Not specified	1250 m^3/yr Certify no impact on gw quantity or quality on adjacent properties	Not specified	Not specified	450 L/day per person	ca. 350 L/day per person
Water quality	CDWQ	CDWQ required for small system and water supply system	CDWQ	MWQSOG	Assess potential impact of OWTS in subdiv development on groundwater – WQ Impact Risk Assessment[8]	CDWQ Assess impact of OWTS on wells down-gradient of subdivision	CDWQ

Water system designations	Water system for 2 – 4 households = **water supply system** defined by Drinking Water Protection Act. Water system for >5 lots = **water utility** (Water Utility Act)	**Private system** - one connection serving a single family residence **Small system** - water system serves < 500 individuals per 24hr **Water Supply System** Serving > 500 Population - two or more connections serving population > 500	Not specified	**Private system – ** wells owned by private citizens **Semi-public**- <15 connections and serve public **Public -** >15 connections	Not specified	Not specified	**Private system –** wells owned by private citizens **Public System** - >15 connections or serves 25 people/day
Regulating agencies and acts	**Water supply system** - Regional Health Authority approval. **Water utility** – provincial approvals needed.	**Private system** – Regional Pubic Health Inspector/Drinking Water Officer approval. If surface supply, require water license from MOE Water Stewardship Div. **Small system** – Must meet BC-DWPAR Construction and operating permits required. **Water supply system** – must meet BC-DWPAR. Require source approval, construction permit, operating permit	Municipalities; Alberta Environment	Manitoba Water Stewardship Office of Drinking Water Manitoba Public Health Act; Manitoba Drinking Water Safety Act	Ontario Ministry of Environment for > 5 lots per development Municipalities have discre-tionary approval for 5 or fewer lots Environmental Protection Act; Ontario Water Resources Act Allowance for Large Sub-surface Sewage Disposal System (<4500L/d; > 5 residences with communal OWTS, or; > 5 residences w. private individual OWTS)	Rural Planning District Commission	NS Dept of Environment and Labour

Density-specific requirements (subdiv lots per ¼ section)	None identified	None identified	< 5 – report for all wells in 800m radius > 6 – report for all wells in 1.6km radius > 15 total in subdiv – AENV approved study	None identified	Lot sizes ≥ 1ha, > 5 lots per development; fewer than 5 lots discretionary review by municipalities	≥10 lots – abbreviated supply report ≥25 lots – comprehensive supply report	None identified
Accreditation requirements for source & supply reports	Public Health Engineer	Well construction: Qualified well driller as per MOE Water Act, Ground Water Protection Regulation	APEGGA certified professional for well and supply reports			Qualified hydrogeologist or PEng	
General					Terrain analysis and hydrogeological report, or an assimilation capacity study following Environmental Protection Act and Ontario Water Resources Act		Specified set-back distances from OWTS

BC-DWPAR = BC Drinking Water Protection Act & Regulation (BC Ministry of Environment 2009)
CDWQ = Guidelines for Canadian Drinking Water Quality (Canada 2008)
MWQSOG = Manitoba Water Quality Standards, Objectives and Guidelines, Final Draft 2002 (Manitoba Conservation 2002)
[1] (Fraser Valley Regional District ; Vancouver Coastal Health 2007; BC Ministry of Environment 2009; BC Ministry of Transport 2009)
[2] (BC Interior Health 2006)
[3] (Alberta Environmental Protection 1998; Municipal District of Rocky View No 44 1999; Municipal District of Rocky View No 44 2001; Municipal District of Rocky View No 44 2004)
[4] (Manitoba Health 2000; Manitoba Conservation 2002)
[5] (Ontario Ministry of Environment 1996; Ontario Ministry of Environment 2008)
[6] (Government of New Brunswick 1998)
[7] (Nova Scotia Environment and Labour 2004; Nova Scotia Environment 2008)
[8] Technical guideline for individual on-site sewage systems: water quality impact risk assessment (Ontario Ministry of Environment 1996). The Regional Director also reserves the right to require more detailed assessment than is specified in section 5.0 of this technical guide.

3.3.2 USA

3.3.2.1 California

The potential impacts of AB 885 on water quality and public health are evaluated in depth in the DEIR (EDAW 2008, Section 4.1). The current regulatory paradigm allows each of the nine Regional Water Boards to set their own water quality objectives for pathogens, resulting in inconsistent requirements across the state. Concerns addressed in the DEIR include direct and indirect impacts of pathogens, nitrogen and other CoCs caused by the construction or operation of OWTS, and whether new regulations could supersede more protective local regulations.

3.4 Subdivision-specific drinking water systems

Based on our review, there are no requirements among jurisdictions outside of Saskatchewan that require a centralized piped water system to be installed during the development of a new subdivision. The issue of jurisdictions specifying particular drinking water supplies for subdivisions does not arise directly in the various regulatory documents. For most Canadian jurisdictions, the quantity of clean groundwater is a critical factor; whether that is delivered via municipal water distribution systems or individual wells is less critical. Rather, some provinces or municipalities prioritise new subdivision developments where connection to existing municipal drinking water distribution systems is feasible.

3.5 Risk Mitigation Practices

Policies and actions to mitigating risks of contamination of drinking water by OWTS in subdivisions are inseparable from the overall OWTS guidelines that are being developed by Saskatchewan. Sufficient care and attention to local and regional parameters are required to achieve adequate protection of public health and ecosystem integrity. The common points of attention among most of the different jurisdictions include:

- Soil and geological characteristics
- Hydrogeological characteristics – groundwater depth, aquifer size and boundaries, groundwater flow and direction
- Groundwater quantity and quality for development property and adjacent properties
- Separation or set-back distances between water sources and OWTS
- Recognition of compounds of concern – pathogens, nitrogen, phosphorus, etc
- Clear definitions of the responsible entities for different water supply options available for subdivisions – i.e. whether more than one household share a well
- Well and OWTS maintenance and water testing

Many of these overlap with those highlighted in our review of onsite wastewater treatment jurisdictional guidelines.

Other risk mitigation initiatives and requirements are evident, such as assessment of the long term water supply for each subdivided lot (Alberta, BC, New Brunswick, and Nova Scotia) and the risk of influence (whether by quantity or quality degradation) on wells on adjacent properties are fundamental risk management actions that are designed to reduce risks associated with aquifer depletion (such as groundwater flow changes, water table fluctuations resulting in fractures, sink-holes, etc) which, in turn, may increase risks of septic field effluents entering groundwater sources. Alberta is the only jurisdiction to require evidence that the subdivision will not influence wells on adjacent properties, however, New Brunswick requires a water quality impact assessment on wells down-gradient of the subdivision.

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4 Review of Saskatchewan Interim Guidance Document for Developments and Subdivisions where Private Sewage Systems are Proposed

Prepared by Cathy Ryan and Angus Chu, June 13, 2009

Note: This report specifically excludes task II, Objectives IV and V (Risk).

4.1 Introduction

The focus of this task is to evaluate the guidance document to determine if the required information and methodologies identified can be applied with a reasonable level of confidence. The intention of the guidance document is to evaluate the impacts of new developments and to ensure that they are protective of human health and the environment. Many studies reviewed for this report have identified hydrogeological sensitive areas, often located in an area of sandy soils underlain by an unconfined permeable aquifer (e.g. (Anderson, Otis et al. 1994; Lu, Tang et al. 2008). Although there is significant interest and research into alternative or advanced Onsite Wastewater Treatment Systems (OWTS) methods, they are not yet proven (e.g. Rich 2008). There were virtually no references that proved there was little to no water quality impact from septic systems to groundwater. At issue then, is the probability that a septic system plume will intersect a water well capture zone. It has been historically impractical and of little interest for researchers to monitor sites with low densities of septic systems where soils effectively treat and dispose of sewage effluent. This fact makes it very difficult to confidently identify geological features that would indicate effective effluent treatment and thus protection of human health and the environment. In areas with a combination of high OWTS densities and hydrogeologic sensitivity, we are able to reasonably identify inappropriate, or hydrogeologically sensitive areas. We have less information about whether properly designed and operated OWTS are indeed effective at remediating effluent in areas of moderate to low hydrogeologic sensitivity.

The following points describe the more significant changes recommended for the guidance document.

4.1.1 'Level 1' and 'Level 2' in lieu of 'Basic' and 'Advanced' Assessment.

We recommend that Basic and Advanced Assessments could be adjusted for more effective and appropriate application. Basic assessments currently contain requirements for potentially costly field program deliverables. There may be situations where non-intrusive assessment tools are adequate for assessment purposes. Currently contaminated site assessment investigations in Canada are basically split into mainly non-intrusive (Phase I) and intrusive (Phase II) methods, with considerably higher expenses for Phase II justified by the outcome of the Phase I assessment. In the current Guidance Document, Level 1 site assessments could include inventory of groundwater drilling well records including geology, depth to aquifer, confined or unconfined, any shallow groundwater encountered, completion details including screened intervals, distance from proposed subdivision etc., distance from lakes and rivers, surface waters, dugouts for use, geological map survey and air photos in time to look at change in site conditions historically. The requirement for test pits in Level 1 Assessments is maintained since it is a standard requirement for OWTS site assessments.

Level 2 site assessment are much more likely to include intrusive measures (in the absence of significant existing data) and monitoring, including field methods to identify restrictive layers and stratigraphy, texture, and structure, deeper than test pits (i.e. drilling with methods that can allow determination of geology), and the requirement and capacity to install and monitor piezometers to appropriate depths. This will probably cost much more than a Level I to conduct.

The Guidance Document currently distinguishes between a Level 2 Site Assessment and a Cumulative Impacts Assessment despite the fact that they are not required independently of each other. We thus recommend that the Cumulative Impacts Assessment should be included as a part of the Level 2 Site Assessment. This will ideally avoid confusion on the part of the proponents.[16]

4.1.2 Level 2 Evaluations should be Conducted by Professionals with Accreditation Appropriate to Hydrogeology

The Level 2 Site Assessment has a clear requirement for hydrogeological expertise and judgment. We are thus recommending that this work be supervised by professionals with appropriate accreditation (e.g. P. Eng. and/or P. Geol.) Given that professional agrologists may have conducted individual OWTS evaluations in the past, they may be inclined to move into Level 2 Assessments. In our view they do not have the appropriate groundwater background to do so. In reality the development of a preliminary conceptual model in Level 1 Assessments should be conducted by a groundwater professional also, although we have not stipulated this.

4.1.3 Level 2 Evaluations should be made publicly available by municipalities

The development of a robust conceptual model is a process that involves a number of iterations (and typically precedes the development of a mathematical model). It is not in the interests of the Regulatory Authorities, or the public interest, to have the development of new conceptual models in a given region without the benefit of earlier conceptual models. Thus, we are recommending that all approved Level 2 Assessment be made publicly available. This will enable the gradual development of an increasingly improved conceptual model. This does not nullify a proponents need to collect new data. Rather, it allows them to produce an improved conceptual model. Further argumentation about this point follows.

4.1.4 Evaluation Requires a Site Specific Conceptual Hydrogeological Model.

Site specific conceptual hydrogeological models are the main way that hydrogeologists understand and communicate subsurface conditions in a practical way. They consist of a semi-quantitative framework of available data that describes how water enters, and

[16] Upon evaluating the Interim Guideline from a risk-based perspective, it became apparent that further restructuring of the Cumulative Assessment was required to maximize risk management efforts, while reducing assessment effort for most development cases. The Cumulative Assessment is described further in Section 5 and Appendix I, Section 6.

eventually leaves a hydrogeologic system. They typically include an idealized graphical representation in plan and cross-section (or block) diagrams that incorporates assumed physical boundaries of the flow system (e.g. appropriate site boundaries and/or watershed divides), the subsurface hydrostratigraphy, material properties like hydraulic conductivity, groundwater levels and flow directions, and groundwater sources (e.g. recharge, surface waters) and sinks (e.g. surface waters, well pumping). Conceptual model development typically requires a review of literature and data in the project area and a good hydrogeological foundation. Information on how to develop, and examples of, conceptual groundwater models can be found at the following three websites:

http://www.connectedwater.gov.au/framework/conceptual_models.html;
http://va.water.usgs.gov/online_pubs/FCT_SHT/Fs099-99/fs099_99.pdf; and
http://www.ccme.ca/assets/pdf/pn_1144_e.pdf .

An example is also shown in Figure 12.

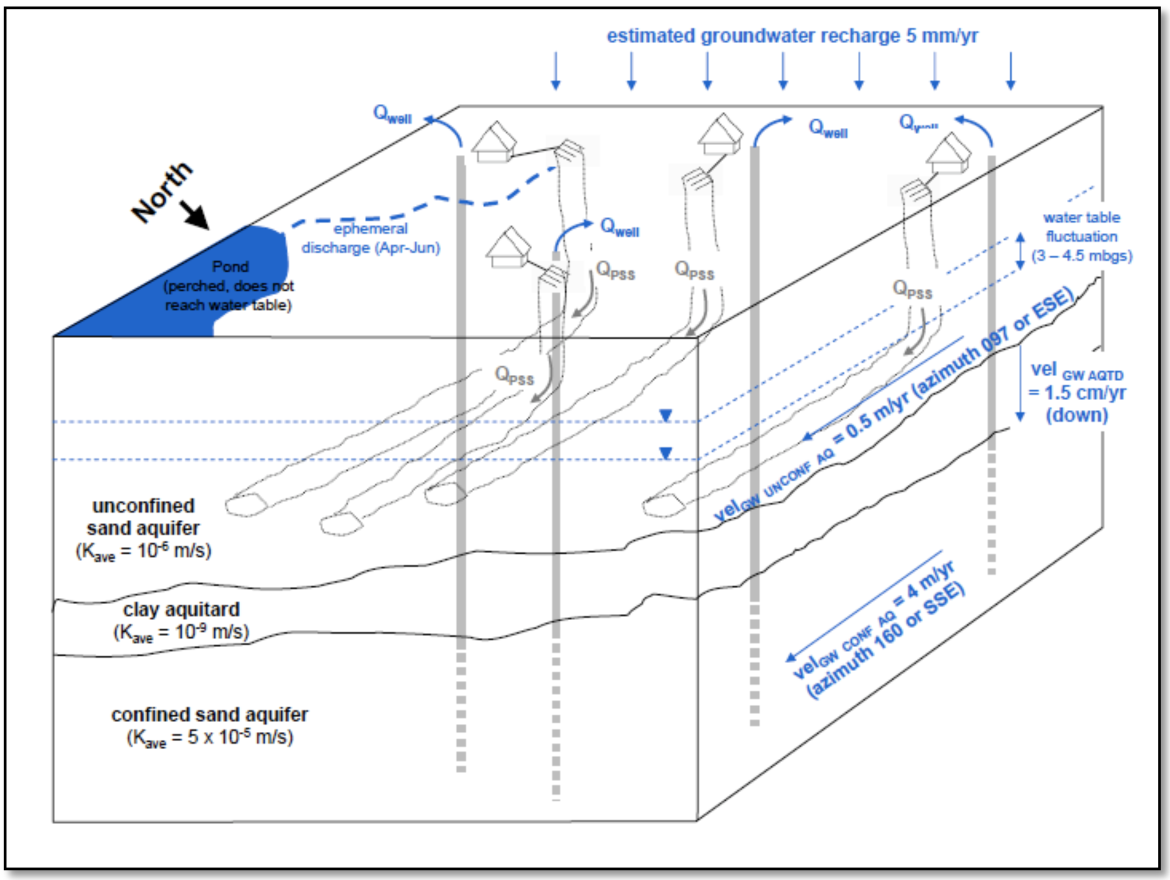

Figure 12. An example of a conceptual hydrogeoelogical model for a site with four houses. OWTS effluent plumes are shown schematically.

Basic water budget for quarter section in conceptual model above:

GW recharge ~ 3,200 m3/yr
Total OWTS recharge (four houses) ~ Q water wells (four houses) ~ 1,280 m3/yr
GW ‘throughflow’ in unconfined aquifer (avg depth ~ 5 m) ~ 6700 m3/yr
Vertical groundwater flow through aquitard ~ 3,840 m3/yr
GW ‘throughflow’ in confined aquifer (avg depth ~ 15 m) ~ 19,200 m3/yr

4.1.5 Data availability for Level 1 Assessment

Most current developments do not have monitoring wells in place. If they do, they are not typically designed for detection and compliance of on site systems. Rather, they are usually in place for things like contaminated site investigations. This leaves drinking water well geochemistry and geology (bore hole logs from water well drillers) and routine analytes from lab testing (i.e. fecal, hardness, alkalinity, pH etc.). This lack of available water quality data would be strengthened considerably by requiring the regulatory authorities and/or municipalities making previous reports publicly available. Since groundwater is a public resource, there is good reason to make reports related to groundwater available to other developers and to homeowners. This requirement may also result in an increased quality of reporting overall, and increasingly better reports with time. All water wells within a radius of 1 km, or the nearest twenty water wells should be assessed (p. 16, 10th bullet). The guidance document should require the water well records be appendicized to the report and relevant details summarized in the report. In particular these water well records should be used to understand the hydrogeologic units that domestic water wells are exploiting.

Given a water well record review has been required, it wouldn't be much more work for the proponents to provide a conceptual cross section indicating the hydrogeologic unit(s) being exploited by water wells, and receiving the OWTS effluent (p. 17, section (1)). If previous assessments were available to proponents, the conceptual model would ideally evolve and become more robust with time. One of the requirements for the Level 1 could be the development of a preliminary conceptual hydrogeologic model. It would be ideal if consultants were asked to schematically illustrate OWTS effluent plumes in groundwater (e.g. Figure 12). This can be very instructive. For instance, if one takes a quarter section and puts 40 lots onto it in a grid section, and draws groundwater plumes (in a horizontal flow field) that are as wide as the tile fields extending to the down-gradient side of the quarter section, it is difficult to imagine how one could have water wells in the same unit without interference (see also Section 2.4.8).

4.1.6 Level 2 Assessments

If a site specific hydrogeological conceptual model cannot be reasonably accomplished with existing data then an intrusive program needs to be planned and conducted. Deep test pits may be advisable to investigate restrictive layers in the stratigraphy (p12 «the consultant must clearly identify…). Deeper pits with large excavators can be as deep as 20 feet in stages or drilling with hollow stem augers to investigate deep restrictive layers. The restrictive layers we currently investigate are shallow in nature and used to determine linear loading rates (Table 5). This soil log shows soil depths to 4 feet and is a prerequisite for site evaluation at the individual lot level. The subsurface information required for Level 2 or Cumulative Impact Assessments would be used to investigate localized groundwater mounding conditions that could be induced with effluent application. The information that could be required include deep restrictive layers as demonstrated by horizon C (45+ inches) in Table 5, but much deeper. Important soil characteristics to identify include mottling, gleying, and any other indication of seasonally high water elevations. The overall number of test pits should be a minimum of 2 or enough to demonstrate the level of heterogeneity of soils in the proposed development. Some sites may require so many test pits that drilling might be in order or both a drilling and test pit program be initiated.

Table 5. Soil log example.

HO107-03 PRIVATE SEWAGE TREATMENT SYSTEM SITE ASSESSMENT FORM

Legal Land Location					Plan	Block	Lot	GPS Coordinates	
LSD	Sec	Twp	Rg	Mer				Easting	Northing
S W	xx	xxx	xx	4	-	-	7	-	-

Aerial Photos:	AS 2621.201	Topography:	Undulating
General Vegetation:	Grasses, w small poplar	Slope in area of test pit %:	**4 to 5 %**
		Position of system on slope:	Upper to mid slope

Site No.	Subgroup	Parent Material	Soil Moisture	Drainage	Depth of sample #1	Depth of sample #2
A 14	DG.SS	Eolean over Bedrock	Dry	Well Drained	28 inches	48"

Horizon	Depth (inches)	Texture	Colour	Gleyed	Mottled	Structure	Consistence	% Coarse Fragments
Ah	0-8"	Silt Loam	10YR 2/2 very dark brown	None	None	Moderate, Medium, Granular	Soft	<5
Ae	8-9"	Sandy Loam	10YR 6/2 Light brownish grey	None	None	Weak, Fine, Platy	Slightly hard	<5
Bnt	9-30"	Silt Loam	10YR 4/3 Dark brown	None	Few Fine Faint	Strong, Course, Subangular blocky	Very Hard	<5
Csk	30-45"	Loam	10YR 5/2 grayish brown	None	Few Fine Faint	Massive	Hard	5 – 10
C	45 +"	Clay	10YR 3/2 very dark grayish brown	None		Weathered shale	Very hard	N/A

Depth to Groundwater	Not encountered	Limiting Soil Layer Characteristic	Weathered shale at 45 inches. Design soil texture is loam.
Depth to Seasonally Saturated Soil	None indicated – (few fine faint mottling is not a concern)		
Depth to Limiting Layer	45 inches (weathered shale)	Limiting Topography	none
Depth to highly Permeable Layer	Not encountered		

Comments

Few roots in the Bnt horizon. Depth of Ah increases going down-slope
Native soil loading rate based on Silt Loam texture = 0.28 gal per square foot.
Linear loading based on linear loading table = Silt Loam texture, strong blocky & granular, to depth of 30" = 3.3 gal per lineal foot. Massive loam at 30" is not considered limiting layer for required 3 foot depth below bottom of mound sand layer.

The following list describes a possible drilling and monitoring program for a Level 2 protocol including:

1. A sufficient number of wells, installed at appropriate locations and depths, to estimate:
    a. groundwater flow direction,
    b. a sufficient number of groundwater samples from the uppermost aquifer;
    c. sufficient field-evaluated hydraulic conductivity tests to provide a reasonable estimate for an average hydraulic conductivity value.
2. Sufficient data points to ensure the measured groundwater represents the quality of background groundwater that has been affected by leakage from on site systems.
3. The groundwater represents the quality passing the relevant point of compliance.
4. The groundwater monitoring and sampling and analysis procedures are designed to ensure monitoring results provide an accurate representation of groundwater quality at background and down gradient wells.
5. Verify that sapling procedures and frequency are protective of human health and the environment
6. Verify that groundwater elevations are measured in each well immediately prior to purging and that it has been determined the rate and direction of groundwater flow each time groundwater is sampled.
7. The groundwater elevations in localized wells be measured within a period of time short enough to avoid temporal variations in groundwater flow that could preclude accurate determination of groundwater flow rate and direction.
8. A background groundwater quality needs to be established in a hydraulically up-gradient for each of the parameters required by the monitoring program.
9. Make sure that the number of samples collected to establish groundwater quality is consistent with accepted statistical procedures.

4.1.7 Matrix of Development Requirements (Interim Guidance, Table 2.1)[17]

The definitions for sensitivity seem arbitrary. Based on a cumulative loading theme it may be acceptable to have high lot densities in good soils. Density is a quantifiable metric and should be calculated and still preserves meaning and gives a lot more discriminatory information. This could be done in addition to division into 3 categories. All in all, decisions should be driven more by sensitivity and less by density. For example high densities in low sensitivity areas are currently being implemented throughout Alberta with little to no obvious problems. High sensitive areas no matter what the densities have shown that there are problems, mostly due to improper design (e.g. site evaluation). Albeit these are simple to diagnose. The use of a one-kilometer distance to differentiate between 'low' and 'medium' sensitivity is reasonable, but arbitrary. The Health Region might want to acknowledge a priori that they understand this to avoid later criticism. This might be as simple as including a footnote to the effect that "While it is recognized that a 1 km distance is somewhat arbitrary, this distance is thought to be reasonable."

[17] This is an analysis of the original assessment matrix in the Interim Guidance document. Impressions developed in this analysis informed our revised matrix table (Table 6). Ultimately, a risk approach to setting up subdivision OWTS assessments favoured the framework presented in Figure 19.

