TIME-OF-TRAVEL OF SOLUTES IN MISSISSIPPI STREAMS[1/]

by

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Within Mississippi, the primary role of the Water Resources Division of the U.S. Geological Survey is to collect water facts. In 1963, the USGS turned part of its attention to the collection of data concerning the time-of-travel of solutes in Mississippi streams. The need for such data is emphasized by the growing problems associated with the use of natural water bodies to dilute and carry away wastes. Time-of-travel information is needed to fully appraise the problems of pollution and to arrive at reasonable solutions to these problems.

Today, I would like to describe the methods used to obtain time-of-travel data. First, I had better explain just what time-of-travel of solutes is, and this will suggest the method of the study. By time-of-travel of solutes, we mean the time it takes an individual particle in solution to move from one point in a stream to some other downstream point. This is not the same as the time-of-travel of flow, which is the time required for some flow event, such as a flood wave, to move from one point in a stream to some other downstream point.

The first attempts to arrive at a value for the time-of-travel of solutes involved the simple process of measuring the velocity at a few points on a stream, determining the river mileage involved, and applying the average velocity computed between the ends of the reach to the entire distance. This method is quite misleading. The biggest error in this relatively simple method is that the measured velocities are not usually representative of the reach. This is true because measuring sections are usually chosen at channel constrictions where the velocity is greater than the true mean velocity. Another error involved in this method, but one which tends to offset the first error, is the assumption that solutes would travel at the same rate as the mean velocity. Actually a portion of the solutes tends to follow the thread of maximum velocity and arrive at downstream points sooner than the mean velocity would indicate.

A more reliable method of determining solute travel time is to inject a tracer in the water and measure the time required for it to move downstream.

Three types of materials have been used as tracers to some degree. These are salts, radio-active materials, and organic fluorescent dyes.

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The use of salt as a tracer has three disadvantages. First is the large quantity of salt needed to obtain detectable concentrations downstream. Second, impurities in the water may make it hard to readily distinguish the leading edge of the tracer as it arrives at downstream points. Third, the injection of a large quantity of salt into a fresh water body is definitely a form of pollution and as such should be avoided. The advantage of using salt as a tracer is that it is cheap and generally available.

Radioactive tracers have the advantage of being detectable in extremely low concentrations. For this reason, the amount of such material required to conduct a time-of-travel study is small. However, isotopes are expensive and require extensive instrumentation for their use. A health hazard is always present and the use of radioactive materials is carefully controlled by law. Often, adverse public opinion is associated with the use of such material in public waters.

Organic fluorescent dyes are non-toxic, are detectable in very low concencentration, are easily distinguished from impurities in natural waters, are relatively inexpensive, and are not likely to arouse public reaction to their use. Some instrumentation is required in the use of these dyes as tracers, but it is not excessive. To date, all time-of-travel of solute studies, utilizing tracers, conducted by the USGS in Mississippi, have used fluorescent dye.

Many dyes are available, no one of which is perfect for all studies. Rhodamine B dye, which is available from several manufacturers, is suited for use in Mississippi streams. The principal advantages of this dye are that it can be detected in concentrations of less than 0.1 part per billion and its cost is less than most other dyes suitable for this type of study.

A few of the disadvantages of rhodamine B are that it has a moderate sorptive tendency, a moderate rate of photochemical decay, and is nearly impossible to remove from anything on which it is spilt. This last point means that caution is required in the handling of the dye.

The simplest type of study would involve injecting dye at one point on a stream and then collecting water samples at one or more downstream points on a periodic basis, determining the amount of dye in each sample collected, and making the necessary calculations to put the field data into a usable form. This is basically the procedure followed by the USGS. However, time and manpower limitations make it necessary to speed up the operation as much as possible. For this reason the usual field procedure is to inject dye at several points within the total reach of streams being studied. Each subreach is sampled at two or more points, including the site at which the next downstream subreach was injected. By this procedure the total time required to complete the study is much reduced.

There are other advantages to using the subreach approach to a time-of-travel of solutes study in addition to the one just mentioned. Ideally, steady flow conditions should be experienced during this type of study. If a stream has a rapidly changing stage it may be impossible to relate the observed travel time to the discharge. By using short subreaches and keeping the total time to a minimum, the adverse effects of changing streamflow conditions can be minimized. Also, shorter times means less breakdown of the dye through natural reaction to its environment.

Generally, at least two studies are conducted on any reach of stream. One is conducted at a time when low-flow conditions exist and the second is conducted at a time of some greater discharge conditions. If possible, a third or even a fourth run should be conducted at different discharges.

If the time-of-travel of solutes were determined for a reach of stream under one flow condition only, it would remain impossible to predict accurately the time-of-travel under other flow conditions. However, if two or more runs are conducted it is possible to determine the relationship between discharge and time-of-travel. Naturally the greater the number of runs conducted, the more accurately this relationship can be defined. Experience shows that the relationship is nearly linear between the logarithms of the discharge and flow velocity for most streams. Exceptions do occur, of course, and for this reason a third run is always advisable.

When rhodamine B dye is first injected into a stream the water is turned a deep red color. As the dye cloud spreads and begins to mix with the water, the color fades to pink and finally, is no longer visible from the streambank. A sample collected at a point sufficiently downstream from the site of injection would not contain visually detectable concentrations of the dye. However, a special instrument called a fluorometer will detect and measure the dye at concentrations far below the visual limit.

A fluorometer may be described as an optical Wheatstone bridge. Fluorescent dyes have the property of absorbing light at one wave length and emitting it at another. Within the fluorometer, light of the wave length absorbed by the dye is passed through the water sample. The light emerging from the sample is filtered so that only light of the wave length emitted by the dye is permitted to pass on. This light is balanced by a servo-balancing device with light from a standard source and a value of relative concentration of dye in the sample is indicated by a readout device on the instrument.

The fluorometer is a rugged, fairly portable instrument suitable for either field or laboratory use. It can be equipped so that water from the stream is pumped directly through the instrument and the relative concentration of dye recorded on a chart.

To date, the U.S. Geological Survey has conducted time-of-travel of solute studies on portions of the Big Black, Pearl, Chunky, and Chickasawhay Rivers and on portions of Sawashee and Okatibbee Creeks. Plans have been made to conduct studies on the Homochitto River and on Bogue Chitto in the coming year. Other studies will probably be made on Mississippi streams as funds become available.

Although a relatively small number of the State's streams have been studied so far, a wide variety of streamflow conditions have been encountered. Streams have been studied in which the leading edge of the dye arrived several hours ahead of even the shortest anticipated travel time. Other streams have been found to have extremely slow mean velocities. A 9-mile reach of the Chunky River southwest of Meridian was found to have a mean velocity of only 0.06 mile per hour at low flow. A mean velocity of 0.3 to 0.4 mile per hour had been anticipated.

It is often said that man learns by experience. This is definitely true when it comes to conducting time-of-travel studies. We feel that each dye run we make goes a little smoother than any earlier run. Manpower requirements and cost per mile of stream studied seems to be lower with each successive run. We have also learned that the old rough-and-ready estimates of solute travel time based on velocities observed at a few points in the stream can be far from correct.