Groundwater Protection and Forestry

Students will…

- Understand the role of forest biodiversity in maintaining groundwater supplies
- Be able to describe some of the effects of timber harvesting on groundwater hydrology
- Understand the importance of urban forestry to groundwater dependent communities in Ontario
- Describe how the effects of climate change on Ontario's forests may affect groundwater

Introduction

Ontario's landscape is characterized by its vast and diverse forests, ranging from the deciduous forests of southern Ontario, to the mixed forest of the Great Lakes-St. Lawrence region in central Ontario, to the conifer-dominated boreal forests of the north.

66 percent of Ontario's land area or about 70.4 million hectares is covered in forests, 90 percent of which are owned by the province (OMNR, 2009). Of that area, 31 percent, or about 22 million hectares, is classified as production forest - that is, forest managed for timber production along side a full range of other benefits (OFA, 2007).

Over the past two decades, there has been great change in the management of natural resources in Ontario and around the world. Ontario's forest policy has shifted to a more balanced ecological approach called **integrated resource management**. This means that the forest is viewed as part of a larger ecosystem which is managed to protect and conserve a whole range of values and uses, including the quality and quantity of groundwater resources (OMNR, 2008).

In the future our forests may need to be managed as much for a sustainable supply of clean water as any other goal. This new view of forests is evolving as both urban and agricultural demands for water continue to increase, and the role of clean water from forests becomes better understood as an "ecosystem service" of great value. Many factors are influencing water supplies from forests, including climate change, wildfires, invasive pest outbreaks, timber harvest, roads, and urban sprawl (Jones, 2008).

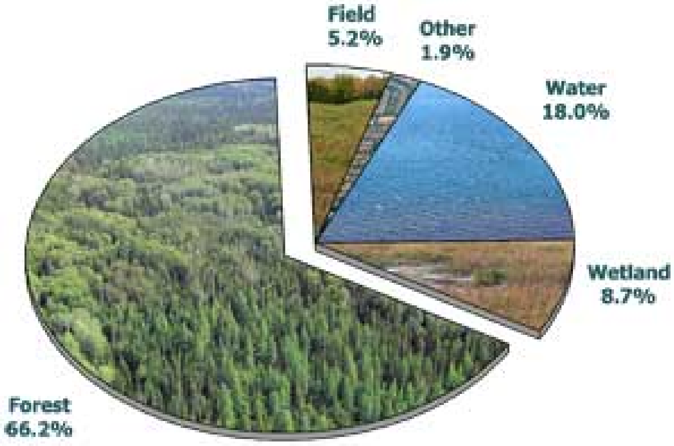

Figure 7: Total land and water area in Ontario - 107.6 million hectares (OMNR, 2009)

Preserving and managing forests can help sustain the quality and quantity of Ontario's water supplies. Forest managers and water managers will have to work together closely in the future to meet the demands of our water problems. Modern forest practices have helped to protect streams and riparian zones, but more needs to be learned about the effects of harvesting and thinning on groundwater in underlying aquifers. The development of "best management practices" will help balance the need for timber harvesting with maintaining sustainable water supplies (Jones, 2008). These practices must take into account our changing climate, which affects the timing and amount of snowmelt runoff, wildfires, and insect and disease outbreaks.

Collaboration between a variety of groups is important when dealing with groundwater and land management issues because it allows the needs of these different groups to be considered and incorporated into management plans. The changes occurring in our forests require continual assessment of current conditions, evaluation of future needs, and communication between many groups so that the best management practices can be determined and resources like groundwater can be protected (Jones, 2008).

The Role of Forest Biodiversity

Forest biological diversity is a broad term that refers to all the life forms found within forested areas and the ecological roles they perform. It encompasses not just trees but the multitude of plants, animals and micro-organisms that inhabit forests and their associated genetic diversity.

Forest biodiversity can be considered at different levels, including ecosystems, landscapes, species, populations and genetics. Complex interactions can occur within and amongst these levels. In biologically diverse forests, this complexity allows organisms to adapt to continually changing environmental conditions and to maintain ecosystem functions despite these changing conditions (Convention on Biological Diversity, 2008). This is due to increased **redundancy**, which occurs when there is more than one species that performs the same or similar functions in an ecosystem. High redundancy is beneficial because if one species is removed from the ecosystem due to a disturbance, there will be another species to perform its function (OFA, 2008). This gives resiliency to ecosystems with high biodiversity and is important to groundwater resources because it maintains the quality and patterns of groundwater delivery to ecosystems despite natural or anthropogenic disturbances.