4.2 The use of nitrate-nitrogen as the critical contaminant.

While nitrate is typically one of the more problematic constituents of OWTS effluent, and is reasonably easy to sample for and measure, pathogen transport in fractured glacial sediments (till or clay) and/or bedrock could be more critical (see Appendix III). This is, of course, the Walkerton situation. Pathogen transport through fractures could be much more rapid than nitrate, which could be attenuated by denitrification and/or diffusion into the glacial sediment matrix. You might want to use the nitrate-nitrogen guideline only if there are no fractures that might extend to the depth of water well use. This could be a footnote in this section indicating that fractured geologic environments require more detailed investigation, or it could be a bullet under 2.2 (3) Sensitive Areas and Conditions. Fractured conditions are already mentioned on p. 10c., but might warrant inclusion in the discussion about critical contaminants. One other issue regarding the use of nitrate as the parameter of concern is the high higher dilution is required to bring fully nitrified effluent fecal coliform value low enough to be safe. While OWTS effluent nitrate typically only needs to be diluted by about five times to be below drinking water guidelines, OWTS concentrations of fecal coliform need about 1,000 to 10,000 times dilution before it can be considered safe for human contact. Therefore these indicator organisms are more sensitive than just about anything else, except for maybe viruses. Their only saving grace is that they tend to stick onto porous media (or soils) and decay with time (Brown, Slowey et al. 1978; Hinkle, Weick et al. 2005). Many pathogens and pathogen indicators have been suggested for monitoring water including *E. coli*, fecal and total coliforms, different *Enterococci spp*, bacteriophages and other viruses. Each has its own advantages and disadvantages. For example, bacteriophages and viruses due to their size are less effectively treated by filtration processes in the soil but are more difficult to culture, especially human viruses that require cell culture methods for quantification. In most water related surveillance programs that investigate the impacts of sewage use either fecal coliforms or *E. coli*.

4.3 Dilution Approach for determination of cumulative impacts

The dilution of effluent in groundwater recharge is a bona fide approach, but could be problematic to apply to southern Saskatchewan (p. 14, section ii). Basically, one needs to show that there will be 4 to 6 more times natural groundwater recharge (with low total N concentrations) than OWTS effluent in order to dilute the effluent nitrogen from 40 to 60 mg N/L to less than 10 mg N/L in the groundwater. This approach may be of limited use, however, in the 'Palliser's Triangle' region (which contains Regina, Moose Jaw, and Saskatoon) due to the net evapotranspirative deficit. For example, groundwater recharge near Saskatoon is estimated to be a 'few millimeters or less' (Keller, van der Kamp et al. 1988). Groundwater recharge of 2mm/year would be equivalent to about 3.8 m^3/day of groundwater recharge on a quarter section. This would be clearly insufficient to dilute OWTS effluent from even a single household (assuming a daily effluent flow of 450 gal/day, or about 2000 L/day). Groundwater recharge in Saskatchewan is also notably spatially variable at multiple scales. We do not know if this is an accurate model of behavior of various pollutants including nitrate, phosphate, total and fecals. This model is most conducive for nitrate only. Denitrification may confuse the matter.

4.4 Additional Considerations for development of Interim Guidelines

The following three sections illustrate important aspects to be considered when decisions are undertaken. Although they are not directly related to any specific objectives of the project, they would have significant effect on what can practically be accomplished within the regulatory framework, and provide 'food for thought' as we move forward in this process. They rely significantly on our experience in Alberta, which is directly applicable to Saskatchewan to a large extent.

4.4.1 Regulations and Compliance

Traditional OWTS are currently not required to monitor or report on any regular basis for a variety of pollutants and their concentrations for compliance purposes. Environment ministries and health regions in Canada typically have mechanisms in the form of approvals to require monitoring, reporting and compliance. Alberta Municipal Affairs does have the 'permitting process', but it doesn't have legislative power to require this level of stringency. The director of private sewage has tried to require homeowners to report efficiencies of their packaged sewage treatment plant on a yearly basis and has not been successful at implementation. On-site cluster systems can treat similar residential densities, but are regulated by the Ministry of the Environment because they are cluster systems. This would seem to have some advantages for on site systems, although cluster systems may be environmentally superior. If compliance is necessary or warranted this would have cost implications. We would not expect homeowners or developers to conduct this type of audit – logically professionals should be used (but homeowners and/or developers may have to pay for this).

On site systems would be significantly challenged to conduct sampling programs that could accurately assess the cumulative impacts of these systems. In treatment plant situations where rural municipalities and utilities are involved there are qualified operators that routinely collect effluent samples for analysis in CAEL accredited labs. This CAEL requirement is in large part due to the potential for using results from labs in court. A composite sample from all the dose chambers in a given development could be done on an appropriate interval and would need some indication of flow rates from all these houses to accurately quantify hydraulic, organic, and contaminant loadings. OWTS loadings cannot be accurately assessed with no measurement of sewage flow rates and concentrations (Section 2.2.1). These measures may want to be incorporated in areas that need an extra level of insurance for compliance.

All OWTS designs are based on a number of assumptions (e.g. 75 gal/person/day, 1.5 people/bedroom and septic tank effluent quality removal efficiencies of 50% for TSS and BOD) that are poorly validated. Therefore loadings are always predicted and not accurately measured. Material balances in these situations are practically not possible. Detection of water quality exceedance is thus thought to be the most practical methods to use. Subdivisions could potentially incorporate flow meters and sampling and analysis in situations that warrant this level of compliance (e.g. sensitive and high density sites).

4.4.2 Prescriptive versus performance based assessment tools

Most of the regulations in the SOP are prescriptive for a very important reason. It is easier for installers and operators because you do not have to comply with performance. Many of Ministry of Environment regulations are performance-based for a very important reason. They provide better protective of human health and the environment. Monitoring to ensure compliance is built into performance based regulations. Prescriptions do not have the prerequisite for function according to their initial design. Ultimately we would like to have performance-based assessment, but it is not currently practical (i.e. are we going to require every homeowner to sample and analyze their effluent?). This exact same issue was seen with storm water effluent loadings into the Bow River in Calgary when total loading (and Total Maximum Daily Loads, or TMDLs) was implemented by Alberta Environment. Up until about the late 1990s Calgary`s performance effluent criteria only applied to their sanitary effluent (2 effluent discharges into the Bow river). When they had to consider storm water they were now dealing with about 600 more point sources of water quality degradation going into the river. So they developed a total loading management plan that included a program to assess loadings from storm water. This is our current situation for on site systems. The city was successful because they had both the human and $$ resources to carry out this exercise. So the question is who will pay for it? We don't believe that the demand or will is there to carry out this type of exercise. Also, developers will surely be resistant.

4.4.3 Case study: on site versus cluster

We came across this recently and would like to use this to illustrate a few important issues. The following email was sent to us:

> "I live out in the Springbank area on an acreage, and a developer is proposing to put in a 700 unit (including senior's housing and assisted living) development in the lands adjacent to our property. We are very concerned about wastewater management obviously as the catchment area for our well is downstream of the development. They are proposing to use a GE membrane based system for wastewater management and an 18 acre septic field. I was wondering if you could direct me in terms of finding out how reliable and effective are these systems. I believe the development (Pradera Springs) will be one of the largest to take advantage of such a system, and I worry about being guinea pigs. I have no expertise in the area of wastewater management, but would like to know if there is data out there (not provided by the company) that might inform us."

An 18 acre septic field for 700 units would be less effective than 700 individual units spread out. There are however many who would argue that the 18 acre field would be more protective of human health and the environment. They have some effective and convincing arguments:

- The cluster system would have a properly operated membrane bioreactor (MBR) with on site, qualified staff. Monitoring and compliance requirements would be more effective and reliable than OWTS;
- Flow measures and maintenance programs would be conducted to ensure accurate cumulative impact assessment on an ongoing basis;
- MBRs are currently the Ministry of Environment's preferred option. (They produce much more consistent effluent quality than activated sludge since they do not rely on gravity for clarification. They are also very expensive and not yet available for on site application.)

4.5 References

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5 Risk Assessment

A "residual risk assessment" of the guidance document consists of the fundamental components of a risk assessment: a problem formulation to define the problem to be addressed by the assessment; an exposure assessment to evaluate the extent that receptors may be exposed to a hazard; a toxicity evaluation to understand the adverse health effects that could occur and their exposure parameters; a risk characterization in which the probability and severity of an effect are evaluated; and, finally, a risk management evaluation that helps the assessors and assessment users understand how various decisions and actions throughout the process can play a substantial role in risk reduction.

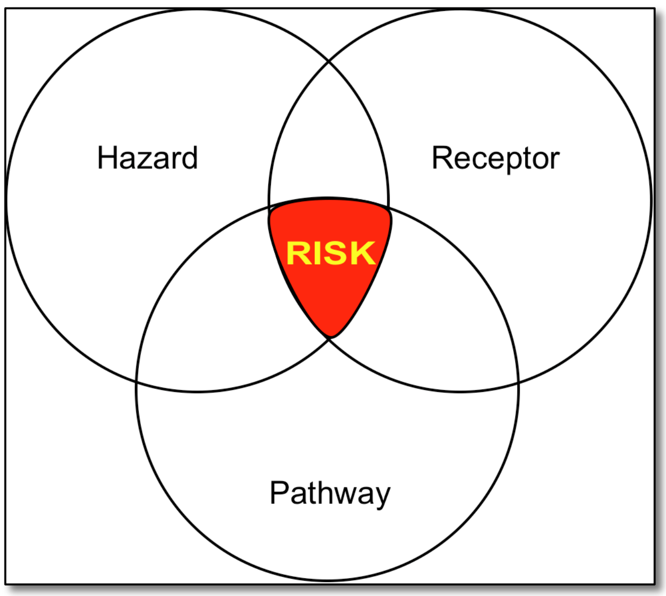

Figure 13. The Hazard – Pathway – Receptor paradigm for the existence of risk.

5.1 Problem Formulation

Risk can be defined as the probability of an adverse outcome, combined with the severity of the outcome. Three factors need to be present in order for a risk to exist:

1. A hazard;
2. Receptor(s) that may be adversely affected by the hazard; and
3. A pathway or mechanism for the receptor(s) to be exposed to the hazard.

The three-circle diagram (Figure 13) represents the necessity for the three factors to co-occur for a risk to exist. Risk is represented by the intersection of the three circles.

5.1.1 Receptor

There are two receptors we are concerned with. 1) Residents of the subdivision and those near the subdivision, particularly those relying on shallow groundwater for their household water supply. We can further break the residents down into age and sensitivity classes – infants, toddler, child, teen, adult, immuno-compromised, etc. 2) Ecological systems in the vicinity, such as surface water (streams, wetlands, lakes). The ecological systems can also be separated in terms of susceptibility to particular hazards, for example, a shallow lake with long water retention time vs. a high-flow stream or river.

For risks to occur, receptors must be present. Because we are considering residential communities, we assume that people live in the subdivision 100% of the time. However, outside of the subdivision we should consider a greater range of possibilities regarding population, residential density, and their distance from the subdivision. For example, at the time of a subdivision development application the area around the proposed subdivision may be agricultural land with one or two residences per ¼ section. No proposal has been made to develop that land into residential lots. From the human receptor perspective, there would be minimal opportunity for risks to arise. If regional planning efforts suggest that the surrounding areas would eventually be developed, precaution would indicate that the risk assessment should assume a similar density of residential development as is proposed for the subdivision currently being assessed.

5.1.2 Hazard

A number of compounds of potential concern were discussed in the literature review, including pathogens, nitrate and phosphate, metals, and other organic compounds. We will focus on pathogens and nitrate as the two most important hazard groups.

Physical or toxicological effects on receptors are our main concern in this exercise. We have all heard the phrase "The dose makes the poison". From this, we understand that the amount of hazard, i.e. concentration of nitrate or total numbers of pathogens, will determine the severity of the adverse effect. Therefore, the more we know about nitrate concentration and pathogens, the more accurately we can estimate the potential degree of exposure.

Pathogens

Pathogens from sewage are removed by several mechanisms through the treatment system, including by filtration and predation within the biofilm that forms at the soil trench bases. Following this, they are attenuated through three different mechanisms in the vadose zone:

a) Retention by the soil matrix;

b) Predation by soil organisms (other microbes, small invertebrates);

c) Die-off of anaerobic pathogens due to exposure to aerobic conditions.

All three of these mechanisms achieve greater performance with increasing retention time by the pathogens in the soil vadose zone.

The pathogen count in groundwater ultimately depends on 1) the amount of pathogen removal within the treatment system proper (i.e., more advanced and effective treatment techniques achieve lower pathogen counts and therefore load the vadose zone less heavily); and 2) whether the effluent spends sufficient retention time for pathogen attenuation in the vadose zone prior to reaching the water table. The retention time is a function of soil type, unsaturated flow velocities, vadose zone thickness, and total loading rate (see Appendix III).

Among pathogens, viruses are the most robust and require the longest time for deactivation. Viruses can break through the vadose zone to the groundwater (Borchardt, Haas et al. 2004; Locas, Barthe et al. 2007), even if bacteria do not, and common potability tests do not test for viruses. Viruses may be retained but not deactivated in the soil, and then released under seasonal water table fluctuations or heavy rains (EDAW 2008).

Nitrate

Nitrate concentration in the septic field effluent is a different problem, because under certain conditions, it passes through the vadose zone with little to no attenuation. A review (Brown and Bicki 1987) of groundwater nitrate concentration and high density OWTS indicated that density is positively correlated with groundwater nitrate, and others have shown increased nitrate in groundwater with increased residential development and OWTS use (Wakida and Lerner 2005; Cole, Kroeger et al. 2006; Kaushal, Lewis et al. 2006; Zessner, Blaschke et al. 2007). Lot size plays a role, and is negatively correlated with groundwater nitrate. Similar observations were reported for a series of subdivisions in Wisconsin (Tinker 1991), where the author showed increasing nitrate from the up-gradient side of each subdivision toward the down-gradient side. Sources other than OWTS also contribute to nitrates beneath subdivision, particularly lawn fertilizers. In many cases, groundwater nitrate is above 10 mg/L nitrate-N.

Under some conditions (e.g. deep vadose zones (>3m to 30m) with sufficient retention times and relatively high organic matter in the soil (or other carbon sources such as in the effluent itself), enough denitrification may occur to prevent nitrate from reaching the groundwater, as predicted in Colorado (Heatwole and McCray 2007), and reported by others (Spalding and Exner 1993). Similar models or observations have not been reported for Saskatchewan soils.

When vadose zone conditions are not ideal for denitrification (i.e., vadose zones containing little to no organic matter, with porous soils [i.e., high flow velocities], and often short retention times to shallow water tables), nitrate can pass through mostly unattenuated and enter the groundwater aquifer. For the purposes of this risk assessment, we will assume that nitrate passes through the vadose zone essentially unattenuated.

Given this assumption, the factors that determine the concentration of nitrate in shallow groundwater are limited to dilution and/or dispersion, and denitrification. A location's evapotranspiration surpluses (if present) will largely determine how much dilution (if any) occurs. Aquifer characteristics, including redox conditions and carbon source availability, groundwater flow velocity, direction, and volumetric flow rates, and distance of travel prior to contact with a well or surface water will further influence the concentrations at potential exposure points.

5.1.3 Pathway

Unless there is a mechanism for the receptor to be exposed to the hazard, there is no risk.

The conceptual model exercise, essentially drawing a picture of how we envision the onsite septic systems to exist individually and in a subdivision, is a valuable tool for evaluating the different ways in which various receptors can be exposed to the identified hazards.

In this case, we are assuming properly designed and functioning septic systems, therefore we will exclude the possibility of effluent ponding on the surface at or near the septic field. If subdivision residents and nearby residents are not exposed to surfacing effluents, the remaining possibilities for exposures are from drinking well water, drinking groundwater-fed surface waters such as streams and lakes, and incidental exposures from recreational uses of those surface waters. Well water from shallow aquifers is the most likely exposure pathway.

OWTS effluent will usually form a plume in the groundwater. Its properties will depend on parameters including the orientation of the dispersion field with respect to the groundwater flow direction, its velocity, and overall aquifer characteristics. These plumes can be very long and narrow, with minimal transverse mixing, and have been observed to travel hundreds of meters to thousands of meters while retaining > 50% of the initial effluent concentration (Tinker 1991).

In the pathway analysis, we incorporate the following assumptions, reported observations, and inferences:

- subdivision and regional residents use shallow groundwater as their drinking water source;
- OWTS effluent, once it reaches groundwater, produces a nitrate-rich plume;
- if the capture zone of a well intersects an OWTS plume, its likely the well water will be higher in nitrate;
- the probability of residents being exposed to an OWTS plume, and therefore nitrate, increases as the density of OWTS increases.

One objective of the Level 2 and Cumulative assessments should be to understand the most likely plume characteristics based on groundwater flow rate and direction, dispersion field orientation, and soil characteristics. If plume formation can be reasonably predicted, risk management options based on informed well placement decisions could be effective in reducing the chance of drawing OWTS sourced nitrate into the drinking water supply.

Pre-development land use, such as intensive agricultural use (Spalding and Exner 1993) or dairy farming (Showers, Genna et al. 2008) can complicate delineating nitrate-rich plumes and sources of groundwater nitrate, and these prior sources of nitrate in the soil can continue to contribute to the groundwater for many years, particularly if the vadose zone is deep and has accumulated substantial nitrogen load. Lawn fertilizers in subdivisions can also contribute significant nitrate to shallow groundwater.

5.1.4 Nitrate Stratification

The issue of OWTS effluent plumes moving along the top of a shallow aquifer should be considered from both the hazard and the pathway perspectives, because it can have a bearing on nitrate concentration (hazard) and the likelihood of drawing plume water into a well (pathway). Stratification of nitrate concentrations in groundwater, particularly shallow, unconfined groundwater, is well established (Spalding and Exner 1993).

If an aquifer is relatively thick (e.g. >15m), drawing water from near the bottom of the aquifer could reduce the likelihood of drawing nitrate-rich water – i.e. we could reduce the chance of drawing water directly from within a plume (pathway risk mitigation). However, over extended time, or extended high volume water withdrawal, draw-down from higher in the aquifer is more likely to occur, particularly if the groundwater velocity is relatively low. In this case, the well is drawing upper level nitrate-rich water along with the lower aquifer water. Dilution will play a role in this case, with water from the draw region mixing with the plume as it is drawn into the well. The amount of dilution would be very site-specific, dependent on variables such as dispersivity, groundwater velocity, pumping rates and number of wells, aquifer thickness, number of plumes in the aquifer, and other non-point sources of nitrate such as lawn fertilizers – prediction of dilution rates and final nitrate concentrations would be implausible without this site-specific information. A groundwater monitoring program that includes stratigraphic sampling is a viable approach to understanding and monitoring nitrate movement in the groundwater and private wells.

5.2 Scenarios

The magnitude of risk can be estimated either qualitatively or quantitatively. The basic arithmetic of risk assessment is simple; it becomes complex very rapidly when there are numerous scenarios in which any of the variables influencing receptor, hazard or pathway change. Table 2.1 in the interim guidance document gives scenarios that cover ranges of hazard and pathway variables (Table 6).

Table 6. Assessment matrix (from Interim Guidance Document for Developments and Subdivisions where Private Sewage Systems are proposed) with revisions based on risk assessment perspective.[18]

		"Sensitivity" Addresses the Hazard aspect of the Risk Assessment: vadose zone retention time determines pathogen die-off; some attenuation of nitrate is expected with distance: 1km is somewhat arbitrary, but *presumed conservatively protective*[1]		
		Low > 1 km from a municipality **and** sufficient vadose zone retention time is easily achieved[2]	**Medium** < 1 km from a municipality **and** sufficient vadose zone retention time is achieved[2]	**High** sufficient vadose zone retention time may not be achieved[2]
Density Addresses part of the Pathway aspect of the Risk Assessment:	**Low** < 5 residential units per ¼ section	No subdivision assessment[3]	No subdivision assessment[3]	No subdivision assessment[3]
	Medium Between 5 and 40 units per ¼ section	Level 1 Assessment	Level 1 Assessment	Level 1 Assessment
	High > 40 residential units per ¼ section	Level 2 Assessment	Level 2 Assessment	Level 2 Assessment + consider advanced systems or alternatives to individual systems[4]

[1]The 1km distance is specified in Subclause 20(1)(d)(i) of *The Plumbing and Drainage Regulation*.

[2] NO system should be approved that cannot be shown to provide adequate protection of groundwater against pathogens.

[3] Approvals for all individual OWTS require field-based assessments, including test pits or bore holes for soil characterization.

[4] Whether advanced OWTS or some other alternative will be required is an outcome of the plume interception probability and subsequent risk assessment steps. It is not a categorical assumption that OWTS are inappropriate for high-sensitivity + high-density developments.

[18] Working through a series of revisions of this assessment matrix was a necessary stage in evolving our risk-based understanding of the issues posed by OWTS in subdivisions. While this revised matrix approach to evaluating OWTS in new subdivision developments better reflects the critical pathogen risk by stressing vadose zone retention time, we believe that the full risk framework approach described in Figure 19 more completely addresses the risk concerns of OWTS use in subdivisions.

Pathogen removal in the vadose zone is dependent on loading from the treatment system, soil characteristics and soil depth, which together define the vadose zone retention time. In a High Sensitivity area, either one or both of the soil parameters may be compromised. Therefore, a solution is to use advanced treatment technology that is designed for the specific soil conditions and keeps pathogen loads within the range that the soil attenuation capacity can handle.

For the case in which sufficient vadose zone retention time may not be achieved, there still may be adequate retention time for pathogen die-off, but without a safety factor to account for recalcitrant viruses or unusual flushing of the vadose zone from flooding or water table fluctuations.

The scenarios shown in Figure 14 through Figure 18 depict primarily pathway aspects of the risk assessment – i.e. how likely is it that a drinking water well will draw water from an OWTS plume, based on a vertical perspective of the Pathway? This is complementary to the Density rows in Table 6 that refer to the horizontal (area) aspect of the Pathway. The cumulative effect on one particular well or a series of wells from increasing the density of septic systems is more difficult to portray in two-dimensional pictures.

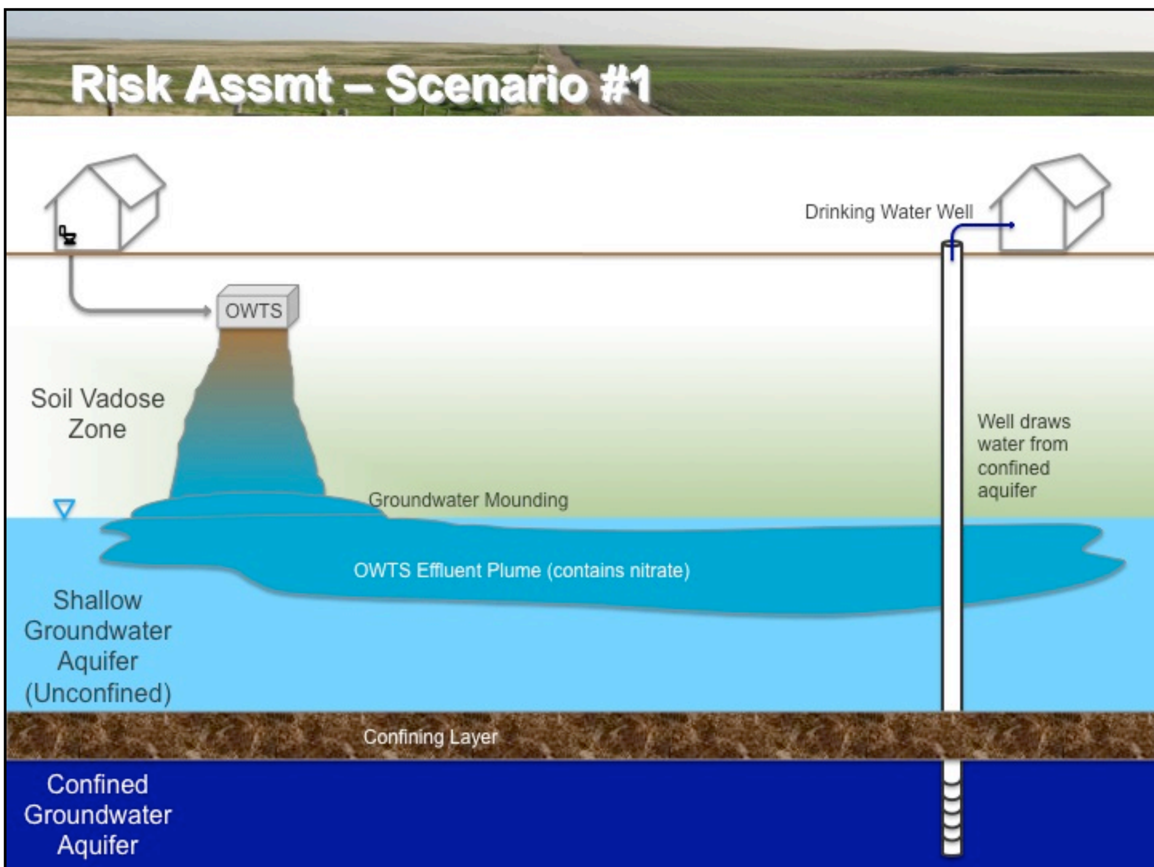

Figure 14. Nearby wells draw water from a confined aquifer. Exposure to pathogens is unlikely; exposure to nitrates is unlikely.

