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Grand River Geoscape Issue

www.geoscapegrandriver.ca

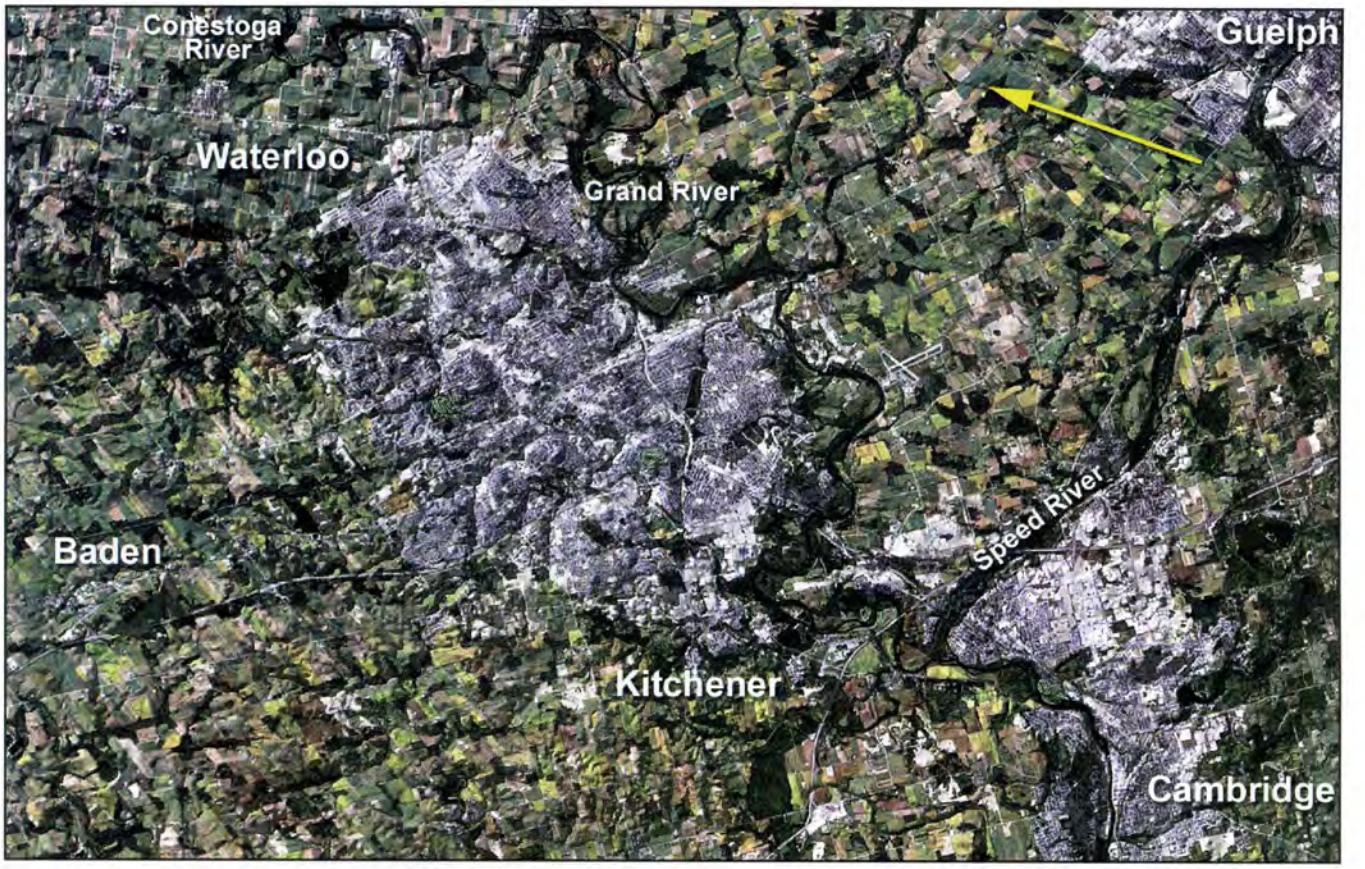

Figure 2: Satellite view of a portion of the central part of the Grand River Basin. Here two major tributaries, the Conestoga and the Speed, join the Grand. Larger settlements are labeled, and the Waterloo International Airport (Breslau) can be seen in the centre right, and to the northeast the yellow arrow indicates glacial flutings that show the ice movement from the southeast. The Waterloo Interlobate Moraine occupies almost the whole area west of Waterloo and Kitchener. It is the principal aquifer for this region.

Figure 3: Two images of bedrock outcrops within the Grand River watershed. Both are of Middle Silurian age, and both areas are different levels within the Guelph Formation. ***The top image*** *is a view looking downstream along the Grand in the Elora Gorge. Meltwater from the decaying ice sheet in the region scoured this bedrock slot about 13,000 to 12,000 years ago. Today it is part of the GRCA (Grand River Conservation Authority) Elora Gorge Conservation area.* ***The lower image*** *is part of the GRCA's Rockwood Conservation area along the Eramosa River. As at Elora, meltwaters from the receding ice sheet scoured the porous dolostones creating near vertical walls and some spectacular nearby glacial potholes described in Wat On Earth, 2001, V 15 (Part 1).*

EDITORIAL

This is a "special" issue of What On Earth. In many ways it has a narrow perspective, but only in that it is a description of a geographically small region. The concepts outlined can be applied to any river basin anywhere in the world. Geoscape Grand River brings together different ways of looking at the natural or human, urban or rural, interfaces in a 7,000km^2 basin that is part of the Great Lakes region of North America.

Geoscape. The term, like landscape and seascape, is characterised by the notion of "viewing" or seeing the world around us from a geological point of view. Taking in a forested vista, the view across rooftops in a city, or gazing along a long sandy beach is easy enough. However, seeing what lies beneath us is a more complex challenge. Earth scientists have developed a sense of these "views" through years of study, but for the average person - student, teacher, or general public - seeing the "geoscape" remains difficult. The concept of a geoscape is to provide a view of the world beneath us and how we interact with it.

This starts with a view from space and then peeling away the various layers to look at the soil, water and rock beneath us. But it is more than that, since humans utilise these "hidden" elements for mined materials, for water resources and for disposal. Through the Geoscape we can gain an educational understanding of our own backyards and explore the relationships between different ongoing relationships that occur each day beneath our feet.

Now, a little about a more regular issue of What On Earth. The first issue of 2005 dealt with the aftermath of the tsunami that devastated southeast Asia after the massive shift in the Indian and Burma plates on December 26, 2004. Our next issue will certainly review some of the devastation, similar in end result, but not origin, that has caused the total evacuation of the City of New Orleans. I notice that few, if any, commentators have mentioned a potential link between global warming and Hurricane Katrina. Perhaps this is because people will say there is no link. However, when I was acting as Global Change Coordinator at the Geological Survey of Canada 15 years ago we were forecasting more and larger hurricanes as the oceans and the atmosphere warmed. Certainly Katrina was a devastating storm when it crossed southern Florida, but it was only a category 1 hurricane with winds of 80 mph (~ 130 km/hr). As Katrina moved into the Gulf of Mexico things became decidedly worse. The abnormally warm waters of the Gulf provided the extra energy to boost Katrina to a Category 5 hurricane just before landfall, with winds of 145 mph (~ 230 km/hr). Although winds decreased as Katrina impacted the Gulf coast, a 5 to 8m storm surge moved ahead, flattening coastal communities, destroying urban infrastructures and rupturing the dyke system of New Orleans - a classic "geo" event. Katrina even impacted the Grand River basin with a heavy rainfall in the southernmost Grand River, but fortunately without any damage.

Most scientists agree that global warming is a human-induced event. The observations made in the last two decades show departures that are far out of line for the past 750,000 years of geological time. Katrina might be an aberrant "normal" hurricane, but on the other hand it might be the start of a new wave of "mega-hurricanes" that are likely to grow in frequency as our oceans warm. It is hard to reconcile the fact that increasing human activity, from increased affluence in China to North American disregard of increasing greenhouse gases, might, just might, be the cause of disasters like Katrina.

Two tornadoes that touched down in the Grand River watershed a few weeks ago are a sobering reminder that latitudinal shifts in storm tracks in a warmer world might move the tornado track from Ohio northward into southern Ontario in the next few decades. As I have commented before, we live in exciting times!

Alan V. Morgan

INSIDE THIS ISSUE

3. Editorial
4. The Grand River Geoscape Project
8. Other Topics -continued on Pg. 20
9. The Bedrock Geology of the Grand River Basin
15. Heritage of the Last Ice Age
18. Water in the Grand River Basin
21. Waste Management and Recycling

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Cover Image Figure 1: The Grand River flows into Lake Erie at Port Maitland. The headland at the bottom is part of Rock Point Provincial Park where fossiliferous of Middle Devonian Amherstburg limestones outcrop on the wave-scoured foreshore. In the upper-centre part of the image the sediment load of the Grand River can be seen entering Lake Erie. The small settlement of Dunnville is on the Grand at the right-hand margin. To the west the edge of the watershed is encountered one-third of the way along the shoreline toward the next headland at Grant Point.

The Grand River Geoscape Project

Introduction

The "Geoscape" concept was initially developed by Robert Turner and John Clague who were concerned about the lack of understanding of "geo-processes" that affect Vancouver and the surrounding region. That tectonically active area has the potential of many disaster scenarios ranging from mega-thrust earthquakes to volcanic activity, and from rock-falls to floods as well as a variety other less hazardous, but quite detrimental, effects to human health and infrastructure. The initial Vancouver Geoscape was developed by the Geological Survey of Canada, aided by teachers and other interested parties. It was produced as a large poster that could be displayed in a classroom (or display wall) setting. Building on the concept came a number of additional materials including slide sets, overheads, notes and a website that expanded on the information established in the poster. Since the late 1990's different "Geoscapes" have been featured across Canada concentrating on urban centres (Victoria, Calgary, Edmonton, Whitehorse, Toronto, Ottawa-Gatineau, Montreal and Quebec, for example); describing their settings with special mention of the geology, geomorphology, water supplies, waste problems and building stones of their regions.

The Grand River Geoscape is part of this national initiative to create awareness of the Earth Sciences and its importance to society. It is conceptually distinct since, unlike any of the others, it encompasses a complete "basin-oriented" approach. The basin approach allows a more comprehensive examination of the interaction of urban and rural communities whilst each is linked throughout the basin with water – the Grand River and its tributaries as well as underground water – as a common thread. The watershed encompasses some 6,800 square kilometres and is the home to about 800,000 people. This figure will rise to more than one million in the course of the next decade or so.

The Grand River Geoscape project is designed to highlight the geological history, development, resources and potential future changes within the Grand River Basin. The production is taking the form of five discrete posters suitable for classroom use, together with a web site that provides basic data as well as smaller modules and projects, many of which will be designed in Power Point form. Hopefully these will be used by teachers at all grade levels, who can integrate the basic information with the "Earth and Space Science strands" that are present in the Ontario curriculum, and perhaps elsewhere. I also hope that the posters will be used by planners and researchers and members of the public to explore different geoscience aspects of the river basin.