Benefits of Forests to Groundwater

Trees and other vegetation play a very important role in protecting both the quality and quantity of groundwater resources. Tree roots help to reduce soil compaction by constantly pushing through and aerating the soil, allowing rain and snowmelt to infiltrate and be filtered by microorganisms before reaching the water table below. By retaining toxins and nutrients such as mercury and phosphorous, forest soils prevent a portion of these substances from entering streams and groundwater. They also help regulate water taste, clarity and colour, and water chemistry factors such as acidity (Canadian Forestry

Association, 2005).

Forests and wetlands also play a role in maintaining steady water table levels by absorbing excess runoff. The extensive root systems of trees prevent runoff and erosion by absorbing water from the soil and holding the soil in place. The runoff from forested watersheds is often 3 to 15 times less than watersheds dominated by agricultural land or development (Maryland Department of Natural Resources, 2009). Water absorbed by plants is used during photosynthesis, the process of creating energy from the sun's light and carbon dioxide. Excess water taken up by plants is expelled to the atmosphere through transpiration and will eventually fall back to the ground as precipitation. Thus, forests also play an important role in the hydrologic cycle (Canadian Forestry Association, 2005).

Maintaining forest cover in critical locations such as floodplains, steep slopes, headwaters, and along streams can help avoid major deterioration in water quality and also reduces the cost and difficulty of water treatment. Nutrients like nitrogen can contaminate drinking water if they are present in high quantities, but forests adjacent to nutrient sources (such as fertilized crops or lawns) can reduce the amount of nutrients that reach the groundwater (Maryland Department of Natural Resources, 2009).

The diversity of the "forest condition" also increases the forest's ability to protect water quality. Forest condition includes characteristics such as tree health, distribution of tree sizes and ages, and number of layers of vegetation (e.g., herbaceous, shrub, sub-canopy, mid-canopy, and upper-canopy). A forest with multiple layers of vegetation and a diversity of ages and sizes of trees can withstand loss of trees most susceptible to damage without losing all of its functions for erosion control and infiltrating water (Maryland Department of Natural Resources, 2009). Sustainable forest management aims to promote forest condition diversity as well as species diversity.

Summary

Forests help protect the quality and quantity of water supplies by performing the following functions:

- Reducing flooding by intercepting runoff and encouraging infiltration
- Improving water quality by reducing the rate of runoff and erosion to rivers and streams and trapping or breaking down some of the pollutants, toxins, and nutrients that are harmful to water quality
- Improving water quality by lowering water temperatures with shade over streams
- Providing fallen leaves to feed soil and aquatic organisms
- Replenishing our drinking water supplies by increasing the amount of rainfall that infiltrates into the soil and becomes groundwater
- Helping the soil recuperate where trees are planted
- Benefiting human water supplies by controlling water yield, peak flows, low flows, sediment levels, and water quality.

(Grand River Conservation Authority, 2009)

Effects of Forest Management on Groundwater Hydrology

If not managed properly, timber harvesting has the potential to alter groundwater levels and flow patterns, negatively impacting ecosystems and communities that depend on these patterns. Good forest management includes an assessment of the groundwater hydrologic regime in the surrounding area, and takes appropriate measures to protect groundwater resources.

Timber Harvesting and the Position of the Water Table

Although the effects specific to one particular area vary depending on the area's geology, topography, soil type, and climate, the removal of trees generally results in wetter soils and a higher water table in the short-term (5 to 10 years following harvest). This is due to a reduction in the amount of water lost through evapotranspiration and **canopy interception** (Smerdon et. al., 2009). Canopy interception refers to the process in which precipitation is intercepted by the forest canopy and evaporates before dripping to the ground (Jackson, 2003). Depending on the forest type, this can account for 10%- 30% of annual precipitation (Jackson, 2003). Timber harvesting reduces canopy interception, allowing more water to reach the ground.

Harvesting reduces evapotranspiration rates as well because the deep root systems of mature forests are much more efficient at taking up soil moisture than the shallow roots of vegetation cover that establishes after a harvest. After timber harvesting, water that infiltrates into the soil is much more likely to reach the water table or flow through the unsaturated zone into streams, since less water is taken up by plant roots and lost to the atmosphere through transpiration. This can raise the level of the water table and cause an increase in base flow in local streams in the years following a harvest (Smerdon et. al., 2009). Higher water tables may cause tree mortality or regeneration failure because some species do not tolerate raised water levels.

