...LIVING LANDSCAPES...
Thompson-Okanagan: Past, Present & Future

Land Use and Environmental Change in the Thompson-Okanagan

Acid Rain and Deposition

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(a). Introduction

Acidic pollutants can be deposited from the atmosphere to the Earth's surface in wet and dry forms. The common term to describe this process is **acid deposition**. The term **acid precipitation** is used to specifically describe wet forms of acid pollution that can be found in rain, sleet, snow, fog, and cloud vapor. An acid can be defined as any substance that when dissolved in water dissociates to yield corrosive hydrogen ions. The acidity of substances dissolved in water is commonly measured in terms of **pH** (defined as the negative logarithm of the concentration of hydrogen ions). According to this measurement scale solutions with pHs less than 7 are described as being

acidic, while a pH greater than 7.0 is considered **alkaline**. Precipitation normally has a pH between 5.0 to 5.6 because of natural atmospheric reactions involving carbon dioxide. Precipitation is considered to be acidic when its pH falls below 5.6 (which is 25 times more acidic than pure water). Some sites in eastern North America have precipitation with pHs as low as 2.3 or about 1000 times more acidic than natural.

Acid deposition is not a recent phenomena. In the 17th century, scientists noted the ill effects that industry and acidic pollution was having on vegetation and people. However, the term **acid rain** was not coined until two centuries later when Angus Smith published a book called '**Acid Rain**' in 1872. In the 1960s, the problems associated with acid deposition became an international problem when fishermen noticed declines in fish numbers and diversity in many lakes throughout North America and Europe.

(b). Acid Deposition Formation

Acid deposition can form as a result of two processes. In some cases, hydrochloric acid can be expelled directly into the atmosphere. More commonly it is due to **secondary pollutants** that form from the oxidation of **nitrogen oxides** (NOx) or **sulphur dioxide** (SO_2) gases that are released into the atmosphere (see **Figure**). The process of altering these gases into their acid counterparts can take several days, and during this time these pollutants can be transferred hundreds of kilometers from their original source. Acid precipitation formation can also take place at the Earth's surface when nitrogen oxides and sulphur dioxide settle on the landscape and interact with dew or frost.

Emissions of sulphur dioxide are responsible for 60-70 % of the acid deposition that occurs globally. More than 90 % of the sulphur in the atmosphere is of human origin. The main sources of sulphur include:

- Coal burning - coal typically contains 2-3 % sulphur so when it is burned sulphur dioxide is liberated.
- The smelting of metal sulfide ores to obtain the pure metals. Metals such as zinc, nickel, and copper are all commonly obtained in this manner.
- Volcanic eruptions - although this is not a widespread problem, a volcanic eruption can add a lot of sulphur to the atmosphere in a regional area.
- Organic decay.

After being released into the atmosphere, sulphur dioxide can either be deposited on the Earth's surface in the form of dry deposition or it can undergo the following reactions to produce acids that are incorporated into the products of wet deposition (also see **Figure**):

$$SO_2 + H_2O \rightarrow H_2SO_3$$
$$SO_2 + 1/2O_2 \rightarrow SO_3 + H_2SO_4$$

Some 95 % of the elevated levels of nitrogen oxides in the atmosphere are the result of human activities. The remaining 5 % comes from several natural processes. The major sources of nitrogen oxides include:

- Combustion of oil, coal, gas.
- Bacterial action in soil.
- Forest fires.
- Volcanic action.

- Lightning.

Acids of nitrogen form as a result of the following atmospheric chemical reactions (also see **Figure**):

$$NO + 1/2O_2 \text{ »»» } NO_2$$
$$2NO_2 + H_2O \text{ »»» } HNO_2 + HNO_3$$
$$NO_2 + OH \text{ »»» } HNO_3$$

Finally, the concentrations of both nitrogen oxides and sulphur dioxides are much lower than atmospheric carbon dioxide which is mainly responsible for making natural rainwater slightly acidic. However, these gases are much more soluble than carbon dioxide and therefore have a much greater effect on the pH of the precipitation.

(c). Effects of Acid Deposition

Acid deposition influences the environment in several different ways. In aquatic systems, acid deposition can effect these ecosystems by lowering their pH. However, not all aquatic systems are effected equally. Streams, ponds or lakes that exist on bedrock or sediments rich in calcium and/or magnesium are naturally buffered from the effects of acid deposition. Aquatic systems on neutral or acidic bedrock are normally very sensitive to acid deposition because they lack basic compounds that buffer acidification (see **Figure**). In Canada, many of the water bodies found on the granitic **Canadian Shield** fall in this group. One of the most obvious effects of aquatic acidification is the decline in fish numbers. Originally it was believed that the fish died because of the increasing acidity of the water. However, in the 1970s scientists discovered that acidified lakes also contained high concentrations of toxic heavy metals like mercury, aluminum, and cadmium. The source of these heavy metals was the soil and bedrock surrounding the water body. Normally, these chemicals are found locked in clay particles, minerals and rocks. However, the acidification of terrestrial soils and bedrock can cause these metals to become soluble. Once soluble, these toxic metals are easily leached by infiltrating water into aquatic systems where they accumulate to toxic levels.

