Journal of Hydrology **9** (1969) 113–116; © *North-Holland Publishing Co., Amsterdam*

WATER BUDGET STUDIES IN KARST AQUIFERS

M. C. BROWN*, T. L. WIGLEY** and D. C. FORD*

Many studies within the field of limestone hydrology have established the existence of direct underground flow routes followed by water[1,2]). A wide variety of tracers have been used[3-8]) and applications of this information to the avoidance and correction of pollution problems are also under way[9]). The rapidity of flow-through, coupled with the inefficiency of cavernous limestones as water purifiers, makes such applications highly desirable.

It would be both useful and interesting to have information other than simple connection routes. We have devised a method which determines the water budget of a karst system. Knowing the existence of a single sink point and spring in a particular aquifer, we can establish with one measuring programme whether a connection exists between the two points, whether there are any other sinks and/or risings which are also significant parts of the drainage network, and what quantities of water are carried by these components of the system. The method integrates stream gauging data with simultaneous dye connection and gauging tests, and thus determines both a water and a dye budget for the aquifer.

Fluorescent tracers have been used in karst areas of the world for many years, but the recent availability of high sensitivity fluorometers has enhanced their value considerably[10]). Fluorescent dyes can be used not only to trace but also to gauge the discharge rates of rivers and streams, and are especially useful under certain conditions when other gauging methods are impracticable[11,12]). If a known quantity of dye (or other tracer) is introduced either as a slug or at a constant rate into a particular sink and its concentration measured continuously at a spring, then the fraction of the sinking water discharging at the rising can be calculated, subject to errors of dye adsorption and disintegration.

If the dye is introduced to a stream sufficiently far above a sink then it can be used there for gauging purposes. However, it cannot be used to gauge the spring discharge rate since not all of the dye may be recovered. By

* M. C. Brown and Dr. D. C. Ford, Department of Geography, McMaster University, Hamilton, Ontario, Canada.

** Dr. T. L. Wigley, Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario.

gauging spring flow mechanically during the dye test, the output dye time/concentration curve can be used to determine the total amount of dye recovered. These three results, input and output flow rates and percentage of dye recovered, are sufficient to determine the water budget of the system.

We tested the method during the summer of 1968 at a large karst system in southern British Columbia[13]). The system is comprised of a glacier-fed stream (Tupper Creek) which sinks in a deep pool and passes beneath a mountain to a well defined spring (Raspberry Rising). The spring is 480 m lower than the sink, and 2 km distant horizontally. An earlier test in 1966[14]) established the connection, and a rapid flow-through time of 53 min. The geology and geomorphology of the region indicated that this system was a particularly simple one, and ideal for a first test of the total water budget method.

Rhodamine WT, a comparatively new fluorescent tracer, was used. This dye is not easily adsorbed by clay, etc., and has few interfering substances fluorescing at its emission wavelength (582 mμ). A slug of 1320 cc of the dye in acetic acid solution was injected into the stream some distance above the sink. Figure 1 shows the time/concentration curve of the slug entering the sink. From this curve the flow rate was calculated at 1.65 m^3/sec.

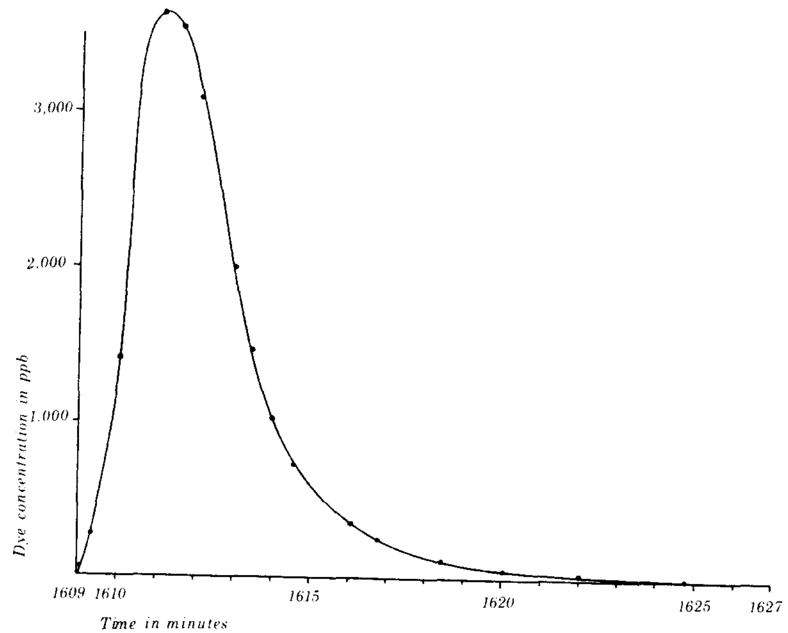

Fig. 1. Time/concentration curve of dye entering Tupper Sink. As flurometer readings are not linear over these concentrations, readings are transformed to true concentrations to calculate discharge rate.

