



Radon-222 as a tracer of surface water – groundwater interactions

Estimating groundwater discharge to tropical rivers using radon

The rivers of northern Australia show very large hydrographic variations throughout the year in response to extremes in rainfall between wet and dry seasons.

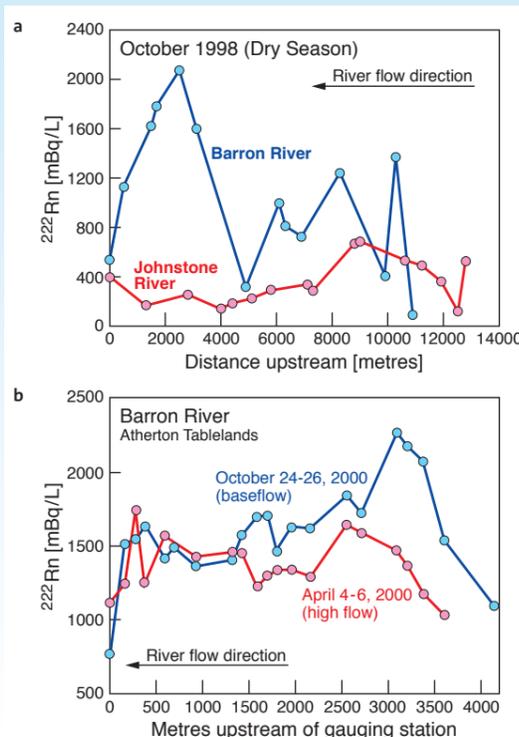
Because of the impetus to develop the supposed abundant water surpluses in the tropics, a good understanding of the extent of interactions between the groundwater and surface water resources in these regions is paramount. Exploitation of groundwater has the potential to impact surface water baseflow and in turn threaten reliable habitat of a range of aquatic animal species in the dry season.

Radon and other chemical tracers are particularly useful in tropical regions where river baseflow in the dry season is almost entirely groundwater supported. Over the past fifteen years several studies using radon-222 have been used to identify points along various northern river transects where there is preferential input of groundwater as determined by elevated ^{222}Rn concentrations.

The radon concentrations measured in two rivers draining parts of the Atherton Tablelands of far north Queensland show elevated concentrations above the background level of about 80 mBq/L along their entire 14 km stream (Figure 2a). The peaks and valleys in the Barron

River transect suggest preferential flow at various points and losses along rapids or other regions not well connected to the weathered basaltic aquifer system. The Johnstone River shows a much more subdued longitudinal profile where groundwater may discharge evenly across the entire reach. Comparison

of wet and dry season results for the lower reaches of the Barron River prior to entering Lake Tinaroo (Figure 2b) shows similar radon patterns between the wet and dry season results. The latter tends to be significantly higher but not as much as might be expected given the three order of magnitude greater surface water discharge during the tail of the wet season (April) compared to baseflow conditions in October. The results suggest that in both wet and dry season the river water is composed predominantly of displaced groundwater.



LEFT Upper panel a): Reconnaissance of radon concentration in the Barron and Johnstone Rivers of far North Queensland towards the end of the 1998 dry season. Lower panel b): Detailed radon transect for the Barron river of North Queensland in the wet and dry season of 2000. (data from Herczeg, AL 2001. Seasonal changes in groundwater flow-paths to tropical rivers traced with ^{222}Rn and stable isotopes of water. Applied Isotope Geochemistry (AIG-4) Conference, Pacific Grove, Ca., USA, June 2001).

FURTHER READING AND LINKS

Cecil, LD, and Green, JR, 2000. Radon-222. In P.G. Cook and A.L. Herczeg (eds.) Environmental Tracers in Subsurface Hydrology. Kluwer Academic Press, p..

Kraemer, TF and Genereux, DP 1998. Applications of Uranium- and Thorium-Series Radionuclides in Catchment Hydrology Studies. In: C Kendall and JJ McDonnell (Eds.), Isotope Tracers in Catchment Hydrology, Elsevier, Amsterdam, pp. 679-722.

CSIRO: www.csiro.au/services/isotope/

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

YOUR CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

FOR FURTHER INFORMATION

Megan LeFournour
Isotope Analysis Service
CSIRO Land and Water
t +61 8 8303 8747
e megan.lefournour@csiro.au
w www.csiro.au

Radon-222 is produced naturally in aquifers as a by-product of the decay of uranium. Its concentration in groundwater is much higher than in surface water. It can be used to estimate where, and how much, groundwater is entering surface water bodies. It is also useful in the reverse case where surface water infiltrates to recharge groundwater. The information helps water managers to identify areas that need to be protected to maintain groundwater dependent ecosystems.

Understanding how groundwater and surface water interact is becoming increasingly important for the management of these resources. In the past, the two were treated as completely independent resources.

Now it is accepted that the two are always connected in some way, and allocation of one of the resources needs to be cognizant of the long-term impacts and consequences of over-use on both water reservoirs. In Australia, overuse of groundwater resources has resulted in the loss of some artesian springs as well as some perennial streams and wetlands.

