Groundwater Protection and Soils

Students will…

- Understand the role of soils in maintaining groundwater quality
- Describe how the nature of various geological deposits affects groundwater recharge
- Be able to identify the major ways in which agricultural practices can harm groundwater quality and quantity
- Provide examples of alternate agricultural practices that are less harmful to groundwater

Introduction

Soils are the combination of four major components: mineral matter, organic matter, air, and water. These components interactively create a framework which supports the vast diversity of plant, animal and microorganism life on earth. As you look around you, you may recognize that every object is directly or indirectly obtained from the soil. The clothes you are wearing may be derived from plants that once grew on soils. The road you travel on to get to school is constructed on the solid body of a soil. The water you drink may be derived from clean groundwater that was filtered with the help of soils. All the agricultural, forestry, and wilderness areas in Canada would disappear entirely without the small accumulation of topsoil that exists on this vast land. Clearly, soils provide for many of our basic needs (OFA, 2007).

Different bodies of soils vary in nature in their physical, chemical, and biological properties. Some soils are rich in nutrients and organic matter; others are thoroughly leached. Some have a high water holding capacity; some allow rapid water infiltration. Soils also differ in age, depth, compaction, and temperature. The varying types and conditions of soils in a region are crucial in determining the region's ability to store and filter groundwater and act as a reservoir (OFA, 2007).

Within the ecosystem, all living organisms depend on soil. Trees and plants obtain water and nutrients from the soil and convert them into energy that can be used by a variety of different consumers. Soils also serve as the structural medium supporting the roots of plants. Some living organisms such as bacteria, fungi, mites, earthworms, snails, and insects exist within the body of the soil. Other organisms such as turtles lay their eggs inside the soil. The diversity of plant and animal communities cannot exist without soil. In this section, we will explore the importance of soils in sustaining natural groundwater resources (OFA, 2007).

Soils and Water Supplies

Soil has the ability to act as a natural purifying and filtering agent for the world's groundwater supplies. All rain and wastewater that percolates down to the groundwater is chemically and biologically treated to become drinkable once again. The sand and silt components of the soil sieve out any solid components, while charged surfaces of clays absorb any hazardous pollutants and contaminants that have been dissolved in the water. Meanwhile, billions of soil organisms act to eliminate pathogens, viruses, dissolved solids, and other colour and taste problems. Soil protozoa prey on pathogens as food. Bacteria and fungi produce antibiotics that destroy harmful pathogens. In addition, the new environment of the soil (temperature, pH, and nutrients) creates conditions that are intolerable for pathogens (Mankiewicz, 2004).

Soils and Groundwater Recharge

The rate of groundwater recharge depends on many factors, including vegetation cover, slope, soil composition, depth to the water table, the presence or absence of confining beds and other factors. Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds (Ground Water Advocates Coalition, 1986).

