The distribution of particle size associated with sulfate weight was mathematically transformed to a count distribution (*6*). A count distribution could also be obtained by observing particles in the optical microscope and equating their areas to those of calibrated circles in an eyepiece graticule. Approximately 90 percent of the sulfate particles are less than 1 μ in equivalent area diameter. Jacobs *et al.* (*7*) found that 84 percent of the suspended dust particles in outdoor air are 1 μ or less in equivalent area diameter. On the basis of Jacobs' work and the low terminal settling velocity of a 1-μ sphere of density 2.0 g/cm^3 in still air (7.0 $\times$ 10^{-3} cm/sec at 20°C and 760 mm-Hg pressure), it is reasonable to assume that sulfate particles in Pittsburgh air remain suspended for long periods of time. Sulfate particles are also hygroscopic and presumably enlarge as the relative humidity of the air increases and become desiccated as the relative humidity decreases.

Sulfate particles can be formed by the photochemical oxidation of sulfur dioxide in the atmosphere (*8*). In natural sunlight in a concentration range of 5 to 30 parts per million, the photochemical oxidation of sulfur dioxide proceeds at 0.1 to 0.2 percent per hour (*9*). In the presence of fog droplets and a manganese catalyst, the oxidation rate can be as high as 1 to 2 percent per minute (*10*). The rate of formation of ammonium sulfate from sulfur dioxide and ammonia gases is proportional to the surface area of the fog droplets down to a diameter of 0.1 mm (*10*). Finally, the average life of a molecule of sulfur dioxide in fog or mist is estimated to be 3 to 4 hours (*11*).

Because of the short life of sulfur dioxide in the atmosphere and the size and associated irritant nature of particulate sulfate formed by its oxidation, suspended particulate sulfate may be a better indication of urban air pollution than sulfur dioxide.

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11 December 1963

Tritium-Hydrologic Research: Some Results of the U.S. Geological Survey Research Program

Abstract. *In general tritium is of limited usefulness as a tool in hydrologic studies because the tritium content of ground water, as a result of radioactive decay, becomes too low to be detectable after about 50 years. Nevertheless, a unique study was made of the hydrologic cycle of small stream basins in Wisconsin and New Jersey on the basis of measurements relative to the peak of tritium fallout in the spring of 1958. The continental and the coastal basins received approximately the same tritium fallout. Approximately 30 percent went into ground-water storage, the remainder being exported as runoff and evapotranspiration. The mean residence time for ground-water recharge for the two basins was 45 and 30 days, respectively.*

From January 1958 to July 1962 I was in charge of the U.S. Geological Survey research program established to explore the value of the radioisotope tritium as a hydrologic tool in groundwater studies. Its 12.26-year half-life suggested that it might be of value as a means of dating ground water. Tritium is produced in huge quantities in hydrogen bomb tests, and the many such bomb tests since 1954 have greatly increased the levels of tritium in precipitation throughout the United States. As a water molecule (HTO), tritium is apparently not subject to selective adsorption by soil or clay particles or to exchange with other elements; therefore, it should represent an ideal water tracer. One publication on the results of the first project to be completed is now in print (*1*). The full results of the research program will be published later; however, certain highlights of the results of the research, involving interpretations for which I am responsible, are believed to be sufficiently timely and of broad enough interest to be presented to the general scientific community at this time. This report should be of further interest in its description of the role of W. F. Libby in the planning of a scientifically fruitful and unique peaceful use of atomic energy in the field of hydrology.

Thatcher (*2*) has concluded that the pre-hydrogen-bomb, or pre-1954, levels of naturally produced tritium in precipitation ranged from 8–10 tritium units (1 tritium unit, or T.U., is one tritium atom per 10^{18} hydrogen atoms) in the continental interior of the United States to 3–5 tritium units along the Atlantic and Pacific coastal margins and to 2 tritium units in southern Florida.

The relatively short half-life of tritium (12.26 years) places a serious limitation on its usefulness for dating ground water. In ground water older than 50 years in the continental interior and 25 to 35 years old in the seaboard regions, so much of the original tritium has been lost through radioactive decay that none is detectable by tritium analysis. About 90 to 95 percent of the available ground-water reserves in the United States are probably older than 50 years; therefore, absence of detectable tritium in ground water has little or no bearing on the general problem of ground-water availability. Only ground water in recently recharged areas can be expected to contain measurable amounts of tritium. When such water is pumped from a well, particularly one without casing, the ground water drawn into the well from the upper part of the aquifer may contain over 100 tritium units, whereas that drawn into the well from the lower parts of the aquifer may contain none. The pumped water is thus a mixture of water of different ages and tritium contents, and to assign a definite age to a mixture of such water is meaningless.

