Isotope hydrology: an overview

By Lucía Ortega and Laura Gil

Isotopic techniques enable scientists to understand the components of the water cycle, helping them better assess the quantity, quality and sustainability of water.

In the water cycle, groundwater is the least understood component. Scientists use naturally occurring isotopes as tracers to find out whether groundwater is being replenished, where it comes from, how it moves underground and if it is vulnerable to pollution and changing climatic conditions.

Water from different places has different isotopic signatures or unique 'fingerprints'. Scientists use these 'fingerprints' to track the movement of water along its path through the entire water cycle: from evaporation, precipitation, infiltration, to runoff and evapotranspiration, then returning to the ocean or the atmosphere, and repeat.

But what are isotopes?

A chemical element, like hydrogen, is made entirely from one type of atom. The type of atom comes in different varieties. These varieties are isotopes, and they all share the same chemical characteristics and number of protons and electrons, but a different number of neutrons. The difference in the number of neutrons makes each isotope weigh differently, and this weight difference is key for hydrological studies.

Isotope hydrology uses both stable and unstable isotopes. Stable isotopes are non-radioactive, meaning they don't emit radiation. Unstable isotopes (or radioisotopes) undergo radioactive decay and are therefore radioactive.

Here is a simple overview of how the science of isotope hydrology works.

Origin and transport of water in the water cycle

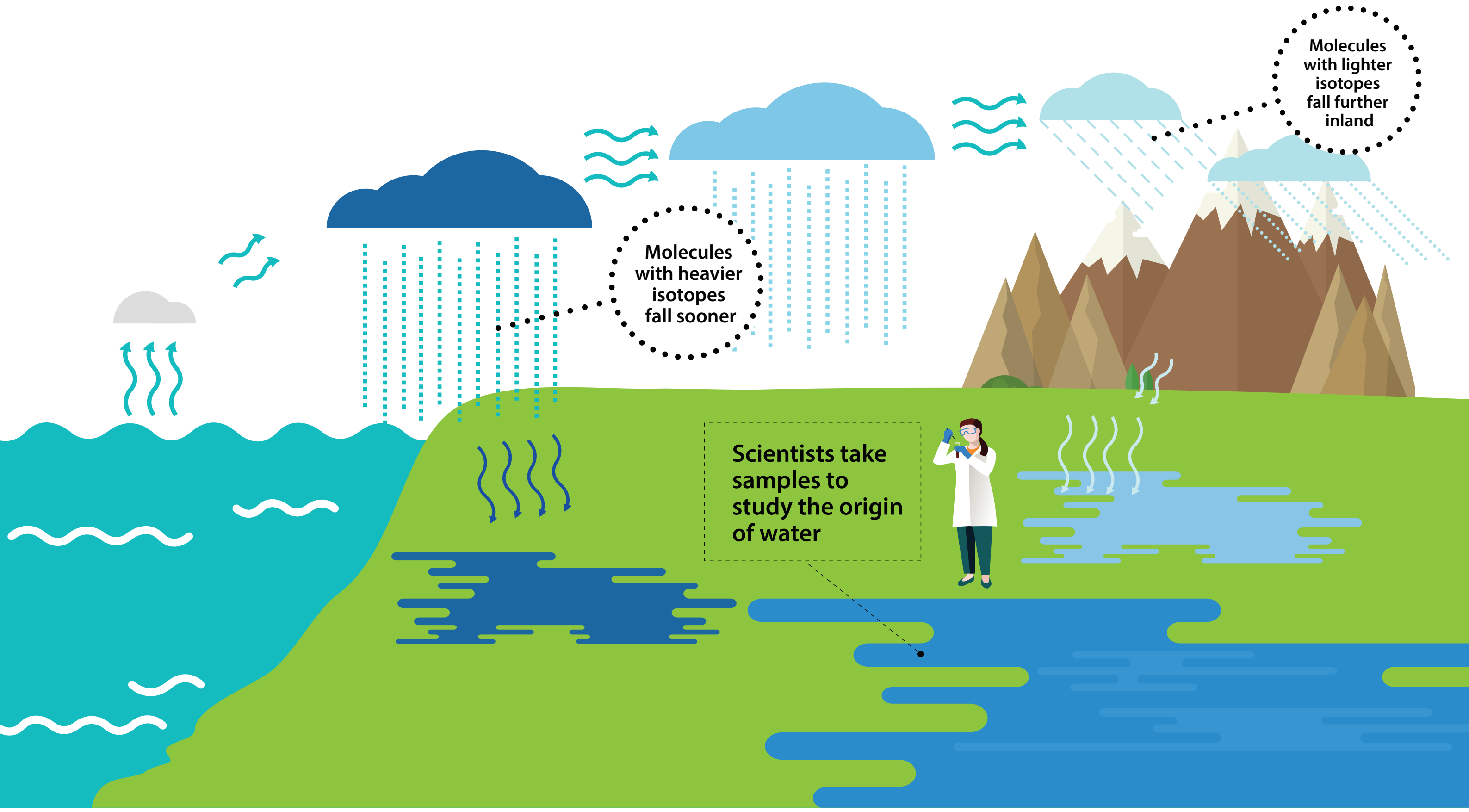
Every water molecule (H_2O) is made of two hydrogen (H) atoms and one oxygen (O) atom, but these are not all the same: some atoms' isotopes are lighter and some are heavier. Scientists use precise analytical equipment to measure these tiny weight differences in water samples. Why?

