Understanding water transit times in headwater streams using tritium: a unique southern hemisphere opportunity

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Documenting the timescales over which rainfall is transmitted through catchments to streams (the transit time) is critical for understanding catchment hydrology and for the protection and management of river systems. However, despite its importance, transit times remain poorly understood in many catchments. By contrast with lowland streams that flow across alluvial sediments, headwater catchments that are developed on indurated or crystalline rocks may not be linked to well-developed groundwater systems. The observation that many headwater streams continue to flow over prolonged dry periods indicates, however, that these catchments contain stores of water in soils, weathered rocks, or fractures with retention times of at least a few years. At times of low streamflows, much of the water in streams and rivers is likely derived from long-term stores such as groundwater. Less well understood is the extent to which older water rather than event water (i.e., that derived from recent rainfall) contributes to higher streamflows. In some catchments, rainfall appears to displace water from the soils and regolith and increase groundwater inflows to streams due to hydraulic loading. In these cases relatively old water may still contribute a significant volume of water to the river at higher streamflows.

Tritium (^{3}H), which has a half-life of 12.32 years, may also be used to determine transit times of relatively young (<100 years) groundwater into streams. ^{3}H is part of the water molecule and its abundance in water is only affected by initial activities and radioactive decay, which makes it an ideal water tracer. The ^{3}H activities in rainfall have been measured globally for several decades and may be used to define the input of ^{3}H into the catchment. Rainfall ^{3}H activities have a distinct peak in the 1950s to 1960s due to the production of ^{3}H in atmospheric nuclear tests (the so-called "bomb pulse"). Traditionally, the propagation of the bomb pulse has been used to trace the flow of water recharged during this period because single measurements of ^{3}H activities yielded non-unique estimates of transit times. However, because bomb pulse ^{3}H activities in the southern hemisphere were several orders of magnitude lower than in the northern hemisphere, ^{3}H activities of remnant bomb pulse water in the southern hemisphere have now decayed well below those of modern rainfall. This situation results in unique transit times being estimated from single ^{3}H measurements, which in turn permits the transit time of water contributing to streams at specific flow conditions to be determined. This presents a unique opportunity to use ^{3}H to estimate residence times of southern hemisphere catchments that will not be possible for several years in the northern hemisphere.

Research projects led by Prof. Ian Cartwright (Monash) together with Uwe Morgenstern (GNS, New Zealand) and Dr Harald Hofmann (University of Queensland) have been using ^{3}H coupled with lumped parameter flow models to estimate catchment transit times in several catchments in southeast Australia. Transit times in headwater catchments at baseflow conditions vary from a few years to several decades and at higher streamflow conditions there is still a significant fraction of "old" water contributing to the river. The observation that the water contributing to these headwater streams has mean transit times of years to decades implies that these streams are buffered against rainfall variations on timescales of a few years, and most of these streams continued to flow through the 1996-2010 Millennium drought. However, the impacts of any changes to landuse in these catchments or longer-term rainfall changes may take years to decades to manifest itself in changes to streamflow or water quality.

The first study, addressing mean transit times in the upper Ovens catchment in Victoria was published in HESS in August 2015 (doi:10.5194/hess-19-3771-2015).

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Figure 1. The Upper Ovens Catchment

Figure 2. Mean transit times in subcatchments of the Upper Ovens