The first poster provides a striking view of the Grand River basin from space, placing it in a southwestern Ontario context with Toronto and Hamilton to the east and Woodstock to the west. The second poster shows the regional bedrock geology with short descriptors of the bedrock units within the watershed as well as illustrating those that are hidden at depth. The right side of the poster shows different views of some of the rocks in a scenic context. The third poster covers materials that were laid down during the Quaternary period – approximately the last two million years of geological time. It shows how the various ice lobes that advanced to the centre of the watershed provided the characteristic landforms of the region, and outlines the position of deposits that were left behind as the ice melted. Many of these are of economic importance in construction. The fourth poster covers water use in the basin. It illustrates how water is a resource that is circulated time after time, from consumer to waste and back again to the next consumer. The fifth poster shows how waste is managed within the basin, covering aspects of both landfills and recycling as handled by selected regions and municipalities.

Elements of the Grand River Geoscape on the web that will be explored include further information on bedrock and Quaternary geology and the recent climatic and environmental history of the watershed. The links will also include water resources, garbage and recycling, and natural hazards together with aggregates and other geo-resources. The last elements include aspects of human modification of the watershed and what the future might hold. A brief overview of each of these elements is provided below.

The Overall View of the Grand River Basin (Poster 1)

One of the most striking aspects of looking at our world has been the relatively recent innovation of examination from space. This poster is designed to provide an insightful view of the watershed and surrounding region. Careful examination will allow

observers to pinpoint where they work, live and play within the basin. Locations of a few communities that lie just outside the watershed have been included. This poster is principally designed to work in a "mix and match" combination with the other four posters outlined above and below.

Bedrock Geology, Grand River Basin (Poster 2)

The Grand River flows almost 300 km from its headwaters near Dundalk to its mouth in Lake Erie at Port Maitland near Dunnville. For most of its course the river crosses Quaternary deposits laid down by the latest ice advances that crossed the basin. Bedrock is rarely exposed at the surface except in places where the river has cut through these younger deposits. However, where this has happened, there are some interesting geological features. Examples include the gorge at Elora, the exposed bedrock areas such as Rockwood east of Guelph, the bedrock bluffs at Cambridge and other regions east and south of Brantford. This section explores the different bedrock units that are known to underlie the watershed. It will be linked to potential mineral resources (oil, gas, gypsum and building stones) as well as the place and environmental setting of each geological unit through time.

Quaternary deposits and landforms (Poster 3)

A time gap of almost 400 million years exists between the deposition of the youngest bedrock units of Early Devonian time and the oldest sequences recorded in the Quaternary Period. Quaternary deposits within the basin range from thin smears of glacial till, or gravels deposited by meltwater, to sequences that are over 100m thick. We know little about early Quaternary events, since these have either been removed or are still concealed beneath younger deposits laid down by the different ice advances. The watershed was crossed many times by ice that moved from each of the Great Lakes basins; Huron in the west, Georgian Bay in the north and Ontario and Erie to the east and south. This section explores the timing and nature of the glacial deposits and the nature and extent of the landforms produced by the ice. Special mention will be made of the different types of processes that created the various topographic features in the watershed; the glacially-fluted till plains in the northern one-third of the basin, the hummocky morainic regions of the central one-third and the lacustrine plains of the southern one-third. This section fits well in the school curriculum with an exploration of the glacial landforms that are present; drumlins, eskers, kames, outwash plains and shorelines of Quaternary lakes.

Students can be introduced to the concept that the thick Quaternary moraines and deeply buried valley systems are our major sources of drinking water. Few people realise that the Grand River in pre-glacial times did not flow to Lake Erie, but turned eastward to enter the Lake Ontario basin through the Brantford – Dundas – Hamilton region. The modern course of the Grand is a purely post-glacial phenomenon and is confined to the last 13,000 years.

Quaternary fauna and flora and past climate changes in the basin (Web only)

The non-glacial history of various parts of the watershed can be resolved by examining two different types of organic deposits. The earliest sequences are buried beneath glacial tills and are very rarely exposed at the surface. The second set post-dates the last ice advance. The latter, peats, marls and gyttjas are found in small depressions described as kettle holes.

In many ways the older sequences are far more interesting since they help to tell us what conditions were like before and during the latest ice advances that have created the modern topography of the watershed. This section describes these differently aged deposits and the associated fauna and flora that help us resolve the past climates of the basin. Students and the public can be introduced to the concept that fauna and flora changes through time, and will continue to do so in the future. It is certain that paleo-Indians hunted mammoth, mastodons and caribou in the Grand River watershed as far back as almost 11,000 years ago. Accompanying the biotic changes are less direct lines of evidence of climate changes provided by physical phenomena such as ice-wedge polygons and glacial sequences. These aspects of ancient faunas and floras as well as human interactions are important because they allow us to imagine how future climate change might modify the basin.

Water and Water Treatment (Poster 4)

The Grand River forms an important water resource for many communities along its course. Water supplies for many other communities are derived from groundwater. These supplies may or may not be sustainable, depending on precipitation, the catchment area, potential surface contamination and population buildup in the areas where the groundwater is extracted. Ultimately wastewater is discharged (sometimes through treatment plants) back into the Grand River where it becomes part of the drinking water supply for communities further downstream. Water problems are starting to become a concern to many Canadians, with contaminants – both natural (*Escherichia coli and Cryptosporidium parvum*) - and human induced (chemical wastes, insecticides, herbicides, fertilisers and salts) entering the water supplies in ever-increasing amounts. The poster explores some of the elements involved in water supply, commenting on the

source, the usage and the ultimate discharge for different communities in the Grand River Basin. Waterloo Region is at the forefront of national initiatives to protect drinking water supplies. Commencing in 2003 detailed three-dimensional Quaternary mapping of the Waterloo Moraine is helping to define the nature and extent of the critical aquifers beneath this region. This is of paramount importance since the moraine supplies drinking water for Waterloo, Kitchener and several other communities. In fact more people obtain their drinking water from the Waterloo Moraine than the persons obtaining drinking water from the Oak Ridges moraine north of Toronto.

Wastes and recycling (Poster 5)

The matter of solid and liquid wastes and recycling is one of increasing concern to society in general. At the start of the 21st century we have seen the controversies that swirl around the matter of garbage disposal of Toronto's wastes. Should it be buried locally, shipped vast distances to northern Ontario for disposal in a mine, or equally long distances for out-of-province disposal in the United States? Should it be incinerated or recycled using different recovery techniques? These are the same dilemmas being faced by all communities, large or small, within the Grand River Basin. Within the watershed different communities treat waste in different ways. Guelph is involved with wet and dry recycling and Waterloo, Kitchener and other communities use "The Blue Box" a national campaign that originated in Kitchener about three decades ago. Part of this Geoscape module examines the relationships of landfills to the Quaternary geology and explores how residential and industrial wastes are handled at different cities, towns and villages within the watershed.

The Tributaries of the Grand (Web only)

The Grand River catchment provides about ten percent of the water that flows to Lake Erie. Although the Grand is the main river there are a number of very important tributaries that join it along its 300 km length. Major confluences exist at Conestogo where the Conestogo River joins the Grand. The Conestogo drains the northwestern part of the watershed. The Nith River drains the west side of the watershed and joins the Grand at Paris. In the northeast the Eramosa and the Speed Rivers that flow through Guelph, form an important contribution, joining the Grand at Preston (Cambridge). In the south several smaller streams join the Grand in the vicinity of, or below, Brantford. These include Fairchild Creek, Whitmans Creek and McKenzie Creek. A web module explores the different tributaries and illustrates their importance within the major catchment area, commenting on the monitoring of the Grand River, the control dams that regulate flow within the watershed and the recreational facilities that are positioned on some of the tributary rivers and streams.

Hazards in the Basin (Web only)

The citizens of the Grand River Basin are fortunate in living in a relatively benign part of North America. Generally the region can be described as gently undulating with little in the way of major surface relief. This removes most (but not all) dangers of rapid mass movement. For example there have been a few substantial rotational shear slumps that have taken place in the Brantford region. Earthquakes are extremely rare and usually very small in scale. Volcanoes are absent and probably last affected this region well over a billion years ago. However, there are a few natural hazards such as infrequent tornadoes, droughts and other meteorological phenomena.

The main geohazard involves the Grand River. Although the Grand River provides substantial benefits to the Basin it is also a source of problems for humans. At no time is this more true than when the Grand and its major tributaries move into flood stage. Heavy spring rains that follow large winter snowfalls can exacerbate this.

The Extractive Industries (Web only)

Few of us realise the importance of the geosciences to our material well-being. Without geologists locating mineral deposits and very efficient extractive industries working these deposits, we would have no electricity, nor houses or home heating and cooling. We would lack roads, cars, buses, trains, aircraft, boats and other transport systems. There would be no computers, televisions, radios or communication devices. We would have only wooden or plant-derived furniture. All plastics and many storage containers, including refrigerators and ovens, could not be produced. There would be no glass, pottery, china and metal utensils. We would be deprived of different foods and many medicines. The Grand River Basin contains many extractive industries, especially those which work the abundant Quaternary-emplaced sands and gravel deposits in outwash spreads, river terraces, eskers and kames. There are also minor works that take advantage of some bedrock outcrops. Several mines extract gypsum although economic conditions are (in 2004 - 2006) forcing the closure of one of the mines at Caledonia. One further aspect of this module sets out to explore the role of the oil (minor) and gas extractive industries of the region.

Population problems (Web only)

The Grand River Basin is an attractive place to live. Bordered on the east by the huge metropolitan area of Toronto and a multitude of satellite cities in the "Golden Horseshoe" the watershed has relatively small cities and many dozens

of villages and settlements scattered through the countryside. However, this is changing. Because of its proximity to Toronto and because of a technical, well-trained populace, the basin has attracted "high-tech" industries and major manufacturers. In turn this places increasing demands on a formerly agrarian environment. Huge tracts of land are being cleared for domestic and industrial development. Population buildup leads to increasing demands for roads and other societal structures. These in turn threaten aquifers and surface water supplies, and create many of the problems explored in other posters and modules. This module attempts to pull together certain aspects of human modification of the watershed.

What might lie in the Future? (Web only)

The future is impossible to predict. What may seem to be realistic assumptions today might be quite inaccurate 100 years from now. We can try to follow through on some logical extensions of trends that seem evident today and explore some assumptions of what our environment might be like 100 years hence. For example, it is likely that there will be far more people living in the watershed; likely larger urban centres with more roads and transit lines, less agricultural land, more aggregate extraction and far more demands on water. Water usuage will certainly have to be modified with enforcement of selective rationing, stricter controls on potential contamination and eventually "big pipes" that will bring water in from Lake Erie. Depending on our success at controlling emissions through Kyoto-like protocols it is highly probable that carbon dioxide levels will continue to increase along the trend lines established for the last 50 years. This in turn is likely to have some major repercussions on climate, affecting both temperatures and precipitation in most regions of Canada including the Grand River Basin. This module explores some of these trends and what might happen within the basin over the next century.

Where do we go from here?

Geoscape is the foundation upon which many of societies' needs and fears are based. Other "Scape" projects that can, and likely should, be built on this foundation might explore water in more detail in the form of a specific "Aquascape" or "Waterscape".