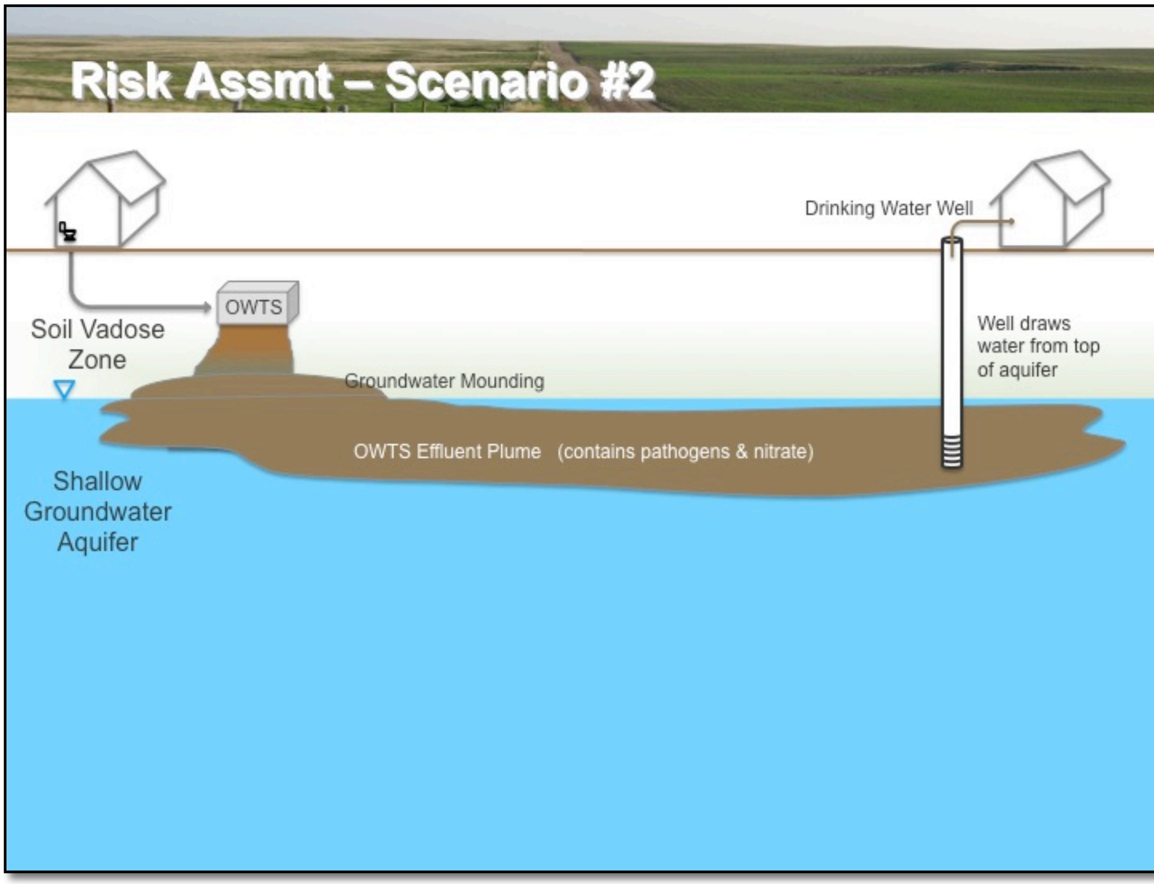

Figure 15. Insufficient retention time in the vadose zone; nearby well draws water from high in the shallow groundwater aquifer. Exposure to pathogens is likely; exposure to nitrate is likely.

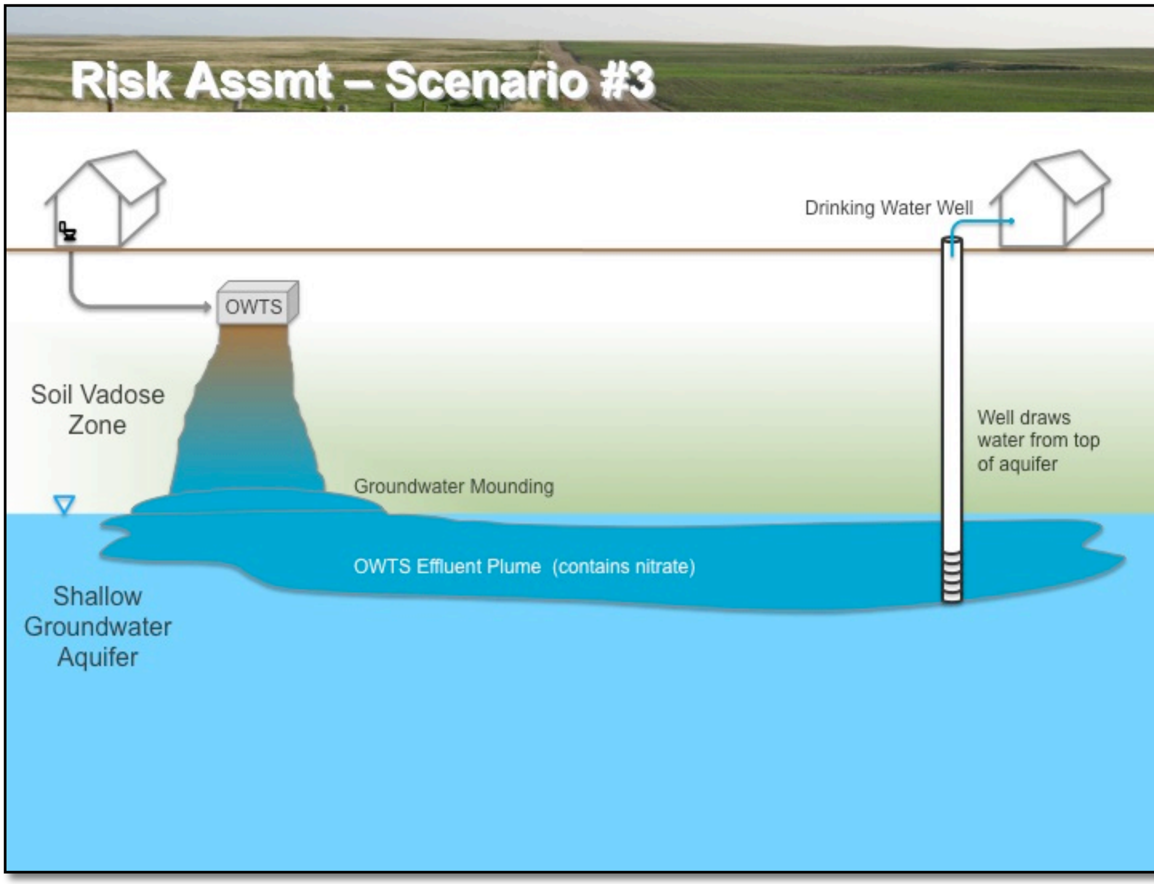

Figure 16. Sufficient retention time is attained in the vadose zone; nearby well draws water from high in the shallow groundwater aquifer. Exposure to pathogens is unlikely; exposure to nitrate is likely, if the well screen intersects the effluent plume or is near enough to draw water from the plume.

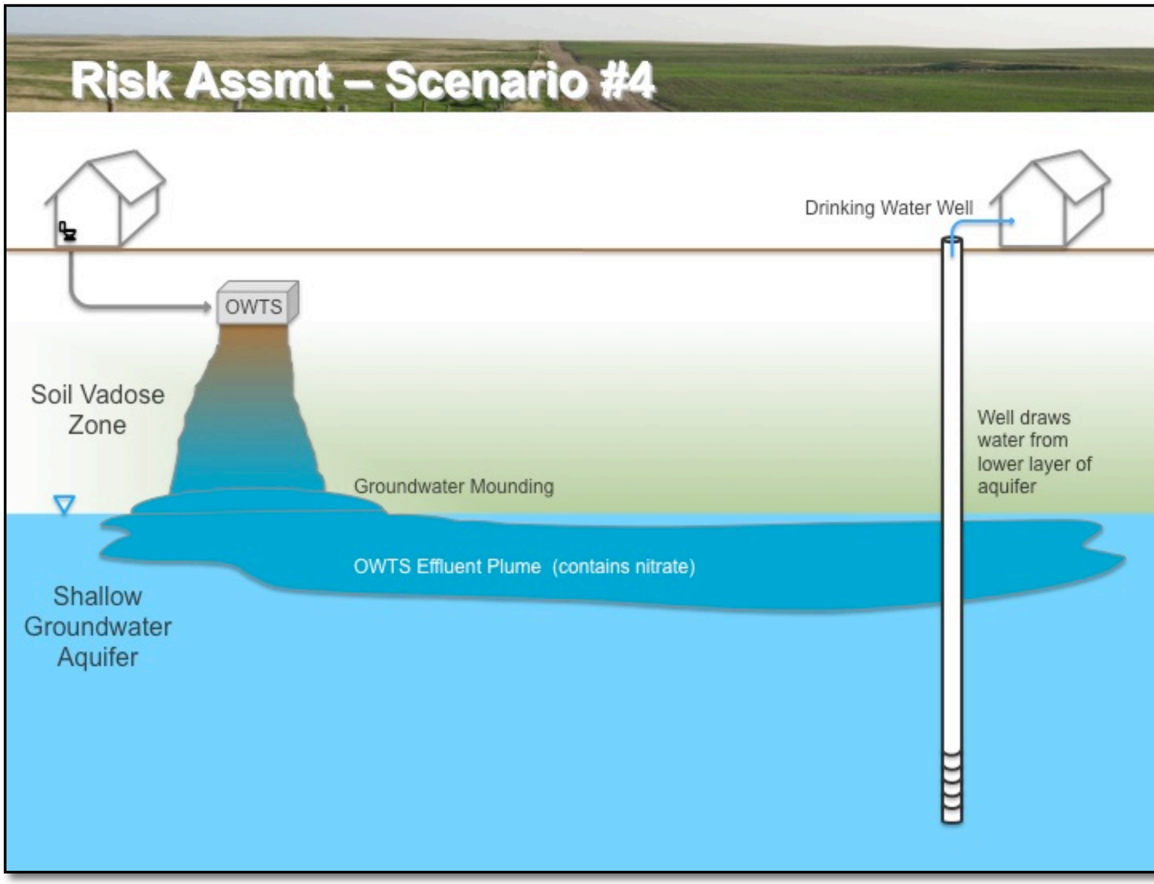

Figure 17. Sufficient retention time is attained in the vadose zone; nearby well draws water from deep in the shallow groundwater aquifer. Exposure to pathogens is unlikely; exposure to nitrate is unlikely for some unknown time; eventually, however, water from upper layers will be drawn downward, so if the effluent plume passes through the capture zone of the well, the nitrate plume could be pulled into the well.

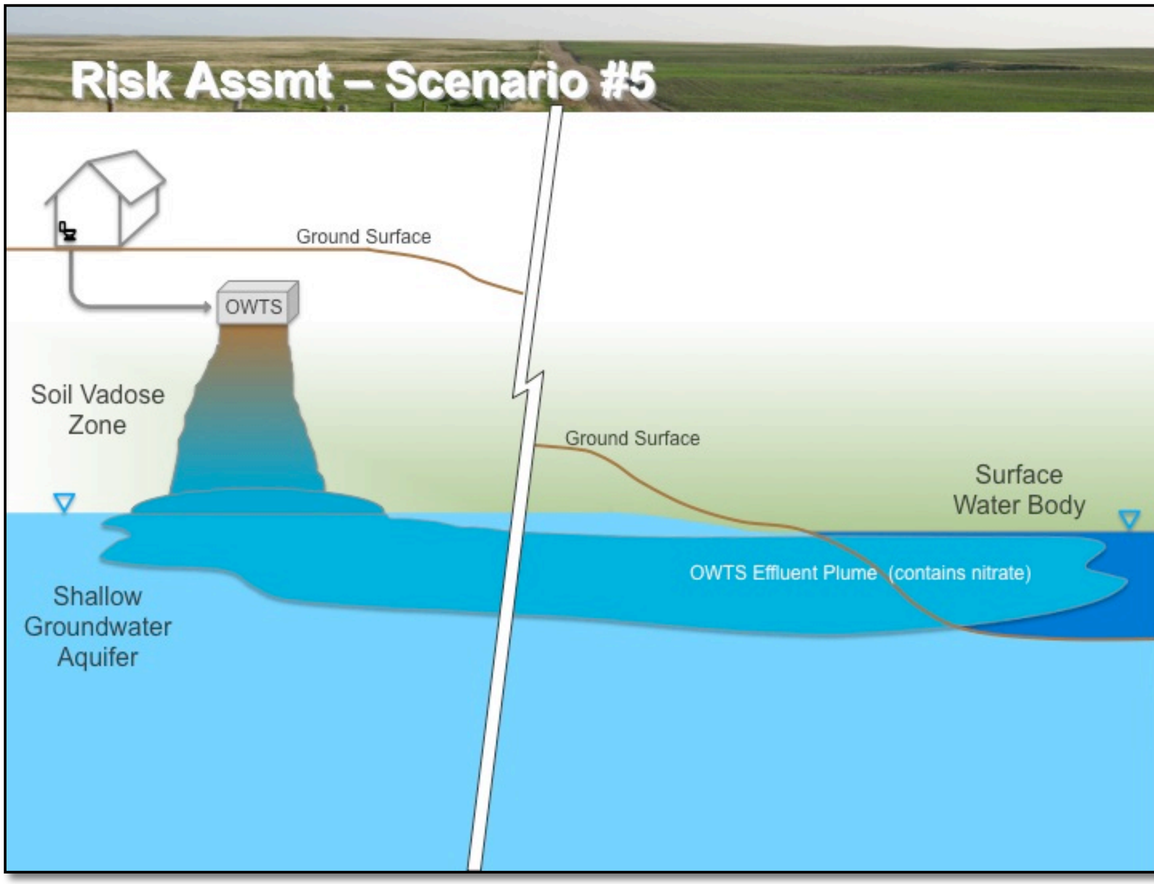

Figure 18. Sufficient retention time is attained in the vadose zone; surface water (stream or shallow lake) receives shallow groundwater. Pathogen load to the surface water is unlikely; nitrate load to the surface water is likely, total load depends on cumulative number of septic plumes reaching waterbody, which is dependent on septic system density. The resulting exposure concentration of nitrate in the surface water body is dependant on the respective flow rates (i.e., groundwater discharge relative to the surface water flow rates) and evapotranspiration rates.

5.3 Exposure evaluation

Exposure assessment is an estimate of the amount of hazard to which a receptor is exposed. This is usually a simple product of hazard (or COC) concentration in various media, the receptor's intake rate (food, water, air), normalized by the receptor's mass. Where this rapidly becomes highly complex is the different conditions under which exposures might take place – receptors may or may not be present at a particular place at a particular time and the probability of exposure and extent of exposure will vary over time, space, and other factors such as OWTS density; different receptors have different intake rates (toddler vs adult); concentrations of COCs vary over time and space. Traditional chemical risk assessment typically assumes either a maximum, an average, or upper 95th percentile of the mean for most of the parameters and follows the calculation to arrive at a worst-case or 'reasonable upper limit' estimate of exposure. When the parameters that influence exposure vary widely or are highly speculative (uncertain), that worst-case exposure estimate is seldom informative for practical risk assessment, risk communication and risk management actions.

5.3.1 Probabilistic evaluation

Each of the parameters that substantially influence risk in the three risk assessment circles could be described using a probability function, such as a Gaussian or logarithmic function. Sometimes this probability function would be the product of two or more variables that define or influence that circle. For example, pathogen die-off in the vadose zone is dependent on retention time (which in turn is determined by soil type, soil depth, hydraulic loading rate per area and soil moisture content). To enable a classical probabilistic analysis of exposure, we need to determine probability distribution functions for each of the primary variables that significantly influence the three aspect of risk that must co-exist. These would include:

- Probability function that describes the concentration of nitrate in groundwater. This is perhaps a logarithmic function with upper limit at 40mg/L nitrate-N (i.e. OWTS effluent), and lower limit at the background value.
- Probability function that describes pathogen counts entering shallow groundwater.
- Probability functions that describe the likelihood of intercepting a septic plume with a well, both vertically (stratification) and horizontally (OWTS density).
- Probability function that describes <u>whether</u> people/receptors are present.

Probability functions can be across space or time – ie. Variation with distance or area, or with time.

Monte Carlo analysis is a method of performing mathematical calculations using ranges of data instead of discrete data. The range of each data point is described by a probability distribution, and the Monte Carlo simulation performs the calculation many times over, each time randomly choosing a single data point from each data range according to its probability distribution. The individual results from each time the calculation is performed combine to make up the outcome distribution. Often, Monte Carlo simulations run 1000x or 10,000x through simple or complex mathematical formulae.

By dividing our probabilistic problem in to discrete "bits" or 'qualitative bits', we can generate a set of pictures to help us understand the bounds/range of the problem – i.e.

residual risks under different conditions. This approach conceptually mimics the quantitative Monte Carlo analysis, but since it is only qualitative it will not be able to determine specific probabilities for a given outcome. Rather, it provides us with a sense of what the range of outcomes may likely be (i.e., "best case", "worst-case" and "likely case"). It helps reduce the chances of us focusing on just the "worst-case" scenario, especially in those situations were this "worst-case" scenario ends up being fairly unlikely.

Many people intuitively assess everyday risks in a 'qualitative' probabilistic manner, understanding that risks do not change equally nor in a linear manner with different scenarios of an activity – e.g. automobile driving. Speed, road conditions, driver ability, traffic density, other drivers' abilities, mechanical factors – each of these have some definable range but that range is seldom linear for each factor, and that relationship can change in different scenarios (e.g. driving too slowly on a highway can be more hazardous than driving slightly above the speed limit, depending on overall traffic flow, whereas the opposite is true in a playground zone).

The qualitative interpretive value of a probabilistic assessment comes in being able to visualize the effect of choosing the 'worst-case' for each variable. For many variables in an exposure calculation, the worst-case is also very unlikely to occur. If we go back to the driving analogy, we recognize that if we always evaluated our risks by assessing the worst case for each variable (untrained, reckless driver; very high speed; rush hour traffic; black-ice and blizzard conditions), we would determine vehicle travel to be unacceptably risky. Very rarely do all of these worst case conditions come together at once. The most likely scenario is the median of each of the variables, in which case standard risk management and risk mitigation actions such as the skills taught in defensive driving schools are sufficient for safely traveling in a vehicle.

Risk is about the probability of an adverse effect combined with the severity of that effect. Nitrate exposure through contaminated groundwater ingestion can be very serious for infants and pregnant women. Guidelines have been established for this reason. Risk management actions, however, are relatively simple for reducing exposures to nitrate in drinking water. Infants that are breast-fed are not exposed; for those infants on formula, bottled water or filtered water can be used. Tap and whole-home filters designed to reduce nitrate to below guideline concentrations are available at reasonable costs.

The primary goal of the subdivision OWTS guidance should be to avoid contaminating potable water aquifers with nitrate or other compounds. However, because risk mitigation is intended to be reasonable, there should not be an "at all cost" effort undertaken to keep nitrates out of groundwater. In most parts of Saskatchewan, recreational and agricultural fertilizers and livestock manures contribute substantially more nitrate to shallow aquifers than subdivision septic systems (see Section 2.4.5.2).

5.4 Cumulative assessment

Most of us can relate to the phrases "the final straw" or "the straw that broke the camel's back". At the simplest level, a cumulative assessment is evaluating the number of straws one is stacking on to the camel's back over a period of time and continually comparing to the load the camel carried at the first straw. Even though we add only one or two straws at a time, each weighing only a few grams - seemingly insignificant by themselves - eventually we will end up with a load of straw that the camel's back can no longer sustain. If we know at the beginning how much weight the camel can carry, each time we add one or a few straws, we can compare the cumulative total weight of all straws to the camel's maximum carrying load. As we near that maximum, we know that the risk of exceeding it is increasing and at some point one more straw will tip the balance, or break the camel's back. If we haven't kept track of the cumulative weight from the beginning, and assume each time that just one more straw is negligible, the camel's broken back will be a complete surprise.[19]

A true cumulative effects assessment should begin with receptors (either populations or individuals) and evaluate the stressors that have an effect on either individual health or the population health. If we set our baseline on the WHO definition of health: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organisation 2007), and then consider the determinants of health (Canada 2008), there are a great many social, cultural, economic and physical factors that influence health, with toxic chemical exposure one contributor.

The oil sands development near Ft McMurray is a good example of the cumulative assessment concept. Oil sands operations officially began with Sun Oil Company (later to become Suncor) in 1967. Over the decades of development since that time, and particularly in the most recent decade, extensive changes to the physical landscape, the social and social-economic landscape and the cultural landscape have occurred. Each of these physical, social, social-economic, and cultural changes has influenced the wellbeing of people and communities in the region. Many of the changes have been positive, such as the overall rise in standard of living. However, substantial negative influences on (community) wellbeing are also evident (high housing costs, infrastructure overuse, health care system unable to cope, substance abuse and violence).

From the chemical exposure and effects perspective (common toxicity-based chemical risk assessment), a cumulative risk assessment should evaluate the comprehensive chemical intake from all sources (naturally occurring plus each industrial project and non-point sources such as towns and cities) and all pathways of exposure (all food sources, soils, water, air). Concentrations of numerous compounds such as locally occurring petroleum and crude-oil compounds, volatile organics, metals (e.g. mercury and arsenic), and airborne particulates *prior to the construction and operation of the first oil sand mine and upgrader* should represent the background to which all future measured and estimated compound concentrations could be compared. As each new proposed project is assessed, the *total additive amount* of emissions from all existing operational and approved projects and developments should be modeled.[20] The result of such an on-going assessment could be a regional map showing concentration isopleths for each compound that is of concern for human health and ecosystem integrity.

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[19] We also shouldn't focus solely on the straw. There may be other stressors the camel experiences that influence its strength, stamina and skeletal integrity – e.g. compromised nutrition, arthritic conditions, sore feet, reduced social interaction or being ostracized by other camels, humiliation or indignation at the need to perpetually carry the straw.

[20] In fact, what has commonly been accepted as a cumulative assessment is really an incremental assessment – emissions from all operating and approved project emissions are treated as the baseline and only the additive influence of the new project application is evaluated in the risk assessment. It becomes clear over time that each project will only contribute a small relative amount of emissions, therefore, the incremental influence on overall risks from chemical emissions from that project will always be minimal. However, just as for the camel, if we only evaluate risks this way, we will have little perspective on when we may reach the proverbial final straw for any particular receptor.

