Heavy Water—A Natural Tracer

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Abstract

All naturally occurring water contains a small percentage of isotopically heavy water molecules. The processes of vaporization and condensation affect the concentration of the heavier water molecules. The changes in concentration of heavy water molecules have been used to study the origin of winter storms, to determine evaporation rates from lakes, and in studies of water movement.

Introduction

Three common heavy water molecules occurring in nature are HDO, HTO, and H_2O^{18}. HDO and H_2O^{18} are stable (non-radioactive) isotopic forms of water and comprise 0.015% and 0.20%, respectively, of naturally occurring water. HTO is radioactive and emits low energy beta radiation. A small amount of HTO occurs naturally, but the use of nuclear devices has increased the amount of HTO in the hydrologic cycle.

The "heavy water" associated with nuclear projects, D_2O, is not important in natural water supplies as it tends to break down and cause the formation of HDO.

Scientists usually work with the natural or bomb-introduced concentrations of heavy water. But, sometimes it is possible to utilize small amounts of artificially concentrated heavy water for a specific study. The concentrations of HDO or H_2O^{18} in a water sample are usually measured with a mass spectrometer. A liquid scintillation counter must be used to measure HTO.

The use of isotopically heavy water as a tracer of water movement is best explained through a series of examples. First, two concepts must be explained.

The vapor pressure of heavy water is slightly less than the vapor pressure of H_2O^{16} at the same temperature. This will cause a slight fractionation to occur whenever the processes of evaporation or condensation takes place. During evaporation the heavy molecules tend to become concentrated in the liquid phase while the vapor phase has a higher percentage of light molecules. During condensation the heavy molecules will tend to condense out more rapidly causing the first condensate to be enriched with heavy molecules and the remaining vapor to have a greater percentage of light molecules.

The heavy water content of a sample is often given as the per cent deviation of the heavy isotope content of the sample relative to the heavy isotope content of average ocean water. A sample of precipitation with a HDO content reported as −7% contains 7% less HDO molecules than ocean water, namely a reference water (SMOW, standard mean ocean water, as recommended by Craig (1)). Precipitation is usually isotopically lighter than ocean water.

Examples

The change in the heavy isotope content of a body of water can be used to determine the evaporative loss from that body of water. The water entering a large lake has an average HDO content of −8.3% and the discharge from the lake has a HDO content of −7.6% (Fig. 1). These measurements indicate that fractionation during evaporation caused an enrichment of the heavy isotope content of the lake water. A knowledge of the amount of increase of HDO in the lake and the vapor pressures of H_2O and HDO allows one to calculate that 15% of the original volume of water has evaporated.

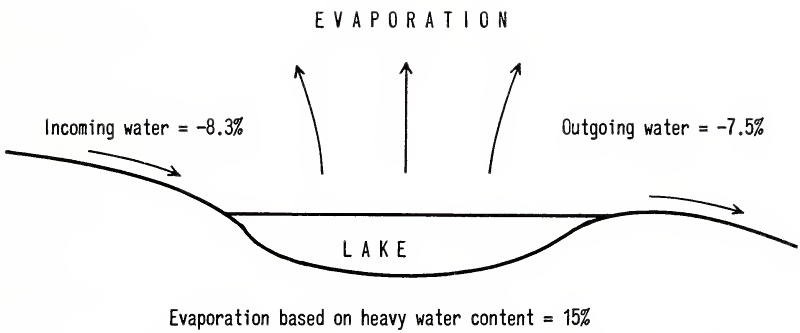

FIGURE 1. *Diagram of heavy water—evaporation relationships of a lake. The amount of evaporation from a lake can be determined by comparing the HDO content of the incoming water with the HDO content of the outgoing water. Diagram after Friedman* et al *(1964).*

On a larger scale, we can follow the changes in the HDO content of the moisture in a storm system (Fig. 2). The HDO (and H_2O^{18} content of precipitation is controlled by the amount of condensation and the temperatures at which this condensation takes place. The moisture evaporating from the ocean will be isotopically lighter than the ocean water. As the processes of evaporation and condensation are opposite, the first condensate from the air mass will have about the same heavy isotope content as the original ocean water. As the air mass moves farther inland it will become depleted in heavy molecules and the resulting precipitation will be isotopically lighter. Snow is usually isotopically lighter than rain and high altitude precipitation is usually lighter than low altitude precipitation.

