

Groundwater Age-Dating for Water Resource Characterization

The following references provide illustrations of the application for the technique:

Books:

- Cook P. G. and Herczeg A. L. (2000) *Environmental Tracers in Subsurface Hydrology*. Kluwer Academic Publishers.
- Kendall C. and McDonnell J. J. (1998) *Isotope tracers in catchment hydrology*. Elsevier.
- Mazor E. (1996) Chemical and Isotopic Groundwater Hydrology: The Applied Approach. Marcel Dekker
- Mook W.G. (2006) Introduction of Isotope Hydrology and Radioactive Isotopes of Hydrogen, Oxygen and Carbon. Taylor & Francis, 226 pages.

Journal Articles

- Aeschbach-Hertig, W., Peeters, F., Beyerle, U., and Kipfer, R. (1999) Interpretation of dissolved atmospheric noble gases in natural waters. *Water Resources Research*, v. 35, p. 2779-2792.
- Aeschbach-Hertig, W., F. Peeters, U. Beyerle & R. Kipfer, 2000. Palaeotemperature reconstruction from noble gases in ground water taking into account equilibration with entrapped air. *Nature* 405: 1040-1044.
- Bethke, C. M. and Johnson, T. M., 2002. Ground water age. *Ground Water* **40**, 337.
- Bethke, C. M. and Johnson, T. M., 2008. Groundwater age and groundwater age dating. *Annual Review of Earth and Planetary Sciences* **36**, 121-152.
- Böhlke, J. K. and J. M. Denver. 1995. Combined use of groundwater dating, chemical, and isotopic analyses to resolve the history and fate of nitrate contamination in two agricultural watersheds, Atlantic coastal plain, Maryland. *Water Resources Research* 31, 2319-2339.
- Cook, P. G. and D. K. Solomon. 1997. Recent advances in dating young groundwater: chlorofluorocarbons, $^3\text{H}/^3\text{He}$ and ^{85}Kr . *Journal of Hydrology* 191, 245-265.
- Corcho Alvarado, J. A.; Purtschert, R.; Barbicot, F.; Chabault, C.; Rueedi, J.; Schneider, V.; Aeschbach-Hertig, W.; Kipfer, R.; Loosli, H. H. Constraining the age distribution of highly mixed groundwater using ^{39}Ar : a multiple environmental tracer ($^3\text{H}/^3\text{He}$, ^{85}Kr , ^{39}Ar , and ^{14}C) study in the semiconfined Fontainebleau Sands Aquifer (France). *Water Resources Research* 2007, 43, W03427.
- Ekwurzel, B., P. Schlosser, W. M. Smethie, Jr., L. N. Plummer, E. Busenburg, R. L. Michel, R. Weppernig, and M. Stute. 1994. Dating of shallow groundwater: comparison of the transient tracers $^3\text{H}/^3\text{He}$, chlorofluorocarbons, and ^{85}Kr . *Water Resources Research* 30, 1693-1708.
- Holocher J. Peeters F. Aeschbach-Hertig W. Hofer M. Brennwald M. Kinzelbach W. Kipfer R. Experimental investigations on the formation of excess air in quasi-saturated porous media. *Geochimica et Cosmochimica Acta*. 66(23):4103-4117, 2002