In the middle latitudes, many acidified aquatic systems experience a phenomenon known as **acid shock**. During the winter the acidic deposits can build-up in the snowpack. With the arrival of spring, snowpack begins to melt quickly and the acids are released over a short period of time at concentrations 5 to 10 times more acidic than rainfall. Most adult fish can survive this shock. However, the eggs and small fry of many spring spawning species are extremely sensitive to this acidification.

The severity of the impact of acid deposition on vegetation is greatly dependent on the type of soil the plants grow in. Similar to surface water acidification, many soils have a natural buffering capacity and are able to neutralize acid inputs. In general, soils that have a lot of lime are better at neutralizing acids than those that are made up of siliceous sand or weathered acidic bedrock. In less buffered soils, vegetation is effected by acid deposition because:

- Increasing acidity results in the leaching of several important plant nutrients, including calcium, potassium, and magnesium. Reductions in the availability of these nutrients causes a decline in plant growth rates.

- The heavy metal aluminum becomes more mobile in acidified soils. Aluminum can damage roots and interfere with plant uptake of other nutrients such as magnesium and potassium.
- Reductions in soil pH can cause germination of seeds and the growth of young seedlings to be inhibited.
- Many important soil organisms cannot survive is soils below a pH of about 6.0. The death of these organism can inhibit decomposition and nutrient cycling.
- High concentrations of nitric acid can increase the availability nitrogen and reduce the availability of other nutrients necessary for plant growth. As a result, the plants become over-fertilized by nitrogen (a condition known as **nitrogen saturation**).
- Acid precipitation can cause direct damage to the foliage on plants especially when the precipitation is in the form of fog or cloud water which is up to ten times more acidic than rainfall.
- Dry deposition of SO_2 and NOx has been found to affect the ability of leaves to retain water when they are under water stress.
- Acidic deposition can leach nutrients from the plant tissues weakening their structure.

The combination of these effects can lead to plants that have reduced growth rates, flowering ability and yields. It also makes plants more vulnerable to diseases, insects, droughts and frosts.

The effects of acidic deposition on humans can be divided into three main categories. Acid deposition can influence human health through the following methods:

- Toxic metals, such as mercury and aluminum can be released into the environment through the acidification of soils. The toxic metals can then end up in the drinking water, crops, and fish and then ingested by humans through consumption. If ingested in great quantities, these metals can have toxic effects on human health. One metal, aluminum, is believed to be related to the occurrence of **Alzheimer's disease**.
- Increased concentrations of sulphur dioxide and oxides of nitrogen have been correlated to increased hospital admissions for respiratory illness.
- Research on children from communities that receive a high amount of acidic pollution show increased frequencies of chest colds, allergies and coughs.

Acid deposition also influences the economic livelihoods of some people. Many lakes and streams on the eastern coast of North America are so acidic that the fish decline significantly in numbers. The reduced fish numbers then influence commercial fishermen and industries that rely on the sport fishing tourism. Forestry and agriculture are effected by the damage caused to vegetation. In some areas of eastern North America and Europe, large die-backs of trees have occurred.

Finally, acid deposition effects a number inanimate features of human construction. Buildings and head stones that are constructed from limestone are easily attacked by acids, as are structures that are constructed of iron or steel. Paint on cars can react with acid deposition causing fading. Many of the churches and cathedrals in Europe are under attack from the effects of acidic deposition.

(d). Acid Deposition in Canada and British Columbia

The acid deposition problem in Canada tends to be localize east of the Manitoba border with Ontario. This area of Canada has a large number of industries that release acid causing substances into the atmosphere. This area is also influenced by pollution from industrial areas in eastern United States. Research has shown that almost half of the acid deposition that falls in southeastern Canada is due to combustion from factories in seven states: Ohio, Indiana, Pennsylvania, Illinois, Missouri, West Virginia, and Tennessee.

In general, high levels of aid deposition in eastern Canada have lead to the following environmental problems:

- More than 300,000 lakes in eastern Canada are now vulnerable to acid deposition. Over 14,000 lakes have been acidified to the point where they have lost significant numbers of their fish.
- Atlantic salmon catches from rivers in Nova Scotia have declined substantially since the 1950s. This decline corresponds to the acidification of the waters in these rivers.
- In eastern Canada, 55 % of forests are in areas where the rainfall is acidic. Some of these forests are showing declines in vigor due to this acidification.
- More than 80 percent of Canadians live in areas where rainfall is quite acidic. Respiratory problems noticed in thousands of people from this area may be related to this form of atmospheric pollution.