In this particular situation (subdivisions with OWTS), there is only one primary exposure pathway (water) and one primary hazard (nitrate) that can carry through to a cumulative assessment – this becomes a cumulative hazard dose. Other exposure pathways are zero. Thus, the cumulative assessment simplifies to an evaluation of all of the regional nitrate sources (within 1.5 km of the development – i.e. the surrounding sections). These nitrate sources must be evaluated with respect to their potential nitrate contribution to shallow groundwater, and then the travel patterns (plume geometry / fate) of these contributions can be modeled. Predictions can then be made regarding the potential cumulative hazard dose at the location(s) of interest.

5.4.1 Density and Layout

The meaning of cumulative impact assessment inferred by the Interim Guidance document is the accumulated impact on human or ecological receptors from multiple septic systems on a ¼ section subdivision. In our case of subdivision developments, the density of residential units and relative layout of their OWTS will be related to the chance of intercepting an effluent plume in a down-gradient well - i.e. the cumulative effect of greater density is increased probability of exposure due to intercepting a plume with a well. However, the probability of intercepting a plume does not determine the concentration of nitrate in the well water. The probability of plume interception must be evaluated in conjunction with the expected nitrate concentrations to which receptors could be exposed.

5.4.2 Nitrate concentration

The parameters needed for estimating nitrate concentrations in a well in a specific location include plume characteristics, stratigraphic nitrate concentration data, well configuration, and well capture calculations. Stratigraphic concentrations should be measured during the site assessment process. However, cumulative loading models that account for regional sources of nitrate should also be used to understand current and future loading to the aquifer. These regional sources should include: nearby agricultural activities – livestock, dairy and poultry operations and crop farming can contribute nitrates to groundwater and surface water through manure and fertilizer applications; recreational facilities, golf courses in particular, can contribute significant nitrate from fertilizer application.

Therefore, our definition of a cumulative assessment is the combined probability of effluent plume interception due to increasing density plus the influences of other nitrate sources on the concentration of nitrate in the shallow potable aquifer.

5.5 Hazard Assessment

Vast amounts of information on toxic effects of pathogens and nitrate exist in primary literature, internet databases, textbooks, and government agencies and resources. We will not re-do or attempt to re-summarize what has been done by many others. We will simply provide directly the information from other sources that, in our opinion, is relevant to the Saskatchewan situation and this risk assessment.

Effects should be assessed with respect to background concentrations; however, this can present a dilemma if the “background” concentration that exists at the time of subdivision planning has been increasing gradually over many years.

5.5.1 Human toxicity

5.5.1.1 Pathogens

From Draft Environmental Impact Report, California AB 885 OWTS (EDAW 2008):

> Pathogens can cause communicable diseases through direct and indirect body contact or ingestion of contaminated water or shellfish. A particular threat occurs when OWTS effluent pools on the ground surface or migrates to recreational waters. Some pathogens can travel substantial distances in groundwater or surface water. Pathogenic microorganisms found in domestic wastewater include a number of different bacteria, viruses, protozoa, and parasites that cause a wide range of gastrointestinal, neurological, respiratory, renal, and other diseases (Table 7). Infection can occur through ingestion (drinking contaminated water; incidental ingestion while bathing, skiing, or fishing), respiration, or contact. In susceptible populations, such as the very young, very old, pregnant, or immuno-compromised, increased potential exists for serious illness or mortality. (EPA 2002, Gerba et al. 1996.) Other less common routes may include inhalation of spray droplets or contact through vectors (EPA 2002, Salvato 1992).
>
> The health risks associated with surfacing sewage, or the degradation of groundwater or surface water, relate to the exposure of persons either through ingestion or contact and environmental factors affecting the viability of the pathogenic microorganisms in the sewage. Many factors are involved in estimating such risks, including the concentration of organisms, soil attenuation, saturated or unsaturated soil conditions, pH, temperature, humidity, nutrients, and others. Life spans of specific microorganisms in soils may vary from days to years depending on environmental conditions. Approximately 40% of the homes served by OWTS also draw their drinking water from groundwater located near an OWTS discharge (CWTRC 2003). With groundwater at depths of 3–5 feet, soil attenuation can promote die-off of bacteria and viruses up to 99.99%. Under other conditions, pathogens have been known to travel long distances in both groundwater and surface water (EPA 2002; Siegrist, Tyler, and Jenssen 2000).
>
> Bacteria
>
> Bacteria are single-celled microscopic organisms whose cells have no true nuclei. Among pathogenic agents, only bacteria have any potential to reproduce and multiply between, as opposed to within, hosts (EPA 2002). Many kinds of bacteria live in the human digestive tract, and human excrement is a primary source of bacteria in domestic wastewater. Very high concentrations of bacteria of many kinds are contained in domestic wastewater, most of which are not pathogenic; that is, they do not cause or produce disease. However, some bacteria that may be found in domestic wastewater can be pathogenic and are a major public health concern. The primary bacterial agents contributing to waterborne illnesses nationwide are shown in Table 7. In an optimally functioning OWTS dispersal field (depicted in Exhibit 2-1), the retention and die-off of most, if not all, observed pathogenic bacterial indicators occurs within 2–3 feet of the infiltrative surface (Anderson et al. 1994; Ayres Associates 1993a, 1993b; Bouma et al. 1972; McGaughey and Krone 1967). With a mature biomat at the infiltrative surface of coarser soils, most bacteria are removed within the first 1 foot vertically or horizontally from he trench-soil interface (University of Wisconsin 1978). Failure to properly site, design, install, and/or operate and maintain OWTS can result in the introduction of potentially pathogenic bacteria into groundwater or surface water. …
>
> Protozoa and Helminthes
>
> Pathogenic protozoa (single-celled animals), helminthes (parasitic worms), and their eggs are sometimes present in domestic wastewater. If ingested by humans, these can cause illnesses that range from minor gastrointestinal episodes to the very serious effects of *Cryptosporidium* (Table 7). If pathogenic protozoa reach groundwater, they can present a contamination risk if the water is ingested without disinfection. Protozoa are generally an order of magnitude larger than bacteria and often feed on bacteria (Wisconsin Department of Commerce 1998).

Viruses

Viruses are composed of a nucleic acid core (either deoxyribonucleic acid [DNA] or ribonucleic acid [RNA]) surrounded by an outer shell of protein called a capsid. Viruses are obligate intracellular parasites; they multiply only within a host cell, where they redirect the cell's biochemical system to reproduce themselves. Viruses can also exist in an extracellular state in which the virus particle (known as a virion) is metabolically inert. Viruses are not a normal part of the fecal flora. They occur in infected persons, and they appear in septic tank effluent intermittently, in varying numbers, reflecting the combined infection and carrier status of OWTS users (Berg 1973). It is estimated that less than 1–2% of the stools excreted in the United States contain enteric viruses (University of Wisconsin 1978), although episodic breakthroughs of virus and bacteria can occur in OWTS (EPA 2002). Therefore, such viruses are difficult to monitor and little is known about their frequency of occurrence and rate of survival in conventional OWTS and OWTS with supplemental treatment units. Common viruses that appear in wastewater are listed in Table 7.

In a study by Hinkle et al. (2005), in samples from wells located down-gradient from OWTS drainfield lines at an Oregon site, coliphage (viruses that infect coliform bacteria and that are found in high concentrations in municipal wastewater) were occasionally detected at low concentrations. These concentrations were below method detection limits; however, they were in replicate or repeat samples collected from the sites. Data indicate that coliphage were effectively attenuated over distances of several feet of transport in the underlying aquifer and/or overlying unsaturated zone. Viruses have been known to persist in soil for up to 125 days and travel in groundwater for distances up to 1,339 feet (ca. 400 m). {However, under certain conditions, viruses can have 2-log removal in 30 cm and 3-log removal in 60-90 cm of vadose soil.} Viruses are less affected by infiltration than bacteria (EPA 2002).

5.5.1.2 Nitrate

From Draft Environmental Impact Report, California AB 885 OWTS (EDAW 2008):

Table 7. Reproduced from Table 4.1-2, Waterborne Pathogens Found in Human Waste and Associated Diseases (EDAW 2008)

Type	Organism	Disease	Effects
Bacteria	*Escherichia coli* (enteropathogenic)	Gastroenteritis	Vomiting, diarrhea, death in susceptible populations (elderly, infants, pregnant, immunocompromised)
	Legionella pneumophilia	Legionellosis	Acute respiratory illness
	Leptospira	Leptospirosis	Jaundice, fever (Well's disease)
	Salmonella typhi	Typhoid fever	High fever, diarrhea, ulceration of the small intestine
	Salmonella	Salmonellosis	Diarrhea, dehydration
	Shigella	Shigellosis	Bacillary dysentery
	Vibrio cholerae	Cholera	Extremely heavy diarrhea, dehydration
	Yersinia enterolitica	Yersinosis	Diarrhea
Protozoa	*Balantidium coli*	Balantidiasis	Diarrhea, dysentery
	Cryptosporidium	Cryptosporidiosis	Diarrhea
	Entamoeba histolytica	Amoebiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
	Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
	Naegleria fowleri	Amoebic meningoencephalitis	Fatal disease; inflammation of the brain
Viruses	Adenovirus (31 types)	Conjunctivitis	Eye, other infections
	Enterovirus (67 types, e.g., polio, echo, coxsackie viruses)	Gastroenteritis	Heart anomalies, meningitis
	Hepatitis A	Infectious hepatitis	Jaundice, fever
	Norwalk agent	Gastroenteritis	Vomiting, diarrhea
	Reovirus	Gastroenteritis	Vomiting, diarrhea
	Rotavirus	Gastroenteritis	Vomiting, diarrhea

Source: EPA 1999 (as cited in EPA 2002).

> Nitrogen is an essential plant nutrient and a fundamental component of proteins and other constituents of living matter. … The most generally available nitrogen compound for plants is the nitrate ion, NO_3. This is the nitrogen compound generally found in groundwater. The drinking water standard for nitrate-N (the weight of the nitrogen content of the nitrate ion, i.e., nitrate as nitrogen) is 10 mg/L. Nitrate is sometimes expressed as the ionic weight of the nitrate ion per unit volume, which results in a concentration approximately 4.5 times higher than that of nitrate-N, or 45 mg/L. This chapter will refer to the nitrate-N form and drinking water standard of 10 mg/L.

Excessive levels of nitrate-N in drinking water can cause “blue baby syndrome” or methemoglobinemia in infants and pregnant women, and other human and ecological problems (Pierzynski et al. 2000). Nitrogen in wastewater is generally present as organic nitrogen (i.e., nitrogen combined in organic molecules such as amino acids, proteins, and polypeptides) or ammonia. Nitrate (NO_3^-) and nitrite (NO_2^-) are two oxidized forms of inorganic nitrogen and are key factors in the nitrogen cycle and in aquatic environments. Total nitrogen concentrations in domestic septic tank effluent are in the range of 40–100 mg/L (EPA 2002).

From the Agency for Toxic Substances and Disease Registry (ATSDR), Case Studies in Environmental Medicine, Nitrate/Nitrite Toxicity (Registry 2007)

What Are the Physiologic Effects of Exposure to Nitrates/Nitrites?

Unless conditions exist for reducing nitrate to nitrite in the gut (i.e., high pH and proper intestinal microbial flora), ingested nitrate (NO_3^-) is metabolized and excreted without producing apparent adverse effects. Nitrate in the diet may even enhance host defenses against gastrointestinal pathogens by modulating platelet activity, and possibly even gastrointestinal motility and microcirculation (37–39). The known toxic effects of nitrate exposure result from the conversion of nitrate to nitrite (22). The effects of nitrite (NO_2^-) are the same whether nitrite-containing compounds are ingested or inhaled, or nitrite is produced in vivo from nitrate.

Hematologic Effects

Acute acquired methemoglobinemia is the most important adverse health effect caused by excessive nitrate or nitrite exposure. Methemoglobinemia may arise from various etiologies (40), including

• ingestion or skin exposure to an oxidizing drug or chemical

• systemic acidosis as a result of diarrhea and dehydration

• nitrate or nitrite ingestion in water

• genetic disorders presenting as cyanosis shortly after birth

Methemoglobinemia is a well-recognized hazard of ingestion of nitrates and nitrites (41, 42). The first reported case of fatal acquired methemoglobinemia in an infant due to ingestion of nitrate-contaminated well water occurred in 1945 (43). In the following 25 years, about 2,000 similar cases of acquired methemoglobinemia in young infants were reported worldwide; about 10% of such cases resulted in death (44). Sporadic cases and occasional fatalities occurred through the 1980s and 1990s, most often resulting from ingestion of nitrate-contaminated well water by infants (33, 45, 46).

Hemoglobin molecules contain iron within a porphyrin heme structure. The iron in hemoglobin is normally found in the Fe^{++} state. The iron moiety of hemoglobin can be oxidized to the Fe^{+++} state to form methemoglobin. Once it is formed, the molecule loses its ability to carry molecular oxygen. Because red blood cells are bathed in oxygen, a certain amount of physiologic methemoglobin formation occurs continuously. Several endogenous reduction systems exist to maintain methemoglobin in the reduced state. In normal individuals only about 1% of total hemoglobin is methemoglobin at any given time (40, 47).

Methemoglobin can be reduced back to hemoglobin by both spontaneous (NADH-dependent and to a lesser degree by NADPH-dependent) methemoglobin reductase enzymes. Depending on the percentage of total methemoglobin, the clinical picture is one of oxygen deprivation with cyanosis, cardiac dysrhythmias and circulatory failure, and progressive central nervous system (CNS) effects. CNS effects can range from mild dizziness and lethargy to coma and convulsions (33, 48, 49).

Cardiovascular Effects

Hypotension is the main cardiovascular effect seen with nitrate and nitrite medications. It is not commonly seen with ingestion of nitrates and nitrites in food and water.

Reproductive and Developmental Effects

Maternal exposure to environmental nitrates and nitrites may increase the risk of pregnancy complications such as anemia, threatened abortion/premature labor, or preeclampsia (29, 50). Recent epidemiologic data have suggested an association between developmental effects in offspring and the maternal ingestion of nitrate from drinking water; however, a definite conclusion on the cause-and-effect relationship cannot be drawn (33). The maternal transfer of nitrate, nitrite, and N-nitroso compounds, and the potential effect on fetal death and malformation have been described (51). A few studies have hinted at a role for nitrate intake in the risk for developing diabetes mellitus in childhood (52–54). All of these reproductive and developmental effects require further study.

Carcinogenicity

Some study results have raised concern about the cancer-causing potential of nitrates and nitrites used as preservatives and color-enhancing agents in meats (55). Nitrates can react with amino acids to form nitrosamines, which have been reported to cause cancer in animals (51). Elevated risk of non-Hodgkin's lymphoma and cancers of the esophagus, nasopharynx, bladder, and prostate have been reported (56–59). An increased incidence of stomach cancer was observed in one group of workers with occupational exposures to nitrate fertilizer; however, the weight of evidence for gastric cancer causation is mixed (60, 61). Epidemiological investigations and human toxicological studies have not shown an unequivocal relationship between nitrate intake and the risk of cancer (31).

Key Points

• Acute acquired methemoglobinemia is the most important adverse health effect caused by excessive nitrate/nitrite exposure.

• Maternal exposure to environmental nitrates and nitrites may increase the risk of pregnancy complications such as anemia, threatened abortion/premature labor, or preeclampsia.

5.5.2 Ecology

A main concern from the ecological perspective is the contribution OWTS effluents could have toward surface water eutrophication.

From the Draft Environmental Impact Report, California AB 885 OWTS (EDAW 2008):

> Eutrophication (algal blooms) describes a condition of excess nutrient (and phosphorus) enrichment, and has been identified as one of the leading causes of surface water quality impairment in the United States today (EPA 1996b). Typical problems associated with eutrophic waters are increased growth of undesirable algae and aquatic weeds; low dissolved oxygen levels after the death of algal blooms and nuisance aquatic weeds, which in turn can result in fish kills; increased turbidity and decreased light penetration through the water column that eventually leads to the loss of benthic plant and animal communities; sedimentation, which negatively affects navigational and recreational uses of surface waters; and increased incidences of foul odors, surface scums, unpalatable drinking waters, and nuisance insect problems (EPRI 2001).

Phosphorous and nitrate are nutrients in aquatic systems, and can both contribute to eutrophication. One often already exists in excess, leaving the other as the limiting nutrient. Nitrate-nitrogen concentrations as low as 0.1 to 0.4 mg/L can trigger eutrophication (Goldman and Horne 1983) p. 123), if phosphate is already in excess.

Eutrophication ultimately results in a balance of growth that skews the natural flora and fauna diversity. Algal growth, phytoplankton and periphyton production can reduce dissolved oxygen. Nitrate can affect macrophyte production, amphibian community and the benthic community. These can combine to affect fish communities. (Efroymson, Jones et al. 2007)

In the Saskatchewan context, however, particularly in southern and central Saskatchewan, agricultural contributions of nitrate and phosphate to surface water in particular will significantly outweigh even high-density septic system contributions due the magnitude of the non-point source nitrate load from the agricultural sector.

5.6 Risk characterisation

Risk characterization is the interpretive stage of risk assessment. It encompasses total exposure to a hazard, the toxicity response to that hazard, the probability of an adverse effect occurring, and the severity of that effect. Many assessments simplify this characterization down to a simple ratio between the total exposure or total daily intake (TDI - the exposure rate) and the toxicity reference value (TRV), also an exposure rate value.

Risk ratio = TDI ÷ TRV

The TRV is determined from in-vivo or in-vitro toxicity studies and adjusted with various uncertainty factors to conservatively account for factors such as species sensitivity differences (in the case that the toxicity studies were done on rats or mice vs humans), and whether the lowest observable adverse effects concentration (LOAEC) or the no-observable adverse effects concentration (NOAEC) was available. Health Canada other agencies determine TRVs according to their agency-specific derivation guidelines and procedures. A TRV, however, is a number derived to provide a high margin of safety; there is more 'policy' than science in these published values. Therefore, when risk characterization is simplified to a quotient between the TDI and the TRV, called either an exposure ratio (ER) or a hazard quotient (HQ), a useful characterization of the probability and severity of an adverse effect on a particular receptor has not been done (Allard, Fairbrother et al.

2009).

In the case of exposure to pathogens or nitrates from OWTS effluent, we don't need to be as concerned with the TRV process. The data on the toxic response (blue baby syndrome) of infants to nitrate comes from human epidemiologic studies and there is very high confidence in the concentrations of nitrate-nitrogen that leads to the health effect – i.e., no uncertainty factors have been applied. Therefore, we can simply conclude that if infants ingest water with > 10mg/L of nitrate, there is a significant probability of methemoglobinemia resulting from the exposure.

So the fundamental questions that define risk are: how likely is one to be exposed to pathogens or nitrate in well water, and if exposure occurs, at what concentration? We have addressed these questions through deconstructing the Sensitivity / Density matrix table (Table 6) from the perspective of the risk-circle paradigm (Figure 13).

- The Sensitivity variable is about soil conditions and set-back from municipalities. The soil characteristics and depth control the retention time in the vadose zone, which is the key factor in pathogen reduction. As we have discussed earlier, no septic system should be approved that cannot meet sufficient pathogen attenuation – i.e. a potable aquifer should not be allowed to be contaminated with pathogens. If soil conditions are insufficient, then advanced treatment should be designed to achieve required attenuation. If sufficient attenuation is achieved, the exposure pathway for pathogens has been disrupted and the risk for adverse health effects is reduced to a negligible amount.
- The Density variable is about the probability of intercepting OWTS effluent plumes. Because we have stated that pathogens should not be entering the groundwater, and we assume that nitrate is not attenuated in the vadose zone, we are concerned with nitrate as the primary CoC in the effluent plumes. Therefore, the fundamental

questions that define risk become: how likely is one to be exposed to nitrate in well water, and at what concentration?

5.6.1 Risk decision framework

The framework presented in Figure 19 is a risk-based process optimization and decision tree for subdivision OWTS assessments. This framework is intended to be complementary to the revised Guidance Document (Appendix I). By evaluating and revising Saskatchewan's Interim Guidance Document using a fundamental risk approach, we were able to restructure that document to focus efforts on the parameters that most influence risks to human health. This approach is consistent with current environmental risk research and practice.

The framework encompasses all phases of the necessary and required desktop and field-based assessment, defines when Level 1 or Level 2 assessment reports are required, and points to where and how the data collected and interpreted in the assessments should be used. A cumulative assessment will be required only when there is a high probability of OWTS effluent interception by a well. The framework includes risk management opportunities for performance-based treatment alternatives and risk mitigation options.

We evaluated the steps in Level 1, Level 2 and Cumulative subdivision assessments to optimize their relative value in estimating residual risk at each phase of the assessment process. What we have arrived at is not a completely new or different process – rather, some of the existing process steps have been re-ordered to allow the information they provide to inform relevant risk-based decisions at more appropriate points in the process. For example, the question of whether OWTS effluents would be isolated from potable groundwater sources in, or down-gradient of the subdivision, is a significant risk question: if the local or regional potable aquifers are very deep or otherwise isolated from effluent sources, the exposure pathway for pathogens and nitrate is incomplete and very little risk[21] of adverse effects can occur. If the developer can show aquifer isolation early in their subdivision assessment, they can submit a more concise report for the approval without having to prepare and submit extensive Level 1 or Level 2 reports.

This reflects an important aspect of understanding risk and its drivers: if any one of the three circles that define risk can be eliminated, there can't be a risk, therefore we look for opportunities to eliminate either the receptors, the hazard, or the exposure pathway early in the risk evaluation and risk management process. In this case, we have not eliminated the pathway through any risk management actions – rather, in the case that supply aquifers are isolated, the exposure pathway does not exist in the first place. As a premise of good risk assessment practice, we need to ensure that we ask the relevant questions and evaluate available data to ascertain whether such cases may exist.

We recommend this framework approach as a better alternative to the assessment matrix originally given as Table 2.1 in the Interim Guidance, and revised in Table 6.

5.6.2 Step-by-step narrative of the framework

When a developer proposes a subdivision where a public wastewater treatment network is economically unfeasible or otherwise unavailable, they will be required to adhere to the

[21] Note that we do not state that no risk would exist. Contamination mechanisms may exist, such as effluents entering a protected aquifer via improperly abandoned wells, compromised well casing or undetected bedrock fissures.

subdivision policy guidance document for on-site wastewater treatment systems. If the development proposal is less than 5 residential lots in a ¼ section, no subdivision-level assessment is required. However, it should be noted that all individual OWTS in Saskatchewan require field-based assessments, including test pits or bore holes for soil characterization, prior to approval. For all developments proposing 5 or more residential lots per ¼ section (Step 1; Revised Guideline Section 1), a desktop data review and a field program that includes test pits, bore holes and hydrogeological characterization will be required (Step 2: Revised Guideline (Appendix I) Section 3.1 – 3.2). The most important aspect at this stage of the subdivision assessment is planning and collecting data and samples that are representative of that particular ¼ section (and the immediately surrounding land). The requirements to defensibly achieve representativeness will be site-specific – if the soil, geography and hydrogeology are very homogeneous across the ¼ section, relatively few randomly sited samples can satisfy the representativeness requirement. However, if there is significant variability in any of these parameters, an increasingly larger number of samples will be required. Note at this stage in the framework that an assessment report is not yet required.

Step 3 in the framework is an inquiry of whether potable aquifers (any aquifers that are used currently or may be used in the future for drinking water) are isolated from the OWTS effluent (Revised Guideline (Appendix I) Section 3.3), either by non-fractured bedrock, impermeable clay seams, significant coal seams, or other means. Developers will need to support conclusions of isolation (Step 3a; Revised Guideline (Appendix I) Section 3.3.1) with data collected in Step 2. An effluent isolation report must be submitted. This report includes field and desktop data from the development site and adjacent area with sufficient interpretation of that data to support the conclusion that OWTS effluents from the subdivision will be isolated from current and future potable water aquifers.