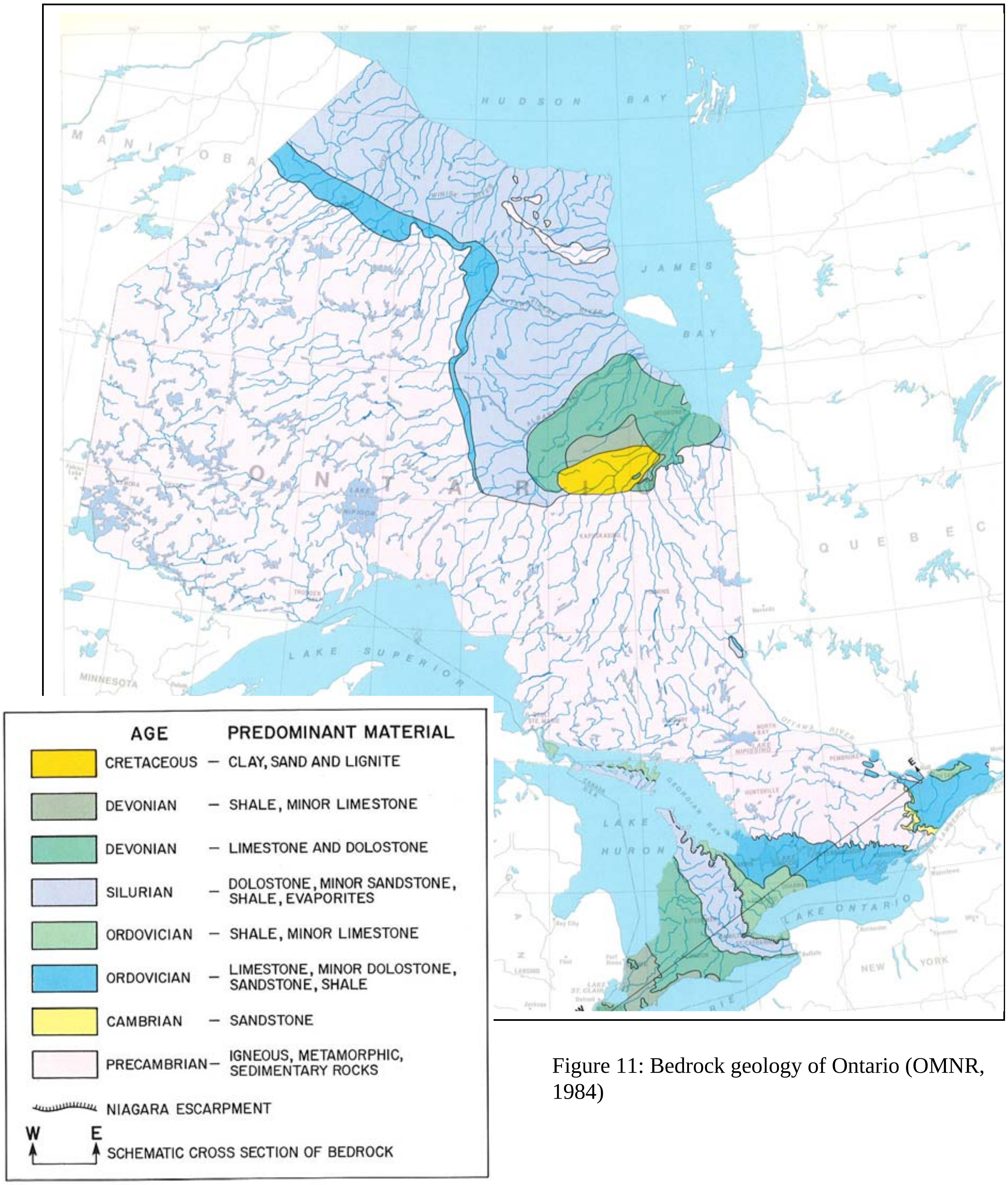

Figure 11: Bedrock geology of Ontario (OMNR, 1984)

One of the most important factors affecting recharge rates is the capacity of the subsurface deposits to store and transmit water. Therefore, to understand the effects of human activities on groundwater recharge, it is important to know what sorts of deposits are present in a particular area and their water-related characteristics.

Figure 11 shows Ontario's land area divided into several major regions based on bedrock geology. Rock ages are listed in order from the youngest cretaceous rocks, which formed between 65 and 145 million years ago, to the oldest Precambrian rocks which date back over 540 million years (Earth's Geological Timeline, n.d.). Precambrian rock is found at or close to the surface in the majority of the province (approximately two thirds). It includes igneous, metamorphic and some sedimentary rocks which form the massive, dense formation known as the Canadian Shield. At some point in their history, these rocks have undergone periods of intense pressure and temperature, which means that they lack systems of interconnected pores which can store groundwater. Openings in these rocks are usually found along narrow fractures or faults and cannot transmit significant quantities of water (OMNR, 1984).

Rocks of the Cambrian, Ordovician, Silurian and Devonian periods are sedimentary rocks which were deposited in relatively flat lying beds at the bottom of ancient seas. These rocks are common in southern Ontario and the area surrounding Hudson Bay and tend to make much better aquifers than Precambrian rock. The amount of openings in these rocks varies depending on the rock type. Shale tends to have few openings in comparison to limestone and dolostone which often have extensive systems of wide, interconnected fractures and pores (OMNR, 1984). Sandstone is usually tightly cemented, retaining only a small fraction of the inter-granular pore space that was present before the rock was consolidated. However, secondary cracks and fractures (which occurred after the rock was formed) typically provide enough open spaces to give sandstone the highest porosity after limestone and dolostone (USGS, 2009).