In early 1958, at the beginning of the tritium research program, W. F. Libby, at that time a member of the

U.S. Atomic Energy Commission, suggested that bomb tests scheduled for the late spring months of 1958 might result in peak concentrations of tritium in precipitation, and that these concentrations could be used as tracers through the hydrologic cycle at suitable test sites. My co-workers at the U.S. Geological Survey and I selected two stream basins for study, one at upper Black Earth Creek basin, just west of Madison, Wisconsin, in a continental climatic environment, the other at McDonalds Branch basin in the pine-barrens region of the central part of the New Jersey coastal plain, in a modified marine climatic environment. Plans for the studies were completed near the end of February 1958. D. R. Cline was in charge of the Wisconsin field study, and E. C. Rhodehamel, of the New Jersey study. We had planned to begin studies in April of that year, but Libby notified us on 28 February of the beginning of new Russian bomb tests, so project work was begun immediately on a "crash" basis.

Upper Black Earth Creek basin is about 120 km^2 in area and is underlain by Cambrian sandstone and Ordovician dolomite and sandstone. Its eastern half is covered with Wisconsin till, and the main valley is flat-floored and filled with glacial outwash which is highly permeable and has a high ground-water storage capacity. The glaciofluvial valley fill, which is up to 45 m thick, has a strong effect on the character of runoff of Black Earth Creek, which is almost entirely goundwater discharge. Possibly a fourth of the runoff is in the form of underflow. McDonalds Branch basin is about 6 km^2 in area and is underlain by highly permeable Tertiary and Quaternary unconsolidated sand. The discharge of McDonalds Branch is also virtually entirely ground-water discharge.

From 28 February through 30 July 1958, samples of accumulated precipitation were collected on a biweekly basis, and at the same time samples of runoff from the streams and of ground water from some wells were collected for tritium analysis. The level of tritium in precipitation before the 1958 bomb tests was determined to be 80 tritium units in Wisconsin and 50 tritium units in New Jersey. The level of tritium in runoff before the tests was about 42 tritium units in Wisconsin and 48 tritium units in New Jersey. All subsequent tritium levels above these bases were considered to represent tritium from the 1958 bomb tests. The total amount of such tritium in precipitation, runoff, and ground-water recharge was computed by multiplying the tritium content (in tritium units) of the water, less the base values, by the thickness (in centimeters) of water involved, to give the quantitative measure, in T.U.-centimeters. A budget of tritium in precipitation, runoff, ground-water recharge, and evapotranspiration was thereby computed for the two basins. It was found that 28 centimeters of precipation at the Wisconsin basin deposited about 13,100 T.U.-centimeters of tritium, and that 82 centimeters of precipitation at the New Jersey basin deposited 12,400 T.U.-centimeters of tritium. As nearly as could be computed, about 30 percent of the tritium imported into the two basins during the period went into ground-water storage. In Wisconsin, only 1 percent of the imported tritium from the 1958 bomb tests was exported in runoff and 70 percent was exported in evapotranspiration, whereas in the New Jersey basin, 10 percent of the tritium from the tests was exported in runoff and 60 percent was exported in evapotranspiration. Thus, about 70 percent of the imported tritium from the tests was very shortly exported from both basins in runoff and evapotranspiration.