If there is insufficient evidence of isolation, or clear evidence of shallow potable groundwater beneath the proposed development, Step 4 is the inquiry of whether sufficient vadose zone retention time will be achieved (Revised Guideline (Appendix I) Section 3.4). If this cannot be substantiated, a risk management action takes the process through an OWTS design loop (Step 4a) that allows the developer to evaluate and propose advanced treatment that can achieve the necessary effluent parameters (pathogen attenuation).

Once Step 4 has been satisfied, either a Level 1 or Level 2 assessment report is required (Step 5; Revised Guideline (Appendix I) Section 4 or 5), with lot density equal to or greater than 40 per ¼ section as the dividing line between Level 1 and Level 2 reports. A required aspect of data interpretation for either assessment report is a calculation of the probability of intercepting an OWTS effluent plume, based on subdivision layout and OWTS orientation with respect to groundwater flow direction and velocity. If this calculation shows greater than 90% probability of plume interception at the down-gradient boundary of the subdivision (Step 6), a cumulative nitrate assessment (see Section 5.4) is required (Step 6a; Revised Guideline (Appendix I) Section 6), following which nitrate concentrations should be predicted for down-gradient wells (Step 7a). If the probability of plume interception is between 10 and 90% (Step 7), the cumulative assessment will not be required – proceed directly to Step 7a to predict nitrate concentrations (see Section 2.4.7).

The inquiry in Step 7b is whether concentration of nitrate in well water (if a plume is intercepted by the well) exceeds the drinking water nitrate guideline of 10mg/L of nitrate-nitrogen[22]. If the 10 mg/L value is exceeded, a site-specific technology selection process and risk characterization is required (Step 7c). This characterization should carry the probability of plume interception from either Step 6 or Step 7 and characteristics of the receptors (people) residing in and down-gradient of the subdivision. Unless there is compelling evidence to support a statement that infants or pregnant mothers would not reside in or visit residences that use shallow groundwater supplies, we must assume that this susceptible population will be present. This is a clear requirement of policy objective 3, consistency with the precautionary approach.

Therefore, the final evaluation of risk compresses down to the probability of a well intercepting an OWTS plume. If this probability is between 10 and 90%, a number of risk mitigation approaches (Step 7d) are available to reduce the chance of exposure or the concentration of nitrate to which one is exposed. If the probability is high (> 90%), risk management requires the developer to assess alternatives for wastewater treatment (Step 7e).

At three stages – following Steps 3a, 7 and 7b – the developer can move on to seek subdivision approval from the Ministry of Municipal Affairs. Additionally, developers can seek approval following risk management actions in Steps 7d or 7e, and subsequent amendments to the subdivision development plan.

In Figure 20 and Figure 21 we have added comment overlays to the framework to provide risk assessment and risk management descriptions at key steps.

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[22] To retain conservatism and adhere to Policy Objectives 1 and 3 in the risk framework, the 90th percentile from the predicted nitrate nitrogen concentration should be used to address the inquiry in Step 7b.

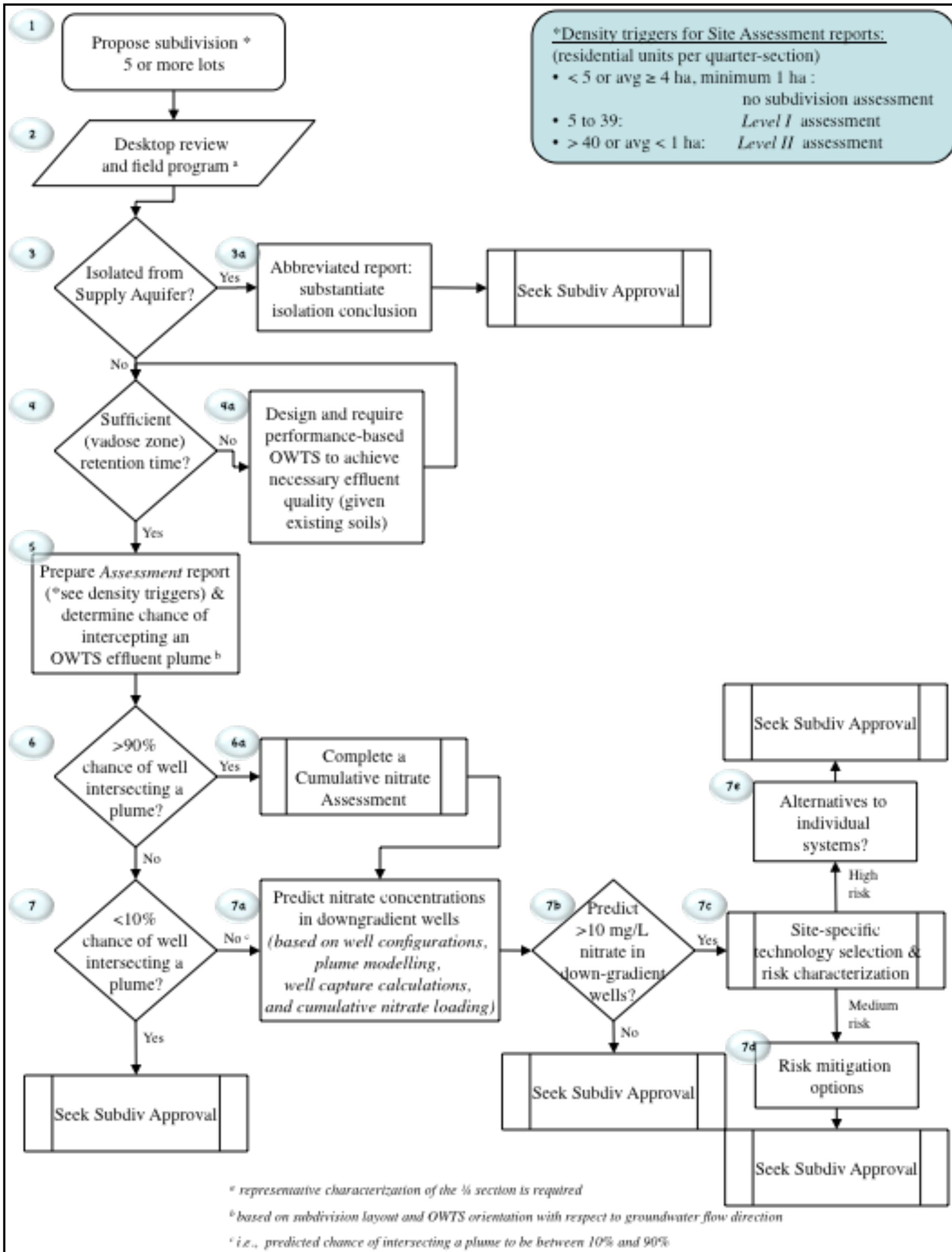

Figure 19. Risk-based Decision Framework for subdivision on-site sewage applications: A provincial on-site optimization process in Saskatchewan's health and environmental evaluation toolkit.

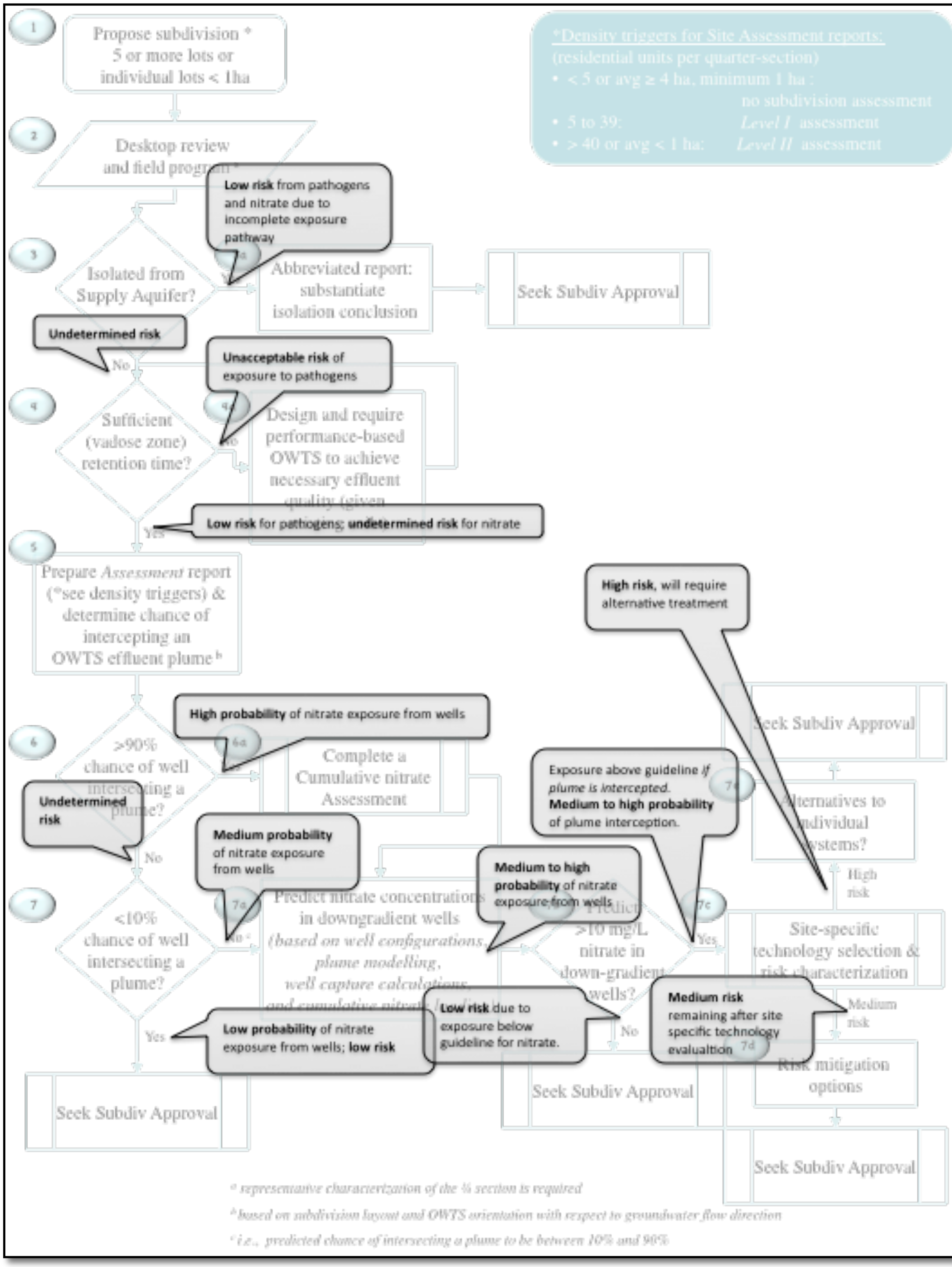

Figure 20. Qualitative risk evaluation overlay on the Decision Framework.

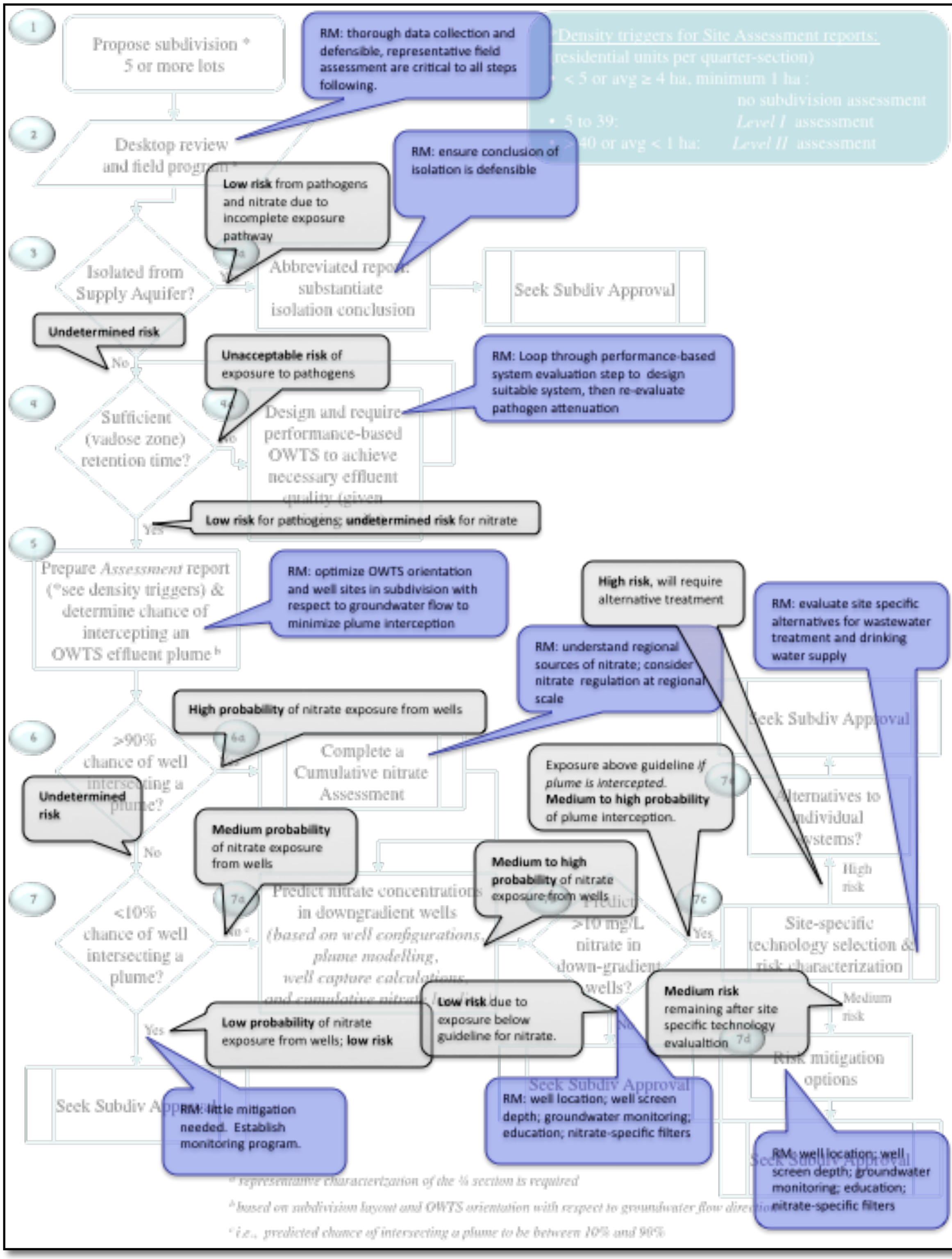

Figure 21. Risk management and qualitative risk overlay on Decision Framework.

5.7 Risk management

Risk avoidance (although not always practical) is the first line of risk management. If we know which parameters are the most influential in characterizing risk, we can target risk management actions and strategies toward these parameters.

We have identified the primary risks of OWTS in subdivisions to be from exposures to pathogens and nitrate via drinking water from shallow aquifers. Any actions taken at the outset of subdivision planning and development that reduce or eliminate either the hazards (pathogens and nitrate) or their pathways of exposure (potable aquifers) will be significant in reducing overall risks from OWTS at a subdivision scale. As we further focused our understanding of the variables that control the availability (or concentration) of pathogens and nitrate in shallow potable aquifers, we arrived at the following key factors:

- for pathogens, the amount of time they are retained in the vadose zone (retention time) is very important. Sufficient retention time is required for adequate pathogen removal, and this must occur before they reach the groundwater, as there is essentially no further bacterial or viral kill-off once they reach groundwater. Retention time is determined by the soil characteristics (e.g. hydraulic conductivity) and the soil depth. (see discussion of Table 6)
- For nitrate, we are conservatively assuming there is no treatment of nitrate in the vadose zone. As the OWTS effluent reaches the groundwater, it will form a nitrate-rich plume; the number of plumes (i.e. density) and their geometry determine the chances of intercepting nitrate-containing water in a drinking water well. (see discussion of Table 6)

Risk management actions or decision at various steps throughout the framework flow

- Desktop and site assessments are requirements for all developments that exceed the 5 residential lot per ¼ section density cut-off (Step 2). *The importance of thorough, relevant, and representative data collection at this phase of the project cannot be overstated.*
  - Risk management action: As a first line of risk management, thorough compilation and review of relevant existing data together with representative soil and groundwater characterization are critical to providing defensible data for all subsequent decisions regarding OWTS on the subdivision.
  - Risk management action: A monitoring network of groundwater monitoring wells (piezometers) should be set, at a minimum, at the up-gradient and down-gradient boundaries of the subdivision. Peizometer placement can be combined with the initial site hydrology assessment to minimize costs and optimize effort.
- If the data supports a conclusion that the subdivision and down-gradient drinking water supplies originate from a protected aquifer (Step 3) – i.e. the OWTS effluent would be isolated from potable drinking water aquifers, no further subdivision-scale risk management actions should be required[23].

[23] Minimal septic system maintenance should still be recommended. Good well practices should be maintained: well head protection from surface run-off and other influences; periodic water quality monitoring to protect against possible well casing breaches that could allow pathogen or contaminant intrusion into the well.

- Soil characterization and vadose zone depth data across the proposed development are used to determine the vadose zone retention time (Step 4). If the retention time is insufficient for adequate pathogen removal:
  - Risk management action: Loop back to designing OWTS *for the specific soil conditions* (Step 4a) and re-evaluating based on pathogen removal criteria as per current Canada and Saskatchewan guidelines.
- An objective of the subdivision assessment (Level 1 and 2) should be to understand the most likely plume characteristics based on groundwater flow rate and direction (Step 5), dispersion field orientation, and soil characteristics. If plume formation can be reasonably predicted, risk management options based on informed well placement decisions could be effective in reducing the chance of drawing OWTS sourced nitrate into the drinking water supply. Note that the requirements for establishing a conceptual model of the subdivision development (and associated plume geometry characterization) differ between Level 1 and Level 2 assessments (see Appendix I, Section 5.1).
  - Risk management action: The developer proposes a strategy (or a number of optional strategies) for septic dispersion field placement (location and orientation) and coordinated well placement within the subdivision as part of the subdivision plan. Such an activity would be a valuable aspect of risk management, particularly for the residential lots on the down-gradient side of the development and current and future private well users outside of the development in the down-gradient direction.
- A cumulative impact assessment (Step 6a) (see Section 5.4; also Appendix I, Section 6) should be carried out to account for all major regional sources of nitrate that can affect surface and groundwater.
  - Risk management action: Consider nitrate accounting at regional scale as part of land use planning.
- Estimate nitrate concentrations in down-gradient wells based on well configurations, plume modeling, well capture calculations, and cumulative assessments (Step 7a). If the estimated nitrate concentration <10 mg/L, risk of effects is low because exposures should remain below effect levels even for susceptible receptors (infants to 4 months and pregnant women).
- If the estimated nitrate concentration >10 mg/L, a site specific risk characterization is required, primarily to evaluate receptor characteristics (demographics and land use down-gradient of subdivision).
  - Risk management action: site specific risk assessment (Step 7c).
- Except for situations in which infant and pregnant women residing down-gradient of the subdivision development can legitimately be ruled out, the outcome of the site specific risk assessment will veer towards the conservative assumption that susceptible receptors are present and will consume well water. Therefore, the case of a high probability of plume interception will translate to high risk of exposure and effects.
  - Risk management action: seek alternatives to individual private systems for wastewater treatment for the proposed subdivision (Step 7e).

- Perhaps extend evaluation of alternatives to drinking water supplies for subdivision and down-gradient users:
  - obtain drinking water from deeper aquifers. Consider drilling new wells for residences down-gradient of the development. Advantage: drawing water from deeper aquifers is likely to reduce nitrate exposure, perhaps eliminating exposure to nitrate from OWTS and other local sources. Periodic monitoring for nitrate and pathogens would remain necessary to ensure protection. Disadvantages: Nitrate-containing water and pathogens can enter deeper aquifer through unprotected wellheads or fractured well casing. Wellhead protection is necessary[24]. Opting for deeper wells in place of alternative treatment implies regulatory acceptance of contamination of shallow supply aquifer – such an approach does not comply with policy objectives.
  - Water distribution from nearby treatment plant; consider extending distribution system to down-gradient residences. Advantage: reduces or eliminates nitrate exposure if supply water for treatment plant meets nitrate guidelines[25].

- The case of a medium probability of plume interception will translate to a medium risk of exposure and therefore a medium overall risk of effects.
  - Risk management action: employ risk mitigation options as applicable (Step 7d):
    - optimize locations and draw depth for all new wells. Consider drilling new wells for residences down-gradient of the development. Optimizing well locations based on subdivision development plans and coinciding with optimized orientation of seepage fields would reduce the probability of intercepting a plume. Wellhead protection is necessary.
    - obtain drinking water from deeper aquifers. Consider drilling new wells for residences down-gradient of the development. Drawing water from deeper aquifers is likely to reduce nitrate exposure, perhaps eliminating exposure to nitrate from OWTS and other local sources. Periodic monitoring for nitrate and pathogens would remain necessary to ensure protection. Wellhead protection is necessary.
    - groundwater (supply and monitoring wells) monitoring program
    - educate regional ground water users on risks associated with nitrate exposures and the susceptible life-stages at which these risks can occur;
    - point-of-use water filters (tap or whole house) that are specific for nitrate are available at substantially lower costs than new well construction (e.g. deeper well screen; deeper aquifer) or denitrification at the wastewater

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[24] Wellhead protection, including proper wellhead design, wellhead and casing maintenance, well location, and surface drainage are essential risk management considerations that are part of all private well ownership responsibilities. Educational campaigns and materials can offer significant benefit. The Walkerton example Hrudey, S. and E. Hrudey (2004). Safe Drinking Water: Lessons from recent outbreaks in affluent nations. London, UK, IWA Publishing. is a good example of a well located in a low-lying area, susceptible to contaminated surface runoff, and having ineffective wellhead protection.

[25] Typical drinking water treatment is focused on pathogen removal or inactivation, and is not designed for chemical contaminant removal. Treatment to specifically remove high concentrations of nitrate at a treatment plant scale may be prohibitively costly.

treatment stage. . Examples of commercial systems include: crystalquest.com/index.html; www.raindancewatersystems.com/nitrate.html; www.mrwaterfilter.com/under-sink/mwfus-02.shtml; and others[26]. The components and media used in these systems should be certified to conform to a consensus standard by recognized agencies. While some suppliers report that they are certified under NSF standard 61, this standard only certifies that the filter components and filtering media that are in contact with drinking water will not degrade the quality of the water. It is not a certification of the nitrate reduction efficiency of the filter. We recommend that in conjunction with well water monitoring, periodic tap water monitoring should be included to monitor the nitrate reduction efficacy of the filters.

- Risk monitoring as part of an on-going risk management plan.
  - A groundwater monitoring program that includes stratigraphic sampling is a viable approach to understanding and monitoring nitrate movement in the groundwater and private wells.
  - Knowledge of the nitrate stratigraphy in the shallow aquifer can be used to recommend deeper well placement wherever this is possible.

5.8 Policy Objectives

Throughout this review and risk-based evaluation of the Interim Guidance Document, we have attempted to remain focused on approaches that adhere to the policy objectives as set out in the Project guidelines in the RFP:

1. Protective of public health & environment;
2. Consistency with other jurisdictions;
3. Consistency with the precautionary principle
   - "The precautionary approach recognizes that the absence of full scientific certainty shall not be used as a reason to postpone decisions where there is a risk of serious or irreversible harm. Even though scientific information may be inconclusive, decisions have to be made to meet society's expectations that risks be addressed and living standards maintained". (Environment 2001)
4. Provide corroborating information to assist Health Regions in the review of sewage permit applications; and,
5. Specify outcomes rather than specific technical solutions.

In Figure 22, we have identified specific policy objectives that are addressed at key steps in the framework.