Leading from this a "Bioscape" could examine the details of the biology (both plant and animal) of the watershed. Wilderness and protected areas are present in limited ways throughout the watershed and students need to find out more about why such areas are of critical importance to humans.

A "Socioscape" could explore the early role of native people in the Grand River Basin and the subsequent arrival and modification of the watershed by European settlers. There are sound reasons why settlements grew up where they are and equally valid reasons for the success of some and the failure of others. Canals, railroads and the road network development have been critical to their well-being through time. A "Socioscape" might fit in well with various "heritage" initiatives within the watershed.

An "Atmoscape" might deal with air mass movements in the watershed with a more detailed analysis of the effects of road and rail corridors, the outputs from industry and urban centres, and the role of power plants, both relatively local and distant. Parts of the watershed are affected by poor air quality, and this is in a relatively non-industrialised part of Canada. Why should this be the case? Where do these poor air quality conditions come from? Finally there is the changing global climate that will affect the basin through time; something that students and the public will become more increasingly aware of as the years pass.

Acknowledgments

This Grand River Geoscape project has been supported by generous financial contributions from the Ontario Ministry of Economic Development and Trade and I wish to express specific thanks to Vic Foster for his patience as this project has developed. The Grand River Conservation Authority has been most generous with information and mapping assistance. Special thanks go to Jeff Pitcher who has always been accommodating and prompt with even obscure requests for visual data. Others at GRCA who have provided much assistance are Dwight Boyd, Ralph Beaumont and Barbara Veale. Additional support has been provided by the Department of Earth Sciences at the University of Waterloo. Peter Russell, Mario Coniglio, Paul Karrow and Dave Rudolph need specific mention and at Graphic Services, Diane Keller and Amy Deutschmann. Former students, Christopher Barber, Jacqueline deGorter, Karrey Gibson, David Kalviainen, Martin Kolodziej and Lief Nelson provided assistance as they completed B.Sc. Honours dissertations. The Region of Waterloo has supported my requests for information on water and waste management, and thanks go to Tammy Middleton and Donald Corbett, as well as many personnel at local landfills, water and waste management and recycling centres in the Region and elsewhere. Special thanks go to Robert Turner (GSC), Christy Vodden and Alexis Morgan for assistance and encouragement during the development of this project, and lastly my appreciation to my wife Anne, for putting up with interminable hours spent on the computer or traveling as this all came together.

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Other topics

This special issue of What On Earth covers the major themes that are illustrated on the Five Posters of Geoscape Grand River. But, in many ways this is just the start of what needs to be done for the site to be really useful to teachers and students, particularly those in the Grand River Basin. Most of the "extra" materials not included in this issue, and not present on the posters, will be placed on the www.geoscapegrandriver.ca website.

In order to expand this site I would like to continually add materials that are sent in from students and especially teachers that pertain to YOUR area of the Grand River or your particular interests in specific topics. For example, the five major themes covered in the posters (Satellite view, Bedrock Geology, Heritage of the Ice Age (Quaternary geology and geomorphology), Waterscape and Waste Management and Recycling) are all themes that pertain to different elements of the Ontario school curriculum at various levels. Each of these themes can be expanded locally and I will be most happy to place the extra knowledge (properly credited) on the main Geoscape Grand River website.

For example schools that are close to bedrock outcrops in the basin might wish to add something on the fossil content of the rocks in your area (below). This is the internal mold of a fossil clam that can be found in rocks near Cruickston on the west side of Cambridge, and in the Elora area. Questions here are; what is it? What age is it? Where did it live when it was alive? How did it get to be like this? All of these are valid questions that can be answered on the website and in the classroom.

Those of you who have gravel pits nearby (top right) might wish to add specific information that can be applied to either the Quaternary section or to another area on "Geo-Resources of the Grand." For example, where does the gravel from your pit go and what is it used for? How many tons are dug out each year? (Is it hundreds or thousands, or much more?). Is the land rehabilitated? What crops grew before and after extraction?

Certainly the themes that deal with water and waste management can be significantly expanded by teacher input. In the posters I concentrated largely on the two main population centres in the watershed, but every community has its own problems of waste disposal. What happens at Dundalk or Dunnville, or Paris or Brantford? Local exploration of waste

management and potential recycling would be of interest. Certainly it is eye-opening to students, and the web site can connect all of us in the basin.

What happens with water? What is going on at Hagersville? Were local wells adversely affected by the tire fire and what has been done to monitor any pollution? These are all real-life "geo" situations that should make everyone, teachers and students, appreciate the delicate interactions in each of these themes.

Some of you most certainly will be far more aware of different features close by that are of interest. Every major storm that sweeps across the basin has the potential for interesting observations. Erosion and deposition in major rainfall events are a case in point. With digital cameras these can be captured and shared with others (below).

In this case the damage (a 4 X 4 through a car windscreen) was caused by the Fergus tornado that swept across the upper Grand region from near Salem to Belwood Lake. Another touched down near Dorking and Conestoga Lake. Both took place on August 19, 2005. Have tornadoes been through your area of the Grand valley? Do you have family pictures that might be shared? Will there be more as global warming continues?

Continued on page 20

The Bedrock Geology of the Grand River Basin

To the casual observer a traverse of the Grand River Basin will not readily reveal many rock outcrops, since the region is mantled with varying thicknesses of sediments deposited by the last ice or laid down following ice retreat. However, for those more familiar with the basin, there are limited outcrops in stream beds and river banks and in a few places the bedrock can form some substantial and outstanding physiographic features. Perhaps the most spectacular is the Elora Gorge in the reach of the Grand between Elora and West Montrose. But there are other outcrops along the Grand and its tributaries, notably at Rockwood on the Eramosa River, at Cruickston near the confluence of the Speed and the Grand, in the eastern part of the watershed near Rockton and also in the Erie shore at Rock Point (cover image and Figure 9). Fortunately we do have a reasonable idea of the extent and types rocks that are found in the "subcrop" - that is underneath the glacial deposits – because of numerous wells that have intersected the bedrock surface.

These have been drilled mainly for water in the northern and central sections of the watershed and also oil and gas (the latter more successfully) in the south. There are over 20,000 wells that penetrate the bedrock surface within the watershed, with some 1,080 wells put down for petroleum exploration. A number of the latter have been drilled to more than one kilometer and many of them penetrate the Precambrian "basement", the subsurface continuation of the Canadian Shield into southern Ontario.

Most of the strata between the glacial deposits and the basement rocks are near flat-lying, undeformed, sedimentary sequences of limestones, dolostones, shales and sandstones. These were originally laid down in the shallow marine inland seas of the Paleozoic Era from about 500 to 400 million years ago. The rocks are draped over a structural uplift known as the Algonquin Arch that trends NE - SW across the watershed centred between Elora and Waterloo (Figure 4). On either side of the Arch rock sequences of the Paleozoic thicken and dip very gently toward depositional centres in basins toward the west (Michigan Basin) and to the southeast (Appalachian Basin).

The Precambrian rocks under the Basin (Basement Rocks).

About 223 deep boreholes within the watershed encounter the Precambrian crystalline rocks at depths that vary from about 700m to 1100m. The basement rocks are distinctly different from the strata above. Firstly, they are extremely ancient, and radiometric dates suggest that most belong in the time frame from 1.8 to 1.25 billion years. Secondly, they are metamorphic and igneous rocks that can be seen at the surface today in the vicinity of Honey Harbour and the eastern shore of Georgian Bay hundreds of kilometers to the north. The igneous rocks originally formed fiery intrusions in the cores of old mountain ranges that existed in this region well over a billion years ago. These deeply buried rocks are granites that have been recovered from cores in many parts of the watershed. . The metamorphic rocks usually were former sediments (limestones and sandstones) that were heated, stressed and altered by tectonic movements between 1300 and 950 million years ago. These rocks are recovered from cores as marbles, quartzites and gneisses.

Because these deeply buried Precambrian rocks are effectively hidden beneath the glacial sediments and the Paleozoic strata, geoscientists use other techniques such as gravity and aeromagnetic measurements to prepare maps of the different rock patterns, or domains, beneath the Grand basin. Five different domains are represented in the Precambrian rocks beneath the Grand River Basin. These are from north to south the Alliston, Huron, Waterloo, Cambridge, and Fishhog domains. Figure 5 shows the approximate boundaries of these domains and their age in millions of years. The few borehole samples recovered from these Precambrian rocks combined with estimated structural trends and other geophysical information have been used to indirectly identify the rock types in their domains. For example, granitic rocks seem most representative of the Alliston and Waterloo domains, and these are also areas with high magnetic readings that indicate relatively dense concentrations of magnetic or iron bearing rocks in the basement rocks. Metamorphosed sands, quartzites and gneisses largely comprise the Huron domain whilst marbles and other meta-sedimentary rocks characterize the Cambridge domain. The Fishog domain is represented by a distinctive aeromagnetic signature and the rocks that dominate this region are highly magnetic igneous rocks composed largely of quartz – mica – diorites.

The Precambrian/Cambrian boundary

The boundary between the Precambrian and the younger, overlying Paleozoic sedimentary rocks represents an unconformity or "time gap" that is over 400 million years, a time gap that is approximately the same as from the last Paleozoic deposition in this area to the present. Deformation of the basement rocks apparently ended about 950 million years ago in the last stage of the

Grenvillian (mountain building) orogeny. Erosion would have started after this time.

Most boreholes drilled to the Precambrian surface grind and break the rocks as they go down, resulting in washed "chips" that are recovered at the surface. However, a number are "continuous cores" that bring long plugs of rock to the surface and these show the nature of the contact between the Precambrian and the Upper Cambrian beds. In some areas the Precambrian surface is heavily weathered with substantial mineral alteration indicating groundwater flow along the contact. In other areas the break is quite sharp with relatively unweathered rock below.

The Paleozoic Rocks under the Basin

About 1 km of Paleozoic rocks underlie the southern part of the Grand River Basin and these thin to the north and west, with about 850m at Brantford, 700m at Kitchener, and 650m at Arthur near the north end of the watershed. A borehole (Figure 6) put down near Kitchener provides a typical cross-section through most of the strata in the subcrop of the central part of the Grand watershed.

The oldest beds overlying the Precambrian are thin (> 2m) sandstones of Cambrian age. These thin from the southern part of the basin and pinch out north of Waterloo. Lower Ordovician strata are absent and the younger sequences commence with the Middle Ordovician Shadow Lake, Gull River, Coboconk, Kirkfield, Sherman Fall and Cobourg Formations. These represent a continuous sequence of carbonates, calcareous mudstones and shales and non-calcareous shales. A number of these deeply buried beds form producing gas horizons at the southern end of the Grand Basin.

Overlying these are Upper Ordovician strata with bituminous Collingwood Shales and grey brown Blue Mountain mudstones. The latter are capped by beds with a striking colour difference, the red-maroon to purple and green Queenston Formation. The uppermost part of the Queenston forms the lower slopes of the Niagara Escarpment at Milton and these beds can be clearly seen in Figure 7. These fine-grained red beds were deposited in shallow inter-tidal flats under shallow marine conditions. The rock is utilized for brick making in several areas east of the Grand River watershed.

