Project Atmosphere Canada

MODULE 14

Acid Rain

Teacher's guide

Canadian Meteorological and Oceanographic Society
La Société Canadienne de Météorologie et d'Océanographie

Environment Canada Environnement Canada

Canada

Project Atmosphere Canada

Project Atmosphere Canada (PAC) is a collaborative initiative of Environment Canada and the Canadian Meteorological and Oceanographic Society (CMOS) directed towards teachers in the primary and secondary schools across Canada. It is designed to promote an interest in meteorology amongst young people, and to encourage and foster the teaching of the atmospheric sciences and related topics in Canada in grades K-12.

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INTRODUCTION

In order to understand acid rain, we need to understand the life cycle of atmospheric pollutants. There are three basic components to this cycle: a) emission, b) transport and transformation, and c) deposition.

The emission component includes natural and anthropogenic (human-made) emissions from various sources.

The transport and transformation component includes everything that happens to the pollutants while they are resident in the atmosphere: dispersion, diffusion, transport, and chemical and physical transformation. In other words, the atmosphere is the "reaction vessel" and the delivery system for the pollutants.

The deposition component includes wet and dry removal processes, as well as effects of the pollutants on the aquatic and terrestrial environment and human health.

BASIC UNDERSTANDINGS

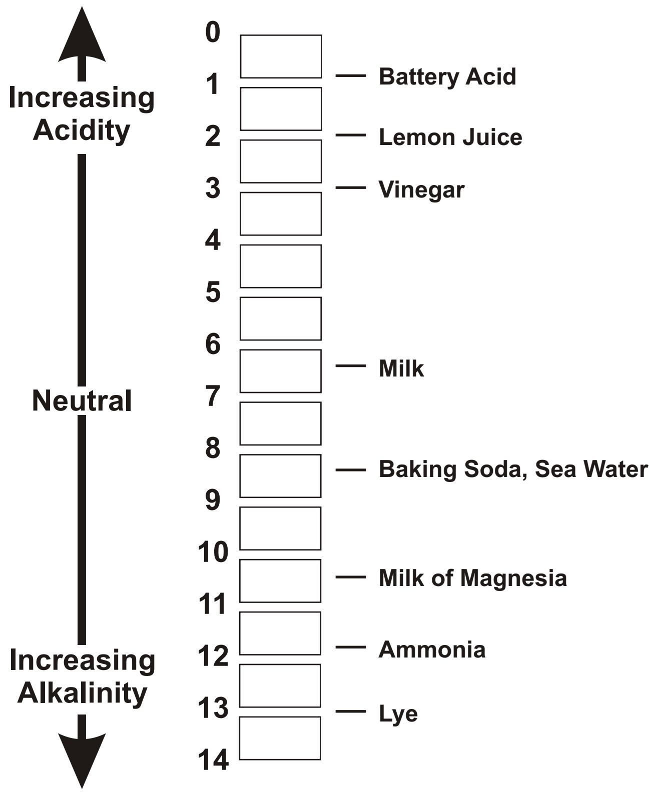

Figure 1 - pH scale

pH AND ACID RAIN

1. The pH scale is commonly used by chemists to indicate the "strength" of an acid (or of an "alkali" or a base, the chemical opposite of acid).

2. Decreasing pH corresponds to increasing acidity, but in a non-linear (logarithmic) way. For example, a pH of 4 is ten times more acidic than a pH of 5, and a hundred times more acidic than a pH of 6.

3. Water that is absolutely pure has a pH of 7 (neutral). Water that is left standing for a long time in contact with non-polluted air, however, becomes slightly acidic with a pH near 5.6. This acidity is derived from absorption of carbon dioxide from the air to produce a weak acid called carbonic acid.

4. Even in remote locations in the Southern Hemisphere, precipitation has a pH of about 5 due to acidifying compounds (such as sulphuric acid) in the atmosphere, derived from both anthropogenic and natural sources (such as volcanoes).

5. When we talk about acid "rain", we are really referring to any liquid, freezing or frozen precipitation that is more acidic than about pH 5. The average rain in eastern Canada is about pH 4.5. Extreme acid rains can have a pH as low as 3.