[26] We are not promoting a specific manufacturer or brand of nitrate-specific filters. Our intent is to demonstrate their availability, general cost ranges and technology currently used.

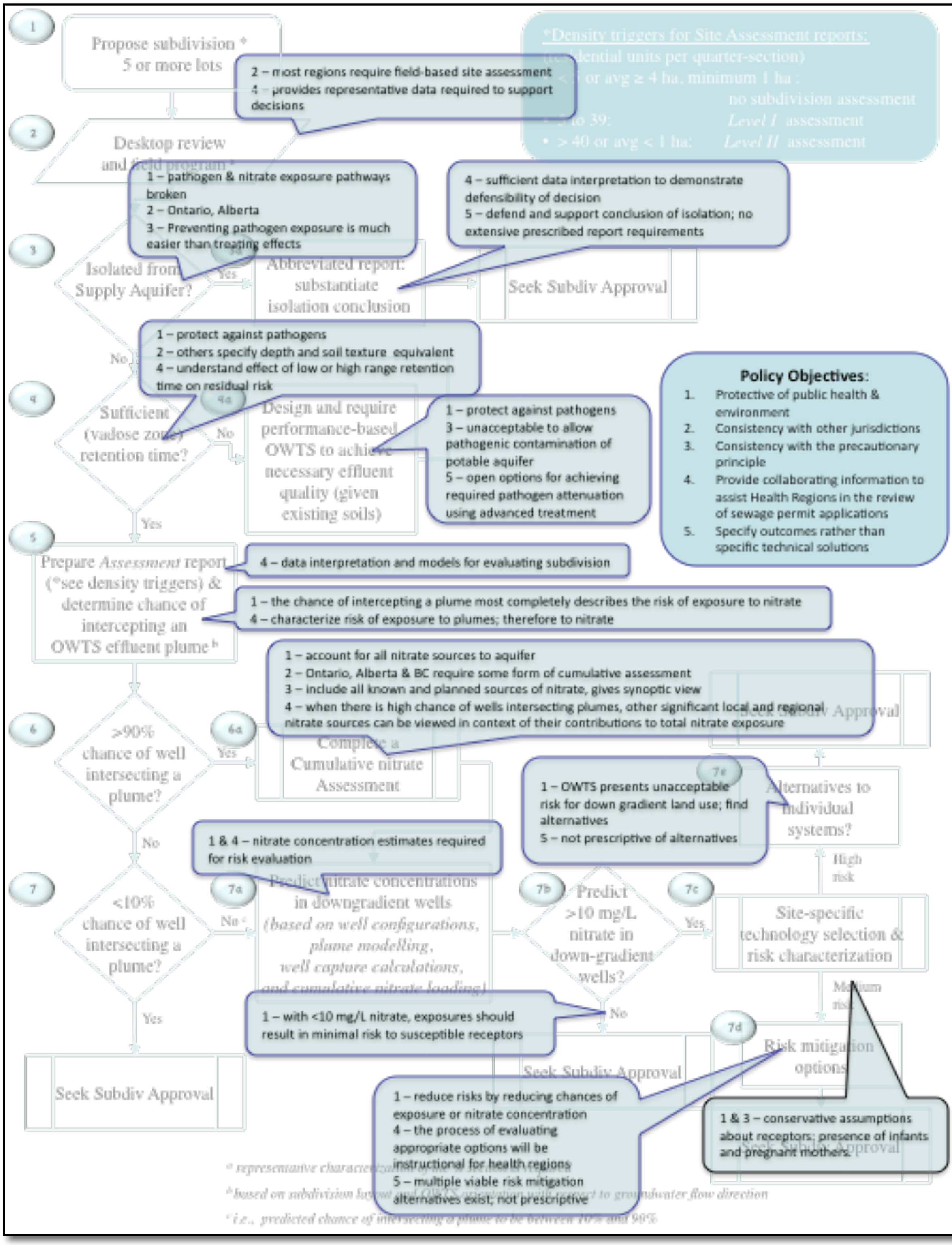

Figure 22. Project policy objectives addressed within the decision framework.

5.9 Proposed approach vs alternatives

Our **proposed approach** to subdivision assessment for OWTS is based on fundamental scientific and engineering "first principles". This foundation allows improved decision-making by increasing the scientific defensibility and reducing technical misunderstandings. Further, the proposed approach is optimized with respect to human health risk drivers, which results in better protection of human and environmental health (ie, significantly greater likelihood of informed risk management decisions and reduced residual risk), and thus helps Agencies fulfill their mandates. Whereas previous OWTS policies, and subdivision-specific OWTS policies, have largely been developed from a soil engineering perspective, this policy approach incorporates fundamental risk assessment and risk management principles throughout. As a result, it might require some initial adjustments on the part of practitioners and policy administrators. Nevertheless, through the clear linkages that we have provided showing how the decision framework achieves the Policy Objectives, our proposed approach offers significant benefits to overall Public Health and government mandates for its protection. The additional requirements / costs that are possible under the proposed approach would be borne by projects proponents (developers). These costs are reasonable and straightforward, and would provide certainty and clarity to the user community.

The **Interim Guidance Document** (ie, December 2008 version) requires less effort than adopting the Proposed Approach, however, does not achieve the Policy Objectives as fully as the Proposed Approach (above), and it is less protective of (ie, higher residual risk to) humans and the environment, compared to the Proposed Approach.

A **"do nothing" approach** (i.e. that Saskatchewan would choose not to develop or adopt a subdivision-level OWTS policy) is not protective of human health or environmental health and such an approach simply fails to meet the mandate of SK Health and SK Watershed Authority.

Banning OWTS would either result in no new developments being allowed, or requiring all new developments to use holding tanks (which have their own issues and constraints). Either of these scenarios would place constraints on the economic well-being and growth of rural communities, which could adversely affect the overall Determinants of Health for these communities. This outcome is not consistent with the mandate of Saskatchewan Health.

5.10 References

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6 Costing Implications for Subdivision OWTS Assessment

Developers and regulators should have a practical concept for the costs anticipated if the proposed framework is adopted as policy by Saskatchewan Health and SWA. Our recommended risk-based assessment approach requires desktop review and representative data collection for soil, geology, hydrology, and groundwater quality as the first stage of all subdivision-level assessments. Representative data (sufficient data to accurately and adequately characterise the soil, water and hydrogeology across the quarter section) is of fundamental importance, because all subsequent decisions regarding waste water treatment and drinking water supply and quality implications will be based on this data. The effort, and therefore cost, of obtaining representative data will be lowest for areas of consistent, homogeneous geology, soil structure, and predictable groundwater movement. Costs will increase substantially if soil, geology, geography, and aquifers are heterogeneous/highly variable across the quarter section. We view these costs as necessary in insuring appropriate public health decision-making. We anticipate the total costs of OWTS assessment would be a small percentage of the residential lot value.

The combined desktop and proposed field evaluation for Saskatchewan OWTS includes well log surveys, on-site geological investigations, etc., and the development of a conceptual hydrogeologic model. Drilling costs are approximately $3000 to $5000/day for an auger or hammer rig with a driller, helper and support truck, not including well consumables (e.g. PVC casing, bentonite, screened PVC, sand, lockable stickup), and the cost of a professional to supervise and log the core. Drillers can do about 3 to 4 holes/day at ≤ 15m (~40 ft). Alternatively, for $1000/day, including mobilization, a track hoe can dig from 5 to 10 test pits/day. None of these include bore hole logging or soil evaluation (e.g. soil texture classification by hydrometer, lab costs $45/sample). These hard costs for a field assessment that requires 3 driller days, 2 track hoe days, and 20 samples for texture analysis would cost on the order of $20,000. The total costs for desktop and field data collection will range from $10,000 to >$25,000, depending on the hydrogeologic setting to be investigated – greater hydrologic variability or geological heterogeneity will require more effort to achieve representative sampling.

With data analysis, hydrological modelling and presenting the conceptual hydrological model, and reporting requirements, Level 1 Assessment reports are estimated to cost an additional $15,000 to $25,000 above the costs for desktop and field data collection. As described above, as the heterogeneity of a development site increases, data interpretation and conceptual model development will become more complex, resulting in higher costs to complete an assessment.

A Level 2 assessment would be significantly more expensive, primarily due to increased data analysis, hydrogeologic modeling/conceptual model development and interpretation requirements and subsequent report development. A Level II report would conceivably cost $30,000 to $60,000 above the cost of data collection depending factors such as the extent and complexity of modelling required for plume prediction, detailed conceptual model development, and competent report writing.

If a Cumulative Nitrate Assessment is required, additional data collection, modelling effort, and interpretation may add $50,000 to $80,000 to the overall cost. This is anticipated only for high-density, high risk developments.

7 Key Messages

In this report, we have reviewed and evaluated Saskatchewan's *Interim Guidance Document for Developments and Subdivisions where Private Sewage Systems are Proposed*. We have offered discussion regarding the potential concerns posed by on-site wastewater treatment, which of these concerns the current state of the art addresses, and what concerns remain (as residual risks to human health and environment).

At the beginning of this evaluation, we posed a series of direct questions as a way of structuring the study objectives. These questions are re-stated below, along with concise answers that flow from the detailed discussion contained within this report.

- Do OWTS work?
  - Yes, if designed, installed and operated appropriately and diligently, scientific studies have shown that OWTS provide effective and appropriate treatment of wastewater. Conducting a thorough site assessment (re: site-specific soil and groundwater conditions) is key to ensuring an effective design.
- How severely and how often do they fail?
  - When OWTS experience performance failures, it tends to manifest itself in one of two different ways: hydraulic failure (e.g., effluent ponding due to insufficient percolation into soil) versus treatment failure (e.g., inadequate treatment of contaminants). The former failure mode is easier to detect than the latter.
  - While the scientific literature contains a number of examples of OWTS failure, it is unclear how the failures that these studies focus on actually relate to the broader performance picture. Anecdotally, the majority of OWTS perform adequately. However, very little quantitative information is available on the actual failure rates of OWTS, because very few of these systems are monitored. In particular, detecting treatment failures requires subsurface effluent sampling and chemical analysis.
- Do these system failures affect drinking water quality? Does this have an adverse affect on human health?
  - We'll make a distinction between performance limitations versus failures.
  - A performance limitation is when a system is incapable of achieving certain types of performance, based on inherent design and technology limitations. The primary performance limitation of most OWTS technologies is an inability to remove nitrate. Nitrate poses a low risk to the majority of the human population. However, public health officials need to adequately protect the segment of the population (pregnant mothers and infants younger than 6 months old) that is sensitive to nitrate above 10 mg/L nitrate-N. Consequences of elevated nitrate discharging to surface water ecosystems can include eutrophication. Risk management for both of these is achievable.

  - Failure is when a system does not deliver the performance it was designed to do (e.g., remove pathogens). Consequences of OWTS failure for human receptors can be very severe (up to and including fatal). OWTS systems need to be properly designed, installed, maintained and monitored to protect against failure. (Centralized wastewater treatment facilities achieve adequate protection through similar means.)
  - Given the serious potential consequences if these systems fail, all parties involved (i.e., regulatory agencies, developers, their consultants) need to ensure that the appropriate level of attention, resources and technical expertise is supplied when planning, designing, approving, installing, operating these systems. Not doing so could result in very unfortunate (and preventable) events.
- How can we achieve widespread occurrence of properly functioning OWTS?
  - See Key Messages (below).
  - Adopt the recommendations contained in this report, and provide sufficient regulatory commitment, resources and oversight to ensure that these recommendations are designed and implemented correctly.
  - A thorough site assessment to adequately understand site-specific and regional conditions and match those to appropriate OWTS technologies (e.g., conventional versus advanced treatment technologies) is a key part of this.
  - Performance monitoring is also critical. You can't manage what you don't measure.
- Is the Saskatchewan Interim Guideline technically adequate to achieve this?
  - With the changes recommended in this report, including the recommended edits to the Interim Guideline, it will be technically adequate to achieve properly functioning OWTS. However, technical aspects alone will not succeed -- they depend on associated policy and regulatory support.
- What are the technical limits of OWTS? Would a properly functioning OWTS be sufficiently protective of human and environmental health? What risks still remain? Are these risks acceptable?
  - The most significant risk is from systems that are inappropriately designed with respect to the specific site conditions. The risks from these inappropriate systems include acute human health risks (pathogens) and environmental effects (nutrient causing eutrophication). Regulators need to insist on appropriate and sufficiently detailed site-specific assessments. A site-appropriate design then needs to be produced that adequately addresses whatever site constraints were identified.
  - Assuming that the above is properly done, then nitrate remains the primary potential issue currently identified by science. Nitrate is an issue for all OWTS (except very advanced systems capable of reliably achieving effective denitrification). Nitrate poses a risk to infants younger than 6 months old, pregnant mothers, and some aquatic ecosystems. With proper planning and management, these risks can be mitigated to acceptable levels.

A number of themes came up consistently throughout our reading, critique, technical analysis and risk-based evaluation of the guidance document and associated literature. Key messages that we consider are important for all stakeholders involved in developing this policy document, and those who will be applying it, are offered as follows:

1. *Context:* Recognize the context of onsite wastewater treatment in the broader scope of public health and environmental protection.
2. *Work from First Principles*: understand the key mechanisms of wastewater treatment and groundwater protection.
3. *Appropriate Technology:* OWTS work if designed properly and are a suitable long-term solution for wastewater treatment. Advanced systems offer potential for increased protection, and flexibility for greater range of site conditions.
4. *Design for the soil*: based on representative site characterization.
5. *Inspect, Maintain, and Monitor*: Insisting that these activities be done on a reoccurring basis improves the chances that the treatment systems will achieve the necessary performance to remain protective of human and environmental health. It also provides a mechanism for identifying and correcting specific system failures and other high-risk operating conditions.
6. *Discrete Plumes:* OWTS effluent discharges produce discrete effluent plumes that may contain nitrate concentrations above the drinking water quality guideline. Individual OWTS discharges **do not** produce widespread changes in nitrate concentration throughout the bulk aquifer. Non-point sources of nitrate are more likely to contribute to widespread aquifer contamination.
7. *Subdivision planning and site assessment are vital:* Up-front effort (and investment) in planning and process will set a strong foundation for subdivision assessments and provide viable data and context for risk-based evaluation.
8. *Consider adjacent / future sub-divisions:* Due to the formation of discrete plumes, different designs and layouts of OWTS within a subdivision will affect the cumulative impact of that subdivision of the shallow groundwater. This in turn may affect the groundwater resource for downstream / future subdivisions. These considerations should be taken into account at the design stage.
9. *The Fundamentals of Risk*: Hazard – Receptor – Pathway. All three of these must co-exist in order for there to be a risk. Also, full understanding of risk is available only when we consider the probability of an effect and the severity of that effect.
10. *Matrix + Flowchart:* The subdivision assessment matrix based on sensitivity and density is a useful tool for portraying fundamental risk drivers for pathogens and nitrate. Combined with the subdivision assessment process framework (see below), a workable tool is available for regional health officers to evaluate subdivision development applications.
11. *Risk-Based Framework*: We developed a risk-based framework for the subdivision assessment process – a provincial onsite optimization procedure from Saskatchewan's health and environment evaluation toolkit. This framework may be used:
    a. To aid developers and their consultants understand and advance through the assessment process;
    b. By regulators at local and regional levels to understand and evaluate the risks that may exist at each step of the subdivision assessment process;
    c. For developers and regulators to understand and apply elements of risk management throughout the subdivision OWTS evaluation and implementation; and,

d. By multiple levels of government and stakeholders to understand the policy considerations that have been implemented in the risk-based approach to subdivision OWTS assessment.

12. *Residual Risks*: risks are site-specific, but in general relate primarily to nitrate. Nitrate > 10mg/L = risk to infants and pregnant mothers. Nitrate > 0.5 mg/L = possible effects to ecosystems. Both of these risk areas can be managed to acceptable limits based on today's understanding, using currently available technology, and thorough engineering, science, and planning techniques.
13. *Risk management:* opportunities exist at many levels, including systems levels, to eliminate one or more of the three co-requisites for risk, reducing the probabilities associated with risk, or mitigating exposure to pathogen and nitrate hazards.

Appendix I

Recommended revisions to the INTERIM GUIDANCE DOCUMENT FOR DEVELOPMENTS AND SUBDIVISIONS WHERE PRIVATE SEWAGE SYSTEMS ARE PROPOSED

1 Introduction

1.1 Guideline Overview and Relationship to other Saskatchewan Legislation

Onsite wastewater treatment and disposal regulations and guidelines are intended to minimize the impact of sewage effluent on water supplies, communities and neighbours. Onsite Wastewater Treatment Systems (OWTS) are not just temporary installations that should be replaced eventually by centralized sewage treatment services, but permanent approaches to treating wastewater for release and reuse in the environment. Onsite systems are recognized as potentially viable, low-cost, long-term, decentralized approaches to wastewater treatment if they are planned, designed, installed, operated, and maintained properly in appropriate hydrogeologic environments.

The overall goal is to protect the environment and human health. This guidance document describes the required considerations for developers and municipalities in various types of locations. Based on both the density of the development and the physical characteristics of the area, a Level 1 or Level 2 Assessment may be required.

This guidance document only addresses the subdivision approval process. The subsequent Sewage Disposal Permit application process addresses the need for the lot-specific site assessment, system design and approval of each treatment system on the individual lots.

In areas where *The Shoreland Pollution Control Regulations, 1976* apply, or where municipal bylaws further restricting the usage of OWTS are in effect, the following guide does not apply. This guide only applies to individual or small, shared treatment systems. Larger OWTS (i.e. greater than 18 m^3/day of flow, or municipally owned systems) must be approved by Saskatchewan Environment.

1.1.1 Holding Tanks

It should be noted that holding tanks can be installed in all locations. However, for new developments, the following requirements should be met prior to considering the use of holding tanks. They are:

1. Local licensed sewage hauler: The proponent must identify a local licensed sewage hauler in the area who agrees to remove sewage[27]. During the application process, the regulatory authorities may chose to confirm the details of the haulers license and their ability to perform the additional work.

[27] Information regarding licensed sewage haulers can be obtained from Saskatchewan Ministry of Environment.

2. Approved disposal location: The proponent must identify the final disposal location of holding tank waste. The Saskatchewan Ministry of Environment should be consulted to determine an acceptable location.
3. Service agreement: The proponent must provide evidence that the municipality in which the development is located will ensure that an approved disposal location is utilized.

The installation of all OWTS, including holding tanks, must be permitted and may be inspected before being approved by the regulatory authorities in accordance with the provisions of the *Saskatchewan Plumbing and Drainage Regulations, 1996* and the information contained in the *Saskatchewan Wastewater Disposal Guide*. Assessments are not required in cases when holding tanks are proposed and if both Community Planning and the regulatory authorities agree that the site conditions and/or regulatory constraints are such that only holding tanks will be possible in the future.

Although the regulatory authorities may support a proposal involving individual OWTS and permit their installation, the authorities do not assume responsibility for the failure of the system(s), for correcting the damage to adjacent properties, or for the construction of OWTS. This is the responsibility of the proponent and the owner of the system.

The next sections are designed to provide guidance on the level of subdivision or development site assessments required to assess whether OWTS are suitable. The type of the site assessments ranges from no subdivision assessment required, to Level 1 and Level 2 Assessment. Under certain conditions, a Cumulative Assessment may also be required. The type of site assessments required initially is determined based on the density (Section 1.3) of the proposed subdivision/development. Regulatory authorities may or may not ask for additional site assessment work depending on their review of the initial assessment materials.

1.2 Vadose Zone Characteristics of Proposed Subdivision/Development Site

Based on public health risk evaluation, acute health effects from pathogen exposures are of greatest concern. As a first step, the proponent must assess whether the proposed OWTS site(s) have the capability of attenuating pathogen loads in the vadose zone before OWTS effluent reaches shallow groundwater. The recommended approach to address vadose zone retention time for pathogen attenuation is to evaluate OWTS technical solutions for the specific soil conditions to achieve sufficient pathogen removal. NO system should be approved that cannot be shown to provide adequate protection of a Supply Aquifer against pathogens.

Fractured geologic environments require more detailed investigation, specifically including assessment of channeling to aquifers. See Section 3.3 regarding aquifer isolation.

All OWTS locations will be 1 km or greater from the boundary of any city, town, village, organized hamlet, or approved subdivision containing at least 2 parcels.

1.3 Density of proposed subdivision/development

The density of the proposed and surrounding development should be determined for each OWTS application. Though the discussion below uses an area of ¼ section (i.e., 160 acres), this can be viewed as any continuous site of similar area (i.e. ½ mile by ½ mile, or 800 m by 800 m). The density of an area may be determined by final development plans for the immediate area of the subdivision based on discussions between the applicant and the Municipality regarding zoning bylaws and Official Community plans.

The average parcel size is determined by using the sizes of those lots, or parcels, subdivided from the existing piece of land. It does not include contingency or utility areas, which will initially remain undeveloped, but may be relied on for reinstallation of new septic systems if the first system(s) fail to perform to expectations.

1.3.1 Low Density Area

All subdivisions/developments are considered low density where:

1. Less than 5 existing or proposed residential units are located on a ¼ section; **or**
2. The average parcel size associated with each existing or potential residential unit is greater than or equal to 4 hectares (10 acres), with no parcel in the ¼ section smaller than 1 hectare (2.5 acres).

1.3.2 Medium Density Area

If a subdivision development is neither low or high density, it is considered a medium density area. In general, a medium density subdivision is characterized by between 5 and 39 existing or potential residential units on an equivalent ¼ section and/or equivalent residential densities on smaller parcel sizes.

1.3.3 High Density Area

Subdivisions are considered high density where:

1. Forty or more existing or proposed residential units will be located on a ¼ section; **or**,
2. The average parcel size associated with each existing or potential residential units is less than 1 hectare (2.5 acres) and more than 4 (four) residential parcels.

1.4 Definitions

Approving Authorities include those agencies with approval roles for new subdivisions/developments: Community Planning of the Ministry of Municipal Affairs is the approving authority for new subdivisions; Municipality is the permitting authority for any new development within an approved subdivision or on an existing parcel of land.

Conceptual Hydrogeological Model is a semi-quantitative framework of available data that describes how water enters, and eventually leaves a hydrogeologic system. It is typically an idealized graphical representation in plan and cross-section (or block) diagrams that incorporates assumed physical boundaries of the flow system (e.g. appropriate site boundaries and/or watershed divides), the subsurface hydrostratigraphy, material properties like hydraulic conductivity, groundwater levels and flow directions, and groundwater sources (e.g. recharge, surface waters) and sinks (e.g. surface waters, well pumping). Conceptual model development typically requires a review of literature and data in the project area and a good hydrogeological foundation. Information on how to develop, and examples of, conceptual groundwater models can be found at http://www.connectedwater.gov.au/framework/conceptual_models.html ;

http://va.water.usgs.gov/online_pubs/FCT_SHT/Fs099-99/fs099_99.pdf ; and

http://www.ccme.ca/assets/pdf/pn_1144_e.pdf .

Contingency areas are areas that will remain undeveloped in the development/subdivision as planned. These areas may be relied on for reinstallation of new septic systems if the first system(s) fail to perform to expectations.

Cumulative impacts are the combined environmental impact that can occur over time from a series of similar or related actions, type of contamination, or projects. Although each action may seem to have a small or negligible impact, cumulative impacts can accumulate over time, and the combined effect can be detrimental.

Cumulative impact assessment is the process of predicting the consequences of cumulative impacts as defined above.

Hydrogeological sensitive areas are those areas known to be susceptible to contamination based on existing geology and groundwater conditions. This is difficult to determine prior to study initiation; however, the determination of whether the area is hydrogeologically sensitive should be an outcome of a Level 1 or 2 Assessment. In general, this will include areas with permeable soils, shallow groundwater tables, and/or near surface permeable fractured rock or sediments.