The upper lip of the Escarpment lies east of the Grand watershed and is capped by the Amabel Group (the caprock of the Escarpment at Milton). Lower Silurian limestones, dolostones and shales of the Cataract Group and Clinton Group occur beneath. The dolostones dip gently to the west and are then overlain by the Guelph Formation. Above the Amabel the dolostones of the Guelph Formation form much of the outcrop and are hidden near surface rock in the eastern half of the Grand watershed. The scenic outcrops at Rockwood and at Elora and Cruickston, west of Cambridge, are formed in the Guelph Formation and were deposited in reefs and inter-reef areas in Middle Silurian time. These dolostones contain a few fossils since the dolomitisation process destroyed many of the more delicate forms. The rocks of the Guelph Formation were utilized locally for building stones and can be seen in many of the older buildings in Guelph and in different parts of Cambridge.

A small time break ensued before deposition of the overlying Upper Silurian Salina Formation occurred. Today the Salina is present beneath the glacial cover under most of the western part of the Grand River Basin. The Salina consists of evaporitic carbonates interbedded with commercial deposits of gypsum and salt. Gypsum was originally mined at Paris, Ontario, from near surface outcrops and underground at mines near Caledonia (Figure 8) and Hagersville. Just west of the watershed a third mine near Innerkip also mined gypsum, although this operation ceased in the 1990's. Salt sequences in the Salina are mined or brine-pumped further west at Goderich and at Windsor. These evaporate sequences were deposited at times of alternating sea levels under arid conditions somewhat similar to that of the Oman – Red Sea – Ethiopia coast lines today. The Salina is overlain by dolostones of the Bass Islands/Bertie Formations and these represent the youngest Silurian strata.

The Devonian in the Grand River watershed is represented by a small area of grey sandstones of the Oriskany Formation and by limited areas of nodular cherts, limestones, and dolomites of the Bois Blanc Formation. These are hidden beneath Quaternary sediments in the south and west side of the basin. The youngest rock sequence in the Grand basin is the Middle Devonian Amherstburg Formation. This can be seen in outcrop as limestone beds, rich in chert but with abundant fossils, at Rock Point just to the east of the mouth of the Grand at Port Maitland (Figures 1 and 9). Many of these fossils (Figure 10) can be seen in living descendants in tropical and subtropical seas today . They remind us that this part of North America was in a near equatorial latitudinal position when these beds were deposited almost 400 million years ago. Continental drift, the closure of one ocean and the opening of the younger Atlantic has resulted in the more temperate positioning of southern Canada today.

Countless marine organisms that lived in the lower Paleozoic oceans died and were deeply covered by sediments. Through time they decomposed and organic compounds migrated through the rock units. Today we search for these as petroleum deposits and both oil and gas pools and fields have been found in the lower Grand Basin (Figure 11). Examples of less familiar organisms that helped to make up these deposits are shown in Figure 12.

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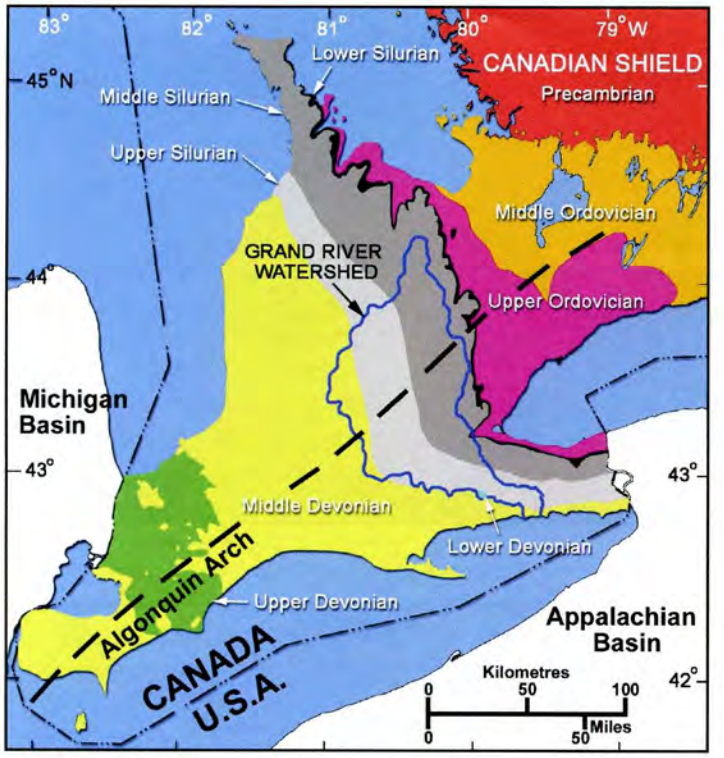

Figure 4: General geology of SW Ontario showing main rock units, the Algonquin Arch and the respective basin areas west and southeast of the Arch.

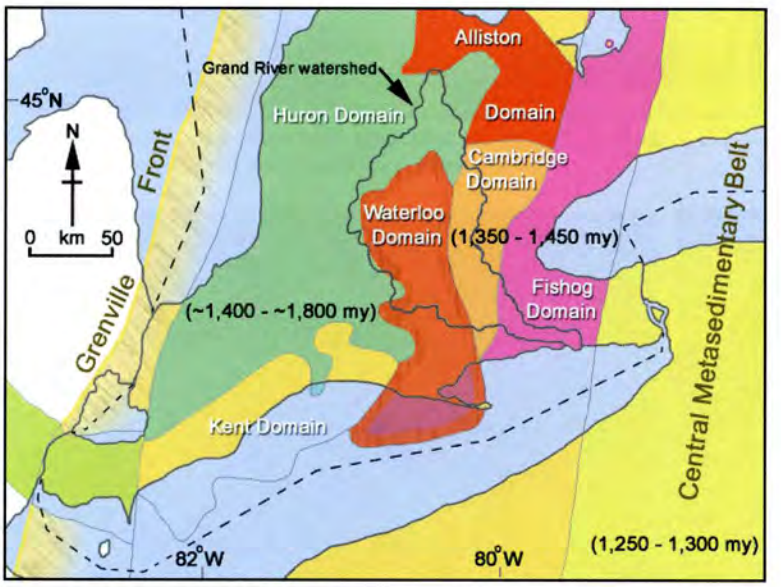

Figure 5: The deeply buried Precambrian rocks under the Grand River basin follow a NNE-SSW trend that is a hidden extension of the Canadian Shield. (Modified from Carter and Easton 1990). The respective domain areas and their ages are given.

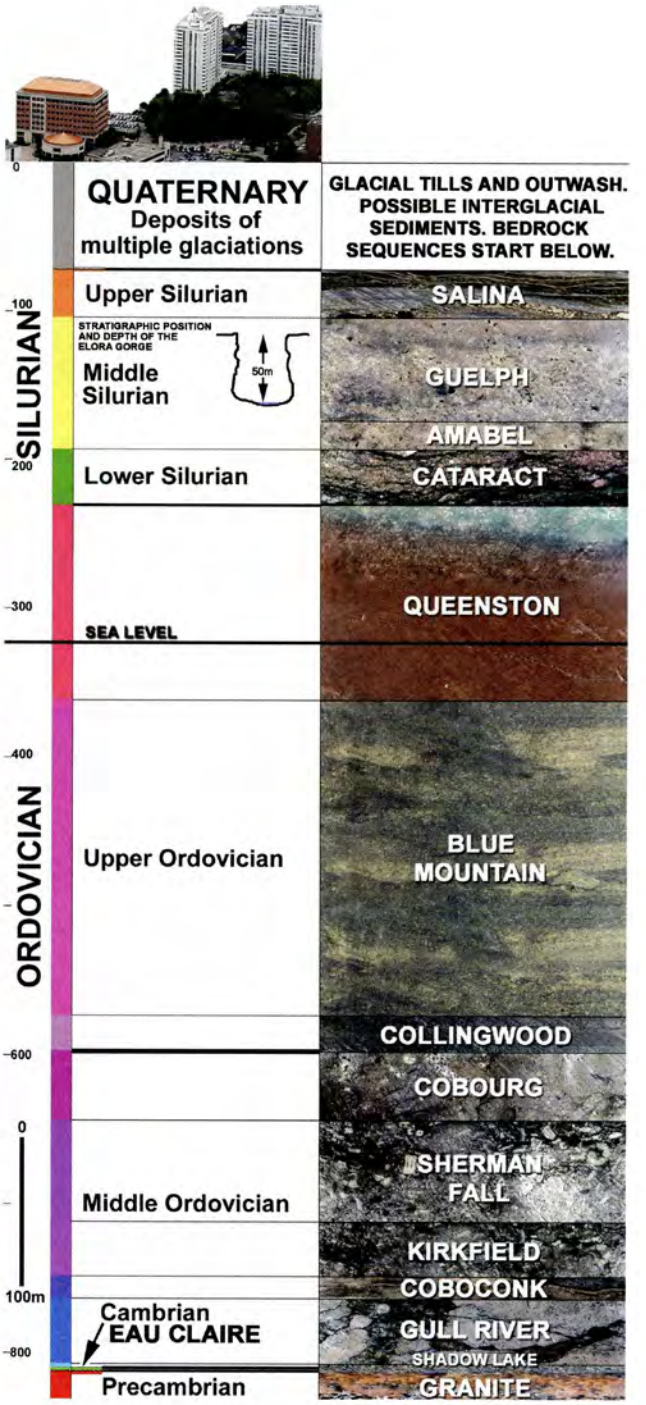

Figure 6: A borehole section that typifies the rock sequence at Kitchener, Ontario. The Precambrian granite can be seen at the base. Quaternary deposits are not illustrated.

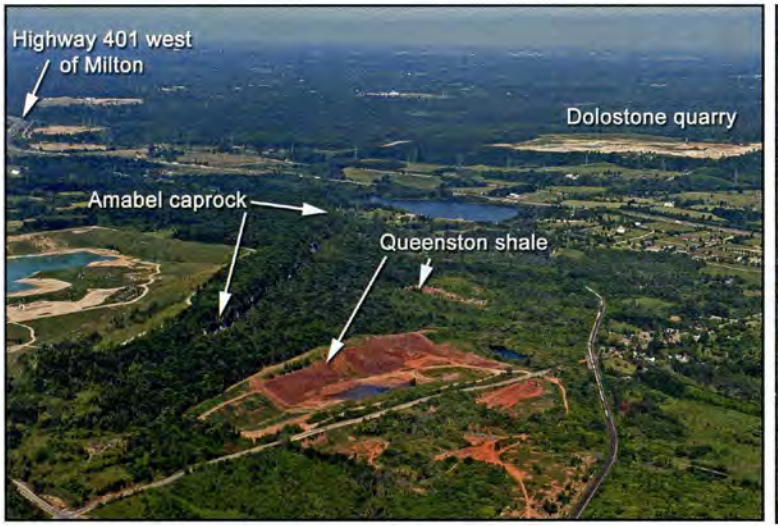

Figure 7: Niagara Escarpment at Milton. This is west of Milton and is just east of the Grand River watershed. The regional dip is west (left).

Figure 10: Composite coral, Rock Point.

Figure 8: A gypsum sequence in the Salina at west of Milton. This is in Georgia-Pacific's mine (Cayuga #3) which is decomissioned.