Recharge rates are highly influenced by the porosity of the underlying geologic materials deposits, whether bedrock or unconsolidated materials. The typical porosity of common geologic materials is given in Table 3. Well aggregated soils have a higher porosity and often allow greater infiltration than soils with little structure.

Table 3: porosity of geological materials. (US Environmental Protection Agency, 2006)

Materials	Porosity (percentage pore space)
Silts and clays (not significantly compacted)	50 - 60
Fine sand	40-50
Medium sand	35 - 40
Coarse sand	25 - 35
Gravel	20 - 30
Sand and gravel mixes	10 - 30
Glacial till	25 - 45
Dense, solid rock	<1

Fractured and weathered igneous rock	2 - 10
Permeable, recent basalt	2 - 5
Sandstone	5 - 30
Carbonate rock with original and secondary openings	10 - 20

Soils and Agriculture

Soils are often referred to as the medium of growth. Without soil, there would be no means of providing crops with the water and nutrients that are essential for growth. In Canada, only about 5% of the nearly 10 million square km of land is considered to be arable (Design Intelligence, 2007). That is, land that is, or has the potential to be, cultivated for crop production. Nevertheless, Canada is one of the world's top suppliers of agricultural products, exporting products to the United States, Europe, and East Asia, with a substantial quantity of food left for domestic consumers. Its main crops include wheat, barley, corn, potatoes, soybeans, rice, and sugar beats.

The use of soil for modern agriculture causes numerous complications that may degrade the quality of soil, deplete or contaminate groundwater resources, and render agriculture impossible. The use of heavy equipment for the purpose of ploughing and tillage often causes soil compaction, preventing precipitation from penetrating the soil, and resulting in runoff and erosion. Crop irrigation can deplete the supply of groundwater in aquifers and leave salts at the root zone of crops, preventing uptake of water. The addition of pesticides, insecticides, and fungicides destroys certain soil organisms, inhibits the natural function of the system, and can leach downward and contaminate underlying stores of groundwater. It is interesting to know that organic agriculture is one of the fastest growing segments of Canadian agriculture, growing at a rate of 20% per year. Currently, there are over 1, 500 registered organic food producers in Canada. Some of the negative impacts of agriculture on groundwater supplies are described below, followed by a discussion of sustainable management practices that reduce these negative impacts (Encyclopedia of the Nations, 2008).

<u>Tillage and Erosion</u>

Despite scientific and empirical evidence explaining processes of runoff and erosion, it is a common misconception that the soil has to be loosened by tillage to increase water infiltration and reduce runoff. Soil erosion by water and runoff is often accepted as an unavoidable phenomenon associated with agriculture on sloping land. But soil loss by erosion or runoff is not an unavoidable process. The occurrence of erosion damage on cultivated land is a symptom of land misuse and inappropriate farming practices for that environment. It is often not slope and rainfall intensity, but rather inappropriate farming methods used by humans, which are responsible for erosion and its negative consequences (Derpsch, n.d).

Through the utilization of site specific and adapted farming systems and management practices, erosion can be effectively controlled, runoff reduced, and water infiltration increased. Runoff water is lost to crops, while infiltrated water can be effectively used by plants. Conventional farming practices utilized in many parts of the world have had negative consequences in terms of soil and water preservation as well as on the conservation of the environment as a whole. This is due to improper soil use, monoculture and the use of tillage tools that leave the soil bare and pulverize it excessively; leaving it in such a condition that it can be carried away by heavy rains (Derpsch, n.d.).