- Manning, Andrew H., D.K. Solomon, and S.A.Thiros, 2005. $^{3}\text{H}/^{3}\text{He}$ age data in assessing the susceptibility of wells to contamination. *Ground Water*, 43 (3), 353-367.
- Moore K., Ekwurzel B. E., Esser B. K., Hudson G. B., and Moran J. E. (2006) Sources of groundwater nitrate revealed using residence time and isotope methods. *Applied Geochemistry* 21(6), 1016-1029.
- Plummer, L.N.; Rupert, M.G.; Busenberg, E.; Schlosser, P. Age of Irrigation Water in Ground Water from the Eastern Snake River Plain Aquifer, South-Central Idaho. *Ground Water*. Vol. 38, no. 2, pp. 264-283. Apr. 2000
- Poreda, R.J., Cerling, T.E., and Solomon, D.K. (1988) Tritium and helium isotopes as hydrologic tracers in a shallow unconfined aquifer: *Journal of Hydrology*, v. 103, p. 1-9.
- Rademacher, L. K., J. F. Clark, G. B. Hudson, D. C. Erman, and N. A. Erman 2001. Chemical evolution of shallow groundwater as recorded by springs, Sagehen basin, Nevada County California. *Chemical Geology*, 179, 37-51.
- Rademacher, L. K., J. F. Clark, and G. B. Hudson 2002. Temporal changes in stable isotope composition of spring waters: Implications for recent changes in climate and atmospheric circulation. *Geology*, 20, 139-142
- Schlosser, P., M. Stute, C. Sonntag, and K. O. Munnich. 1988. Tritium/ ^{3}He dating of shallow groundwater. *Earth and Planetary Science Letters* 89, 353-362.
- Singleton M. J., Esser B. K., Moran J. E., Hudson G. B., McNab W. W., and Harter T. (2007) Saturated Zone Denitrification: Potential for Natural Attenuation of Nitrate Contamination in Shallow Groundwater Under Dairy Operations. *Environmental Science & Technology* 41(3), 759-765.
- Solomon, D.K., Poreda, R.J., Schiff, S.L., and Cherry, J.A. (1992) Tritium and helium-3 as groundwater age tracers in the Borden aquifer. *Water Resources Research*, v. 28, p. 741-755.
- Solomon DK. Schiff SL. Poreda RJ. Clarke WB. (1993) A Validation Of The $\text{H-3}/\text{He-3}$ Method For Determining Groundwater Recharge. *Water Resources Research*. 29(9):2951-2962.
- Solomon DK. Poreda RJ. Cook PG. Hunt A. (1995) Site Characterization Using $\text{H-3}/\text{He-3}$ Ground-Water Ages, Cape Cod, MA. *Ground Water*. 33(6):988-996.
- Solomon D.K; Hunt A; Poreda R.J. (1996) Source Of Radiogenic Helium 4 In Shallow Aquifers - Implications For Dating Young Groundwater. *Water Resources Research*, v. 32, n. 6, p. 1805-1813.
- Szabo, Z., Rice, D.E., Plummer, L.N., Busenberg, E., Drenkard, S., and Schlosser, P.(1996) Age dating of shallow groundwater with chlorofluorocarbons, tritium helium 3, and flow path analysis, southern New Jersey coastal plain: *Water Resources Research*, v. 32, no. 4, p. 1023-1038.
- Surano, K. A., G. B. Hudson, R. A. Failor, J. M. Sims, R. C. Holland, S. C. MacLean, and J. C. Garrison. 1992. Helium-3 mass spectrometry for low-level tritium analysis of environmental samples *Journal of Radioanalytical and Nuclear Chemistry-Articles* 161, 443-453.

Tompson, A. F. B., S. F. Carle, N. D. Rosenberg, and R. M. Maxwell. 1999. Analysis of groundwater migration from artificial recharge in a large urban aquifer: A simulation perspective. *Water Resources Research*, 35, 2981-2998.

Reports:

- Burow, K.R., Panshin, S.Y., Dubrovsky, N.M., VanBrocklin, David, and Fogg, G.E., 1999, Evaluation of processes affecting 1,2-Dibromo-3-Chloropropane (DBCP) concentrations in ground water in the eastern San Joaquin Valley, California: Analysis of chemical data and ground-water flow and transport simulations: U.S. Geological Survey Water-Resources Investigations Report 99-4059, 57p.
- Davisson, M. L., Hudson, G. B., Moran, J. E., Niemeyer, S. and Herndon, R. 1998. Isotope tracer approaches for characterizing artificial recharge and demonstrating regulatory compliance. Annual UC Water Reuse Research Conference, Monterey, California. UCRL-JC-129656-ABS
- Davisson, M. L., Hudson, G. B., Clark, J. F., Woodside, G. and Herndon, R. Final report on isotope tracer investigations in the Forebay of the Orange County groundwater basin. UCRL-TR-201735, 116 pp.
- Hudson, G.B., Moran, J.E., and Eaton, G.F. (2002) Interpretation of Tritium-3Helium groundwater ages and associated dissolved noble gas results from public water supply wells in the Los Angeles Physiographic Basin. Lawrence Livermore National Laboratory internal report, UCRL-AR-151447, 26 pp.
- Moran J.E., Hudson, G.B., Eaton, G.F., and Leif, R. (2005) California GAMA Program: A contamination vulnerability assessment for the Bakersfield Area. Lawrence Livermore National Laboratory internal report, UCRL-TR-208179, 34 pp.
- Moran J.E., Hudson, G.B., Eaton, G.F., and Leif, R. (2005) California GAMA Program: Groundwater Ambient Monitoring and Assessment Results for the Sacramento Valley and Volcanic Provinces of Northern California. Lawrence Livermore National Laboratory internal report, UCRL-TR-209191, 71 pp.
- Moran, J.E. and Halliwell, M. (2003) Characterizing groundwater recharge: A comprehensive isotopic approach. American Water Works Association, final report 90941, 199 pp.
- Moran J.E., Hudson, G.B., Eaton, G.F., and Leif, R. (2003) A contamination vulnerability assessment for the Sacramento Area Groundwater Basin. Lawrence Livermore National Laboratory internal report, UCRL-TR-203258, 44 pp.
- Moran J.E., Hudson, G.B., Eaton, G.F., and Leif, R. (2002) A contamination vulnerability assessment for the Livermore-Amador and Niles Cone Groundwater Basins. Lawrence Livermore National Laboratory internal report, UCRL-AR-148831, 25 pp.
- Moran J.E., Hudson, G.B., Eaton, G.F., and Leif, R. (2002) A contamination vulnerability assessment for the Santa Clara and San Mateo County Groundwater Basins. Lawrence Livermore National Laboratory internal report, UCRL-TR-201929, 49 pp.