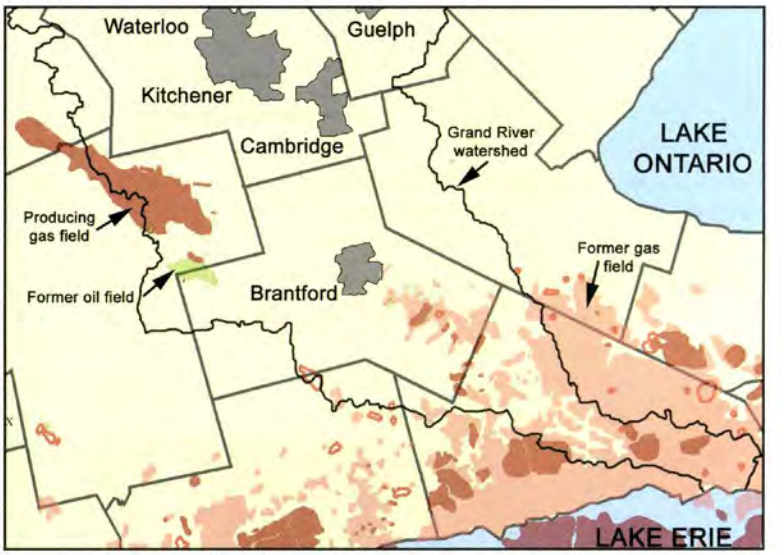

Figure 11: Oil and Gas fields in the lower Grand basin. County boundaries and main settlements are marked and producing and older fields.

Figure 9: Middle Devonian rocks at Rock Point.

Figure 12: Bryozoan and mollusc remains in red calcareous shales of the Grimsby Formation (Upper Cataract Group) near Dundas.

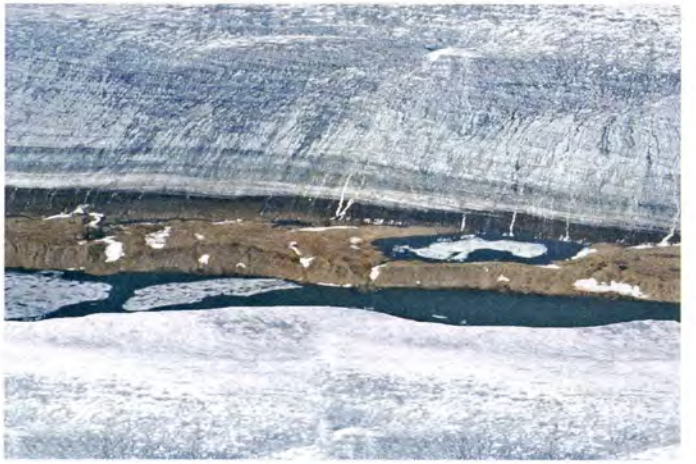

Figure 14: Near confluent ice-margins ~15,000 years ago.The Huron lobe (foreground) and the Ontario lobe (backgrond) deposited the kame materials between.

Figure 15: The Hawkesville Kame; a gravel and sand deposit formed near the confluence of the retreating lobes of the Laurentide Ice Sheet.

Figure 16: Drumlins in the southern Guelph Drumlin Field, east central Grand watershed.

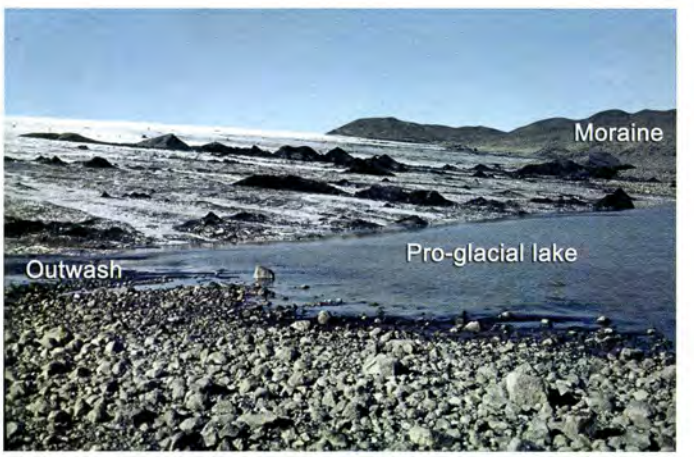

Figure 17: Modern ice-front with materials mentioned in text.

Figure 18: Glacial erratic on striated bedrock formed by Erie lobe ice.

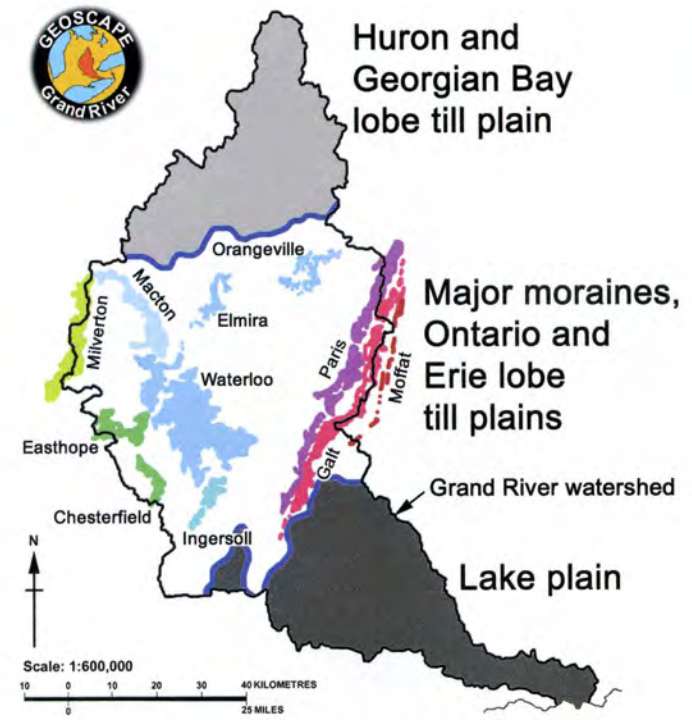

Figure 19: Major moraines of the Grand Basin.

Figure 21: Ice sheet and braided streams.

Figure 23: This depression is a small kettle hole in the Waterloo Moraine.

Figure 20: An esker near West Montrose.

Figure 22: Fossil ice-wedge polygons at Muir.

Figure 24: Mammoths as they would have appeared in the watershed about 13,000 years ago.

Heritage of the Last Ice Age

As mentioned above, most of the Grand River Basin is thickly mantled in sediments that were deposited during the last glaciation. Earth scientists have been busy mapping these deposits for the last 100 years and they are critically important to us as sources of clean groundwater and also for aggregates.

Just when, where and how did these sediments arrive in the basin? We are uncertain just how old the oldest of these "ice age" materials are, but conservatively they extend back at least 100,000 years, and some might be substantially older.

The where and how questions are easier to answer, but they reveal a great deal of complexity and a fair degree of uncertainty. We know that the great Quaternary ice sheets crossed the Grand basin on a number of occasions. Unfortunately each crossing removed most of the record of earlier invasions and then covered these early records with younger deposits. It seems likely that deposits of the last interglacial (the last time that the climate was as warm as today) are present, since these are believed encountered in a borehole at Waterloo and about seven kilometres outside the western boundary of the watershed at Innerkip. Exposed in a small creek section is a sequence of peat and organic silt that contains the remains of Blanding's turtle, Pennsylvania vole, muskrat and white-tailed deer as well as dozens of beetle species and other insects. Most of these currently live within the Grand Basin and indicate that the climate at the time of deposition (over 50,000 radiocarbon years ago, and likely about 110,000 years ago) was close to that of today.

Almost 30,000 relatively deep boreholes in the Grand River watershed reveal a complex of glacial tills (a slurry of material ground up beneath, and deposited from, the ice sheets), often separated by sands and gravels, that usually have direct association with the advancing or retreating ice. Occasionally there are scattered pockets of organic materials (clay, marl and peat) that were deposited in ice-free episodes sometime during the last 100,000 years. These are encountered on a hit or miss basis by boreholes that are usually being put down for water or for construction.

Our more detailed knowledge of the subsurface geology is continually being improved by targeted scientific drilling that allows better correlation of different units. It is also aided by increasing use of geophysical methods of exploring hidden units.

Work largely conducted by Karrow (1989) and others clearly demonstrates that ice covered the Grand basin many times during the past 100,000 years, but most of the recent deposition (and resulting landforms) is confined to the last major ice advance. The Laurentide Ice Sheet that formed over northern Canada crossed the region commencing perhaps 24,000 - 23,000 years ago and reached a maximum advance position in Ohio and Illinois about 19,000 years ago. At this time ice covered the whole of the Grand Basin in the time frame known as the Nissouri Stadial (Figure 13). The main till deposited beneath this ice-sheet was the Catfish Creek Till, a hard, compact till that is easily detected in boreholes. Shortly after its maximum advance, and for reasons that are still not understood, the Laurentide Ice Sheet commenced a relatively rapid retreat at about 18,000 years before present. As the ice moved back across the southernmost watersheds in the Great Lakes basins meltwater began to be ponded between the northward retreating ice margin and the height of land to the south. In southwestern Ontario a series of lakes were created in the position of present day Lake Erie. Because the weight of the ice actually depressed the land surface many of these early lakes are now situated on areas well above modern lake level.

About 16,000 years ago the extreme southwestern part of Ontario became ice-free during the Erie Interstadial (Fig. 13), and it is likely that the vertically-melting ice surface also intersected the highest sub-ice topography producing a ribbon of land in the Waterloo to London area. This would have crossed the western edge of the Grand River watershed, and deposition at the very wet ice margins would have commenced the formation of the largely water-deposited sands and gravels of the Waterloo Moraine, the Elmira Moraine and the Orangeville Moraine (Figure 14). The Baden Hills likely originated at this time from kame sediments (such as the Hawkesville Kame; Figure 15) that accumulated on the ice or in ice-confined areas near the ice margins.

The retreating Laurentide ice margin was constantly fluctuating probably in response to precipitation that was falling up-ice at higher elevations. Ice

thickness was greatest in the lake basins and about 15,000 to 14,000 years ago major ice advances occurred during the next cold phase – the Port Bruce Stadial. Ice moved across the Grand River watershed from the northwest (Huron and Georgian Bay lobe ice) and from the south and east (Erie and Ontario lobe ice). The former advances can be seen in the extreme north near Dundalk, along the western edge of the watershed at Woodstock, in the east around Guelph (Figure 16) and near Caledonia in the south. The Caledonia-Cayuga drumlins rise through glaciolacustrine sediments deposited in Lakes Whittlesey and Warren.