Estimating the location and rate of groundwater discharge to surface water bodies is difficult to do using conventional hydrological methods because of very low hydraulic gradients and large variations in hydraulic properties within and near rivers or lakes. Groundwater and surface water often have different chemical and isotopic properties and this property may be exploited to trace mixing and interactions between the two. The natural isotope radon-222 is particularly suited for this because concentrations in groundwater are often two to three orders of magnitude greater than in surface water. Thus, even a small amount of groundwater input to rivers can be detected by sampling the surface water at a number of locations.

In the absence of groundwater input, surface waters have a low background radon concentration caused by release from stream sediments (hyporheic exchange). In the absence of large external inputs, radon concentrations in surface water remain low because it rapidly escapes to the atmosphere, especially in turbulent conditions. Often groundwater tends to discharge to surface waters along

specific zones such as faults or fissures, which accounts for the sharp spikes in radon activity often found in streams.

How does the technique work?

Essentially, the radon technique for evaluating groundwater and surface water exchange is possible because groundwater generally has a higher radon concentration than surface water. It is like a natural “dye” in which the groundwater with its very high radon is easily detected above the background radon in the surface water body.

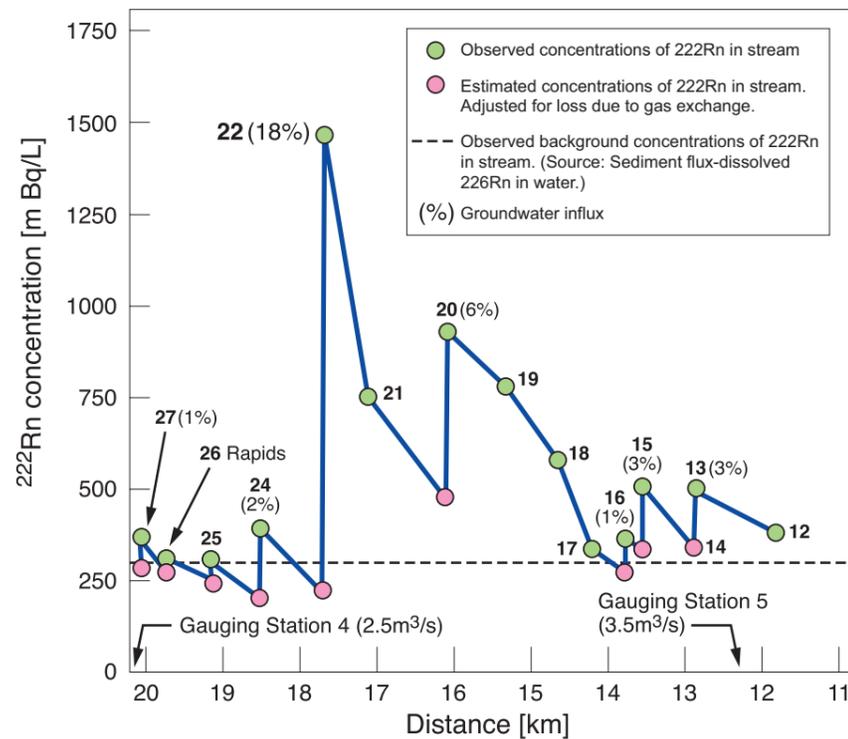
Radon-222 has a half-life of 3.8 days, so it is ideal for evaluating processes that occur on time scales of up to 3 weeks. Being a noble gas, it is chemically inert, therefore its concentration is governed only by production, transport and decay. The production of radon in groundwater is determined by how much uranium and radium is within the aquifer minerals and the physical properties such as porosity and grain size. It reaches steady-state concentration in groundwater within a few weeks. Surface water that has no groundwater input will generally have radon concentrations of <0.1 Bq/L (Becquerel per litre) while groundwater is generally in the tens to hundreds Bq/L.

The procedure for sampling of water for radon analysis is also straightforward. Essentially, all that is required is to collect water in a 1.25 L soft drink bottle with minimal exposure to the atmosphere. These bottles can either be sent to our laboratories or radon extracted from them in the field, which takes about 10 minutes. Radon is also very easy to measure by decay counting techniques. There are even some commercially

CSIRO's Isotope Analysis Service supports the research projects of CSIRO and provides an effective and readily-accessible service for hydrology and environmental communities, including Government and private sectors, to obtain measurements of environmental isotopes and trace gases. The service undertakes approximately 3000 analyses each year for Australian and international clients. The results of these analyses guide informed natural resource management decisions.

available detectors that can provide radon concentrations in real time in the field, at the cost of lower detection limit and precision than for the laboratory methods.

