**Geologic Nitrate in Groundwater in the Oldman River Watershed of Southern Alberta, Canada**

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*Note: All nitrate concentrations are reported in the standard units of mg/L as nitrogen. 1 mg/L is equivalent to 1 part per million.*

Canadian guidelines stipulate nitrate concentrations in drinking water should not exceed 10 mg N/L because consumption of nitrate is associated with adverse health effects. Worldwide, agriculture is the most common source of nitrate in groundwater. Nitrate can be from point sources such as confined feeding operations or manure storages, or non-point sources such as manured or fertilized fields. Southern Alberta is unusual because groundwater often contains geologic nitrate derived naturally from glacial till. This fact sheet summarizes what is currently known and still unknown about geologic nitrate, and it provides criteria that can be used to help distinguish it from agricultural nitrate.

**Geology and Groundwater on the Prairies**

geology schematic figure 1 for wmf.wmfBedrock in the prairie landscape in southern Alberta consists mainly of softrock (sandstone, siltstone, mudstone or shale) deposited in freshwater, deltaic or marine settings about 75 to 60 million years ago. It is commonly overlain by glacial till, which is an unsorted mixture of sand, silt and clay deposited directly by glaciers (shown schematically in Figure 1). The particle sizes in glacial till range from fine-grained clay to sandy materials, with few to many stones of varying sizes and lithology. At some locations the glacial till is overlain by sediments deposited during deglaciation, ranging from fine-grained glacial lake sediments to coarse-grained sands and gravels deposited from flowing meltwater. Sands and gravels deposited by pre-glacial rivers also occur between till and bedrock at many prairie locations (Figure 1).

**Figure 1. Simplified geology in a prairie glacial till landscape. Settings with geologic nitrate are shown schematically with the letter “N”**

*Note: The water-table is the upper surface of the groundwater zone. Recharge occurs when water from rain and snowmelt travels through the soil zone to the water table.*

Groundwater is water that fills the pore spaces between underground sediments. Aquifers are geologic units that can supply water wells with at least enough groundwater to comfortably supply a household. Prairie aquifers include pre-glacial sands and gravels, fractured or coarse-textured bedrock, and some shallow sandy or gravelly deposits related to deglaciation. Glacial till and glacial lake sediments do not form aquifers because groundwater flow through these deposits is usually insufficient to supply a modern household.

*Note: Tritium is a hydrogen molecule with one more neutron in its nucleus than usual. Tritium levels in modern (i.e. post-1950s) precipitation can be elevated compared to old, or ‘paleo-groundwater’, where no tritium is detected, but concentrations are so low that ‘enriched’ tritium analysis must be conducted to identify modern groundwater.*

**Glacial Till: Three Depth Zones, and Nitrate Occurrence**

Groundwater in till can be divided into three main zones with increasing depth, as shown in Figure 1.

1. **The shallow active zone.** Newly recharged groundwater in till flows mainly through the shallow highly fractured zone where it is short-circuited through fractures back into creeks and rivers. Groundwater in the shallow active zone usually contains detectable tritium, so it can also be called the tritiated zone. In glacial till this zone usually extends no more than about 5 to 7 meters below ground, although there are exceptions. Groundwater in the tritiated zone is ‘modern’, and nitrate from ‘modern’ agricultural sources can occur in this zone.
2. **The oxidized ‘sluggish-flow’ zone.** Shallow glacial till was dried out and oxidized during an extended dry period known as the altithermal, which occurred about 4,000 to 6,000 years ago. Oxidized till is fractured with rust-like colours that range from yellowish to reddish brown. Groundwater in the oxidized sluggish-flow zone was typically recharged hundreds to thousands of years ago, and groundwater movement is relatively slow. Since the groundwater tends to be old, nitrate in this zone does not tend to be from agricultural sources - rather it is has a geologic origin.
3. **Reduced ‘no-flow’ zone.** Till below the oxidized zone was never dried out or exposed to oxygen. It is called reduced till, and is dark gray. Nitrate does not occur in reduced till because it is not geochemically stable due to the low oxygen levels. The boundary between oxidized till and the underlying unoxidized (reduced) gray till is called the redox boundary. This boundary can be sharp but it is often gradual, with till colours becoming gradually grayer with increasing depth. Sometimes wide brown haloes around fractures extend many meters into gray till, indicating oxygen permeated the fractures but not the surrounding matrix.

**Distinguishing Agricultural Nitrate from Till-Related Nitrate**

Land owners, regulators, researchers and others require criteria to distinguish between agricultural and geologic nitrate. Agricultural nitrate most commonly occurs in shallow, active groundwater that is tritiated, typically located near point or non-point agricultural sources. The six most useful criteria for the identification of geologic nitrate are summarized below.