Erratics are scattered throughout the whole of the basin. They are frequently about $1m^3$ in size (many can be significantly larger), but they range down to granule size. Erratics simply are bedrock fragments that have been transported by ice. Many have distinctive lithologies that show that these have been transported by the

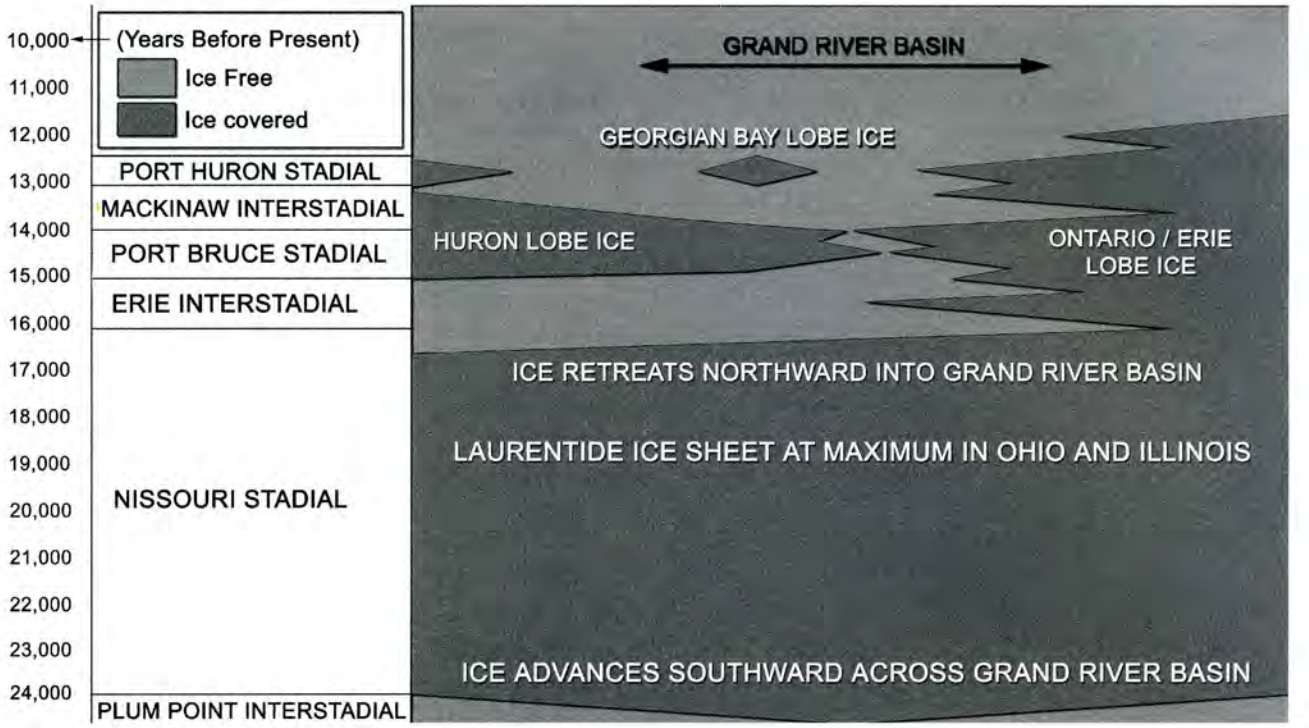

Figure 13: Ice advances and retreats centred on the Grand River Basin.

can be clearly seen in pronounced NW-SE aligned glacial flutings seen near Conestoga Lake. Similar flutings, but aligned from ESE to WNW can be seen on the east side of the central watershed, near Breslau (Figure 2).

Further evidence of ice flow can be seen in the different drumlin fields in various parts of the watershed. Drumlins are sub-glacially formed streamlined features with high, rounded, upstream noses and long downstream tapering tails. They often occur in groups of tens or hundreds known as drumlin fields. Such fields

The retreating ice also deposited many moraines made up of largely unsorted piles of glacial debris (Figure 17). They differ from the generally well-sorted sediments of the Waterloo, Elmira and Orangeville Moraines, in that large boulders or erratics (Figure 18) are scattered throughout piles of poorly-sorted, clay-rich, silt-rich or sand-rich sediments. The Milverton, Macton and Easthope moraines are present in the area of the Huron ice lobe. In the south and east the Ingersoll, Paris, Galt and Moffat moraines represent retreat phases of the Erie and Ontario ice lobes (Figure 19).

Laurentide ice from the Canadian Shield areas north of Manitoulin Island or from east of Georgian Bay. The minimum distance of transport of Shield erratics is 100 km, and the maximum recorded distance is about 500 km. Some erratics can be seen sitting on striated bedrock surfaces where debris in the basal ice has scoured and polished the rock surface. (Figure 18).

The water from the melting ice produced a number of spectacular landforms. Water flowing beneath the ice produced hundreds of potholes in

the sub-glacial bedrock. These are particularly pronounced in the Rockwood / Eramosa area east of Guelph where "giant potholes" are well seen (Morgan 2001). Potholes are erosional features and debris carried from these as well as other more distant regions was often carried in long sub-glacial river courses that, in the decaying ice, were left draped across the landscape in features known as eskers.

Unfortunately most of the eskers in the Grand River watershed have been at least partially removed by aggregate extraction since these features are an excellent local source of sands and gravels (Figure 20). Large esker systems existed in the Grand basin near Dundalk and in the Guelph – West Montrose area. Many of these are 10 - 15m in height and extend near-continuously for distances of 15 to 25 km.

Most of the meltwater from the ablating ice flowed away from, and sometimes parallel to, the ice margins. Huge areas of sand and gravel can be seen between moraines in the central Grand basin. These are called outwash plains and were originally the sites of braided streams (Figure 21). Braided streams are created where river channels are choked with sediment, causing the streams to wander across broad flood plains. Water levels are low in the early morning, but rise throughout the day and evening as the sun's warmth causes the ice to melt. Outwash gravel and sand is widespread, particularly in the central Grand basin where many aggregate companies operate.

Meltwater flowing through the Grand Valley deposited great spreads of gravel and sand on either side of the main valley and some of the tributaries. Later erosion has cut the river down to the modern floodplain that can often be tens of metres below the top surfaces of the glacial gravels. These former levels of the river are called terraces and many aggregate pits are situated in these deposits along the river.

Immediately following ice retreat the watershed area was subject to cold air flowing off the ice surfaces. These katabatic winds cooled the ground and allowed permafrost to form in the cold climate of 14,000 to 13,000 years ago. The average mean annual temperature was perhaps -2° to -4° C; July temperatures were about 10°C, but winter temperatures were very cold. Ice wedges formed in many areas within the Grand basin and today these signs of a former periglacial regime can be easily seen in vertical air photographs. At certain times of the year they are visible from oblique air views (Figure 22) or even from the ground (Morgan 1982).

About 13,000 years ago ice-wedge networks stopped forming and it is assumed that temperatures rose rapidly, probably because of changes in the ice front configuration. Black spruce and other trees that today would be found in northern Canada invaded southern Ontario about this time. Small musk-ox, mammoth and caribou crossed into the Ontario Island, and these were followed by bands of paleo-indian hunters recorded in southwestern Ontario as early as 10,500 years ago. At this time ice had retreated north of Manitoulin Island and the Grand River basin was totally ice-free. As the climate continued to warm, the flora evolved into a true boreal ecotone and summer temperatures around 10,000 years ago would have been relatively warm (perhaps 18° - 20° C) - although winters still would have been far colder than today.

How do we understand this early history of deglaciation? The answer lies in the myriads of "kettle lakes" that dot the former glaciated landscape. A kettle hole (Figure 23) is usually seen today as a small lake, a marsh, a boggy peat-filled hollow, or even just as a slight depression in the ground. Kettles are the former sites of ice-blocks left behind by glacial ice as it melted. The ice bocks were covered for hundreds and possibly as much as a thousand years, by an insulating layer of debris. Eventually the ice under the sand and gravel melted producing a depression on the ground surface. This usually became a small lake that gradually filled with plants and sediments swept in from the surrounding land surface. Quaternary geoscientists examine these sediments to recover fossil remains of organisms that lived in the past. A typical kettle will produce a near-complete record of many organisms that existed in the region through time, and this can be from about 13,000 years ago right to the present. A typical scene about 13,000 years ago is shown in Figure 24. Because many of the ancient organisms are still alive today – although usually much further north – their present locations and living requirements can be analysed and the data applied to their past occurrences.

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Water in the Grand River Basin

Most people really don't understand the limitations of water use. In the 20th and 21st centuries we have grown up with water as a convenient, cheap, easily available and seemingly unlimited resource. Water! There, just at the turn of a tap to shower (how many times a day?), to drench lawns (even in the worst drought), to wash cars, flush toilets and to utilise in a myriad different ways. What is not recognised is that water is re-used time after time, that it is costly to process, that the consumer only pays a minute fraction of the real cost, and that supplies certainly do have limitations.

The residents of the Grand River Basin live in a watershed with a catchment that flows to Lake Erie. If any part of that watershed runs out of water then water must be brought from elsewhere, and that "elsewhere" has to be within the basin, or from the ultimate repository of the river – Lake Erie. No pristine waters from Lake Huron or Georgian Bay, but water from probably the most heavily polluted of all of the Great Lakes.

Let's delve into the general concepts of water (Figure 25). Water that evaporates from the oceans forms clouds that are blown inland by prevailing winds. Condensation under changing temperature creates precipitation (rain at low altitudes and elevations and snow at higher latitudes and elevations).

Precipitation falling to the ground will either run off through streams and lakes to the sea or will soak into the ground. This route has various flow times depending on the nature of the substrate. In some sediments (sand and gravel), or certain rock types that are porous or highly fractured (sandstones and limestones) water will move underground quite rapidly. In other sediment types (clays) or bedrock such as shale, mudstone or unweathered granite, infiltration is slow.

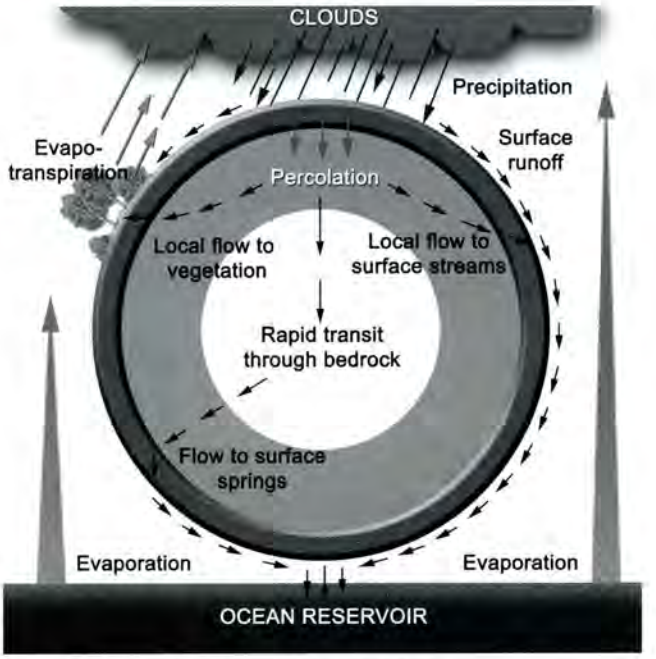

Figure 25: Schematic diagram of the water cycle.

Most water that percolates into the ground ends up flowing at various rates to some point where it will emerge again, usually as a spring. Sediment and rock units that store water are known as aquifers. Units that impede water flow are aquitards and units that are totally impervious to water flow are called aquicludes. Water flowing from higher to lower levels is under hydraulic pressure. If the aquifer is confined between two impermeable units and a well is drilled into it through the upper confining layer, the water will often naturally jet into the air. This may be barely above the ground surface, or it can jet to considerable heights in what is known as artesian flow (Figure 26).