Besides making agricultural soil unproductive, erosion of agricultural land and runoff results in the deposition of soil particles in unwanted areas (sedimentation of roads, creeks, rivers, lakes, dams, etc.) with negative consequences for traffic, electric power generation, the delivery of drinking water, aquatic ecosystems etc., resulting in important expenditures for the government as well as for society as a whole. Furthermore, the importance of erosion control is not restricted to the maintenance of the productivity and fertility of soils for future generations; it is also an effective means to ensure employment in rural areas (Derpsch, n.d.). Efficient erosion control is therefore very advantageous from the ecologic and social perspectives, besides being highly significant from an economic point of view.

Runoff and erosion start with raindrop impact on bare soil surface. Soil splash seen on fence posts, or on walls next to bare soil, is evidence of the force of large raindrops striking bare soil. The impact of falling raindrops breaks down the soil structure into very fine particles, which clog soil pores at the surface and create a seal that impedes infiltration and increases runoff and erosion. The drying of surface seal, results in soil crusting, which may hinder or impede the germination and emergence of crop seeds. Soil crusting only develops under a condition of bare soil (Derpsch, n.d.).

Conservation tillage is a series of agricultural practices that attempt to prevent soil degradation by reducing (reduced tillage) or eliminating (no-tillage) the ploughing of the soil before sowing. Tillage can cause soil compaction, loss of organic matter, degradation of soil aggregates, death or disruption of soil organisms, and exacerbates erosion. In addition to changes in cultivation, conservation tillage also requires that plant residue is deliberately left on the ground rather than burning or incorporating it into the ground by ploughing. At least 30% of the ground must be covered by residue (OFA, 2007).

Plant residue offers numerous benefits to the soil. First, it absorbs the impact of falling raindrops and slows down running water, thereby increasing infiltration and reducing water erosion. Since the surface of the soil is covered and protected, the incidence of wind erosion is also less likely on conservation tilled soils. Plant residue also helps to reduce soil temperature, conserve nutrients, add organic matter, improve water absorption and infiltration, slow down the rate of moisture evaporation, and conserve biodiversity (OFA, 2007).

Cover crops offer similar benefits as the use of plant residue in conservation tillage.
Cover crops are vegetation that is planted on bare soils during seasons when no crops are grown in order to reduce wind and water erosion. Some cover crops such as ‘green manures’ add nitrogen to the soil and help improve the quality and fertility. They also

serve to protect the soils against wind and water, add organic matter to the soil, and increase absorption of water. Conservation tillage systems and cover crops offer the most effective and affordable strategy to control soil erosion, improving soil fertility, and achieving sustainable agriculture (OFA, 2007).

Irrigation and Salinization

Proper irrigation is one of the biggest challenges in arid lands where a moisture deficiency makes it impossible for farming to occur without artificial irrigation. Irrigation in arid lands can lead to depletion of groundwater supplies in underlying aquifers and decreased water availability to ecosystems as a result of soil degradation by salinization and alkalinization (OFA, 2007).

Salinization occurs when irrigation water evaporates quickly, leaving natural salts (e.g. chlorides, sulfates, and carbonates) at the surface of the soil. Over a long time, excessive quantities of salts accumulate at or near the soil surface, reducing infiltration rates and making it increasing difficult for plants to extract water from the soil. Salinization also gives rise to compacted soil structure, decreased permeability and porosity, decreased biological activity, and unfavourable changes in pH (OFA, 2007).

Alkalinization is a similar process, where the accumulation of sodium ions causes the disintegration of soil aggregates, resulting in a weakened soil structure. Poor soil structure generally leads to decreased porosity and aeration, reduced infiltration, oxygen deficiency, and increased runoff and erosion (OFA, 2007). The final result is a reduced capacity of the soil to support vegetation and crops.

Sodium causes clay and organic matter of the soil to disperse. The soil becomes compacted and hampers the growth of roots. When these soils become dry, the sodium-clay forms a hard crust that is characterized by a white surface coating. Crusted soils are impenetrable to plant roots and may even limit the emergence of seedlings (OFA, 2007).

Soil salinization may occur naturally or due to conditions resulting from anthropogenic mismanagement of the land. Salinization occurs when conditions of low rainfall, high evaporation, high water table, and the presence of soluble salts in the soil co-occur and work hand in hand to augment salt build-up (OFA, 2007).