CAUSES OF ACID RAIN

6. The most common acidifying chemicals found in precipitation are sulphuric acid (H_2SO_4) and nitric acid (HNO_3). They are formed from sulphur dioxide (SO_2) and nitrogen oxides (NO_x=NO+NO_2), respectively, that are emitted from anthropogenic sources such as power plants, smelters and vehicles.

7. These compounds are mixed into the atmosphere, and carried downwind for hundreds or thousands of kilometres while being chemically transformed into acids. Eventually they fall to earth either as wet deposition in precipitation or as dry deposition (particles or gases), where they can impact on sensitive ecosystems.

8. Regions that receive acid rain are areas with and downwind of industrialization (eastern North America, western Europe, Japan).

9. Acid rain is a problem in the Atlantic Provinces and other parts of eastern Canada and the northeastern U.S. because of factors related to the three components of the air pollution cycle:
   Firstly, the major SO_2 and NO_x sources are in the eastern U.S. and southern Ontario and Québec.
   Secondly, weather systems (prevailing winds) transport this pollution towards Atlantic Canada.
   Thirdly, much of eastern Canada, including the Atlantic Provinces, is very sensitive to inputs of acidity.

10. Neutralization can occur in the soils and waters of the receiving environment if it has the buffering capacity, which is dependent on the availability of substances such as limestone.
   Unfortunately, the bedrock of acid sensitive regions is composed of granite, quartzite and slate, and associated soils are generally thin and deficient in chemicals which can neutralize acidity.

THE CONCEPT OF "CRITICAL LOADS"

11. The critical load is a measure of how much pollution an ecosystem can tolerate; in other words, the threshold above which the pollutant load, acid deposition in this case, harms the environment. Ecosystems that can tolerate acidic pollution have high critical loads, while sensitive ecosystems have low critical loads.

12. Critical loads vary across Canada. They depend on the ability of each particular ecosystem to neutralize acids. Scientists have defined the critical load for aquatic ecosystems as the amount of wet sulphate (which makes sulphuric acid) deposition which will maintain a pH of 6 or more in at least 95% of the lakes in a region.

13. Much of Atlantic Canada and portions of Quebec and Ontario have critical loads of less than 8 kilograms of wet sulphate per hectare per year (kg/ha/yr). (100 ha = 1 km^2) Unfortunately, the critical load is being exceeded over much of this region, and environmental damage is occurring.

ECOSYSTEM IMPACTS

14. What impacts have been seen from this excessive acidic deposition? Many aquatic organisms are very sensitive to acidic waters, so the aquatic environment was the first to show noticeable impacts of acid rain.

15. Many species of amphibians are very sensitive to acid water, with high mortality occurring in the egg stage. Damage starts at pH less than 6.5.

16. Many species of fish begin to disappear below pH 6. Changes in blood chemistry are observed in fish, as well as retardation of egg development.

17. One species endangered by acid rain is the Atlantic salmon. Most of the salmon cannot survive when the water pH drops to 5. When it drops to about 4.7, the salmon disappear from the river. This has occurred in 14 rivers in the southern part of Nova Scotia. In addition, 35 more rivers in this area have been adversely impacted by acid rain.

18. Research has shown that acid rain has direct and indirect effects on forests. The main concern is the indirect effect that acid rain has through its impact on soil chemistry, through both losses of soil nutrients and increases in metals that are

toxic to roots (see 23, 24). In this process, acid rain leaches essential nutrients (e.g., calcium, magnesium) from forest soils, thus causing nutrient deficiencies and imbalances for the forest.

19. Some tree species are less tolerant than others. For example, since sugar maples need more calcium than most tree species, they are among the first affected.

20. Acid rain also has direct effects on the forest; in particular, it affects the cuticle (the waxy covering on the upper surface of the leaf). Cuticle damage accelerates the natural ageing process of the leaves, which impairs the ability of the tree to cope with other stresses, such as other pollutants, drought, insect infestations, disease and increased ultraviolet radiation due to a thinner ozone layer.