Water Pollution

Water can become contaminated in any one of these stages (Figure 27). Rain can be "acidified" by transit through industrial plumes that contain sulphur dioxide gases. The combination of water plus the gas produces weak sulphuric acid-rich precipitation. This will erode buildings that have limestones or calcareous cements, kill many aquatic organisms and cause problems with plant growth. Surface runoff can be polluted by oil or chemical spills, for example by unthinking persons, disposing of thinners or oils by pouring them into storm drains or onto the ground. In winter excessive use of road salt is already impacting urban water supplies. In rural areas agricultural waste, fuel or chemical spills, heavy applications of fertilisers and pesticides may contaminate water. Poorly contained farm sewage from intensive stock rearing, or even cows in ponds, streams and rivers all have varying degrees of impact on water quality (Figure 28).

Underground water supplies become contaminated by exchange with surface runoff or by underground contamination of aquifers. This might be caused by percolation of toxic materials buried in surface pits (coal tar, oil residues, buried fuel drums or

drums of toxic waste) by dry cleaning fluids and poor disposal practices at chemical facilities (Figure 29). The former Uniroyal plant at Elmira, now owned by Chemtura, is a classic case where the main aquifer under the town has been contaminated. The Elmira chemical plant has, since 1942, manufactured a long list of truly toxic products, including substantial amounts of "Agent Orange" the Vietnam war defoliant, that have contaminated surface soils and sediments, as well as groundwater. Many of the chemicals are proven carcinogens and these have been "remediated" by storage in surface facilities (the large barn-like structure seen in the right of Fig. 29). Badly designed or leaking landfills can also create problems with leachate and other unrecorded or indeterminate disposals can force well-fields to shut down until sources are identified or remediation can take place (Figure 30). The chemical 1,4 dioxane "possibly carcinogenic to humans" was found in the Greenbrook well field in the summer of 2004. These five wells that were shut down, provided some 12 million litres/day (about 5 %) to the regional water supply. Until suitable methods of determining "safe" levels of 1,4 dioxane are resolved and appropriate remediation measures implemented, the wells remain off-line.

Figure 26: Artesian flow in Waterloo Region. Early development of the top regional aquifer frequently saw water jetting 1 to 5 metres into the air under hydrostatic head. Today, with increasing demand, all water must be pumped. Photo courtesy of the Region of Waterloo.

Water in the Grand Basin is reused time after time. In many areas it is possible that the water you flushed down the toilet on one day, may return to your drinking water tap – after being cleansed – a week or two later! Each community down the Grand River takes in, as drinking water, water that has already been though animals and people farther upstream. Of most concern is whether there is enough water for day to day demand, and whether the water quality is maintained. Drinking water supplies in the basin currently come from two sources.

Surface water supplies

The Grand River and its tributaries have a number of major dams in place that are operated by the Grand River Conservation Authority. These serve to control run-off and help to mitigate major flood incidents like the catastrophic flood of May 1974 (Figure 31). In the long term they are more important in allowing a regulated flow of water through the basin. In recent years, during the summer low flow season, up to 80 or even 90 percent of the flow in the Grand River through Kitchener - Waterloo and 60 percent of the flow in the Grand River through Brantford is released from storage in upstream reservoirs (D. Boyd, pers. com. 2005). A series of abnormally dry seasons could seriously diminish the flow in the Grand River. Other water that feeds the tributary streams comes from springs and seepages either in the bedrock or from aquifers in the glacial sequences. The Nith River on the west side of the watershed derives most of its water from runoff and some from the west side of the Waterloo Moraine.

Subsurface water

Tens of thousands of water wells throughout the basin extract groundwater for farms, crop irrigation, individual homes and cottages, municipal water supplies and commercial and industrial purposes. Most of this water either evaporates or is returned to surface flow through field drainage or run-off to streams. Industry has been a major extractor with water being taken for bottled water, beer and other products. Irrigation agriculture is relatively restricted in the basin, although the extreme southwest has a network of wells that are associated with the drier sandy plains of the Norwich region.

Probably the most significant water extraction is for municipal supplies from wells that terminate in glacial deposits. Certain well fields utilise multiple aquifers that are separated by aquitards and some fields might also use bedrock wells (Figure 32). As seen above, these can be rendered unpotable by accidental or inconsiderate introduction of toxic materials to the water supply. Should alternative uncontaminated water supplies be insufficient, especially with burgeoning urban growth in many parts of the watershed, the only practical alternative is to build one or more pipelines to Lake Erie. Costs of such endeavours will be considerable and urban growth should be carefully weighed against the financial implications of limited water supplies. Any risk to aquifers in the region by covering them with buildings or new roads or industries that can provide potential contamination must be carefully considered against the "economic benefits" of having a larger population base.

Continued from page 8

Additional topics might include water hazards such as local stream variations in flood or drought, geological hazards such as local slumping (below). This image is from GRCA files and it shows some of the slumping that has occurred in the Brantford area.

A comment to teachers in the Grand River Basin. If you need teaching materials, I and my colleagues at the University of Waterloo, will be willing to help. We can, for example, run

EdGEO workshops for teachers to show basic elements of rocks and minerals, geomorphic features, fossils and geological time and many other "geo-themes", including one on this teaching set. Contact me and these can be set up at mutually agreeable times. In the same way, if you have really interesting teaching exercises that you are willing to share, especially some that might be related to the topics covered in this issue we can work these in to an EdGEO outreach get-together for teachers at all levels in the school system.

Exercises that did not get into the posters cover topics such as changing climates in the Grand. This might cover everything from changing ice age climates to the last time when the climate was as warm as present; or perhaps the climate of today and even to future climates.

A few of the other themes that have been alluded to are shown above and these will be gradually expanded on the website.

To all our readers elsewhere in Canada and in other countries, thanks for your patience in what has been a very "local" exposé. However, what has been dealt with in this issue IS of relevance to the area that you live. Wherever you call home, you live in a river catchment basin. There is likely an "upstream" or a "downstream" and your part of the world is just as susceptible to "geo-consequences" as anywhere else. You do not have to live on an active volcano or on a subduction zone to experience a major geo-hazard as we have just seen in the disaster of the Gulf Coast of the USA in recent weeks. See if you can apply some of these themes to your area and watch for expanding news on Geoscape Grand River.

Waste Management and Recycling

For the past 50 years or more western societies have been generating more waste materials as a result of increased earnings and higher living standards. Almost everything that we purchase comes wrapped with plastic films, paper, styrofoam or cardboard. At stores most items are packed again in plastic as a convenient way to transport purchases to vehicles and homes. Few people give any thought to bringing cloth bags for shopping and stores certainly do not provide any incentives to break this cycle of consumer waste. Plastic bags that are brought home seldom get re-used and are discarded to trash. All of this increases the use of resources, creates costs for safe disposal and, at its worst, really harms the environment. For example, some animals die after ingesting plastic film thinking that it is food or after utilizing it in nesting materials where it remains wet or conducts water, harming offspring. North American society has a long way to go before it realizes the sense of the 3Rs (Reduce, Reuse, and Recycle).

People within the watershed want to dispose of a wide variety of different materials on a regular basis and so within the Grand River Basin different urban and rural municipalities deal with waste materials in different ways. However, they are all faced with the same dilemma. Some of the waste is bulky, some is toxic, some is valuable and some is apparently valueless, truly "yucky" and really "garbage" in the proper sense. The problem is what to do with it all?

Unscrupulous individuals (and, unfortunately, some businesses) care little about the environment. Materials thrown from car windows or dropped by walkers (styrofoam, aluminum, cardboard, and plastic drinking containers) are an example of the former and illegal dumping of tyres, garbage, oil, chemicals, and other waste are examples of the latter. A common attitude is either, "I can't be bothered to carry this any farther" or "nobody can see me, and I don't care". Unfortunately this waste is visible, is unsightly, is costly – in time or money – for someone else to clean up and does, in many cases, adversely impact the environment. Kitchener experienced one example where waste materials had been dumped in a small pond that was subsequently filled in and built upon. Twenty years later houses on Ralgreen Crescent began to crack and waste materials seeped into basements. Remediation required the city purchasing 27 properties and demolishing 20 units and garages, removing ~ 75,000 tons of old fill and replacing it with new soil and then constructing new units. Financial costs ran in the tens of millions of dollars.

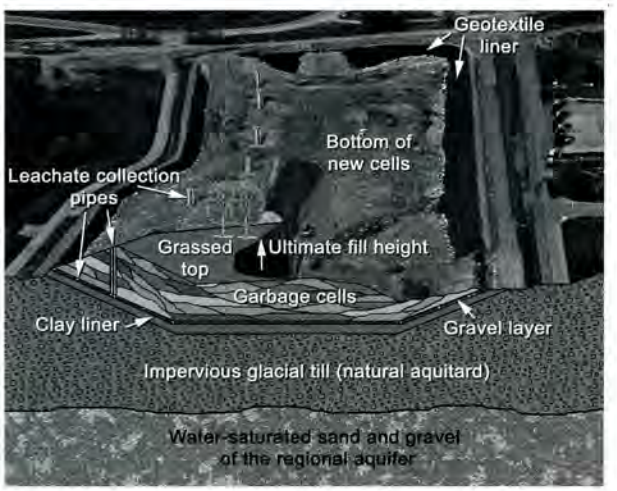

Figure 33: Region of Waterloo Landfill schematic showing the relationship of garbage, the respective liners and protection areas and the leachate gathering system. Not shown is the methane gathering system, used to generate electricity (Figure 36).

Farther south the Hagersville "Tire Fire" started in a dump owned by Tyre King with over 14 million tires. A legal appeal "loophole" had delayed implementation of dividing the tires into discrete piles. An estimated 12 million tires burned for 17 days forcing the evacuation of all people within a 4 km radius. The fire cost over $12 million, produced ~ 20,000m^3 of solid waste and created polluted groundwater from oily waste water and carcinogenic materials that were released during the fire. As a result of this fire, new regulations were established for storage, taxes introduced on tire disposal and recycling of tires established in many parts of Canada.

For the vast majority of citizens the question of garbage is taken seriously. In rural areas most garbage is taken to a regional dump where it is landfilled using similar techniques to those described below. Much organic waste material is composted somewhere on the larger rural properties. In urban centres where population numbers are higher there are regular pickup times each week for certain neighbourhoods. All households are encouraged to compost on their own property, with larger brush being collected at curbside for mulch production in some areas. Free compost bins and vermicomposters are available in some communities. Worm bins are ideal for apartment dwellers without gardens. Small red earthworms will readily convert plant waste (tomato skins, vegetable peelings and newspaper strips) into good quality soil. However, for most, curbside pickup is the standard route.

Materials that are placed out for pickup fall into different categories and municipalities are becoming more selective about what you can or cannot do with them. Thirty years ago almost anything and everything went to landfill. Today there are strict limitations about what should be done with waste materials, with anywhere from 40 to 60 percent being diverted from the landfill to some other destination. Toxic wastes (paints, thinners, batteries, solvents, pesticides, herbicides, household cleaning materials and others) usually have special disposal requirements. Computer and electronic materials have just been added to the "hazardous" list.

