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Isotope Studies on Mechanisms of Groundwater Recharge to an Alluvial Aquifer in Gatton, Queensland, Australia

J K DHARMASIRI[1], LIDIA MORAWSKA[1] AND JOHN HILLIER[2]

1. Centre for Medical & Health Physics, Queensland University of Technology, P O Box 2434 Brisbane, Qld. 4001.
2. Department of Natural Resources, 80, Meiers Road, Indooroopilly, Qld. 4068.

SUMMARY. Naturally occurring isotopes, ^{2}H, ^{3}H, ^{18}O, ^{13}C and ^{14}C have been used to assist in understanding recharge mechanisms to groundwater in an alluvial aquifer in Gatton, Queensland, Australia. The stable isotopes clearly indicated the source origin of groundwater as the seasonal infiltration of creek flows. The Crowley Vale irrigation area, a sub-section of Gatton, is recharged by infiltrating rain water through sandstone outcrops outside the alluvium. Natural tritium confirmed creeks as the active recharge source in general. Residence times deduced from ^{14}C measurements showed older water in the Crowley Vale area. Soil moisture movement studies using tritium tracer indicated very small tracer movement amounting up to 50 mm of infiltration through top soil per annum.

1. INTRODUCTION

Gatton, (152° 20'E, 27° 33'S) about 80 km west of Brisbane, is located on the flat alluvial flood plain of the Lockyer creek, a tributary of Brisbane river. About 40 % of Queensland's vegetable needs are produced here. Cultivation of various crops has been possible over the last 50 years by using groundwater from an alluvial aquifer located about 30 m below the fertile alluvial soils. The area under cultivation is around 12 000 ha with an annual water use of around 47 000 megalitres (1), which is about twice of estimated recharge. Water supply shortages are common, with severe droughts experienced during 1980-81, 1986-87 and 1994-96. Crowley Vale irrigation area (Figure 1) has shown consistent decline of groundwater levels in bores since 1970.

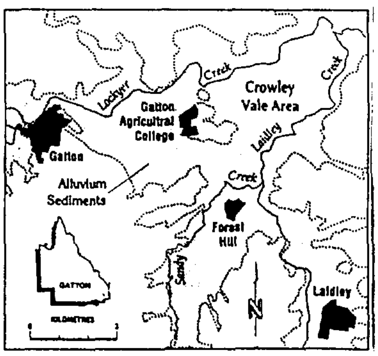

Figure 1 : Location map of the study area in Gatton, Queensland.

The situation has been under investigation (2,3,4) over a long time and several recharge weirs have been built to boost infiltration through creek beds as groundwater levels respond to floods.

The present study, initiated in 1993, was centred around Gatton Agricultural College (Figure 1) covering an area of 72 km^2 of which Crowley Vale area represented 9 km^2. The source of recharge to Crowley Vale irrigation area was not fully understood as the weirs have only a small effect on the groundwater levels. The present study used an isotope approach with naturally occurring isotopic tracers ^{2}H, ^{3}H, ^{18}O and ^{14}C. The stable isotopes are suited for identifying source origins of groundwater as demonstrated in many studies e.g. Issar et al (5), Gat et al (6) and Chambers et al (7). Natural tritium is useful for delineating recent recharge and identifying active recharge areas/ sources as demonstrated in Burdon et al (8) and Kroitoru et al (9). Much older groundwater (older than 50 years) can be identified based on ^{14}C measurements of dissolved inorganic carbon as demonstrated in Munnich et al (10) and Landmeyer et al (11).

Direct infiltration through top soil layers was expected to be small due to the presence of clay layers in the soil profile. In an attempt to quantify this component of recharge, an established technique by Zimmermann et al

(12), Datta et al (13) and Dharmasiri et al (14), was used with tritium as a tracer to follow soil moisture movement in the unsaturated soil zone for the first time in Australia.

2. EXPERIMENTAL METHODS

2.1 Stable Isotope Measurements

A total of 51 irrigating bores were sampled during 1993-94 for stable isotopes within the study area. A submersible pump (5-cm-diameter) was used to pump out a minimum of 3 times the volume of water in a bore and a 20 ml water sample was collected from each bore in a glass bottle with a good screw cap. Initial 30 samples were analysed using mass spectrometry at the Department of Earth Science of the University of Queensland. The subsequent measurements were carried out by the Isotope Analytical Service of the Division of Water Resources, CSIRO, in Adelaide.

A network of three rain water collection stations was set up in 1993 at Brisbane, Gatton and Toowoomba. The first two stations provided rain water samples on a monthly basis until 1996. The station at Toowoomba had to be discontinued in February 1995 due to infrastructure changes. A total of 75 monthly stable isotope measurements were available from this study. The Brisbane station was part of IAEA/WMO global network and a valuable data base was available in Yurtsever et al (15) covering the period 1961-93. The present study added three more years to this data base.

