This document is made available electronically by the Minnesota Legislative Reference Library
as part of an ongoing digital archiving project. http://www.leg.state.mn.us/lrl/lrl.asp

METEOROLOGICAL CONSIDERATIONS AFFECTING DISPERSION OF ATMOSPHERIC CONSTITUENTS IN THE DULUTH AREA

Prepared by
Bruce F. Watson
in cooperation with the Regional
Copper-Nickel Study
Minnesota Environmental Quality Board

February, 1979

The climate of Duluth and the area surrounding Lake Superior is unique in the world, with the sole exception of the area around Lake Baikal in Siberia. The reasons for this are primarily that each of these lakes contain a tremendous amount of water, and that the water in the lakes is contained--not subject to seasonally varying currents as is true with the oceans. The magnitude of the uniqueness of Lake Superior and Lake Baikal can be appreciated in that together they contain nearly half of the liquid fresh water in the world--with each of the two lakes being nearly equal in volume. They are truly super-lakes. Lake Superior is aptly named.

Because of the great amount of water in Lake Superior, the bulk of the Lake remains at very near $4^{O}C$, the temperature of the maximum density of water. Only about once every 20 years does the Lake freeze over. In most years, the frozen portion of the lake is very small, confined to the shoreline. As a consequence of this, the lake exerts a very special influence on its environs.

For one, it is an important source of moisture in the winter, bringing heavy amounts of precipitation to the White River region of Ontario, the hill areas of the upper Peninsula of Michigan, the Gogebice Range of Wisconsin, and the ridge line of Minnesota extending just west of Duluth through Isabella to the Ontario border. The lake's moisture is fed into the air by evaporation, and then extracted from the air by clouds, produced by uplift, which subsequently precipitate. In summer the lake is a region of sinking air, so that the immediate margin is appreriably drier than the hinterland.

Temperature and resulting air movement effects are also controlled to an extreme degree. In the warm season, the lake is nearly always colder than its environs, by both day and night, so that airflow in the absence of an adequately strong pressure gradient is directed away from the lake to the beaches. The flow, however, is impeded by the high ground which impedes outflow, resulting in a common situation of a mound of cold air sitting over the lake, very often encroching on the beach regions. Tremendous inversions are created as warmer air, less dense than cold air, flows over the lake air. The commonness of the situation is enhanced by the fact that summer pressure gradients are usually weak. Clear skies rule in the sinking air over the lake and even mighty thunderstorms are killed as cold air is ingested.

Pressure gradients provide the main component of air movement on the earth. Air moves from areas of high pressure to areas of low pressure due to the effects of gravity--the weight of the overlying mass of air of the high pressure area pushes the air outward, with the ultimate direction of movement being influenced also by the rotation of the earth and friction.

However, density differences also cause air to move in the direction from high density to low density. Temperature, in the real atmosphere, is the greatest controller of density. Because of the tremendous temperature differences often present around Lake Superior, density circulations are important--indeed, when pressure gradient is weak, density flow becomes the controlling factor to air movement. At nearly all times, however, it is an important modifier of the large-scale pressure gradient flow.

In weak pressure gradients, air flow to or from the lake is mostly generated by density differences--cold air being denser than warm air. Under the influence of gravity, the cold air moves to underlay warm air at the same level. In summer, when the lake air is denser, the high ground around the lake serves as a dam to the cold air. The St. Louis River valley cuts through the high ground dam, so flow in summer must often be directed up the valley. Rising air along the warm high-ground dam, however, will draw in lake air along the slope.

In winter, the density flow is reversed with cold air flowing down the slopes onto the lake, generating a rising air region over the lake.

Because of the complex shape of the topography in the Duluth area, there is a tremendous variation over the region in the frequency of the direction and speed of the air flow from the different directions. It would take a large-scale study to fully define flow in the region, although a smaller study could shed much light on the complex flow so important to air quality. Because of the intricate pressure-density-wind flow relationships, the solution to understanding the problem by modeling or wind tunnel experiments is impractical.

In the cold season, the lake is nearly always warmer than its environs by day and night alike. The result is an inflow of air to the lake in the absence of adequately strong pressure gradients. This, along with the rising air currents generated by warm lake air, results in heavy cloudiness over the lake. However, in the winter the pressure gradient component of the wind is usually significantly greater than the lake-to-land density component, with the result that onshore winds are usually found on one side of the lake, and offshore winds on the opposite side. The Minnesota high ground running through Isabella receives maximum snow when the general wind direction falls between east and south. In many of the cases, rain falls the first 10 or 20 kilometers inland because of the warmth of the lake air. Often times the area along the lake is free of snow when depths at Isabella are one or two meters, or more.

There are two brief periods in the year when the land and water diurnally alternate at being the colder. The periods are found around the two weeks centered on April 10 and October 28. Thus, from late March through late April and from mid-October to around November 12th land and lake density wind systems may operate to some extent. However, the density wind systems are impeded in the spring period by the time of the year with the strongest pressure gradient winds.

Violent winds may move off the lake in the Duluth area when low pressure systems with warmer-than-lake air approach from the southwest. In such a situation, the density wind component is added to the pressure gradient component to produce a strong northeast wind. To add to the velocity, the smooth lake surface, low in roughness and frictional effect on the air, enables the northeast wind to gain great momentum.

In summer, the lake has a most important effect on air quality in Duluth (and along the north shore). The lake air is then relatively cold and dense, and being in a depression, mixes very poorly with warm air moving in aloft. Rather, the air aloft tends to flow over the lake air, producing super inversions, often exceeding values of $10^{\circ}C$ from the lake level to the top of the ridge. In summer, the inversion is present approximately two-thirds of the time.

In winter the overriding effects on air quality are largely governed by the large scale pressure systems which create inversions aloft when pressure gradient becomes weak in the Duluth area. The lake acts to make modifications in some situations, but since strong northwesterly pressure gradient winds prevail in the cold season, the effects of the lake in Duluth itself are damped.

Air flow in the Duluth area should be considered for further study because of the complex relationships that are involved.