Different systems for collection of waste materials are used in the two largest population bases in the basin (Region of Waterloo, ~ 500,000 persons in Cambridge, Kitchener and Waterloo and in smaller towns), and the City of Guelph (~ 120,000). In the region of Waterloo all waste is directed from satellite substations to the main landfill on Erb Street west of Waterloo. As seen in Figs. 33 and 36, this facility sits on top of the main drinking water aquifer and so care must be taken to protect the water supply from leachate contamination. This is accomplished by "layering" the fill area. A prepared clay liner sits on top of the natural glacial till aquitard. This is overlain by a geotextile cloth liner (Figure 34) that prevents erosion of the clay layer until the garbage cells cover the complete area. A basal layer of gravel overlying the clay allows water that percolates through the garbage cells to be collected by a leachate collection system either under gravity or by pumping. Each increment of trucked garbage is protected from wind by movable screens, is continuously compacted and then daily covered with soil (Figure 35). This prevents odours, wind-blown paper and plastic detritus from moving off-site and also removes potential food material from animal scavengers (largely seagulls and rats).

Garbage that sits over long periods of time generates methane gas. This is smelly and environmentally unfriendly in that methane (CH_4) is a greenhouse gas that is 20 to 30 times more powerful than CO_2. For these reasons most facilities will flare off the methane that is gathered from the landfill by a specially constructed methane collection system.

In the Waterloo Regional facility Toromont Energy captures methane from a network of over 70 wells in the landfill. The methane is diverted to a 4.6 Mw plant that generates electricity for the Ontario Power Grid. It helps to reduce the Region's greenhouse gas emissions by ~ 150,000 tonnes of CO_2 equivalent (or the output of ~ 37,000 cars) and provides electrical power for about 3,500 homes.

The other significant difference between the Region of Waterloo and Guelph is the method of recycling. The Blue Box programme that is now widespread across Canada, as well as being adopted in other countries such as the United States, Australia, France and Britain started in Kitchener. The initial programme was launched on September 17, 1981 and was expanded to the whole of Kitchener in 1983. Aluminum and steel, plastics labelled 1 to 7, newspapers, corrugated cardboard, boxboard, and glass can all be placed in the blue box.

Tree and shrub clippings can be placed in paper bags or tied in bundles. Other commodities can be collected on special pickups or taken directly to the recycling centre. Special leaf collecting is completed on a number of occasions in the fall and residents will often rake leaves to curbside for pickup. Leaves are matured to compost in long windrows (Figure 36). Waterloo sells some and allows free pickup by residents twice a year. Similarly mulched wood can be obtained in mulch piles at the centre.

All other materials are regarded as "waste" and will be landfilled. The rate of diversion of recycled materials from the landfill is about 41 percent.

The wet and dry system used by Guelph appears to be more efficient with significantly higher diversion rates. Guelph uses a WetDry + system. Waste is placed in three bags by the householder. The Wet bag (green in colour) contains a wide variety of materials such as food scraps, fireplace ashes and pet waste that would be landfilled at Waterloo. The Dry (blue bag) handles most commodities that would be recycled in the blue box programme. The Waste is packed in clear bags. Since all three are "see through", rejection may take place at curbside. Nevertheless Guelph claims a 58 percent diversion rate from the landfill for Wet and a 61 percent diversion rate for Dry materials. Since Waterloo uses opaque plastic bags some recyclable materials are certainly inadvertently landfilled.

Materials in Guelph that pass the curbside visual examination are placed in a compartmentalised truck and taken to the Guelph Waste Resource Innovation Centre (the recycling plant) where the wet waste is dumped, bulldozed into a screw auger debagger, conveyed to a trommel screen and the "fines" sent on to a composter. Coarse materials are passed though the screen a second time and any oversize fraction is sent to the landfill. After the composting process is finished materials are sent outside to static piles to mature and eventually go to windrows for sorting. The final product, after screening, is a good quality compost that can be sold to residents and commercial operators.

Both Guelph and Waterloo have special storage areas for hazardous wastes (mentioned above), and also for used commodities such as old refrigerators and washing machines (white goods), styrofoam items and tires.

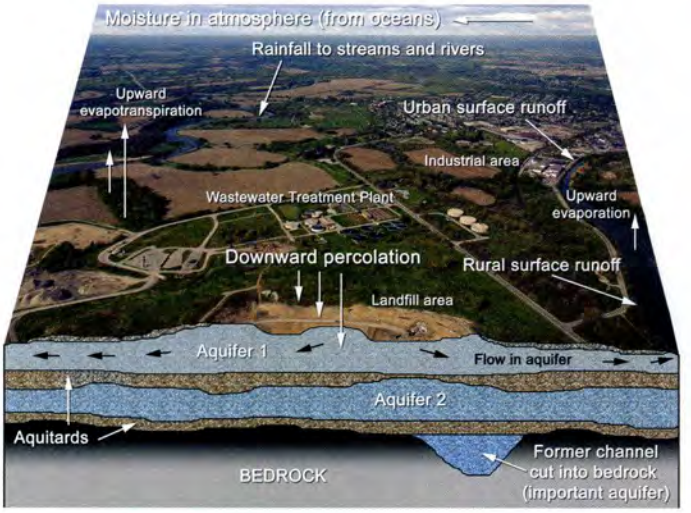

Figure 27: Water cycle in the Brantford area.

Figure 29: Crompton – (a Chemtura Company) – plant at Elmira (formerly Uniroyal), see text.

Figure 31: Brantford, 18 May 1974, Courtesy GRCA.

Figure 28: Potential surface water contamination in a rural, pastoral setting.

Figure 30: Greenbrook pumping station, now closed, Kitchener; see text.

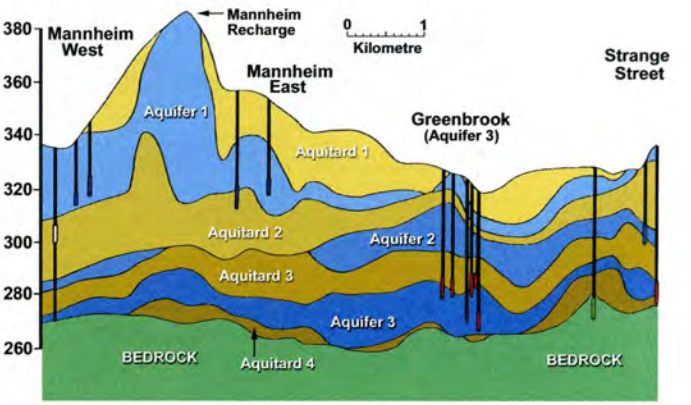

Figure 32: Some bedrock wells (i.e. east of the Greenbrook field) are used for water supplies.

Figure 34: Textile cloth covering clay liner at the bottom of a new cell, Waterloo Regional landfill, July 2005.

Figure 35: Compactor working over trash pile. Note wind screen catchment (right) and the top grader placing soil over garbage.

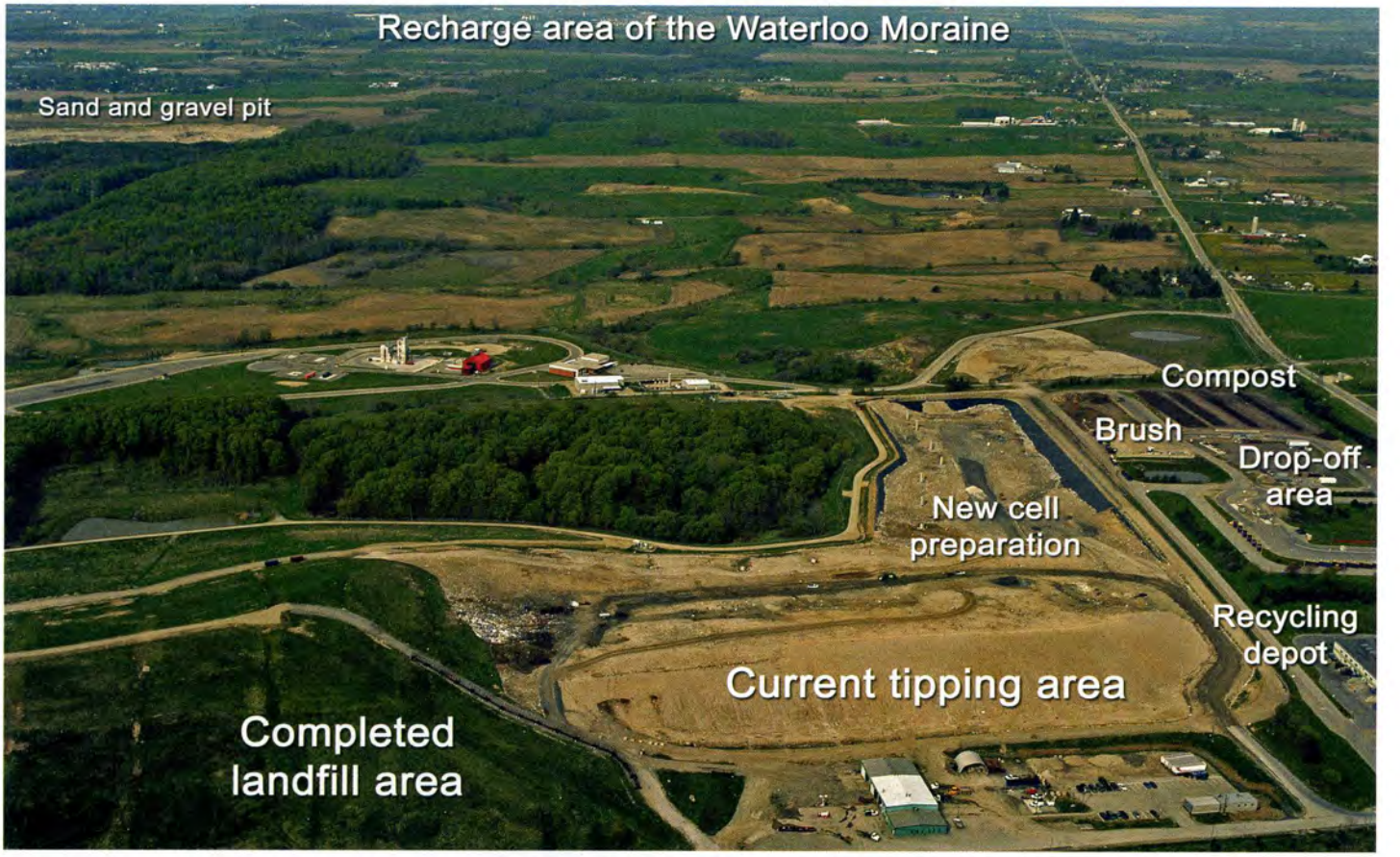

Figure 36: Waterloo Regional Landfill and Waste Management area. The view is west along Erb Street (right). The north end of the 1972 landfill can be seen (left). This is the area where methane is being extracted for the Toromont electrical plant (centre). The cell area (current) is in the foreground and new cell preparation is to the west (see Figs. 33, 34). The edge of the recycling depot is on the right. Note the rolling nature of the Waterloo Moraine (background).

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