Since the initial collection of three surface water samples from Lockyer and Laidley creeks in 1993, a long dry period prevailed with no further stream flows until November 1995. A total of 30 surface water samples have been measured for stable isotopes.

To understand the stable isotope variation in the short term, another set of 18 bores (from the initial 51) was sampled again in 1994.

A further 12 bores were sampled from outside the study area in sandstone outcrops to the north and south, Sandy creek area, sandstone to the west of Gatton and a few basalt bores around Toowoomba.

2.2 Natural Tritium

A total of 28 bores were sampled in November 1993 for natural tritium measurements. One litre of water was collected in a high density polyethylene bottle with a screw cap which was sealed in the field with paraffin wax. Groundwater samples were measured for natural tritium at the Lucas Heights Research Laboratories (ANSTO) in Sydney using electrolytic enrichment followed by liquid scintillation analysis as explained in Calf et al (16). A second set of 17 bores was sampled in July-August 1994 to determine short term variations. Nine out of the 12 groundwater samples from outside the study area were also measured for natural tritium.

2.3 ^{14}C Measurements

Those bores that did not contain measurable natural tritium were sampled again for ^{14}C measurements at ANSTO by Accelerator Mass Spectrometry. A total of 24 groundwater samples were measured during 1994-95. A litre of pumped groundwater in a high density polyethylene bottle from each bore was sent to ANSTO for analysis.

2.4 Tritium Tracing Experiments

The technique of tritium tracing for unsaturated soil moisture studies has been thoroughly covered by Datta et al (13) and Dharmasiri et al (14). Ten sites were selected for tritium tracer injection and two locations were injected with tritium tracer at each site. A five-point injection technique as explained in Dharmasiri et al (14) was used and 0.74 MBq of tritium as tritiated water was injected at each location in April 1995. Once injected, tritiated water was distributed within a horizontal soil layer of 0.5 m in diameter. First soil sampling was carried out in April 1996. Soil samples were collected at 10-cm intervals using a mechanical auger. Two soil samples were sealed in bottles, one for soil moisture content and the other for tritium measurement. The soil moisture content was determined in the laboratory gravimetrically.

Soil moisture from soil samples were extracted by vacuum distillation at 120°C using an apparatus that can process 10 samples in one run. Collected soil moisture (1 ml) was mixed with a commercially available liquid scintillant (Ultima-Gold from Canberra-Packard, USA) in a glass bottle for analysis in Packard Tri-Carb Mod. 2550 AB/TR Liquid Scintillation

Analyser at the School of Physical Sciences of the Queensland University of Technology in Brisbane. Aqueous tritium was analysed with a background of 17 counts/min and an efficiency of 41 %.

3. DISCUSSION

3.1 Rain Water Stable Isotopes

As Brisbane was part of the IAEA/WMO Global Monitoring Network for isotopes in rain water, the stable isotope data for 1961-93 were used along with data for 1993-96 from this study. The following relationship for $\delta^{18}O$ against $\delta^{2}H$ was obtained (Equation 1).

$$\delta\,^{2}H = 7.75\,\delta\,^{18}O + 12.75 \quad (1)$$

Figure 2 shows the plot of this data with the regression line ($R^2 = 0.93$).

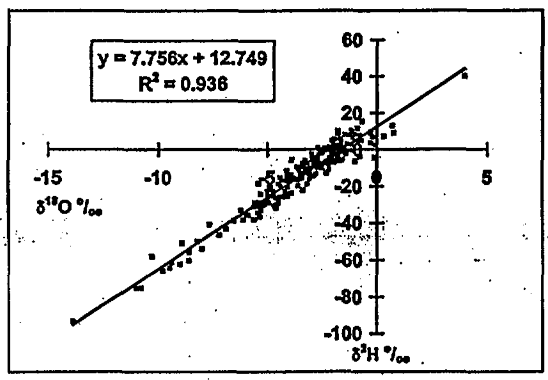

Figure 2 : $\delta^{18}O$ - $\delta^{2}H$ relationship for monthly rain water in Brisbane (1961-96).