21. Until recently, sulphuric acid has been our chief acidification concern. The impact of nitric acid is also important, but has been perceived as a lesser problem because nitrogen acts as a fertilizer, taken up by plants rather than appearing in soils and surface waters as acid.

22. However, extra nitrogen-based atmospheric compounds may lead to nitrogen saturation and subsequent release of nitric acid into surface waters. Nitrogen-based acidification has occurred for a large number of lakes in south central Ontario and southwestern Quebec.

23. The same emission sources that discharge sulphur and other acidifying substances also discharge toxic metals in trace amounts. In addition, acid rain itself impacts soil and water systems through its effect on metals. The solubility of trace metals, whether from emissions or already present in the aquatic and terrestrial environment, increases with increasing acidity.

HUMAN HEALTH AND OTHER IMPACTS

24. Dissolved metals are not only toxic to fish, trees and other organisms, but metals such as aluminum in drinking water present a serious human health hazard if levels are too high. Cadmium has already reached dangerous levels in wildlife in acid-sensitive areas, thus necessitating a ban on organ meats for human consumption in some areas.

25. Another health-related component of the acid rain phenomenon is the aspect of acidic aerosols, or tiny solid or liquid atmospheric particles with a high acid content. When these particles are inhaled, they can be associated with increased hospital admissions, respiratory diseases (bronchitis, asthma and emphysema) and premature death.

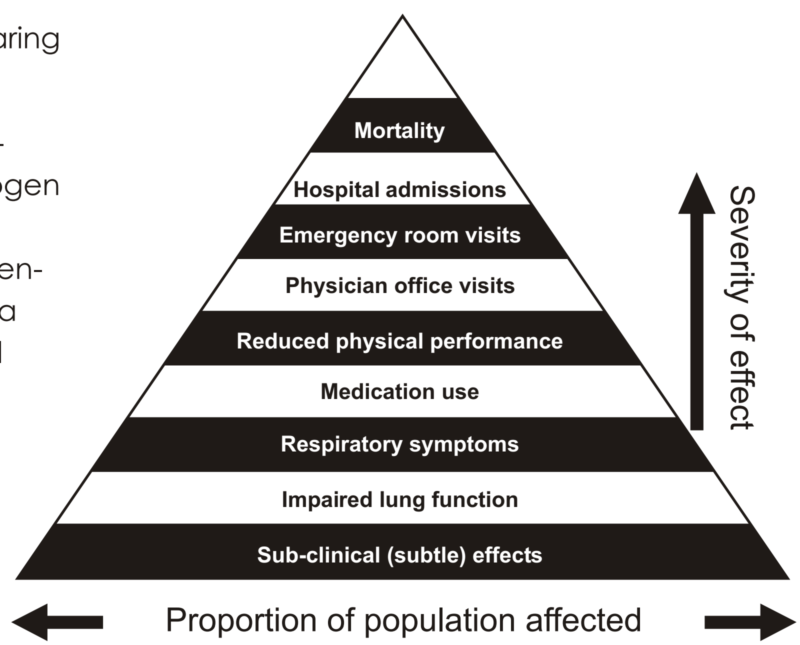

Figure 2 - Air pollution health effects pyramid

26. Another issue related to acid rain is the reduction in visibility in eastern North America due to sulphate aerosols. Impaired visibility is a safety issue for airport traffic control and can affect tourism as well.

27. In addition, acid rain and acidifying pollutants can accelerate corrosion of building materials such as stone, brick, concrete and metal.

EMISSION CONTROLS

28. In 1985 the governments of Canada and the seven eastern provinces joined forces to take action on reducing sulphur dioxide, the major contributor to acid rain. They launched a program to cut sulphur dioxide emissions in the eastern provinces in half by 1994, which was more than successful. By 1994, sulphur dioxide emissions in eastern Canada were 54% lower than 1980 levels.

29. Since about half of the acid rain in eastern Canada comes from American sources, the co-operation of the U.S. was also needed. In 1990, the U.S. acted to reduce emissions of sulphur dioxide by amending its *Clean Air Act* and, in 1991, by signing the *Canada-U.S. Air Quality Agreement*.

30. By 1996, U.S. sulphur dioxide emissions had declined to 27% lower than they were in 1980, and by 2010, they should decrease by a total of about 40%. With decreasing emissions, the amount of acid rain has also decreased.