Timber Harvesting and Groundwater Recharge

In cases where harvesting has lead to a complete removal of surface cover, more water reaching the ground does not necessarily translate into higher infiltration and recharge rates. Soils beneath mature forests typically have a well developed litter layer and high porosity which results in very high rates of infiltration. This pattern is not altered significantly when timber harvesting follows good management practices by leaving sufficient groundcover. However, there is the danger that post-harvest infiltration rates may be altered dramatically when harvesting equipment leaves bare soils exposed. This is of particular concern in regions such as the boreal forest where clear cutting is used.

The impact of precipitation on bare soil breaks down the soil structure into very fine particles which clog soil pores at the surface, creating a seal. This seal impedes water infiltration, leading to high rates of surface runoff and erosion (Derpsch, n.d.). Furthermore, the surface seal may dry to form a crust which slows the reestablishment of vegetation, leading to continued runoff and erosion. In such cases, sedimentation of nearby streams, rivers and lakes can become a serious concern.

When enough surface cover remains after timber harvesting to prevent significant amounts of surface runoff and erosion, the excess water present can lead to a higher net rate of groundwater recharge in the short-term. The rate of recharge depends highly on the ability of the soil and underlying deposits to store and transmit water (Smerdon et. al., 2009). For a more complete discussion of the factors affecting recharge rates, see the *Groundwater Protection and Soils* section of this study guide.

The effect of timber harvesting on groundwater recharge can be inferred from changes in base flow to streams, but whether these changes will have a significant impact on ecosystems depends on the scale of groundwater flow (Smerdon et. al., 2009). If the groundwater flow is local and the retention time is short, the impact of harvesting may be very noticeable, whereas if the groundwater flow is on a regional scale and the retention time is a matter of centuries, effects of harvesting may be undetectable. This is why it is important to understand the groundwater flow patterns in a region before harvesting takes place - so that a risk assessment can be conducted and proper measures taken to avoid negative impacts on local ecosystems and groundwater users (Smerdon et. al., 2009).

Effect of Roads on Groundwater Hydrology

Soil compaction is potentially the most significant impact of logging roads on the forest ecosystem. Soil compaction lowers the rate of infiltration by reducing pore space in the soil, which also reduces the rate of groundwater recharge. The result is a decrease in groundwater levels, and an increase in the amount of runoff and erosion along roadways. This can lead to sedimentation of streams or other surface waters, and reduced water quality in some cases (Smerdon et. al., 2009).

The impact of roads on groundwater hydrology can range from being almost undetectable to quite severe depending on the climate, soil type, topography etc. Many of the severe impacts can easily be avoided by properly planning when and where the roads will be constructed and used (Smerdon et. al., 2009). Harvesting in the springtime is usually avoided because soil moisture is high and wetter soils are more susceptible to compaction. Large ruts can form where water pools and runs off the surface rather than infiltrating into the soil (Figure 8). Likewise, logging roads should avoid wetland areas and steep terrain where erosion is more likely to occur.

Figure 8: soil compaction from a road. (Ottawa Field-Naturalists' Club, 2007)

Implications for Forest Management Activities

The potential effects of forest management activities on local and regional groundwater flow and storage need to be considered as a part of forest planning. Predicting the effects of harvest activities and forest road construction on groundwater hydrology is often very site-specific. An appropriate first step is to establish whether any groundwater-dependent ecosystems exist in a watershed or whether there are nearby water users (Smerdon et. al., 2009). Once the level of groundwater dependency has been established, mapping groundwater flow is the next step toward assessing the potential of forestry activities to impact groundwater. From this basis, the timing of effects can be estimated, the potential alteration of flow patterns and interaction with surface water can be assessed, and the best management practices for that particular site can be established (Smerdon et. al., 2009).

The effects of forest management activities on groundwater can be difficult to determine. Higher water tables following a harvest may be short-lived or could take many years to return to pre-harvest conditions. It is thought that nurse-crops that promote higher evapotranspiration could be used to help re-equilibrate the water table in a recently harvested and replanted site (Smerdon et. al., 2009). Restoration of a vegetative cover that has similar evapotranspiration characteristics as the original species on a site is an important step toward minimizing the long-term effects of harvesting and other forest activities on groundwater systems, and toward maintaining site productivity.