However, studies in the province of British Columbia have shown that at the present time there is no noticeable environmental damage is occurring from acid deposition. A habitat sensitivity map of the province British Columbia , based on the pH of water bodies and ability of soils and bedrock to neutralize acid deposition, have been constructed by the Ministry of Environment, Lands and Parks. This map indicates that habitats in the Rockies and central British Columbia have the highest potential to neutralize acidic inputs. Habitats on the west coast of Vancouver Island and coastal mountainous regions have the lowest potential for neutralization.

Large amounts of acid-forming pollutants are created in British Columbia. Most of the nitrogen oxide emissions are created from the combustion of fuels by vehicles. Many industries in British Columbia release sulphur dioxide into the atmosphere including natural gas processing plants, pulp mills, smelters, oil refineries and power plants. Data from recordings stations in several cities indicate that sulphate deposition levels from these sources are well below the eastern Canadian standard developed for the protection of moderately sensitivity aquatic systems (see **Figure**). However, some researchers have suggested that a target value of 8-12 kilograms of wet sulphate deposition per hectare per year should be put in place to protect more sensitive habitats. Measurements of acidity indicate that precipitation falling in British Columbia generally has a pH similar to naturally occurring rainwater with no pollutants (see **Figure**). Finally, a province wide survey of over 750 lakes between 1977 and 1986 found acidic 10 lakes. Subsequent investigations of these 10 lakes revealed that their acidic nature was due to natural causes.

(e). Solutions

There are several things that can be done in order to alleviate the problems of acid deposition. For lakes that have been acidified, the pH can be increased by a technique called **liming**. This process involves adding large quantities of hydrated lime, quick lime or soda ash to the waters in order to increase the alkalinity and pH. Areas

that have employed this method have had some success with it. In West Wales, the pH of some lakes was increased from 5.5 to 7.0 and once again brown trout stocks can survive there. Liming, however, does not always work, as getting to the necessary lake may be impossible, the lake may be too big and therefore economically unfeasible, or the lake may have a high flush rate so that they quickly become acidified again after liming.

The best overall solution to the problems of acid deposition is to limit the emission of pollutants at their source. In eastern Canada, environmental regulations now limit the amount of sulphuric pollution that can now enter the atmosphere from industrial sources. Industrials have limited their emission of acidic pollutants through two methods. Many industries have switched to using fuels that have no sulphur or a low sulphur content. Other industries have used **scrubbers** installed on smokestacks to reduce the amount of sulphur dioxide being released into the atmosphere. The application of these two methods has created some promising results. For example, the once acidified Clearwater Lake near Sudbury, Ontario is now on its way to recovery. The pH of this lake dropped to 4.1 before regulations were put in place. By 1986, the pH of the lake measured 4.7. The reduction in nitrogen oxides is a more difficult problem to deal with because this type of acidic pollution is primarily created from automobile exhaust. A drastic reduction in number of motor vehicles used in eastern Canada over the next few decades seems unlikely. However, emissions from this non-point source could be controlled by regulating the use of specially designed catalytic converters.

In 1991, Canada and the United States established the **Air Quality Accord** that controls the air pollution that flows across international boundaries. In this agreement, acid deposition causing emissions are permanently capped in both countries (13.3 million tonnes for the U.S. and 3.2 million tonnes of sulphur for Canada) and plans were implemented for the reduction of nitrogen oxides.

Additional References Available in Public Libraries, Okanagan University College Library, or University College of the Cariboo Library

Environment Canada: Major Programs and Initiatives

Environment Canada: National Environmental Indicator Series

Environment Canada: Publication List

Other Related Home Pages On This Topic

- American Meteorological Society: Acid Deposition
- Econet: Acid Rain Resources
- Environet: Acid Rain Formation

- Environmental Defense Fund: Stopping Acid Rain at its Source
- Environment Canada: Acid Rain
- Environment Canada: Acid Rain FAQ
- Environment Canada: Acid Rain Index
- Michigan Technological University: Acid Deposition and its Ecological Effects
- Missouri Department of Natural Resources: FAQ - Acid Rain
- Norway Ministry of Environment: Acid Rain
- Southhampton University: Acid Rain
- University of Guelph: Acid Rain on the Net!
- University of Wisconsin: Acid Rain
- US Environmental Protection Agency: Acid Rain Program
- US Environmental Protection Agency: Effects of Acid Rain on Forests
- US Environmental Protection Agency: Effects of Acid Rain on People
- US Environmental Protection Agency: Effects of Acid Rain on Water
- US Natural Gas Council: Acid Rain

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Created by Tracy Gow and Michael Pidwirny, 1996
Email Comments and Suggestions to: mpidwirny@okanagan.bc.ca