In poorly drained soils, where the water table is 3 m or less from the surface of the soil, water is unable to leach down, and instead rises to the surface by capillary action. In hot and dry regions, this water leaves the surface of the soil through evaporation. Since groundwater contains naturally dissolved salts, the water evaporates leaving salts behind. The phenomenon repeats constantly, and over time salts concentrate until they reach levels in the root zone that are detrimental to plants (OFA, 2007).

Salinization Control

Though it is difficult to reverse soil acidity, there are ways to manage soils that have been affected by salinity. Here are some recommendations made by the Federation of Ontario Naturalists and Soil and Water Conservation Society:

- Summer plowing of land should be decreased
- Deep-rooted crops that require high moisture levels should be grown in the groundwater recharge area
- Salt-tolerant plants should be planted in the salt-affected area
- Growing crops continually uses more water than summer plowing
- When the amount of water entering the groundwater recharge area is decreased, the water table drops and there is less water available for soil salinization processes
- If salinization in caused by water from irrigation, tile drainage will remove the excess water and slow the salinization process. (A tile drainage system consists of a network of underground pipes that drain subsurface water from an agricultural field).

(OFA, 2007)

Groundwater Contamination from Agriculture

Since drinking water in rural Ontario is usually obtained from ground water sources, every effort should be made to protect these ground water sources from contamination. Potential contaminants from agriculture such as pesticides, manure and fertilizers can pose a threat to ground water quality if not properly managed.

The quality of ground water is degraded when water carries contaminants downward infiltrating through the soil to the ground water without being adequately filtered or naturally treated. Once a ground water aquifer is contaminated, all water wells drawing water from that aquifer are at risk of being polluted. A contaminated water well can result in health problems and a costly cleanup process.

The potential for ground water contamination and subsequent water well pollution depends on many factors. We will focus on the following three key factors:

1. Permeability
2. Depth to bedrock
3. Depth to ground water

Permeability

The texture of the soil is the most important factor in determining the soil permeability, and consequently the speed with which water and contaminants can move through the soil to groundwater. Coarse textured soils such as sands have large pore spaces between the soil particles, allowing water to quickly percolate downward to the ground water. There is minimal time in which filtration and/or natural treatment of the water can take place. Conversely, in fine textured soils such as clays, the movement of water and contaminants through the soil is very slow. These fine textured soils act as a natural filter, allowing bacteria and other soil organisms to break down contaminants before they reach the ground water. Fine textured soils provide much better natural protection for groundwater than coarse grained soils.

Depth to Bedrock

Open fractures in bedrock such as limestone or dolostone allow rapid movement of water and contaminants to the ground water. If the depth of soil over the bedrock is shallow, there is little opportunity for the soil or soil organisms to treat the water as it moves through this shallow layer of soil to the bedrock. Once the water and contaminants reach highly porous bedrock, movement to the ground water is often very swift.

Depth to Groundwater

The treatment of contaminated water primarily takes place in the unsaturated zone. A high water table results in a short travel time for water and contaminants to move through this unsaturated soil before reaching the ground water, therefore, there is little opportunity for the treatment of water to occur. Water table depths can fluctuate dramatically depending on the season of the year and is usually the highest in the spring or fall.

Assessing the Potential for Groundwater Contamination

On a farm, there are many potential sources of contaminants. They are usually classified as **point source contaminants** where potential contaminants are concentrated or stored in one spot (e.g., manure piles, fuel storages, etc.) or **non-point source contaminants** where the potential contaminants are spread out over a greater area (e.g., pesticide or fertilizer applied to fields). Regardless of the source, some farms or areas of farms may be much more susceptible to groundwater contamination if contaminants enter the ground. Table 4 is a simple approach to estimate the potential for ground water contamination. Please note that this assessment method is only intended to be a guide to what might happen, taking into account the three factors previously discussed - soil permeability, bedrock, and depth to ground water. The primary consideration is the relative speed with which contaminants might move through the soil. It is assumed that the soil profile is uniform and not layered.