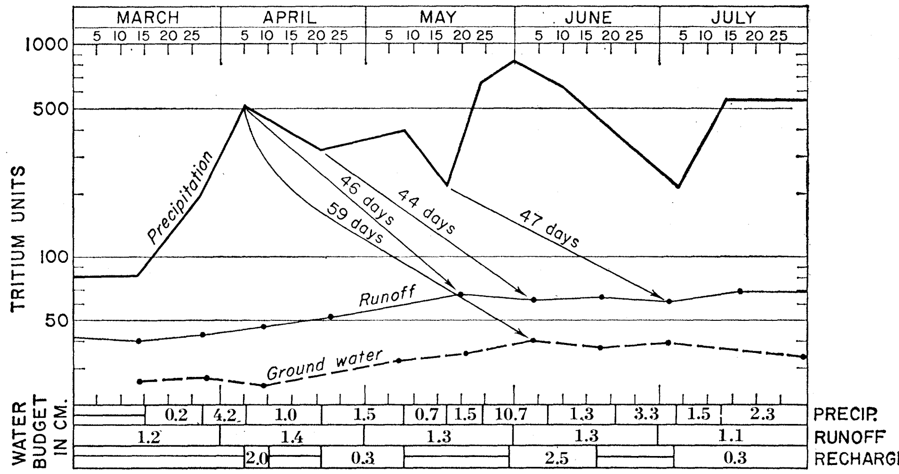

Fig. 1. Tritium content of precipitation, runoff, and ground water (well 7/8/7-272) at upper Black Earth Creek basin, Wisconsin, from March to July 1958. Arrows correlate variations in tritium content of precipitation with corresponding variations in tritium content of runoff and ground water. The water budgets of precipitation, runoff, and ground-water recharge are given at the bottom of the graph.

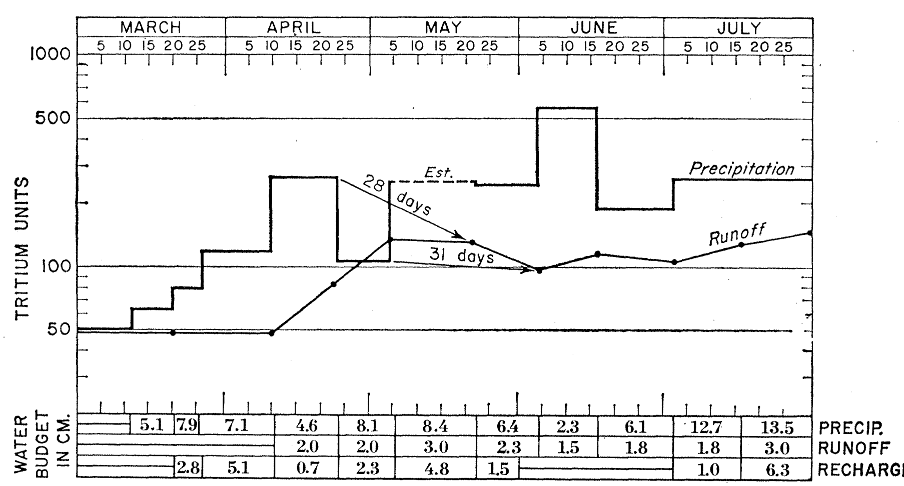

Fig. 2. Tritium content of precipitation and runoff at McDonalds Branch basin, New Jersey, from March to July 1958. Arrows correlate variations in tritium content of precipitation with corresponding variations in tritium content of runoff. The water budgets of precipitation, runoff, and ground-water recharge are given at the bottom of the graph.

By comparing variations in the tritium content of precipitation with corresponding variations in the tritium content of runoff in the two basins, it was possible to determine the travel time of precipitation through the ground-water system to the stream, or the mean residence time of recharge in the two basins. The correlations are shown in Figs. 1 and 2, together with the values for the water budgets of precipitation, runoff, and ground-water recharge. The appearance in ground-water recharge of tritium from the bomb tests, as indicated by analyses of samples from one of the wells in the Wisconsin project, is shown in Fig. 1. The curve for tritium content of ground water is for water from well 7/8/7-272, which is located in the glaciofluvial fill of Black Earth Creek. It is 7 m deep and cased to about 5.5 m, and the depth to the water table is about 2.1 m. It may be noted in Fig. 1 that the value for ground water for 30 July was 34 tritium units. The 59-day lag indicated for the 4 April peak suggests a new and higher peak, of about 43 to 45 tritium units, for the ground water on 30 July, and other wells sampled in this basin show such an expected increase in tritium content. In laboratory analysis of samples having low concentrations of tritium, electrolytic enrichment is required, and this may result in errors of the same order of magnitude. The lower the tritium content of water, the greater the required enrichment and the greater the possibility of analytical error.

The mean residence time of ground-water recharge in the Wisconsin basin was about 45 days, and in the much smaller New Jersey basin, about 30 days.