Forest management effects on regional groundwater resources are rarely studied because of the significant timeframes involved. The long groundwater travel times in regional-scale flow systems tend to buffer short-term changes in climate and land use (including forestry), but integrate long-term changes, making deleterious impacts more difficult to reverse (Smerdon et. al., 2009). With forest harvesting, for example, this means that effects of widespread forest cover changes in upland recharge areas might go unnoticed for decades in adjacent valley-bottom aquifers. The effects may also be masked or magnified by climate change. In North America, the recovery of watersheds to pre-disturbance conditions is an area of considerable research, and depends highly on climate, geology, intensity and extent of the disturbance, and rate of forest regeneration (Smerdon et. al., 2009).

Forestry and Groundwater Protection in Urban Spaces

Urban forestry can make a significant difference in the lives of Canadians who live in urban areas. In the city, summer temperatures and noise levels are higher than in the surrounding countryside, air pollution problems are more concentrated, and the landscape is significantly altered, reducing the health benefits of having access to wooded areas and green open spaces. Trees help mitigate these problems, but many cities in Canada have recorded a drop in their number of street trees due to development, pollution, disease and neglect. As we learn more about trees and how they benefit the public, we can do a better job of managing urban forests (South Carolina Forestry Commission, n.d.).

Benefits of Trees in the City

Urban forests provide us with many long-term environmental, social and economic benefits:

- A single large tree can release over 1000 litres of water into the atmosphere each day.
- Tree foliage filters dust and can help remove toxic pollutants from the atmosphere. The foliage captures and removes a wide range of smog-producing compounds such as ozone, carbon monoxide, nitrogen oxide, airborne ammonia and some sulfur dioxide.
- Through photosynthesis, trees take in carbon dioxide and release oxygen for us to breath. A single, fully grown sycamore tree can transform 26 pounds of carbon dioxide into oxygen every year.
- Mature trees improve our aesthetic environment, absorb noise, are traffic calming, reduce stress, and create a peaceful place to relax or socialize.
- Trees intercept rainwater aiding soil absorption for gradual release into streams, preventing flooding, filtering toxins and impurities, and extending water availability into dry months when it is most needed.
- Trees improve property values. The addition of trees and shrubs can increase property values by 10 - 20%.
- Water from roots is drawn up to the leaves where it evaporates. The conversion from water to gas absorbs huge amounts of heat, cooling hot city air and helping to offset the "heat island" effect resulting from glass and concrete surfaces.
- Urban neighborhoods with mature trees can be up to 11 degrees cooler in summer heat than neighborhoods without trees.
- Trees and shrubs slow down rainwater, helping runoff to soak into the soil at a slow and even rate. This takes the pressure off storm sewers and allows for groundwater recharge.
- One acre of trees produces enough oxygen for 18 people every day and absorbs enough carbon dioxide per year to match that emitted by driving a car 42,000 km.
- Studies have proven for every dollar spent on maintaining trees, the public receives three dollars worth of benefits. It stands to reason that the public receives the most benefit from the preservation of larger mature tees and significant stands of forest.

(City of San Diego, n.d.)

Climate Change

Many studies of tree ring size have shown that forest productivity if highly dependent on water availability. Drier than normal seasons reduce tree growth and moist conditions tend to promote growth. Water availability to forests varies with precipitation, evaporation rates and the capacity of the soil to store water. Climate warming can affect water availability by changing precipitation and evaporation rates. However, forest ecosystems can also modify the local hydrology and environment. In the summer, forests can cool the local environment through albedo (i.e., reflectivity of sunlight), and transpiration. Under favourable conditions, forests also have the potential to mitigate some of the local effects of climate change expected in the next century, for example by acting as carbon sinks (Colombo et. al., 1998).

The impacts of climate change on major air circulation patterns are complex, and as a result, some areas will receive more precipitation while others will receive less. Higher summer temperatures will also increase evapotranspiration from forests and evaporation of water from soils. Where soil water storage is poor (e.g., coarse textured and thin soils), an increase in evaporation may reduce soil water availability, and gradually change the productivity, distribution and survival of forest plants (Colombo et. al., 1998).