Regulatory authorities include agencies with authority and/or interest in this issue. They can include the Ministry of Environment, Ministry of Health, Regional Health Authorities, the Municipality, Saskatchewan Watershed Authority, and Ministry of Municipal Affairs.

Supply Aquifer is any groundwater aquifer that is potable, and therefore is being, or could be, used to supply drinking water.

2 Description of the Subdivision/Development Site Assessments Process

Based on the proposed subdivision development density and location, either a Level 1 or a Level 2 Assessment may be required in order for the regulatory authorities to consider the potential for utilizing OWTS over the long-term in the subdivision development. The proponent can determine which type(s) of Assessments need to be conducted initially, based on the proposed subdivision/development density and sensitivity (Table 1). In essence, the higher the density and sensitivity are, the more likely a Level 2 Assessment will be required.

This Site Assessments Process will benefit builders, as the assessment(s) will result in appropriately designed and located OWTS. Adherence to recommendations made in the Site Assessment(s) should reduce the occurrence of unexpected requirements and limited choices having to be met in future OWTS construction. Completion of the Site Assessment(s) and following the associated recommendations will also help to protect public health and the environment by safeguarding the site and the region in which the development is proposed.

The intent of this process is for the proponent to demonstrate a sufficient degree of understanding and evaluation of site conditions such that the potential impact of the proposed development can be shown and methods of mitigating adverse effects determined. All calculations and assumptions must be documented in the assessment(s).

The assessment(s) will be used by regulatory authorities so they can adequately comment on a subdivision application proposing to use OWTS. In some cases, the regulatory authorities may determine that they have sufficient existing evidence, and not require additional assessment(s). However, in these cases, the project proponent must still suggest an onsite treatment methodology and support that selection based on available information. In other cases, the authorities may require additional work in order to ascertain an appropriate level of risk.

In cases where holding tanks are proposed, this Site Assessment Process will be required unless the regulatory authorities and Municipal Affairs explicitly agree that it is not necessary. For instance, the Site Assessment Process may not be considered necessary if the land makes an onsite system virtually impossible, or other legislation restricts the type of system used.

Each proposed lot might also require an individual site investigation as part of the Sewage Disposal Permit application process to be completed separately at the time of OWTS construction. The local Regional Health Authority must be contacted for approval to construct any OWTS.

The objectives of the Level 1 and Level 2 Assessments outlined in subsequent sections of this guideline are as follows:

- To provide technical guidance to professionals involved in land development to assessing the potential for unacceptable groundwater impacts resulting from the use of individual OWTS, through an assessment process;
- To ensure that proposals are submitted with the required technical support to allow the regulatory authorities to either support the proposed subdivision/development, to ask for more detailed site evaluation to reach a decision, or to recommend against approval.

The regulatory authorities recognize that many aspects of the Site Assessment Process, including the development of conceptual hydrogeological models, the assumptions required for predicting the fate of effluent constituents like nitrate-nitrogen, the use of nitrate-nitrogen as the critical contaminant etc., may not be technically supported in every case. Regulatory authorities recognize that as research continues, new information, approaches, and technologies may become available which warrant minor or substantial revisions to this guideline.

Project proponents or other organizations are encouraged to retain, on their behalf, professionals with demonstrated expertise in hydrogeology, specifically, those with expertise in developments that reply on onsite wastewater treatment systems. Their role is to assist in reviewing studies or reports prepared in accordance with this Guideline.

Proponents or other organizations should have Level 2 Assessments conducted by scientists or engineers with professional accreditation that is appropriate to hydrogeology. Further, approved Level 2 Assessment reports should be made publicly available so that a body of knowledge begins to develop with the consequent continual improvement of the conceptual hydrogeological model.

This guideline **does not apply** to the following:

- Municipal or communal sewage disposal systems;
- The assessment or approval of individual OWTS for residences that are not in a subdivision.
- The assessment of impacts of existing OWTS. Where the use of individual onsite systems has resulted in unacceptable impairment of water quality, the issue should be discussed with the Health Region;

2.1 Note regarding Sensitive Areas and Conditions

It is important to note that even though a proponent may meet the requirements for a particular the type of Assessment in Section 2 of this guideline, the regulatory authorities reserve the right to require a more detailed level assessment on any site it deems to be particularly sensitive, or with unusual conditions. The likelihood of this occurring is greater where:

- The development proposed has a higher density than previous developments in the area;
- The scale of the proposal is such that any increased degree of assurance is appropriate, or;
- It is known that pre-existing high levels of groundwater contamination by nitrate-nitrogen and/or pathogens exist in the region.

Although the regulatory authorities may support a subdivision application involving OWTS on a sensitive area or under sensitive conditions, the regulatory authorities do not assume responsibility for failure of the system(s), for correcting damage to adjacent properties, or for the construction of new OWTS. This is the responsibility of the proponent and/or owner of the system.

3 Data Collection and preliminary site evaluation

If a subdivision development of more than 5 residential lots is proposed, some form of subdivision–scale assessment will be required. The first required step for any assessment is data collection – desktop and field data. The basic required desktop data and field program are listed as follows. Additional data may be required for a Level 2 Assessment. Analysis and reporting requirements are described later in Sections 4 and 5; they are more detailed for a Level 2 Assessment. The key requirement is *representative* data, which may differ on a site-specific basis, and which must be defensible as such by the developer/consultant.

3.1 Desktop review

A desktop review of available geological and hydrogeological information should be conducted prior to conducting the preliminary field program. The review should include but not necessarily be limited to:

- Topographic maps (ideally at a scale of 1:20,000 or better)
- Soil and aggregate reports
- Geology maps (Note that regional scale maps are available on the Saskatchewan Watershed Authority website);
- Hydrogeology reports or publications for the region;
- Hydrogeologic or septic suitability reports for adjacent subdivision developments;
- Available water well records (Saskatchewan Watershed Authority);
- Available reports for nearby developments;
- Air photo and/or orthophotos of area.

3.2 Field Program

Based on the results of the review of available information, a field program should be designed. The purpose of the field program is to conduct a preliminary assessment of the feasibility of onsite wastewater treatment in the development. The program should include:

- A field survey of existing monitoring and/or water wells to establish the depth to the water table, water table gradient, etc.
- A field inventory of water supply wells within 1.0 km of the proposed development should be conducted to verify and update the provincial water well database. This survey should also include all springs and dugouts that access shallow ground water. The results should also determine the number of down-gradient wells within 1.0 km that could be potentially impacted by the proposed development.
- Test-pitting to identify any restrictive layers, stratigraphy, texture, structure, water table information, and to determine near surface conditions. The number of test pits (to a minimum depth of 3 meters) must be sufficient to delineate the local geological and hydrogeological conditions. A justification for the depth and number of test pits selected must be included in the final report. Proponents and

contractors should ensure that all Occupational Health and Safety requirements for excavations are met.

  - Fractured geologic environments require more detailed investigation, specifically including assessment of channeling to aquifers. See Section 3.3 regarding aquifer isolation.

- Representative grab soil samples from both test pitting and drilling should be analyzed in the laboratory to determine the grain size distribution for soil classification and hydraulic conductivity estimation where appropriate. The report should justify the number of samples as sufficient to determine representative conditions.
- Drilling, logging, and the installation of groundwater monitoring wells should be conducted when there is not sufficient subsurface data (e.g. water well records) below the depth of test pitting available for the desktop review.
- Where tractable, a groundwater monitoring well should be fully developed, sampled for water quality, and monitored for fluctuations in water table elevation. A number of representative groundwater samples (from either water wells or monitoring wells) should be collected for analysis of samples for major ions (specifically including chloride since it can be a conservative tracer of OWTS effluent), and water quality and redox analyses for constituents like nitrate, total coliforms, *E.Coli*, dissolved oxygen, and reduced iron. The consultant/proponent should be prepared to support the number of samples taken and location of standpipes as representative.

3.3 Evaluate supply aquifer isolation

Developments will normally be considered as low risk where it can be demonstrated that sewage effluent is hydrogeologically isolated from existing or potential Supply Aquifer(s) and will not degrade groundwater quality in more shallow aquifers to an unacceptable level. In making this assessment, the proponent and/or the consultant must evaluate the most probable groundwater receiver for sewage effluent: its definition must be defended by hydrogeological data and information obtained through a test pit and/or test drilling program. The potential for OWTS isolation from groundwater aquifers must be assessed on a site-specific basis. In some cases, it may also be necessary to demonstrate isolation from sensitive surface water environments.

When it is demonstrated that the sewage effluent will not enter water supply aquifers, the lot density of the proposed development may be dictated by factors such as wastewater treatment and disposal system replacement (or contingency) areas (if proposed), and by the minimum setback distances, such as between the OWTS and wells (as defined by *Saskatchewan Onsite Wastewater Disposal Guide*).

3.3.1 Report requirements for aquifer isolation

If isolation is ascertained, an abbreviated assessment report may be submitted for subdivision approval. This report should include Part 1 of the Level 1 Report (Section 4.1) along with sufficient interpretation of the hydrogeological data reviewed and collected at the site to defend the conclusion of isolation.

3.4 Evaluate vadose zone conditions

Assess soil conditions and vadose zone depth to determine whether sufficient retention time would be attained for pathogen removal, and whether there is sufficient 'safety' to that retention time to allow for virus attenuation.

Pathogens are the most critical acute hazard from OWTS. Sufficient steps MUST be taken to sufficiently reduce the risk of pathogens entering potable water supplies.

Depending on the OWTS technology employed, differing levels of pathogens are removed within the treatment system, with the remaining being discharged into the soil. Proper operation of the OWTS depends on these unsaturated soils (i.e., the vadose zone) removing the remaining pathogens from the effluent prior to it entering the groundwater.

Pathogen removal within the vadose zone is dependent on the pathogens being retained long enough to be sufficiently subjected to environmental conditions that result in their inactivation or die-off. Retention time is dependent on how fast the effluent will flow through the soil. This is governed by the soil's hydraulic conductivity. Since hydraulic conductivity can vary by several orders of magnitude between different soils, the required vadose zone depth to yield a sufficient retention time will be dependant on the hydraulic conductivity of the soil present at any given site.

Thus, specifying a single vadose zone depth that needs to be met at all sites would result in being significantly overly cautious for some sites (with slow hydraulic conductivities) and significantly under-protective for other sites (with fast hydraulic conductivities). Instead, a more performance-based approach is being employed, to reduce the likelihood of being unnecessarily cautious or restrictive, but also being sufficiently protective.

Based on currently available scientific knowledge, a reasonable minimum effluent retention time of 60 days through the vadose zone is likely necessary to achieve at least a 3-log (i.e., 99.9%) removal of the pathogen loadings observed with today's conventional OWTS configurations. Given this retention time, the required vadose zone depth can be determined, based on site-specific hydraulic conductivity field measurements. Table 1 gives some examples of the vadose zone depth (as measured from the bottom of dispersal trench, etc to the water table) that is necessary to provide sufficient retention time under various hydraulic conductivities. Actual depths should be based on site-specific soil measurements.

Table 1. Examples of vadose zone depths needed to provide a 60 day hydraulic retention time.

Soil Type	**Unsaturated Hydraulic Conductivity** (1) **(m/day)** (indicative examples)	**Depth needed (m)** (for 60-day retention time)
Sands - *wet* (2)	0.1 m/day	6.0 m
Sands - *damp* (2)	0.017 m/day	1.0 m
Silts - *wet*	0.017 m/day	1.0 m
Silts - *damp*	0.004 m/day	0.25 m (3)
Clays - *wet*	0.002 m/day	0.13 m (3)
Clays - *damp*	0.0001 m/day	0.006 m (3)

1. Assumes absence of macropores, such as fractured soils.
2. In this example, "wet" refers to 90% saturation, and "damp" refers to 60% saturation. Conductivities extrapolated from Figure 4 of Schaap and Leij 2000. Actual conductivities to be determined on a site-specific basis.
3. Recommended minimum vadose zone depth is 1.0 m (see text below).

Consideration should also be given to whether this retention time (and hence, vadose zone depth) provides sufficient safety with regards to pathogen removal. The critical factor here is how much uncertainty exists regarding the characterization of soil conditions within the vadose zone. Areas with greater variety in soil conditions should either be assessed more thoroughly (to reduce the uncertainty) or have more protective assumptions placed on them (i.e., require deeper vadose zones). Other factors that may need to be considered include whether fractured soils/bedrock (or other macropores and similar features) are present which will dramatically reduce effluent retention time within the vadose zone.

It is critical that no systems be approved that cannot be shown to provide adequate protection of a Supply Aquifer against pathogens. In some cases this may require incorporating more stringent pathogen treatment components within the OWTS.

4 Level 1 Assessment Report

The goal of the Level 1 Assessment is to develop a sufficiently robust conceptual model (i.e. schematic diagram) of the site hydrogeology to evaluate the fate of OWTS effluent in the subsurface and groundwater system.

The Level 1 Assessment report should include a description of a preliminary conceptual hydrogeological model and related interpretation, in addition to information about proposed and existing parcels and OWTS. Conclusions on the fate of OWTS effluent in the context of the conceptual hydrogeological model, and recommendations on whether OWTS use is protective of human health and the environment must be included in the assessment.

The conclusions and recommendations of the Level 1 Assessment should consider the suitability of each proposed lot, and the overall subdivision, for onsite wastewater treatment and disposal. Specifically, conclusions and recommendations should describe any site restrictions, alternative design criteria, treatment potential, impact of treated effluent, mounding concerns, and other technical issues/topics related to onsite wastewater treatment and disposal should be made. It is expected that these conclusions be based on current scientific knowledge and properly referenced in the report.

4.1 Level 1 Report constituents

The Level 1 Assessment report should include the following five parts:

(1) Details about the proposed subdivision/development.

Site drawing(s) and associated report sections should include the following for the proposed and *surrounding areas*, including;

- The development/subdivision area, including identification of all parcels, lot boundaries, the type of development expected;
- The number of existing (or proposed) parcels on surrounding quarter sections (or other adjacent areas);
- Description of the proposed land use and type of development expected;
- Proposed and existing sewage systems in area;
- Existing and proposed water supply points (including private water wells), including their depths and the expected formations that they will be screened in;
- Any reserve or contingency areas proposed for development/subdivision;
- Surface drainage characteristics present or planned that may affect the system(s)
- Identification of any cuts, banks, slopes, or other features that might cause stability concerns created by a proposed on-site system;
- Identification of any vegetation indicative of soil moisture conditions;
- Description of the type of on-site systems and include typical installation design information;

- An estimation of the anticipated or typical sewage volumes used in assessment considerations;
- Other appropriate and relevant information.

(2) Develop a preliminary conceptual hydrogeological model (e.g. main document, Section 4.1.4) and associated water budget. At a minimum, drawings in this part of the report should include the following information for the proposed subdivision *and surrounding* area:

- regional and local hydrogeology and geology information;
- springs, dugouts or water wells accessing shallow groundwater to provide water for domestic purposes;
- any surface water bodies, whether perennial or ephemeral, that may be affected by OWTS;
- existing or planned drainage courses;
- topographic contour lines;
- water table and/or piezometric surface contours for individual hydrogeologic units;
- any relevant separation distances;
- at least one vertical cross-section that illustrates the preliminary hydrogeological conceptual model of regional and local groundwater system(s), the identification of all aquifers being used for well water supplies, and schematic diagrams indicating where the groundwater plumes of OWTS effluent will travel in the subsurface
- Climate conditions (including, for instance, estimates of precipitation, evapotranspiration, and groundwater recharge).

(3) The following *soils* information should be in the report:

- The predominant soil series or mapping unit of the subdivision area, and any significant minor soil series shown on soil maps in the area
- Summary of soil information (soil logs should be appended to the document) including
    1. Soil profile description (texture, structure, and parent material) of expected soil series on the site
    2. Description of soil moisture conditions, or any indications of soil moisture conditions;
    3. Description of permeability or drainage classifications/characterizations;
    4. Identification of any soil water or soil structure and/or characteristics that might affect soil suitability, system design, and location of the system;
    5. Indicate the existence of soil moisture conditions that will adversely affect suitability for onsite systems;
    6. Any evidence of a seasonally high water table should be included in the soil log.

(4) A preliminary assessment of the fate of OWTS effluent, using nitrate-nitrogen as an indicator **and** a comparison of the fate of OWTS effluent with proposed and existing water supply aquifer(s).

Available information should be used to estimate the potential recharge to the site via infiltration of precipitation and the subsequent fate of the OWTS effluent in the subsurface according to the conceptual hydrogeologic model. Recharge rates should be scientifically determined. They are likely to be based on available literature, meteorological data, and the nature of the soils beneath the soil treatment system and down gradient areas as determined during the test pit program. The results can be used in conjunction with the average daily sewage flow to estimate the potential for dilution of nitrate-nitrogen in groundwater. Emphasis should be given to predicting where nitrate and other contaminants could travel in the long term and their ultimate cumulative impact on aquifers (particularly those being used for water supply), wetlands, stream and lakes.

If there is significant natural groundwater recharge at the site (i.e. central and northern Saskatchewan), dilution of OWTS effluent by natural recharge before reaching by the downgradient property boundary can be considered for this preliminary assessment.

Arguments for other attenuating mechanisms can also be incorporated if adequately supported by scientific research or field monitoring data. All assumptions used in the preliminary OWTS effluent and nitrate impact assessment should be stated and substantiated.

Detailed predictions of the shape of individual contaminant plumes and a description of specific contaminant concentrations over space and time are not required for a Level 1 Assessment, although they should be approximated in the conceptual model so the predicted fate of the OWTS effluent in the subsurface is clear. The hydrogeologic unit that the OWTS effluent ultimately resides in should be shown in the context of the water supply aquifer(s) and well sites.

(5) Classification of the Subdivision/Development's suitability for OWTS, and their recommended locations

Considering the information collected in the Level 1 Assessment, the report should classify subdivision/development's suitability for the proposed type of OWTS as:

- Unsuitable except for holding tank
- Severe limitations
- Moderate limitations
- Well suited

The report should also illustrate the optimum location and orientation of the proposed OWTS, considering wastewater treatment and disposal design and water supply issues.

- Determine the proposed number of lots.
- Where it has been demonstrated that the sewage effluent will not enter ground water resources, the lot density of the proposed development may be dictated by factors such as OWTS replacement areas (if proposed) and by the minimum set-back distances for individual on-site beds (and their contingency areas).

5 Level 2 Assessment

5.1 Additional Field program requirements

In general, a more detailed analysis and resulting conclusions should be completed in a Level 2 Assessment. This will typically involve all of the activities included in the Level 1 Assessment, **and** the drilling, core logging, and installation of groundwater monitoring wells to obtain an improved understanding of the subsurface, and to support a more robust site hydrogeology conceptual model. It also involves an increased level of hydrogeological interpretation.

In addition to the information contained within the Level 1 assessment, proponents required to submit a Level 2 Assessment should perform a more detailed analysis that includes (but is not limited to) the following:

The field program should include a door-to-door inventory of:

- water supply, irrigation, or industrial water wells within 1.0 km of the proposed development (and any high pumping rate wells in a larger area). The survey should be conducted to determine the condition and details of local wells, including the method of construction, water level, pump intake and well depths, water use, general water quality and suitability of the well for future monitoring, if required. This should also include all springs and dugouts that access shallow ground water. The results of this survey should also allow estimation of the number of down-gradient wells within 1.0 km that could be potentially impacted by the proposed development and the extent to which these wells are used.
- Any municipal/communal wells within 1.5 kms down-gradient should be located.
- Any onsite wastewater systems (excepting holding tanks) within 1.0 km of the proposed development.

Where warranted, the hydrogeological conceptual model should include

- field estimates of hydraulic conductivity if warranted (i.e. from single well tests, single well pump tests, and/or pump tests with monitoring wells),
- field-measured vertical and/or horizontal hydraulic gradients.

In addition to the Level 1 Assessment requirements, any storm water management plan features and a minimum of two geological cross-sections should be included on the site drawings.

When determining the type of onsite system to be used, the proponent should also determine characteristics of the proposed water supply that may affect sewage system long-term performance.

When considering impacts, the proponent should identify the existence of any surface water body that may be impacted by the OWTS in the subdivision. A preliminary Nitrate

Impact Assessment is NOT required *per se* in the Level 2 Assessment, but may come out of the Cumulative Assessment.

6 Cumulative Assessment

A hydrogeologic study is required to assess whether the development's OWTS, in conjunction with other local and regional nitrate sources, can cause concentrations of nitrate-nitrogen in groundwater to be such that the environment and/or human health are adversely affected.

6.1 Cumulative Nitrate Concentration from Regional Sources

A cumulative nitrate assessment is the evaluation of all known and planned sources of nitrate in a region that could influence surface or groundwater quality. It includes estimation or modeling of the influence of these sources on the nitrate concentration in groundwater at the down-gradient boundary of the proposed subdivision. It should be required only if the probability of intercepting an OWTS effluent plume by a well at the down-gradient subdivision boundary is greater than a defined percentage, for example 75% or 90%. This percentage should be a policy decision.

The cumulative nitrate assessment includes the following key steps:

1) Construct a conceptual model of all significant regional point and non-point nitrate sources e.g. within a 1 km radius of the proposed development.
    a) Point sources: OWTS; golf courses; feedlots; lagoons; landfills; industrial facilities; etc.
    b) Non-point sources: agricultural sources, including manure and sludge spreading and fertilizer application; industrial activities; etc.
2) Estimate (model) nitrate contributions (mass loading) from each of the sources, and their potential influence on the nitrate concentration profiles in the aquifer beneath the proposed development or down-gradient of that development. Predictive assessment such as described in Section 6.2.3 may be used as applicable and justifiable.
    a) Field verification of nitrate loading estimates and nitrate concentration profiles (emphasis on proposed development footprint and down-gradient to 1 km of the proposed development). Monitoring-based assessments such as described in Sections 6.2.1 and 6.2.2 may be used as applicable and justifiable.
    b) Point sources: identify existing or install new sampling wells down-gradient, in the plume (confirm that plume is sampled by using chloride tracer or other appropriate plume markers)
    c) Non-point sources: make use of existing wells down-gradient of the non-point areas
3) Use estimated and field verified aquifer nitrate concentrations, along with well capture zone calculations to predict nitrate concentration in well water in those cases where an OWTS effluent plume is likely to be intercepted by a well. Apply this concentration to the risk characterization phase of the subdivision assessment.

6.2 Monitoring-Based Assessments

The regulatory authorities recognize that groundwater, infiltrating precipitation, and sewage effluent will not be completely mixed at the property boundary. It is also recognized that processes such as absorption, denitrification, filtration and biodegradation may attenuate contaminants as the effluent passes down through the unsaturated zone and moves into the saturated zone. Since these processes are extremely difficult to quantify with any accuracy, they are usually only considered as a safety factor. However, if the consultant can provide documentation to the satisfaction of the regulatory authorities regarding the presence and extent of these processes onsite, their impact on nitrate concentrations can be considered. As discussed below, there are a number of ways in which this can be done.

6.2.1 Monitoring Existing Development

In some situations, there may be nearby developments replying on OWTS in a similar hydrogeological environment. If this development has been in place for a lengthy period of time, information on existing groundwater quality could be used to demonstrate the combined effect of all available attenuation processes to assess the impact of the proposed development. The onus is on the proponent and/or the consultant to demonstrate adequately that:

1) the existing and proposed developments are located in similar hydrogeological environments;
2) sewage effluent (quantity and quality) from the existing and proposed developments are comparable; and,
3) monitoring produces results which accurately represent water quality conditions beneath the existing development and ideally identify that treated OWTS effluent is present in the subsurface (by using tracers like chloride, etc).

The consultant must provide a clear rationale for the number of times the site is sampled, the period of time over which the sampling has been undertaken (capturing seasonal variations), and the rationale for the way in which this information is used in the assessment.