The most common way that radon is used is by sampling along longitudinal stream transects (or ‘run-of-river surveys’). In lakes and wetlands radon is also sampled at various locations across the water bodies. Zones of high radon concentration relative to other ‘dead’ zones, is indicative of preferential inflow of groundwater to the surface water. An example shown in Figure 1 is from one of the earliest studies done using radon to detect locations of groundwater inflow into a river in Puerto Rico that is incised into a limestone aquifer system. The “spikes” in radon concentration at various sampling points along the stream transect indicate the zones of groundwater input. It is possible to estimate the fraction of groundwater contributing to stream discharge at these points if the radon concentration in groundwater is known, and if the stream discharge is known. One can see from Figure 1 that even as little



ABOVE Figure 1: An example of Radon-222 transect along a river reach (Data from Ellins, KK, Roman-Mas, A. and Lee, R., 1990. Using ^{222}Rn to examine groundwater/surface discharge interaction in the Rio Grande, De Manati, Puerto Rico. *J. Hydrol.*, 115: 319)

as a few percent of groundwater can be detected, and fractions of >10% easily determined by this method.

Advantages and limitations

As discussed above, a major advantage of using radon for studying surface water and groundwater interactions is the large contrast between very high concentrations of radon-222 in groundwater compared with surface water. This means it is possible to detect as little as a few percent of groundwater contribution to stream flow.

Another advantage is that as stream flows further downstream, radon eventually escapes to the atmosphere by gas exchange or decreases by natural radioactive decay. This “resets” the surface water, which means other zones of groundwater input can be detected along a stream transect. Other tracers such as chloride and stable isotopes persist in surface water and mask groundwater input at further locations downstream.

Methods for sampling and analysis of radon are fairly straightforward and no more difficult than say a field alkalinity or oxygen titration. Sampling for radon in the field takes about 20 minutes per sample, including collection of water and field radon extraction. The main constraint is to avoid aeration and subsequent radon loss during sampling. There are several decay counting methods that are either laboratory or field based. For price information see the homepage of CSIRO Isotope analysis Service (IAS).

Radon’s short half-life means that it needs to be counted as soon as possible after sampling. If a sample is stored for two weeks the signal decreases by a factor of ten and the analytical uncertainty increases as the radon concentration approaches background. The short half-life also means that ^{222}Rn is not suitable for tracing processes longer than about 3 weeks. This is often about the right time scale for near stream surface water groundwater exchange.

Naturally ^{222}Rn is produced by ^{226}Ra , therefore storing a water sample for more than four weeks and re-measuring the ^{222}Rn which is now in radioactive equilibrium with ^{226}Ra , will allow measurements of ^{226}Ra as well, with a detection limit around 5mBq/l.



Sampling remote tropical rivers in the dry season by helicopter. Image by Glenn Harrington.

FAQs

Q: How are samples collected?

A: There are a number of sampling and measurement techniques available and the choice depends on circumstances and availability. The CSIRO laboratories use standard plastic soft drink bottles, available through supermarkets, for extraction of radon. These are used for both groundwater and surface water samples. Water samples are collected in 1.25 L plastic soft drink bottles. The bottles can either be sent directly to the CLW laboratory. Alternatively it can be shaken with about 20 ml of mineral oil to extract radon and only the vial containing oil sent to the laboratory (contact the CLW lab prior to your field trip to obtain, vials and instructions). The vial containing the oil is placed in a liquid scintillation counter capable of analyzing alpha emitting radionuclides for determination of ^{222}Rn activity. Because of the short half-life of radon (3.8 days), the samples should be counted as soon as possible. The mineral oil scintillant is safe to be mailed through the post or shipped via courier to the CSIRO laboratories. Further details are given in: Leaney, FW and Herczeg, AL, 2006. A rapid method for radon analysis in surface water and groundwater, *Limnology Oceanography Methods*, 4, 254-259, available at: <http://www.aslo.org/lomethods/free/2006/0254.pdf>

Q: How soon can I expect results?

A: The CSIRO laboratory will count the radon samples as soon as practicable upon receipt in the lab. Results for ^{222}Rn analyses should be available within two weeks from receipt of samples. Results for ^{226}Ra analyses require an extra 2 months to allow the ^{222}Rn to establish radioactive equilibrium before analysis.



LEFT Transferring mineral oil scintillant from a plastic sample bottle into a LPE vial.

Q: Can the scintillant be sent through normal postage and couriers?

A: The scintillant supplied is a mineral oil cocktail that is not volatile and is safe to ship through regular postal or courier services. Nevertheless, samples should be packed carefully to avoid breakage and loss of samples in transit.

Q: How much does it cost?

A: For actual price information see the homepage of CSIRO Isotope analysis Service (IAS) <http://www.clw.csiro.au/services/isotope/>

Q: Are there any alternative methods?

A: There are several other tracer methods that can potentially detect groundwater input to streams, however they tend not to have the dynamic range in concentrations that is characteristic of radon.

For example the salinity of groundwater is usually much higher than surface water, but because of dilution it is not as easily detected as radon, nor can it be used easily at different locations (see section above). Measurements of ^{222}Rn , however, can be complemented by other tracers like ^4He , CFCs/SF₆ and $^3\text{H}/^3\text{He}$ to investigate the origin and flow rates of the groundwater system. See the corresponding fact sheets for further information.

Q: Is radon-222 dangerous to handle?

A: Radon is perfectly harmless in the natural environment because it escapes quickly to the atmosphere. It is only a potential health hazard in confined spaces for extended periods such as uranium mines or in well-sealed houses in parts of Europe and North America.