Table 4: Potential for Groundwater Contamination. (OMAFRA, 2009)

Hydrologic Soil Group (Soil Texture)	Depth to Groundwater			
	Less than 0.9 m (3 ft)	0.9-4.5 m (3-15 ft)	4.6 -13.5 m (16-45 ft)	Greater than 13.5 m (45 ft)
Bedrock (within 0.9 m) (3 ft)	high	high	high	high
Muck/Organic	high	-	-	-

Rapid (Sand)	high	high	high	moderate
Moderate (Loam)	high	high	moderate	low
Slow (Clay Loam)	high	moderate	low	very low
Very Slow (Clay)	high	low	very low	very low

Forms of Contamination and their Sources

Table 5: Potential pathways and sources for materials found commonly in rural areas that can contaminate groundwater (OMAFRA, 2006)

Material	**Potential Sources/Pathways**
Pathogens	• Septic systems • Surface application of manure and municipal biosolids • Municipal sewers • Storage of manure and human wastes • Poor well seals or construction
Nitrate	• Lawn fertilizers • Septic systems • Surface application of fertilizers, manure and municipal biosolids
Pesticides	• Application to fields • Leakage from bulk storage
Solvents	• Leakage from workshops and bulk storage • Discharge of hazardous household or farm wastes to septic systems or onto the ground • Some septic system cleaners • Discharge from dumps and landfills
Fuels	• Leakage from vehicles, workshops and bulk storage • Leaks from underground storage tanks and piping • Accidental discharge to septic systems
Salt	• Surface application of winter de-icing and dust suppression chemicals • Naturally occurring formations

Measures to Counteract a High Potential for Groundwater Contamination

A high or moderate ground water contamination potential is an indication of the speed that contaminants could move downward to the water table if a spill or leak occurred. The result could be a rapidly contaminated aquifer and potentially polluted water well. If this high risk exists on a farm, special care should be taken not to have leaks or spills of contaminants. Regular inspection, maintenance, and water testing of the well should be done. Containment of manure, livestock yard runoff, milking centre wash-water, etc. is necessary to reduce leaching down to groundwater. As for field areas, manure and fertilizer must be applied at the proper rate to meet the crop's requirements and at the proper time of year to maximize the use of the nutrients, otherwise, valuable nutrients such as nitrate could infiltrate down into the groundwater (OMAFRA, 2009).

Nitrate Contamination

Nitrate (NO3) is the most common form of nitrogen found in water. It comes from nitrogen, a plant nutrient supplied by inorganic fertilizer and animal manure. Additionally, airborne nitrogen compounds given off by industry and automobiles are deposited on the land in precipitation and dry particles. Other nonagricultural sources of nitrate include lawn fertilizers, septic systems, and domestic animals in residential areas (Nolan et. al., 2009).

Beneath agricultural lands, nitrate is the primary form of nitrogen. It is soluble in water and can easily pass through soil to the water table. Nitrate can persist in groundwater for decades and accumulate to high levels as more nitrogen is applied to the land surface every year (Nolan et. al., 2009). In water, nitrate has no taste or scent and can only be detected through a chemical test.

Knowing where and what type of risks to groundwater exist can alert water-resource managers and private users of the need to protect water supplies. Though nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water can harm infants by reducing the ability of blood to transport oxygen. In babies, especially those under six months old, *methaemoglobinaemia*, commonly called "blue-baby syndrome," can result from oxygen deprivation caused by drinking water high in nitrate. Death can occur in extreme cases (British Columbia Ministry of Environment, 2007).

Irrigation creates conditions that can increase the risk of groundwater contamination from fertilizers. Irrigation generally occurs on coarse-textured soils that have good drainage and are prone to leaching. Because irrigation increases the potential crop yield, increased nitrogen levels are required to meet that potential yield. Excessive inputs of either nitrogen or water, particularly on irrigated coarse-textured soils, substantially increase the potential for nitrogen leaching and consequent nitrate contamination of groundwater (Weston and Seelig, 1994).