Soil drainage has a great influence on the available moisture to plants. For example, even if the amount of rainfall increases, causing the rate of infiltration to increase, this does not necessarily imply that more water is available to forest plants. Although there is abundant water in the soil, the soil may not have the capacity to retain this water and supply it steadily to trees. In large areas in northwestern Ontario, where soils are shallow and stony, they are particularly prone to low water availability (Colombo et. al., 1998). The expected increase in variability of rains with climate change may result in more frequent and longer occurrences of drought.

Soil permeability, which significantly affects soil water regime, depends greatly on soil texture - the coarser the soil, the greater the permeability. While organic matter significantly improves soil water retention by reducing permeability, unfortunately, the organic layer of most soils in Ontario (with the exception of peat-lands) is thin. In addition, site disturbances, such as ground fires and some forms of mechanical site preparation, can greatly reduce the thickness of the organic layer, leading to increased soil water deficits. Sites with coarse-textured soils overlain by thin organic layers are most susceptible to low water availability. Organic matter can be enhanced silviculturally by promoting hardwood species (Colombo et. al., 1998).

Some of the forest species that grow in Ontario may be affected by climate warming more severely than others. These include the commercial species black spruce, jack pine, and red pine, which are shallow-rooted species that depend on moisture available in the first meter of soil. Currently, these species are productive because rains are frequent or humidity is high, which either re-supplies the soil with water or results in low evaporation. However, in a warmer climate with increased evapotranspiration, these species are likely to suffer moisture stress more frequently and for longer periods (Colombo et. al., 1998). The expected increase in rainfall intensity may make the situation worse because large rainfalls result in large amounts of precipitation lost to rapid percolation through the soil. Under these conditions, shallow-rooted species may be affected by reduced productivity and mortality. Deeply rooted species are expected to be better adapted to the increased evapotranspiration rates and soil moisture deficits that may occur in some areas of Ontario (Colombo et. al., 1998).

In the next century, we might expect that in southwestern Ontario existing forest ecosystems will experience increased moisture stress. In the clay belt, water availability is expected to remain high. On some low-lying peat-land sites in northeastern Ontario, where water tables are already high and drainage is poor, a 10 to 20 percent projected increase in precipitation may raise the water table enough to cause flooding in some stands (Colombo et. al., 1998). In the boreal forests in northwestern Ontario, where soils are shallow over shield or till deposits, vegetation is expected to experience high levels of soil moisture stress as a result of climate change. This area is already prone to forest fires, which are predicted to increase in the future. The establishment of mixed conifer hardwood forests is one way to promote the buildup of forest litter and humus, which will improve soil moisture retention (Colombo et. al., 1998).

Case Study: The Oak Ridges Moraine

One of the most distinctive landscapes in southern Ontario, the Oak Ridges Moraine is a belt of rolling hills and valleys that runs 160 km along the northern edge of the Greater Toronto Area (GTA) from the Niagara escarpment in the west to the Trent River system in the east (Figure 9) (Crandall, 2007). It was formed by advancing glaciers during the last glacial period, which reached its maximum extent about twenty thousand years ago. Even with millions of people living nearby, the moraine is still 30% forested (Earthroots, 2009), and with so few large areas of forest left in southern Ontario, it is a refuge for many threatened wildlife species and home to a host of diverse ecosystems and locally rare flora and fauna.

Figure 9: map of the Oak Ridges Moraine (No author, n.d.)

One of the most critical functions of the Moraine is as a recharge and discharge area for groundwater. It has often been called the 'rain barrel' of southern Ontario, and for good reason. The Moraine is composed of porous deposits of glacial till, mainly sand and gravel that average 150 meters deep (Crandall, 2007). Rainwater and snowmelt on the Moraine infiltrates into the soil where it is filtered and stored in one of the largest unconsolidated aquifer complexes in southern Ontario. Over a quarter of a million people who live on the Moraine and in the north Greater Toronto Area rely directly on water from these aquifers as their main source of drinking water (Earthroots, 2009). Furthermore, groundwater that is discharged feeds hundreds of wetlands and unique kettle lakes on the Moraine, and serves as the head waters to over 65 watercourses that flow north into Georgian Bay, Lake Simcoe, and Rice Lake and south into Lake Ontario (Crandall, 2007). Protecting the Moraine protects the health of these groundwater-dependent ecosystems and communities as well.

