Water travelling through hydrological landscapes (such as catchments) can take a variety of times before reaching a neighboring stream. In other words, water in streamflow has a distribution of ages. Travel time distributions (TTDs) characterize the water ages in catchment outflows and are fundamental descriptions of how catchments store and release water that entered days, months, and years ago as precipitation. The overarching objective of my PhD work was to understand what controls the shape and time variability of the streamflow TTD, and how it can be determined from tracer data. This was achieved with a combination of theoretical investigations, experimental (field and laboratory) work, and modeling efforts to go beyond previous limitations. Isotopic tracers (2H, 18O, and 3H) were collected at high frequency (sub-daily) in precipitation and streamflow of experimental catchments in Luxembourg over 2 years. Improved parameterizations of streamflow TTDs and novel analytical models were proposed based on theoretical and experimental grounds, notably using the acquired isotopic data set in Luxembourg. A method to leverage water age information from a dual-isotopic approach (using both 2H and 3H) was suggested to clarify an emerging misunderstanding about the limitations of the stable isotopes of O and H compared to 3H. This work showed that streamflow TTDs can have more varied shapes and more intricate variability than hypothesized in studies over the last decade. It was also shown that only multiple tracers used jointly such as 2H and 3H can help to decipher the multiple peaks in the TTDs and their long tails associated with old water. TTDs are essential for a better management of water resources because they give insights about water flow paths and velocity in hydrological systems, and they are key to gear hydrological models towards water quality simulations. The more efficient and more accurate determination of unsteady streamflow TTDs from isotopic tracers, and their improved parameterization proposed in my thesis thus pave the way for a holistic understanding of water flow paths and water quality in catchments. The research questions tackled in my PhD work also lead to new research interests at the interface between biogeochemistry and hydrological modeling.