Declining soil organic matter content due to erosion has also contributed to increased nitrogen fertilizer use. The need for additional nitrogen fertilizer will continue, due to the high crop needs and an insufficient amount of nitrogen released from soil organic matter. This shows the critical nature of organic matter management. Erosion control and residue management are needed to conserve organic matter (Weston and Seelig, 1994). A management plan that conserves organic matter makes good sense from both the water quality and crop productivity standpoint.

Managing nitrogen fertilizer to reduce groundwater contamination must strike a balance between nitrogen needs for profitable crop production, seasonal rainfall, and soil water retention characteristics for the field being cropped. Both groundwater quality and production economics are best served when the management program followed does not waste nitrogen fertilizer. Nitrogen fertilizer provided to the crop during peak demand will reduce the potential loss to the groundwater. Also, well-timed applications of water and nitrogen fertilizer can effectively eliminate nitrogen leaching on coarse soils for most crops. Attention must be paid to water and nitrogen applications so that rates in excess of the crop's needs are avoided. Following careful management practices such as these can effectively balance the need for crop production with the need to protect our groundwater resources from contamination (Weston and Seelig, 1994).

Pesticide Contamination

Pesticides, which include herbicides, insecticides and fungicides, are used widely for a variety of applications. Pesticide use and management by farmers, private and public businesses and institutions, manufacturers and distributors, and the general public provide many possible sources and opportunities for pesticide contamination. The ideal outcome of pesticide use occurs when a pesticide accomplishes the purposes for which it was applied and then rapidly breaks down into harmless components such as carbon dioxide and water. This happens in most cases, but the process and time vary among pesticide chemicals, and the application is affected by the physical, chemical, and biological characteristics of the pesticide and the associated environment (Ohio State University, n.d.).

The fate of a pesticide may be affected by such factors as method of application, type of formulation, soil and plant characteristics, solubility of the pesticide, adsorption on soil or plant surfaces, the persistence of the pesticide, and climatic conditions. Not all pesticides are mobile or threaten groundwater, but it is important to take measures to protect groundwater from those that are a danger (Ohio State University, n.d.). The best way to prevent contamination is to understand the characteristics of the soil and underlying geologic deposits so that the vulnerability of local aquifers to contamination may be assessed. If an aquifer is particularly vulnerable, the use of pesticides should be highly restricted or avoided altogether.

It is also important to understand the chemical nature of the pesticide being used. Some pesticides are highly biodegradable, while others are not. Whenever possible, those that break down more quickly should be used, as they have a much lower risk of reaching groundwater supplies. Proper application and storage of the chemical, according to the product directions is also important (Ohio State University, n.d.).

Case Study: Smithville
(Source: O'Neill, n.d.)

In 1978 a company located in Smithville, Ontario (near Niagara Falls) known as Chemical Waste Management Limited (CWML) began operating a hazardous waste transfer station. The company received over 400,000 liters of liquid waste between 1978 and 1985, more than half of which was estimated to be toxic polychlorinated biphenyl (PCB) wastes.

CWML had planned to ship the wastes to a hazardous waste facility in the United States but this option was lost when the Canada-United States border was closed to hazardous waste shipments in 1980. More and more wastes were accumulated at the CWML site until 1985 when a group of local environmentalists discovered PCB oil in a shallow stormwater lagoon on the site. The PCB leakage quickly became the focus of intense attention from the news media and the public, and the Ontario Ministry of the Environment immediately took control of the site to initiate a remediation program.

In 1987, PCB oil was discovered to have escaped into the groundwater in the bedrock aquifer beneath the site. The contaminated groundwater was found extending south from the CWML site threatening the municipal well supplying drinking water to the town. The well was shut down and the Ministry funded construction of a water pipeline to provide a secure potable water source for the town. Subsequent investigations concluded that there was approximately 10,000-30,000 liters of PCB-bearing DNAPLs (dense non-aqueous phase liquids) located in the upper portion of the bedrock aquifer beneath and adjacent to the former CWML site. By 1989, a pump and treat system was implemented to prevent further spread of the contaminant plume. By 1993, the surface of the site had been restored; however, contamination remained in the aquifer beneath the site.