The three years of monthly stable isotope data for Gatton shows a similar trend (Equation 2) with the regression equation ($R^2 = 0.90$) given below.

$$\delta\,^{2}H = 7.73\,\delta\,^{18}O + 13.94 \quad (2)$$

These equations are similar to what is generally known as the world meteoric water line by Craig (17) with a gradient of 8 and intercept of 10. Lower gradient and higher intercept for Australian rain water have been explained as caused by evaporation taking place on rain drops during their fall through dry air masses (18). Typically, Australian groundwater recharged by rain water has this effect reflected in the stable isotopes by locating above the Craig's meteoric water line. The weighted mean stable isotope composition (weighted for rain fall amount) using all the data for Brisbane provided values of -4.6 ‰ for $\delta^{18}O$ and -17.8 ‰ for $\delta\,^{2}H$. These values are considered to be close to those of groundwater in Brisbane recharged by rain water over a long period of time. Gatton, being located 80 km to the west of Brisbane at an altitude of 120 m above sea level, is expected to receive more depleted stable isotopes in rain water. In fact, the measured $\delta^{18}O$ values of groundwater in sandstone of Gatton and Withcott (30 km to the west and at an altitude of 270 m) were -5.4 and -5.8 ‰ reflecting the expected trend.

3.2 Stable Isotopes in Stream Water

A total of 30 creek water samples were collected during 1993-96 from Lockyer and Laidley creeks. This included a major flood event in the Lockyer Valley in May 1996. Large evaporation enrichment was noted for three water samples collected in 1993 indicating evaporation effect in creek water after the rainy season. All other samples located on the Craig's meteoric water line suggesting no evaporation. Yet, rain water in Gatton was located above the meteoric water line. One explanation would be the high relative humidity in air during major rain events promoting no evaoration. Another likely one would be a certain degree of evaporation taking place due to spreading of flood water which changes its stable isotopes towards the meteoric water line. The average $\delta^{18}O$ for this set of data was -4.3 ‰. If creek water recharges groundwater significantly, the groundwater would have a similar stable isotope content.

3.3 Groundwater Stable Isotopes

Figure 3 shows the plot of $\delta^{18}O$ against $\delta^{2}H$ for all the groundwater sampled from bores located within the study area.
The variation observed in stable isotopes for such a small area is very striking. Four groups of groundwater can be identified based on stable isotope variability.

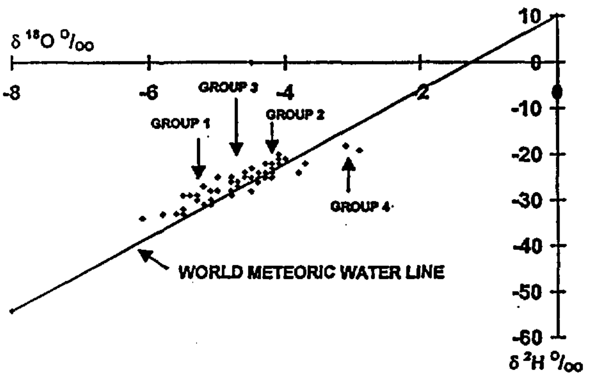

Figure 3 : Stable isotope plot for groundwater in Gatton including Crowley Vale area.

Group 1 : This group represents groundwater sampled within the Crowley Vale area having a $\delta^{18}O$ value around -5.4 $^{o}/_{oo}$ which was very close to the expected stable isotope composition for groundwater in Gatton recharged only by rain water infiltration over a long period of time. Sandstone groundwater to the north and south of the study area had similar stable isotope compositions suggesting that Crowley vale groundwater was recharged by rain water infiltration either locally or through sandstone outcrops outside the alluvium.

Group 2 : This group represents the rest of the study area , having an average $\delta^{18}O$ value of -4.4 $^{o}/_{oo}$ which was very close to that of major summer flood flows of Lockyer and Laidley creeks. Like the creek water samples, this group of groundwater was located on the world meteoric water line. Hence the source of recharge for this group is most likely the creek flows during major floods that happens rarely (20-30 years).

Group 3 : This group represents intermediate stable isotope values between group 1 and 2. The bores within this group are located in the transition zone between Crowley Vale and the rest of Gatton as well as bores located closer to the sandstone outcrops. An average $\delta^{18}O$ value of -4.7 $^{o}/_{oo}$ was calculated for this group.

Group 4 : This group represents two bores located next to the Lockyer and Laidley creeks, indicating evaporation of source water before recharge from the creeks. Such evaporation was observed in creek water in 1993 after floods caused by evaporation due to water storage behind weirs. The absence of any such large evaporation in bores elsewhere raises a question as to how effective weirs are in recharge of groundwater in the long term.

3.4 Natural Tritium

A total of 34 groundwater samples were collected within the study area in November 1993 and August 1994. The groundwater in Crowley Vale area had no measurable tritium in it indicating older groundwater having no recent contribution to recharge. The bores located closest to the creeks had the highest tritium levels (2-4 TU), showing recent and active recharge. As the distance from the creeks to the bores increased, tritium levels also decreased, supporting creeks as a source of recharge.