6.2.2 Monitoring Phased Development

In situations where there is no existing development, it may be possible to develop lands considered in the planning document in phases, beginning with the up-gradient portion. Information obtained from monitoring effluent discharged from OWTS in the up-gradient phase, and its impact on groundwater, can then be used to determine the extent to which the down-gradient portion of the site can be developed. Before recommending the approval of such a phased development, the regulatory authorities must be satisfied that adequate planning controls, based on discussions with the Municipality regarding zoning bylaws and municipal development plans, are in place to regulate development of the down-gradient portion of the site.

6.2.3 Predictive Assessment

The following considerations and assumptions should be used in assessing the combined nitrate load of individual OWTS and other point and non-point nitrate sources at the boundary of residential developments in a predictive sense:

1) Contaminant Source: In most cases, total nitrogen (all species) converted to nitrate-nitrogen is considered as the critical contaminant. For the purposes of predicting the potential for groundwater impacts, total nitrate loading and an average day flow should be selected and supported by the proponent.
2) Contaminant Attenuation: only dilution will typically be accepted by the regulatory authorities as a quantifiable attenuation mechanism for nitrate unless there is clear evidence for groundwater denitrification in the hydrogeological unit being evaluated. The fate of bacteria must also be considered.
3) Dilution with infiltrating precipitation. Mixing with groundwater flowing through the site will normally not be allowed because it is usually not possible to control upgradient land uses. 'Flow through' will not be considered where sensitive hydrogeological conditions exist. However, where upgradient lands have been fully developed for a considerable period of time, the quantity and quality of groundwater flow available to dilute the effluent entering the receiving groundwater may be considered.
4) Published groundwater recharge estimates should be used if available for the region. If not, the amount of available moisture surplus should normally be obtained from Environment Canada. Where available, reliable, long-term, site-specific information, obtained for detailed water balance and/or groundwater studies, can be used. Estimates of the amount of this surplus that infiltrates into the ground must be based on site specific factors such as soils, topography, surface geology, and impermeable areas (including roof tops and paved areas).
5) The volume of sewage effluent, if used as dilution water in mass balance calculations, should be based on the average day flow.
6) Mathematical (computer) models may be used to assess the impact potential. Although the selection of model software will be left to the proponent, the regulatory authorities must be provided with information on the model's validation and how its limitations and assumptions affect the results. All model simulations must include appropriate sensitivity analyses.

The proponent must use a dilution model that is reasonable and the selection of the model can be defended to the satisfaction of the regulatory authorities.

7 Risk decision framework

The framework presented in Figure 1 is a risk-based process optimization and decision tree for subdivision OWTS assessments. This approach is consistent with current environmental risk research and practice.

The framework encompasses all phases of the necessary and required desktop and field-based assessment, defines when Level 1 or Level 2 assessment reports are required, and points to where and how the data collected and interpreted in the assessments should be used. A cumulative assessment will be required only when there is a high probability of OWTS effluent interception by a well. The framework includes risk management opportunities for performance-based treatment alternatives and risk mitigation options.

We evaluated the steps in Level 1, Level 2 and Cumulative subdivision assessments to optimize their relative value in estimating residual risk at each phase of the assessment process. What we have arrived at is not a completely new or different process – rather, some of the existing process steps have been re-ordered to allow the information they provide to inform relevant risk-based decisions at more appropriate points in the process. For example, the question of whether OWTS effluents would be isolated from potable groundwater sources in, or down-gradient of the subdivision, is a significant risk question: if the local or regional potable aquifers are very deep or otherwise isolated from effluent sources, the exposure pathway for pathogens and nitrate is incomplete and very little risk[28] of adverse effects can occur. If the developer can show aquifer isolation early in their subdivision assessment, they can submit a more concise report for the approval without having to prepare and submit extensive Level 1 or Level 2 reports.

[28] Note that we do not state that no risk would exist. Contamination mechanisms may exist, such as effluents entering a protected aquifer via improperly abandoned wells, compromised well casing or undetected bedrock fissures.

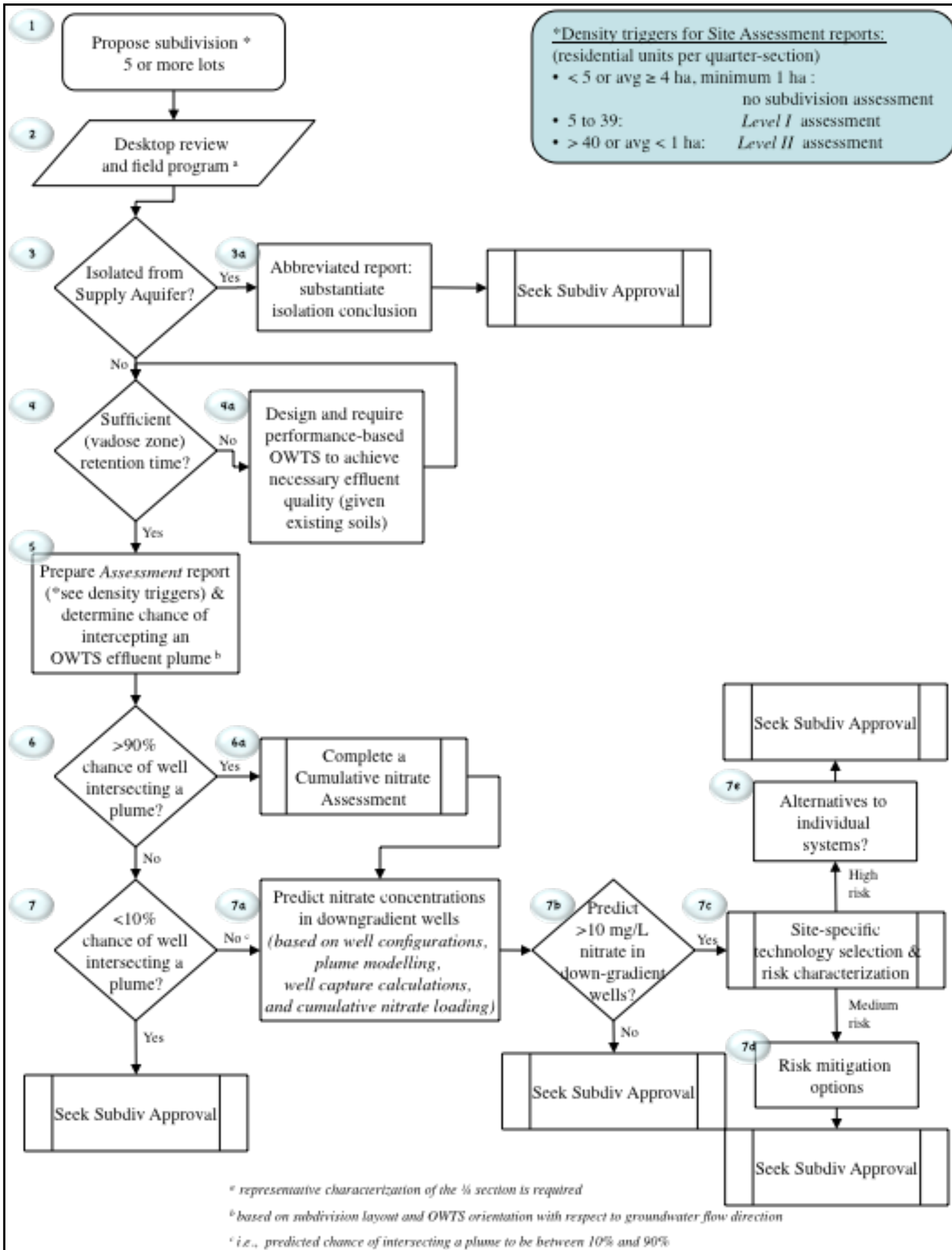

Figure 1. Risk-based framework for subdivision OWTS assessment. The recommended revisions to the interim guidance document (Sections 3 through 6) are encompassed in this framework.

7.1 Step-by-step narrative of the framework

When a developer proposes a subdivision where a public wastewater treatment network is economically unfeasible or otherwise unavailable, they will be required to adhere to the subdivision policy guidance document for on-site wastewater treatment systems. If the development proposal is less than 5 residential lots in a ¼ section, no subdivision-level assessment is required. However, it should be noted that all individual OWTS in Saskatchewan require field-based assessments, including test pits or bore holes for soil characterization, prior to approval. For all developments proposing 5 or more residential lots per ¼ section (Step 1: Section 1), a desktop data review and a field program that includes test pits, bore holes and hydrogeological characterization will be required (Step 2: Section 3.1 – 3.2). The most important aspect at this stage of the subdivision assessment is planning and collecting data and samples that are representative of that particular ¼ section (and the immediately surrounding land). The requirements to defensibly achieve representativeness will be site-specific – if the soil, geography and hydrogeology are very homogeneous across the ¼ section, relatively few randomly sited samples can satisfy the representativeness requirement. However, if there is significant variability in any of these parameters, an increasingly larger number of samples will be required. Note at this stage in the framework that an assessment report is not yet required.

Step 3 in the framework is an inquiry of whether potable aquifers (any aquifers that are used currently or may be used in the future for drinking water) are isolated from the OWTS effluent (Section 3.3), either by non-fractured bedrock, impermeable clay seams, significant coal seams, or other means. Developers will need to support conclusions of isolation (Step 3a: Section 3.3.1) with data collected in Step 2. An effluent isolation report must be submitted. This report includes field and desktop data from the development site and adjacent area with sufficient interpretation of that data to support the conclusion that OWTS effluents from the subdivision will be isolated from current and future potable water aquifers.

If there is insufficient evidence of isolation, or clear evidence of shallow potable groundwater beneath the proposed development, Step 4 is the inquiry of whether sufficient vadose zone retention time will be achieved (Section 3.4). If this cannot be substantiated, a risk management action takes the process through an OWTS design loop (Step 4a) that allows the developer to evaluate and propose advanced treatment that can achieve the necessary effluent parameters (pathogen attenuation).

Once Step 4 has been satisfied, either a Level 1 or Level 2 assessment report is required (Step 5: Section 4 or 5), with lot density equal to or greater than 40 per ¼ section as the dividing line between Level 1 and Level 2 reports. A required aspect of data interpretation for either assessment report is a calculation of the probability of intercepting an OWTS effluent plume, based on subdivision layout and OWTS orientation with respect to groundwater flow direction and velocity. If this calculation shows greater than 90% probability of plume interception at the down-gradient boundary of the subdivision (Step 6), a cumulative nitrate assessment (see Section 5.4) is required (Step 6a: Section 6), following which nitrate concentrations should be predicted for down-gradient wells (Step 7a). If the probability of plume interception is between 10 and 90% (Step 7), the cumulative assessment will not be required – proceed directly to Step 7a to predict nitrate concentrations (see Main Document Section 2.4.7).

The inquiry in Step 7b is whether concentration of nitrate in well water (if a plume is intercepted by the well) exceeds the drinking water nitrate guideline of 10mg/L of nitrate-nitrogen[29]. If the 10 mg/L value is exceeded, a site-specific technology selection process and risk characterization is required (Step 7c). This characterization should carry the probability of plume interception from either Step 6 or Step 7 and characteristics of the receptors (people) residing in and down-gradient of the subdivision. Unless there is compelling evidence to support a statement that infants or pregnant mothers would not reside in or visit residences that use shallow groundwater supplies, we must assume that this susceptible population will be present. This is a clear requirement of policy objective 3, consistency with the precautionary approach.

Therefore, the final evaluation of risk compresses down to the probability of a well intercepting an OWTS plume. If this probability is between 10 and 90%, a number of risk mitigation approaches (Step 7d) are available to reduce the chance of exposure or the concentration of nitrate to which one is exposed. If the probability is high (> 90%), risk management requires the developer to assess alternatives for wastewater treatment (Step 7e).

At three stages – following Steps 3a, 7 and 7b – the developer can move on to seek subdivision approval from the Ministry of Municipal Affairs. Additionally, developers can seek approval following risk management actions in Steps 7d or 7e, and subsequent amendments to the subdivision development plan.

[29] To retain conservatism and adhere to Policy Objectives 1 and 3 in the risk framework, the 90th percentile from the predicted nitrate nitrogen concentration should be used to address the inquiry in Step 7b.

8 References

The list below is provided to assist potential contractors. It is not a complete list of literature that may need to be reviewed or obtained as part of this project.

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Appendix II

Synthetic Organic Compounds Discussion (from California's OWTS *Environmental Impacts Report*)

(quoted from EDAW 2008, pg's 2-22 to 2-23)

ORGANIC WASTEWATER COMPOUNDS

Household, industrial, and agricultural pesticides; pharmaceuticals; and endocrine-disrupting compounds are newly recognized classes of organic compounds that are often associated with wastewater. These organic wastewater compounds are characterized by high usage rates, potential health effects, and continuous release into the environment through human activities (Halling-Sorensen et al. 1998, Daughton and Ternes 1999). Organic wastewater compounds can enter the environment through a variety of sources and may not be completely removed in wastewater treatment systems (Richardson and Bowron 1985, Ternesa et al. 1996, Ternes 1998) resulting in potentially continuous sources of organic wastewater compounds to surface water and groundwater.

The continual introduction of organic wastewater compounds into the environment may have undesirable effects on humans and animals (Daughton and Ternes 1999). Much of the concern has focused on the potential for endocrine disruption (change in normal processes in the endocrine system) in fish. Field investigations in Europe and the United States suggest that selected organic wastewater compounds (nonionic-detergent metabolites, plasticizers, pesticides, and natural or synthetic sterols and hormones) have caused changes in the endocrine systems of fish (Purdom et al. 1994, Jobling and Sumpter 1993, Folmar et al. 1996, Folmar et al. 2001, Goodbred et al. 1997).

An additional concern is the introduction of antibiotics and other pharmaceuticals into the environment. Antibiotics and other pharmaceuticals administered to humans and animals are not always completely metabolized and are excreted in urine or feces as the original product or as metabolites (Daughton and Ternes 1999). The introduction of antibiotics into the environment may result in strains of bacteria that become resistant to antibiotic treatment (Daughton and Ternes 1999).

Toxic organic compounds (TOCs), which are usually found in household products like solvents and cleaners, are also of concern. The TOCs that have been found to be the most prevalent in wastewater are 1, 4-dichlorobenzene, methylbenzene (toluene), dimethylbenzenes (xylenes), 1,1-dichloroethane, 1,1,1-trychloroethane, and dimethylketone (acetone). No studies are known to have been conducted to determine toxic organic treatment efficiency in single-family home septic tanks. A study of toxic organics in domestic wastewater and effluent from a community septic tank found that removal of low molecular-weight alkalized benzenes (e.g., toluene, xylene) was noticeable, whereas virtually no removal was noted for higher molecular-weight compounds (DeWalle et al. 1985). Removal efficiency was observed to be directly related to tank detention time, which is directly related to settling efficiency. It should be noted that significantly high levels of toxic organic compounds can cause tank (and biomat) microorganisms to die off, which could reduce treatment performance.

Appendix III

Pathogen Removal Considerations

One of the most critical functions of an OWTS is to prevent contact between human receptors and pathogens. This contact must not only be prevented at the site itself (by preventing direct contact with untreated sewage), but also must be prevented at downgradient locations (by preventing travel of pathogens into surface water or groundwater supplies that could be ingested later, some distance away from the site).

While most configurations of OWTS achieve a certain level of pathogen attenuation, they also rely on the mechanisms in the soils to effectively achieve the total necessary pathogen attenuation.

Two locations in particular are important in this regard: the biomat and the vadose zone.

Biomat

In all OWTS configurations that release a certain amount of organic material to a soil absorption area, a biomat will form on the bottom and porous sides of the trenches, infiltration galleries, etc. The biomat is a complex layer of microbial organisms (bacteria, fungi, etc) that provide several important functions.

If the upstream unit processes in the treatment train (see Section 2.4.2) are not effectively removing enough organic material (e.g., a septic tank is overdue for a pump-out to remove the accumulated solids), then *too much* organic material will flow into the soil absorption field and excessive biomat growth will occur, to the point where the soil absorption area will become clogged and cause a hydraulic failure of the system (e.g., effluent will no longer flow into the field, and will either back-up or pond on the ground surface). Conversely, if the upstream unit processes are releasing *insufficient* organic matter (either through overly aggressive treatment effectiveness or too low a hydraulic loading), the biomat will "starve" and diminish or completely disappear. (This is the mechanism being employed when a clogged field is rejuvenated by being rested -- by not using the field for a certain amount of time, no organic material is supplied and the biomat diminishes.)

A healthy biomat is maintained through a combination of employing the correct configuration of upstream unit processes that are loaded correctly and are properly maintained. A health biomat will perform a number of important functions, including:

- *Evens out hydraulic loading to the vadose zone*: Flow of effluent through the biomat is slower than through coarser-grains soils. Therefore in coarser grained soils, the biomat somewhat reduces the hydraulic loading rate to the underlying vadose zone and makes the loading rate more similar to that found in finer grained soils. For example, Beal et al. (2006) reported that biomat formation reduced the range of effluent acceptance rates from six orders of magnitude to one. This is important for two reasons: (i) it reduces the extreme range of performance variability that would otherwise be present between systems constructed over different types of soils, thereby making their performance more similar and easier to predict; and (ii) it further reduces the chance of surge loading to the vadose zone, thereby providing it with a more consistent moisture regime, and hence maintaining a more consistent unsaturated hydraulic conductivity, which results in a more consistent vadose zone effluent retention time (Beach et al. 2005).

- *Filter out organic matter*: Due to its physical characteristics, the biomat will physically filter out and retain suspended organic matter, along with other materials such as nutrients (Beal et al. 2008).
- *Remove pathogens*: Similarly, the biomat will also filter out an important amount of the pathogens, including viruses. Once entrained in the biomat, the pathogens can be subjected to predation and other attenuation mechanisms (Stevik et al. 1999; van Cuyk et al. 2001; van Cuyk et al. 2004; van Cuyk and Siegrist 2007).

Vadose Zone Retention Time

With regards to pathogen removal, one of the most important vadose zone soil conditions is hydraulic retention time. This is governed primarily by the site's unsaturated hydraulic conductivity, hydraulic loading rate, and the depth of the vadose zone.

Longer vadose zone retention times provide more opportunity for pathogen removal, either through redox stress resulting in die-off, predation, or the other pathogen attenuation mechanisms at work within the vadose zone (Lane and Weaver 1999).

The time is takes the effluent to drain vertically through the soil is directly related to the depth of soil it needs to travel through. If all other factors are constant then, obviously, deeper vadose zones provide longer retention times.

Finer-grained soils have lower hydraulic conductivities (i.e., slower "percolation rates"), which directly result in slower vertical drainage, hence longer retention times. Slower percolation velocities can also result in better adhesion of the pathogens to the soil particles (Lane and Weaver 1999).

However, for any soil, unsaturated hydraulic conductivity increases with soil moisture content, until saturation is reached[30] (Schaap and Leij 2000). Therefore it is important to maintain as low a hydraulic loading rate as practical, to keep the vadose zone moisture regime as unsaturated as practical.

Table 1. Examples of vadose zone depths needed to provide a 60 day hydraulic retention time.

Soil Type	**Unsaturated Hydraulic Conductivity** [1] **(m/day)** (indicative examples)	**Depth needed (m)** (for 60-day retention time)
Sands - *wet* [2]	0.1 m/day	6.0 m
Sands - *damp* [2]	0.017 m/day	1.0 m
Silts - *wet*	0.017 m/day	1.0 m
Silts - *damp*	0.004 m/day	0.25 m [3]
Clays - *wet*	0.002 m/day	0.13 m [3]
Clays - *damp*	0.0001 m/day	0.006 m [3]

1. Assumes absence of macropores, such as fractured soils.
2. In this example, "wet" refers to 90% saturation, and "damp" refers to 60% saturation. Conductivities extrapolated from Figure 4 of Schaap and Leij 2000. Actual conductivities to be determined on a site-specific basis.

[30] i.e., For any given soil, its unsaturated hydraulic conductivity is less (i.e., slower flow) than its saturated hydraulic conductivity.

3. Recommended minimum vadose zone depth is 1.0 m (see text below).

At certain sites, other factors that effect effluent flow velocities and/or retention time may also come into play. These may include significant seasonal variation in depth to the groundwater table (and hence vadose zone depth); presence of fractured till, sand-filled desiccation cracks or other features that result in macropores; presence of coarse-grained (e.g., sand) seams and lens; and highly heterogeneous or variable soils. The site assessment work needs to adequately characterize these situations where they exist, so they can be properly taken into account during system design, including specifying the minimum required vadose zone depth for that site, or other mitigating measures, as appropriate.

Providing definitive statements concerning how much retention time is needed to sufficiently attenuate pathogens is a challenge, due to a number of factors, including the wide variety of pathogens; immense variation in how they survive under various environmental conditions (moisture, temperature, etc); and how the various soil characteristics (e.g., grain size and attachment sites / cation exchange capacity; organic matter content; presence of natural predators) also affect their survival (Goss and Richards 2008). The scientific literature contains a wide range of observations about how quickly pathogens are attenuated in unsaturated soils.

It has been observed that under certain conditions it may take a minimum depth of 0.5 to 0.9 meters of *unsaturated* soil to effectively remove pathogenic bacteria and viruses (Bouwer et al. 1974; Hunt et al. 1980; Lance and Gerba 1984; Lane and Weaver 1999; McConnell et al. 1984; van Cuyk et al. 2004; Wang et al. 1981).

Under *saturated* conditions, the minimum depth was 2 meters or more (Lance et al. 1976; Lance and Gerba 1984; Moore and Beehier 1984).

Under the right conditions, viruses and certain bacteria can survive for extended periods of time (>200 days) in the soil (Cools et al. 2001; Duboise et al. 1974; Edmond 1976; Goss and Richards 2008; Kibbey et al. 1978). However, if the proper unsaturated flow conditions are maintained (e.g., low flow velocities, no high-volume water surges), the pathogens should remain within the soil matrix (i.e., not travel downward with the water), and thereby be retained long enough for deactivation to occur.

Both of the preceding points underline the importance of keeping the hydraulic loading rate as low as is practical.

More typically reported attenuation periods in the scientific literature for various pathogens fall within the range of 5 to 65 days to achieve a one- to four-log (i.e., 90% to 99.99%) removal (Lance and Weaver 1999; Hijnen et al. 2005).

Given this, a reasonable minimum effluent retention time of 60 days through the vadose zone is likely necessary to achieve at least a 3-log (i.e., 99.9%) removal of the pathogen loadings observed with today's conventional OWTS configurations (e.g., a typical septic tank + tile field). Ultimately, setting the required retention time is a policy decision, to be made by the appropriate Agencies -- longer retention times provide higher levels of protection.

As a further precaution, a minimum vadose zone depth of at least 1.0 meter should be required, even in soils with low hydraulic conductivities (i.e., long retention times). In other words, the required vadose zone depth should be the *deeper* of (i) a sufficient depth to yield an average retention time of 60 days; or (ii) 1.0 meter. (Again, this minimum depth is ultimately a policy decision, to be made by the appropriate Agencies.)

This vadose zone retention time will translate into different depths, depending on a site's unsaturated hydraulic conductivity (see Table 1 above for indicative examples).

Design Considerations

From the above, it can be seen that there are a number of design considerations that can be used to optimize pathogen removal within the overall system. These include:

- Remove as many pathogens as possible in the upstream unit processes, to reduce the pathogen loading to the vadose zone.[31]
- Provide conditions conducive to a healthy, but not excessive, biomat.
- Reduce hydraulic loading rates (e.g., through use of low-flow fixtures and/or larger soil absorption fields), especially at locations with highly conductive soils.
- Select locations that have deeper (and/or less conductive) vadose zones.

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[31] This can be accomplished through employing more advanced treatment techniques, such as low-maintenance constructed wetlands, sand filters, or more energy-intensive processes (e.g., biomechanical "package plants"). Care should be taken to ensure that the unit processes employed do not adversely effect the ability of subsequent unit processes to perform adequately (e.g., a chemical disinfection unit might impair downstream biologically-based units).

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