As water evaporates from the sea, the molecules with lighter isotopes tend to preferentially rise, forming clouds with specific isotopic signatures. These clouds have a mix of water molecules that fall in the form of rain. The water molecules with heavier isotopes fall first. Then, as the clouds lose these heavy isotopes and move further inland, lighter isotopes fall in a greater proportion.

As water falls to the earth, it fills lakes, rivers and aquifers. By measuring the ratio between heavy and light isotopes in these water bodies, scientists can decipher the origin and movement of water.

Groundwater age

Isotopes are the most direct and powerful tools available to estimate the age, vulnerability and sustainability of water resources. When the groundwater in an aquifer is 'old', this means that the water flow is slow and that the aquifer can take a long time to replenish. On the contrary, young groundwater is easily and quickly renewed by rainwater, but can also be easily affected by pollution and changing climatic conditions. Understanding water's age gives scientists and governments a good idea of how quickly aquifers are being replenished.



In hydrology, some naturally occurring radioactive isotopes present in water, such as tritium (^{3}H), carbon-14 (^{14}C) and noble gas radioisotopes, are used to estimate groundwater age. This age can be from a few months up to a million years.

Because these isotopes decay over time, their abundance decreases as the years go by. Higher values mean 'younger' water, while lower values mean 'older' water. For example, groundwater with a detectable amount of tritium may be up to around 60 years old, whereas groundwater with no tritium must be older. While tritium is used for dating groundwater that has been recently recharged, i.e. that is younger than about 60 years, carbon-14 is used for water up to 40 000 years of age and krypton-81 for water that can be up to a million years old (see page 21).

Water quality

Pollutants in surface water and groundwater come from various sources — such as agriculture, industry, or human waste — or may be present naturally due to geochemical processes taking place in aquifers.

Agriculture, industry and households each produce different kinds of pollutants. By studying the chemical and isotopic composition of a pollutant, scientists can determine its origins.

For example, nitrate ion (NO_3^-), which is made up of nitrogen and oxygen, is a common pollutant. Nitrogen has two stable isotopes of different weight. This difference in weight is not the same in human waste and in fertilizers. Fertilizers use nitrogen from the air, whereas humans and animals go through a biological process that changes nitrogen into different forms. As a result, pollutants derived from various sources can be identified based on these isotopic weight differences.

Knowing the origins of pollutants is the first step in addressing problems with water quality. The data isotope hydrologists gather are useful to policymakers in their strategic planning and management of water resources.

The IAEA supports scientists from around the world by promoting the use of isotope techniques, transferring scientific know-how to local water professionals. To learn more about how we do this, read on.