In late 1993, the municipality and the Ontario Government signed an agreement to establish a Board consisting of representatives from each of the main stakeholder groups in the remediation program: the Ontario Ministry of Environment, the municipality and a public liaison committee. Technologies for remediating DNAPL-contaminated bedrock aquifers were very limited at that time, so the need to establish partnerships and collaborative efforts to develop and evaluate potential solutions was recognized. Funding for the Board is provided by the Ontario Ministry of the Environment.

The Board first established and consulted a network of international expert advisors to identify and evaluate potential remedial technologies for the Smithville PCB spill site. In 1994, the newly formed Board achieved an early and very significant milestone when it secured a collaborative research agreement with the U.S. Environmental Protection Agency (EPA), Environment Canada, the University of Waterloo and other universities to assist with numerous hydraulic tests, and studies of DNAPL and bedrock properties. As a result of this leading edge work, Smithville is now regarded as one of the best characterized DNAPL-contaminated bedrock sites anywhere.

Thanks to the collaboration of many individuals and groups, the management approach used at Smithville site has been very successful and serves as an example for other site owners and regulators faced with remediation at similar sites. Following are the main lessons learned at Smithville:

1. The management strategy to place stakeholders of the clean-up on the managing Board responsible for overseeing the remediation program greatly increases trust among the stakeholders and the public, provides for an open method of conducting business, reduces costs by avoiding duplication of work and enhances the likelihood that the recommended remedial actions will be acceptable to stakeholders.
2. A clear, traceable and transparent decision-making process with ample opportunity for public review and comment is essential.
3. Partnerships and collaborative agreements contribute significantly towards the cost effective development and evaluation of potential solutions. They increase credibility and enhance technical knowledge while reducing cost.

4. Regular liaison with a network of technical experts, colleagues and practitioners is absolutely essential in order to remain abreast with the rapidly advancing technical field of fractured rock characterization and remediation.
5. Effective solutions are best developed by using a team from academia, government, consulting and private industry.

There is tremendous opportunity to continue and enhance the current collaborative efforts between the Smithville Remediation Program, the Ontario Ministry of the Environment, Environmental Protection Agency and Department of Energy. These initial agreements have been very successful thus far and could be expanded both in terms of areas of cooperation and partners. Continued partnerships and collaboration which allow the sharing of information will help, not only in the remediation of contaminated sites, but also in the prevention of future contamination.

Activity: Estimating Groundwater Vulnerability
(Source: United States Environmental Protection Agency, 2009)

This activity uses a simple mathematical model of groundwater vulnerability to allow you to estimate how vulnerable the groundwater in your area is to contamination.

There are many factors affecting the vulnerability of a water supply, but we will only look at the five factors described in Table 4. A value of 1 means it is harder for rain water (and pollutants) to reach the supply, while a value of 3 means it is easier.

Directions: Use Table 4 to find out how many points should be given for each of the five factors in the area where you live. Then add them up and compare your result to the values in Table 5 to determine the vulnerability of your groundwater to contamination.

Table 4: Factors affecting groundwater vulnerability (US environmental protection agency, 2009)

Factor	**Value**
Annual rainfall	3 …if more than 100 cm 2 …if from 40 to 100 cm 1 …if less than 40 cm
Depth to water table	3 …if less than 3 m 2 …if from 3 to 23 m 1 …if greater than 23 m
Aquifer type	3 …if sand or gravel 2 …if limestone/dolostone 1 …if shale
Type of soil or rock above aquifer	4 …if sand or gravel 3 …if limestone/dolostone 2 …if loam or silt 1 …if clay or shale
Topography	3 …if flat 2 …if gently rolling hills 1 …if steep hills

Table 5: Vulnerability score (US environmental protection agency, 2009)

Vulnerability Score	**Relative vulnerability**
5	very low
7.5	low
10	moderate
12.5	high
15	very high

Questions for Discussion

1. Why are soils called “natural water purifiers”?
2. How does the type of bedrock in your area affect the productivity of local aquifers?

3. What are some of the potential impacts of agriculture on groundwater quality and quantity?
4. How can these impacts be mitigated?

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