The measurement for the total amount of tritium fallout in the two basins during the period March through July 1958 is in close agreement with measurements of solid debris in fallout from fission bombs. Although the levels of tritium activity were much lower in the New Jersey precipitation samples than in the Wisconsin samples, in the New Jersey samples the tritium was contained in much larger quantities of precipitation. The measurements of 13,100 T.U.-centimeters for the Wisconsin basin and 12,400 T.U.-centimeters for New Jersey differ by only about 6 percent. According to Alexander and others (*3*), a measurement for strontium-90 accumulated at the University of Wisconsin at Madison in October 1959 was 23.7 mc/km^2, and one for strontium-90 accumulated at Rutgers University in New Jersey in the same month was 24.4 mc/km^2. These measurements differed by only about 3 percent, and in both cases the variations were within the range of sampling and analytical error.

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1 November 1963

Conchostracans: Living and Fossil from Chihuahua and Sonora, Mexico

Abstract. *In August 1963, living conchostracans (branchipod Crustacea) of the genera* Leptestheria *and* Eulimnadia *were collected at three stations in Chihuahua. One Sonoran locality yielded Triassic fossils of the family Cyzicidae, a widespread North American group. The geographic range of the geologically younger families Leptestheriidae and Limnadidae (particularly the genus* Eulimnadia*) thus extended to Chihuahua during post-Mesozoic time.*

Relatively little is known about living conchostracan populations in Mexico (*1*). A recent comprehensive review of Mexican crustaceans did not list any study on the subject (*2*). Mattox (*3*) merely cited species of *Leptestheria, Eulimnadia, Cyzicus,* and *Lynceus*. Fossil conchostracans have not been reported previously. This report is based on collections made by Shaffer while he was engaged in a palynological survey (*4*). The Chihuahua sites chosen at random cannot be said to be representative of the entire area. Several turbid roadside ponds were sampled but no conchostracans were found either in the Durango area, about 600 km south of Chihuahua, or on the Central Mexican Plateau.

Locality 1: State of Chihuahua; 90 km west of Chihuahua, Highway 16. Elevation, 2000 m; pond, 6 m longest dimension, 7.6 cm maximum depth; water clear; bottom rocky and gravelly; algal mats on bottom; tadpoles, beetles, and conchostracans. Collection made 16 August 1963. Conchostracans: *Eulimnadia antillarum* (Baird) (*5*), two specimens, both females bearing eggs; four growth lines on shell; ratio of width to length of shell, 0.57 to 0.71. *Leptestheria compleximanus* (Packard), 1 specimen, female, 18 growth lines on shell. *Eulimnadia* sp., 14 complete specimens, 5 empty valves; length of shell, 5.1 to 6.9 mm, width, 3.2 to 5.2 mm; 5 to 7 growth lines; 12 to 15 spines on telson; ratio of females to males, 13:1. This may be a new species (*3, 5–7*). Cultures from dried algal mats and sparse silty mud in constantly aerated water yielded three naupliids. Two naupliids developed into adult females with valves of glass-like transparency (*Eulimnadia* sp.) and succumbed after 2 months.

Locality 2: State of Chihuahua; 164 km west of Chihuahua, Highway 16. Roadside ditch extending intermittently for 100 to 200 meters; water turbid; depth, 0.3 m maximum; clay and silt-mud bottom; tadpoles, beetles, anostracans, and conchostracans. Collection made 16 August 1963. Conchostracans: *Leptestheria compleximanus* (Packard), seven specimens, ratio of females to males, 6:1. One specimen, a female, shows shell repair. The last five growth lines are curved upward in echelon fashion across the injured site, with a niche on ventral margin indicating shell repair was incomplete at the time of collection (*8*).

Locality 3: State of Chihuahua, Laguna Bustillos; 90 km north-northwest of locality 1. Puddles on mudflat margining laguna on the east side; depth, 5 to 10 cm. One puddle, a dry depression bearing empty conchostracan valves, another puddle with living conchostracans all belonging to *Leptestheria compleximanus* (Packard); 80 complete individuals, a few showing shell repair. Ratio of females to males, 4:1; length, 3 to 5 mm, width, 1 to 3 mm; growth lines variable from 5 to 10. Characteristic spine at anterodorsal extremity of rostrum occasionally oblique or perpendicular to rostrum. Numerous other puddles and water-filled hoofprints on the flat were teeming with conchostracans. Cultures from dried muds have yielded an actively breeding population (*L. compleximanus*). Some individuals have survived almost 3 months in constantly turbid water to which no nutrient has been added.

Locality 4: State of Sonora, Santa Clara; 5 km west of Tonichi, 130 miles west of locality 2 (for map and measured section, see *9*; sample from coal mine diggings along steep hillside). No water-filled ponds occurred in the Triassic outcrop area. There was no evidence of