In California, isotope measurements have been used as an indication that during a winter of heavy snowfall there may have been a change in circulation patterns not detected by the conventional meteorologist. An extensive series of HDO or H_2O^{18} measurements should help the meteorologists obtain some quantitative information on the processes

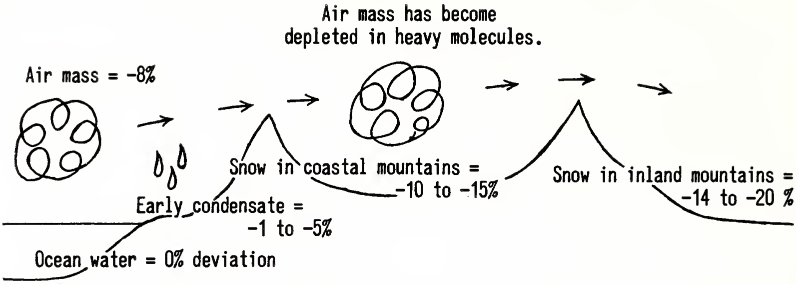

FIGURE 2. *Diagram of the variations in the HDO content of the precipitation as an air mass moves inland. Preferential condensation of the heavier molecules causes the moisture in the air mass to become isotopically lighter as it travels farther inland.*

occurring in the atmosphere. The main problem is a lack of sufficient available data on the heavy isotope content of precipitation.

The variation in the heavy isotope content of precipitation may be used in some hydrologic studies. Perhaps a city near a mountain range is dependent upon ground water for a public water supply and the city would like to determine the recharge area of the aquifer they are using (Fig. 3). Basic information could be obtained by measuring the heavy isotope content of the ground water and comparing it to the heavy isotope content of precipitation in various areas. If the well water was isotopically light, it could be assumed that the recharge area was high in the mountains.

The uses of the isotopically heavy forms of water are not limited to those just mentioned. HDO has been used in snowmelt studies, to

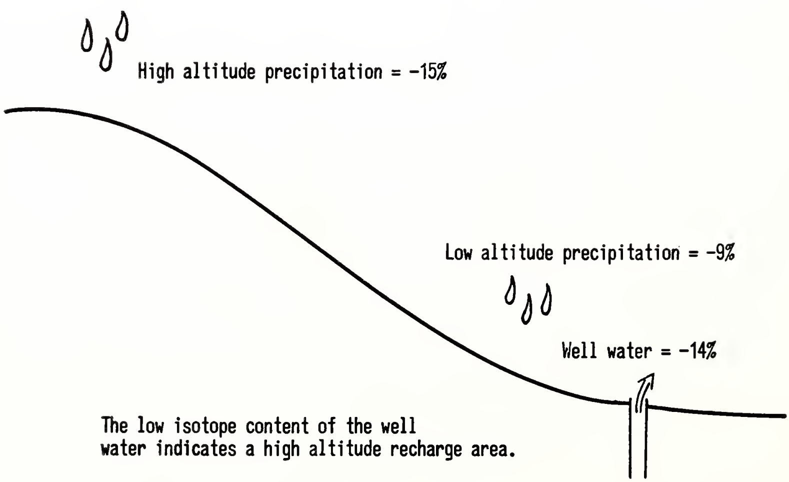

FIGURE 3. *Diagram of how the HDO content of water of unknown origin can be used to indicate which of several areas is the actual source of the water.*

help date layers of ice in glaciers, to trace the movement of soil moisture, and in biological studies. The list of references that follows expands on several of the applications. Friedman *et al.* reviewed much of the work done with HDO (3). Dansgaard reviewed some of the work done with H_2O^{18} (2).

There are several advantages to using heavy water as a tracer of water movement. Water is actually being used to trace water, so there is little problem with the selective absorption of an introduced tracer. HDO and H_2O^{18} are naturally occurring and are not radioactive so people will not be upset by their use. The slight fractionation upon evaporation and condensation allows a quantitative measurement of many hydrological and meteorological processes.

There is one disadvantage. The cost of sample analysis (currently about $50 per sample) is high. This has restricted the accumulation of large amounts of data and background knowledge about HDO and H_2O^{18} in the hydrologic cycle.

Literature Cited

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