1. **Location.** The occurrence of geologic nitrate in groundwater in the oxidized sluggish till zone was documented in detail in a few locations (areas A, B, and C; Figure 2) by Alberta Agriculture in the 1980s and 1990s. Nielsen (1971) reported that many shallow wells in an area south of Lethbridge (shown with a dotted outline and yellow shading in Figure 2) contained high nitrate but assumed the wells were “contaminated” by agricultural activities. Geologic nitrate was more recently documented in area D. The aerial extent of the zone of geologic nitrate has not been defined in southern Alberta, but geologic nitrate has not been reported elsewhere in the province, or in Canada. Nitrate concentrations (shown as mg N/L in Figure 2) are highest near Vauxhall and decrease in a southwesterly direction in the Oldman Basin. Since the geologic nitrate resides in the till, a till-related source is logical, and consistent with the criteria listed below.
2. **Stability with Time.** Concentrations of agricultural nitrate in shallow groundwater can increase or decrease with time and changes in soil and crop management on individual fields, whereas concentrations of geologic nitrate are stable with time over decades or more.

**map.wmf**

**Figure 2. Study areas with documented geologic nitrate (shaded in yellow), with maximum concentrations indicated. The area outlined in red is the Oldman River Watershed.**

1. **Land Use.** Agricultural nitrate tends to occur in shallow groundwater as a consequence of surface runoff and leaching from manure or fertilizer sources. Agricultural nitrate is less likely to leach at concentrations of concern beneath non-irrigated annual crops that are fertilized at agronomic rates, and it is unlikely to leach below grazed grasslands.
2. **Groundwater Age.** Nitrate that occurs in groundwater without detectable enriched tritium is most likely from a geologic source.
3. **Nitrate Concentrations with Depth.** Concentrations of geologic nitrate are usually higher at depth (i.e. in the ‘sluggish flow zone’), with lower concentrations in the overlying shallow active zone near the water table.
4. **Geologic Setting.** A geologic origin is supported for nitrate that occurs in one of the following three geologic scenarios. The first two scenarios have been clearly documented in detailed studies in areas A, B and C (Figure 2), which have simple geologic systems and well-defined land uses. Investigations in Area D were less detailed and results were complicated by complex geology. Area D contains both agricultural and geologic nitrate. Some of the geologic nitrate occurrences are consistent with the first two geologic scenarios, but it also contains nitrate occurrences that require additional investigation, as described in the third scenario below.

* **In the Oxidized Sluggish Zone of Glacial Till**

Geologic nitrate in areas A, B and C (Figure 2) most commonly occurs in the oxidized sluggish till zone, below a depth of about 5 m, and extending to the bottom of the oxidized zone, which can be more than 20 m thick in southern Alberta. Till-related nitrate in this scenario sometimes extends into the shallow active zone in local discharge areas (e.g., location (i) in Figure 1).

* **In Aquifers below the Oxidized Sluggish Zone of Glacial Till**

Till at many locations in Alberta is too thin to have a reduced zone, in which case till-related nitrate can move down from the oxidized sluggish zone to underlying bedrock, or to gravel aquifers where they occur. This scenario occurs at several locations in area A (Figure 2), where till-related nitrate was detected in the uppermost few meters of bedrock that is in direct contact with the overlying sluggish till zone (e.g. location (ii) in Figure 1). Nitrate in this scenario most commonly occurs within a few meters below the contact with oxidized till, especially where the oxidized till is at least 6 to 8 meters thick. This setting also occurs in area D, where pre-glacial gravel and softrock aquifers contain nitrate that was logically derived from the overlying oxidized sluggish zone (e.g. location (iii) in Figure 1. Till in the vicinity of Picture Butte, Lethbridge, and areas to the south is often of sufficient thickness to have a zone of reduced till, which prevents till-related nitrate from the oxidized sluggish zone from entering underlying aquifers (e.g. location (iv) in Figure 1).

* **In Aquifers in Contact with Upslope Till or where Till has been Eroded**

Groundwater nitrate is common in softrock and gravel aquifers in Area D. Some of the occurrences are related to near-by manure sources, but current evidence suggests much of the nitrate was geologically derived – the groundwater has pre-modern groundwater ages, the concentrations have remained stable over decades, and there is widespread nitrate occurrence in a low-intensity agricultural area dominated by grazing land use. Some of the detections of geologic (non-agricultural) nitrate are consistent with an origin in overlying till, but at other locations the geologic nitrate occurs in near-surface aquifers that are not overlain by significant thicknesses of till. Preliminary evidence suggests some near-surface gravel aquifers at higher elevations in area D may contain geologic nitrate derived from upslope till with thick oxidized sluggish zones, as illustrated schematically for location (v) in Figure 1. Preliminary evidence suggests some near-surface bedrock aquifers contain till-related nitrate that entered the bedrock during an earlier geologic time when the bedrock was overlain by till that was subsequently eroded (as shown for location (vi) in Figure 1). Both hypotheses require additional investigation.

**For More Information**

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