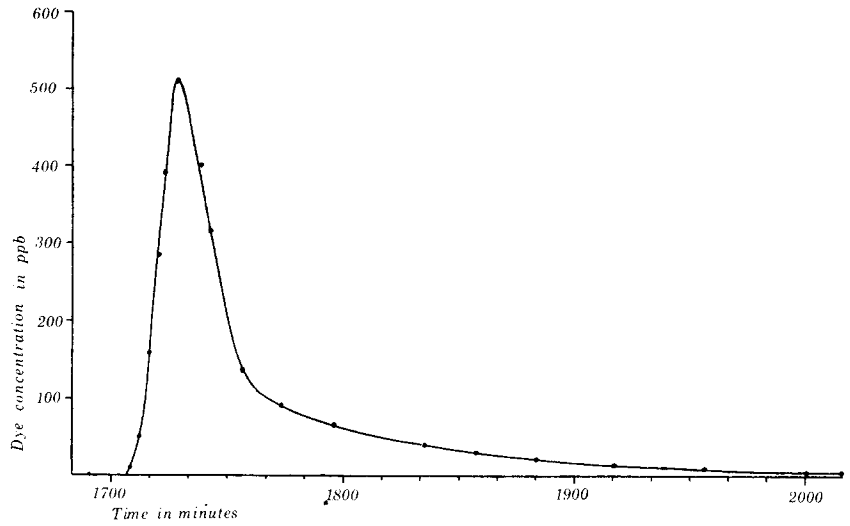

Fig. 2. Time/concentration curve of dye at rising.

Figure 2 shows the time/concentration curve of the slug at the spring. The spring discharge rate was calculated with a Gurley flowmeter[15]) and was 1.71 m^3/sec$\pm$5%. This value, together with the time/concentration curve area, indicates that 98% of the injected dye was recovered. As the 2% loss is less than the flow measurement error, no appreciable amount of dye can be considered to have been lost, and thus all of the input goes to the single output. The close agreement of the input and output discharge rates proves the existence of a system without major distributaries or additional inputs.

Although this system is a simple one, exactly the same experimental procedure can be used in more complex cases and the results interpreted to determine the flow characteristics and water budget of the aquifer, provided only that the flow-through times are not inordinately long. Further work is planned to determine if simultaneous multiple tracing and gauging is possible (using fluorescent tracers with different emission peaks but individually characteristic spectra), and to use the technique in conjunction with Ashton's pulse method for the study of phreatic components of limestone aquifers[16]).

This work was supported by the National Parks Branch, Department of Indian Affairs and Northern Development; the National Research Council of Canada; and Hamilton College, McMaster University.

References

1) W. B. White and V. Schmidt, Water Res. Research **2** (1966) 549–560

2) Cave Res. Group, Trans. 10,2.; Symp. on Cave Hydrol. and Water Tracing (1968)
3) J. R. Dunn, Nat. Spel. Soc. Bull **10** (1957) 3–9
4) D. P. Drew, Cave Res. Group. Trans. **10** (1968) 107–114
5) J. Zötl, Mitteil. Österreich. Geogr. Ges. **102** (1960) 199–206
6) M. Ashton, Cave Res. Group News Letter **98** (1965) 2–5
7) W. B. White, Steirische Beit. zur Hydrogeologie, Jahr 1966/67 (1967) 151–158
8) D. L. Feuerstein and R. E. Selleck, San. Eng. Res. Lab. Report 63-1 (University of Calif., Berkeley, 1963) 1–69
9) J. Zötl, Steirische Beit. zur Hydrologie Jahr 1959 (1959) 125–157
10) R. R. Wright and M. R. Collings, Am. Water Works Assoc. Jour. **56** (1964) 748–54
11) F. A. Kilpatrick et al., Am. Soc. Civil Eng. Hyd. Div. **93**, (HY4) (1967) 298–308
12) F. A. Kilpatrick, Water Res. Div. Bull. (July–Dec. 1967) (1967) 41–50
13) D. C. Ford, Canadian Geographer **11** (1967) 49–52
14) *ibid.*, p. 52
15) R. W. Carter and I. E. Anderson, Am. Soc. Civil Eng. Hyd. Div. **89**, (HY4) (1963) 105–115
16) M. Ashton, *op. cit.*