At present, the greatest threat to the Moraine comes from suburban sprawl north of the city of Toronto. As the population of the GTA continues to grow, new developments are constantly being proposed and approved. The full extent of the impact that these developments will have on the Moraine is still unknown, but some results are already quite clear. First, the impervious surfaces of roads and housing reduce the amount of water available to recharge groundwater supplies and divert it to urban storm systems with the potential for flooding. There are also potential hazards to groundwater quality associated with development, including contamination from herbicides and pesticides and increased salinity of aquifers and downstream water bodies due to road salting in winter (International Association for Great Lakes Research, 2002). Because the flow of groundwater is so slow compared to surface water systems, it may take years to determine the severity of such water quality issues.


Figure 10: ORM (Unknown author, 2008)

Another issue that has yet to be fully investigated is the effect of large scale withdrawal of groundwater for consumption or other commercial and industrial purposes on water levels in the Moraine's aquifers. The high number of golf courses on the Moraine use particularly large amounts of groundwater to maintain open lawns in areas that are naturally forested. A 2008 study by Earthroots, a conservation organization, found that nine golf courses in the Aurora area were extracting over three billion litres of groundwater per year, while Aurora's 50,000 residents use approximately 5.4 billion litres of water per year (Earthroots, 2009). In the Aurora/Newmarket area there is such a high concentration of large groundwater users that water levels in the underlying aquifers have been steadily declining for over ten years. Both Aurora and Newmarket have been forced to begin piping water all the way up from Lake Ontario to meet municipal demands that have historically been supplied solely from the moraine (Earthroots, 2009).

Due to increasing pressure from environmental groups, scientists and concerned members of the public, in 2001 the Ontario government enacted the Oak Ridges Moraine Conservation Act (ORMCA) which established a six month moratorium for development on the moraine, allowing the government time to develop a plan that would determine how and where sustainable development should occur. The resulting Oak Ridges Moraine Conservation Plan divides the Moraine into four separate land use designations which each have their own protection measures. Under this plan, only 8% of the moraine is designated as settlement area where development is allowed to occur without significant restrictions (Earthroots, 2009). The ORMCA represents a significant leap ahead in government policy regarding the protection of natural landscapes and resources. By allowing development to occur in approved areas, it balances the need to protect forested corridors, agricultural land and water resources with the need for new housing and infrastructure to support the area's growing population.

Activity: Nature's Drinking Straws

(Source: Forestry Canada, 1991)

A large, leafy tree can take as much as three-quarters of a tonne of water from the soil every day. This helps to maintain the position of the water table by preventing flooded conditions and facilitating infiltration. How does water travel from the roots to the crown of the tree against the flow of gravity?

Materials: Several pieces of clear plastic tubing at least 1 m long and 13 mm in diameter, water, masking tape, clear glass jars, food colouring (blue or red), small live tree branches, celery stocks

Experiment 1 Directions:

1. Try standing on a chair and drawing water from a bucket placed on the floor through a long piece of clear plastic tubing. How can a tree draw water from the soil when you can't draw it up through a straw?
2. Bend the sections of clear plastic tubing into a U-shape. Secure them by taping them to boards or placing them in large containers.
3. Pour water into one end of the plastic tubing until it rises part way up the other side of the tube. If you wish the water to be more visible, add food colouring.
4. Place a small live tree branch into one side of the tube. Use a piece of masking tape to mark the water level on the opposite side of the tube. Predict what will happen.
5. After one day, note the water level on one side of the tube. Did it change? Why?

Experiment 2 Directions:

1. Pour 4-6 cm of water into the bottom of a clear glass jar. Add several drops of blue or red food colouring.
2. Place a small, actively growing tree branch and a piece of celery into the jar. Predict what will happen.
3. At one hour intervals, observe and record any colour change in the stem or the leaves of the tree branch and celery. Leave overnight and observe again the next day.

Explanation: Trees, like all green plants, lose water through tiny pores in their leaves called stomata. This process, called transpiration, creates a tug or tension within the columns of water in the tree. This tension, combined with the process of capillary action, pulls water from the roots up to the leaves. These processes transport minerals from the roots to the leaves of the tree. Some of the water is absorbed and used by cells and tissues along the way and excess water vapour is lost through the stomata in the leaves.

Questions for Discussion

1. How does a diversity of forest species and forest condition increase the resiliency of a forest ecosystem?
2. What are some of the potential negative impacts of forest harvesting on groundwater hydrology?
3. How can the impacts of timber harvesting on groundwater be reduced?
4. How does urban forestry help to improve the quality and quantity of groundwater supplies to urban communities?

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