3.5 Carbon-14 Results

Those bores that had little or no natural tritium in their groundwater were sampled again in December 1994 for ^{14}C measurement by accelerator mass spectrometry at ANSTO in Sydney. A total of 24 samples were measured and the 'ages' ranged from 490 - 4810 years BP (conventional ages corrected using ^{13}C). The younger ages belonged to groundwater in bores near the creeks. The Crowley Vale irrigation area generally had older groundwater except for one bore on north side near the Lockyer creek yet suggesting no creek water recharge based on stable isotopes. A few bores that contained around 1 TU of tritium were found to have ^{14}C ages above 1000 years BP indicating mixing of older and recently recharged groundwater.

3.6 TRITIUM TRACING EXPERIMENTS

The first sampling program of soil at tracer injection sites in April 1996 revealed essentially Gaussian distributions with depth as seen in Figure 4. The shapes of tracer distributions suggest that a piston-type soil moisture movement is applicable for alluvial soils of Gatton. The site G-1 was uncultivated and al other sites were located on paddocks where various crops have been cultivated for the last 50 years. The shift of the peak or the centre of gravity of the tracer distribution for all 10 sites was only 5-15 cm per year indicating very small infiltration. The total

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rainfall and irrigation water input was close to 1000 mm in 1995-96.

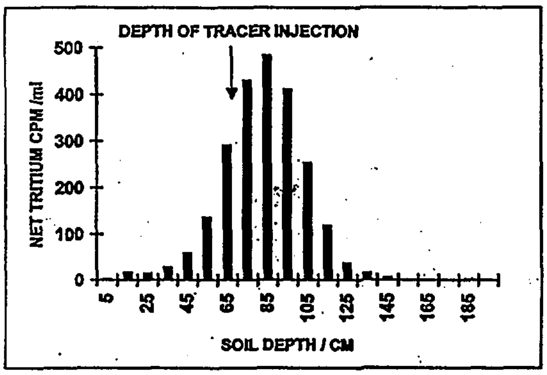

Figure 4 : Tritium tracer - depth profile at G-1. (Uncultivated site)

The site at Forest Hill towards the southern end of the study area showed a different tracer distribution with deeper tracer movement. This profile is shown in Figure 5.

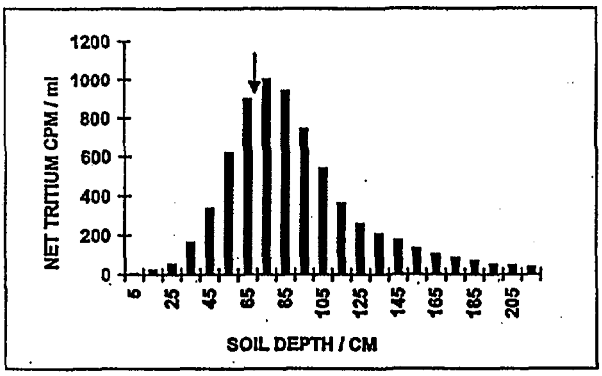

Figure 5 : Tritium tracer - depth profile at Forest Hill (G-8).

The infiltration data for all the sites (G 1-10) are listed in Table 1 below.

Table 1 - Soil Physical Properties, Tritium Tracer and Infiltration Data for Gatton Soil Moisture Tracing Study

Location	Bulk density g/cm³	Soil Moisture % w/w	Tracer Peak Shift / cm	Infiltration / mm
G-1	1.95	17.4	15	51
G-2	2.32	17.5	5	20
G-3	2.93	24.6	5	36
G-4	1.76	23.7	5	21
G-5	2.02	23.7	10	49
G-6	1.55	19.9	5	20
G-7	1.55	25.0	10	39
G-8	2.28	17.6	20	80
G-9	2.23	26.5	10	59
G-10	1.96	26.8	5	26

The infiltration rates were calculated assuming a piston-type flow model for soil moisture movement using soil moisture and bulk density data for soil at the time of tracer injection.

4. CONCLUSIONS

The alluvial aquifer in Gatton is mostly recharged by infiltrating creek water from Lockyer and Laidley creeks. The stable isotopes indicated that major summer floods were the significant source of recharge. The Crowley Vale irrigation area is recharged from the underlying sandstone which received its recharge by infiltrating rain water through sandstone outcrops outside the boundary of alluvium. Natural tritium clearly established the creeks as the major active source of recharge to the general area. The ^{14}C ages of groundwater ranged from 490 to 4810 years BP with older groundwater found within Crowley Vale area. The tritium tracing of soil moisture showed 5-15 cm of tracer peak movement in one year. The total infiltration was less than 50 mm per year.

5. ACKNOWLEDGEMENT

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