OUTSTANDING CONCERNS

31. Despite this progress, an acid rain science assessment conducted in the mid-1990's showed that some serious problems remained. More action was needed to fully protect Canada's ecosystems.

32. Without further emission reductions beyond those required under the 1991 *Air Quality Agreement*, scientists estimated that an area of some 800,000 square kilometres, extending from central Ontario through southern Quebec and across much of Atlantic Canada, would still be receiving more sulphate than its natural systems could tolerate.

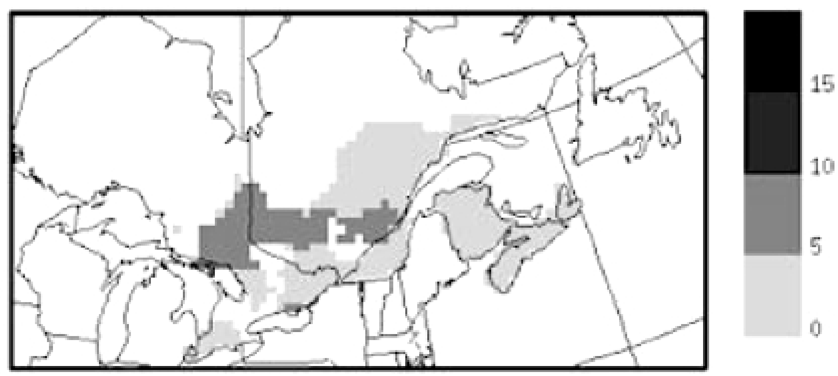

Figure 3 - Predicted wet sulphate deposition in excess of critical loads in 2010, without further controls (in kg/ha/yr)

33. Atmospheric modelling conducted as part of the science assessment showed that a further 75% reduction in sulphur dioxide emissions (beyond current commitments) in targeted regions of eastern Canada and the U.S. would be necessary to protect all of the 95,000 lakes in this area.

34. Some acidified lakes showed signs of recovery, but many more did not. The greatest improvements were seen in the Sudbury area, where lakes had been very badly damaged. Here, fish populations rebounded and fish-eating birds such as loons increased.

35. However, no substantial wildlife recovery has been seen beyond the Sudbury area. The least improvement was seen in Atlantic Canada, although lakes in this region were never as highly acidified as those in some parts of Ontario and Quebec.

36. Reducing nitrogen oxides is becoming more important. If nitrate deposition continues at current levels, its contribution to acidification will eventually erode the benefits gained from the reductions in sulphur dioxide.

37. Because nitrogen oxides also contribute to ground-level ozone, the main ingredient in smog, reducing these emissions would also help to improve air quality.

FUTURE ENDEAVOURS

38. On October 19, 1998, federal, provincial, and territorial Energy and Environment Ministers signed *The Canada-wide Acid Rain Strategy for Post-2000*. The Strategy laid the framework for how Canada would manage acid rain in the future. The primary long-term goal of The Strategy is to achieve critical loads (or the threshold level) for acid deposition across Canada.

39. Current priorities under *The Strategy* include formalizing the new targets for emission reductions in eastern Canada through federal-provincial agreements, pursuing further U.S. emission reduction commitments, and conducting further scientific work on the role of nitrogen in acidification.

WHAT YOU CAN DO

40. Sulphur dioxide and nitrogen oxides are the main pollutants that cause acid rain. These pollutants are emitted largely by the combustion of fossil fuels. Reducing the use of fossil fuels therefore, including the use of electricity generated by coal- and oil-fired power plants, will help reduce acid rain-causing emissions.

41. For more specific suggestions on what you, as an individual, can do, please see: *http://www.ec.gc.ca/acidrain/done-you.html*
Here are a few examples:

In the home

- Install a low-flow showerhead.
- Run the dishwasher and washing machine only with a full load.
- Hang-dry the laundry.
- Buy energy-efficient appliances.

Transportation

- Walk, ride your bike or take a bus to work.
- Have your engine tuned at least once every six months.
- Check your car tire pressure regularly.
- Drive at moderate speeds.